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Plant diversity in Mediterranean coastal dune systems subjected to anthropogenic disturbances

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Abstract. Mediterranean coastal dunes have an undeniable value in terms of floristic diversity as a result of their well-adapted plant species, such as psammophytes and halophytes. Unfortunately, these ecosystems are often disturbed by anthropogenic activities, such as the use of bathing settlements and trampling, the construction of paths or roads, and grazing by livestock. In this paper, these environmental factors were considered to determine their relative influences on several Algerian coastal dune systems undergoing ecological disturbance, by measuring in these systems various ecological gradients. Using ecological indices, multivariate analysis of data, and the analysis of variance, we compared the composition of the flora of 7 study sites that were subjected to various scales and types of disturbances. A total of 83 plant species were identified, reflecting the floristic richness of the sites. They seemed to be unevenly distributed and considerably modified according to environmental and human impact descriptors. The composition, abundance, and distribution of plant diversity are positively correlated with the height and width of the dunes. Regrettably, the floristic diversity of coastal dunes is more and more degraded by disturbance pressures (particularly grazing).

Key words: shoreline dunes, floristic richness, plant diversity, vegetation, environmental factors, human impact

1. Introduction

Coastal dunes are extremely complex sandy habitats, with considerable exchanges of mass and energy that support valuable and specialized biodiversity. Due to their transitional natures, these ecosystems are ecologically complicated and influenced by numerous factors that either destabilize them (e.g. groundwater flow, local hydrodynamics, beach morphology, prevailing winds, and waves) or stabilize them (e.g. the effects of particular plant species and plant communities) (Martínez & Psuty 2004; Maun 2009; Fenu *et al.* 2013; Calderisi *et al.* 2021). Coastal dunes are characterized by strong environmental gradients, which modulate the coexistence of different plant communities in a relatively small area (Barbour *et al.* 1985; Frederiksen *et al.* 2006; Acosta *et al.* 2009; Fenu *et al.* 2012, 2013). The composition and distribution of coastal plant communities is related to temperature, rainfall, and wind speed. Variation in edaphic factors refers above all to saline aerosol, pH, texture, organic matter, and nutrients (Wilson & Sykes 1999; Maun 2004; Fenu *et al.* 2013; Ruocco *et al.* 2014; Pinna *et al.* 2015). That is why sand dune communities are characterized by high complexity and uniqueness at both the species and community levels. In addition, the unique ecological characteristics of coastal dune systems result in their particular fragility (van der Meulen & Salman 1996; Carboni *et al.* 2009; Prisco *et al.* 2021).

Coastal dune habitats are declining worldwide, and the biodiversity of even the most protected dune systems is severely threatened (Pinna *et al.* 2022). On the shores of the Mediterranean Sea, where human disturbance is exceptionally frequent, coastal dunes are particularly fragile and threatened ecosystems (Comor *et al.* 2008; Pinna *et al.* 2015; Chelli *et al.* 2022). Negative impacts on dune ecosystems are often caused by human activities, such as high numbers of people visiting beaches, coastal urbanization, trampling, pollution, and the spread of invasive species (Honrado *et al.* 2010; Ciccarelli *et al.* 2017; Pinna *et al.* 2019). These environments attract highly diverse activities related to fishing, tourism, and leisure real estate. In addition, coastal dunes are naturally affected by high salinity, strong winter winds, silting, and sea spray.

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In Algeria, coastal dunes have been the subject of various studies addressing plant diversity and mostly describing vegetation, through phytosociological and syntaxonomic analysis (e.g. Thomas 1968; Alcaraz 1977; Meziani 1984; Grimes 2003; Hanifi *et al.* 2007; Meziane 2004). Those studies, however, are rather outdated, hence there is a need for further research that uses new approaches to investigation of these habitats and the ways how they interact with disturbance factors, including anthropogenic activities related to clearing, grazing, sand extraction, urbanization, and tourist activities.

The coastline of Jijel (a region in Algeria) is characterized by a great variety of ecological landscapes and remarkable flora and fauna (De Belair & Samraoui 2000; Bouldjedri *et al.* 2011; Khennouf 2018). This area is part of the meso-hotspot of the Mediterranean basin in eastern Algeria (Médail & Quézel 1999; Myers *et al.* 2000; Norman 2003; Cañadas *et al.* 2014), which was named "Kabylias-Nymidie-Kroumirie" by Véla and Benhouhou (2007) and was also described by Derneği (2010), who evoked the narrow coastal hotspot (<200 km^2) of Algeria. According to the latter author, the major pressures on biodiversity are the intensification of agriculture and the development of residential areas and tourist complexes, which particularly threaten coastal wetlands and dunes (Derneği 2010). These ecosystems, including those of Jijel, are considered to be priority habitats for conservation and sustainable development.

The present study aims to highlight the factors determining both the distribution and composition of the flora of dune formations subjected to different levels of human-related pressure. Plants are often the best indicators of environmental conditions, so this study used quantitative and qualitative floristic surveys to provide valuable information regarding the various components of the ecosystem.

2. Material and methods

2.1. Study sites

The province of Jijel, where we conducted this study, is located in north-eastern Algeria and is part of the small Kabyle region. It covers a coastal area, 123.9 km long, representing 10.32% of the Algerian coastline.

