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Benthic macrophyte diversity and physicochemical drivers in the Guerbes-Senhadja wetland complex (Northeastern Algeria): Taxonomic richness, conservation status and bioindicator value

Abstract

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The Guerbes-Senhadja wetland complex (wilaya of Skikda, north-eastern Algeria) is one of the most floristically significant wetland systems of Numidia, yet the ecology of its benthic macrophyte communities has remained largely undocumented. This study presents the first systematic inventory of aquatic macrophytes across nine representative waterbodies of the complex, conducted during the spring of 2025, alongside an analysis of the physicochemical parameters structuring their distribution. A total of 31 benthic macrophyte taxa belonging to 12 families and 16 genera were recorded. Floristic richness varied markedly with habitat type: saline semi-temporary marshes harboured four to seven taxa, temporary ponds supported up to 13 species, while peaty lakes and alder carrs yielded 11 to 18 taxa with greater abundance. The broadly distributed chorological element dominated (38.71%), followed by the northern (29.03%) and Mediterranean (25.80%) elements. Seventeen taxa were identified as holding patrimonial value, including 14 rare or very rare species, 7 protected under Algerian law, and 9 listed on the IUCN Red List. Six new floristic records for western Numidia are reported. A Principal Component Analysis (PCA) of 18 environmental and physico-chemical variables distinguished three ecological site typologies along gradients of anthropogenic disturbance, topography and hydrological regime. A co-inertia analysis ($RV = 0.63$, $p < 0.05$) confirmed a significant co-structure between the macrophyte assemblages and the environmental descriptors, with axis 1 reflecting a freshwater-to-brackish salinity gradient and axis 2 opposing degraded lacustrine systems to deep alder carr formations. Four plant community types were identified, anchored by *Nitella opaca*, *Lemna minor*, *Nymphaea alba* and *Myriophyllum* spp., each tracking distinct hydrochemical conditions. The results highlight the critical conservation status of this wetland complex, threatened by sand encroachment, urban expansion and water pumping, and underscore the potential of benthic macrophytes as reliable bioindicators of water quality in Mediterranean wetland systems.

Key words: Floristics, plant communities, North Africa.

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Introduction

Algeria's wetlands, which shelter a remarkable natural heritage, constitute a major component of regional biodiversity hotspots (Véla & Benhouhou 2007). Highly sensitive and vulnerable, these habitats have sustained considerable and, in some cases, irreversible damage (de Bélair 2005). As a result of rapid demographic growth and accelerating technological development over recent decades, this heritage is currently threatened by urbanisation, agriculture, industrial expansion, and tourism. These activities generate an excessive demand for water that is incompatible with a climate characterised by a prolonged dry season and recurrent droughts (Belouahem-Abed & al. 2011).

Today, numerous cases of species rarefaction and even local extinction have been reported for taxa strictly associated with these habitats (Laribi & al. 2016). Yet, despite the considerable patrimonial stakes involved in their conservation, only a limited number of recent studies have been dedicated to them (e.g. de Bélair 2005; Bouldjedri & al. 2011; Laribi & al. 2016; Allem & al. 2017; Fetnaci & al. 2019; Kamel-Eddine 2022; Ali Tatar & al. 2023; Hammana & al. 2024; Zediri & al. 2026).

The extreme north-east of Algeria, or Numidia (K_3 , *sensu* Quézel & Santa 1962), encompasses numerous Key Biodiversity Areas (KBAs) for plants (Yahi & al. 2012; Benhouhou & al. 2018). Within this vast zone under Mediterranean influence, the Guerbes-Senhadja wetland complex is already identified as particularly noteworthy. It is known to harbour endemic and sub-endemic plant species with fragmented ranges, extremely rare in Algeria and often stenoendemics (Quézel & Santa 1962-1963; Yahi & al. 2012).

Studies conducted to date on this poorly known region of Algeria (Véla & de Bélair 2013) have focused primarily on its hydrology and avifauna (Samraoui & Samraoui 2008; Metallaoui & al. 2013), while botanical contributions have remained sparse (Samraoui & de Bélair 1997; de Bélair & Véla 2011; Toubal & al. 2014; Hamel & al. 2017, 2025).

It is within this context that the present work is framed, aiming to address this knowledge gap through a systematic inventory of benthic macrophytes across the ponds and lakes of the Guerbes-Senhadja wetland complex.

The primary objective is to characterise the benthic vegetation of the study region. More specifically, the study seeks to: (1) document the distribution of this plant group across the nine known waterbodies of the complex; (2) assess the influence of water physicochemical parameters on the composition and abundance of the recorded taxa; (3) evaluate the potential of these taxa as bioindicators of water quality; and (4) appraise their conservation status and prioritise the conservation actions required to safeguard them within their wetland and dune ecosystems.

Materials and Methods

Study area

Located in northeastern Algeria within the wilaya of Skikda, the Guerbes-Senhadja wetland complex is situated within the coordinates 36°46'-37°1'N and 7°8'-7°25'E and spans approximately 42,100 ha, of which nearly half consists of actively hydro-morphic ecosystems.

This wetland complex is bordered by distinct natural formations: the Edough peninsula to the northeast, the Filfila massif to the northwest, and the Boumaïza massif to the southwest, extending south-eastward towards Lake Fetzara. The wetland ecosystem itself covers around 20,000 hectares, primarily distributed across the alluvial plain of Benazouz. The hydrology of the site is structured by the meandering Oued Kebir and its tributaries (Magroune and El-Aneb), which generate dune depressions, marshes, garaets (standing waterbodies occupying closed depressions) and intermittent lakes. The coastal dune system stretches up to 14 km inland, shaping the interface between terrestrial and aquatic habitats and contributing to the site's complex geomorphology and ecological heterogeneity (Samraoui & de Bélair 1997; Toubal & al. 2014).

From a climatological standpoint, the Guerbes-Senhadja wetland complex falls within the thermo-Mediterranean sub-humid bioclimatic belt with a temperate variant (Quézel 1979). In the absence of site-specific climatological data, the interpolation method (Seltzer & al. 1946) was applied to determine the climatic type of each study site. Mean annual precipitation is approximately 793 mm at Aïn-Mokra (encompassing: Garaet Khemissa, Garaet Chichaya, Garaet Sidi Makhoulf, Garaet Ouajaa and Lake Sidi Freitis); 614 mm at Cap de Fer (encompassing: Garaet Beni M'hamed, Garaet Haoua and Demnet Atoua); and 830 mm at Philippeville (encompassing: Garaet Hadj Tahir).

The nine study sites are: Demnat El Aatoua (DAT); Garaet Beni Mahammed (GBM); Garaet Chaychia (GCH); Garaet Hadj Tahar (GHT); Garaet Khemissa (GKH); Garaet Ouajaa (GOU); Garaet Sidi Makhoulf (GSM); Lake Sidi Freitis (LSF); Garaet Haoua (GHA) (Fig. 1; Tab.1).

