sciendo

Environmental & Socio-economic Studies

environ ses

DOI: 10.2478/environ-2026-0006

Environ. Socio.-econ. Stud., **2026, 14, 1: 72-84**

Original article

Floristic diversity and distribution patterns along a salinity gradient in three Ramsar wetlands in Northeastern Algeria

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ABSTRACT

This study investigates the floristic, biological, and chorological diversity of three Ramsar wetlands in the Sebkhetes of Aurès Wetlands Complex (SAWC) Algeria: Garaet Timerganine (freshwater), Chott Tinsilt (brackish water), and Sebkhet Ezzmoul (saline water). 154 taxa were recorded during field surveys. Asteraceae, Poaceae, and Fabaceae were the most represented families. Total taxa richness, Shannon diversity index (H′) and Pielou's equitability (E) showed relatively high values at Garaet Timerganine (S = 78, H' = 5.07, E = 0.82) and Sebkhet Ezzmoul (S = 52, H' = 5.38, E = 0.94), while Chott Tinsilt (S = 63, H' = 4.43, E = 0.73) exhibited moderate diversity with strong floristic homogeneity. The flora was predominantly composed of therophytes (48%) and hemicryptophytes (37 %), reflecting adaptations to salinity variability. Chamaephytes (9%), Geophytes (3%), Nanophanerophytes, Microphanerophytes and Phanerophytes were present in meaningfully lower proportions (1%). The chorology of recorded flora was dominated by the Mediterranean set encompassing 74 taxa, which constitutes 48.07% of the total flora. Species with a wide distribution set accounted for 56 species (36.30%), while the Northern set had a notable presence with 23 species (15%). *Limonium pruinosum* (Plumbaginaceae) was the only Saharan species exclusively recorded in Sebkhet Ezzmoul. Using Correspondence Factor Analysis (CFA), species distribution patterns were clearly aligned along a salinity gradient. Garaet Timerganine was associated with mesophilous taxa, Chott Tinsilt with stress-tolerant brackish species, and Ezzmoul with halophytes ones. This study highlights the fact that salinity shapes floristic diversity and guides adaptive wetland management in arid regions.

KEY WORDS: floristic diversity, Ramsar sites, salinity gradient, Sebkhetes of Aurès wetlands complex, North Africa

ARTICLE HISTORY: received 6 July 2025; received in revised form 21 December 2025; accepted 8 January 2026

1. Introduction

Transitional lands between terrestrial and aquatic environments, including wetlands comprise a mosaic of habitats adapted to varying gradients of moisture and, in some cases, salinity (De Billy et al., 2015). The latter is one of the key environmental drivers shaping the structure and composition of plant communities in wetlands. Indeed, variations in salinity levels create distinct ecological gradients that determine species distribution, abundance, and physiological adaptations (Flowers & Colmer, 2008). Despite covering only about 6% of the Earth's surface (Zou et al., 2022), wetlands are crucial for biodiversity conservation, supporting often endemic as well as rare flora and fauna (TAYLOR ET AL., 2021; HAMMANA ET AL., 2024). These vital ecosystems also play a critical role in hydrological and biogeochemical regulation, providing essential ecological, scientific, and socio-economic services (AMIGUES & CHEVASSUS-AU-LOUIS, 2011; GALLET ET AL., 2017). However, despite ongoing conservation efforts, wetlands remain particularly vulnerable to human activities, including agricultural and tourist exploitation, and climate change (TAYLOR ET AL., 2021; LABED ET AL., 2024). Recognized as a biodiversity hotspot (ADLOFF ET AL., 2015), Mediterranean wetlands have experienced a significant decline in recent decades (PERENNOU ET AL., 2012, SBIKI ET AL., 2025), with their degradation occurring at a faster rate than that of any other ecosystem type (DAVIDSON, 2014).

Algeria, situated on the southern rim of the Mediterranean Basin, has inherently modest freshwater reserves that are highly sensitive to climatic variability and recurrent droughts (BENZINA ET AL., 2018; TOUITOU & AL-AMINB, 2020; MERADI ET AL., 2024). Despite these constraints, the country's diverse climate and unique geomorphological configuration have given rise to a rich mosaic of wetlands, considered ecological strongholds due to their exceptional floristic diversity and high natural productivity (BOUGOFFA, 2024). Nevertheless, Algeria's plant biodiversity is experiencing a marked decline, affecting both ecosystem integrity and floral richness (FETNACI ET AL., 2019; BENZINA ET AL., 2024), while remaining insufficiently documented. Significant studies addressing these issues include the works of ZEMOUCHI & OUNISSI (2004), ADJAL & MOUICI (2004), SIDI ALI (2013), NEFFAR ET AL. (2016), ALIAT (2017), and BOUGOFFA ET AL. (2023). In Algeria, a total of 5,404 wetlands have been recorded, comprising 4,252 natural and 1,152 artificial sites (SAIFOUNI, 2021), among which 50 have been designated of international importance under the Ramsar Convention (DGF, 2016).

This study was conducted in three Ramsar sites belonging to the Sebkhetes of Aurès Wetlands Complex (SAWC), one of the sixteen wetland complexes in Algeria, as defined by the new national strategy for wetlands. It presents a major ecological interest in a semi-arid context: Garaet Timerganine (one of the rare freshwater wetlands in the region), Chott Tinsilt (brackish water) and Sebkhet Ezzmoul (saline water). The main objective of this study was to enhance the knowledge base on the floristic biodiversity, of the biological and chorological status of the three surveyed Ramsar wetlands. The aim was also to establish a novel comparative approach to understanding the distribution patterns of flora between these wetlands that differ in salinity levels.

2. Material and methods

2.1. Study area

The study area is situated within the expansive Sebkhetes of Aurès Wetlands Complex (SAWC), located in the highlands of north eastern Algeria, covering an area of 2,492,330 hectares (DGF, 2016). Early geographers have historically referred to this region as "the great country of lakes" owing to the dense concentration of endorheic saline water bodies scattered throughout the landscape. The study area encompasses three natural wetlands: Gareat Timerganine, Chott Tinsilt, and Sebkhet Ezzmoul each characterized by varying salinity levels (Table 1, Fig. 1). The wetlands are located in Oum El Bouaghi province, which has an average population density of 120 inhabitants per km^2 (BOUGOFFA ET AL., 2023).