In terms of resources, this territory has a significant potential: it supports fisheries, agriculture, forestry, tourism, and mining, and it contains a large amount of freshwater. It includes exceptional landscape, also in terms of flora and fauna (Grimes 2004).

The climate of this region is a typical Mediterranean one, with a rainy winter (1200 mm of rain per year) and a dry and humid summer, which is sometimes marked by the passage of sirocco wind.

The study sites were located in the dune ecosystems of the Mediterranean coastline near Jijel. Human communities and dwellings have been established in these sites. These establishments have a socio-economiccharacter with multiple uses, mainly oriented towards coastal agriculture and seaside tourism, thus developing an intense anthropogenic impact (Fig. 1 and Table 1).

Fig. 1. Location of the 7 study sites on the coastal dunes of Jijel (source: Google Earth 2022)

Table 1. Rating (0-5 scale, explained in Appendix 2) of 10 environmental parameters characterizing the study sites

	Parameters	Code	Study sites						
			Beni Belaid	Ledjnah	Le Rocher	Sidi Abdelaziz	Messila	Sanoubar	Kennar
Characteristics of dunes	Dune height	Hau	3	1	1	2	4	5	2
	Dune width	lar	3	5	1	2	3	4	3
	Vegetation cover	Cov	3	2	1	1	4	4	3
	Corridors	cor	2	3	3	3	1	1	2
Disturbances	Urbanization	urb	2	1	5	4	0	0	3
	Health tourism	Tba	4	1	5	5	1	0	3
	Farming activity	agr	4	2	0	1	0	0	4
	Pastoralism	pas	4	5	1	0	0	0	0
	Pollution	pol	0	5	1	3	0	0	2
	Sand extraction	esa	2	1	1	2	0	0	4
Geographical coordinates (km)		X	243.45	239.46	238.16	236.41	235.46	234.10	765.84
		Y	408.58	408.42	408.35	408.27	408.23	408.18	408.07

2.2. Study methods

2.2.1. Data collection

Seven coastal dune sites were considered. They qualified as homogeneous strata and demonstrated different scales and types along a dune cordon crossing 3 coastal municipalities. Within each stratum we opted for systematic sampling, following Gounot (1969), combining the transecting method from the top of a beach to the semi-fixed or transition dunes, while respecting the principle of the species-area curve regarding strip width. Note that beyond the semi-fixed dunes, our region's coastal environment is often significantly modified by road crossings, railways, border plantations, dwellings, and even crop fields, which were excluded from our study.

In each study site, 3 transects perpendicular to the shoreline were randomly positioned in the coastal zone (a total of 21 transects spread over a length of 20 km) to sample the full spectrum of plant species and communities. The research consisted in surveying the vegetation studied within a homogeneous plant community; this was also noted by Guinochet (1973). A total of 76 surveys were conducted in transects measuring between 200 m and 320 m in length. The adopted minimum area varied according to vegetation structure (Kadik & Godron 2004), focusing on homogeneous surfaces ranging from 2 m^2 to 16 m^2.

The number of recorded species was multiplied by a coefficient of abundance-dominance and sociability, reflecting the growing importance of each species within the group according to Braun-Blanquet *et al.* (1952) conventional scale. The vegetation cover from the different sites was first evaluated in an overall manner by assigning an average value from Daget & Poissonnet's (1971) scale. Next, the relative recovery was assessed for each species by transforming the coefficient of abundance-dominance by using van der Maarel's (1979) proposed conversion**.**

The species found were identified and verified by referencing the appropriate floras (Maire 1952; Quézel & Santa 1963) and IdentiPlante Website Tool of Tela Botanica. Next**,** they were summarized in a double-entry table (surveys/species) (Appendix 1).

2.2.2. Environmental factors

A total of 10 environmental factors, grouped into 2 main sets, were considered to characterize both the dunes and disturbances. The factors included dune height (Hau) and width (lar), vegetation cover (Cov), corridors (cor), urbanization (urb), tourism intensity (Tba), farming activity (agr), pastoralism (pas), sand extraction (esa), and pollution (pol), including solid waste, debris, and organic matter deposits. Each parameter was quantified according to an ordinal scale ranging from 0 to 5 (Table 1, scales explained in Appendix 2) according to *in situ* observations (dunes and environmental characteristics) and the available tourism statistics.

2.2.3. Data analysis

Two approaches prevail in this analysis: the analytical approach (ecological profiles) and the global approach (multivariate analysis). The following sets of parameters were used:

Qualitative diversity (numbers of families and species within families): based on the general floristic list of all surveys.

Species richness: regarding the number of species expressed at several hierarchical levels: local, global, and original richness. Local richness is the mean number of species per plot. Global richness is the number of different species found in at least one of the plots of a particular vegetation type. Original richness is the number of species found in only one vegetation type.

Species diversity, using the Shannon index:

$$H' = -\sum_{j=1}^{ni} \left[\frac{R_{ij}}{\sum_{j=1}^{ni} R_{ij}} \times log2 \left(\frac{R_{ij}}{\sum_{j=1}^{ni} R_{ij}} \right) \right]$$

(Shannon & Weaver 1949 in Peet 1975). It considers the number of species (n_i) and the relative recovery (R_{ij}) of different species (*j*) in the survey (*i*) (Gallandat *et al.* 1995; Spellerberg & Fedor 2003). The recovery percentage of species *j* is obtained by converting the abundance-dominance coefficients as proposed by van der Maarel (1979). This index is smaller (close to 0) if the number of species is low and one or a few species dominate. It is larger if the number of species is high and they are distributed more equally.

