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RESEARCH ARTICLE

Biogeography and ecology of the Algerian island flora

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Abstract

Background and aims – In spite of their proximity to the coasts, the flora of the islands and islets of the Algerian coasts has been poorly studied. This work is the first to provide an overall view of the richness and the determinants of the Algerian island flora.
Material and methods – The study is based on a compilation of original floristic data. Two classifications of 30 islands and islets were derived from PCA and HCPC performed on the species occurrence matrix and on a matrix of flora descriptors including species richness, functional traits (life form, seed dispersal, pollination), and biogeographic range. We performed an RDA to explain the variation in flora characteristics by a set of physiographic (longitude, latitude, elevation, area, isolation, steepness index, and area/perimeter ratio) and biotic (seabird density and human presence) variables.
Key results – The floristic inventory encompassed a total richness of 295 vascular plant taxa (including subspecies and varieties) on the 30 studied sites. Five main groups of islands and islets can be distinguished based on vegetation composition and three from flora descriptors. RDA model selection revealed that the combination of four variables (seabird density, area, latitude, and longitude) explained 26.6% of the variation in flora characteristics. Taken alone, the density of yellow-legged gull colonies and the island area were the main drivers of this variation. Results showed that floristic richness was associated with larger island area and higher seabird density, the importance of some plant functional traits, such as zoochory and entomogamy, and with a higher proportion of Eurasian holarctic species.
Conclusion – In the context of island flora conservation, some of these small islands of Algeria can be considered as "modern refuges" from human pressures, and this is particularly important in the context of Mediterranean ecosystems characterised by a quasi-permanent human impact in various habitats. Two new important plant areas (IPAs) for Algeria are proposed following the results of these floristic inventories.

Keywords

biotic factors, chorology, important plant area (IPA), Mediterranean small islands, perimeter/area ratio (PAR), physiography, species richness, steepness index (SI)

INTRODUCTION

Even though they represent only 3.5% of the land surface, islands contribute disproportionately to global biodiversity, hosting 15–20% of terrestrial species (Whittaker and Fernández-Palacios 2007). According to Denslow (2001), islands are of key interest for studies and experimental research in ecology, biogeography, and evolution, particularly as their small size and isolation make them biologically unique.

These areas frequently host endemic or genetically distinct taxa as well as taxonomic and trophically unbalanced species assemblages (Williamson 1981). This makes their communities and biotic interactions simpler,

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but also very sensitive to any new ecological disturbance, as they have a low resilience capacity due to dispersal/colonisation phenomena (see for example Whitehead and Jones 1969; Eliasson 1995; Greuter 1995). The smaller the island, the higher the species turn-over on a short timescale, a pattern mainly driven by seabirds like gulls (Vidal et al. 1998, 2000) and not by physiographic parameters (Panitsa et al. 2008). The challenge of quickly changing plant communities and the taxonomical vicariance across geography can be bypassed by using ecological/biological traits in addition to the classical taxonomy (Vidal et al. 1998, 2000; Gachet et al. 2005). This particularity (endemism, genetics, taxonomic and trophic imbalances, etc.), which allows islands to be used as ecological and evolutionary study models, is a major commitment in terms of our responsibility for global biodiversity conservation (Médail 2022). Especially since islands play a key role in the current extinction crisis, such that 60% of documented extinctions of terrestrial species since 1500 AD were island endemics (Johnson et al. 2017; Whittaker et al. 2017).

Among the 36 major hotspots of global biodiversity, the Mediterranean basin hotspot (Médail and Myers 2004) is famous for its numerous islands (ca 11,100 islands according to the recent synthesis of Médail 2022), most of which are small islands or rocky islets, concentrated mainly in the eastern and central sub-basin. The majority of them have a continental origin and host numerous endemic and narrow-ranged plant taxa (Thompson et al. 2005; Vogiatzakis et al. 2008; Médail 2013, 2022). Their high phytodiversity reflects their complex palaeogeographic history (Médail and Quézel 1997), superposing and combining many diversification processes such as long persistence coupled with old vicariance (Magri et al. 2007, about *Quercus suber* L.), cumulative clinal speciation by vicariance plus local adaptation (Jeanmonod 1984; Naciri et al. 2010, 2022, about *Silene* L. sect. *Siphonomorpha*/*Italicae*), active polyploid complexes with hybridogenic speciation (Lidén 1986, about the genus *Fumaria* Tourn. ex L.; Mifsud and Mifsud 2018, about *Allium* L. sect. *Allium*), and active intense radiation by pollinator ethology (Baguette et al. 2020, about *Ophrys* L.).