Demnet Ataoua (DAT)

Located west of the Edough peninsula on the left bank of Oued El-Kebir (36°56'9.264"N, 7°15'16.732"E), this site covers approximately 208 ha and is notable for its alder carr and associated wetland complex. The depression follows a general NW-SE orientation, with a sandy substrate in the northwest reflecting dune inputs, transitioning progressively to alluvial clay in the southeast. The site is fed by two tributaries (Oued Ras El Ma and Oued El Kebir) both sourced at the dune base. The combination of hydrological and geomorphological gradients supports a rich vegetation dynamic, encompassing temporary water bodies, willow stands, alder carr, and cork oak forest, for a total of 93 recorded plant species (Belouahem-Abed & al. 2011).

Garaet Beni M'Hamed (GBM)

This saline marsh, extending over approximately 520 ha (36°57'58.03"N, 7°17'57.913"E), is situated near the estuary of Oued El-Kebir, along its right bank. It is fed by seasonal overflow from this wadi and is dominated by halophilic plant communities. The substrate consists of Numidian clays, supplemented by alluvial and colluvial hill deposits (Samraoui & de Bélair 1997).

Garaet Chichaya (GCH)

This marsh (36°53'45.334"N, 7°18'4.37"E) extends over approximately 46 ha in a NW-SE oriented fan-shaped depression, sloping gently towards the alluvial plain of Oued El-Kebir, with which it maintains hydrological continuity via Garaet Sidi Makhoulf. The



Fig. 1. Geographical location of the study area and sites.

northwest sector is underlain by dunary sands mixed with peat, transitioning to silty clay in the southeast. The northwestern portion is occupied by an alder carr of *Alnus glutinosa* (L.) Gaertn. and *Salix pedicellata* Desf., while the southeastern sector grades into a marsh and, depending on annual rainfall and pumping pressure, open water. Fifty plant species have been recorded to date (Samraoui & de Bélair 1997; Belouahem-Abed & al. 2011).

Garaet Hadj Tahir (GHT)

Garaet Hadj Tahir is a freshwater lake covering approximately 127 ha (36°51'52.674"N, 7°15'58.337"E) at a mean altitude of 25 m, located some twenty kilo-

Table 1. Geographical characteristics of the study area and sites.

N°	Code	Site	GPS Coordinates	Altitude (m)	Distance from agglomeration (Km)	Surface Area (Ha)	Perimeter (Km)	Depth (Cm)	Slope (%)	Exposure	Hydrological regime	Tmp and facs
1	DAT	Demnet Ataoua	36°56'9.264"N - 7°15'16.732"E	4	7.26	208	10.03	310	7	South-East	Permanent	Permanent stagnation
2	GBM	Garaet Beni M'Hamed	36°57'58.031"N - 7°17'57.913"E	2	8.85	520	13.82	70	2	North-East	Semi-permanent	Temporary current
3	GCH	Garaet Chichaya	36°53'45.334"N - 7°18'4.37"E	12	0.42	46	3.47	330	2	East	Permanent	Permanent stagnation
4	GHT	Garaet Hadj Tahir	36°51'52.674"N - 7°15'58.337"E	25	2.13	127	9.27	350	11	East	Permanent	Permanent stagnation
5	GKH	Garaet Khemissa	36°48'35.473"N - 7°19'47.024"E	19	1.85	31	3.64	120	5	South-West	Semi-permanent	Temporary stagnation
6	GOU	Garaet Ouajaa	36°52'28.463"N - 7°18'31.158"E	13	0.58	4	1.14	55	1	South-East	Temporaire	Temporary stagnation
7	GSM	Garaet Sidi Makhoulf	36°53'6.512"N - 7°18'58.678"E	10	0.7	46	4.57	330	1	North-East	Permanent	Permanent stagnation
8	LSF	Lake Sidi Freitis	36°53'25.642"N - 7°17'34.444"E	41	4,53	109	4.4	250	8	North-East	Permanent	Permanent stagnation
9	GHA	Garaet Haoua	36°58'43.38"N - 7°16'21.905"E	2	10.32	289	11.54	45	1	East	Semi-permanent	Temporary current

meters from the Mediterranean coast. The depression, oriented NW-SE, is enclosed to the northwest by clay and sandstone hills rising gradually to 200 m, to the east by coastal dunes, and to the southeast by the alluvial plain of Oued El-Kebir, whose tributaries constitute the main water source. Water levels persist throughout the year during wet periods, despite summer evaporation and local water pumping, though the site may dry partially in drought years. The depth does not exceed 2 m. Vegetation is structured in four distinct belts around open water, with a reduced alder carr, totalling 89 recorded plant species (Belouahem-Abed & al. 2011). The site represents a major wintering ground for waterfowl, hosting over 10,000 birds, including three rare breeding species: *Oxyura leucocephala* (Scopoli, 1769), *Aythya nyroca* (Güldenstädt, 1770), and *Porphyrio porphyrio* (Linnaeus, 1758). Colonies of *Chlidonias hybrida* (Pallas, 1811) and *Ardea ibis* (Linnaeus, 1758) are also documented. Of particular biogeographical interest is the presence of the Afrotropical belostomid relict *Hydrocyrius columbiae* Spin. (Samraoui & de Bélair 1997).

Garaet Khemissa (GKH)

Garaet Khemissa is a shallow seasonal wetland covering approximately 31 ha (36°48'35.473"N, 7°19'47.024"E), located within the Guerbes-Senhadja plain, in the immediate vicinity of the Garaet Chichaya–Sidi Makhlouf complex. Like the surrounding marshes, it occupies a low-lying depression influenced by both dune groundwater inputs and seasonal rainfall. The substrate is predominantly sandy to silty, and the site supports hygrophilous and helophytic vegetation characteristic of the regional wetland complex. It experiences marked seasonal fluctuations in water level, with partial or complete drying during summer months.

Garaet Ouajaa (GOU)

Garaet Ouajaa (36°52'28.463"N, 7°18'31.158"E) is a shallow marshy depression of approximately 5 ha, situated on the northwestern margin of Oued Esseghir. It is bounded to the north by Guareat Nechmaya, to the south by the commune of Ben Azzouz, to the east by Oued Magroun and by Lake Sidi Freitis to the West (Hamel & al. 2017).

Its hydrological regime is subject to seasonal variation, with water levels closely linked to rainfall and groundwater inputs from adjacent dunes. The site supports hygrophilous vegetation and constitutes a documented breeding locality for the Ferruginous Duck (*Aythya nyroca* (Güldenstädt, 1770)) and the Western swamphen (*Porphyrio porphyrio* (Linnaeus, 1758)), underlining its ecological significance within the Guerbes-Senhadja wetland complex (Samraoui & de Bélair 1997).

Garaet Sidi Makhlouf (GSM)

Covering approximately 46 ha (36°53'6.512"N, 7°18'58.678"E), this site shares the same geomorphological setting and substrate as Garaet Chichaya, with which it forms a single hydrological unit, oriented NW-SE towards the alluvial plain. The vegetation encompasses a dry meadow, a wet meadow, a marsh, and open water, supporting 102 plant species in total. The alder carr transitions at its margin towards a cork oak forest (Belouahem-Abed & al. 2011). Ornithologically, the site is notable for the sporadic breeding of the Ferruginous Duck (*Aythya nyroca* (Güldenstädt, 1770)) and the regular presence of Western swamphen (*Porphyrio porphyrio* (Linnaeus, 1758)) (Samraoui & de Bélair 1997).