Table 1. Geographical location and general characteristics of the study sites

Characteristics	Site		
	Garaet Timerganine	Chott Tinsilt	Sebkhet Ezzmoul
Latitude	35°39’56’’N	35°53’14’’N	35°53’14’’N
Longitude	06°57’08’’E	6°28’44’’E	06°30’20’’E
Altitude [m]	830	792	800
Surface [ha]	1460	3600	6765
Water salinity [mg/l]	0.1-0.3 (Fresh)	30-40 (Brackish)	300-400 (Salty)
Date of Ramsar classification	18/12/2009	12/12/2004	18/12/2009

The climate of the study area is classified as Mediterranean semi-arid, characterized by cold, rainy winters and hot, dry summers. The dry season typically extends from May to November, and the combination of limited winter precipitation and high evaporation rates can occasionally lead to the complete drying up of the water bodies during this period (BENZINA ET AL., 2022). Over the past 20 years, the mean daily maximum temperatures (± SD) were 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. The studied wetlands are characterized by saline to extremely saline soils (3 to 46 dS/m), with a neutral to alkaline pH (7.0 to 7.6), and they are moderately to highly calcareous ($CaCO_3$ from 18.7% to 33.7%). Gypsum levels range from 2.1% to 39.4%. The dominant soil texture classes are medium textures (loam to sandy loam) (ALIAT ET AL., 2016).

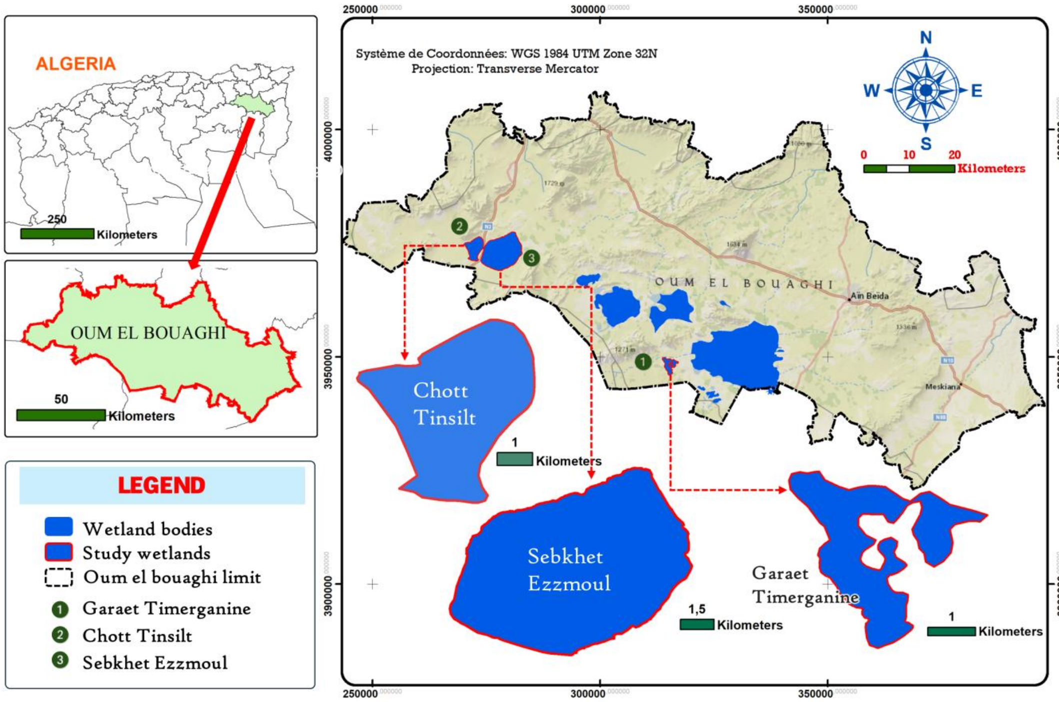

Fig. 1. Geographical location of study area and the three studied wetlands. (1) Gareat Timerganine, (2) Chott Tinsilt, (3) Sebkhet Ezzmoul

2.2. Flora sampling

This study was conducted in 2018, 2019, and 2021, during the months of April, May, and June, an optimal period typically preceded by rainfall that promotes the emergence of annual plant species (BENKHETTOU ET AL., 2015). The discontinuity in the years of study is due to the interruption of fieldwork during 2020 because of restrictions related to the Covid-19 pandemic. Following a preliminary survey of the studied wetlands, homogeneous and representative belts were selected based on physiognomic, floristic, and ecological criteria (GUINOCHET, 1973; GÉHU & RIVAS-MARTINEZ, 1981).

The sampling method used in this study was based on stratified sampling by transects, which is particularly suitable for heterogeneous environments such as wetlands (SIDI ALI, 2013). A total of 20 floristic plots were sampled, using four transects oriented according to the cardinal directions, and stratified by distance from the water body (belts C1, C2, and C3): Belt C1 (nearest to the shoreline), Belt C2 (intermediate), and Belt C3 (outermost). These belts exhibited clear vegetation gradients and partially overlapped. Each belt was explored as thoroughly as possible, the layout of which was adjusted to the area and topography of each site (TATAR ET AL., 2023). The width of each vegetation belt was measured in metres using a measuring tape, starting from the water's edge and extending toward the terrestrial periphery. At Garaet Timerganine, the belt width ranged from 4 to 50 m; at Chott Tinsilt, from 4 to 90 m; and at Sebkhet Ezzemoul, from 25 to 150 m. Representative samples of each species were collected and prepared for identification. This sampling strategy facilitated the collection of an inventory of the floristic diversity within each wetland site, ensuring a representative characterization of plant communities across the moisture and salinity gradients.

2.3. Data exploitation and analysis

The identification of flora taxa was carried out according to the new Flora of Algeria and southern desert regions (QUÉZEL & SANTA, 1962, 1963). The nomenclature adopted has been updated according to the synonymic index of the Flora of North Africa (DOBIGNARD & CHATELAIN, 2010, 2013). The listed plant species were classified according to their biological types based on RAUNKIAER'S classification system (1934). Their chorological types were determined following the works of QUÉZEL & SANTA (1963).