According to the Mediterranean Small Islands Initiative (PIM: Petites Iles de Méditerranée, http://initiative-pim.org), the western Mediterranean contains ca 1,500 small islands (i.e. uninhabited and/or smaller than 1,000 hectares); 168 of these are located off the coasts of Algeria, Tunisia, and Morocco (approximately 70 in Algeria). Most of the small islands of the North African coasts of the western Mediterranean belong to two regional biodiversity hotspots, the Baetic-Rifan complex and the Kabylies-Numidie-Kroumirie complex (Médail and Quézel 1997; Véla and Benhouhou 2007; Véla and Pavon 2013; Véla et al. 2013; Véla 2017), showing a bipolar biogeography from western Algeria (Ibero-Maghrebian assemblages in Oranie), to eastern Algeria / northern Tunisia (Tyrrhenian affinities between Kabylies and Sardinia and between Cap Bon and Sicily).

On the northern shores of the Mediterranean, many studies concerning island biodiversity, and more particularly plant diversity of the archipelagos of islands and islets, have been carried out. However, on the southern shore, studies concerning island phytodiversity are less numerous: for Tunisia, we can cite the works of Pavon and Véla (2011), Véla and Pavon (2013), Médail et al. (2016), Médail and Véla (2020), Médail et al. (2020), as well as Médail et al. (2015) on the effect of sea level change on plant biodiversity in island environments. In Algeria, despite a coastline of more than 1600 km, the number of islands and islets is quite low. The phytodiversity is generally poorly known, notwithstanding the proximity of the shores and coastal towns. The only studies that have been carried out are very sparse and concern only a few sites such as the Habibas islands (Maire and Wilczek 1936; Delauge and Véla 2007; Véla et al. 2013), Rachgoun island (Ghermaoui et al. 2016; Véla 2017), Serijina island (Véla 2008), and the island systems of Béjaïa and Jijel (Benhamiche-Hanifi and Moulaï 2012).

In 2013, Véla and Pavon published a more comprehensive study on the small islands' flora of the Tunisian and Algerian coasts, covering a total of 25 small islands (14 in Algeria and 11 in Tunisia). This study highlighted the importance of small islands as refuges for biodiversity, local and regional endemic species, as well as their role in global and Mediterranean plant biodiversity conservation programs. The authors highlighted that several Algerian islands or archipelagos can be considered as key biodiversity areas for plants, also named "Important Plant Areas" (Yahi et al. 2012; Benhouhou et al. 2018). The main one, the Habibas archipelago, is considered as an autonomous IPA itself thanks to criterion "A" (significant population of threatened species), while the newly assessed one, the El Aouana archipelago, is considered an IPA in accordance with criterion "B" (exceptionally rich flora in a regional context), according to the guidelines by Plantlife International (2004).

As far as we know, the present work is the first to provide an overview of the diversity and functional traits of the Algerian island flora. Thirty islands and islets were surveyed along the entire Algerian coastline. Species assemblages and synthetic flora descriptors (species richness, life forms, dispersal and pollination modes, biogeographic range) were related to physiographic characteristics of the islands (e.g. area, isolation, elevation) and to biotic factors that can affect the structure of the island vegetation, such as the number of breeding pairs of yellow-legged gull (*Larus michahellis* Naumann, 1840). The floristic results are analysed from a biogeographical, ecological, and functional point of view in order to identify their heritage status and draw up priority actions for the management and conservation of the Algerian island flora. Our study can be seen as a baseline survey, in light of possible future diachronic studies of Algerian island vegetation.

MATERIAL AND METHODS

The studied sites are islets (< 1 ha) and very small islands (< 50 ha) with low elevations (< 200 m), of continental origin, close to the shore (< 10 km) and separated by shallow waters (< 100 m). The small islands and islets considered here are distributed along the Algerian coast, from the west to the east of the country (Fig. 1). The data used in this work are those of recently published works, mission reports from the PIM Initiative, as well as unpublished data and the results of our own surveys (Tables 1, 2).

This study gathers data for 30 islands and islets, distributed along the Algerian coast. This dataset contains the results of surveys carried out between 2003 and 2018. The surface area and distance from the mainland (isolation) of the surveyed sites were determined using Google Earth Pro. The areas are very variable, ranging from 0.1 ha to 34.5 ha, and because of their continental origin, these islands and islets are characterised by small distances from the mainland, ranging from 7 m to almost 10 km (Table 1).

The elevations of the islands and islets have been determined, in decreasing order of priority, by using the old French military maps at 1:50,000 scale, using the technical data of the lighthouses (focal height – height of the lighthouse = height of the island) available on Wikipedia, or on the basis of photos including landmarks such as standing humans (private collection and/or available on Google Panoramio), and otherwise through the use of digital models on QGIS, which are admittedly very inaccurate at this scale.

