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Research Article

Floristic Diversity of *Zygophyllum album* Communities Associated with Water Towers in the Algerian Sahara

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Abstract
Zygophyllum album L. (Zygophyllaceae) is a species of arid and hyperarid zones that has been the subject of many biochemical, pharmaceutical, and medicinal studies, but this species is largely unknown ecologically. This work aims to study the diversity and describe the characteristics of the functional traits of plant species of *Zygophyllum album* communities associated with water towers in the Algerian Sahara. Based on subjective sampling, 17 phytoecological relevés were carried out at six sites in the Algerian Sahara. *Zygophyllum album* plant communities were analyzed using diversity parameters (species richness, Shannon-Weaver index, Pielou equitability) and plant functional traits (life forms, dispersal types, morphological and phytogeographic types). The results revealed the presence of 30 plant species belonging to 16 families and 28 genera. Asteraceae, Poaceae, Amaranthaceae and Apocynaceae were the most species-rich families, accounting for 60% of the total species studied. The plant communities studied were characterized by a high presence of hemicryptophytes (58.84%), anemochores (78.53%), perennial species (86.07%) and cosmopolitan species (41.55%) which witness the anthropogenic impact. Based on ordinary species values, three plant communities were individualized according to the hierarchical ascending classification. The species that dominate these communities are *Phragmites communis* (82.9%), *Imperata cylindrica* (35.2%) and *Calotropis procera* (28%) for community 1, *Zygophyllum album* (15.1%), *Cistanche phelypaea* (10%) and *Launaea glomerata* (5.1%) for community 2, *Launaea resedifolia* (10.2%), *Hyoscyamus muticus* (5.3%) and *Cistanche Phelypaea* (5.1%) for community 3. Community 1 is the most diverse (H'= 2.88; E= 0.88), while community 3 is the least diverse (H'=2.32; E= 0.93). This study provides baseline data for managing and conserving *Zygophyllum album* plant communities in arid areas.

Keywords: Diversity, plant community, Sahara, Algeria, *Zygophyllum album*.

Introduction

Deserts cover about 20% of the global land area [1]. The Algerian Sahara represents about 85% of the total area of the country, i.e., 2 million km² [2]. The latest is characterized by its extreme aridity, its low availability of water and vegetation [3-4] and its particular flora which adapts well to its environment [4]. The Saharan vegetation is discontinuous, sparse and covers large areas composed of xerophytic plants [5]. These plants mainly inhabit the areas best benefited by the water balance and adapt to the difficult conditions of deserts (drought and aridity) [4]. Some plants, such as Zygophyllaceae, are distributed over large areas and form the only permanent vegetation.

The Zygophyllaceae are a cosmopolitan family widespread in arid and semi-arid areas of the World [1]. This family includes about 27 genera and 285 species [6-7].

In Algeria, the Zygophyllaceae are represented by three main genera: *Fagonia*, *Zygophyllum* and *Tribulus* [4]. The flora of the Algerian Sahara includes 7 genera and 27 species, i.e., the

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Zygophyllaceae form more than 3% of the desert flora [4,8].

Zygophyllum is the largest genus of Zygophyllaceae, with 80 species and the only genus of the Zygophyllinae sub-tribe present in the old world [1, 8-9]. Other genera in this family are native to North or South America [9]. In Algeria, this genus is represented by four species: *Zygophyllum simplex* L., *Zygophyllum gaetulum*, *Zygophyllum cornutum* Coss. and *Zygophyllum album* L. [10-11]. This genus is common in sandy areas, sabkhas and saline soils, where the salt content reaches 5.5% in the upper layer (0-25 cm) and the carbonate content ranges from 1.5% to 31,5% [12]. *Zygophyllum album* L. known as "Agga" or "Aggaya" in the vernacular Algerian dialect, is a perennial herb (20-50 cm high), with branched stems and opposite bifoliolate succulent leaves [13-14]. This species is tolerant to drought and salinity [15] and plays an important role in the rehabilitation of degraded soils [14, 16]. The soils that support its growth are characterized by high levels of sand, salinity, chlorides, sodium and sulfate [17]. In Algeria, the leaves, stems and fruits of *Zygophyllum album* are used in traditional medicine in the form of an infusion as an active drug against rheumatism and hypertension [18]. They are also used as a diuretic agent, local anesthetic, antihistamine, antidiabetic, antispasmolytic, antihyperlipidemic, antidiarrheal, anti-inflammatory, carminative, antiseptic and stimulant agent for the treatment of skin diseases, diarrhea and typhoid [19-22]. In addition, this plant is well-grazed by camels [20]. The use of this plant in the form of crude extracts, infusions and plasters is a widespread practice in the treatment of many pathologies in Algeria [18].