The floristic diversity of the three studied Ramsar sites was assessed by the total taxa richness (S) which is the total number of taxa (species or genera) contained in a given community and the Shannon Diversity Index ($H' = -\sum pi \log_2 pi$; $pi = ni/N$) and Pielou index (equitability) ($E = \frac{H'}{H'max}$) (MAGURRAN, 2004). Where Pi represents the relative frequency of the i taxa; ni: the total number of individuals of the i taxa and N: the total number of individuals.

A Correspondence Factor Analysis (CFA) was applied to the presence-absence matrix of the taxa recorded across the 20 floristic surveys. This analysis aimed to identify the relationships and proximities between the survey plots that share similar floristic compositions, as well as to group taxonomic entities (taxa) that tend to co-occur. AFC is usually used to study the spatio-temporal conditions of taxon occurrence in surveys. Our data meet the conditions for preprocessing and analysis, namely that the data are qualitative and the samples are independent of each other.

3. Results

3.1. Floristic diversity and bio-ecological status

The floristic surveys conducted across the three studied wetlands revealed a total of 154 plant taxa, distributed among 98 genera and 32 botanical families. The Asteraceae family emerges as the most dominant in the floristic composition of the three studied sites, accounting for 32.46% of the total recorded flora, with 50 species spread across numerous genera. Poaceae family ranked second, representing 10.38% of the flora with 16 species, followed by the Fabaceae (7.14%; 11 species) and Amaranthaceae (4.54%; 7 species). Together, these four families comprise more than 54% of all species identified in the wetland ecosystems of Timerganine, Tinsilt, and Ezzmoul (Table 2).

Table 2. Systematic list, biological types and chorology of inventoried floristic taxa in the studied sites. M: Garaet Timerganine, T: Chott Tinsilt, Z: Sebkhet Ezzmoul. (+): present, (-): absent (Abbreviations of biological and chorology types are given in Appendix 1)

Family	Taxa	Biological type	Chorology	Studied wetland			Code CFA
				M	T	Z	
Aizoaceae	*Aizoanthemum hispanicum* (L.) H.E.K. Hartmann	Th	Med-Iran-Tur	-	+	+	3
Amaranthaceae	*Arthrocnemum macrostachyum* (Moric.) K. Koch	Ch	Anc W	-	+	-	13
	Atriplex glauca L.	Ch	Sah-Med	+	-	+	23
	Atriplex halimus L.	Nph	Cosmop	+	+	+	22
	Atriplex sp.	Ph	Cosmop	-	+	-	24
	Salsola vermiculata L.	Th	Sah-Med	-	-	+	122
	Sarcocornia fruticose (L.) A.J. Scott	Ch	Cosmop	+	+	+	121
	Suaeda vermiculata Forssk. ex J.F. Gmel.	Ch	Sah-Sind	-	+	-	141
Apiaceae	*Bupleurum semicompositum* L.	Th	Med	-	-	+	29
	Daucus carota L.	Hem	Med	+	-	-	47
	Seseli varium Trev.	Th	Eur	-	-	+	131
	Torilis arvensis (Huds.) Link	Th	Paleo-Temp	-	+	-	147
Asparagaceae	*Asparagus horridus* L.	Ch	Macar.-Med	-	-	+	14
Asteraceae	*Anacyclus clavatus* (Desf.) Pers.	Th	Eur-Med	+	+	+	4
	Anacyclus pyrethrum (L.) Link	Hem	Ibero-Maur	+	-	-	5
	Anthemis confusa Pomel	Th	Med	+	-	-	7
	Anthemis maritima L.	Hem	W Med	+	-	-	8
	Artemisia absinthium L.	Hem	Euras-Alg-Mar	-	+	-	10
	Artemisia campestris L.	Hem	Circumbor	-	-	+	11
	Artemisia herba alba Asso	Th	Med-As	-	+	-	12
	Atractylis cancellata L.	Th	Circummed	+	-	+	19
	Atractylis sp.	Th	Med	-	+	-	21
	Bombycilaena discolor (Pers.) M. Laínz	Th	Euras-N.A	+	-	+	97
	Calendula arvensis (Vaill.)L.	Th	Submed	+	+	+	30
	Carduus nutans L.	Hem	Eur-Sib-N.A	+	-	-	32
	Carduus sp.	Hem	Euras	+	-	-	33
	Carduus tenuiflorus Curt.	Hem	Euras	-	-	+	34
	Carlina gummifera (L.) Less.	Hem	Med	-	-	+	20

