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Evaluation of changes in the Sebkhet of Aures wetlands complex by remote sensing and their importance for the reception of Anatidae

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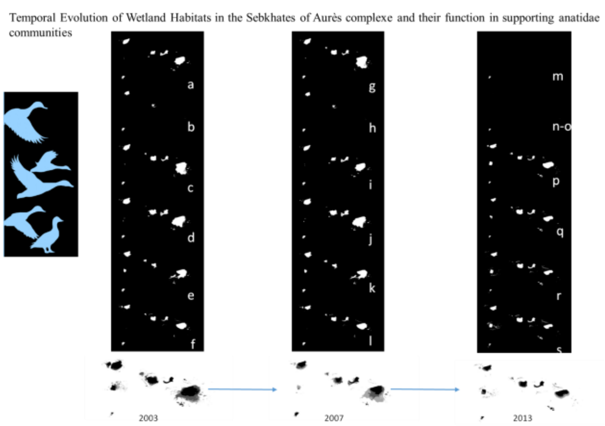
Graphical abstract



Abstract

By employing spatial observation methods and analyzing satellite imagery on both intra- and inter-annual scales, we were able to delineate the boundaries of the Sebkhet of Aurès Wetlands Complex (SAWC) located in northeastern Algeria. The study focused on seven major wetlands, encompassing a total surface area of 48,540 hectares, with altitudes ranging from 370 to 900 meters, which supports a high level of ecological diversity. The treatment, by classifying the water surfaces and the wet surfaces present on 19 images used, enabled to visualize the variation within the timeframe of each site submersion. The results indicated that precipitation is the primary factor driving these variations. In 2003, an annual precipitation of 502.06 mm corresponded to a total flooded area of 30,305.15 hectares. By 2007, with rainfall dropping to 340.7 mm, the inundated surface declined to 27,090.14 hectares, marking a 10.6% reduction. This downward trend continued in 2013, when precipitation further decreased to 304.8 mm, and the flooded area contracted significantly to 16,736.16 hectares, a 44.8% decrease over the 11-year period. This study investigates whether fluctuations in wintering duck numbers are linked to both total wetland area and the extent of main habitat types. Population counts from 2003, 2007 and 2013 were compared with temporal changes in open-water and flood-prone surfaces, derived from satellite imagery and GIS analysis. The results indicated that, besides the surface area of flooded zones being a key condition for supporting large numbers of waterfowl, factors such as safety, the absence of disturbances and predators, and the availability of food are also crucial in attracting these species.

Keywords: Wetlands, flooded area, precipitation, wintering ducks, remote sensing.

1. Introduction

Wetlands are dynamic and complex ecosystems that vary significantly across different regions and climates. To effectively assess and monitor their status and trends, it is essential to obtain timely and accurate information on their spatial and temporal characteristics (Luo *et al*. 2024). For a long time, the Mediterranean wetlands have been damaged, or heavily regained, for agricultural purposes, improvement of tourist areas and perceived health benefits (Parrinello and Bécot, 2019). During the last twenty years, the Mediterranean region has lost more than half of its wetlands (Bonnet *et al*. 2005; Taylor *et al.* 2021). Considered as a hot spot area (Adloff *et al.* 2015), Mediterranean wetlands and their biodiversity are in sharp decline in recent decades (Perennou *et al.* 2012) and their degradation is faster than that of any other ecosystem (Davidson, 2014).

Algeria ranks 4th in terms of wetland surface area among 27 Mediterranean countries (Taylor *et al*. 2021), and where its water resources are limited and depend on the influence of the climate (Touitou and Al-Aminb, 2020). In the last survey carried out by the General Direction of Forests, Algeria records 2,375 wetlands, 2,056 are natural and 319 are artificial including 50 wetlands of international importance (Ramsar, 2019). These wetlands play an important role in vital processes, maintaining hydrological cycles and housing an important flora and fauna (Gherzouli, 2013). They offer numerous invaluable services for ecosystems and society, e.g., controlling runoff, floods, erosion, and nutrient recycling, as well as providing people with food, animal fodder, raw materials, water for drinking and household use, and crop irrigation (Bougoffa *et al.* 2023).

The Sebkhat of Aures wetlands complex (SAWC) in northeastern of Algeria is one of the 16 wetland complexes that are important for the conservation of local and regional biodiversity (Boulkhssaim *et al*. 2009; Seddik *et al.* 2010; Bougoffa *et al.* 2023; Benzina *et al.* 2024). These habitats play a critical role as a wintering area for migratory birds and breeding area for rare and endangered species in the Palearctic and the world (Bouaguel, 2014; Benzina *et al.* 2022). Given its complex and variable climate, the SAWC plays a crucial role in shaping hydrological cycles, land use patterns and ecosystem functions. Therefore, most of these ecosystems are ephemeral and fill with water only for a short period of the year, often during winter (Houhamdi *et al.* 2009; Benzina *et al.* 2021). Despite their intermittency, they are recognized as winter habitats for surface ducks, waders and coots (Bougoudjil, 2016).

The use of satellite imagery for wetland inventories and monitoring offers a great potential because of repeated, homogeneous coverage of large areas (Dadaser-Celik *et al.* 2008; Ozesmi and Bauer, 2002; Rebelo *et al.* 2009; Rosenqvist *et al.* 2007). One of the primary reasons for monitoring Mediterranean wetlands, particularly in semi-arid regions, is to assess changes in habitat size and their impact on biodiversity. Among the species found in Mediterranean wetlands, a significant proportion is endemic, and many species listed as endangered rely on these natural wetland environments (MWO, 2012; Riservato *et al.* 2009).

RS (remote sensing) technology has become a robust asset for this purpose, offering extensive and high-resolution data on the distribution and types of wetlands. Nevertheless, current wetland RS products, mainly available at global or continental scales, face challenges in accurately capturing local variations and dynamics with high spatial and temporal resolution (Luo *et al.* 2024). Landsat data have been used in many studies on wetlands (Thomas *et al.* 2011), including the classification of wetlands (Berberoglu *et al.* 2004; Castaneda and Ducrot, 2009) and change detection (Baker *et al.* 2007; Kassawmar *et al*. 2011; Nielsen *et al.* 2008). Hence, the lack of remote sensing studies in our study area shows the urge of extensive remote sensing research.

This study aims to evaluate and monitor, for the first time, changes in the wetland areas of the SAWC during the reference years of 2003, 2007 and 2013, utilizing remote sensing and GIS technologies. Our objective is to compare these findings with the changes in duck populations, drawing on statistical data related to waterbirds. These findings provide essential scientific backing and create a strong foundation for decision-making in wetland conservation and management, aligning with the objectives of sustainable development.

