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Urban Wetlands: A Case Study of Wild Waterbirds Social Behavior at Laalaligue Pond, Northeastern Algeria

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ABSTRACT

This study was conducted over three wintering seasons, for the years 2016-2017, 2017-2018, and 2018-2019 in the Laalaligue pond (an urban site in the city of Annaba, North-eastern of Algeria). The objectives were to conduct an inventory, a regular count of the birds, and to characterize the waterbirds population assemblage in the Laalaligue pond. During our study, we counted 10 families represented by 23 species. The most represented family is the Anatidae family with 7 species encountered. These species have shown different phenological statuses. Among them, 2 species are listed on the IUCN Red List as the Common Pochard (*Aythya ferina*) and the Ferruginous Duck (*Aythya nyroca*). Others are included in international bird protection agreements (AEWA, CMS) or are protected by Algerian legislation. Throughout the entire study, 8,745 individuals were recorded. The monthly evolution of the total population of this body of water shows that for the year 2016/2017, February 2017 is the most abundant with 936 individuals out of the 2079 recorded. The month of October 2016, on the other hand, is the least abundant with only 17 individuals. The count for the year 2017/2018 shows a total of 5,397 individuals, with the maximum abundance recorded in January 2017, reaching a population of 1,782 individuals. The month of May 2018 shows the lowest abundance with a total of 49 individuals. The year 2018/2019 was represented by only 1269 individuals in total. The month of December 2018 is the most abundant with a total of 346 individuals. The month of May 2019 is the least abundant with 30 individuals. According to our study, the majority of species left the Laalaligue site after the wintering period.

INTRODUCTION

Wetlands are areas of transition between land and water, constituting a remarkable natural heritage **(Hough, 2005)**. Through the Ramsar Convention, they are the subject of a specific convention which recognizes their importance and defines the elements of strategy for their conservation **(Bonnet *et al.*, 2005)**.

These environments are not only exceptionally rich in biodiversity and extremely productive; they also play major ecological and landscape roles, including freshwater conservation and management, flood control, recharge aquifers, trap toxic chemicals and recycle nutrients **(Keddy, 2000; Williams, 2006)**. In addition, these wetlands throughout the world provide a significant source of income for a growing population and therefore have significant socio-economic importance for local populations **(Raachi, 2007)**. Mediterranean wetlands are ranked among the richest ecosystems on the planet **(Quézel, 1998; Médail & Quézel, 1999)**. Indeed, the Mediterranean basin is one of the 25 «Hot spots» or «hot spots» of the planet, catalogued as an area of high biodiversity **(Myers *et al*., 2000; Zediri, 2015)**.

Urbanization changes landscapes in a profound way **(McDonnell & Pickett, 1990; Chamberlain *et al*., 2009)**, which led to a significant reorganization of the habitat and avifauna structure **(Shochat *et al*., 2006; Chamberlain *et al*., 2009)**. The turn of events and the excessive development of urban areas have really changed the environmental and ecological conditions of these habitats **(Partecke *et al*., 2005)**. More and more evidences indicate that humans are the main drivers of this change **(Sukopp *et al*., 1979; Gilbert, 1989; Pickett *et al*., 2001; Alberti *et al*., 2003; Goddard *et al*., 2010; Kowarik, 2011)**, hence species that have settled into these new ecosystems are exposed to considerable variations in environmental conditions relative to their "wild" conspecifics **(Partecke *et al*., 2005)**. To understand and predict how different species could respond to anthropization, **Chamberlain *et al*. (2009)** state that the effects of urbanization on wildlife must therefore be examined in depth in order to understand both the ecological consequences of increasing urbanization and how to mitigate its threat to global biodiversity. Urban landscapes encompass significant variations in bird habitat, from urban centers dominated by the built environment to suburban areas of low-density housing, often with a relatively high proportion of green space in the form of private parks or gardens. Nevertheless, urban landscapes as a whole differ widely and significantly from natural/semi-natural habitats **(Marzluff *et al*., 2001; Chace & Walsh, 2006)**. This difference includes, for example, food resources, weather conditions **(Haggard, 1990)** and disturbance in addition to increased noise levels **(Fuller *et al*., 2007; Chamberlain *et al*., 2009)**.

Birds are one of the wildlife groups that has become most acclimatized to urbanization, given their physical, physiological, ecological and behavioral adaptability. This leads us to avian urbanity **(Mahler & Magne**, **2010)**.

Waterbirds form a significant group among avian species, often forming gregarious communities that make them more conspicuous in wetland environments. This behavioral trait allows for easier observation and assessment **(Hamdi *et al.*, 2008; Bediaf *et al.*, 2020)**. Furthermore, waterbirds are considered excellent bioindicators of ecosystem health due to their sensitivity to environmental changes **(Skinner *et al.*, 1994; Cézilly & Hafner, 1995; Malaisse, 1997; Tassin & Rivière, 1998)**. As such, their presence and behavioral patterns can offer valuable insights into climatic variations and their resulting botanical and zoological impacts on local ecosystems **(Lougbégnon, 2002)**.

In Algeria, while the arid regions are home to extensive salt depressions (such as chotts, sebkhas, and oases), the majority of wetlands are located in the northeastern part of the country, near the Mediterranean coast **(Bouldjedri *et al.*, 2011)**. These wetlands support significant biological diversity that extends beyond ornithology, contributing to the broader ecological richness of the region **(Kadid *et al.*, 2007; Belouahem-Abed *et al.*, 2011; Zediri, 2015)**.

This study aimed to improve the understanding of the dynamics of natural bird populations within urban environments and to assess the impacts of urbanization on local biodiversity. To this end, the following objectives were established:

1. Conducting an inventory and regular monitoring of waterbird species visiting the Laalaligue pond, an urban wetland located in northeastern Algeria, during three wintering seasons: 2016/2017, 2017/2018, and 2018/2019.
2. Characterizing the structure and composition of the waterbird population inhabiting the Laalaligue pond.