	Carthamus lanatus L.	Th	Eur-Med	+	+	+	35
	Centaurea calcitrapa L.	Hem	Eurymed	+	+	-	36
	Centaurea pubescens Willd.	Hem	Ibero-Maur	+	-	+	37
	Centaurea sp.	Hem	Med	+	-	-	38
	Chondrilla juncea L.	Hem	Eur-Med	-	-	+	39
	Cichorium intybus L.	Hem	Euras-Med	+	-	-	40
	Crepis sp.	Th	Eur-Med	-	-	+	45
	Filagogallica L	Th	Submed-subatl	-	+	-	55
	Filago germanica (L.) Huds.	Th	Eur-Med	-	+	-	54
	Filago pyramidata L.	Th	Med	-	-	+	56
	Hedypnois rhagadioloides (L.) F.W. Schmidt	Th	Med	+	-	-	63
	Lactuca saligna L.	Hem	Submed	-	+	-	72
	Lactuca sp.	Th	Med	+	-	-	73
	Lactuca viminea (L.) J.Presl & C.Presl	Hem	Med	+	-	-	74
	Launaea nudicaulis (L.) Hook.f.	Hem	Med-Sah.-Sind	-	-	+	75
	Leontodon saxatilis Lam.	Hem	W Med	-	-	+	78
	Mantisalca salmantica (L.) Briq. & Cavill.	Hem	Eur-Med	+	-	-	88
	Micropus supinus L.	Th	SMed	+	-	-	98
	Notobasis syriaca (L.) Cass.	Th	Med	+	-	-	42
	Pallenis maritima (L.) Greuter	Hem	Med	-	-	+	15
	Picnomon acarna (L.) Cass.	Th	Med	+	-	-	41
	Picris hispanica (Willd.) P.D. Sell	Hem	Ibero-Maur	+	-	-	76
	Rhaponticum coniferum (L.) Greuter	Hem	W Med	+	-	-	79
	Scolymus grandiflorus Desf.	Hem	Eurymed	+	-	+	125
	Scolymus hispanicus L.	Hem	Med	+	-	-	126
	Scorzonera undulata Vahl	Hem	Med	-	+	-	127
	Scorzoneroides muelleri (Sch. Bip.) Greuter & Talavera	Hem	Med	-	+	-	77
	Senecio leucanthemifolius Poiret.	Th	W Med-Canar-Syria	-	+	-	130
	Senecio vulgaris L	Th	Subcosm	-	+	-	129
	Silybum eburneum(L.) Gaertn.	Hem	Cosmop	-	+	-	132
	Sonchus oleraceus L.	Th	Cosmop	+	-	-	134
	Taraxacum erythrospermum aggr.	Hem	Med	+	-	-	143
	Taraxacum officinale aggr.	Hem	Eur-Med	+	-	-	144
	Urospermum dalechampii (L.) F.W.Schmidt	Hem	Circummed	-	+	-	152
	Xanthium spinosum L.	Th	Subcosm.	-	-	+	154
Boraginaceae	*Echium plantagineum* L.	Hem	Med	-	+	-	48
	Echium sp.	Hem	Med	-	-	+	49
Brassicaceae	*Eruca vesicaria* subsp. *sativa* (Mill.) Thell.	Th	Med	-	+	-	52
	Matthiola incana (L.) R.Br.	Hem	E Med	-	+	-	90
	Matthiola lunata DC.	Th	Ibero-Maur	+	-	-	91
	Moricandia arvensis (L.)DC.	Th	Med-Sah.-Sind	+	+	+	99
	*Rapistrum rugosum (*L.) All.	Th	Med	-	+	-	114
	Sinapis arvensis L.	Th	Paleo-Temp	+	+	-	133
Caryophyllaceae	*Arenaria serpyllifolia* L.	Th	Euras	+	-	-	9
	Herniaria hirsuta L.	Th	Paleo-Temp.	+	-	-	65
	Paronychia argentea Lam.	Hem	Med	+	-	-	105
	Paronychia kapela (Hacq.) A. Kern.	Hem	Med	-	+	-	106
	Spergularia diandra (Guss.) Boiss.	Hem	Sah-Sind-Iran-Tur.	+	+	-	136
	Spergularia marina (L.) Besser	Th	Med-Stepp	+	-	-	135
	Spergularia sp.	Ch	Med	+	-	-	137
Cistaceae	*Fumana scoparia* Pomel	Hem	Euras-Med	-	-	+	58
	Helianthemum sp.	Hem	Med	-	-	+	64
Convolvulaceae	*Calystegia sepium* (L.) R. Br.	Hem	Paleo-Temp	+	-	-	31
	Convolvulus arvensis L.	Hem	Euras	+	-	-	43
Crassulaceae	*Sedum* sp.	Th	Med	-	+	-	128
Euphorbiaceae	*Euphorbia helioscopia* L.	Th	Euras	-	+	-	53
Fabaceae	*Astragalus echinatus* Murray	Th	Med	-	+	-	17
	Astragalus sesameus L.	Th	W Med	-	-	+	18
	Medicago arabica (L.) Huds.	Th	Med	+	-	-	92
	Medicago minima (L.) L.	Th	Eur-Med	+	-	-	93