2. Materials and methods

2.1. Overview of the study region

The SAWC is located in the Algerian northeastern highlands between 800 and 1200 m asl. It extends over 100.3 km (north to south) and 278 km (east to west), with an effective surface area of 16,020 km^2 and a perimeter of 942.3 km (DGF, 2016). This extensive area encompasses the whole watershed of the Constantinois high plateau (9,578 km^2), and a significant portion of the Medjerda basin (7,870 km^2) of its Algerian section, extending into Tunisia. The region is characterized by vegetation that is resistant to salinity and drought (Bensizerara *et al.* 2013). The weather of the region is influenced by its location in an ecotone region, straddling between semi-arid and arid climate with humid variants in high altitude. The area suffers a long period of summer drought which dries out wetlands from May to November. Over the past 20 years, the mean of daily maximum temperatures (± SD) was 36.9 ± 2.04 °C, and minima were 8.94 ± 0.38 °C. Annual precipitation varies from year to year (160.8 to 362.2 mm) with a very irregular seasonal distribution (Bougoffa *et al*. 2023).

Table1. General characteristics of the studied wetlands in the Sebkhet Aures wetlands complex (North-East of Algeria).

Name	International code *	Date of designation	Elevation(m) / Area (ha)	Water salinity
Gareat El Taref	1DZ 034	12 December 2004	830 / 33460	Salt water
Garaet Guellif	1DZ 035	12 December 2004	890 / 24000	Salt water
Sebkhet Ezzmoul	1DZ 045	18 December 2009	800 / 6765	Salt water
Chott Tinsilt	1DZ 031	12 December 2004	792 / 2154	Brackish water
Garaet Annk Djemel & El Merhsel	1DZ 033	12 December 2004	844 / 18140	Brackish water
Sebkhet Djendli	-	Not classified	836 / 3700	Salt water
Koudiet Medaouar dam	-	Not classified	395 / 590	freshwater

The SAWC contains many natural wetlands (garaets, sebkhets and chotts) and artificial wetlands (dams, reservoirs, basins), that play a key role in wintering and breeding of many species of waterbirds during their migratory transit. The majority of which are shallow, ranging in size from a few hectares to hundreds of thousands of hectares (DGF, 2016).

This study focused on seven sites: Gareat El Taref, Gareat Guellif, Sebkhet Ezzmoul, Chott Tinsilt, Garaet Annk Djemel & El Merhsel, which are classified as Ramsar sites and are located in the administrative department of Oum el Bouaghi covering a total area of 44,250 ha. The other two sites Sebkhet Djendli and Koudiet Medaouar dam are located in Batna province, covering an area of 4,290 ha. Location, land cover and general characteristics of the seven studied sites are provided in **Table 1** and **Figure 1**.

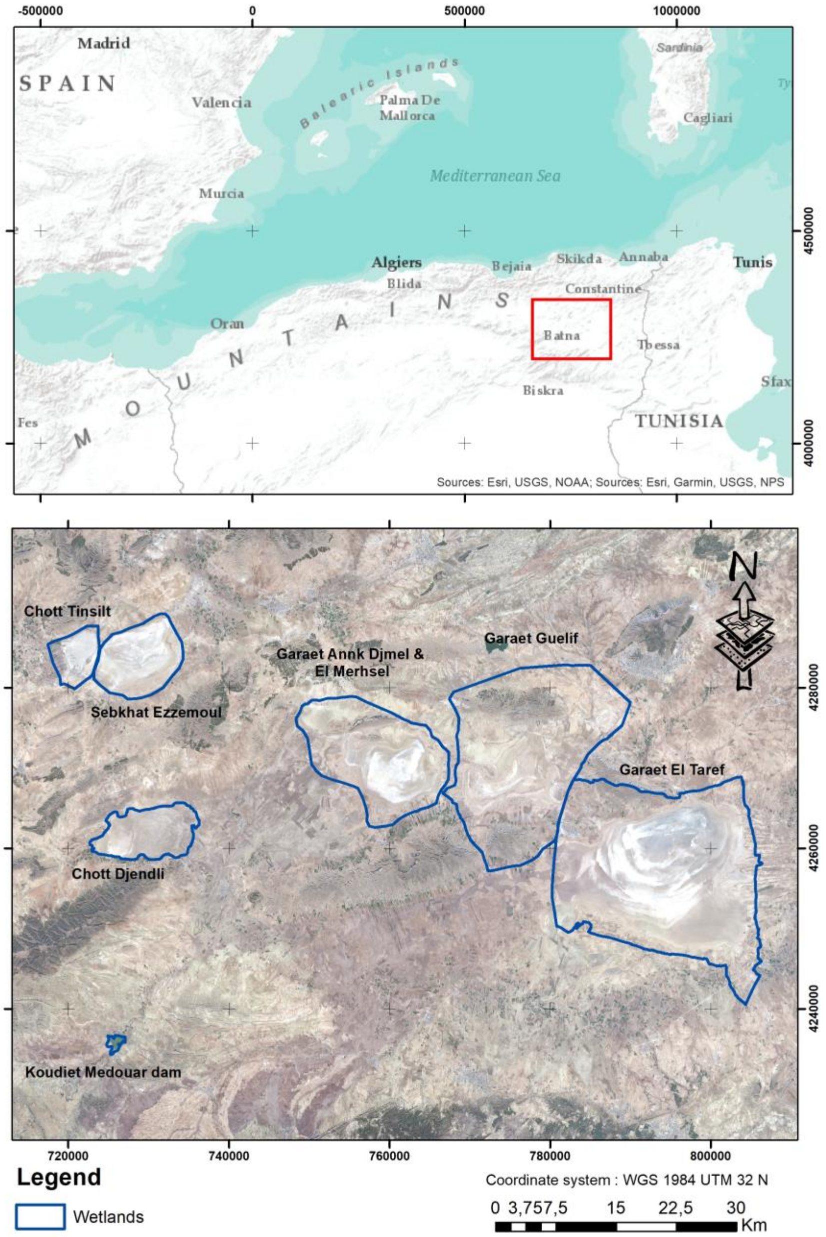


Figure 1. Location of the studied wetlands in the Sebkhet Aures wetlands complex (North-East of Algeria).

2.2. Data acquisition and processing

The spatiotemporal assessment of water surface was carried out using nineteen images sourced from the Landsat satellite (TM, ETM and OLI_TIRS). A Landsat TM image, which possesses a resolution of 30 meters, includes seasonal data from 2003, 2007 and 2013. Due to the issue of cloud cover: Satellite images are often disrupted by cloud cover, especially in wetlands where the climate is humid. To ensure phenological continuity, two additional dates were added: December 2002, which is close to January 2003, and January 2014, which is close to December 2013. This minimizes seasonal variations and ensures complete spatial coverage for the analysis.

This information was acquired from Earth Explorer, a platform overseen by the United States Geological Survey (USGS) at http://earthexplorer.usgs.gov/, using the download tool to support our time series analysis. Our study area is located on a Landsat scene (path: 193, row: 35). Each image was visually rated for quality, and only cloudless images were chosen (**Table 2**).

2.3. Mapping the spaciotemporel dynamics of water surface

In order to delimit and highlight flooded areas, a thresholding treatment was performed for each image. This pretreatment was carried out from the Middle Infrared (MIR) channel, which reacts specifically in wetlands highlighting water surfaces and the vegetation with high water content. This treatment was performed by calculating the normalized difference of water index (NDWI) (Gao, 1996).