Lake Sidi Freitis (LSF)

Situated in an interdune depression oriented NW-SE (36°53'25.642''N, 7°17'34.444''E), this lake covers approximately 109 ha and comprises two distinct units: a marshy scrub of ~26 ha to the northwest and an open lake of ~13 ha to the southeast. Water depth does not exceed 1.5 m, and the site typically dries in summer due to irrigation pumping. It is bordered to the west by a 57 m dune and to the east by a dry meadow at the foot of a 28 m dune. Groundwater from surrounding dunes constitutes the primary water input. Known to science since 1861 for its biological richness, this site is floristically the most diverse of the regional wetland complex, with 113 vascular plant species recorded, including notable *Orchidaceae*, *Cyperaceae*, *Juncaceae*, and *Poaceae*, as well as 46 algal species. The relative isolation of the site has historically favoured its preservation, though recent invasion by *Gambusia affinis* (S. F. Baird & Girard, 1853) has negatively impacted endemic fish and invertebrate communities (Samraoui & de Bélair 1997).

Garaet Haoua (GHA)

Covering approximately 289 ha (36°58'43.38''N, 7°16'21.905''E), this marsh occupies the left bank of Oued El-Kebir, stretching between the dunes of Guerbes to the west and the river banks to the east. The substrate is composed of alluvial deposits and dune sand. The floristic composition broadly mirrors that of the adjacent right-bank marsh, with the exception of the dune fringe, where three alder carrs (*Alnus glutinosa* (L.) Gaertn.) are established. A total of 42 plant species have been recorded (Samraoui & de Bélair 1997).

Methodology

Field-based water quality analysis

Water physicochemical characterisation was carried out using a WTW MultiLine® IDS 3630 portable multiparameter probe, which allowed the direct field measurement of four key parameters: pH, dissolved oxygen (DO), electrical conductivity (EC) and water temperature (T). Acquiring these data directly at the sampling point is methodologically decisive, as it preserves the natural state of the water column and captures transient conditions that would otherwise be lost during sample transport to the laboratory (Stefanidis & Papastergiadou 2024). Indeed, even brief delays between collection and analysis can alter dissolved gas concentrations, ionic equilibria and thermal properties through degassing, atmospheric exchange and pressure fluctuations artefacts that systematically compromise the ecological interpretation of the results. Four parameters per site were retained for analysis, as detailed in the Electronic Supplementary File 1, Table S1.

Measurement of other environmental variables

Alongside the water ecological variables, the sensorial and physiographic characteristics of the nine study waterbodies were recorded. These include distance from the nearest agglomeration, surface area, hydrological regime, temporality and facies, color and odor, perimeter, altitude, depth, aspect, slope, woody and herbaceous species cover rate, and human activity indicators: grazing, fire, agricultural activity and pumping intensity (ESF 1, Table S2). Qualitative field descriptors were converted into numerical scores on the basis of predefined ordinal ranges

assigned to each variable, following a standardised attribute classification scheme (ESF1, Table S2). These encoded values were subsequently integrated into the multivariate analyses.

Floristic study

The inventory of benthic macrophytes in the Guerbes-Senhadja wetland complex was conducted during the spring of 2025. Species abundance was estimated visually using four categories defined for this study: 0, absent; 1, few individuals; 2, small population; 3, continuous meadow-forming stand.

Identification proceeded through several steps: primary reference was made to the Algerian flora of Quézel & Santa (1962-1963), complemented by the North African flora of René Maire (1952-1987) and the reference works of Battandier (1888-1890) and Battandier & Trabut (1895) for the relevant families. Most identification were subsequently verified, completed and updated by consulting the flora of eastern Andalusia (Blanca & al. 2011). Nomenclature was adjusted according to the synonymic index of Dobignard & Chatelain (2010-2013) and its updated online version (APD 2026). Recorded taxa were characterised by their chorological and biological types in the sense of Raunkiaer (1934), following the floras and databases of Jeanmonod & Gamisans (2013), Pignatti & al. (2017-2019) and Euro+Med Plant Base (2006-2021).

The list of rare species was compiled on the basis of rarity criteria established by Quézel & Santa (1962-1963) and vulnerability criteria defined by the IUCN (2026) at the global scale. Species listed in Executive Decree No. 03-12/12-28 supplementing the list of protected non-cultivated plant species in Algeria (Law 2012), and/or on the IUCN Red List (2026) (<https://www.iucnredlist.org/>), and/or classified as rare or very rare, were regarded as taxa of patrimonial value.

Statistical analysis

Excel 2021 and R 4.4.3 were used for the statistical analysis. The database comprising raw field data for each measured variable was systematically arranged into Excel spreadsheets, classified by numerical or abbreviated letter codes for taxa, some of which represent values within specific intervals. A normalization process was subsequently executed to minimize the size of each sample and reformat the data to meet the systems' needs.

Excel 2021 and R 4.4.3 were used for the statistical analysis. The raw field data were systematically arranged into Excel spreadsheets, classified by numerical or abbreviated letter codes for taxa, with values falling within predefined intervals. A normalisation procedure was applied to standardise data prior to multivariate analyses.

A co-inertia analysis (CIA) was carried out using the ade4 package (Dolédéc & Chessel 1994; Dray & al. 2003) to test the co-structure between floristic taxon assemblages and the measured environmental descriptors. The floristic matrix comprised the abundance of each taxon at each waterbody. The vector correlation coefficient (RV) of the CIA quantified the overall correspondence between the recorded taxa and the environmental descriptors, ranging from 0 (complete independence) to 1 (perfect co-structure). Statistical significance of the RV coefficient was tested using a Monte-Carlo permutation test (random permutation of rows in both matrices; Dray & al. 2003). A Principal Component Analysis (PCA) of 18 environmental variables was additionally performed to characterise site typologies. All analyses were conducted using R version 4.4.3 (R Core Team 2023).

Results

Floristic richness and originality

The present study recorded 31 benthic macrophyte species distributed across 12 families and 16 genera. Pteridophytes are represented by a single family, as are the green algae, while angiosperms predominate with 10 botanical families. The best-represented families are the *Characeae* (5 taxa), followed by *Potamogetonaceae* and *Plantaginaceae* with four taxa each. The remaining families are more sparsely represented (Table. 2).

Floristic richness and originality varied considerably among the study sites according to their geographic situation and hydrological character. Saline semi-temporary marshes were relatively species-poor, with four to seven taxa per site and low abundance. Temporary ponds displayed notably higher richness (up to 13 species), though macrophyte abundance remained low owing to summer desiccation. Peaty lakes and alder carrs yielded the greatest richness (11 to 18 taxa) with comparatively strong abundance, dominated by multi-species meadow-forming stands, the most frequent combinations being *Chara vulgaris* L. with *Lemna minor* L. and *Callitriche obtusangula* Le Gall, and *Salvinia natans* (L.) All. with *Ranunculus peltatus* subsp. *baudotii* (Gren. & Godr.) C.D.K.Cook and *R. trichophyllus* Chaix.