The Saharan vegetation is currently well known on the floristic and ecological levels [4, 2, 20, 23-33]. Despite this, few studies have been reported on the ecology of *Zygophyllum album* communities in different Saharan habitats. In this perspective, the objective of this work is to study the plant communities of *Zygophyllum album* associated with water towers to contribute to the sustainable development of the arid and Saharan zones of Algeria.

Material and methods

Study area

The study area (daïra of Fenoughil-wilaya d'Adrar) is located in the southwestern part of Algeria. This daïra includes three municipalities, which are: Fenoughil, Tamantit and Tamest. This daïra is limited to the north by the daïra of Adrar and the daïra of Aougrout, to the south by the daïra of Zaouiet Kounta, to the west by the daïra of Tabelbala and to the east by the daïra of Aoulef (Figure 1).

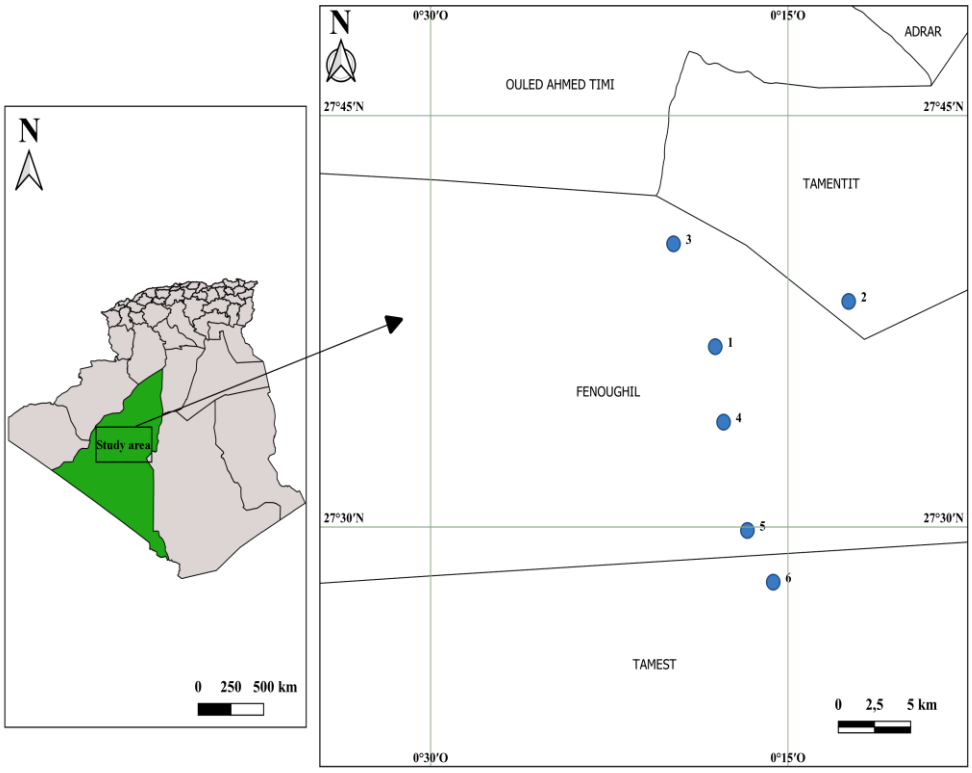


Figure 1. Map of the study area

Climate

The climate of the study area is desert-type which is characterized by a significant thermal amplitude and strong sunshine with an average of 3000 h/year [29]. Precipitation is rare and has considerable annual variability [4]. According to data obtained by the infoclimat site (www.infoclimat.com) from the Adrar meteorological station for the period 1981-2021, the average annual rainfall is 10.2 mm. The minimum temperature is 5.2°C (January) and the maximum temperature is 45.9°C (July).