The MIR channels of the spectral images acquired was treated in Arcgis 10 software in order to be reclassified with the pixel codes of the "water" class defined by thresholding. The reclassification algorithm-processing module "Spacial Analyst" reclassify the extent of the threshold "water" as a new pixel value of 1. All other pixels were reclassified as value 0 corresponding to no water plots. The resulting image is characterized by a binary pixel coding: 0 for dry plots and 1 for wet plots. This image result was used to identify and delineate the flooded areas.

The sum of the various images that were reclassified earlier was assessed utilizing the Raster Calculator algorithm provided by this module. The pixel value of the image thus obtained after calculation corresponds to the sum of the pixel values of each image. The latter ranged from 0, indicating the absence of water pixels in any image, to N which represents the total number of pixels inundated across all analyzed dates. Here, N corresponds to the number of images analyzed; the regression model produced a map with a gradient of colors (Davranche *et al.* 2013).

2.4. Grouping of Anatidae and environmental factors

In our study we opted for the monitoring of Anatidae family over three winter seasons. Our observations conducted in mid-January during the years 2003, 2007, and 2014 indicated the presence of nine species: *Tadorna tadorna* (Belon shelduck), *Casarca ferruginae* (Shelduck casarca), *Anas platyrhynhos* (Mallard), *Anas penelope* (Whistling duck), *Anas clypeata* (Shoveler), *Anas acuta* (Northern pintail), *Anas crecca* (Winter teal), *Anas strepera* (Gadwall duck) and *Marmaronetta angustirostris* (Marbled teal).

To ascertain the relationship between duck numbers and the flooded areas of the studied wetlands, as well as their connection to environmental factors, we conducted analysis of variance. We studied the correlations between Anatidae numbers and several factors: (i) Environmental factors: Temperature (°C): for each date of each satellite image, we recorded the maximum temperatures (Tmax), minimum temperatures (Tmin), and average temperatures (T) for each considered month. Precipitation (mm): p1- precipitation from the two previous months, p2 - precipitation from the three previous months, and p3 - precipitation from the current month. (ii) Positioning factors: t. In order to conduct a thorough analysis of our study area, we took into account several essential positioning factors, including altitude (m), latitude (in degrees, minutes, and seconds) and longitude (in degrees, minutes, and seconds). (iii) Surfaces of flooded areas: to assess the extent of flooding, we mesured the areas that have been inundated with water during the studying periods. (iv) Yearly variation: to take into account fluctuations that may occur between the studied years.

2.5. Statistical analysis

Pearson correlations were calculated to examine the relationships between site area, total Anatidae population, and the different species recorded, in relation to the climatic and geographic parameters of the sites. The species abundance matrix across the various studied locations was analyzed using principal component analysis (PCA). A significance threshold of $P<0.05$ was established, and the analyses were performed utilizing XLSTAT 2009.1.02 software.

Table 2. The Landsat images used and their characteristics*

Sensors	Platform	Path/Row	Acquisition date	Code image
ETM	LANDSAT 7	193/35	2002/12/10	a
ETM	LANDSAT 7	193/35	2003/02/25	b
ETM	LANDSAT 7	193/35	2003/05/03	c
ETM	LANDSAT 7	193/35	2003/06/28	d
ETM	LANDSAT 7	193/35	2003/07/30	e
ETM	LANDSAT 7	193/35	2003/10/02	f
TM	LANDSAT 5	193/35	2007/01/14	g
TM	LANDSAT 5	193/35	2007/03/19	h
TM	LANDSAT 5	193/35	2007/06/23	i
TM	LANDSAT 5	193/35	2007/08/31	j
TM	LANDSAT 5	193/35	2007/09/27	k
TM	LANDSAT 5	193/35	2007/10/16	l
OLI_TIRS	LANDSAT 8	193/35	2013/05/06	m
OLI_TIRS	LANDSAT 8	193/35	2013/06/07	n
OLI_TIRS	LANDSAT 8	193/35	2013/07/25	o
OLI_TIRS	LANDSAT 8	193/35	2013/09/11	p
OLI_TIRS	LANDSAT 8	193/35	2013/10/29	q
OLI_TIRS	LANDSAT 8	193/35	2013/12/16	r
OLI_TIRS	LANDSAT 8	193/35	2014/01/01	s

Table 3. Changes in the total surface areas (ha) of the studied wetlands within the Sebkhet of Aures complex.

Date	Code	Garaet El Taref	Garaet Guellif	Sebkhet Ezzemoul & Chott Tinsillt	Annk Djemel & El Merhsel	Sebkhet Djendli	Dam Koudiet Medouar	Total(Ha)
2002.12.10	a	16155.44	3247.4	5092.4	4982.07	15513.36	0	44990,67
2003.02.25	b	15361.73	2663.97	3143.19	3808.63	1154.02	17.88	26149.43
2003.05.03	c	13639.22	4186.98	5965.73	16070.13	1999.56	241.44	42103.06
2003.06.28	d	7325.93	2322.87	5011.26	37155.58	1448.74	261.25	53525.63
2003.07.30	e	7050.71	934.64	4150.52	2500.66	1071.54	260,18	15708.07
2003.12.02	f	17846.71	4296.94	6536.03	6590.23	3847.53	574.82	39692.26
2007.01.14	g	5569.05	1254.98	2194.65	2351.24	10.26	605.49	11985.67
2007.03.19	h	11843.74	1588.87	3079.62	2823.93	53.22	611.58	20000.96
2007.06.23	i	0	0	1520.19	609.75	0	591.81	2721.75
2007.08.31	j	6973.13	1991.95	2791.44	15944.5	0	620.91	28321.93
2007.09.27	k	8211.05	0	2791.44	2047.87	747.49	638.12	14435,97
2007.10.16	l	11459.67	2750.31	3693.53	3356.74	92.81	604.63	21957.69
2013.05.06	m	0	0	0	0	0	340	340
2013.06.07	n	0	0	0	0	0	316.53	316.53
2013.07.25	o	0	0	0	0	0	278.61	278.61
2013.09.11	p	6172.85	1116.88	2374.46	1815.95	1125.15	295.63	12900.92
2013.10.29	q	4436.36	1604.5	1227.04	3111.56	551.6	247.32	11178.38
2013.12.16	r	3842.91	1617.82	1968.3	2631.56	1330.31	283.97	11674.87
2014.01.01	s	3647.88	1601.42	2141.97	2711.35	1913.72	299.15	12315.49