Chorological diversity

The floristic list reveals a diversity of biogeographical origins (Tab. 4). Analysis of the raw phytogeographical spectrum shows that the broadly distributed element is the most important component of the entire aquatic flora of the Guerbes-Senhadja complex, comprising 11 species (38.71%), of which two are of tropical origin (*Utricularia gibba* L. and *Wolffia arrhiza* (L.) Horkel ex Wimm.). Despite this dominance, the northern element retains a substantial share with 9 taxa (29.03% of the inventory). Mediterranean taxa number 8, accounting for 25.80% of the recorded flora. The introduced element ranks last, comprising only two taxa (*Callitriche deflexa* A.Br. ex Hegelm. and *Ludwigia grandiflora* (Michx.) Greuter & Burdet).

Patrimonial Value of the Flora

Rarity analysis based on Quézel & Santa (1962-1963) identified 13 rare taxa sensu lato (43.33% of the studied flora), of which 7 are very rare and 7 are rare (ESF1, Table S3). Seven species are listed under the Algerian decree on protected non-cultivated plant species (Executive Decree No. 12-03, 2012). Nine recorded taxa appear on the IUCN Red List (2026) with Least Concern status. In total, the studied areas harbour 14 taxa of patrimonial and conservation significance.

Hydrological and physicochemical characteristics

This section presents an analysis of the physicochemical properties of the water samples collected across the nine study sites. The data provide insights into the hydrochemical gradients structuring the studied waterbodies. Tables S4 and S5 serve as complementary references, summarising the full set of measured parameters alongside the narrative interpretation.

Among the nine study sites, electrical conductivity ranged from 3.117 $\mu\text{S}/\text{cm}$ (GOU) to 1865 $\mu\text{S}/\text{cm}$ (GHT), reflecting a pronounced hydrochemical gradient from highly dilute

Table 2. Inventory of benthic macrophytes recorded within the Guerbes Senhadja wetland complex (Woody and herbaceous species cover rate (Wspr): 1 = 25–50%; 2 = 51–75%; 3 = 76–100%).

Code	Taxon	Family	Biogeography	DAT	GBM	GCH	GHT	GKH	GOU	GSM	LSF	GHA
Cabr	<i>Callitriche brutia</i> Petagna	Plantaginaceae	Subcosm				3		1			
Cade	<i>Callitriche deflexa</i> A.Br. ex Hegelm.	Plantaginaceae	Intr								3	
Caob	<i>Callitriche obtusangula</i> Le Gall	Plantaginaceae	Med-atl	3	1	2	3	1	1	2	3	
Cede	<i>Ceratophyllum demersum</i> L.	Ceratophyllaceae	Subcosm	1			2		1			
Cesu	<i>Ceratophyllum submersum</i> L.	Ceratophyllaceae	Med								1	
Chco	<i>Chara connivens</i> P. Salzmann ex A. Braun	Characeae	Med	2	1	2					2	
Chgl	<i>Chara globularis</i> J.L. Thuiller	Characeae	Med	3		2	3					
Chgy	<i>Chara gymnophylla</i> (A.Braun) A.Braun	Characeae	Med				2			1		
Chvu	<i>Chara vulgaris</i> L.	Characeae	Med			3	3			3		
Legi	<i>Lemna gibba</i> L.	Lemnaceae	Cosm			2				1		
Lemi	<i>Lemna minor</i> L.	Lemnaceae	Subcosm	3		3	3		1	2		2
Letr	<i>Lemna trisulca</i> L.	Lemnaceae	Cosm						1			
Lugr	<i>Ludwigia grandiflora</i> (Michx.) Greuter & Burdet	Onagraceae	Intr							3		
Lupa	<i>Ludwigia palustris</i> (L.) Elliott	Onagraceae	Holar	2		2	2	1		1	3	
Myal	<i>Myriophyllum alterniflorum</i> DC.	Haloragaceae	Med-atl			2			1		3	
Mysp	<i>Myriophyllum spicatum</i> L.	Haloragaceae	Subcosm				1					
Myve	<i>Myriophyllum verticillatum</i> L.	Haloragaceae	Holar								2	
Niop	<i>Nitella opaca</i> (Bruzellius) C. Agardh	Characeae	Med	2	3					2		
Nyal	<i>Nymphaea alba</i> L.	Nymphaeaceae	Euras				3		1	3	3	
Nype	<i>Nymphaea peltata</i> (S.G. Gmel) Kuntze	Menyanthaceae	Euras						1			
Polu	<i>Potamogeton lucens</i> L.	Potamogetonaceae	Circumbor			1	2		1		2	
Pono	<i>Potamogeton nodosus</i> Poir.	Potamogetonaceae	Subcosm								1	
Potr	<i>Potamogeton trichoides</i> Cham. & Schldtl.	Potamogetonaceae	Euras	2			2		1			
Rapb	<i>Ranunculus peltatus</i> subsp. <i>baudotii</i> (Gren. & Godr.) C.D.K.Cook	Ranunculaceae	Europ	2	1	3	3	2	2	3	3	2
Ratr	<i>Ranunculus trichophyllus</i> Chaix	Ranunculaceae	Holar				2	2	2	3	3	
Sana	<i>Salvinia natans</i> (L.) All.	Salvinaceae	Euras	2		3	2		2	3	2	
Utau	<i>Utricularia australis</i> R. Br.	Lentibulariaceae	Subcosm							1		
Utgi	<i>Utricularia gibba</i> L.	Lentibulariaceae	Trop				1					
Veau	<i>Veronica anagallodes</i> Guss.	Plantaginaceae	Subcosm	2		1	1	1	1	2		
Woar	<i>Wolffia arrhiza</i> (L.) Horkel ex Wimm.	Lemnaceae	Paleotrop			2	1			1		
Zapa	<i>Zannichellia palustris</i> L.	Potamogetonaceae	Subcosm									2

Circumbor: Circumboreal; Cosm: Cosmopolitan; Euras: Eurasian; Europ: European; Holar: Holarctic; Intr: Introduced; Med: Mediterranean; Med-atl: Mediterranean-Atlantic; Paleotrop: Paleotropical; Subcosm: Subcosmopolitan; Trop: Tropical.

freshwater to moderately mineralised conditions, with the anomalously low GOU value possibly indicating instrument scaling or a near-distilled water input at that date. Dissolved oxygen values varied between 3.197 mg/L (GHA) and 9.620 mg/L (LSF), revealing contrasting oxygenation regimes. pH ranged from 6.848 (DAT) to 8.863 (LSF), indicating sites spanning acidic to slightly alkaline conditions. Water temperature oscillated between 24.054°C (GHA) and 31.722°C (GBM), reflecting the influence of exposure and shallow depth on thermal regime. Sites dominated by brown coloration and odor (DAT, GCH, GOU, GSM, LSF) displayed higher organic matter inputs, consistent with their alder carr and peaty substrate context.

