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# Distribution of waterbird communities in North-Eastern Algeria

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**Abstract** Understanding how bird species interact with local environmental conditions is fundamental to grasping habitat preferences and their effects on species distribution. This study examined the influence of abiotic factors on waterbird assemblages across three wetlands within the Sidi Fredj Complex (Souk Ahras, northeastern Algeria): Mkimen Marsh, Medjen Djedj and Medjen Bouhsane. Monthly bird surveys were conducted from July 2018 to July 2019, combined with water quality measurements at each site. A suite of multivariate analyses including Principal Component Analysis (PCA), Canonical Correspondence Analysis (CCA), Redundancy Analysis (RDA) and Non-Metric Multidimensional Scaling (NMDS) was applied to explore species environment relationships. My results showed that environmental variation significantly structured bird community composition. Mkimen, characterized by higher pH, salinity, dissolved oxygen, chloride, nitrate and nitrite, supported high species richness and was dominated by taxa such as the Little Egret *(Egretta garzetta)*, Mallard *(Anas platyrhynchos)*, White Stork *(Ciconia ciconia)*, Yellow-legged Gull *(Larus michahellis)* and Grey Heron *(Ardea cinerea)*. It also exhibited significantly higher diversity and evenness indices compared to the other sites. In contrast, the Green Sandpiper *(Tringa ochropus)* and Black-throated Diver *(Gavia arctica)* showed strong affinities for higher dissolved oxygen and chloride levels at Medjen Djedj. Medjen Bouhsane, characterized by lower temperature and phosphorus levels, favored species such as the Northern Pintail *(Anas acuta)*, Northern Shoveler *(Anas clypeata)*, Eurasian Coot *(Fulica atra)*, Great Cormorant *(Phalacrocorax carbo)*, Great Crested Grebe *(Podiceps cristatus)*, Common Moorhen *(Gallinula chloropus)* and Eurasian Teal *(Anas crecca)*. These findings highlight that waterbird species respond in species-specific ways to environmental gradients, although ecologically similar species often share habitat preferences. The strong associations between bird presence and physico-chemical conditions underscore the role of waterbirds as effective bioindicators of wetland health. This study also confirms the importance of incorporating habitat heterogeneity and environmental variability into conservation strategies. Understanding these ecological relationships is essential for preserving waterbird diversity in Mediterranean wetland ecosystems facing increasing anthropogenic pressures.

Keywords: waterbirds, environmental factors, indicator species, species diversity

**Összefoglalás** Annak megértése, hogy a madárfajok hogyan lépnek kölcsönhatásba a helyi környezeti feltételekkel, alapvető fontosságú az élőhelypreferenciák és a fajok elterjedésére gyakorolt hatásuk megértéséhez. Ez a tanulmány az abiotikus tényezők hatását vizsgálta a Sidi Fredj komplexum (Souk Ahras, Algéria északkeleti része) három vizes élőhelyén (Mkimen-mocsár, Medjen Djedj és Medjen Bouhsane) a vízimadár-összetételre. Havi madárfelméréseket végeztem 2018 júliusától 2019 júliusáig, amelyeket vízminőségi mérésekkel kombináltunk az egyes helyszíneken. Többváltozós elemzéseket alkalmaztam, beleértve a főkomponens-elemzést (PCA), a kanonikus korreszpondenciaelemzést (CCA), a redundanciaelemzést (RDA) és a nem-metrikus többdimenziós skálázást (NMDS) a fajok és a környezet közötti kapcsolatok feltárására. Eredményeim azt mutatták, hogy a környezeti különbségek jelentősen strukturálták a madárközösségek összetételét. A magasabb pH, sótartalom, oldott oxigén, klorid, nitrát és nitrit által jellemzett Mkimen magas fajgazdagsággal rendelkezett, és olyan taxonok domináltak, mint a kis kócsag *(Egretta garzetta)*, a tőkés réce *(Anas platyrhynchos)*, a fehér gólya *(Ciconia ciconia)*, a sárgalábú sirály *(Larus michahellis)* és a szürke gém *(Ardea cinerea)*. A többi helyszínhez képest szignifikánsan magasabb diverzitási és egyenletességi indexet mutatott. Ezzel szemben az erdei cankó *(Tringa ochropus)* és a sarki búvár *(Gavia arctica)* erős affinitást mutatott a magasabb oldott oxigén- és kloridszintekhez Medjen Djedjben. Az alacsonyabb hőmérséklet és foszforszint által jellemzett Medjen Bouhsane olyan fajoknak kedvezett, mint a nyílfarkú réce *(Anas acuta)*, a kanalas réce *(Anas clypeata)*, a szárcsa *(Fulica atra)*, a kárókatona *(Phalacrocorax carbo)*, a búbos vöcsök *(Podiceps cristatus)*, a vízityúk *(Gallinula chloropus)* és a csörgő réce *(Anas crecca)*. Ezek az eredmények rávilágítanak arra, hogy a vízimadárfajok fajspecifikus módon reagálnak a környezeti grádiensekre, bár az ökológiailag hasonló fajok gyakran azonos élőhelypreferenciákkal rendelkeznek. A madarak jelenléte és a fizikai-kémiai viszonyok közötti szoros összefüggések kiemelik a vízimadarak szerepét a vizes élőhelyek állapotának hatékony bioindikátoraiként. Ez a tanulmány megerősíti az élőhelyek heterogenitásának és a környezeti változékonyságnak a természetvédelmi stratégiákba való beépítésének fontosságát. Ezeknek az ökológiai összefüggéseknek a megértése elengedhetetlen a vízimadarak sokféleségének megőrzéséhez a mediterrán vizes élőhelyek ökoszisztémáiban, amelyekre egyre nagyobb antropogén nyomás nehezedik.