In order to cover the gaps and data deficiencies in our island biodiversity, and more particularly phytodiversity, all sites were systematically sampled, covering almost the entirety of each site. The floristic surveys were carried out during the optimal vegetation period (Ozenda 1982), distributed between March and June (optimum flowering period and easy access to the sites). The taxonomic identification is based on the Flora of Algeria by Quézel and Santa (1962–1963), supplemented by the Flora of North Africa by Battandier (1888–1890), Battandier and Trabut (1895), and Maire (1952–1987), by using photos and samples collected in the field. The taxonomy was then adapted according to the synonymic index of Dobignard and Chatelain (2010–2013) updated by the African Plant Database (2022) and the corresponding recent literature as needed.

The inventory concerned only vascular plants, identified at the species or subspecies level, for which ecological requirements have been widely studied, thus facilitating the interpretation of the diversity patterns of this group, often used as an ecological indicator (Alignier 2010). For each taxon, we recorded various biological and biogeographical attributes. The life form sensu Raunkiaer (1934) was given according to Flora Gallica (Tison and de Foucault 2014) and the Flore pratique du Maroc (Fennane et al. 2014), supplemented for the endemics by our personal observations. The chorological type sensu Quézel and Santa (1962–1963, modified) was based

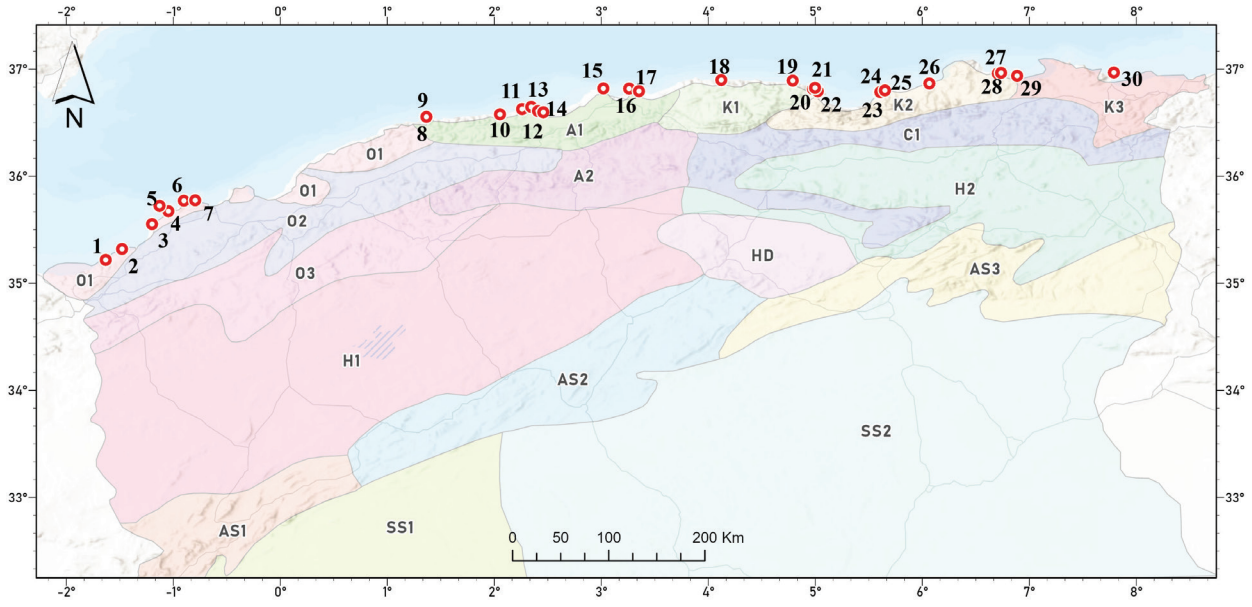

Figure 1. Location of the small islands and islets surveyed along the Algerian coast. Biogeographic divisions: O1: Coastal Sahels subsector; O2: Coastal plains subsector; A1: Coastal subsector; K1: Great Kabylie; K2: Little Kabylie; K3: Numidia. Study sites: 1: Mokreum; 2: Rachgoun; 3: Sbiaat; 4: île Ronde; 5 (×2): Grande Habibas and Petite Habibas; 6: île Plane; 7: île aux Rats; 8: Sekia; 9: Dziria; 10: Hadjret Ennos; 11: Les 3 îlots; 12: Rocher Barbare; 13: Rocher aux Galets; 14: Tipaza; 15: Pointe Pescade; 16: Sandja; 17: Aguéli; 18: Tigzirt; 19: El-Euch; 20: îlot à l'Ail; 21: Pisans; 22: Sahel; 23: Grand-Cavallo; 24: îlot Grand-Cavallo; 25: Petit-Cavallo; 26: Tazerout; 27: Rahbet Teffah; 28: Ras-Bibi; 29: Serijina; 30: Vivier. Map created with QGIS v.3.36.2 (QGIS Development Team 2024).