	Medicago polymorpha L.	Th	Med	-	-	+	94
	Medicago sp.	Th	Med	-	+	-	95
	Trifolium resupinatum L.	Th	Med	+	-	-	148
	Trifolium sp.	Hem	Med	-	+	-	149
	Trifolium tomentosum L.	Th	Med	+	-	-	150
	Trigonella polycerata L.	Th	Ibero-Maur	-	+	-	151
	Vicia sativa L.	Th	Eur-Med	-	+	-	153
Frankeniaceae	*Frankenia corymbosa* Desf.	Th	Med	-	+	+	57
Geraniaceae	*Erodium cicutarium* (L.) L'Hér.	Th	Med	-	+	-	51
	Eroduim malacoides (L.) L'Hér.	Th	Med	+	-	-	50
Hyacinthaceae	*Muscari comosum* (L.) Mill.	Geo	Med	-	+	-	100
Iridaceae	*Gladiolus italicus* Mill.	Geo	Med	-	+	-	61
	Moraea sisyrinchium (L.) Ker Gawl.	Geo	Paleo-subtrop	+	-	-	68
Juncaceae	*Juncus bufonius* L.	Th	Cosmop	+	-	-	69
	Juncus inflexus L.	Hem	Paleo-Temp.	-	-	+	70
Lamiaceae	*Marrubium alysson* L.	Hem	Ibero-Maur	+	+	+	89
	Mentha pulegium L.	Hem	Euras	+	-	-	97
	Salvia verbenaca L.	Hem	Med-Atl	+	-	+	123
Malvaceae	*Malva neglecta* Wallr.	Th	Med	+	-	-	85
	Malva nicaeensis All.	Th	Med	-	+	-	86
	Malva sylvestris L.	Hem	Euras	+	-	+	87
Nitrariaceae	*Peganum harmala* L.	Ch	Iran-Tur-Eur	+	+	+	107
Orobanchaceae	*Orobanche* sp.	Th	Cosmop	-	+	-	102
Papaveraceae	*Fumaria officinalis* L.	Th	Paleo-Temp	-	+	-	59
	Fumaria sp.	Th	Med	-	+	-	60
	Glaucium corniculatum (L.) H. Rudolph	Th	Med	-	-	+	62
	Papaver rhoeas L.	Th	Paleo-Temp	+	-	-	103
	Papaver somniferum L.	Th	Med-As	-	+	-	104
	Roemeria hybrida (L.) DC.	Th	Med-Iran-Tur	-	+	-	117
Plantaginaceae	*Linaria reflexa* (L.) Desf.	Th	C Med	+	-	-	81
	Linaria sp.	Hem	Med	-	+	-	82
	Plantago afra L.	Th	Submed	-	-	+	108
	Plantago amplexicaulis Cav.	Th	Med	+	-	-	109
	Plantago coronopus L.	Hem	Euras	+	+	+	110
	Plantago lanceolata L.	Hem	Euras	+	+	-	111
Plumbaginaceae	*Limonium pruinosum* (L.) Chaz.	Ch	Sah	-	-	+	80
Poaceae	*Anisantha madritensis* (L.) Nevski	Th	Eur-Med	-	+	-	27
	Anisantha rubens (L.) Nevski	Th	Paleo-Subtrop	-	-	+	28
	Bromus commutatus Schrad	Th	Atl-W-Med	-	+	-	25
	Bromus hordeaceus L.	Th	Paleo-Temp	+	-	-	26
	Cynodon dactylon (L.) Pers.	Geo	Thermocosm	+	-	+	46
	Eremopyrum orientale (L.) Jaub. & Spach	Ch	Med	-	+	-	2
	Hordeum marinum Huds.	Th	Med-Eur-Amer	+	-	-	66
	Hordeum murinum L.	Th	Circumbor	+	+	+	67
	Lolium rigidum Gaudin	Th	Paleo-subtrop	+	-	-	83
	Lygeum spartum L.	Ch	W Med	-	+	-	84
	Macrochloa tenacissima (L.) Kunth	Hem	Ibero.-Maur				139
	Nardus stricta L.	Hem	Med	-	-	+	101
	Rostraria cristata(L.) Tzvelev	Th	Subcosm	+	-	-	71
	Sclerochloa dura (L.) P.Beauv.	Th	Med	+	-	-	124
	Stipa barbata Desf.	Hem	W Med	-	-	+	138
	Stipa sp.	Hem	Med	+	-	-	140
Polygonaceae	*Polygonum aviculare* L.	Th	Cosmop	+	-	-	112
	Polygonum maritimum L.	Ch	Cosmop	+	-	-	113
	Rumex pulcher L.	Hem	Med	+	-	+	118
	Rumex sp.	Hem	Med	-	+	-	119
	Rumex tuberosus L.	Geo	Med	+	-	-	120
Primulaceae	*Coris monspeliensis* L.	Hem	Med	-	-	+	44
	Lysimachia arvensis (L.) U. Manns & Anderb.	Th	Subcosm	+	+	-	6
	*Lysimachia linum-stellatum*L.	Th	Med	-	-	+	16

Ranunculaceae	*Adonis annua* L.	Th	Euras	+	-	-	1
Resedaceae	*Reseda alba* L.	Hem	Euras	+	+	-	115
	Reseda lutea L.	Hem	Euras	+	-	-	116
Tamaricaceae	*Tamarix aphylla* (L.) H. Karst.	Mph	Sah-Sind	-	+	-	142
Thymelaeaceae	*Thymelaea hirsuta* (L.) Endl.	Ch	Med	+	+	+	145
	Thymelaea sp.	Ch	Med	-	-	+	146

The analysis of the floral diversity highlights notable differences in species richness, diversity, and evenness throughout the three studied sites. Garaet Timerganine recorded the highest taxa richness with 78 species, followed by Chott Tinsilt (63), and Sebkhet Ezzmoul (52). However, Shannon diversity index (H′) was highest in Sebkhet Ezzmoul (5.38), compared to Garaet Timerganine (5.07) and Chott Tinsilt (4.43). Pielou's evenness index was highest in Sebkhet Ezzmoul with 0.94. Garaet Timerganine and Chott Tinsilt followed with evenness values of 0.82 and 0.73, respectively (Table 3).

The analysis of biological types across the three studied sites revealed a clear dominance of two life forms: therophytes (48%) and hemicryptophytes (37%) (Table 4). In Garaet Timerganine, therophytes constituted 47% and hemicryptophytes 40% of the total recorded taxa. In Chott Tinsilt, the proportion of therophytes was 52%, while hemicryptophytes were represented by 28%. Sebkhet Ezzmoul had a predominance of hemicryptophytes, which accounted for 42%, compared to 40% for therophytes. Other life forms such as chamaephytes (9%), geophytes (3%), nanophanerophytes (1%), microphanerophytes (1%), and phanerophytes (1%) were present in meaningfully lower proportions (Table 4).

The biogeographical spectrum analysis of the recorded taxa across the three sites revealed four main chorological types, with three of them shared among all sites. The Mediterranean set appeared as the most dominant, encompassing 74 species, which constituted 48.07% of the total flora (Fig. 2). Taxa with a wide distribution set accounted for 56 species (36.30%). The Northern set also had a notable presence of 23 species (15%). The Saharan set was extremely limited, represented by only one species (*Limonium pruinosum*) exclusively recorded in Sebkhet Ezzmoul.

Table 3. Total taxa richness and diversity indices of plant communities studied in three Ramsar wetlands

Ecological parameters	Garaet Timerganine	Chott Tinsilt	Sebkhet Ezzmoul
Total taxa richness (S)	78	63	52
H' (bits)	5.07	4.43	5.38
H' max (bits)	6.22	6	5.72
Equitability (E)	0.82	0.73	0.94

Table 4. Biological types of flora inventoried in wetlands of Garaet Timerganine, Sebkhet Ezzmoul and Chott Tinsilt

Sites	Gareat Timerganine		Chott Tinsilt		Sebkhet Ezzmoul		Total	
Biological types	Number of taxa	%	Number of taxa	%	Number of taxa	%	Number of taxa	%
Therophytes	37	47	33	52	21	40	75	48
Hemicryptophytes	31	40	18	28	22	42	58	37
Chamaephytes	6	8	7	11	6	12	13	9
Geophytes	3	4	2	3	2	4	5	3
Phanerophytes	0	0	1	3	0	0	1	1
Nanophanerophytes	1	1	1	1	1	2	1	1
Microphanerophytes	0	0	1	2	0	0	1	1