Kulcsszavak: vízimadarak, környezeti tényezők, indikátorfajok, fajdiverzitás

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## Introduction

Over recent decades, waterbird diversity has experienced significant declines, largely as a result of both natural environmental fluctuations and escalating human activities (Yasué 2006, Ma *et al.* 2014, Hamza *et al.* 2015, Tavares *et al.* 2015, Wei *et al.* 2017, Jackson *et al.* 2021). This biodiversity loss has intensified interest in assessing the structure of bird communities, especially from a taxonomic perspective, to better understand ecological patterns and guide conservation planning (Gaston 2000). Numerous studies have highlighted that waterbird populations are highly responsive to environmental parameters and anthropogenic disturbances (Ge *et al.* 2006, Hamza 2020, Wang *et al.* 2020). Factors such as the extent of open water, the availability of tidal flats and mangroves, and the expansion of aquaculture and urban areas all contribute significantly to shaping waterbird assemblages (Acevedo & Aide 2008, Walton *et al.* 2015, Burger 2018, Fonseca & Navedo 2020, Wang *et al.* 2021). In wetland ecosystems, bird diversity serves as a robust indicator of habitat health and ecological integrity (Ma *et al.* 2010, Kahara *et al.* 2012). However, relying solely on species richness may not provide a full picture of ecosystem function and resilience (Weller 1999). A more nuanced understanding requires considering habitat heterogeneity, which encompasses not only the diversity and area of habitat types (Magurran 1988) but also the spatial configuration and complexity of these habitats (González-Gajardo *et al.* 2009, Schipper *et al.* 2011). Additionally, temporal and spatial variability in environmental conditions further contributes to shaping bird communities (Morrison *et al.* 2006). Recognizing how such heterogeneity influences species composition is crucial for freshwater biodiversity conservation, a key global research priority (Heino 2011, Tisseuil *et al.* 2013). Beyond species counts, studies of avian behavior offer insights into habitat suitability, as changes in foraging, nesting, or movement patterns often reflect environmental stress or degradation (Blanco 1999). Waterbirds select habitats based on a combination of ecological factors, including prey availability, habitat complexity, interspecific interactions, and levels of human disturbance (Burger & Gochfeld 1991, Maccarone & Arons 1994, Gawlik 2002, Barbieri & Pinna 2005). In this context, the present study investigates the composition, diversity and spatial distribution of waterbird communities across three wetlands in the Sidi Fredj Complex, Medjen Bouhsane, Medjen Djedj, and Mkimen Marsh located in the Souk Ahras province of northeastern Algeria. These sites are ecologically significant yet remain understudied. This research aims to clarify how local physico-chemical conditions influence species presence and abundance. Based on the hypothesis that high-quality wetlands support greater bird diversity through enhanced habitat complexity and resource availability, I expect to find: (1) distinct assemblage structures across the three wetlands, reflecting site-specific environmental features, and (2) stronger similarities in habitat preferences among species with shared ecological traits. This work contributes essential baseline data for regional conservation efforts and underscores the role of wetland quality in shaping bird communities in Mediterranean North Africa.