Table 1. Small islands and islets studied along the Algerian coast, and source of floristic data used. PIM: Petites Iles de Méditerranée; NPR: National Program of research.

Wilaya	Island or islet	Mission	Surveyors	Date	Reference
Tlemcen	1 Mokreum	PIM Mission	O. Peyre	12 and 13 May 2017	Unpublished
Aïn Témouchent	2 Rachgoun	PIM Mission	E. Véla	30 April 2006	Véla (2017)
Oran	3 Sbiaat (île Ouest)	PIM Mission	T. Mokhtari	29 & 30 April 2015	Unpublished
	4 Île Ronde		S. Bakour & R. Moulaï	December 2018	Unpublished
	5 Grande Habibas 5 Petite Habibas	PIM Mission	E. Véla	May 2006/May 2007	Delauge and Véla (2007)
	6 Île Plane (Paloma)		S. Bakour & R. Moulaï	April 2016	Unpublished
	7 Île aux Rats	PIM Mission	T. Mokhtari	April 2015	Unpublished
Chlef	8 Sekia 9 Dziria		M. Hamimeche	May 2017	Unpublished
Tipaza	10 Hadjret Ennos 11 Les Trois Îlots 12 Rocher Barbare 13 Rocher au Galets		M. Hamimeche	May 2018	Unpublished
	14 Tipaza		M. Hamimeche & R. Moulaï	May 2016	Unpublished
Alger	15 Pointe Pescade 16 Sandja		M. Hamimeche	June 2015	Unpublished
	17 Aguéli	NPR Mission	K. Hamadi & R. Moulaï	2005	Moulaï et al. (2011)
Tizi-Ouzou	18 Tigzirt		R. Djadda, N. Bedjih & R. Moulaï	May 2011	Djadda and Bedjih (2011)
Bejaia	19 El-Euch 21 Pisans 22 Sahel		S. Benhamiche-Hanifi & R. Moulaï	May 2010	Benhamiche-Hanifi and Moulaï (2012)
	20 Îlot à l'ail		E. Véla et al.	June/July 2011	Véla et al. (2012)
Jijel	23 Grand Cavallo 25 Petit Cavallo 24 Îlot Grand Cavallo		S. Benhamiche-Hanifi & R. Moulaï	May 2009	Benhamiche-Hanifi and Moulaï (2012)
	26 Tazerout		M. Hamimeche & R. Moulaï	July 2016/May 2017	Unpublished
Skikda	27 Rahbet Teffah 28 Ras Bibi		T. Lachouri, L. Mouloudj & R. Moulaï	April 2016	Lachouri and Mouloudj (2016)
	29 Serijina	PIM Mission	E. Véla	May 2008	Véla et al. (2008)
Annaba	30 Vivier		E. Véla & G. de Bélair	2013	Unpublished

on Flora Gallica (Tison and de Foucault 2014) and the African Plant Database (2022). The dispersal mode and pollination mode were given based on Julve (1998–2022), modified and completed by us in agreement with the author (Supplementary material 1). We merged the three categories of the zoochorous dispersal syndrome, namely zoochorous, endozoochorous, and epizoochorous, into a single category "zoochorous".

In addition to the floristic characteristics of each site studied, the total species richness (S, the total number of observed native and alien plant species), the percentage of life forms and chorological types, dispersal and pollination syndrome, three biological variables were taken into account: the number and density of seagull pairs (nbGull and dGull) provided by Vidal et al. (2007), Djadda and Bedjih (2011), Benhamiche-Hanifi and Moulaï (2012), Telailia et al. (2015), Ghermaoui et al. (2016), Lachouri and Mouloudj (2016), or estimated by us in the field (sites surveyed by ourselves, Table 1); human presence, which was coded as a binary variable: 0 = occasional, 1 = frequent (Supplementary material 2).

Other variables related to the physical environment were considered, such as total area, elevation, isolation (distance from the mainland), perimeter/area ratio (PAR) that is the relative length of an island, an indication of the relative amount of edge versus interior habitat (McGarigal and Marks 1995; Wu et al. 2002; Wu 2004; Yu et al. 2012) (Supplementary material 3). We also calculated the

Table 2. The physiographic attributes and the floristic richness of the 30 small islands and islets sampled along the Algerian coast.