MATERIALS AND METHODS

Presentation of the study area

The present study was conducted in the extreme northeast of the Algerian Tell, specifically within the Annaba Wilaya (between latitudes 36°30′N and 37°03′N, and longitudes 7°20′E and 8°40′E). This region lies approximately 600km east of the capital, Algiers, and features an 80km-long coastline along the Mediterranean Sea. Annaba covers a total area of 1,412km² and is geographically bordered to the North by the Mediterranean Sea, to the South by Guelma Wilaya, to the East by El-Tarf Wilaya, and to the West by Skikda Wilaya **(Belabed *et al.*, 2015; Belabed *et al.*, 2017)** (Fig. 1).

Study site: General description of the Laalaligue pond

The study was conducted at the Laalaligue pond over three consecutive wintering seasons: 2016/2017, 2017/2018, and 2018/2019. The pond is located in the municipality of El Bouni, approximately 7 kilometers from the capital of Annaba Wilaya, at coordinates 36°51′13.16″N and 07°45′17.65″E. Covering an area of 15 hectares, Laalaligue pond is a temporary urban wetland surrounded by residential and industrial developments. It is bordered to the West by National Road 16, to the East by a railway line, to the North by the Laalaligue neighborhood, and to the South by the CITAL Annaba company. The site is subject to considerable daily human activity due to its proximity to major transportation and industrial zones (Fig. 1)

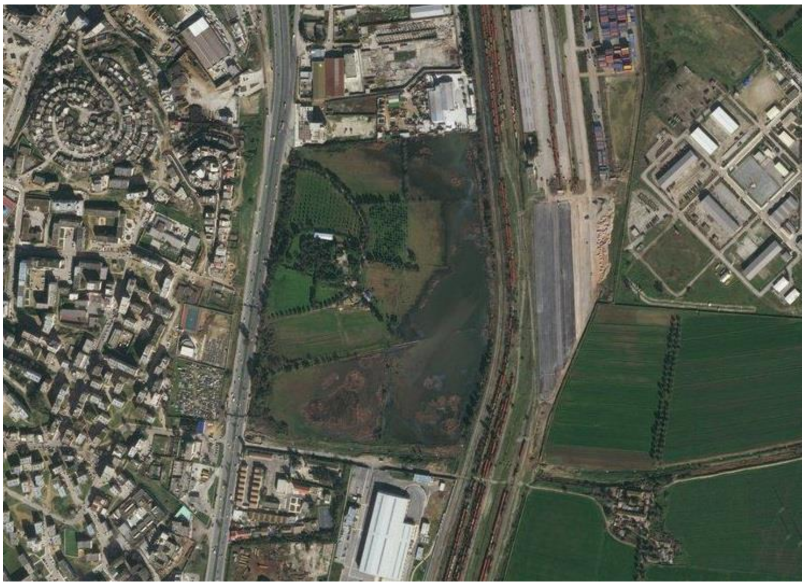

Fig. 1. Satellite map of the Laalaligue pond

Photos 1. and 2. The Laalaligue pond

Dates and frequencies of counts

Our study was conducted from October to May for three wintering seasons (2016/2017), (2017/2018) & (2018/2019). A total of fifty-six (56) field visits were conducted for the purpose of bird observation, at a rate of one visit per week. Four observation points were selected based on their accessibility and unobstructed visibility (one each in the North, East, West, and South) (Fig. 2). Each field session lasted eight hours, with two hours of bird counting conducted at each point.

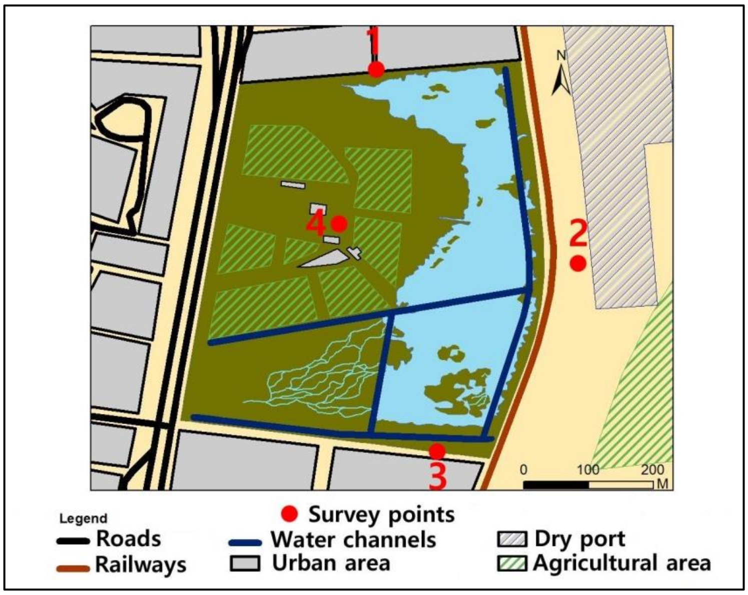

Fig. 2. Locations of waterbird survey points in the Laalaligue pond

Sampling methods

For all methods used in this study, bird counts were conducted based on the principle of individual enumeration or estimation. When bird groups were observed within a distance of less than 200 meters from the observation point and did not exceed 200 individuals, a direct individual count was performed. However, in case where the number of individuals exceeded 200 or the group was located beyond 200 meters, a quantitative estimation method was applied.

In this estimation approach, the visual field was divided into several bands. The number of birds in an average band was counted and then extrapolated by multiplying it by the number of bands covering the entire field of view **(Blondel, 1969; Lamotte & Bourlière, 1969; Bibby *et al.*, 1998)**. This method has a reported margin of error of approximately 5–10% **(Lamotte & Bourlière, 1969)**, with accuracy largely influenced by the observer's experience and the quality of the optical equipment used **(Legendre & Legendre, 1984; Tamisier *et al.*, 1999)**.

Equipment used

To conduct this study, a set of essential field equipments was employed to ensure accurate observation and reliable data collection. A pair of SBS VERGÜTET binoculars (6×50) was used to observe birds from a distance, minimizing disturbance to their natural behavior. Geographic coordinates of the observation points were recorded using a Garmin GPS device for precise spatial referencing.