## Materials and Methods

### Study area

The study was conducted in the Sidi Fredj Complex (36°0’84.51” N, 8°28’03.59” E), which comprises three wetlands: Medjen Bouhsane, Medjen Djedj, and Mkimen, located in the Souk Ahras province of northeastern Algeria. The study area spans over 26 hectares and features a diverse landscape, including mountains, plateaus, and plains, with elevations ranging from 340 to 550 meters above sea level.

The region experiences an annual rainfall ranging from 129 to 496 mm, with over 70% occurring during the winter months. Temperature fluctuations are notable, with recorded extremes ranging from a minimum of 4.52 °C in December to a maximum of 30.93 °C in July (Boukrouma *et al.* 2018). Most of the wetlands in this area are situated within arid to semi-arid zones, making them essential refuges for a wide array of species, particularly waterbirds. These lakes are also utilized for multiple human activities, including fishing, tourism, agriculture, and irrigation.

### Bird surveys

Bird surveys were conducted seasonally between 15 July 2018 and 15 July 2019, covering winter, spring, summer, and autumn. Each season included monthly visits to the three wetlands (Medjen Djedj, Mkimen Marsh, and Medjen Bouhsane), with an average of two observation days per month at each site (ranging from one to three days depending on weather and logistical conditions). Observations were carried out between 06:00 and 16:00 hours. To minimize bias related to daily variation in bird activity, the timing of surveys was rotated among sites and seasons so that no wetland was consistently visited at the same time of day. Whenever possible, counts were concentrated during peak activity periods (06:00–11:00) under favorable weather conditions (low wind, absence of rain).

Despite these precautions, the study presents some temporal limitations. Surveys were restricted to daylight hours, potentially underrepresenting nocturnal or crepuscular species, and were conducted over a single annual cycle, which does not capture interannual variability in species abundance or phenology. Therefore, while the results provide a robust overview of seasonal variation within the study year, they should be interpreted with caution when extrapolating to longer-term trends.

**Water analysis**

Water samples were collected from four distinct points within each of the three study sites. Concentrations of total nitrates, nitrites, phosphorus, chlorides, and dissolved oxygen were determined using MERCK Spectroquant cuvette tests analyzed with a UV-VIS spectrophotometer. At each site, physico-chemical parameters such as conductivity (measured in mS) and pH were recorded using a combined digital meter. Surface water samples were collected, kept refrigerated to preserve their integrity, and transported to the laboratory for analysis following established protocols (Rodier 1996). All measured values were subsequently adjusted to standard temperature and pressure conditions (1 atm and 25 °C).

**Data analyses**

To compare diversity among the study sites, several community parameters were calculated, including the Shannon–Wiener diversity index (H'), Simpson index, Evenness index (E), species richness (S), and relative abundance (A) (Anjos *et al.* 2010). 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 physico-chemical parameters between sites were tested using one-way analysis of variance (ANOVA), followed by Tukey's post-hoc test to identify pairwise differences.

Diversity indices (H') were computed with the "vegan" package (Oksanen *et al.* 2020). Boxplots for data visualization were generated using "ggplot2". Relationships between environmental variables and waterbird communities were explored using Principal Component Analysis (PCA) implemented in R with the packages "FactoMineR" (Lê *et al.* 2008), "ggbiplot" (Vu 2011), "factoextra" (Kassambara & Mundt 2020), "grid" (R Core Team 2024), and. Additionally, Redundancy Analysis (RDA) and Canonical Analyses (CCA) were conducted using the "vegan" package to assess the influence of environmental factors on waterbird distribution.

To compare bird community composition and wetland characteristics, non-metric multidimensional scaling (NMDS) and PERMANOVA analyses were performed using the "vegan" package (Oksanen *et al.* 2020) in R, aggregating species relative abundances by site and bird groups. Statistical significance (p-values) for group differences was estimated using random permutations of site assignments. Graphical outputs were generated with "ggplot2" (Wickham 2016). All statistical analyses were performed using R software (version 4.5.0) on an i386 platform (R Core Team 2024).

## Results

### Comparison of water bird assemblages among sites

The Non-metric Multidimensional Scaling (NMDS) analysis revealed distinct waterbird assemblages among the three study sites, with species distribution largely restricted to specific wetlands, reflecting unique community compositions at each site *(Figure 1)*.