Number	Island or islet	Area (ha)	Isolation (m)	Elevation (m)	Total richness
1	Mokreum	2.6	388	57	11
2	Rachgoun	25	2327	64	55
3	Sbiaat (île Ouest)	1.05	143	9	20
3	Ronde	0.64	590	13	14
5	Grande Habibas	34.5	9749	105	93
	Petite Habibas	6.3	9875	24	22
6	Île Plane (Paloma)	2.3	6688	18	8
7	Île aux Rats	1.74	124	29	11
8	Sekia	0.40	23	15	11
9	Dziria	0.41	99	20	7
10	Hadjret Ennos	0.35	134	20	9
11	Les 3 îlots	0.2	187	20	18
12	Rocher Barbare	0.33	357	30	11
13	Rocher au Galets	0.10	27	7	20
14	Tipaza	0.57	150	7	5
15	Pointe Pescade	0.57	175	20	11
17	Aguéli	1.17	649	15	6
18	Tigzirt	0.46	150	20	36
19	El-Euch	1.88	120	20	60
21	Pisans	1.31	1250	31	52
22	Sahel	0.46	7	15	44
20	Îlot à l'ail	0.46	113	10	21
23	Grand Cavallo	3.6	950	50	82
25	Petit Cavallo	3.9	750	10	101
24	Ilot G. Cavallo	0.44	50	30	23
26	Tazerout	0.74	154	15	11
27	Rahbet Teffah	2.5	1000	60	18
28	Ras Bibi	0.40	1800	70	6
29	Serijina	2.2	630	40	34
30	Vivier	1.06	17	14	23

steepness index (SI), which is a measure of the verticality of the island (in angular units), calculated by simplifying the three-dimensional geometric shape of each island into a cone:

$$SI = Arctan\left(\frac{R}{E}\right)$$

with R representing

$$\sqrt{\frac{A}{\pi}}$$

E is the elevation (in m a.s.l.) and A is the island's area (in ha). The SI equals 1 when the shape is a perfect circle and increases as the shape becomes more irregular and complex (Yu et al. 2012).

Data analysis

The overall floristic pattern of the Algerian islands and islets was analysed through multivariate analyses, i.e. Principal Component Analysis (PCA) coupled with Hierarchical Clustering on Principal Components (HCPC), for two sets of variables. The first PCA compared sites described by their floristic composition (occurrence of plant species and subspecies in each island or islet). Presence-absence data were Hellinger-transformed to account for the double-zero problem (Borcard et al. 2018). The second PCA was applied to flora descriptors (chorological type, life form, seed dispersal syndrome, pollination syndrome, species richness), scaled to zero mean and unit variance. PCA and HCPC were performed using functions of the R package FactoMineR v.2.11 (Le et al. 2008). The HCPC function applied the Ward clustering

Table 3. Variation of the flora descriptors explained by each physiographic and biotic variable in separate RDAs (tested with 9999 permutations). dGull: density of seagulls; nbGull: number of seagulls; PAR: perimeter/area ratio; SI: steepness index. Significance: ** p < 0.01, * p < 0.05, . p < 0.1, ns not significant.

Variable	Variation explained (%)	p value	Significance
dGull	8.88	0.002	**
Area	8.06	0.009	**
Latitude	6.57	0.023	*
Longitude	6.46	0.026	*
Elevation	5.69	0.066	.
PAR	5.54	0.092	.
SI	4.85	0.141	ns
Isolation	4.59	0.188	ns
nbGull	4.13	0.230	ns
Human	2.87	0.642	ns

method to the Euclidean distances between site scores across the first ten PCA axes.

A Redundancy Analysis (RDA) was used to explain flora descriptors by physiographic (elevation, area, distance from the mainland, SI, PAR, latitude and longitude) and biotic (human presence, number and density of yellow-legged gulls *Larus michahellis*) variables. RDA was performed using the rda function of the vegan package v.2.6-4 (Oksanen et al. 2022). A stepwise selection of explanatory variables was applied to retain the most parsimonious model, using the ordistep function of the same package. In addition, each explanatory variable was tested in separate RDAs using the vartest function (Borcard et al. 2018).

All analyses were performed in R v.4.3.2 (R Core Team 2023).

RESULTS

Typology of islands and islets based on floristic composition

The HCPC analysis applied to the sites × species occurrence matrix allowed us to identify five main groups of islands and islets (Fig. 2, Table 3).

The two first components of the PCA represent 20.8% and the ten first components 61.4% of the total variance. Group 1 is differentiated by the presence of *Mesembryanthemum crystallinum* L., *Fumaria munbyi*, *Lycium intricatum* Boiss., and *Malva durieui* Spach (Fig. 3B) with often a high species richness (Fig. 4A). Groups 2 and 3 are characterized by the lowest species richness, with the presence of *Mesembryanthemum nodiflorum* L. and *Suaeda vera* Forssk. ex J.F.Gmel. (group 2), and of *Malva arborea*, and *Senecio leucanthemifolius* Poir. (group 3). Group 4 represents species-rich small islands with