3. Results and Discussion

3.1. Flooded areas

NDWI results can be presented in the form of maps and graphs, providing information on both spatial distribution of water bodies and their temporal evolution over longer periods. Flood maps illustrate variations that occur on a monthly and yearly basis. The analysis of flood-prone areas for each site conducted from December 10, 2002, to January 1, 2014, revealed considerable fluctuations in flood extent on various dates within the same year as well as across different years (**Figure 2**). The NDWI analysis were employed to determine the surface areas of each water body for the specified dates (**Table 3**). A significant drought was recorded in 2013, during which the sites experienced complete desiccation in the months of June, July and August. This statement summarizes the observed fluctuations in wetland surface area across sites, years and months and highlights the instances where the surface area is recorded as 0, potentially indicating arid conditions. The wetlands exhibit significant variations in total areas over the years and across seasons. The highest recorded total area was on 2002.12.10 (44990.67 ha), while the lowest was on 2013.07.25 (278.61 ha). This highlights a drastic decline in flooded areas over time. There is a marked seasonal dynamic, with larger flooded areas during winter and spring (e.g., 2003.02.25 and 2003.12.02). Conversely, summer periods, such as 2003.07.30 or 2007.06.23, show significant reductions in wetland areas, reflecting seasonal drying. The data from 2007 reveal a significant reduction in areas compared to 2002 and 2003, potentially due to climatic (increased drought) or anthropogenic factors (water extraction, urbanization). The years 2013 and 2014 show near-complete drying of wetlands during May, June, and July (2013.05.06, 2013.06.07, 2013.07.25), highlighting a severe deterioration in these ecosystems over the decade. When examining behavior of specific sites, Garaet El Taref demonstrated extreme variations, with maximal areas recorded in 2002 and complete drying in 2013. In addition, Sebkhet Djendli after peaks in 2002 and 2003, the flooded area disappeared entirely in 2007 and 2013. Annk Djemel & El Merhsel recorded the maximum total area of 37,155.58 ha by July 28, 2003 to a complete drying in June and July 2013. Other wetlands, such as Garaet Guellif, Sebkhet Ezzemoul & Chott Tinsillt, have shown more gradual but still substantial reductions.

Despite its relatively small size, Dam Koudiet Medouar remained relatively stable even in 2013, possibly due to specific hydrological management. Seasonal wetlands situated within arid climates, such as chotts and sebkhas, present a distinctive challenge owing to their pronounced hydrological variability (Wang *et al*. 2023, Labed *et al*. 2024). In these arid regions, precipitation occurs sporadically and unpredictably, leading to erratic fluctuations in the extent of inundation within these wetlands. These fluctuations can be attributed to the lack of precipitation and the increase in temperatures (Meradi *et al*. 2024). Dawson *et al*. (2003) highlighted that variations in precipitation and temperature play a crucial role in shaping physiological functions and have a significant impact on wetlands. Temperature, in particular, is a key factor influencing the dynamics of wetland landscape patterns (Wang *et al*. 2023). Additionally, research has shown that fluctuations in precipitation and air temperature are the primary drivers of evapotranspiration variability. In fact, between the studied periods, Sebkhates of Aures wetland complex region experienced significant climate variability, particularly in terms of precipitation (Bentercia, 2022). In 2003, relatively high rainfall was recorded, especially during winter and spring, contributing to the expansion and stability of wetland areas.

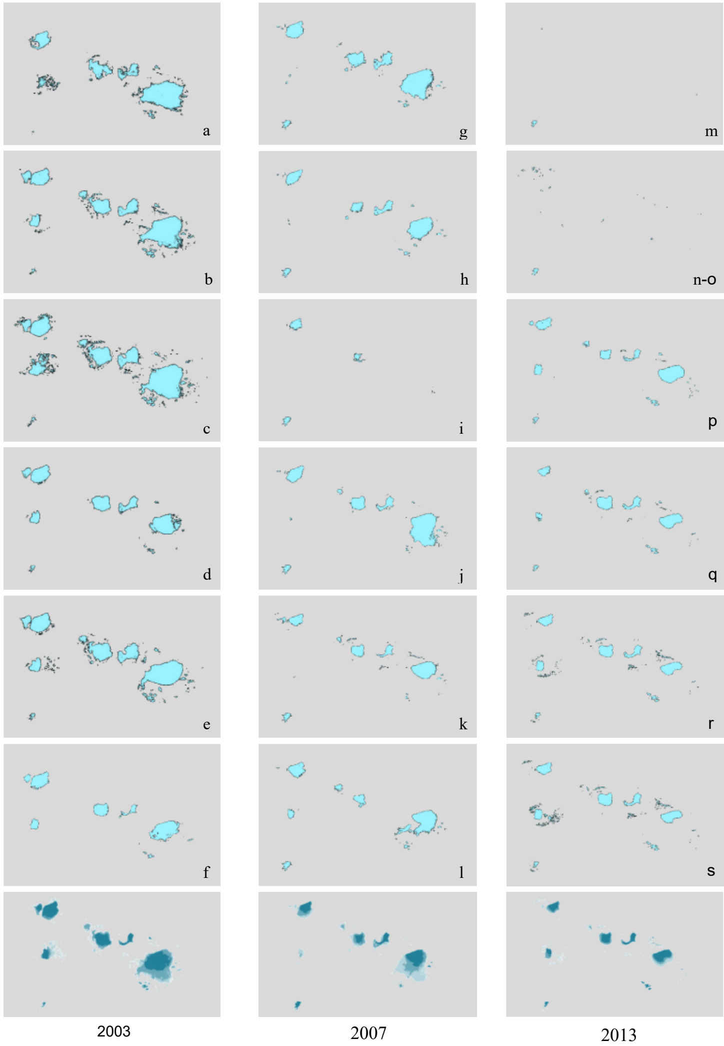


Figure 2. Flood maps along with intra-annual and inter-annual variations observed in the studied Sebkhet of Aures wetlands complex. (a – s: NDWI from October 12, 2002, to January 1, 2014).

However, by 2007, a noticeable decline in precipitation, coupled with rising temperatures, led to drier conditions and a significant reduction in wetland surface areas, with some drying up completely during the summer months. The situation worsened in 2013, which was among the driest years, with extremely low rainfall and prolonged drought conditions. This resulted in a drastic shrinkage of wetlands, as high evaporation rates further exacerbated water loss. The accurate identification of long-term trends in wetland flooding is a crucial issue, especially considering the influence of climatic factors (Perennou *et al*. 2018) and the increasing anthropogenic pressures (e.g., MWO, 2012) on freshwater resources in arid regions. One method to address this challenge is to recognize that an assessment of flood regimes' trends necessitates the use of multiple seasonal maps spanning several years, such as the Global Surface Water (GSW) dataset produced by Pekel *et al*. in 2016, which covers a 32-year period from 1984.

3.2. Evolution of wintering anatidae populations

The wetlands of north-eastern Algeria are characterised by a great diversity of waterbirds. The inventory established in the 7 studied sites over three winter seasons, in mid-January of the three years (2003, 2007 and 2014) revealed the presence of nine species (**Figure 3**). The populations of wintering ducks vary from one year to another, from one species to another and from one site to another. 2014 showed the highest overall counts, particularly at Garaet El Taref, which hosted a large population of Tadorna tadorna (140,000 individuals) suggesting a shift in wintering preference and an improved habitat condition in that year. In addition, the dominance of this species suggests that the species may have adapted well to the environmental conditions of that year, potentially benefiting from improved wetland conditions or reduced competition from other species. In contrast, 2003 recorded higher numbers for certain species such as Anas platyrhynchos, Anas penelope, and Anas clypeata, particularly at Sebkhet Ezzmoul and Chott Tinsilt. This suggests that the site provided favorable conditions for these species throughout that period. On the other hand, the decline of these species after 2003 could indicate a shift in migration patterns, possibly due to long-term climatic changes or habitat degradation. The year 2007 had generally lower counts across most sites and species, except for Tadorna ferruginea at Sebkhet Ezzmoul and Chott Tinsilt, indicating a potential shift in species distribution or environmental factors affecting the studied wetlands. Other sites (e.g., Sebkhet Djendli, Garaet Annk Djemel and El Merhsel, and Koudiet Medaouar Dam) showed relatively lower numbers across all years, possibly due to fluctuating water levels, habitat degradation, or changing migratory routes. The presence of Marmaronetta angustirostris in 2014 is ecologically significant, as this species is considered vulnerable in some regions.