Methodology

The study was carried out in the daïra of Fenoughil located south of the capital of Adrar (Figure 1). Six sites in the study area were studied in the spring of 2022. In each site at *Zygophyllum album*, 2 to 4 phytoecological relevés were conducted using subjective sampling [34]. The relevés area is 100 m^2 (10 m x 10 m) chosen on the basis of studies of Saharan plant communities [30-32, 35-36]. In each relevés, we listed all species present with their abundance-dominance coefficients [37]. The species were identified according to the work of Quézel & Santa [10-11] and Ozenda [4]. The data of abundance-dominance coefficients were transformed to a numerical scale ('+'=2, '1'=3, '2'=4, '3'=5, '4'=6, '5'= 7) to calculate diversity (H') and equitability (E) for the different communities studied [30, 38].

Data analysis

Hierarchical ascending classification is applied to relevés data to distinguish plant communities. This method has been used by many researchers in arid and semi-arid areas [30,39-40]. A hierarchical classification was carried out on the basis of the ordinary values of the species, in order to highlight the main groups of observations that emerge. Each vegetation group includes a set of relevés with similar vegetation [30, 39].

Characterization of the studied plant communities

In this study, we will characterize the individualized communities on functional levels (life forms, dispersal types, morphological and phytogeographic types). For the characterization using raw spectra (qualitative data: specific richness) and real spectra (quantitative data: abundance). The raw spectrum takes into account the proportions of specific richness, while the real spectrum uses species abundances in communities [30, 40]. These spectra provide information that can help evaluate the response of vegetation to variations in environmental factors [41].

Life forms

The biological types of the inventoried plant species were determined according to the definitions of Raunkiaer [42] which is based on the position of the renovation buds relative to the soil surface during unfavorable periods. The main life forms are: therophytes, geophytes, hemicryptophytes, chamaephytes and phanerophytes.

Dispersal types

The dispersal of species was determined according to the classification of Van der Pijl [43] who classified the plants into: anemochores, barochores, hydrochores, zoochores and autochore.

Morphological types

Plants are classified according to the persistence of the aerial vegetative part during the unfavorable season into two categories (perennial and annual) [30].

Chorological types

The biogeographic origin of the recorded species was determined from the work of Quézel & Santa [10-11] and Quézel [44].

Community biodiversity

Two measures of diversity were used:

The specific richness (S) within each vegetation group is the total number of species present in a given sample [45].

Shannon-Weaver diversity index was calculated by the formula: $H'=-\Sigma\ pi\ \log_2 pi$, where pi = ni/N is the relative abundance of species i in the sample, ni is the number of individuals of a given species, i ranging from 1 to S (total number of species) and N is the total number of individuals of all species present [46].

The equitability of Pielou (E) was calculated using the formula: $E = H'/H_{max}$

H': represents the Shannon diversity index;

$H_{max} = \log_2 S$: the theoretical value of maximum diversity.

It varies between 0 and 1, with E = 1 when individuals are uniformly distributed among species [47].

Results and discussion

Plant communities

The hierarchical ascending classification allows the individualization of three plant communities (Figure 2). Community 1 consists of 9 releves; Community 2 consists of 4 releves and Community 3 consists of 4 releves.