*Figure 1.* Non-metric multidimensional scaling (NMDS) plot using Bray–Curtis dissimilarity distances for water bird's composition in Wetlands. Each point represents the water bird's community of a transect section for the wetlands. Ellipses show the 95% CI of multivariate t-distribution for each area (stress = 0.0488) (stress < 0.05 indicates good fit)

*1. ábra* Nem-metrikus többdimenziós skálázási (NMDS) diagram a Bray–Curtis különbözőségi távolságok felhasználásával a vizes élőhelyek vízimadár-közösségének összetételére. Minden pont a vizes élőhelyek egy-egy metszetének vízimadár-közösségét jelöli. Az ellipszisek a többváltozós t-eloszlás 95%-os konfidencia intervallumát mutatják az egyes területekre

The Mkimen wetland was notably associated with species such as the Yellow-legged Gull *(Larus michahellis)* (NMDS1 = -0.220, NMDS2 = 0.179), Little Egret *(Egretta garzetta)* (-0.184, 0.118), Mallard *(Anas platyrhynchos)* (-0.307, -0.048), Gadwall *(Mareca strepera)* (-0.133, 0.020), and White Stork *(Ciconia ciconia)* (-0.251, -0.071). In contrast, species such as the Eurasian Teal *(Anas crecca)* (0.270, 0.056) and Great Cormorant *(Phalacrocorax carbo)* (0.230, -0.014) were more closely associated with the Medjen Bouhsane and Medjen Djedj sites. Additionally, species including the Common Coot *(Fulica atra)* (0.121, -0.038), Black-throated Loon *(Gavia arctica)* (-0.012, -0.052), Northern Pintail *(Anas acuta)* (0.166, -0.095), Northern Shoveler *(Spatula clypeata)*

*Table 1.* Principal Component Analysis (PCA) results summarizing Species and Environmental Factors associations

*1. táblázat* A fajok és környezeti tényezők közötti összefüggéseket összefoglaló főkomponens-elemzés (PCA) eredményei

| Variable | PCA1 | PCA2 | PCA1 p-value | PCA2 p-value |
|---|---|---|---|---|
| **Species** | | | | |
| Little Egret | 0.5864 | -0.0944 | $p < 0.0001$ | - |
| Mallard | 0.6336 | 0.1682 | $p < 0.0001$ | - |
| Northern Pintail | -0.7569 | 0.4027 | $p < 0.0001$ | - |
| Gadwall | 0.0734 | 0.2680 | - | - |
| Northern Shoveler | -0.5883 | -0.5461 | $p < 0.0001$ | - |
| Green Sandpiper | -0.5997 | 0.7265 | $p < 0.0001$ | $p < 0.0001$ |
| White Stork | 0.7051 | 0.3328 | $p < 0.0001$ | - |
| Common Coot | -0.9093 | 0.2107 | $p < 0.0001$ | - |
| Yellow-legged | 0.8170 | -0.3563 | $p < 0.0001$ | - |
| Great Cormorant | -0.9061 | 0.0740 | $p < 0.0001$ | - |
| Great-crested | -0.9359 | 0.1637 | $p < 0.0001$ | - |
| Grey Heron | 0.8820 | -0.3736 | $p < 0.0001$ | - |
| Common Moorhen | -0.9028 | -0.1900 | $p < 0.0001$ | - |
| Black-throated Loon | -0.3829 | 0.7404 | - | $p < 0.0001$ |
| Eurasian Teal | -0.9010 | -0.1882 | $p < 0.0001$ | - |
| **Environmental factors** | | | | |
| pH | 0.8881 | -0.3444 | $p < 0.0001$ | - |
| Temperature | -0.5968 | -0.7688 | $p < 0.0001$ | $p < 0.0001$ |
| Conductivity | 0.3257 | 0.3229 | - | - |
| Salinity | 0.6122 | -0.1833 | $p < 0.0001$ | - |
| Dissolved oxygen | 0.8160 | 0.5148 | $p < 0.0001$ | - |
| Chloride | 0.4923 | 0.7443 | - | $p < 0.0001$ |
| Nitrate | 0.5264 | 0.1685 | - | - |
| Nitrite | 0.9575 | -0.2348 | $p < 0.0001$ | - |
| Phosphorus | -0.3895 | -0.7509 | - | $p < 0.0001$ |

(0.015, 0.101), and Green Sandpiper *(Tringa ochropus)* (0.161, -0.163) showed a stronger association with Medjen Djedj.