Photographic documentation was carried out with a Nikon D7100 digital camera equipped with a 300mm zoom lens, enabling the capture of high-resolution images and videos critical for species identification and behavioral documentation. For field identification, the *Heinzel Pocket Guide to the Birds of Europe, North Africa, and the Middle East* was used as a primary reference, providing detailed visual and descriptive support for confirming species *in situ*.

The integration of these tools contributed to a rigorous methodological framework, supporting both qualitative observations and quantitative analyses throughout the study.

Ecological parameters

1. Abundance (N): A measure of the total number of individuals of all species.

2. Species richness (S): A simple measure of species richness. The species richness described by Blondel refers to the number of species recorded at least once in terms of N samples **(Blondel, 1975)**. This parameter gives a primary importance to dominant species **(Faurie *et al*., 2011)**.

3. Shannon's diversity index (H'): This is the most popular diversity index among ecologists. It is based on the information theory and is a measure of the average degree of uncertainty in predicting to what species an individual chosen at random from a collection of species *S* and *N* individuals will belong **(Poole, 1974)**. The Shannon's equation is:

$$\mathbf{H'} = -\sum_{i=1}^{S} p_i \log_2 p_i$$

Where, n_i is the number of individuals of the *i*th species in the sample and *n*, the total number of individuals in the sample **(Karydis & Tsirtsis, 1996)**.

4. Equitability index of Piélou (J'): It expresses the degree of equality in species abundance in the sample. The Equitability index reaches a maximum value when all species in the sample are equally abundant and decreases toward zero when the relative abundances of the species diverge away from equitability **(Ludwig & Reynolds, 1988; Karydis & Tsirtsis, 1996)**.

$$\mathbf{J'} = \frac{\mathrm{H'}}{\mathrm{H'}_{\mathrm{max}}}$$

Where, *H'* is the sample diversity and H'_{max}, the maximum sample diversity.

5. Dominance Index (C): An uniformity index and small diversity indicates a high dominance of a species against other species. The dominance index formula as follows **(Odum, 1971; Jalil *et al*., 2020)**.

$$C = \sum_{i=1}^{S} {p_i}^2$$

Where, *C*= Dominance Index, *pi*= The proportion of individuals in each species, *i*= 1, 2…, *n.*

Statistical analysis

The mean and standard deviation for each parameter were calculated using basic statistics using Microsoft Excel 2021 and the results are processed by parametric tests. The population assemblage characterization was performed using Past 5.1 software.

The counts of the species studied are treated by a multivariate analysis, a Principal Component Analysis (PCA) was performed using the R 4.4.3 software.

RESULTS

Composition of the population assemblage

Twenty-three species of waterbirds belonging to ten families were recorded over the three years of study. The Anatidae family was the most abundant during the first two years of study, with 7 species in total, including 5 species during the 2016-2017 and 2017-2018 years. In the final year, the Ardeidae family became the most abundant, with 3 species in 2018-2019 (Fig. 3).

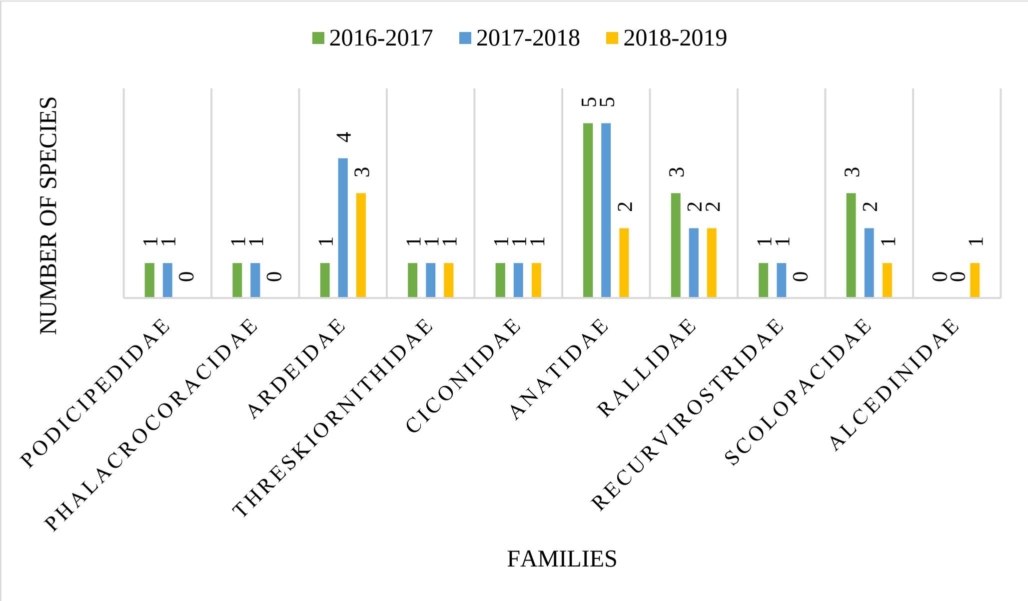

Fig. 3. Composition of the waterbird population in Laalaligue pond

Among the species recorded, two are listed on the IUCN Red List: Common Pochard (*Aythya ferina*) and Ferruginous Duck (*Aythya nyroca*), representing 9% of the species (Table 1). Twenty-two (22) species are protected under the AEWA agreement, representing 96% of the total number of waterbird species recorded (Fig. 4). Thirteen (13) species are listed in Annexes I and II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS), representing 57% of the total (Table 1).