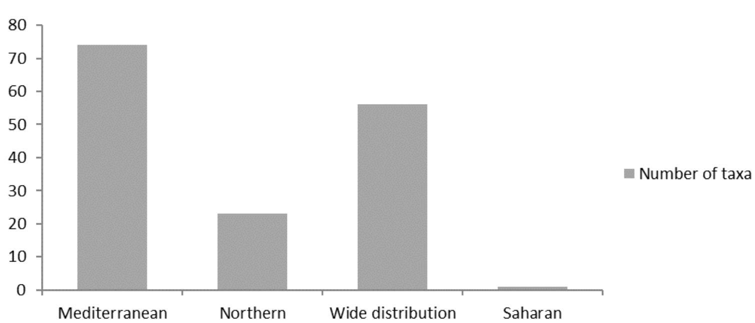

Fig. 2. Spectrum of chorological types of the flora in the three studied wetlands: Garaet Timerganine, Sebkhet Ezzmoul and Chott Tinsilt

3.2. Distribution patterns of flora

The examination of the sequence of successive eigen values from the factorial correspondence analysis carried out on the presence-absence matrix of taxa in the surveys showed a regularly regressive form, without a sudden break. The first nine factorial axes absorbed 62.40% of the total variance. When the eigen values are close, it is preferable to consider the subspace defined by the associated axes, because their position is not significant (VOLLE, 1985). However, the first two factorial axes suggest a meaning to the structure of the point cloud in the corresponding plane (Fig. 3).

The factor plane 1-2 presents a classic and characteristic structure of continuous data with a parabolic gradient: illustrating the Guttman effect (BENZECRI & COLL, 1973; JUMBO, 1989). The analysis revealed a clear spatial differentiation among the three Ramsar wetlands. Three distinct groups were identified: Garaet Timerganine (blue group) indicates a relatively homogeneous floristic composition across its belts. Chott Tinsilt (red group) suggests a stronger similarity among transects and belts under brackish conditions. Sebkhet Ezzmoul (green group) reflects the distinctiveness of the vegetation structure under saline conditions. The distance from the other two groups confirms a higher degree of floristic specificity (Fig. 3).

The factorial map produced by the CFA highlights the distribution and association patterns of the 154 plant taxa identified across the three wetlands. The ordination of taxa along the first (F1) and second (F2) axes reveals clear floristic segregation aligned with salinity gradients and site-specific ecological conditions (Fig. 4).

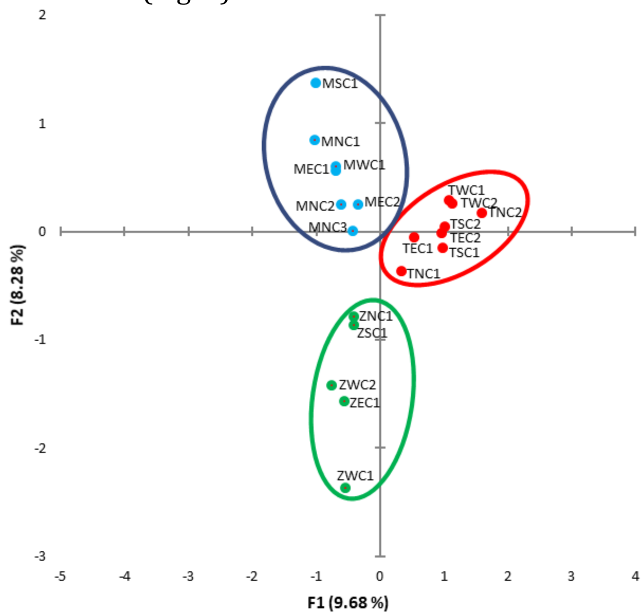

Fig. 3. 1x2 factorial plan of survey points (M : Gareat Timerganine, T: Chott Tinsilt, Z: Sebkhet Ezzmoul). N = North, W = West, E = East and S = South. C1 = 1st belt, C2 = 2nd belt and C3 = 3rd belt)

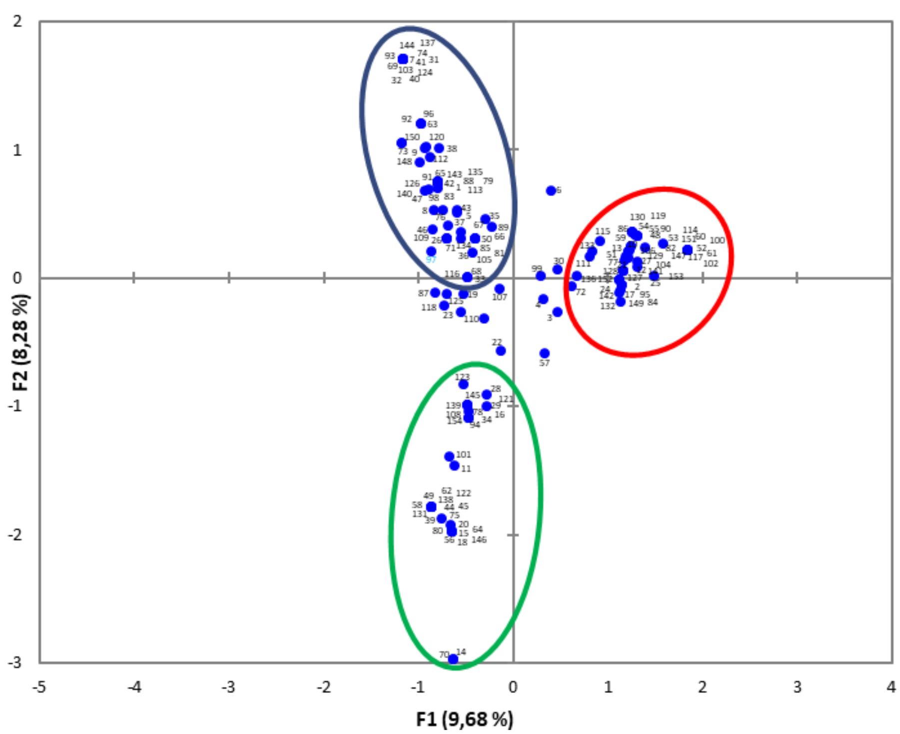

Fig. 4. 1x2 factorial design of survey points of flora in three Ramsar wetlands (taxa coding from 1 to 154 are shown in Table 2)

The blue cluster groups species predominantly associated with Garaet Timerganine (freshwater). The green cluster includes species closely linked to Sebkhet Ezzmoul (salty water). The red cluster corresponds to species characteristic of Chott Tinsilt (brackish water). One group of taxa occupies a pivotal position between the groups for the three types of water. We also note a high degree of compactness of the survey points and characteristic taxa, especially at Chott Tinsilt (Fig. 4).