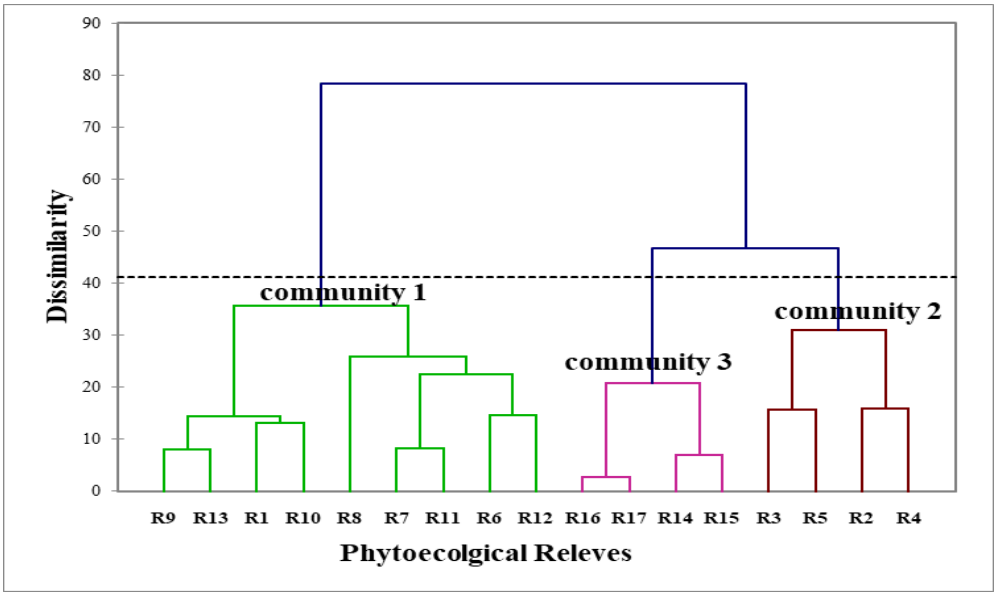


Figure 2. Dendrogram illustrating the three-vegetation communities in the study area

Characterization of individualized plant communities

Composition and structure

A total of 30 plant species representing 28 genres and 16 families develop in the study area (Table 1). The flora is characterized by a good representation of taxa belonging to the families of Asteraceae with 6 species. Poaceae with 5 species, while the families Amaranthaceae and Apocynaceae are represented by 4 and 3 species respectively. 12 families are represented by only one species (Primulaceae, Orobanchaceae, Sapindaceae, Heliotropiaceae, Solanaceae, Fabaceae, Malvaceae, Arecaceae, Resedaceae, Convovulaceae, Tamaricaceae and Zygophyllaceae).

According to the plant formations, community 1 consists of 27 species with a good representation of Asteraceae (18.54%), Poaceae (14.82%), Amaranthaceae (11.12%) and Apocynaceae (11.12%). The dominant species are *Phragmites communis* (82.9%), *Imperata cylindrica* (35.2%) and *Calotropis procera* (28%). The species that record low vegetation cover (0.1%) are *Anagallis arvensis*, *Cynanchum acutum*, *Dodonaea viscosa*, *Heliotropium bacciferum*, *Launaea glomerata*, *Launaea resedifolia*, *Leucaena leucocephala*, *Malva parviflora*, *Merremia dissecta*, *Phalaris minor* and *Senecio massaicus*.

Community 2 consists of 19 species with a good representation of Asteraceae (26.33%), Amaranthaceae (21.05%) and Poaceae (15.8%). The dominant species are *Zygophyllum album* (15.1%), *Cistanche Phelypaea* (10%) and *Launaea glomerata* (5.1%). The species that record low vegetation cover (0.1%) are *Cornulaca monacantha*, *Cutandia dichotoma*, *Cynanchum acutum*, *Imperata cylindrica*, *Launaea resedifolia*, *Pergularia tomentosa*, *Phoenix dactylifera*, *Phragmites communis*, *Randonia africana* and *Senecio massaicus*.