Similarity index of Dice or Czekanowski (Saporta 1990) according to the formula:

$$Dji = 2a/(2a + b + c),$$

where *a* is the number of species common to survey *i* and survey *j*, *b* is the number of species present only in survey *i*, and *c* is the number of species present only in survey *j*. This index allows comparison between 2 sites because it evaluates the resemblance between 2 surveys by comparing the species common to both surveys and those unique to each survey. Values of this index vary between 0 (no species common to both records) and 1 (identical records). Thus it refers to the presence or absence of species and not to their coefficient of abundance. Two surveys containing the same species with different abundance coefficients will have a similarity index of 1. We used the Dice index because it increases more quickly than the Jaccard index for low to medium coefficients (lower than 0.7). This leads to noticeable differences in the strongest indices (Gégout 1995).

Biological spectrum: we considered Raunkiaer's plant-life forms, based on the position of dormant meristems in relation to the ground level during the unfavourable season. The biological basis for this classification has been widely confirmed (Verlaque *et al.* 2001). It provides information on plant response to the local environment and disturbances.

For the multivariate approach, we chose principal component analysis (PCA) followed by hierarchical ascending classification. PCA is a linear model that explains the variation in species abundance studied in relation to environmental factors. It is very suitable for floristic studies, as it provides a synthetic view of the links between species and environmental data (Romane 1972).

As part of the overall approach, we also used multiple averages (ANOVA) and correlations that might reveal the essential relationships between vegetation and the environment. For these statistical analyses, we used XLSTAT software version 2016.

3. Results

3.1. Floristic wealth and diversity indices of coastal dunes

The dune flora was composed of 83 plant species in 76 surveys. Except one species of the family Cupressaceae (gymnosperms), all the others were angiosperms. The 82 species were distributed across 33 families: 28 of dicotyledons and 5 of monocotyledons (Appendix 1). The flora inventoried in this study indicates that dicotyledons were the most represented, by 69 species, as opposed to 15 species of monocotyledons. Of all the plant families, 3 predominant ones accounted

Table 2. Characteristics of floristic richness and diversity in the study sites

Site	Site code	No. of families (N Fam)	Global richness (N Sp)	Original species richness	Abundance	Shannon index *H'*	Group
Sanoubar	San	17	38	7	149	3.01	A
Kennar	Ken	15	24	6	143	2.69	B
Messila	Mes	19	40	21	166	2.69	B
Sidi Abdelaziz	SAL	12	28	3	134	2.61	B
Ledjnah	Lad	11	14	6	94	2.08	C
Le Rocher	LeR	14	19	2	89	1.69	D
Beni Belaid	Bni	8	10	2	185	1.18	E

Table 3. Dice index values quantifying floristic similarity (in %) and distances (in km) between study sites

Sites	Beni Belaid	Ledjnah	Le Rocher	Sidi Abdelaziz	Messila	Sanoubar
Kennar	29% 13.94 km	26% 9.65 km	33% 8.19 km	50% 6.25 km	38% 5.23 km	55% 3.83 km
Sanoubar	29% 10.14 km	27% 5.85 km	53% 4.40 km	70% 2.48 km	41% 1.42 km	
Messila	20% 8.71 km	22% 4.45 km	34% 3.00 km	47% 1.07 km		
Sidi Abdelaziz	21% 7.65 km	29% 3.40 km	60% 1.94 km			
Le Rocher	21% 5.75 km	30% 1.64 km				
Ledjnah	25% 4.29 km					

for more than 45% of all species: the Asteraceae (18 species), Fabaceae (12), and Poaceae (9) (Appendix 1).

The floristic Shannon diversity index (*H'*) calculated for each site allowed us to identify 5 different groups (Table 2), by using the Hutcheson *t*-test with a statistical significance of $p < 0.05$. The identified groups were labelled as follows: A – group with the highest diversity, B – group with intermediate diversity, and C, D, E – groups with low to very low diversity. In the last 3 groups, biodiversity was strongly affected by pastoralism and tourism, especially in Beni Belaid with a dominance of 2 species – *Eryngium maritimum* and *Echinophora spinosa* – which are considered unpalatable and highly resistant.

The Dice similarity index (D), calculated for pairs of study sites, was very low for Ledjnah and Beni Belaid due to excessive grazing (Table 3). However, this observation also indicates a certain similarity with the decrease in disturbance pressures in the other sites.

A correlation analysis of the Dice similarity index with respect to the distances separating the sites showed a significant effect. The index was inversely proportional, with $r = -0.475$ and $p = 0.030$, suggesting that the distance separating the sites influenced their species but not very strongly. Indeed, the similarity between sites is mostly weakened due to disturbance pressures, including grazing. For example, the pair Ledjnah and Le Rocher, which are among the closest (1.46 km), have a *D* value of only 30%, whereas Sidi Abdelaziz and Kennar have a *D* value of 50%, despite a distance of 6.25 km.