4. Discussion

4.1. Floristic diversity

The floristic richness of the three studied wetlands, totaling 154 taxa. This richness represents approximately 3.58% of the total Algerian flora, which is currently estimated at around 4,300 species (Taibaoui et al., 2020). These results exceed the floristic richness reported in previous studies conducted in the same region (Aliat, 2017; Bougoffa, 2024). Our study records 53 genera and 62 species not previously documented in earlier inventories such as *Arenaria serpyllifolia, Asparagus horridus, Atractylis cancellata, Bombycilaena discolor, Calystegia sepium, Chondrilla juncea, Euphorbia helioscopia, Fumana scoparia, Herniaria hirsute, Mentha pulegium, Pallenis maritime, Rapistrum rugosum, Sinapis arvensis, Trigonella polycerata, Urospermum dalechampii, Vicia sativa* and *Xanthium spinosum*.

The graphical distribution showed a significant disparity between the most species-rich families (notably Asteraceae) and those represented by only one or two species. This strong taxonomic dominance suggests a community structure that favours highly opportunistic, stress-tolerant plant families, especially in habitats marked by fluctuating salinity and seasonal moisture variation. Their occurrence reflects specific adaptive strategies that allow persistence under fluctuating environmental conditions, particularly in habitats exposed to seasonal desiccation and salinization (Sidi Ali, 2013). Moreover, the high number of genera within Asteraceae and Poaceae indicates not only richness in species but also a broad taxonomic diversity, pointing to ecological plasticity and prospective resilience to environmental stresses (Yamauchi et al., 2021). Conversely, families such as Tamaricaceae, Resedaceae, or Thymelaeaceae are slightly represented, likely reflecting more specific ecological requirements or limited dispersal capacity (Sidi Ali, 2013; Neffar et al., 2016; Arias et al., 2018).

The relatively high values of Shannon's diversity index and Pielou's equitability at Garaet Timerganine and Sebkhet Ezzmoul suggest a rich species composition and a more even distribution of individuals among species, showing stable and heterogeneous ecological conditions. In contrast, the lower values noted at Chott Tinsilt specify restrained diversity and a less balanced community structure, hypothetically due to environmental constraints such as anthropogenic disturbances. These include proximity to major infrastructure such as roads and railways, poaching and overgrazing/ agriculture, plant collection, tourism and leisure activities (Bougoffa, 2024), all of which can harm and disturb plant communities by shifting soil structure, increasing salinity, and damaging habitats. The high equitability observed at Sebkhet Ezzmoul (E = 0.94) shows a predominantly homogeneous dispersal of individuals between species, offering ecological constancy despite the extreme abiotic conditions linked to the high salinity of the wetland (Benhouhou et al., 2013).

Regarding the five biological types, we found that they are frequently present in the three studied sites, with a dominance of therophytes, which stand out for their adaptation to disturbances through their short life cycle (Megharbi et al., 2016; Hamel & Boulemtafes, 2017).

The significant presence of hemicryptophytes suggests favourable microhabitat conditions, particularly in transitional zones where soil retains moisture seasonally, supporting a stable root system and constant growth strategies (Kazi Tani et al., 2010). This demonstrates the ability of these species to withstand the seasonal droughts that are characteristic of wetlands, while revealing a certain floristic homogeneity within these ecosystems despite their local specificities in the study area. These two groups of plants are taxa that are traditionally considered to be favoured by disturbances caused by zoopopulations (Allem, 2022). Although they are less common, chamaephytes still play an important role in these ecosystems. Grazing in general favours these species and they are often avoided by herds (Benabadji et al., 2004). Furthermore, they are well adapted to soil salinity, in contrast to phanerophytes (Ghezlaoui et al., 2011). The low percentage of the rest of the biological types could be attributed to soil and moisture conditions that do not favour their development.

Analysis of chorological types showed that the Mediterranean set was dominant in the three studied Ramsar sites, which was also highlighted by Quézel (2004) for all North African countries. This strong representation reflects the regional chorological identity of the studied area, which is situated within a Mediterranean bioclimatic context. Species with a wide distribution set illustrated the capacity of cosmopolitan, or widely adapted taxa, to persist in diverse or transitional environments. The northern set had a noteworthy presence suggesting influences from temperate floristic regions, probably due to the seasonal and altitudinal variability across the sites. Their presence in semi-arid regions like the SAWC area indicates that these sites act as microrefugia harbouring species with temperate affinities that are otherwise rare in xeric landscapes (Benhouhou et al., 2013). The Saharan flora was quite limited, with only one species (*Limonium pruinosum*) found in Sebkhet Ezzmoul, which is characterized by higher salinity and a more arid microclimate. This low presence reflects both the ecological boundaries of these highland salt flats and the limited niche availability (Le Houérou, 2001). This species is known for its high salt tolerance and xerophytic traits, reflecting the extreme ecological conditions that characterise saline depressions in arid zones. Its limited presence indicates that, although Sebkhet Ezzemoul shares some ecological features with Saharan environments, such as high evapotranspiration and salinity, it is not fully representative of them (Quézel & Médail, 2003).