The variation in the population of wintering Anatidae is primarily influenced by factors such as safety and food availability (Li *et al*. 2021). Ducks require protection from predators and human disturbances, as well as access to suitable food sources like aquatic plants, invertebrates, and grains, which are essential for their survival during the harsh winter months. Additionally, each species has specific habitat and ecological requirements. For instance, *Anas strepera*, *Anas acuta*, and *Anas penelope* are surface-feeding ducks, also known as dabbling ducks, which prefer shallow waters where they can easily access aquatic plants and micro-invertebrates. The size and typology of a site also affect the distribution of wintering ducks, with larger sites supporting higher numbers of ducks (Meng *et al*. 2019). This was evident in Garaet El Tarf, the largest site in our study area, which is particularly frequented by *Tadorna tadorna*, *Tadorna ferruginea*, and *Anas crecca*.

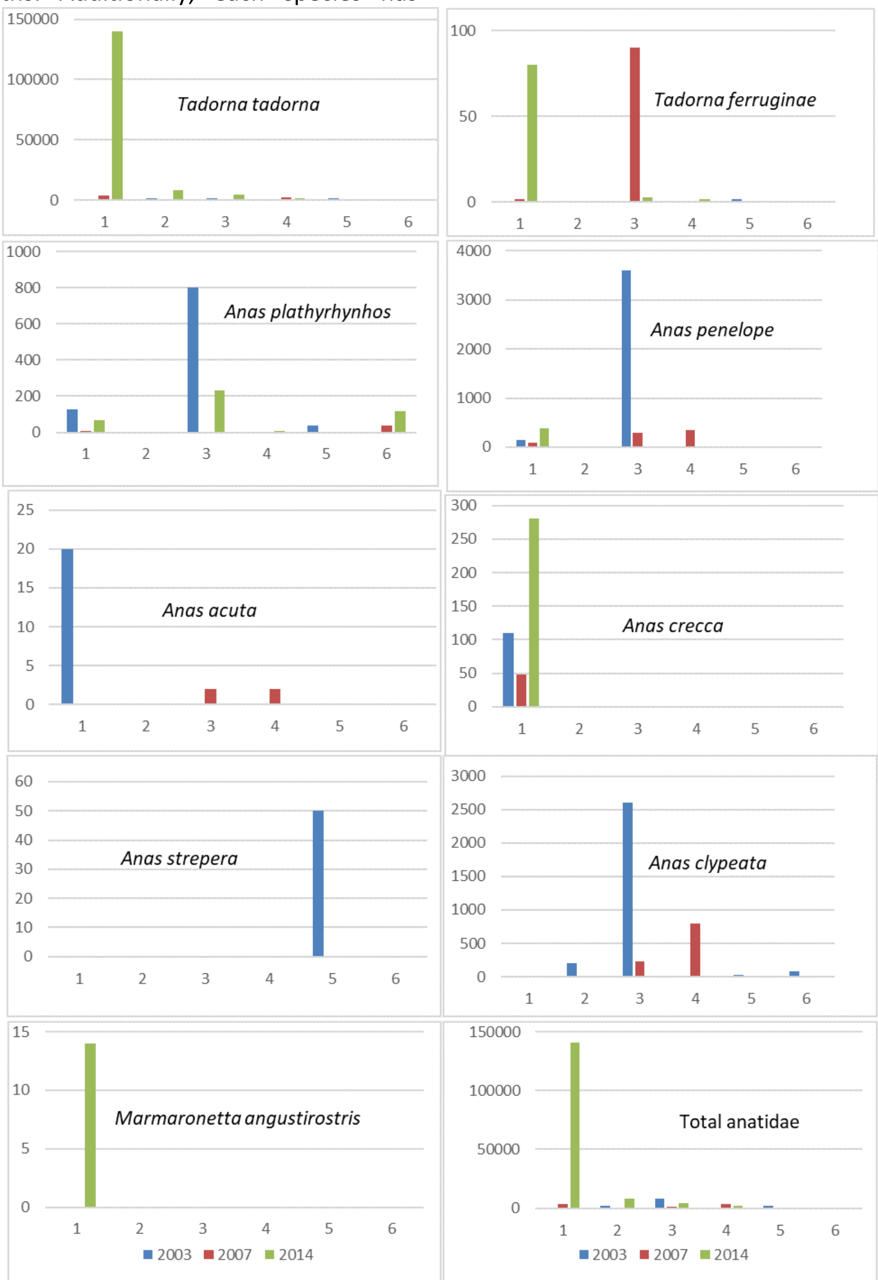


Figure 3. Evolution in the population counts of each wintering Anatidae species by site and year mid-January of the three years (2003, 2007 and 2014). 1: Gareat El Taref, 2: Gareat Guellif, 3: Sebkhet Ezzmoul & Chott Tinsilt, 4: Garaet Annk Djemel & El Merhsel, 5: Sebkhet Djendli, 6: Koudiet Medaouar dam.

3.3. Relationship between the total areas, abundance of anatidae and ecological parameters

To examine the relationship between the number of wintering ducks surveyed and the surface area of the water bodies, we chose to use Pearson's correlation coefficient to measure the strength of the association between these factors (**Table 4**). Pearson's parametric correlations between site areas, climatic and geographic variables on the one hand, and Anatidea numbers and the same climatic and geographic variables on the other hand, showed overall weak, insignificant relationships (P <0.05). The analyses showed a significant negative correlation (r = -0.518) between surface area and maximum temperature, indicating that as maximum temperature increases, site area decreases. A positive correlation with P3 (r = 0.391) showed that higher precipitation in P3 is associated with a larger surface area. Furthermore, the number of Anatidae exhibited a positive correlation with longitude (0.485), indicating that the number of Anatidae increases as one moves east or west. *Tadorna tadorna* exhibited a moderate positive correlation both with T max (0.461) and T mean (0.405), suggesting that elevated maximum and mean temperatures may foster increased population sizes of this species. *Anas acuta* demonstrated a particularly strong positive correlation with surface area (0.853), a particularly strong positive correlation with the surface of the site (0.853), suggesting that this species is more prevalent in larger areas. *Anas strepera* shows a positive correlation with P1 (mm) (0.535) and P2 (mm) (0.530), suggesting that this species thrives in areas with higher rainfall during these periods. Other species, such as *Anas clypeata* and *Anas crecca*, show varying degrees of correlation with other climatic parameters, indicating that their presence may be influenced by factors like temperature and precipitation patterns.