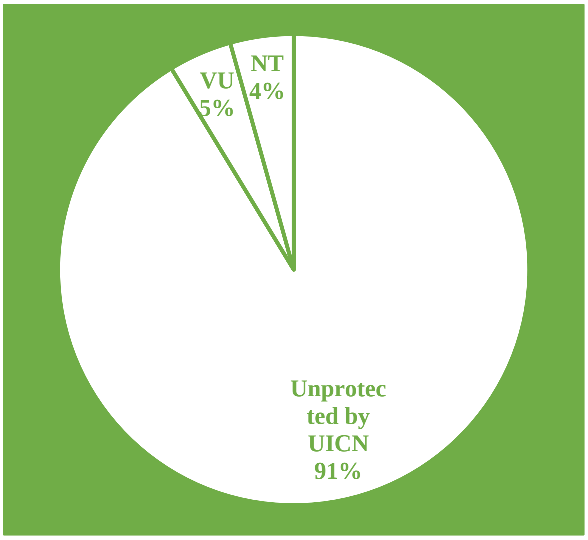

Fig. 4. Percentages of protected and non-protected species according to the IUCN red list categories. Abbreviations: VU: Vulnerable, QM: Near Threatened, EN: Endangered

Other species are protected by Algerian legislation, specifically Executive Decree No. 12-235 of the 24th of May, 2012, which sets the list of protected non-domestic animal species. Of the twenty-three (23) species inventoried during the study period, nine (09) are protected by Algerian legislation, representing 39%, while 14 are not protected, representing 61% (Fig. 5).

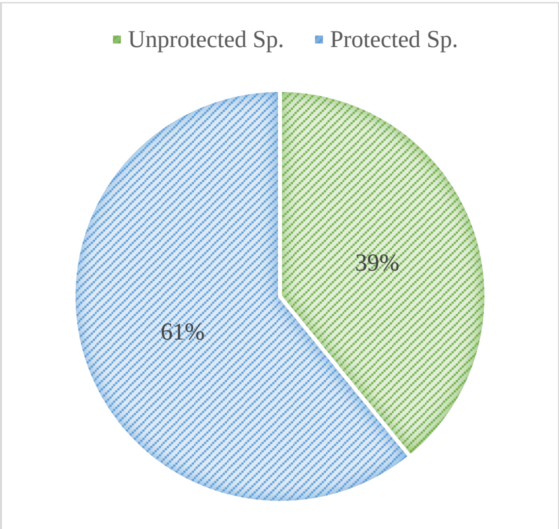

Fig. 5. Percentages of protected and non-protected species according to the Algerian legislations

Table 1. Check-list, phenological and protection status of wintering waterbirds identified at Laalaligue pond (Abbreviations: **WV**: winter visitor, **MB**: migrant breeder, **CB**: casual breeder, **RB**: resident breeder, **PV**: occasional visitor, **AV**: accidental visitor, **SB**: Summer breeder)

Family	Species	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Min.	Max.	Phenological Status	Protection Status
Podicipedidae	Little Grebe *Tachybaptus ruficollis*			X	X	X	X	X	X	3	16	RB	AEWA
Phalacrocoracidae	Great Cormorant *Phalacrocorax carbo*				X	X				1	2	WV	AEWA/Algerian legislation
Ardeidae	Squacco Heron *Ardeola ralloides*					X		X	X	1	10	SB	AEWA/Algerian legislation
	Western Cattle Egret *Bubulcus ibis*	X	X	X	X	X	X	X	X	1	59	RB	AEWA
	Little Egret *Egretta garzetta*		X	X			X	X		1	5	RB/WV	AEWA/Algerian legislation
	Grey Heron *Ardea cinerea*		X			X			X	1	2	RB	AEWA
Threskiornithidae	Glossy Ibis *Plegadis falcinellus*			X	X	X	X			1	21	RB/WV	AEWA/ CMS (A.II)/Algerian legislation
Ciconiidae	White Stork *Ciconia ciconia*			X	X	X	X	X	X	1	9	MB/WV	AEWA/ CMS (A.II)/Algerian legislation
Anatidae	Mallard *Anas platyrhynchos*		X	X	X	X	X	X	X	3	89	RB	AEWA
	Eurasian Teal *Anas crecca*	X	X	X	X	X	X			4	444	WV	AEWA
	Garganey *Spatula querquedula*							X		15	15	CB/ WV	AEWA
	Northern Pintail *Anas acuta*			X	X	X				7	22	WV	AEWA
	Northern Shoveler *Spatula clypeata*		X	X	X	X	X			22	464	WV	AEWA
	Common Pochard *Aythya ferina*					X				1	1	AV/WV	AEWA
	Ferruginous Duck *Aythya nyroca*					X				3	3	SB	AEWA/CMS (A.I)/UICN (Near Threatened)/Algerian legislation
Rallidae	Common Moorhen *Gallinula chloropus*	X	X	X	X	X	X	X	X	5	75	RB/WV	AEWA
	Western Swamphen *Porphyrio porphyrio*					X	X			1	1	RB/WV	Algerian legislation
	Common Coot *Fulica atra*	X	X	X	X	X	X	X	X	5	532	RB/WV	AEWA
Recurvirostridae	Black-winged Stilt *Himantopus himantopus*			X	X	X	X	X		5	196	RB/WV	AEWA/Algerian legislation
Scolopacidae	Common Snipe *Gallinago gallinago*	X	X	X	X	X	X	X		3	59	WV	AEWA
	Wood Sandpiper *Tringa glareola*							X		2	2	WV	AEWA
	Common Sandpiper *Actitis hypoleucos*					X	X	X		1	5	WV	AEWA
Alcedinidae	Common Kingfisher *Alcedo atthis*			X	X					1	2	RB	Algerian legislation

Phenological status of species

During the three years of the study, the pond was frequented by a large number of species showing different phenological status: seven (7) species of wintering visitors, six (6) species of resident breeder, as well as Migrant Breeders, Accidental Visitors, Casual Breeders and Summer breeders (Fig. 6).