3.2. Multivariate analysis

The comparison of species richness of sites subjected to different environmental factors revealed positive correlations concerning the number of families ($r = 0.774$, $p = 0.041$) and the height of the dunes ($r = 0.932$, $p = 0.002$). However, negative correlations were found for pollution ($r = -0.79$, $p = 0.033$), and the corridors 0.820, $p = 0.024$), reflecting a reduction in floristic wealth.

The eigenvalues of PCA display the quality of the projection when moving from 9 to a smaller number of dimensions (Table 4). In our case, the first eigenvalue of 7.17 represents 55.13% of the variability for the F1 axis, which accumulates at only 71.34% with the F2 axis. Therefore, on the one hand, it is necessary to examine the results for factors F1 and F2, but on the other hand, to refer to other factors: F3 and F4 with F1.

In the PCA plot of the first 2 components (Fig. 2), a circle showing significant correlations between the

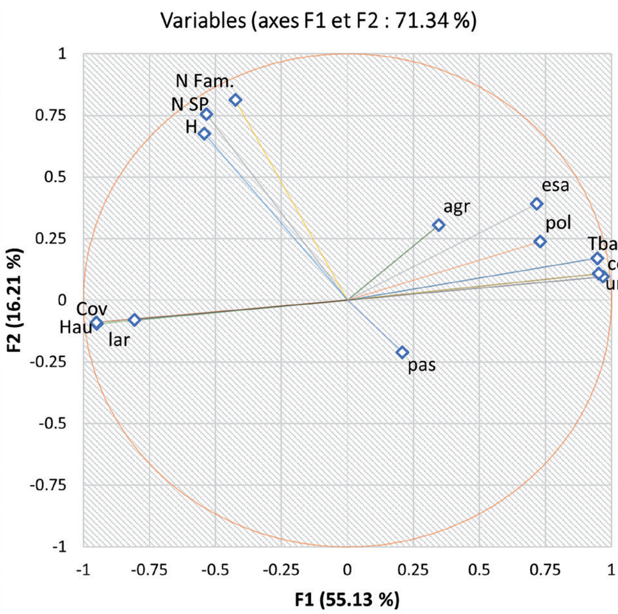

Fig. 2. Representation of the environmental variables considered on the plane of the first 2 principal components

Explanations: Hau – dune height, lar – dune width, Cov – vegetation cover, cor – corridors, urb – urbanization, Tba – tourism intensity, agr – farming activity, pas – pastoralism, esa – sand extraction, pol – pollution

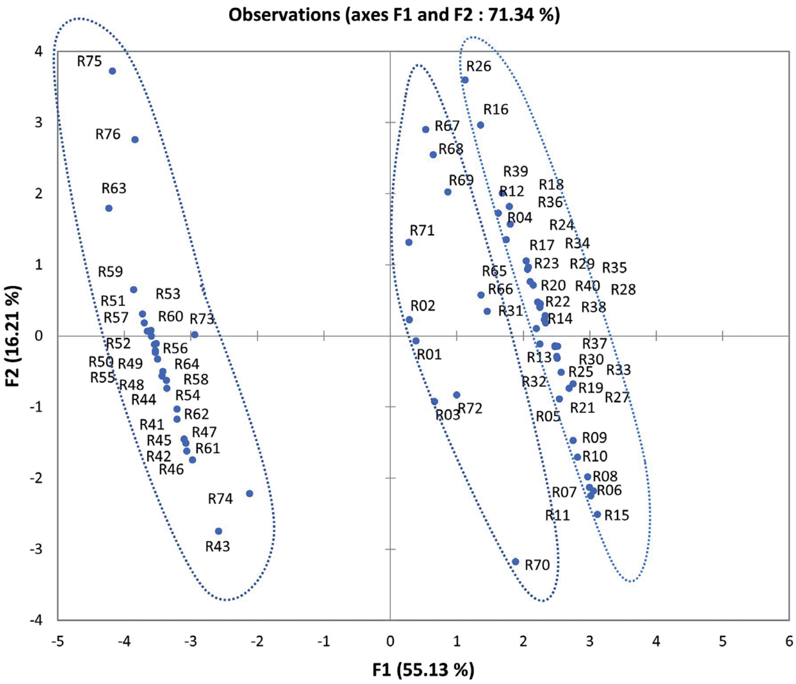

Fig. 3. Position of the surveys on the PCA plane of the first 2 principal components. Survey of each site: Beni Belaid (R01-R03), Le Rocher (R04-R15), Sidi Abdelaziz (R16-R40), Sanoubar (R41-R64), Kennar (R65-R69), Ledjnah (R70-R82), Messila (R73-R76)

variables is located far from the centre of the graph. The F1 dimension is mainly structured by the various pressures exerted on biodiversity, combining variables with strong positive (Tba, cor, and urb) and negative (lar, Cov, and Hau) correlations, while the F2 dimension summarized the biodiversity variables (N Fam, N Sp, and *H*'). Pastoralism (pas) is related more to axis F3, while relative recovery rate (Cov) was related to axis F4.

The dune vegetation cover (Cov) was found to be strongly correlated with dune height (Hau) and width (lar). These 3 variables, in particular the cover, were inversely correlated with seaside tourism (Tba), corridors (cor), and urbanization (urb), thus indicating the places most exposed to disturbances.