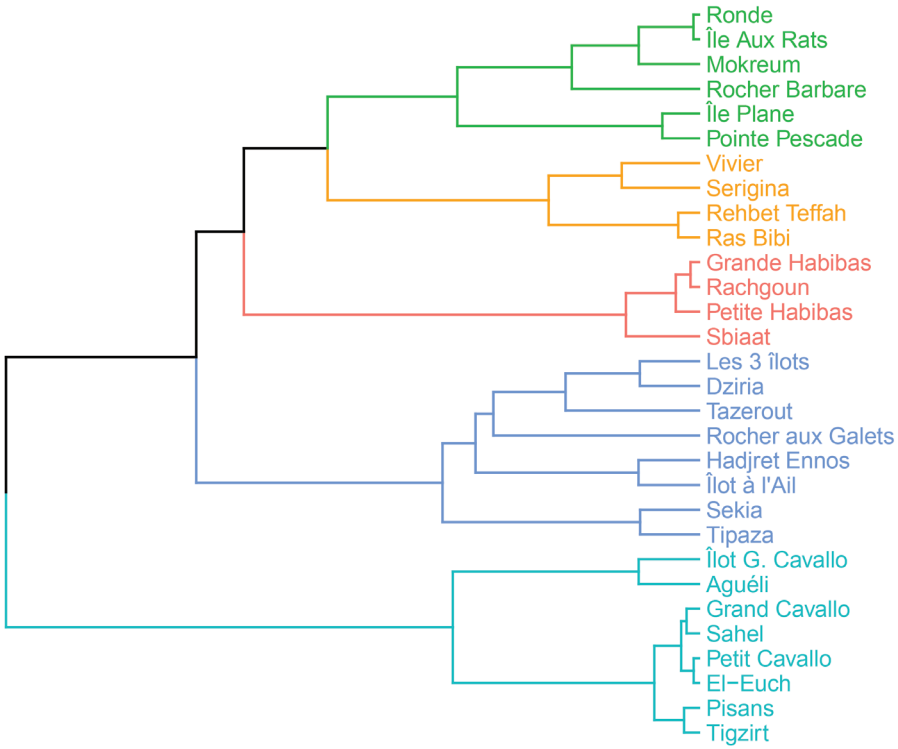

Figure 2. Dendrogram of the 30 islands and islets of Algeria classified according to their floristic composition.

Limbarda crithmoides (L.) Dumort., *Anthemis maritima*, and *Beta vulgaris* subsp. *maritima* (L.) Arcang. (Fig. 3B). Group 5 features islands with the highest species richness, and the presence of *Lotus ornithopodioides* L., *Solanum nigrum* L., and *Phillyrea latifolia* L. (Supplementary material 1).

The five groups of islands and islets identified from the PCA scores (Fig. 3A) are characterized by contrasted environmental conditions (Fig. 4). Group 1 is composed of five large, including the three largest islands (Grande Habibas, Rachgoun, and Petite Habibas) (Fig. 4B), isolated (Fig. 4D) islands of the western Algerian costline, hosting a big gull population (Fig. 4H) with a frequent human presence. Group 2 is made of six relatively small islands and islets (Fig. 4B), located close to the mainland (Fig. 4D), with a low gull density (Fig. 4H). Group 3 contains the eight smallest islands with low human frequentation and the lowest concentration of seabirds (Fig. 4H, I). Group 4 comprises four islands moderately isolated from the coast, with low gull concentration. Group 5 corresponds to eight islands with the highest gull density (Fig. 4H).