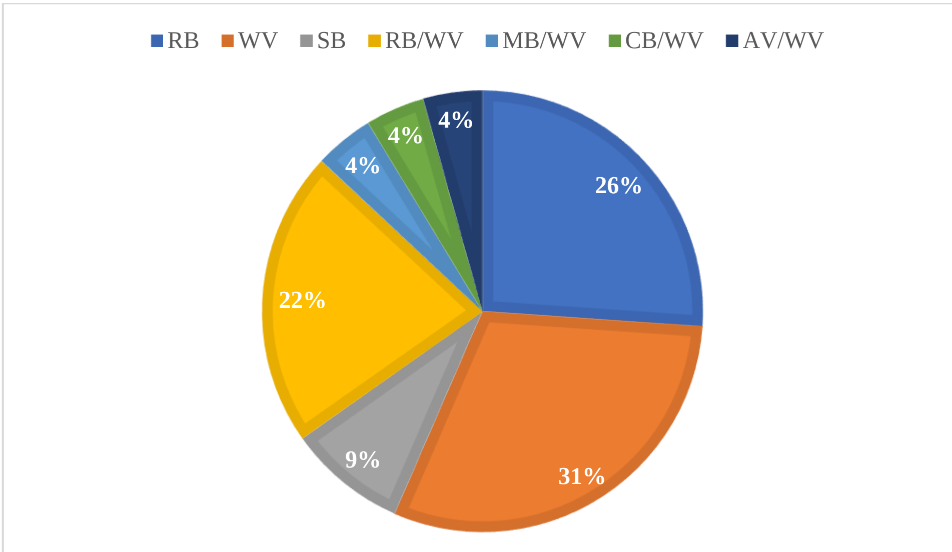

Fig. 6. Phenological status of the different waterbird species found in Laalaligue Pond. Abbreviations: (**WV**: Winter visitor; **MB**: Migratory breeder; **CB**: Casual breeder; **RB**: Resident breeder; **AV**: Accidental visitor; **SB**: Summer breeder)

Trends of ecological parameters

Abundance

During the study period, the maximum waterbird populations recorded in Laalaligue Pond were 936 individuals in February 2017 (first wintering season), 1,782 individuals in January 2018 (second season), and 346 individuals in December 2018 (third season). The most abundant species overall was the Common Coot (*Fulica atra*), with a cumulative total of 2,546 individuals across the three years. It was followed by the Eurasian Teal (*Anas crecca*) with 1,841 individuals and the Northern Shoveler (*Spatula clypeata*) with 1,454 individuals.

When analyzed by individual years, the Common Coot was the most numerous in both 2016–2017 (1,076 individuals) and 2017–2018 (1,366 individuals). In 2018–2019, however, the Eurasian Teal became the most abundant species, with 391 individuals. The least abundant species was the Common Pochard (*Aythya ferina*), represented by a single individual over the entire study period (Fig. 7).

A total of ten (10) species were consistently recorded across all three wintering seasons:

- Western Cattle Egret (*Bubulcus ibis*)
- Little Egret (*Egretta garzetta*)

- Grey Heron (*Ardea cinerea*)
- Glossy Ibis (*Plegadis falcinellus*)
- White Stork (*Ciconia ciconia*)
- Mallard (*Anas platyrhynchos*)
- Eurasian Teal (*Anas crecca*)
- Common Moorhen (*Gallinula chloropus*)
- Common Coot (*Fulica atra*)
- Common Snipe (*Gallinago gallinago*)

Some species were observed only in specific years:

- Only in the first year (2016–2017): Common Pochard (*Aythya ferina*), Ferruginous Duck (*Aythya nyroca*), Western Swamphen (*Porphyrio porphyrio*), and Wood Sandpiper (*Tringa glareola*).
- Only in the second year (2017–2018): Squacco Heron (*Ardeola ralloides*), Garganey (*Spatula querquedula*), and Northern Pintail (*Anas acuta*).
- Only in the third year (2018–2019): Common Kingfisher (*Alcedo atthis*).

Certain species, such as the Common Moorhen (*Gallinula chloropus*), maintained a relatively stable presence throughout the study period, with only slight fluctuations in numbers. In contrast, other species showed a clear increasing trend in population, including:

- Western Cattle Egret (*Bubulcus ibis*)
- Little Egret (*Egretta garzetta*)
- Grey Heron (*Ardea cinerea*)
- White Stork (*Ciconia ciconia*)
- Eurasian Teal (*Anas crecca*)
- Common Snipe (*Gallinago gallinago*)

This increase may reflect improved availability of breeding habitats or other favorable ecological conditions.

Conversely, several species showed a marked decline during the study period, such as:

- Little Grebe (*Tachybaptus ruficollis*)
- Great Cormorant (*Phalacrocorax carbo*)
- Glossy Ibis (*Plegadis falcinellus*)
- Mallard (*Anas platyrhynchos*)
- Northern Shoveler (*Spatula clypeata*)
- Common Coot (*Fulica atra*)
- Black-winged Stilt (*Himantopus himantopus*)
- Common Sandpiper (*Actitis hypoleucos*)

These seasonal variations in abundance may be attributed to factors such as migratory patterns, shifts in habitat conditions, or fluctuations in food availability.

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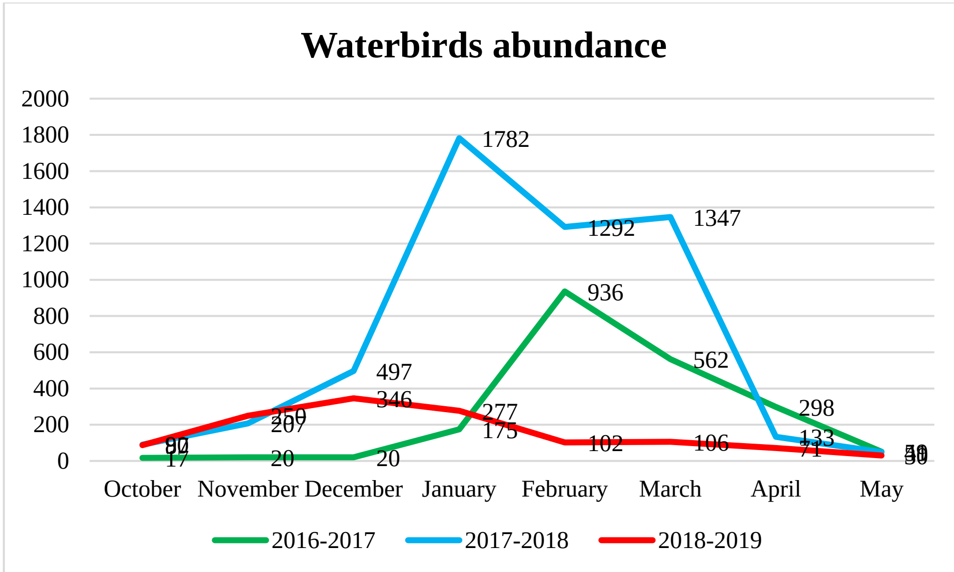