As for the parameters of plant diversity (N Sp, *H*', and N Fam), the PCA analysis indicated grazing as the only impact factor negatively affecting species richness, whereas the other pressure variables (agr, esa, pol, Tba, cor, and urb) showed no dependence and thus no influence on biodiversity.

The PCA plane of the first 2 components identifying the trends indicates that the surveys tended to be grouped according to the study sites (Fig. 3). Thus, we can point out that 2 sites – Ledjnah and Messila – represent more favourable biodiversity compared to other sites.

3.3. Plant life-forms

Raunkiaer's plant life-forms in the analysis of variance with 2 classification criteria (life-form and site) revealed very highly significant differences (Table 5; Appendix 3). The comparison of the means by using the Tukey test showed no difference between the sites. As for plant life-forms, 4 different groups were distinguished. They showed a predominance of hemicryptophytes (group A, with an average value of 50.14%), followed by therophytes (group B), geophytes (group

Table 4. Eigenvalues of principal component analysis

Axis	F1	F2	F3	F4	F5	F6	F7	F8	F9
Eigenvalue	7.166	2.107	1.723	0.949	0.663	0.230	0.081	0.063	0.017
Variability (%)	55.126	16.210	13.256	7.297	5.096	1.772	0.626	0.487	0.130
Cumulative variability (%)	55.126	71.336	84.592	91.890	96.986	98.758	99.384	99.870	100

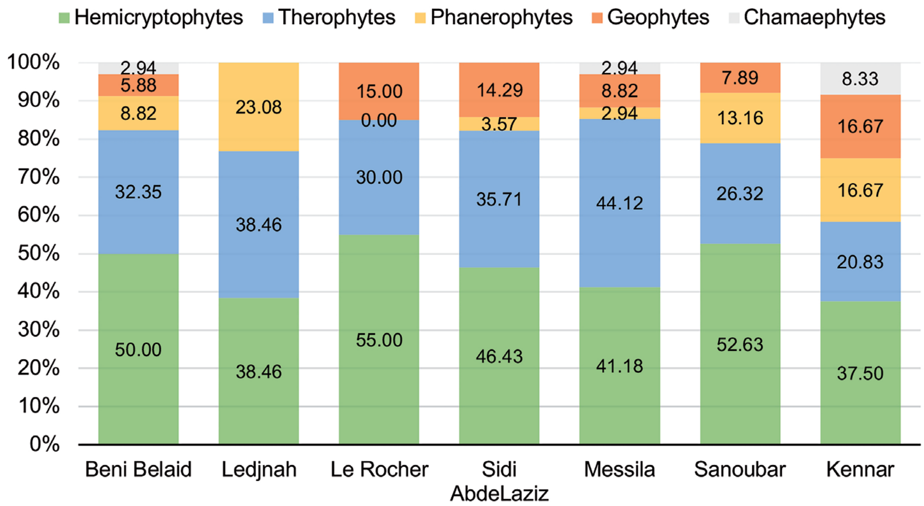

Fig. 4. Biological spectrum (according to the Raunkiaer classification) expressed as proportions of the number of species recorded in the study sites

C), and finally phanerophytes (group D) and chamaephytes (group E), with average values of 26.95%, 13.80%, 7.48%, and 1.33%, respectively (Fig. 4).

4. Discussion

In this work we described and compared the floristic diversity of dunes in 7 coastal study sites subjected to different scales and types of anthropogenic disturbances. In fact, as part of a regional monograph, it is often necessary to stratify the sample by selecting in advance the sites that comprise a complete and balanced sample of the different synusiae and/or plant communities, according to a series of criteria related to the problem (Gillet 2000; Schwal 2004; Forey 2007; Hammada 2007). The sites were chosen to present various degrees of human pressure, such as those discussed by Schwal (2004).

4.1. Plant diversity

Our analysis of plant diversity of the sites along the dune cord showed considerable species richness (particularly of the family Asteraceae) within which the hemicryptophytes dominated.

The values of overall α and β original richness, defined by Bruhier *et al.* (1998), varied from 40 to 10 and from 21 to 2, respectively (see Table 2). The most virgin sites still contained most species. The Messila site showed the highest original diversity, with 21 species, which seems atypical, compared to the other sites. We posit that the width of the dune partly explains this value because it could allow particular plant succession.

Our results agree with the autogenic succession model proposed by Cowles (1899), taken up by Clements (1916) and cited by Forey (2007), in which the plant communities succeed in amending and improving the initial medium resources. This medium becomes less stressful as the distance from the sea increases.

The Shannon index of diversity (*H'*) showed that biodiversity was rich in the pristine sites but minimal in sites subjected to anthropogenic disturbances, such as grazing and tourism. This index reached its maximum value in Sanoubar, which qualifies as the most virgin and balanced site, and thus promotes a spontaneous

Table 5. Average proportions of plant life-forms in the surveys

Plant life-forms	Mean (%)	Standard error	Group
Hemicryptophytes	50.138	1.624	A
Therophytes	26.950	1.624	B
Geophytes	13.804	1.624	C
Phanerophytes	7.478	1.624	D
Chamaephytes	1.332	1.624	E

flora spurt on the coastal dune. Grazing was the most detrimental factor for biodiversity, surpassing other anthropogenic pressures. It is worth mentioning that tourism-related facilities, as reported by Ernoul (2009), contribute to the majority of disturbance in sandy habitats through activities like the trampling of dune vegetation and buildings on beach sand.