Measurement of other environmental variables

Beyond water physicochemical data, each study site was characterised by a set of sensorial and physiographic descriptors recorded during field campaigns. Because these variables were inherently qualitative in nature, they were converted into ordinal numerical scores using a predefined classification scheme in which each descriptor was assigned ranked intervals reflecting field observation categories. The resulting encoded matrix is presented in Table 7. These quantitative surrogates were subsequently incorporated into the multivariate statistical framework as explanatory variables, enabling a joint assessment of the environmental gradients both physicochemical and physiographic that govern the spatial organisation of benthic macrophyte communities across the nine study sites.

Principal component analysis

A Principal Component Analysis (PCA) was conducted to explore patterns among 18 environmental variables across the nine wetland sites (Fig. 2). These sites, ranging from Lake Sidi Freitis (LSF) to Gareat Hadj Tahir (GHT), represent a diverse gradient of ecological conditions, anthropogenic pressures, and geographical settings. The variables included physico-chemical indicators (e.g., dissolved oxygen, electrical conductivity, pH, temperature), hydromorphological traits (depth, slope, perimeter, altitude), and anthropogenic factors such as grazing, fire activity, and pumping.

The first two principal components accounted for a substantial portion of the total variance: PC1 explained 39.3%, while PC2 accounted for 19.9%, totaling 60.2%. This highlights a strong underlying structure driven by ecological gradients across the study region.

PC1 captures a clear ecological axis transitioning from highly disturbed, shallow, and anthropogenically impacted wetlands characterized by elevated values for grazing, fire and agriculture, smell, pumping activity, and electrical conductivity, toward deeper, vegetated wetlands with stronger natural features. These include higher values for depth, woody and herbaceous cover, and hydrological integrity.

PC2 reflects a topographic and climatic gradient. Positive loadings correspond to sites with greater altitude, steeper slopes, and lower ambient temperatures, while negative loadings are linked to lowland wetlands with larger perimeters and greater distances from urban areas. This axis thus differentiates mountainous, cooler wetlands from those in warmer, expansive basins.

The orthogonality of certain variables (e.g., *Altitude* vs. *Color*) suggests independent ecological gradients, reinforcing the multivariate nature of wetland ecological structuring.

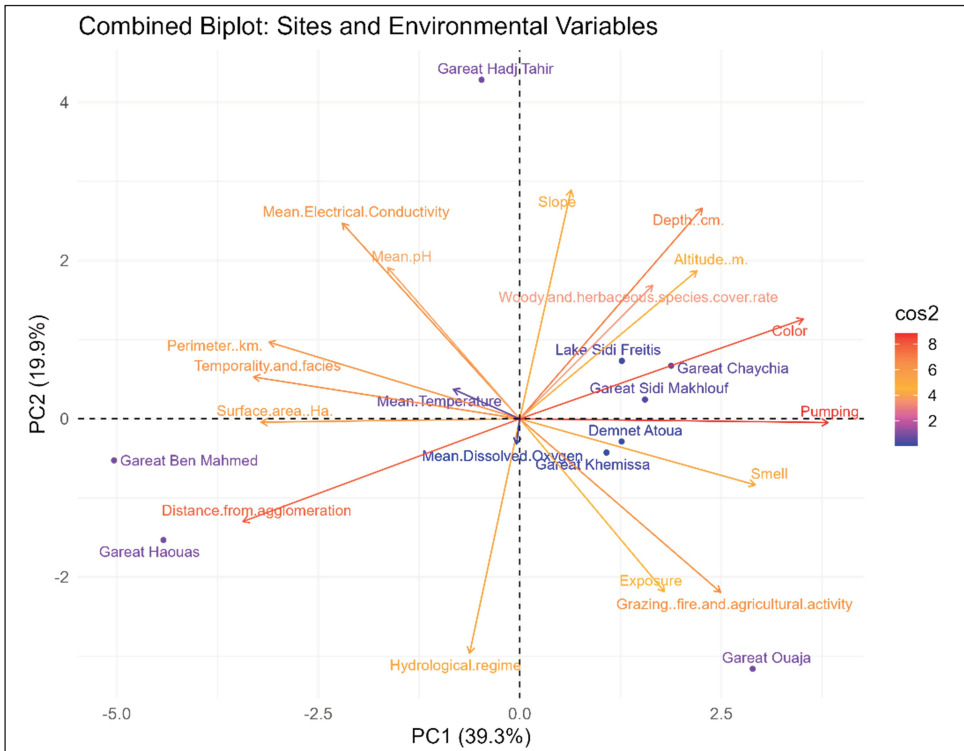


Fig. 2. Representation of the F1 × F2 factorial planes of the PCA for all variables.

Site projections in the PCA biplot allowed for clear three ecological typologies:

1st group (Dunary depression and riparian systems): LSF (Lake Sidi Freitis), GOU (Gareat Ouajaa) and GSM (Gareat Sidi Makhoulouf) are associated with positive PC1 and PC2 scores, identifying them as disturbed, lowland wetlands under substantial anthropogenic stress. Their elevated conductivity and land-use pressures signal the need for targeted management.

2nd group (Peaty alder carr formations): GCH (Gareat Chaychia) and GHT (Gareat Hadj Tahir) occupy the negative quadrant of both components, representing deeper, less impacted wetlands with greater vegetation and natural hydrological regimes. These sites may serve as reference conditions for conservation benchmarks.

3rd group (Temporary and semi-temporary marshes): GBM (Gareat Ben Mahmed), GKH (Gareat Khemissa), GHA (Gareat Haoua) and DAT (Demnet Atoua) fall in intermediary positions, indicating transitional systems that are influenced by both natural features and moderate human disturbance.

This PCA reveals the complex interplay between landscape morphology, anthropogenic influence, and ecological resilience. Such insights offer strategic direction for wetland management, enabling prioritization for restoration, zoning decisions, and the design of nature-based solutions tailored to site-specific realities.

Ecological implications

The PCA highlights the complexity and heterogeneity of wetland ecosystems in the study area. Gradients of disturbance, topography, and hydrology interact to shape the ecological identity of each wetland. These findings have clear implications for wetland management:

Wetlands like Lake Sidi Freitis, heavily impacted by pumping and grazing, may require urgent conservation measures;

Conversely, sites such as Garaet Chichaya offer opportunities for long-term conservation, representing reference conditions;

The positioning of sites along these gradients provides a basis for zoning, restoration prioritization, and the implementation of nature-based solutions.

Floristic, environmental and physicochemical variability

A co-inertia analysis was performed on the species abundance matrix and the environmental and water physicochemical descriptor matrix. The resulting co-structure is captured by the first two co-inertia axes, accounting for 35.49% and 12.47% of total inertia respectively (Fig. 3a, b & c). These axes reveal a strong correspondence between the structures independently provided by each table (environmental descriptors and benthic macrophytes) and that derived from the co-inertia. The vector correlation coefficient (RV) of the co-inertia analysis quantifies the degree of coupling between the recorded taxa and the sampled environmental descriptors. The RV coefficient is statistically significant ($RV = 0.63$), confirming the existence of a meaningful co-structure between the field variables and the strictly aquatic flora of the Guerbes-Senhadja wetland complex.