Fig. 7. Changes in waterbird abundance in Laalaligue Pond during the study period (2016/2017 – 2017/2018 – 2018/2019)

Species richness (S)

From a species diversity perspective, Laalaligue Pond was frequented by a total of twenty-three (23) waterbird species over the entire study period. In the first wintering season (2016–2017), species richness was relatively low from October to January, followed by a sharp increase in February, reaching a peak of seventeen (17) species. This peak was subsequently followed by a gradual decline until May.

During the second season (2017–2018), a steady increase in species richness was recorded from October through February, culminating in a maximum of fourteen (14) species, after which richness declined gradually toward May. In the third season (2018–2019), species richness increased at a more moderate pace compared to previous years, reaching a plateau of approximately ten (10) species in December 2018, followed by a decline to a minimum of four (04) species in May 2019 (Fig. 8).

From an ecological standpoint, the winter peaks in species richness observed in January and February likely reflect favorable climatic conditions and the seasonal arrival of migratory species. The period 2016–2017 appears to be atypical due to the pronounced February peak, which may be attributed to exceptional weather conditions, changes in habitat or food resource availability, or other ecological disturbances. In contrast, the relatively stable pattern observed in 2018–2019 suggests more consistent environmental conditions, with fewer fluctuations influencing species presence.

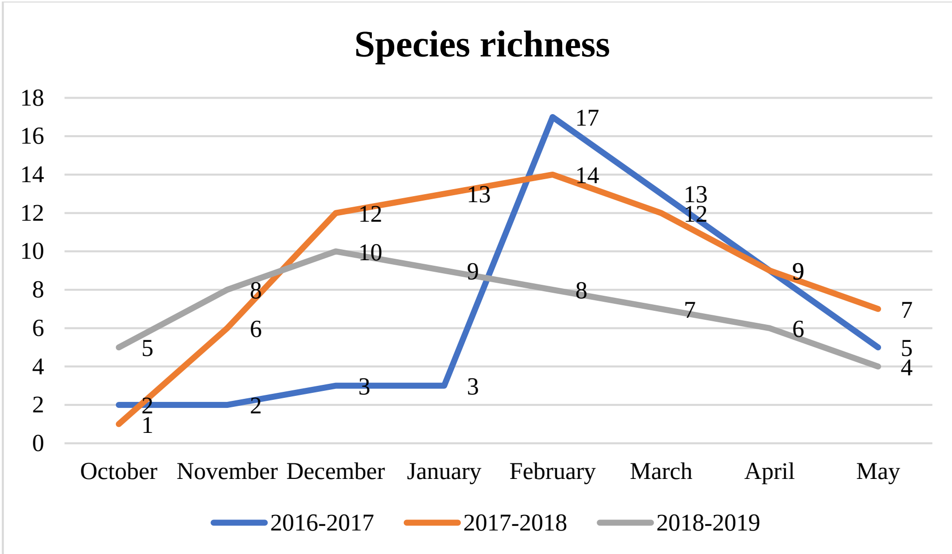

Fig. 8. Changes in waterbird species richness in Laalaligue pond during the study period (2016/2017 – 2017/2018 – 2018/2019)

Shannon's diversity index (H')

The Shannon diversity index (H') mirrored the variations in species richness and evenness across years. In 2016–2017, diversity was low in autumn, with few species recorded, but improved toward spring as migratory waterbirds like *Anas crecca*, *Anas platyrhynchos*, and *Gallinago gallinago* increased in number. In 2017–2018, a substantial rise in diversity was observed from November onward, peaking in March with numerous individuals of *Spatula clypeata*, *Anas crecca*, and *Gallinula chloropus*, indicating a more complex and diversified community. During 2018–2019, the Shannon index remained relatively high throughout the season, supported by a consistent presence of species such as *Anas crecca*, *Fulica atra*, and occasional appearances of Squacco Heron (*Ardeola ralloides*) and Glossy Ibis (*Plegadis falcinellus*) (Table 2).

Equitability index of Piélou (J')

Equitability, reflecting the balance of species abundances, increased progressively each year. In 2016–2017, despite the dominance of *Fulica atra* and *Anas platyrhynchos*, equitability rose during spring when more species such as *Gallinago gallinago* and *Spatula clypeata* contributed to the community. The 2017–2018 season showed a moderate but steady improvement in equitability, reaching 0.9199 in May, as various species such as *Anas crecca*, *Spatula clypeata*, and *Gallinula chloropus* maintained stable populations. In 2018–2019, equitability values were particularly high, often exceeding 0.9, reflecting a more balanced bird community where no single species overwhelmingly dominated, highlighting a healthier and more resilient ecosystem (Table 2).

Dominance index (C)

The dominance index varied considerably across the three monitoring periods and was strongly influenced by the abundance of certain key species. During 2016–2017, dominance was relatively high, peaking at 0.82 in November, largely due to the overwhelming presence of *Fulica atra* (Common Coot), reaching 532 individuals in February. Other dominant species included *Anas platyrhynchos* (Mallard) and *Anas crecca* (Eurasian Teal), particularly noticeable in late winter. In 2017–2018, the season started with maximum dominance (1) in October, reflecting an extremely unbalanced community, but quickly decreased as species such as *Anas crecca*, *Spatula clypeata* (Northern Shoveler), and *Gallinula chloropus* (Common Moorhen) became more abundant and diversified. During 2018–2019, dominance values remained low and stable, thanks to a more balanced distribution of species such as *Anas crecca*, *Common Snipe* (*Gallinago gallinago*), and *Fulica atra* (Table 2).