Community 3 consists of 12 species with a good representation of Asteraceae (25%), Amaranthaceae (21.05%) and Apocynaceae (16.67%). The dominant species are *Launaea resedifolia* (10.2%), *Hyoscyamus muticus* (5.3%) and *Cistanche Phelypaea* (5.1%). Species with low vegetation cover (0.1%) are *Bassia muricata*, *Leucaena leucocephala*, *Pergularia tomentosa* and *Sonchus oleraceus*.

The analysis of the floristic composition of *Zygophyllum album* communities studied in the Algerian Sahara showed the dominance of the Asteraceae family. This family is represented by a large number of species. Other major families of angiosperms (Poaceae, Amaranthaceae and Apocynaceae) are well represented in the study area. These families are also reported as the most frequent families in the Algerian Sahara [2, 24, 27, 32, 36, 40, 48]. In addition, Ozenda [4] underlined the importance of these families which proved to be the most frequent families in the Algerian flora.

Table 1. List of plant species present in the study area

Family	Species	Life forms	Dispersal types	Morphological types	Chorological types	Community	Sum cover vegetal
Amaranthaceae (13.35%)	*Bassia muricata* (L.) Asch.	Ther	Zoo	Annual	M-SA	2, 3	0.4
	Cornulaca monacantha Del.	Cham	Baro	Perennial	SA	1,2	5.3
	Salsola foetida Del.	Cham	Anemo	Perennial	SA	1, 2, 3	0.8
	Traganum nudatum Del.	Cham	Baro	Perennial	SA	1,2	0.5
Apocynaceae (10%)	*Calotropis procera* Act.	Phan	Anemo	Perennial	Tr-SA	1, 3	28.4
	Cynanchum acutum L.	Hemi	Anemo	Perennial	M-As	1,2	0.2
	Pergularia tomentosa L.	Cham	Anemo	Perennial	SA	1, 2, 3	0.4
Arecaceae (3.33%)	*Phoenix dactylifera* L.	Phan	Anthro	Perennial	N. Afr	1, 2, 3	0.7
Asteraceae (20%)	*Launaea glomerata* (Cass.) Hook.	Ther	Anemo	Annual	M-SA	1, 2, 3	5.4
	Launaea nudicaulis (L.) Hook. f.	Ther	Anemo	Annual	SA	2	0.2
	Launaea resedifolia O.K	Ther	Anemo	Annual	M-SA	1, 2, 3	10.4
	Pulicaria arabica (L.) Cass.	Hemi	Anemo	Perennial	SA	1	5
	Senecio massaicus (Maire) Maire	Ther	Anemo	Annual	SA	1, 2	0.2
	Sonchus oleraceus L.	Ther	Anemo	Annual	Cosm	1, 2, 3	0.5
Convovulaceae (3.33%)	*Merremia dissecta* (Jacq.) Hallier f.	Ther	Anthro	Annual	T-Amer	1	0.1
Fabaceae (3.33%)	*Leucaena leucocephala* (Lam.) de Wit	Phan	Anthro	Perennial	CA	1, 3	0.2
Heliotropiaceae (3.33%)	*Heliotropium bacciferum* Forsk	Cham	Baro	Perennial	SA	1	0.1
Malvaceae (3.33%)	*Malva parviflora* L.	Ther	Baro	Annual	M	1	0.1
Orobanchaceae (3.33%)	*Cistanche Phelypaea* (L.) P. Cout.	Ther	Anemo	Annual	M-SA	1, 2, 3	15.3
Poaceae (16.69%)	*Cutandia dichotoma* (Forssk.) Trab.	Ther	Anemo	Annual	M	2	0.1
	Cynodon dactylon (L.) Pers.	Hemi	Baro	Perennial	Cosm	1	5.1
	Imperata cylindrica (L.) PB.	Hemi	Anemo	Perennial	Tr-M-SA	1, 2	35.3
	Phalaris minor Retz.	Ther	Zoo	Annual	PSTr	1	0.1
	Phragmites communis Trin.	Hemi	Anemo	Perennial	Cosm	1, 2	83
Primulaceae (3.33%)	*Anagallis arvensis* L.	Ther	Anemo	Annual	Cosm	1	0.1
Resedaceae (3.33%)	*Randonia africana* Coss.	Cham	Baro	Perennial	SA	1, 2	0.7
Sapindaceae (3.33%)	*Dodonaea viscosa* (L.) Jacq.	Phan	Anemo	Perennial	Tr-STr	1	0.1
Solanaceae (3.33%)	*Hyoscyamus muticus* L.	Hemi	Zoo	Perennial	SA	1, 3	10.3
Tamaricaceae (3.33%)	*Tamarix gallica* L.	Phan	Baro	Perennial	M-SA	1, 2	0.9
Zygophyllaceae (3.33%)	*Zygophyllum album* L.	Cham	Baro	Perennial	SA	1, 2, 3	26.2