Examining the different levels of anthropogenic pressures and the distances between sites, we found that the floristic similarity between selected sites was not explained by distance but rather by the degree and type of human disturbance. This similarity, mirroring the Shannon index (*H*'), was more affected and weakened by grazing.

4.2. Relationship with environmental factors

We used environmental factors to analyse the composition and structure of dune plant communities. This subject was explored earlier by Schulze and Mooney (1994), van der Maarel (1993), Lavorel and Chesson (1995), Callaway and Walker (1997), and Grime (1998). Grime (2006) was the first to classify the abiotic factors into disturbance and stress factors. A study of the East-Algerian coastline demonstrated that increased stress and disruption lead to a decline in floristic wealth (Bouziane *et al.* 2020). Changes were noted in the floristic composition in a few years following the degradation of this coastal environment. Thereafter, new harsher environmental conditions resulted in the loss of much biodiversity and the establishment of new taxa highly resistant to stress and disturbance (Hanifi *et al.* 2007).

We checked the significance of correlations for diversity parameters, but they were only negatively influenced by grazing pressure and independent of the other parameters of pressure. Positively significant correlations were recorded for the parameters characterizing the dunes (their height, width, and vegetation cover). They were also negatively correlated with pressure parameters (urbanization, sand extraction, and pollution).

Vegetation cover was therefore favoured by greater height and width of the coastal strip and was affected by pressure factors (urbanization, corridors, and sand extraction, among others). These findings are similar to those of Forey (2007), who reported that, at the local level, disturbance appears to be the most important factor in explaining the structuring of plant communities.

Furthermore, we observed that the dune flora composition and its distribution, changed profoundly and sometimes were even eliminated by human actions, thus altering the abundance, sociability, and structure of the vegetation. These findings parallel those of Hammada *et al.* (2009) and Bouziane *et al.* (2020). Nevertheless, in our study, the major scourge of floristic degradation and its dynamics lay in the grazing, which Díaz *et al.* (2007) described as a major factor in vegetation dynamics, too. Moreover, according to Huntly (1991), it is the most important source of disturbance after fire in terms of surface and biomass loss.

In another perspective, the analysis of Raunkiaer's plant life-forms according to McIntyre *et al.* (1995) and Dupré and Diekmann (2001), was relevant to studying plant responses to grazing but did not highlight any significant peculiarities between the sites. The environmental factors that raise disturbance levels and local conditions did not influence the distribution of plant life-forms, which were rather dependent on the physicochemical characteristics of the dune. Thus we can say that the dune cord promotes better biological uptake of hemicryptophytes, which accounted for about a half (50.14%) of the total of the inventoried species. McIntyre *et al.* (1995) also showed that hemicryptophytes are less sensitive than the chamaephytes. For example, they are less sensitive to an increase in grazing pressure, a predominant element of disturbance and stress in the ecosystem.

Finally, the distribution of the surveys, considered as a whole, according to the first 2 principal components, shows only 3 groups well distinguished from the total of 7 sites. The 76 surveys, redistributed by referring to the hierarchical ascending classification, summarize the different characteristics of the sites, which are natural or anthropogenic. The first group contains the records of 2 sites that are the most exposed to whaling tourism: Le Rocher and Sidi Abdelaziz. The second group is composed of Ledjnah, Beni Belaid, and Kennar, which have the most abundant grazing. Sanoubar and Messila, forming the last group, are less disturbed and seemed the most valuable in terms of biodiversity, contrasting with the other 2 groups, with a significantly negative correlation.

5. Conclusions

This study of the coastal dune cordon located in the eastern part of the province of Jijel in Algeria testifies its valuable plant diversity, constituting a true natural heritage. However, this type of dune ecosystem is classified as vulnerable, due to the aggressiveness of natural conditions (wind, salinity, and silting) and the effect of multiplied and accentuated anthropogenic actions (tourism, agriculture, and urbanization).

These coastal biotopes harbour species of great ecological value, contributing to the balance of the dune environment. For example, *Ammophila arenaria*, *Elymus farctus, Carpobrotus edulis*, and *Lotus creticus* help to fix the sand and favour its colonization by a diverse flora. It is also noteworthy that *Glaucium flavum*, *Helichrysum stoechas*, and *Pancratium maritimum* have an aesthetic appearance.

This dune ecosystem shows various forms of floristic adaptation, including *Otanthus maritimus*, *Salsola kali* and *Cakile maritima*, which develop first in the unstable and high saline dunes. *Eryngium maritimum* and *Echinophora spinosa* defend themselves well against grazing. On the other hand, there are species sensitive to anthropogenic actions, such as *Elymus farctus* and *Polygonum maritimum*.

The results show that dune plant diversity is positively correlated with dune width and height. It varies continually in composition and distribution due to the intensity of anthropogenic activities that threaten some already rare species, such as *Euphorbia peplis* and *Lotus creticus*. However, the main scourges that affect coastal dune biodiversity are: grazing, seaside tourism, urbanization, and coastal agriculture.