Table 2. Changes in Shannon's diversity, equitability and dominance indexes of waterbird species in Laalaligue pond during the study period (2016/2017 – 2017/2018 – 2018/2019)

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Shannon 2016-2017	0,3622	0,3251	0,746	0,7337	1,553	1,98	1,459	1,252
Shannon 2017-2018	0	1,262	1,552	1,819	1,808	1,861	1,664	1,79
Shannon 2018-2019	1,536	1,775	1,528	1,639	1,624	1,801	1,695	1,357
Equitability 2016-2017	0,5226	0,469	0,6791	0,6679	0,548	0,7719	0,6642	0,7776
Equitability 2017-2018	/	0,7043	0,6247	0,7091	0,6851	0,7491	0,7575	0,9199
Equitability 2018-2019	0,9541	0,8536	0,6637	0,7461	0,7809	0,9257	0,9458	0,9788
Dominance 2016-2017	0,7924	0,82	0,555	0,5886	0,3552	0,1906	0,3094	0,3533
Dominance 2017-2018	1	0,3424	0,2634	0,2038	0,2159	0,1873	0,2623	0,182
Dominance 2018-2019	0,2274	0,1873	0,2966	0,2552	0,232	0,1823	0,1934	0,2644

Principal component analysis (PCA)

The principal component analysis (PCA), conducted based on the monthly abundances (February to May 2017) of the twenty-three (23) species of waterbirds, highlights several distinct groups according to their seasonal dynamics. Each group is characterized by a set of twenty-four variables (Months). The first two factorial axes account for 53.45% and 21.42% of the variance, or about 74.87% of the total variance. Only the first two axes were retained for interpretation of the analysis. The dot-area is proportional to the values taken by the variables.

Projected onto the F1xF2 Plan, point clouds are structured into three distinct groups (Fig. 9). The first axis F1 (53.45%) captures a seasonal variation, with opposite months indicating a difference between seasons. The spring/summer months could be positively correlated with certain species, while the winter months would be the opposite. This axis contrasts species with high spring abundance, such as the Western Cattle Egret, Mallard, and Common Coot, with species that are poorly represented or sporadic, such as the Great Cormorant, Squacco Heron, and Little Egret. This gradient probably reflects a distinction between sedentary or locally breeding species active in spring, and wintering or occasional species.

The second axis F2 (21.42%), reflects an interannual variation (differences between years). This axis, on the other hand, weakly differentiates species according to more subtle monthly occurrence patterns, but allows for the distinction of certain early or transient breeders like the Little Grebe.

On this basis, we can propose three groups:

(1) a "spring abundant" group including Western Cattle Egret, Mallard, Common Moorhen, and Common Coot, all well represented in March-April;

(2) a "occasional" or "rare" group consisting of species with very low or absent presence such as Garganey, Northern Pintail, and Ferruginous Duck; and

(3) a "discreet-wintering" group including Great Cormorant, Glossy Ibis, and Little Egret. These results suggest differentiated ecological strategies related to reproductive phenology, habitat preferences, or migratory patterns.

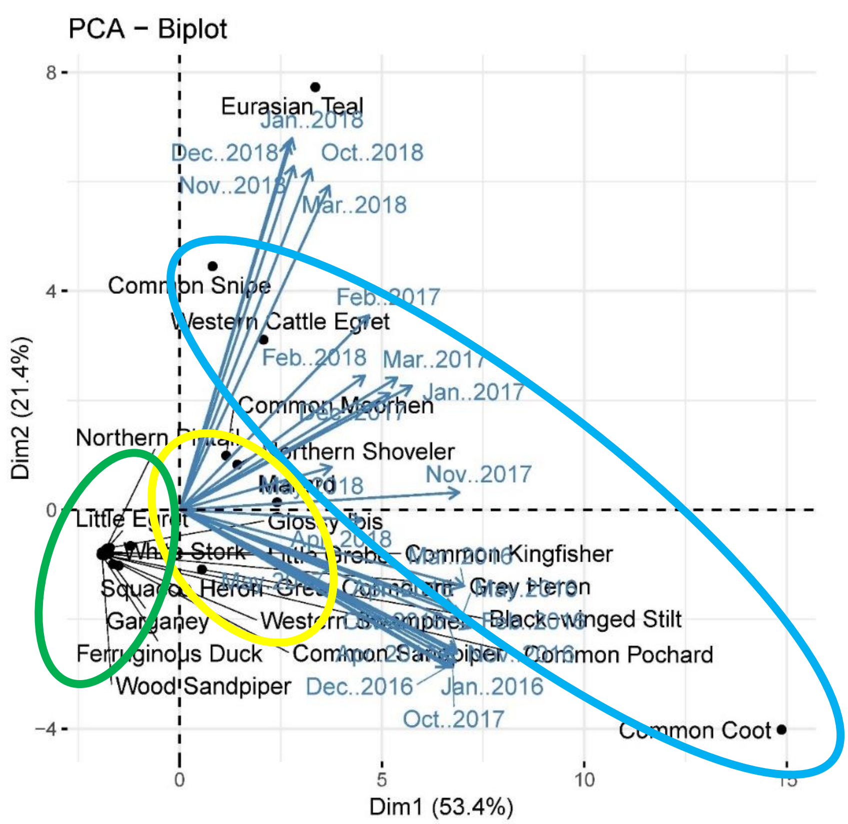

Fig. 9. Biplot of principal components (F1 x F2) showing seasonal and interannual patterns of waterbird species based on monthly abundance in Laalaligue pond during the study period (2016/2017 – 2017/2018 – 2018/2019)

DISCUSSION

The Laalaligue pond emerges as a critical wintering and stopover site for migratory waterbirds within the urban context of Annaba, northeastern Algeria. Over the course of three wintering seasons (2016–2019), the pond was frequented by 23 waterbird species representing several taxonomic families, notably Anatidae, Ardeidae, and Scolopacidae. These findings are consistent with observations from other Mediterranean wetlands, where shallow water bodies rich in emergent vegetation serve as preferred habitats for migratory waterbirds **(Green *et al.*, 2017; Gaget *et al.*, 2018)**.