One-way ANOVA tests demonstrated significant differences in community diversity indices among the three wetlands. Specifically, Shannon diversity index (H') ($F = 5.351$, $p = 0.0294$), species richness (S) ($F = 4.397$, $p = 0.0466$), Simpson index ($F = 4.397$, $p = 0.0466$), and evenness index (E) ($F = 4.519$, $p = 0.0438$) all varied significantly across sites ($p < 0.05$). Post-hoc Tukey's HSD tests indicated that Mkimen exhibited significantly higher diversity, richness, and evenness compared to Medjen Djedj and Medjen Bouhsane ($p < 0.05$). However, total abundance (A) did not differ significantly between sites ($F = 3.835$,

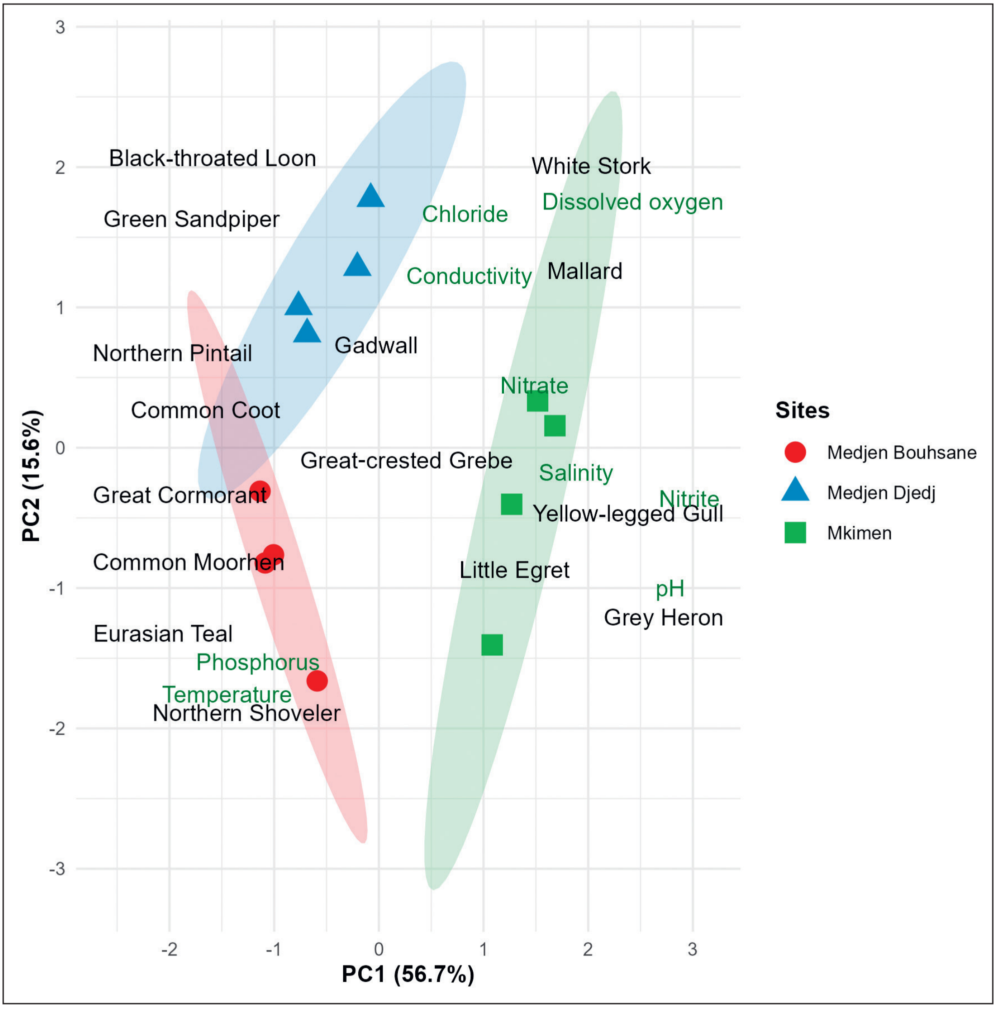


*Figure 2.* A plot of water birds against their values for axes 1 and 2, Sidi Fredj Complex Sites (Medjen Bouhsane, Medjen Djedj, Mkimen Marsh), northeastern Algeria

*2. ábra* A vízimadarak helyzetének ábrázolása az 1. és 2. tengely értékeinek függvényében a Sidi Fredj vizesélőhely-komplexum területén (Medjen Bouhsane, Medjen Djedj, Mkimen Marsh), Algéria északkeleti részén