Description of sampling sites

Along axis 1, sampling sites are arranged according to a salinity gradient, progressing from freshwater formations (negative side) towards brackish-water formations (positive side) (Fig. 3d).

The site groupings emerging in the F2 plane reveal a vegetation zonation governed by the interplay of several overriding environmental factors. Drawing on the known ecological requirements of the constituent species, the second axis reflects water depth and inundation regime: the positive side gathers sites characterised by degraded riparian woodland in contact with lacustrine systems of intermediate depth, whereas the negative side brings together stations supporting dense, mature alder carr formations that have evolved towards deep peat-forming wetlands.

Benthic macrophyte community structure in the Guerbes-Senhadja complex

Axis 1 separates species associated with semi-permanent brackish waters like *Zannichellia palustris* L. and *Nitella opaca* (Bruzellius) C. Agardh from taxa characteristic of all categories of stagnant freshwater, including *Salvinia natans*, *Ludwigia palustris* (L.) Elliott, *Ranunculus peltatus* subsp. *baudotii*, *Callitriche obtusangula*, *Nymphaea alba* L. and *Chara vulgaris* (Fig. 3e). Axis 2 contrasts species capable of colonising fast-flowing reaches devoid of riparian cover (*Myriophyllum alterniflorum* DC., *M. verticillatum* L., *Ranunculus trichophyllus* and *Callitriche deflexa*) with taxa that occur in waterbodies shaded by dense riparian canopy, such as *Lemna minor*,

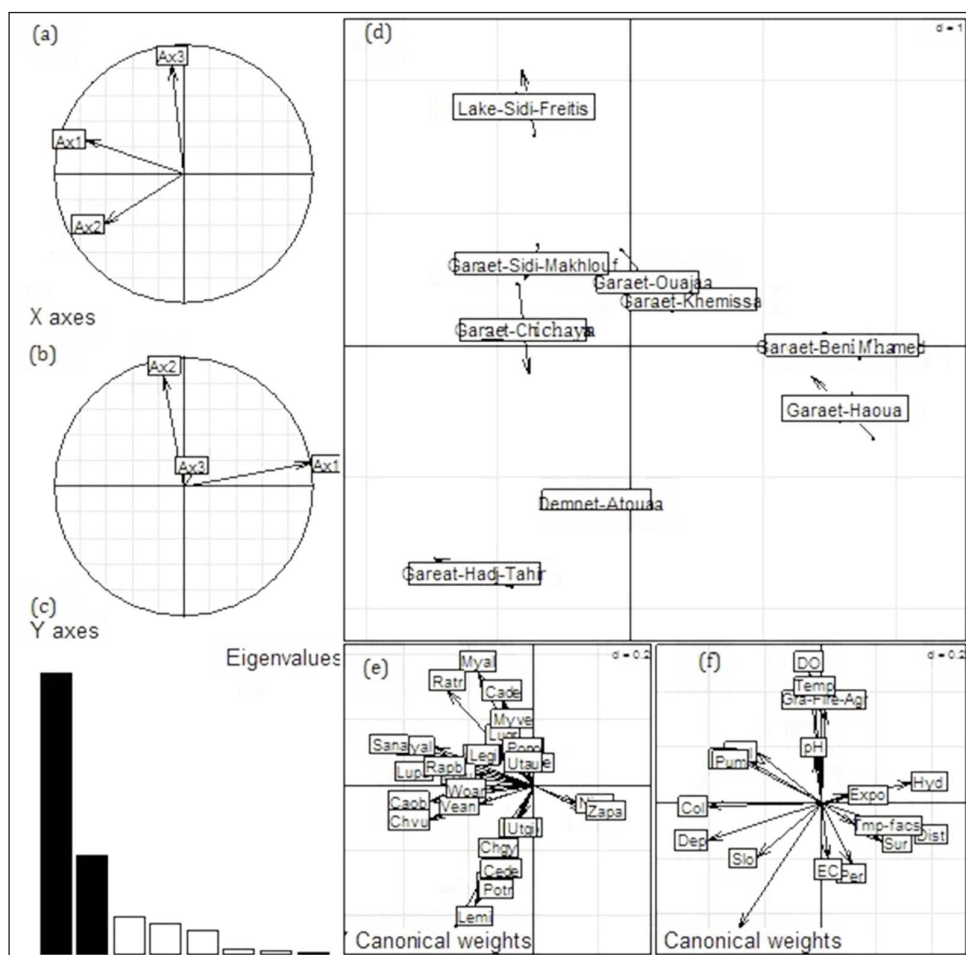


Fig. 3. Co-inertia analysis results based on recorded benthic macrophyte abundances and measured environmental and physicochemical water descriptors. (a) Components of the standardized principal component analysis for the environmental and physicochemical dataset projected onto the co-inertia axes; and (b) components of the centered principal component analysis for the floristic dataset projected onto the same co-inertia axes. (c) Eigenvalue distribution of the co-inertia analysis. (d) F1 x F2 factorial plane of the co-inertia, displaying arrows that link the sampling sites according to their physicochemical and environmental descriptors (arrow bases) and the benthic macrophytes (arrow heads). (e) Species distribution plotted on the F1 x F2 co-inertia factorial plane. (f) Spatial distribution of field descriptors across the F1 x F2 co-inertia factorial plane.

Potamogeton trichoides Cham. & Schltdl., *Ceratophyllum demersum* L. and *Chara gymnophylla* (A.Braun) A.Braun, whose typical habitats include the alder carr of Demnet Atoua and the lake of Garaet Hadj El Tahir.

Environmental and physicochemical descriptors

Axis 1 is driven by a set of complementary descriptors, hydrological regime, aspect, surface area, water colour, depth, among others and delineates a gradient of hydrological functioning across the sampled waterbodies (Fig. 3f). Axis 2 opposes sites with well-developed riparian vegetation at higher altitude to those characterised by degraded vegetation cover, flowing water conditions, and elevated pH and dissolved oxygen values.

Discussion

Distribution limits and community structure

Species fidelity constitutes an important characteristic in the study of plant communities, as faithful species express a preference for a particular environment through greater abundance or vitality (Zouaïdia & al. 2015). The results of this work allow the distinction of four principal macrophyte communities.

The *Nitella opaca* community: in this grouping, *N. opaca*, which confers a distinctive physiognomy to the vegetation, is associated with *Zannichellia palustris*. *Nitella opaca* is one of the most abundant macrophytes at Garaet Beni Mahammed, where it was previously considered rare in North Africa (Elkhiati & al. 2002). This species occurs in both exposed and inundated conditions, at depths ranging from 0.25 to 1 m. *Nitella* species display moderate salt tolerance and can persist in areas with surface salt efflorescences (Soulié-Märsche 2008).