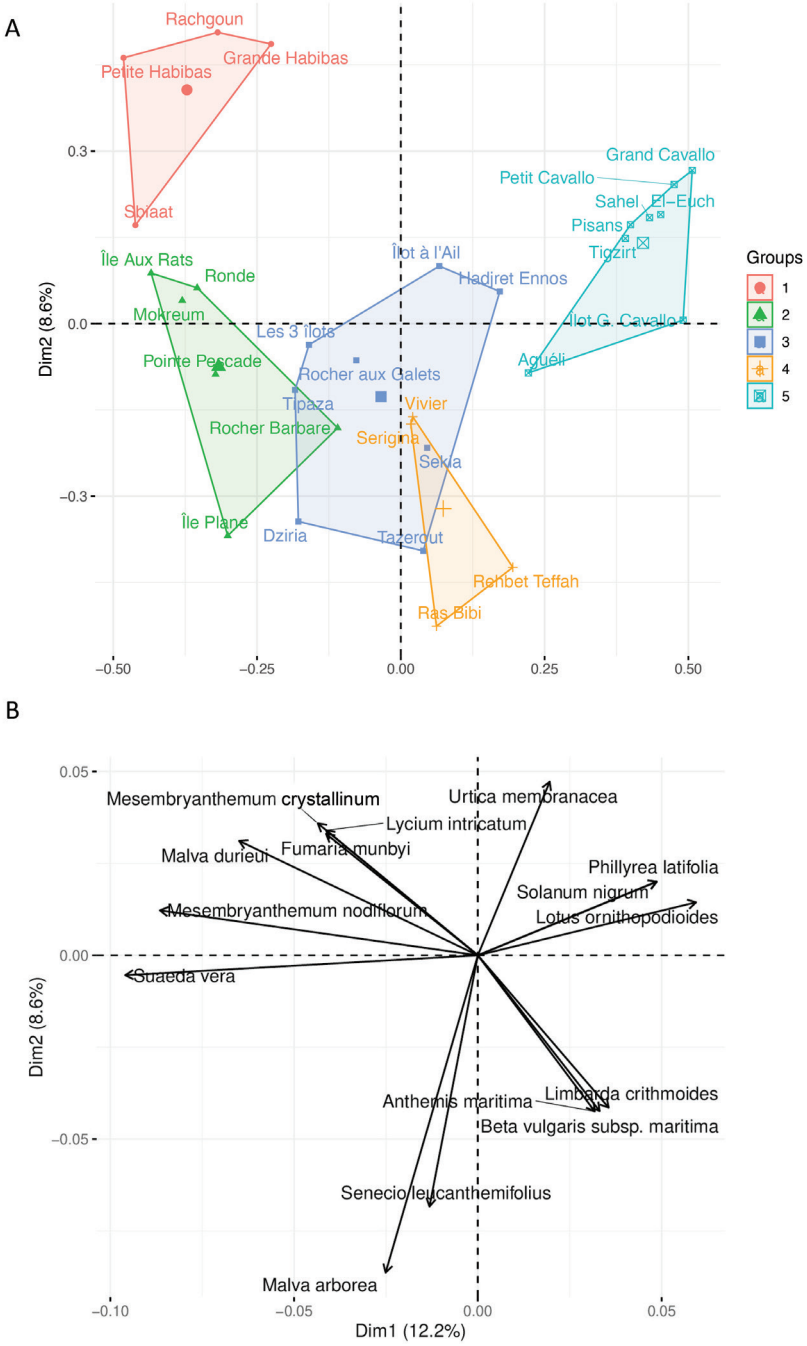

Figure 3. PCA ordination of the 30 islands and islets of Algeria (**A**) according to the floristic composition (**B**). Only the 15 species with the highest contribution to the two first components are drawn.

No significant difference was shown between the five groups concerning steepness index and human presence (Fig. 4F, G, respectively).

Typology of islands and islets based on flora descriptors

The PCA of the matrix sites × flora descriptors, in combination with a HCPC (Fig. 5), allowed us to classify islands and islets into three main groups (Fig. 6A).

The two first components of the PCA represent 36.1% of the variance and the ten first 84.9%. The first axis is strongly positively correlated to the species richness (S), a zoochorous dispersal syndrome, the proportion of geophytes (Ge) and of introduced species, and negatively to the proportion of chamaephytes (Ch), Mediterranean (Medsl), and barochorous species (Fig. 6B). Axis 2 is negatively influenced by the percentage of entomogame species and of phanerophytes (Ph), and positively by the proportion of anemochorous species.

Group 1 is represented by eight islets or small islands (Fig. 7B), mainly located in front of the central and central-western coasts of the country (Aguéli, Hadjrat Ennos, Sekia, and Dziria), and a low gull concentration (Fig.