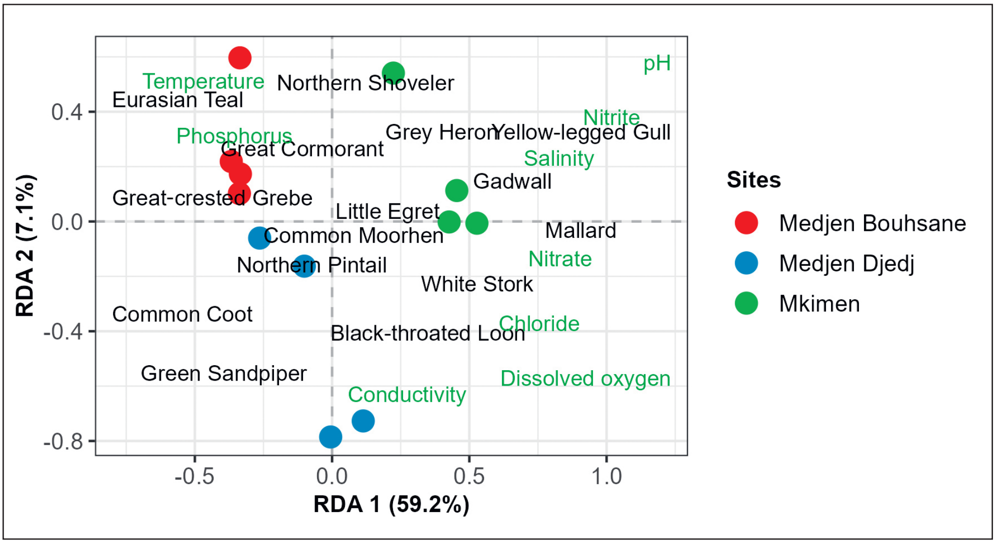


*Figure 3.* Ordination plot from a redundancy analysis (RDA) of the distribution of waterbirds in relation to environmental factors. The biplot of axes 1 and 2 is presented; the orientation of each variable in relation to each of these axes is presented by an arrow, the length of which indicates the degree of correlation with those axes in Sidi Fredj Complex Sites (Medjen Bouhsane, Medjen Djedj, Mkimen Marsh), northeastern Algeria

*3. ábra* A vízimadarak környezeti tényezőkkel kapcsolatos eloszlásának redundanciaelemzésből (RDA) származó ordinációs diagramja. Az 1. és 2. tengelyek biplotja látható; az egyes változóknak az egyes tengelyekhez viszonyított irányultságát egy-egy nyíl mutatja, amelynek hossza jelzi a korreláció mértékét az adott tengelyekkel a Sidi Fredj vizesélőhely-komplexum helyszínein (Medjen Bouhsane, Medjen Djedj, Mkimen Marsh), Algéria északkeleti részén

$p = 0.0624$, $p > 0.05$), as confirmed by the post-hoc analysis. The one-way ANOVA analysis showed that all measured physico-chemical parameters differed significantly among the three study sites. Specifically, significant differences were found for pH ($F = 4.243$, $p = 0.0323$), conductivity ($F = 5.597$, $p = 0.0375$), salinity ($F = 1.789$, $p = 0.0289$), chlorides ($F = 3.467$, $p = 0.0438$), nitrate concentration ($F = 8.345$, $p = 0.0266$), nitrite concentration ($F = 5.397$, $p = 0.0356$), phosphate concentration ($F = 2.678$, $p = 0.0145$), temperature ($F = 2.123$, $p = 0.0332$), and dissolved oxygen ($F = 2.345$, $p = 0.0234$) (all $p < 0.05$).

## Relationships among waterbird and physico-chemical parameters

Multivariate analysis revealed a strong influence of physico-chemical parameters on the spatial distribution of waterbirds. Principal Component Analysis (PCA) indicated that the first two axes explained 72.3% of the total variance *(Table 1)*.