The *Lemna minor* community is broadly distributed across all degraded zones of the Guerbes-Senhadja complex, associated with less water-quality-demanding species. The assemblage includes *Potamogeton trichoides* and *Chara gymnophylla* (A. Braun) A. Braun. Common duckweed is well documented for its high tolerance to fertiliser pollution, detergents and pumping, as well as to anthropogenic disturbances such as accelerating urbanisation and intensive agricultural practice (Vámos & al. 2024).

The *Nymphaea alba* community develops at the boundary of the *Lemna minor* zone, towards deeper water. This emergent floating macrophyte (Paillisson & Marion 2006) was recorded predominantly in the stagnant waters of three large lakes of the Guerbes-Senhadja complex, where it can form extensive colonies (Samraoui & de Bélair 1997). The community includes *Salvinia natans*, *Ludwigia palustris*, *Ranunculus peltatus* subsp. *baudotii*, *Callitriche obtusangula* and *Chara vulgaris*. A clear spatial relationship exists among *Callitriche obtusangula*, *Salvinia natans* and *Ranunculus peltatus* subsp. *baudotii*: when the three species coexist, the common water-crowfoot occupies the deepest part of the depression while *Callitriche* and *Salvinia* form an outer fringe (Allem & al. 2017).

The *Myriophyllum* community (*M. alterniflorum* and *M. verticillatum*): these two species occur in environments where they associate with *Ranunculus trichophyllus* and *Callitriche deflexa*. This hydrophytic flora is broadly comparable to that of the châabas (stream channels and ravines) crossing alder carrs, most commonly concentrated along freshwater watercourses (Belouahem-Abed & al. 2009).

New floristic records for the region

As is characteristic of chorological and floristic inventory work, particularly in countries that have received limited botanical attention and where national floras have not been continuously

updated as is the case in Algeria, the most recent national flora of Quézel & Santa (1962-1963) and the synonymic index of North Africa by Dobignard & Chatelain (2010-2013) resolve certain taxonomic conflicts while simultaneously bringing others to light, with others remaining overlooked. To these must be added *Nymphoides peltata* (S.G. Gmel) Kuntze, indicated as a new record for Algerian flora at Garaet Ouajaa by de Bélair & Vêla (2011) and Hamel & al. (2017), subsequently overlooked, and not appearing in the reference floras (Battandier & Trabut 1888-1890; Maire 1952-1987; Quézel & Santa 1962-1963). Furthermore, five taxa constitute new records for the Guerbes-Senhadja region, although they have been previously noted in the adjacent wetland complexes of Bône and La Calle or neighbouring biogeographical sectors (cf. Quézel & Santa 1962-1963). This situation positions the study region, situated at the western boundary of Numidia, as an important transitional zone towards other biogeographical sectors, a further justification for its exceptional species richness (de Bélair & Vêla 2011). It must also be noted that some of these records cannot be considered entirely new, given the very limited botanical exploration the region has received (Saci & al. 2022) (Table 3).

Environmental drivers of benthic macrophyte species richness in the Guerbes-Senhadja wetland complex

The spatial patterns of benthic macrophyte diversity across the nine study sites reflect the simultaneous action of multiple, hierarchically nested environmental filters rather than

Table 3. New distribution in Algeria of some noteworthy benthic macrophytes observed in the Guerbes-Senhadja wetland complex (new records underlined).

Taxon	Distribution in Algeria (Quézel & Santa, 1962–1963, modified)	Bibliographic data
<i>Ceratophyllum submersum</i> L.	K ₃ : Lakes of the Bône-La Calle region + <u>Guerbes-Senhadja</u> + <u>Swamp of Boussedra</u>	Samraoui & Belair 1997; Zediri & al. 2026
<i>Lemna gibba</i> L.	A ₁ : Algiers, Bouira; O ₃ : Tlemcen, Tiaret; K ₃ : + <u>Guerbes-Senhadja</u> + <u>Pond of Wadi Nil</u> + <u>Pond of Fertial</u>	Samraoui & Belair 1997; Zediri & al. 2026
<i>Lemna trisulca</i> L.	K ₃ : La Calle, Bône, Tonga Lake + <u>Guerbes-Senhadja</u> ; C ₁ : Constantine	Present study
<i>Ludwigia palustris</i> (L.) Elliott	K ₃ : Lakes of La Calle + <u>Bône and Guerbes-Senhadja</u> ; <u>Gareat Ouajaa</u>	de Bélair (unpublished); Allem & al. 2017; Fetnaci & al. 2019; Hamel & Saci 2024
<i>Nymphaea alba</i> L.	K ₃ : Bône, La Calle + <u>Guerbes-Senhadja</u> . Introduced here and there	de Bélair (unpublished); Hamel & Saci 2024
<i>Nymphoides peltata</i> (S.G. Gmel) Kuntze	K ₃ : Guerbes-Senhadja: Gareat Ouajaa	de Bélair & Vêla 2011; Hamel & al. 2017
<i>Utricularia gibba</i> L.	K ₃ : La Calle + <u>Guerbes-Senhadja</u> , SC: Tassili n'Ajjers	Present study

the effect of any single variable (Lacoul & Freedman 2006; Keddy 2010). At the uppermost level of this hierarchy, the hydrological regime operates as the most decisive ecological filter. Sites sustaining permanent stagnant water (GHT, GSM, GCH, DAT, LSF) consistently harbour the highest macrophyte richness (11–18 taxa), whereas sites subject to temporary or semi-permanent regimes with flowing water (GBM, GHA) support no more than 3–4 taxa. This contrast reflects the fundamental dependence of aquatic plant populations on inundation duration: permanent water bodies allow species to complete their life cycles, maintain viable propagule banks and develop the stratified microhabitats that accommodate the full range of macrophyte growth forms, from surface-floating lemnids to deeply submerged charophytes (Sand-Jensen & Søndergaard 1981; Brock & Casanova 1997; Rhazi & al. 2012). Conversely, summer desiccation imposes a phenological constraint that selectively eliminates hydrologically sensitive taxa such as *Nymphaea alba* and *Potamogeton lucens*, while hydraulic stress at sites with temporary currents further inhibits the attachment and growth of delicate floating species such as *Wolffia arrhiza* and *Salvinia natans* (Casanova & Brock 2000; Chambers & al. 2008; Çelekli & al. 2024).