4.2. Flora distribution patterns according to salinity gradient

The CFA analysis clearly indicates that the salinity gradient is the principal environmental driver structuring plant communities across the three Ramsar sites. Along the F1–F2 factorial plane, taxa segregate into three coherent clusters that mirror the hydrological spectrum. The dominance of mesophilous species in Garaet Timerganine wetland reflects the ecological specificity of this freshwater wetland, where relatively stable and low-salinity conditions promote the growth of moisture-loving species. This pattern aligns with findings in other Mediterranean freshwater environments (e.g., Marín et al., 2020; Montesinos-Navarro et al., 2017), where similar hydrological constancy supports high floristic richness and functional diversity. According to the presence of these species, freshwater depressions can be ecological refuges, fostering plant communities with narrow environmental tolerances and high conservation value, even in a semi-arid context. The brackish water of Chott Tinsilt is characterised by taxa adapted to moderate salinity levels, reflecting its intermediate ecological conditions (Molina et al., 2021). The tight spatial arrangement of both taxa and survey points within this plant group suggests strong environmental filtering, likely driven by ionic concentration thresholds that limit species establishment (Fernández-González et al., 2021). This quite homogeneous vegetation structure is indicative of ecological convergence, where only species with specific tolerance traits develop. Such patterns have also been observed in similar Mediterranean environments, notably the Spanish Salada wetlands, where brackish conditions lead to reduced floristic turnover and dominance of halo-tolerant taxa (Castillo-Jáimez et al., 2019; Molina et al., 2021), reinforcing the role of salinity as a key driver of plant community assembly in transitional wetlands.

The flora in wetlands with saline water like Sebkhet Ezzmoul is mainly composed of halophytic taxa such as *Sarcocornia fruticosa* (121), *Salsola vermiculata* (122), *Thymelaea hirsuta* (145), *Thymelaea sp* (146), *Plantago afra* (108) and *Limonium pruinosum* (80), which are well adapted to high salinity and harsh environmental conditions. These taxa have evolved specific physiological mechanisms that enable them to survive in saline soils that frequently experience desiccation and high evaporation rates. Such adaptations are typical of vegetation in North African sebkhas (referring to salty wetlands), where seasonal fluctuations and shallow saline groundwater strongly influence plant community structure (Benhouhou et al., 2013; Flowers & Colmer, 2015). Our study clearly showed that few species could tolerate such extreme conditions, leading to low species richness but a high degree of specialization. Similar patterns have been observed in the Chotts of Tunisia and salt lakes in southern Spain (Rhazi et al., 2001; Castillo-Jáimez et al., 2019). The position of *Juncus inflexus* (70) and *Asparagus horridus* (14) within the cluster in the CFA biplot, explains their extreme position and suggests that they are ecologically distinct from the core group of halophytes that dominate the site.

Our analysis revealed that a small set of taxa occupies an intermediate position between the three clusters. This indicates ecological plasticity, which enables certain species (e.g. *Juncus maritimus*) to persist across a broad salinity range. The strong floristic homogeneity detected within Chott Tinsilt contrasts with the greater internal heterogeneity recorded at Gareat Timerganine (where there are freshwater belts with variable moisture levels) and Sebkhet Ezzmoul (where there are salty gradients).

5. Conclusions

This study highlights a remarkable floristic diversity within the SAWC region, which is structured along a clear salinity gradient. This gradient is the primary ecological factor influencing the distribution of plants across the studied wetlands. The dominance of therophytes and hemicryptophytes across all sites reflects a strong ecological adaptation to moisture and salinity fluctuations, typical of Mediterranean semi-arid climates. These biological types represent over two-thirds of the recorded species, underscoring their importance in maintaining ecosystem resilience under environmental stress. Furthermore, ecological indices confirm these patterns: Timerganine and Ezzmoul both exhibit high diversity and well-balanced species distributions, whereas Tinsilt, although less diverse, demonstrates strong environmental filtering supporting a stable halophytic flora likely shaped by elevated salinity and reinforced by anthropogenic pressures. Despite their ecological significance and Ramsar designation, these wetlands are increasingly threatened by anthropogenic pressures including water overexploitation, agricultural encroachment, pollution and overgrazing. Such stressors are already contributing to vegetation degradation and biodiversity loss. To ensure the long-term conservation of these fragile ecosystems, it is critical to reinforce legal protection measures and to implement community-centered environmental education initiatives.

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Appendix 1. Meaning of abbreviations used in Table 2 for chorology and biological types

Abbreviation	Meaning	Abbreviation	Meaning
Chorology types			
Med	Mediterranean	Eur	European
Med-As	Mediterranean-Asian	Euras	Eurasian
Med-Atl	Mediterranean Atlantic	Euras-Alg-Mar	Eurasian Algerian-Moroccan
Med-Eur-Amer	Mediterranean-European-American	Euras-Med	Eurasian Mediterranean
S Med	Southern Mediterranean	Euras-N.A	Eurasian North-African
E Med	East Mediterranean	Anc W	Ancient World
W Med	West Mediterranean	Eur-Sib-N.A	European-Siberian North African
Med-Iran-Tur	Mediterranean Iranian-Turanian	Eurymed	Eurymediterranean
Med-Sah.-Sind	Mediterranean Saharo-Sindian	Ibero.-Maur	Ibero-Mauritanian
Med-Stepp	Mediterranean Steppic	Iran-Tur-Eur	Irano-Turanian-European
C Med	Central Mediterranean	Wide dis	Wide distribution
Paleo-subtrop	Paleo-subtropical	Macar.-Med	Macaronesian-Mediterranean
Paleo-Temp	Paleo-temperate	Sah-Sind	Sahara-Sindian
Sah	Saharian	Sah-Sind-Iran-Tur	Sahara-Sindien-Irano-Turanian
Sah-Med	Sahara Mediterranean	Subcosm	Subcosmopolitan
Atl-W-Med	Atlantic Western Mediterranean	Submed	Submediterranean
Circumbor	Circumboreal	Submed-subatl	Submediterranean-Subatlantic
Circummed	Circummediterranean	Thermocosm	Thermocosmopolite
Cosmop	Cosmopolitan	W Med-Canar-Syria	West Mediterranean Canary-Syria
Biological types			
Th	Theophytes	Geo	Geophytes
Ch	Chamaephytes	Ph	Phanerophytes
Hem	Hemicryptophytes	Nph/Mph	Nanophanerophytes/ Microphanerophytes