Table 4. Values of the Pearson correlation between the surface of the site, the total number of Anatidae and the different species inventoried with the climatic and geographical parameters of the sites. Values in bold are significant (P <0.05).

Variables	**Surface**	**Altitude (m)**	**Longitude**	**Latitude**	**P1 (mm)**	**P2 (mm)**	**P3 (mm)**	**T max (°C)**	**T min (°C)**	**T average (°C)**
Surface of the site	1	-0.175	0.186	0.366	-0.132	0.133	0.391	**-0.518**	0.331	-0.164
Anatidae	0.058	-0.111	**0.485**	-0.097	0.012	0.083	-0.169	-0.213	**0.470**	0.276
Tadorna tadorna	-0.091	-0.050	0.331	0.011	0.102	0.091	-0.384	-0.062	**0.461**	0.405
T. ferruginae	-0.062	0.017	0.189	0.135	0.104	-0.015	-0.331	0.179	0.258	**0.411**
Anas plathyrhynchos	0.251	0.057	0.274	-0.105	-0.256	0.024	0.341	-0.379	0.043	-0.260
Anas Penelope	0.217	-0.070	0.339	-0.136	-0.129	0.022	0.246	-0.295	0.149	-0.119
Anas clypeata	0.152	-0.147	0.367	-0.239	-0.069	0.031	0.216	-0.226	0.163	-0.058
Anas Acuta	**0.853**	-0.002	-0.031	0.309	-0.112	0.019	0.241	-0.261	0.127	-0.115
Anas crecca	0.248	0.187	-0.321	0.365	-0.146	-0.214	-0.180	0.001	-0.035	0.052
Anas strepera	0.016	0.084	-0.012	0.306	**0.535**	**0.530**	0.221	-0.152	-0.020	-0.262
Marmaronetta angustirostra	0.009	0.050	-0.081	0.346	-0.044	0.006	-0.183	-0.087	0.159	0.113

Table 5. Eigenvalues and inertia of the first 5 factorial axes.

	F1	F2	F3	F4	F5
Eigenvalue	2.909	2.325	1.238	1.124	0.900
Variability %	29.089	23.248	12.377	11.239	8.999
Cumulative %	29.089	52.338	64.715	75.954	84.953

The analysis of the eigenvalue matrix reveals a noticeable decrease in their values after the second axis (F2). suggesting that **F1** and **F2** should be retained for further analysis. Together, they explain **52.3%** of the total variability, which is significantly more than the remaining axes (**Table 5**). Following the reasoning of Benzecri *et al.* (1973) and Wermuth (1976) in multidimensional analysis, where the complexity of the data and the results make it unlikely that any outcome derived from random fluctuations would be interpretable. We can confidently assert that the interpretable results are valid. Consequently, this analysis distinguishes two groups of species based on strong correlations: **Group 1** includes ***Marmaronetta angustirostra, Anas crecca*** and ***Tadorna ferruginae,*** while **Group 2** consists of ***Anas penelope, Anas plathyrhynchos*** and ***Anas clypeata***.

However, contrasting trends are evident among different taxonomic groups. Waterbirds, for instance, have exhibited an average increase in population. This phenomenon can be attributed to three primary factors. Firstly, the intensive hunting of waterbirds in the past has led to a significant decline in their numbers and range, resulting in a low baseline for 1990. Secondly, the implementation of specific protection laws (e.g., the European Union Birds Directive) in conjunction with effective governance has resulted in a substantial increase in the number of breeding populations in certain countries, including the European Union. Thirdly, the presence of artificial water bodies has increased, and, in contrast to many other wetland species, these have provided additional habitat space for some water birds.

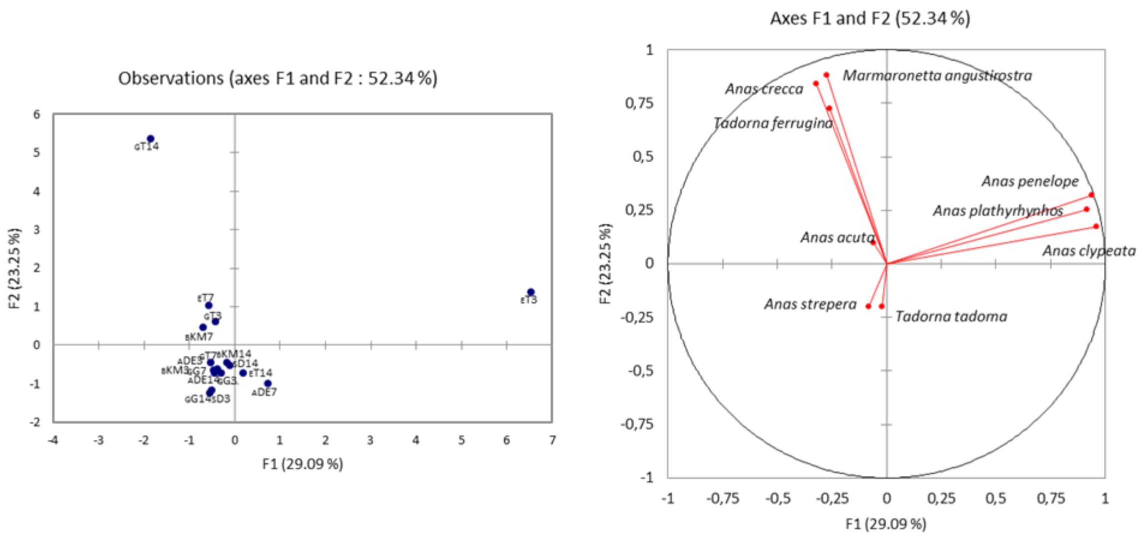


Figure 4. Principal Component Analysis (PCA) of Studied Wetland Sites and Inventoried Bird Species: Representation in the 1×2 Plane

Understanding the relationship between species and their environment is crucial to studying their ecological requirements and spatial distribution. Anatidae usually inhabit diverse water bodies, like lakes, rivers, marshes and others, thriving on a diet that includes aquatic plants, algae, insects, fish, crustaceans, and other aquatic animals.

The principal component analysis (PCA) performed on species of the genera *Anas*, *Tadorna*, and *Marmaronetta* reveals a clear structuring of individuals based on two main axes that together explain 52.34% of the total variance **(Figure 4).** This structuring reflects ecological, morphological, and behavioral differences that are well documented in the scientific literature.

The first axis (F1: 29.09% of variance) appears to distinguish species based on foraging strategies and habitat use. Species with high positive loadings on F1, such as *Anas clypeata*, *A. platyrhynchos*, and *A. penelope*, share filtering or dabbling feeding behaviors, as reported by Johnsgard (1960). These species are typically associated with shallow wetland environments. Conversely, *Tadorna tadorna* and *Anas strepera*, located on the negative end of F1, are known for broader, more generalist foraging strategies and occupy more open habitats (Worthy and Lee, 2008).