Our findings suggest that the role of protection and sustainable development of the dune ecosystem can help to revitalize it, to preserve or increase plant diversity. The goal is to develop an approach to integrated management of the coastal environment by using a management plan that follows multi-objective and multi-criteria methodologies and by defining the general orientations of the different zones (those devoted to agricultural, touristic, and industrial development). Clarifying the protection measures necessary for the preservation of coastal dunes is also recommended.

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Research concept and design: S. E. Younsi
Collection and/or assembly of data: S. E. Younsi
Data analysis and interpretation: S. E. Younsi, Z. Bouziane
Writing the article: S. E. Younsi
Critical revision of the article: S. E. Younsi
Final approval of article: S. E. Younsi, Z. Bouziane

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Appendix 1. List of plant species classified by family with their life-forms, identified in the coastal dune cord of Jijel

Name of species	Name of family	Life-forms	Surveys numbers (R)
Acacia longifolia (Andrews) Willd.	Fabaceae	Ph	56
Ammophila arenaria (L.) Link	Poaceae	G	20, 32, 41, 42, 45, 46, 50, 53-55, 58, 60, 62-70, 74, 75
Anagallis arvensis L.	Myrsinaceae	Th	13
Anagallis foemina Mill.	Myrsinaceae	Th	76
Andryala integrifolia L.	Asteraceae	Th	04, 76
Anthemis maritima L.	Asteraceae	Th	04, 76
Anthoxanthum ovatum Lag.	Poaceae	Th	04, 17, 21, 40, 45, 58, 64, 65, 68-70, 72, 74, 76
Asparagus acutifolius L.	Asparagaceae	H	64, 69
Asphodelus fistulosus L.	Xanthorrhoeaceae	Th	4
Bromus hordeaceus L.	Poaceae	Th	04, 05, 13-15, 17, 20, 21, 25, 27, 30, 33, 35, 37, 42, 43, 48-50, 52, 53, 56-61, 76
Bromus sterilis L.	Poaceae	Th	04, 76
Bunias erucago L.	Brassicaceae	Th	76
Cakile maritima Scop.	Brassicaceae	Th	05-07, 13, 15, 29, 30, 44, 45, 49-54, 56-59, 61, 63, 65-58, 71, 72, 75
Calendula arvensis L.	Asteraceae	Th	05, 13, 17, 57, 65, 69, 74
Calicotome spinosa (L.) Link	Fabaceae	Ph	69
Carpobrotus edulis (L.) N.E.Br.	Aizoaceae	H	64, 70
Carthamus lanatus L.	Asteraceae	Th	76
Centaurea solstitialis L.	Asteraceae	Th	66, 67
Centaurea sphaerocephala L.	Asteraceae	H	05, 06, 14, 15, 17, 19, 21, 24, 25, 29, 30, 32, 35, 37, 40, 54-56, 59, 61, 64, 65, 69
Charybdis maritima (L.) Speta	Asparagaceae	G	02, 03
Cistus monspeliensis L.	Cistaceae	Ch	69
Coreopsis verticillata L.	Asteraceae	Th	27, 37
Crepis foetida L.	Asteraceae	Th	52
Cynodon dactylon (L.) Pers.	Poaceae	G	04, 38, 76
Cyperus capitatus Vand.	Cyperaceae	H	19, 24, 27, 46, 47, 50, 53-55, 57, 59-64, 68
Daphne gnidium L.	Thymelaeaceae	Ph	69
Datura stramonium L.	Solanaceae	Th	68
Delphinium peregrinum L.	Ranunculaceae	Th	04, 76
Echinophora spinosa L.	Apiaceae	H	01-03, 05, 21-24, 35, 39-50, 53-55, 58-64, 66, 68, 70-72, 74, 75
Echinops ritro L.	Asteraceae	H	04, 76
Echium plantagineum L.	Boraginaceae	H	04, 76
Elymus farctus (Viv.) Runemark ex Melderis	Poaceae	G	17-37, 39-46, 48-55, 60, 61, 74
Erodium cicutarium (L.) L'Her.	Geraniaceae	Th	04, 76
Eryngium maritimum L.	Apiaceae	H	01-03, 17-20, 22-29, 31-36, 38-43, 45-58, 60-64, 66-68, 74, 75
Euphorbia paralias L.	Euphorbiaceae	G	11, 14
Euphorbia peplis L.	Euphorbiaceae	Th	01-03
Euphorbia pithyusa L.	Euphorbiaceae	Ch	68, 70, 74
Genista monosperma (L.) Lam.	Fabaceae	Ph	01, 02, 04, 27, 42, 43, 48, 49, 51-54, 57, 58, 60, 64, 65, 68-70, 72, 73
Glaucium flavum Crantz	Papaveraceae	H	01, 02, 05, 72
Helichrysum stoechas (L.) Moench	Asteraceae	Ch	64, 68, 70
Hypochaeris radicata L.	Asteraceae	H	50
Ipomoea stolonifera (Cyr.) J.F.Gmel.	Convolvulaceae	H	08, 10, 17, 18, 20, 22-29, 32-36, 38-43, 45, 45, 49, 50, 53, 54, 58, 60, 61
Juniperus oxycedrus L.	Cupressaceae	Ph	65
Lagurus ovatus L.	Poaceae	Th	04, 27, 76
Leontodon autumnalis L.	Asteraceae	H	72, 73
Limbarda crithmoides (L.) Dumort.	Asteraceae	Ch	60
Lobularia maritima (L.) Desv.	Brassicaceae	H	04, 13, 59, 65, 76
Lotus corniculatus L.	Fabaceae	H	76