Life forms :(Cham: Chamaephyte, Hemi: Hemicryptophyte, Phan: Phanerophyte, Ther: Therophyte).
Dispersal types: (Anemo: Anemochorus, Baro: Barochorus, Zoo: Zoochorus; Anthro: Anthropogenic).
Chorological types: M-SA: Mediterranean Saharo-Arabian, SA: Saharo- Arabian, Tr-SA: Tropical Saharo- Arabian, M-As: Mediterranean-Asian, N. Afr: North African, Cosm: cosmopolitan, T-Amer: Tropical American, CA: Central America, M: Mediterranean, Tr-M-SA: Tropico-Mediterranean Saharo-Arabian, PSTr: Paleo-subtropical, Tr-STr: Tropico-subtropical.

Phragmites communis is a dominant species by their vegetation cover in community 1. The common reed (*Phragmites communis*) is a heliophilous species that mainly colonizes wetlands [49] or marshy and very salty environments [50].

The ability of *Phragmites communis* to dominate space can be attributed to (1) its potential for drought resistance, which allows it to also colonize drier environments [49]; (2) seed dissemination by wind or water [51] or by rooting a stem fragment or rhizome [52-53].

Zygophyllum album is the dominant species in Community 2. *Zygophyllum album* is an omnipresent species with a wide geographic range [10]. It has been recognized in several habitats such as sandy areas, sebkhas and saline soils rich in chlorides, sodium and sulfates [15, 17]. The different species of *Zygophyllum* represent a group of succulent plants that are drought-resistant and/or salt-tolerant, and grow in severe and dry climatic conditions. The abundance of *Zygophyllum* species may be related to their high tolerance to environmental stresses [16].

Launaea resedifolia is the dominant species in Community 3. This plant is one of the common weeds in the oases of the Algerian Sahara. It was recorded in all three groups, as it has a wide range of distribution favored by the high production of seeds dispersed by the wind and a large ecological amplitude.

Functional traits, phytogeography and diversity

The studied parameters of each plant community are shown in Figure 3. According to the real spectrum of the study area, hemicryptophytes are the most dominant life form, representing 58.84% of the species recorded. Chamaephytes are represented by 14.4%. Therophytes and phanerophytes are represented by 13.93% and 12.83% respectively. Plant dispersal shows a good representation of anemochorous species (78.53%), followed by barochorous species (16.48%). The real morphological spectrum of the study area shows a dominance of perennial species (86.07%); however, annual species represent only 13.93%.

The phytogeographic analysis in the study area revealed that cosmopolitan species represent 37.57% of the total species. The Saharo-Arabian species occupies the second position with 21.05 %.

According to the plant formations, concerning community 1, the raw spectrum of biological types shows that therophytes are the most represented (33.33%), followed by chamaephytes (25.93%). On the other hand, in the real spectrum, hemicryptophytes show a strong presence (75.74%), followed by Phanerophytes (16.53%). In the raw and real spectra, plant dispersal is dominated by anemochorous species (51.85%; 86.7%), followed by barochorous species (29.63%; 10.17%). In the raw and real spectra of morphological types, perennial species show a strong representation (66.67%; 99.37%) compared to annual species (33.33%; 0.63%). For the chorological types, the Saharo-Arabian element dominates the raw spectrum (37.06%). In the real spectrum, the cosmopolitan element shows a strong presence (50.17%), followed by the tropical Saharo-Arabian elements (15.91%). Shannon diversity index is 2.89 bits and Pielou equitability is 0.88.