Once permissive hydrological conditions are met, water chemistry constitutes the second-order filter shaping community composition. Electrical conductivity (EC), as a proxy for total mineralisation, shows a non-linear relationship with richness: sites with EC below 600 $\mu\text{S}/\text{cm}$ under permanent hydrology (GCH, GSM) support 13–15 taxa, while GHT, despite recording the highest EC of the dataset (1865 $\mu\text{S}/\text{cm}$), simultaneously harbours the greatest richness (18 taxa), illustrating that moderate mineralisation can enhance nutrient availability without triggering eutrophication (Grillas & al. 1993; Céréghino & al. 2008). It is the interaction between elevated conductivity and hydrological instability, not conductivity alone that proves most restrictive, as evidenced by GBM (EC = 1391 $\mu\text{S}/\text{cm}$, temporary current, 4 taxa). At the brackish end of the salinity gradient, *Zannichellia palustris* and *Nitella opaca* act as ecological sentinels, their exclusive occurrence in the most mineralised sites signalling a community-level ionic filter that progressively excludes salt-sensitive taxa (Soulié-Märsche 2008; Kaushal & al. 2021). Water pH further modulates assemblage composition through its control over inorganic carbon speciation: the circumneutral to slightly acidic conditions recorded at DAT, GCH, GHT and GOU (pH 6.8–7.5) sustain the highest charophyte diversity, consistent with the oligotrophic, circumneutral preferences of *Chara* and *Nitella* (Krause 1997), while alkaline conditions (pH > 8.5 at LSF and GKH) favour carbonate precipitation and shift competitive dynamics towards tolerant angiosperms (Wetzel 2001). Dissolved oxygen (DO) acts as a threshold rather than a gradient variable: below approximately 3.2 mg/L, root anoxia impairs nutrient uptake and anchoring in rooted species such as *Potamogeton nodosus* and *Ludwigia palustris* (Cronk & Fennessy 2001), while the exceptionally high DO at LSF (9.620 mg/L) reflects the positive feedback between macrophyte photosynthesis and oxygenation that self-reinforces community persistence (Carpenter & Lodge 1986).

At the third and most modulating level, vegetation structure and light availability fine-tune assemblage composition within the hydrochemically defined community framework. Although no direct light measurements were taken, water colour, canopy cover (Wspr), depth and DO jointly serve as proxies for the prevailing light regime. The dataset yields a counter-intuitive pattern: the sites with the greatest estimated light availability (open canopy, clear or slightly coloured water, shallow depth) (GHA, GBM, GKH) are paradoxically the species-

poorest, while the richest sites (GHT, GSM, GCH) are characterised by brown-tinted, organically enriched water under partial canopy. This apparent contradiction resolves when the nature of the brown coloration is considered: dissolved humic and fulvic acids in alder carr and peat-influenced systems absorb light selectively without generating the turbidity of phytoplankton blooms, creating a stable low-irradiance environment at depth that is precisely suited to the shade-tolerant charophytes dominating these assemblages (Wetzel 2001; Lacoul & Freedman 2006). At open sites, hydrological instability overrides the benefit of greater irradiance by curtailing the growing season below the minimum threshold for most macrophyte life forms. The sole site combining favourable light conditions with permanent hydrology and adequate depth (LSF) accordingly supports 13 taxa including deepwater specialists (*Potamogeton lucens*, *Utricularia australis*), confirming the positive role of light when decoupled from hydrological stress (Chambers et al. 2008). Dense riparian cover ($W_{spr} \geq 65\%$) correlates strongly with high richness (≥ 11 taxa) by stabilising banks, limiting sediment resuspension, moderating thermal fluctuations and sustaining the oligotrophic humic conditions preferred by specialist macrophytes, functions epitomised by the alder carrs of DAT and GCH (Naiman & Décamps 1997; Belouahem-Abed & al. 2011).

Anthropogenic disturbances (grazing, agricultural pressure, fire and water pumping) act as a compound disturbance filter superimposed on the natural environmental gradients. Pumping is particularly consequential: it directly reduces water depth below the minimum threshold for submerged macrophytes and indirectly increases turbidity through sediment resuspension and nutrient enrichment during refilling, thereby selecting for disturbance-tolerant generalists such as *Lemna minor* and *Callitriche obtusangula* at the expense of specialist assemblages (Romo & al. 2007; Lévesque & al. 2017; Vámos & al. 2024). Sand encroachment from coastal dunes adds a geomorphologically driven disturbance layer specific to this complex, progressively infilling depressions and reducing available water volume, a process already documented at the adjacent Beni-Belaïd wetland (Bouldjedri & al. 2011). Taken together, these findings are consistent with the hierarchical assembly framework of Keddy (2010) and corroborate empirical results from comparable Mediterranean wetlands (Grillas & al. 1993; Rhazi & al. 2012; Hammana & al. 2024; Zediri & al. 2026), confirming that macrophyte richness in the Guerbes-Senhadja complex is governed by a cascade of filters in which hydrology sets the boundary conditions, water chemistry shapes functional community types, and vegetation structure together with light availability and disturbance regime determines the final assemblage composition and diversity.

Threats and conservation measures

Despite growing conservation concerns, the wetlands of North Africa continue to be disturbed, drained and polluted. Today, the majority are in a state of degradation (Médail & al. 1998; Rhazi & al. 2012; Hammana & al. 2024), and several have simply disappeared (Muller & al. 2011; Fetnaci & al. 2019).

Among the threats weighing on the biodiversity of the Guerbes-Senhadja complex, aeolian sand drift from coastal dunes is particularly significant. The advance of sand constitutes a growing risk for benthic macrophyte habitats, a problem already documented at the Beni-Belaïd wetland to the east (Bouldjedri & al. 2011). Concurrently, increasing urban contiguity driven by peri-urbanisation and the densification of the rural-urban fringe, generates mounting pollution from illegal dumping and untreated wastewater discharge. This form of diffuse pollution

degrades not only plant diversity but also the landscape function of the region's wetlands. Furthermore, benthic macrophytes are recognised as reliable bioindicators of standing water quality precisely because they decline rapidly in response to water pollution and pumping-induced disturbance. The influence of this pollution is primarily direct, manifesting as reduced light penetration through increased turbidity in nutrient-enriched waters, which constrains the growth of floating and submerged macrophytes (Romo & al. 2007; Lévesque & al. 2017).

Conservation management must be conducted under the oversight of scientists or land managers capable of evaluating shifts in plant community composition and guiding land-use practices accordingly. Land users must be made aware of both the ecological value and the fragility of these habitats as a necessary precondition for the implementation of targeted protection measures. Regular monitoring of the composition and spatial distribution of macrophyte communities in the Guerbes-Senhadja complex is equally essential, as it provides a precise record of changes in the physicochemical and hydrological parameters of the waterbodies, and allows the evaluation of the ecological consequences of hydraulic infrastructure and drought episodes both of which have already exerted considerable effects on the composition and distribution of benthic macrophytes across the study sites.

Conclusion

The inventory of nine waterbodies in the Guerbes-Senhadja wetland complex conducted during 2025 documented 31 benthic macrophyte taxa and identified 17 taxa of patrimonial value with conservation significance, of which six constitute new records for western Numidia. The analysis of the spatial distribution of the main plant communities identified a co-structure between hydrohygrophilic and amphibious vegetation that emerges as an effective management tool for the nine study sites and for the entire lake-marsh system of Guerbes-Senhadja.

This work establishes a baseline for more targeted investigations into the functioning and diversity of benthic macrophyte communities in this poorly documented region. Future priorities should include: (1) the continuation and expansion of the initiated floristic surveys, through systematic prospecting of Numidian wetlands at multiple periods across successive annual cycles; (2) the concurrent development of functional ecology studies aimed at elucidating the processes and determinants governing the distribution of these high-value plant communities; and (3) the translation of these findings into concrete, evidence-based proposals for the conservation and sustainable management of the Guerbes-Senhadja wetland complex.

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