The first component (56.7%) was positively correlated with pH, salinity, dissolved oxygen, chlorides, nitrate, and nitrite, and was associated with species such as Mallard, White Stork, Little Egret, Grey Heron *(Ardea cinerea)*, and Yellow-legged Gull, primarily at the Mkimen site. In contrast, temperature and phosphorus were negatively associated with PC1 and favored species like Northern Pintail, Northern Shoveler, Eurasian Teal, Common

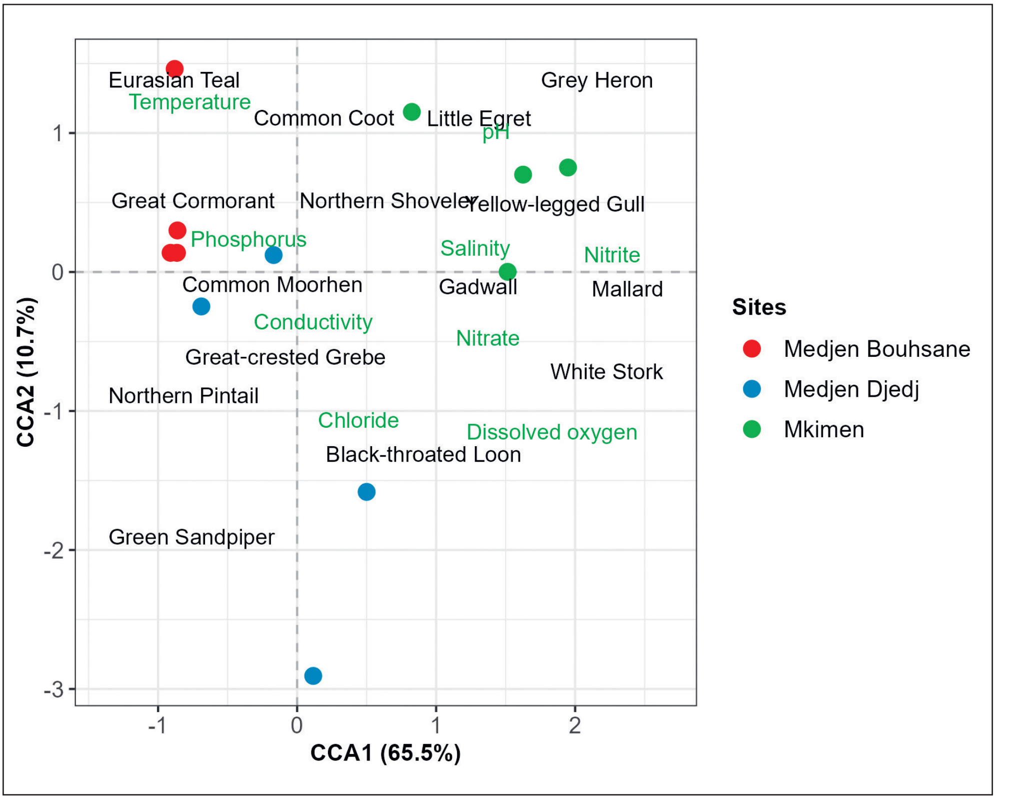


*Figure 4.* Association between different environmental factors and species composition of birds in Sidi Fredj Complex Sites (Medjen Bouhsane, Medjen Djedj, Mkimen Marsh), northeastern Algeria

*4. ábra* A különböző környezeti tényezők és a madárfajok összetétele közötti összefüggés a Sidi Fredj vizesélőhely-komplexum területén (Medjen Bouhsane, Medjen Djedj, Mkimen mocsár) Északkelet-Algériában

Coot, Great Cormorant *(Phalacrocorax carbo)*, and Great-crested Grebe *(Podiceps cristatus)* mostly observed at Medjen Bouhsane. The second component (15.6%) correlated positively with dissolved oxygen and chlorides, reflecting the environmental conditions of Medjen Djedj and species like Green Sandpiper *(Tringa ochropus)* and Black-throated Loon *(Gavia arctica) (Figure 2)*. Redundancy Analysis (RDA) revealed clear associations between waterbird species and environmental variables across the studied wetlands. Axis 1 was strongly and positively correlated with pH (RDA1 = 0.89, p = 0.001), nitrite (RDA1 = 0.92, p = 0.001), and dissolved oxygen (RDA1 = 0.82, p = 0.004). Species such as Little Egret (RDA1 = 0.15), Mallard (RDA1 = 0.44), White Stork (RDA1 = 0.24), and Yellow-legged Gull (RDA1 = 0.24) were positively associated with these environmental factors. Conversely, temperature showed a significant negative correlation with axis 1 (RDA1 = -0.59, p = 0.022), and species such as Great Cormorant (RDA1 = -0.11) and Northern Pintail (RDA1 = -0.12) were negatively related to this gradient. Axis 2 showed significant relationships with Temperature (RDA2 = 0.47, p = 0.022) and chlorides (RDA2 = -0.36, p =

0.109, not significant). Green Sandpiper (RDA2 = -0.13) and Northern Shoveler (RDA2 = 0.05) demonstrated associations along this axis, suggesting that conductivity, temperature, and other less significant variables may influence species distribution on this secondary gradient *(Figure 3)*.