Concerning community 2, the raw and real biological spectra show a strong presence of therophytes (42.1%; 49.39%), followed by chamaephytes (31.58%; 48.77%). Plant dispersal is dominated by anemochorus species (63.16%; 50.61%), followed by barochorous species (26.32%; 48.16%) for both spectra. In the raw and real spectra of morphological types, perennial species are in the majority (57.89%; 50.61%) compared to annual species (42.11%; 49.39%). The flora of this group is dominated by the Saharo-Arabian elements (42.11%; 49.68%) for the raw and real spectra. Shannon diversity index is 2.78 bits; the equitability of Pielou is 0.94.

Concerning community 3, the raw and real biological spectra show a strong presence of therophytes (41.67%; 57.1%), followed by chamaephytes (25%; 20.36%). Plant dispersal is dominated by anemochorous species (58.33%; 59.27%) for both spectra. In the raw spectrum of morphological types, perennial species show a high representation (58.33%) compared to annual species (41.67%). In contrast, the annual species are in the majority (57.09%) compared to the perennial species (42.91%) in the real spectrum. The two spectra of this group show that the flora is dominated by the Mediterranean-Saharo-Arabian elements (33.34%; 56.74%) and Saharo-Arabian elements (33.34%; 39.64%). Shannon diversity index is 2.32 bits; the equitability of Pielou is 0.93.

Analysis of biological spectra has shown that there is a dominance of hemicryptophyte, this dominance is probably related to the richness of organic matter and soil humidity [54]. According to Danin [55], the high rate of hemicryptophytes in sandy dune habitats is related to their ability to resist drought, sand accumulation and grazing.