Interannual comparisons reveal significant spatiotemporal variation in both species composition and community structure. The 2016–2017 season was marked by high dominance (index > 0.5 in several months), primarily due to the overwhelming presence of Fulica atra (Common Coot). Such dominance may be linked to favorable hydrological conditions and high food availability, as supported by findings from **Guillemain *et al.* (2021)**.

In contrast, the 2017–2018 and 2018–2019 seasons showed a clear decline in dominance, suggesting a more balanced species composition. This trend was reflected in higher Shannon diversity indices (values > 1.5), accompanied by increased evenness, particularly during spring. These ecological patterns are likely associated with seasonal changes in food resources and partial pond desiccation, both of which promote habitat heterogeneity. The observed structure aligns with the dynamics reported in larger Mediterranean wetlands such as Doñana National Park in Spain, which hosts over 80 waterbird species with significant year-to-year variation depending on rainfall **(Rendón *et al.*, 2008; Green *et al.*, 2017)**.

Numerically, the Anatidae family dominated, reflecting trends across Mediterranean wetlands **(Gaget *et al.*, 2020)**. Species such as *Anas crecca* (Eurasian Teal) and *Spatula clypeata* (Northern Shoveler) were particularly abundant during wetter winters. These results support earlier observations that associate benthic resource availability, enhanced by winter floods, with higher duck abundance **(Dubois *et al.*, 2021)**.

In addition to ducks, the consistent presence of Ardeidae species (e.g., *Ardeola ralloides*, *Bubulcus ibis*, *Egretta garzetta*, *Ardea cinerea*) and Scolopacidae species (e.g., *Gallinago gallinago*, *Tringa glareola*, *Actitis hypoleucos*) underscores the site's functional diversity. Ardeidae species were particularly prominent in April and May, suggesting adaptive responses to lower water levels that facilitate foraging **(Perennou, 2020)**.

Seasonal trends further confirmed that abundance peaks generally occurred between December and March, coinciding with the core wintering period of many Palearctic migrants. The presence of spring migrants, such as *Spatula querquedula* (Garganey) and *Ardeola ralloides* (Squacco Heron), highlights the pond's role as a migratory stopover.

Beyond species richness, community composition and structural indicators provide insight into habitat quality. The high evenness observed in spring 2019 (values > 0.9) suggests relatively undisturbed conditions and good ecological integrity **(Green & Elmberg, 2014)**. However, the low occurrence of species like ***Aythya nyroca*** (Ferruginous Duck) and ***Porphyrio porphyrio*** (Western Swamphen)—both sensitive to disturbance—raises concerns about habitat degradation **(Belabed-Zediri *et al.*, 2020)**.

Moreover, the rarity of waders such as *Tringa glareola* (Wood Sandpiper) may reflect habitat constraints, particularly dense vegetation in spring, which limits the open muddy areas preferred by these species **(Ma *et al.*, 2022)**.

Climatic variation was also found to influence waterbird abundance. Wet winters were associated with higher diversity and greater use by open-water species, while drier winters led to greater dominance by generalist species. This reinforces the strong linkage between hydrological conditions and avian community dynamics, as demonstrated in broader Mediterranean wetland studies **(Pérez-Ruzafa *et al.*, 2024)**.

CONCLUSION

The analysis of bird communities frequenting Laalaligue pond over a three-year period revealed remarkable species richness, with a total of twenty-three (23) regularly recorded waterbird species, primarily belonging to the families Anatidae, Ardeidae, and Rallidae. This diversity showed notable seasonal and interannual fluctuations, as reflected in variations in the Shannon-Wiener index, species dominance, and evenness. These patterns point to a dynamic ecological system influenced by seasonal cycles, local climatic variability, and anthropogenic pressures.

For more generalized conclusions, future research should incorporate multi-seasonal monitoring, expand time intervals for observation, and increase sampling frequency. Such enhancements would improve the understanding of species turnover, breeding behavior, and the role of Laalaligue pond as a migratory stopover.

Despite its ecological value, Laalaligue pond is subject to considerable environmental threats, including industrial pollution, overgrazing, drainage, and untreated wastewater discharge. These pressures endanger the pond’s stability and the long-term viability of its biodiversity. Urgent and coordinated conservation measures are needed to mitigate these impacts.

In conclusion, the findings of this study contribute significantly to the knowledge of urban aquatic avifauna in a previously unstudied area. They support the designation of Laalaligue pond as a conservation priority site. Integrating these results into a broader conservation strategy—especially one that involves local stakeholders—could enhance the ecosystem's resilience to environmental change.

Adopting adaptive management practices for Laalaligue pond is recommended. This would include comprehensive hydrological monitoring and limiting direct human impacts such as drainage, recreational pressure, and urban encroachment. Similar approaches have been successfully implemented in other Mediterranean wetlands, such as the Camargue (France) and Albufera (Spain), where adaptive management programs have led to improvements in species richness and ecosystem service provision.

As a vital element of the urban wetland network in Annaba, Laalaligue pond warrants focused attention to ensure the continuity of its ecological functions, particularly in supporting Palearctic migratory routes. The patterns observed in bird diversity and abundance provide actionable insights for urban biodiversity conservation and planning, especially within rapidly urbanizing regions.

We propose the following practical recommendations:

- Establish bird refuges within or adjacent to urban zones;
- Regulate human activity, particularly during sensitive periods such as breeding or migration;
- Integrate wetland conservation into broader urban planning and sustainability initiatives.

These suggestions align with global efforts advocating for biodiversity-sensitive urban design and nature-based solutions. Protecting and sustainably managing Laalaligue pond not only supports avian biodiversity but also reinforces the ecological infrastructure of urban Annaba, contributing to regional and migratory conservation goals.

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