The second axis (F2: 23.25%) likely reflects microhabitat preferences or reproductive behaviors. For example, *Anas crecca* and *Tadorna ferruginea*, positioned in the upper part of the PCA plot, exhibit high ecological plasticity and broad geographic ranges traits discussed in neuroecological terms by Kalisińska (2005). The unique position of *Marmaronetta angustirostris* may highlight its rarity and ecological specialization, as supported by paleontological and osteological studies (Zelenkov, 2024; Haruda *et al*. 2024).

PCA results are consistent with molecular findings by Sun et al. (2017), who reported rapid and recent diversification within the genus *Anas*, contrasting with the more conservative structure of *Tadorna*. This reinforces the idea that the PCA not only reflects present-day ecological contrasts but also evolutionary divergence patterns (Livezey, 1986; Livezey, 1991). Furthermore, the morphometric proximity of some species on the PCA plot (e.g., *Anas platyrhynchos* and *A. clypeata*) aligns with studies by Chernova et al. (2022), who demonstrated a strong correlation between macroscopic traits (e.g., body size) and microscopic feather structure across Anseriformes.

4. Conclusion

This study demonstrates the effectiveness of remote sensing and spatial analysis in monitoring the temporal evolution of wetland hydrology and its ecological implications. By delineating the Sebkhet of Aurès Wetlands Complex (SAWC) and assessing surface water dynamics across a decadal timescale, we revealed a strong correlation between precipitation patterns and the extent of flooded areas. The significant reduction in inundated surface—from 30,305 ha in 2003 to 16,736 ha in 2013—reflects the impact of declining rainfall and highlights the sensitivity of these wetlands to climatic fluctuations. Furthermore, the analysis of Anatidae wintering populations suggests that hydrological extent is a key determinant of waterfowl presence, although habitat quality—defined by factors such as food availability, disturbance levels, and refuge conditions—plays a complementary role. These findings underscore the need for integrated wetland management strategies that consider both hydrometeorological variability and ecological functionality to support waterbird conservation in arid and semi-arid landscapes.

5. Conflicts of interest

The authors declare no conflict of interest.

During the preparation of this work, the authors used ArcGIS by Esri in order to process and analyze geospatial data and to generate the maps presented in this study, XLSTAT 2009.1.02 software in order to perform statistical analysis of the data. The analyses were performed on a Lenovo laptop equipped with an Intel Core i7 vPro 10th generation processor. After using thess tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication

References

Adloff F., Somot S., Sevault F., Jordà G., Aznar R., Déqué M. and Herrmann M., et al. (2015). Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios? *Climate Dynamics*, 45, 9–10: 2775–2802.

Baker C., Lawrence R., Montagne C. and Patten D. (2007). Change detection of wetland ecosystems using Landsat imagery and change vector analysis. *Wetlands,* 27, 610–619.

Bensizerara D., Chenchouni H., Si Bachir A. and Houhamdi M. (2013), Ecological status interactions for assessing bird diversity in relation to a heterogeneous landscape structure, *Avian Biology Research,* 6: 67–77.

Bentercia L. (2022), Atlas des zones humides classes Ramsar du complexe des Sebkhates des Aures (Nord-Est Algérien). Dissertation, University of Batna 2, 35p.

Benzecri J.P. (1973), L'Analyse des Données. Tome 1: lA Taxinomie. Tome 2: L'Analyse des Correspondances (2nd ED). Dunod, Paris

Benzina I., Si Bachir A., Santoul F. and Céréghino R. (2021), Macroinvertebrate functional trait responses to environmental gradients and anthropogenic disturbance in arid-land streams of North Africa. *Journal of Arid Environment,* 195,104626.

Benzina I., Si Bachir A. and Perennou C. (2022), Waterbird diversity at the Sebkhet of Aures wetlands complex, North East Algeria, *Der Ornithologische Beobachter*, 119, 318–329.

Benzina I., Si Bachir A., Arar A., Perennou C.and Guelmami A. (2024), Using DPSIR framework for the implementation of wetlands observatory: case study Sebkhates of Aures wetlands complex (Northerneast, Algeria), *Present Environment and Sustainable Development*, 18 (1), 293–309.

Berberoglu S., Yilmaz K.T. and Özkan C. (2004), Mapping and monitoring of coastal wetlands of Çukurova Delta in the Eastern Mediterranean region, *Biodiversity and Conservation,* 13, 615–633.

Bonnet B., Aulong S., Goyet S., Lutz M. and Mathevet R. (2005), Integrated management of Mediterranean wetlands, 160 pp. *Conservation of Mediterranean Wetlands*, 13. Arles, Tour du Valat.

Bouaguel L. (2014), Structure et écologie des Phoenicoptéridés dans l'éco-complexe de zones humides de l'Est algérien. Doctoral thesis, University of Annaba, Algeria.

Bougoffa S., Benzina I., Telailia S. and Si Bachir A. (2023), Ecosystem services, vulnerability and threat levels of Ramsar wetlands in the complex of Aurès Sbkhates, North-Eastern Algeria. *Environmental & Socio-Economic studies*, 11 (2).

Bougoudjil S. (2016), Ecologie des *Tadornes casarca, Tadorna ferruginea* dans l'éco-complexe de zones humides des hautes plaines de l'Est algérien. Doctoral thesis, University of Annaba, Algeria.

Boulkhssaim M., Ouldjaoui A. and Baaziz N., et al., 2009. Mass reproduction of the Greater Flamingo at Ezzemoul, Algeria in 2009 the need to reassess the role of North African wetlands, *Flamingo,* 17, 48–53.

Castaneda C. and Ducrot D. (2009), Land cover mapping of wetland areas in an agricultural landscape using SAR and Landsat imagery, *Journal of Environmental Management*, 90, 2270–2277.

Chernova E., Petrova N., Smirnov P. and Ivanov V. (2022), Migratory and wintering patterns of *Anas platyrhynchos* and *A. clypeata* in Eurasian wetlands, *Journal of Avian Biology*, 53(4), e02910.

Dadaser-Celik F., Bauer M.E., Brezonik P.L. and Stefan H.G. (2008), Changes in the Sultan marshes ecosystem (Turkey) in satellite images 1980–2003, *Wetlands,* 28, 852–865.

Davidson N.C. (2014), How much wetland has the world lost? Long-term and recent trends in global wetland area. CSIRO Publishing, *Marine and Freshwater Research*, 65, 10, 936-941.

Davranche A., Poulin B. and Lefebvre G. (2013), Mapping flooding regimes in Camargue wetlands using seasonal multispectral data, *Remote Sensing of Environment*, 138, 165–171.

Dawson T.P., Berry P.M. and Harrison P.A. (2003), SPECIES: a spatial evaluation of climate impact on the envelope of species, *Ecological Modelling*, 154, 289–300.

DGF. (2016), Stratégie nationale de gestion ècosystèmique des zones humides d'Algérie, Alger, Algérie, 10p.

Gao B.C. (1996), NDWI- A Normalized Difference Water Index for Remote Sensing of Vegetation Liquid Water from Space, *Remote Sensing of Environment*, 58, 257-266.