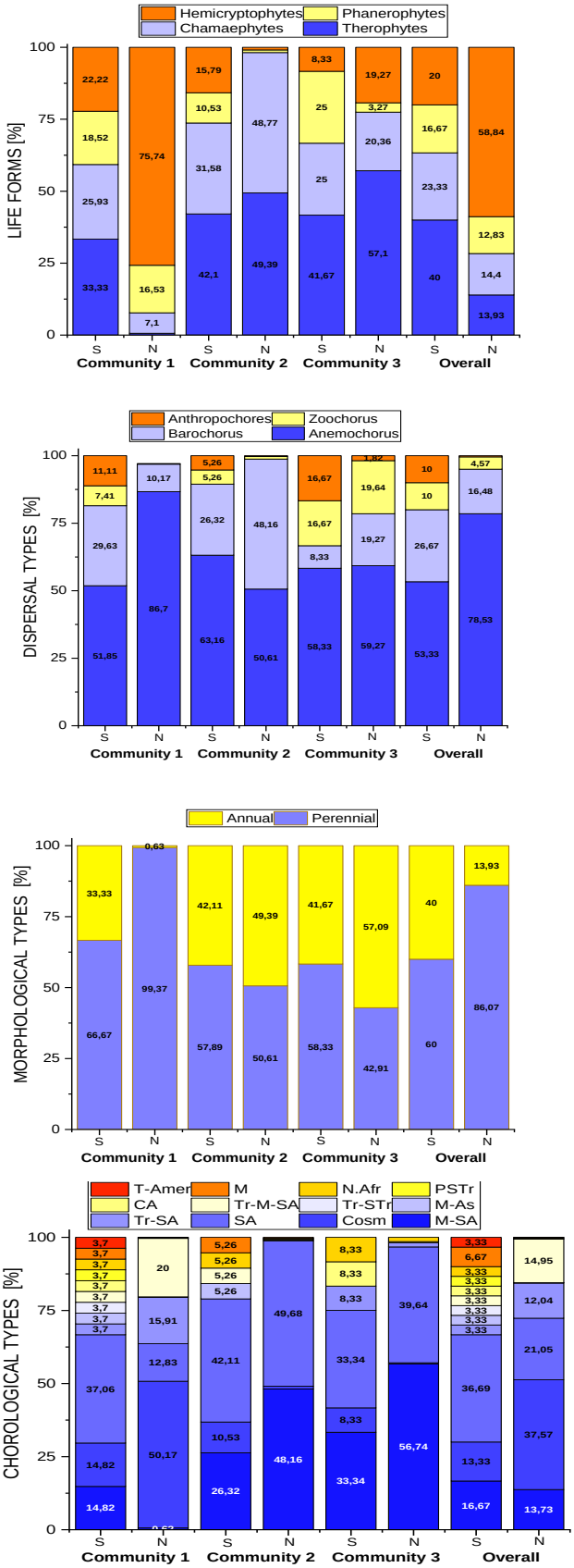


Figure 3. Spectra of raw functional traits (based on specific richness 'S') and real (based on abundance 'N') and spectra of chorological types characterizing vegetation associated with *Z. album* in the Algerian Sahara

The presence of Chamaephytes shows their good adaptation to the ecological conditions of arid and hyperarid hot environments through the development of strategies specific to drought, by reducing leaf surface and by their powerful root system [31, 40]. The presence of Therophytes is an indicator of an arid climate because these species are characterized by high reproductive capacity, ecological and genetic plasticity, and strong adaptation to a mild, wet winter and a hot, dry summer [1]. Phanerophytes are poorly represented. They are less adapted to drought than chamaephytes because they are less xerophilic [56]. The low percentage of recorded phanerophytes is consistent with studies dealing with plant biodiversity in Saharan areas [2, 31, 40]
In this study, the species recorded are mainly anemochores, which shows the importance of wind in the dispersal of plants in arid regions [2, 40]. The dissemination of plants by barochorie can be explained by the low spatial dispersion of some plant species [40]. The presence of zoochorous species could be explained by the large number of animals that ensure the dispersal of plant diaspores in arid and hyperarid zones [2]. Animals can disseminate seeds, either through the consumption of seeds or fruits, or with other foods (endozoochory) or they attach to feathers or bare body parts (epizoochory) [57]. These animals transport and disperse the diaspores during their movements between different sites and during their search for water.
The real morphological spectrum of the study area shows a dominance of perennial species over annual species. The dominance of perennial species can be related to the reproductive capacity, the morphological, ecological and genetic plasticity of the species [58]. Faye et al. [59] explains the dominance of perennial species by several factors, including adaptation to climate and salinization and seed dissemination by animals.
The real phytogeographic spectrum of the study area showed a strong presence of the cosmopolitan element followed by the Saharo-Arabian element. The dominance of cosmopolitan species can be explained by the fact that this biotope is a very open environment, regularly disturbed, and hosts many species accidentally introduced [40]. The presence of the Saharo-Arabian element can be explained by the situation of the study area in the Saharan domain and probably by the adaptation of this element to the bioclimatic conditions of the area [10-11, 40]. Abd El-Ghani and Amer [60] reported that plants of the Saharo-Arabian species are good indicators of the quality of desert environmental conditions.
The Shannon index for the three communities is greater than 2, indicating that these communities have high diversity [45]. This diversity is important for the provision of ecosystem services [61-62]. A high diversity of species in a community may be due to the presence of water [40]. The strong similarity observed between communities reflects the spatial homogenization of vegetation, which is an indicator of the state of degradation [40].

Conclusions

This study made it possible to know the phytodiversity of plant communities with *Zygophyllum album* in the Algerian Sahara. The specific richness is composed of 30 species represented mainly by perennial species. The communities studied are characterized by the dominance of hemicryptophytes and chamaephytes which develop specific adaptation strategies. In terms of phytogeography, cosmopolitan plants are the most abundant, reflecting their adaptation to anthropogenic activities and ecosystem disturbances. This study showed that water towers constitute a reservoir of spontaneous species that adapt well to the Saharan environment.

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