Overall, these results highlight how specific environmental gradients particularly pH, nitrite concentration, dissolved oxygen, and temperature structure waterbird communities, with species distributions reflecting their ecological preferences for these factors *(Figure 4)*.

## Discussion

Waterbird species distributions in the Sidi Fredj wetlands are strongly influenced by environmental factors like pH, dissolved oxygen, temperature, and nutrients, which shape distinct community assemblages. Productive, oxygen-rich sites favor species such as Little Egret and Mallard, while cooler, less nutrient-rich areas support species like Northern Pintail and Great Crested Grebe.

Wetlands serve as critical habitats for waterbird communities by offering abundant food resources supported by high primary productivity (Weller 2004, Branco 2007, Gatto *et al.* 2008, Ebert *et al.* 2014). In the Sidi Fredj Complex, species were not randomly distributed but rather closely associated with specific environmental gradients, as revealed by multivariate analyses (PCA, RDA, CCA). These patterns underline the influence of physico-chemical variables such as pH, salinity, nutrients, temperature and oxygen availability on bird assemblages, as also suggested by King *et al.* (2010) and Brandolin and Blendinger (2016). At the Mkimen site, conditions characterized by higher pH, salinity, dissolved oxygen, and nutrient levels (nitrates, nitrites, chlorides) supported species such as Little Egret, Mallard, White Stork, Yellow-legged Gull and Grey Heron. These species benefit from productive and oxygen-rich waters, which promote the growth of aquatic invertebrates and fishkey food sources for waders and piscivorous birds (Pip 1979, Nagarajan & Thiyagesan 1996, Masifwa *et al.* 2001). For instance, high pH levels enhance phytoplankton and macroinvertebrate diversity, benefiting generalist foragers like Mallards, while higher nitrate and chloride concentrations contribute to the proliferation of amphibians and benthic invertebrates, favoring opportunistic feeders like the White Stork (Tuttle *et al.* 1984). Similarly, slight to moderate salinity may limit less tolerant species but still favor birds like the Yellow-legged Gull, which thrive in brackish environments due to their broader ecological tolerance (Hannam *et al.* 2003, Ma *et al.* 2010). At Medjen Djedj, species such as the Green Sandpiper and Black-throated Diver were more prevalent. These birds typically feed on aquatic macroinvertebrates and fish in shallow or moderately deep areas. Their association with higher dissolved oxygen and chloride concentrations likely reflects a preference for well-aerated wetlands that support active benthic communities (Masfiwa *et al.* 2001). In contrast, at Medjen Bouhsane, a distinct set of species including the Northern Pintail, Northern Shoveler, Common Coot, Great Cormorant, Great Crested Grebe, Common Scoter *(Melanitta nigra)* and Eurasian Teal was recorded. These birds were associated with relatively lower temperatures and phosphorus concentrations, which may reflect more stable, less eutrophic aquatic systems. Lower phosphorus levels can help maintain better water clarity, favoring species that rely on submerged vegetation (e.g. Common Coot) or on visual detection of prey (e.g. Great Crested Grebe, Great Cormorant. Species such as the Northern Pintail and Northern Shoveler, which are dabbling ducks, often prefer shallow waters with good water quality and diverse aquatic invertebrates, while diving birds like the Common Scoter and Great Cormorant are attracted to deeper waters with sufficient conductivity and ionic content that support fish populations (Hoyer & Canfield 1994, Nagarajan & Thiyagesan 1996). These preferences suggest that conductivity and nitrite levels can act as indicators of prey abundance and water quality for species that depend on aquatic fauna.

Furthermore, the diversity indices (Shannon, Simpson, Evenness and Species Richness) were significantly higher at Mkimen, likely due to its ecological heterogeneity and role as a migratory stopover for Afrotropical and Palearctic species (Kershaw & Cranswick 2003). These variations highlight that certain species are strongly influenced by pH and dissolved oxygen due to their effect on prey availability, whereas others are more responsive to temperature, salinity, or phosphorus, depending on their foraging strategy and physiological tolerance (Lovett *et al.* 2001).

Overall, the results confirm that the environmental parameters examined act as key ecological filters, determining the suitability of each wetland for different waterbird species by shaping food availability, habitat structure and water chemistry (Wright 1983).

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