Lotus creticus L.	Fabaceae	H	28-30, 32, 33, 37, 48, 49, 51, 52-58, 60
Medicago littoralis Rohde ex Loisel.	Fabaceae	Th	27, 37
Medicago marina L.	Fabaceae	H	05, 06, 09, 11-16, 64, 65
Medicago rigidula (L.) All.	Fabaceae	Th	73
Melica magnolii Godr. & Gren.	Poaceae	H	04, 76
Nerium oleander L.	Apocynaceae	Ph	72
Ononis cristata Mill.	Fabaceae	H	4
Ononis variegata L.	Fabaceae	H	05-15, 17, 18, 21, 24, 25, 27, 28, 30-32, 34-40, 42, 47, 52, 55-61, 63-65, 68, 74
Otanthus maritimus (L.) Hoffmanns. & Link	Asteraceae	H	01, 02, 43-46, 54, 62, 64
Pancratium maritimum L.	Amaryllidaceae	G	01-03, 05-20, 22, 23, 26-28, 31, 36, 38, 41, 45, 50-53, 57, 60-67, 69, 70, 74
Paronychia argentea Lam.	Caryophyllaceae	H	04, 76
Phragmites australis (Cav.) Trin.	Poaceae	G	26, 34, 54, 70.
Pistacia lentiscus L.	Anacardiaceae	Ph	01, 02, 04, 64, 69, 75
Plantago lagopus L.	Plantaginaceae	H	04, 13, 17, 19, 27, 51, 52, 76
Plantago serraria L.	Plantaginaceae	H	04, 76
Polygonum maritimum L.	Polygonaceae	H	05, 13, 25
Pseudorlaya pumila (L.) Grande	Apiaceae	Th	51-53, 55
Reseda alba L.	Resedaceae	Th	13, 40, 56, 59
Ricinus communis L.	Euphorbiaceae	Ph	72
Rumex bucephalophorus L.	Polygonaceae	H	04, 05, 13, 15, 17, 19, 27, 37, 47, 56, 57, 59, 64, 65, 68, 70, 72, 73, 74, 76
Salsola kali L.	Amaranthaceae	Th	72, 73
Scabiosa columbaria L.	Caprifoliaceae	H	17, 19, 27, 37, 40
Scolymus hispanicus L.	Asteraceae	H	30, 35, 37, 41, 51, 58
Sedum pubescens Vahl	Crassulaceae	Th	76
Senecio vulgaris L.	Asteraceae	H	52
Silene ciliata Pourr.	Caryophyllaceae	H	73
Silene nicaeensis All.	Caryophyllaceae	H	05-10, 12-15, 17-19 , 21, 23, 25, 27, 28, 30, 31, 33, 35, 37, 39, 40, 42, 47-49, 51, 53-56, 58-61
Tamarix gallica L.	Tamaricaceae	Ph	64, 72
Thymelaea hirsuta (L.) Endl.	Thymelaeaceae	Ch	04
Trifolium arvense L.	Fabaceae	H	04
Trifolium campestre Schreb.	Fabaceae	H	04, 76
Verbascum sinuatum L.	Scrophulariaceae	H	04
Xanthium spinosum L.	Asteraceae	Th	01, 03, 62
Xanthium strumarium L.	Asteraceae	Th	14, 15, 17-19, 27, 30-32, 40, 44, 49-52, 60, 63, 72, 74, 75
Ziziphus lotus (L.) Lam.	Rhamnaceae	Ph	04

Appendix 2. The meaning of values between 0 and 5 used in Table 1

Parameter	Abbrev.	Explanation	Scale
Dune height	Hau	average dune height (m)	0 (Hau?1 m), 1 (1 m<Hau?3 m) 2 (3 m<Hau?5 m), 3 (5 m<Hau?7 m), 4 (7 m<Hau?9 m), 5 (Hau>9 m)
Dune width	lar	average dune width (m)	0 (lar?50 m), 1 (50 m<lar?100 m), 2 (100 m<lar?150 m), 3 (150 m<lar ?300 m), 4 (300 m<lar ?350 m), 5 (lar>350 m)
Vegetation cover	Cov	relative recovery rate (%)	0 (Cov?10%), 1 (10%<Cov?20%) 2 (20%<Cov?40%), 3 (40%<Cov?60%), 4 (60%<Cov?80%), 5 (Cov>80%)
Corridors	cor	number and area occupied	
Urbanization	urb	density of bordering urbanization	
Health tourism	Tba	frequency	0 (none), 1 (very low) 2 (low), 3 (medium), 4 (high), 5 (very high)
Farming activity	agr	agricultural area	
Pastoralism	pas	frequency	
Pollution	pol	solid waste pollution	
Sand extraction	esa	extraction volume	

Appendix 3. Analysis of variance with 2 criteria of classification (plant life-form and site)

Source	d.f.	Sum of squares	Average squares	*F*	*p*
Model only	34	159131.704	4680.344	46.392	<0.0001
Error	345	34806.181	100.887		
Total corrected	379	193937.885			