Gherzouli C. (2013), Anthropisation et dynamique des zones humides dans le nord-est-algérien: apport des études palynologiques pour une gestion conservatoire. Thèse de doctorat Université Toulouse le Mirail - Toulouse II, 2013. Français. (NNT: 2013TOU20128).

Haruda A., Mazzucato C. and Yeomans L. (2024), On the wing: Morphological variation in the osteology of Mediterranean, Near Eastern, and European Anatidae (excluding Anserinae). *Journal of Morphology*, 285(8), e21750.

Houhamdi M., Maazi M.C., Seddik S., Bouaguel L., Bougoudjil S., Saheb M. (2009), Statut et écologie de l'Erismature à tête blanche (Oxyura leucocephala) dans les hauts plateaux de l'est de l'Algérie, *Aves* 45 (2), 129–148.

Johnsgard P.A. (1960), A Quantitative Study of Sexual Behavior of Mallards and Black Ducks, *Wilson Bulletin,* 72, 2.

Kalisińska E. (2005), Anseriform Brain and Its Parts versus Taxonomic and Ecological Categories. Brain, *Behavior and Evolution*, 65(4), 244–261.

Kassawmar N.T., Rao K.R.M. and Abraha G.L. (2011), An integrated approach for spatio-temporal variability analysis of wetlands: A case study of Abaya and Chamo lakes, Ethiopia. *Environmental Monitoring and Assessment*, 180, 313–324.

Labed A., Si Bachir A., Benzina I., Ghazi C. and Chaibi R. (2024), Structure and seasonal distribution patterns of phytoplankton in a natural mountain pond of the Belezma biosphere reserve (Northern East Algeria), *Die Bodenkultur: Journal of Land Management, Food and Environment* 75(2), 77–89.

Li X., Cheng R., Xiao W., Sun G., Ma T., Liu F., Liu X., Qian F. and Pan K. (2021), Assessment of the Suitability of Wintering Anatidae Habitats before and after Impoundment in the Three Gorges Reservoir Region, *Sustainability*, 13(9), 4743.

Livezey B.C. (1986), A phylogenetic analysis of Recent anseriform genera using morphological characters. Auk 103:737-754.

Livezey B.C. (1991), A phylogenetic analysis and classification of Recent dabbling ducks (tribe Anatini) based on comparative morphology. Auk 108:471-507.

Luo K., Samat A., Abuduwaili J. and Li W. (2024), Evaluation of Remote Sensing Products for Wetland Mapping in the Irtysh River Basin, *Geosciences*, 14(1), 14.

Meng F., Li H. and Wang X. et al. (2019), Size matters: wintering ducks stay longer and use fewer habitats on largest Chinese lakes, *Avian Research*, 10, 27.

Meradi K., Bounar R., Benzina I., Meradi S., Si Bachir A. and Céréghino R. (2024), How do substrate types affect the seasonal richness and functional feeding groups variation of benthic insects in an arid region (northeastern Algeria)? *Biologia*, 79, 1749–1759.

MWO (Mediterranean Wetlands Observatory) (2012),Biodiversity—*status and trends of species in Mediterranean Wetlands*. MWO Thematic collection, 1. Tour du Valat Research Institute for the Conservation of Mediterranean Wetlands, Arles, France.

Nielsen E.M., Prince S.D. and Koeln G. T. (2008), Wetland change mapping for the US mid-Atlantic region using an outlier detection technique, *Remote Sensing of Environment*, 112, 4061–4074.

Ozesmi S.L., Bauer M.E. (2002), Satellite remote sensing of wetlands, *Wetlands Ecology and Management,* 10(5), 381–402.

Parrinello G., Bécot R. (2019), Regional planning and the environmental impact of coastal tourism: The mission racine for the redevelopment of Languedoc-Roussillon’s littoral, *Humanities*, 8, 1: 13.

Pekel J.F., Cottam A., Gorelick N. and Belward A.S. (2016), High-resolution mapping of global surface water and its long-term changes, *Nature*, 540 (7633), 418–422.

Perennou C., Beltrame C., Guelmami A., Tomàs V.P. and Caessteker P. (2012), Existing areas and past changes of wetland extent in the Mediterranean region: an overview, *Ecologia Mediterranea*, 38, 2: 53–66.

Perennou C., Guelmami A., Paganini M., Philipson P., Poulin B., Strauch A., Tottrup C., Truckenbrodt J. and Geijzendorffer I.R. (2018), Mapping Mediterranean Wetlands with Remote Sensing: A Good-Looking Map Is Not Always a Good Map, *Advances in Ecological Research*, 58.

Ramsar. (2019), The list of wetlands of international importance. Ramsar website. Retrieved from https://www.ramsar.org/sites/default/files/documents/library/sitelist.pdf

Rebelo L.M., Finlayson C.M. and Nagabhatla N. (2009), Remote sensing and GIS for wetland inventory, mapping and change analysis, *Journal of Environmental Management*, 90, 2144–2153.

Riservato E., Boudot J.P., Ferreira S., Jovi M., Kalkman V.J., Schneider W., Samraoui B. and Cuttelod A. (2009). The Status and Distribution of Dragonflies of the Mediterranean Basin. IUCN, Gland, Switzerland/Malaga, Spain.

Rosenqvist A., Finlayson C.M., Lowry J. and Taylor D.M. (2007), The potential of spaceborne (L-band) radar to support wetland applications and the Ramsar Convention, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 17, 229–244.

Seddik S., Maazi M.C., Hafid H., Saheb M., Mayache B. and Houhamdi M. (2010), Statut et écologie des peuplements Laro-Limicoles et Echassiers dans les zones humides des hauts plateaux de l’Est de l’Algérie, *Bulletin de l’Institut Scientifique de Rabat,* 32 (2), 111–118.

Taylor N.G., Grillas P. and Al Hreisha H. et al. (2021), The future for Mediterranean wetlands: 50 key issues and 50 important conservation research questions, *Regional Environmental Change*, 21, 33.

Thomas R.F., Kingsford R.T., Lu Y. and Hunter S.J. (2011), Landsat mapping of annual inundation (1979–2006) of the Macquarie Marshes in semi-arid Australia, *International Journal of Remote Sensing*, 32, 4545–4569.

Touitou M. and Al-Aminb A. (2020), Climate change and water resources in Algeria: vulnerability, impact and adaptation strategy, *Economic and Environmental Studies*, 18, 45: 411–429.

Wang Y., Meili N. and Fatichi S. (2023), Evidence and controls of the acceleration of the hydrological cycle over land, *Nature Communications*, 14(1), 281.

Wermuth N. (1976), Analogies between multiplicative models in contingency tables and covariance selection. Biometrics, 32, p 95-108.

Worthy T.H. and Lee M.S.Y. (2008), Affinities of Miocene (19–16 Ma) waterfowl (Anatidae: Manuherikia, Dunstanetta and Miotadorna) from the St Bathans Fauna, New Zealand, *Palaeontology,* 51, 677–708.

Zelenkov N.V. (2024), Chapter 1. Comparative Osteology and Phylogeny of Quails and Allies (Coturnicini), *Paleontological Journal*, 58, 1093–1106.