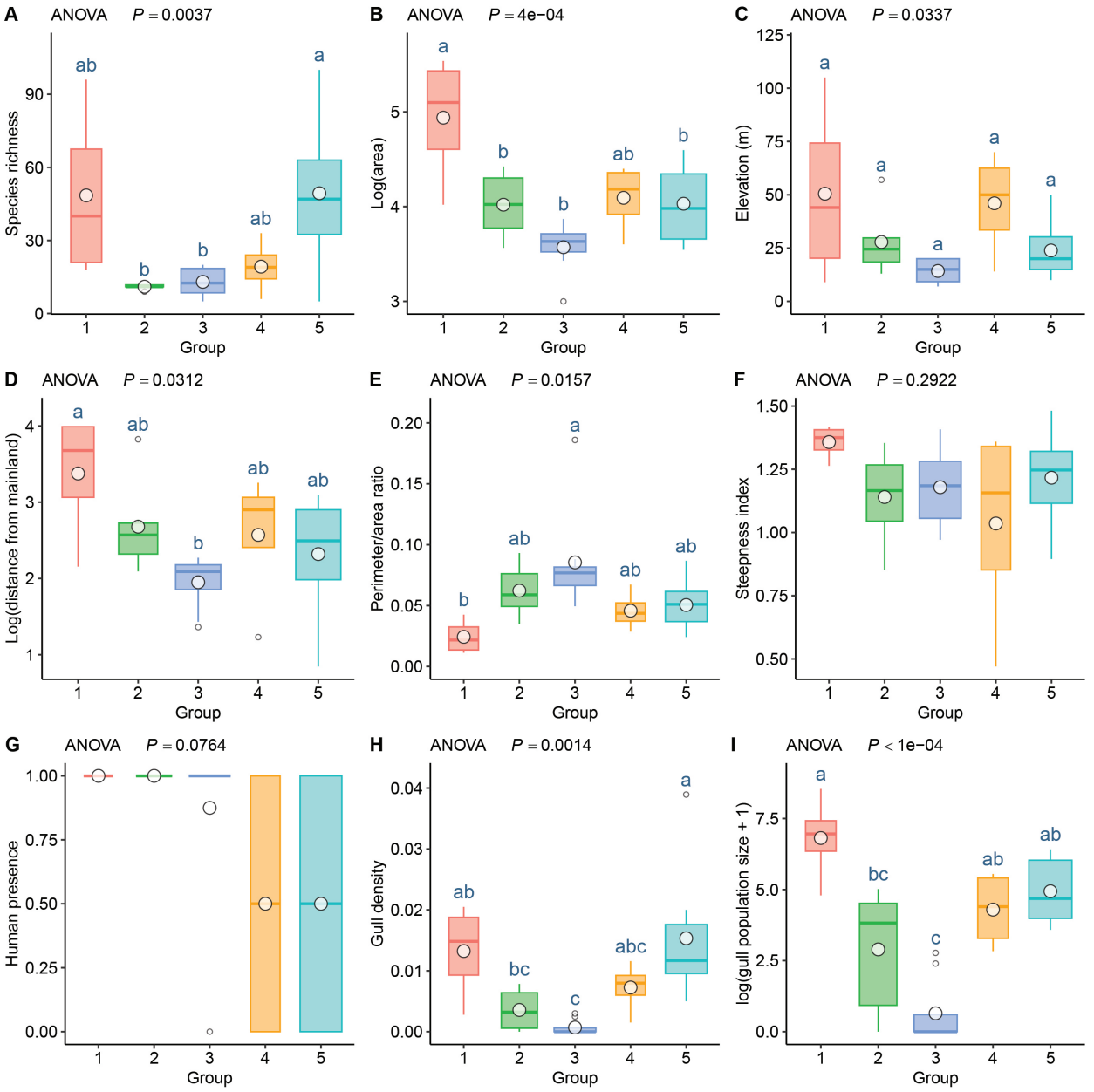

Figure 4. Main characteristics of the five groups of Algerian islands and islets derived from the floristic composition. **A**. Species richness. **B**. Log_{10}-transformed area (m). **C**. Elevation (m a.s.l.). **D**. Perimeter/area ratio. **E**. Steepness index. **F**. Log_{10}-transformed isolation (distance in m from the mainland). **G**. Gull density. **H**. Gull population size. Mean values are added as white circles on the boxplots. Differences between group means were tested by ANOVA (p value) and Tukey post-hoc tests: different letters indicate significant differences, in decreasing order.

7H, I). It is characterised by a low species richness (mean = 8, Fig. 7A) and a higher proportion of chamaephytic, barochorous, and Mediterranean species.

Group 2 contains fourteen islands and islets. The main sites that best characterise this group are relatively small islands (Fig. 7B) with high proportions of entomogamous and phanerophytic species, a relatively low species richness (mean = 18, Fig. 7A), and a low gull density (Fig. 7H).

Group 3 includes eight large islands (Fig. 7B), which host the highest number of plant species (mean = 65, Fig. 7A), mainly composed of zoochorous and geophytic species, with the lowest proportion of Mediterranean species in the broad sense, the highest proportion of Eurasian-holarctic and introduced species, and a higher gull density (Fig. 7H, I).

The three groups differ markedly concerning the biotic variables (Fig. 7H, I), the islands in group 3 hosting the largest populations of gulls. No significant difference was shown between the three groups concerning elevation, isolation, perimeter/area ratio, steepness index, and human presence (Fig. 7C, D, E, F, G, respectively).

Drivers of floristic attributes

Taken alone, the density of gull colonies (dGull) and the island area were the variables that best explained the variation of the flora descriptor matrix (Table 3). After the stepwise selection of explanatory variables, a combination of four of them were retained in the parcimonious RDA model: gull density, area, latitude, and longitude. These variables explained together 26.6% of the variance of the flora descriptor matrix.

This RDA (Fig. 8) reveals that the segregation of the sites along the first canonical axis is influenced by the density of the gull population (dGull) and the area of the islands or islets. This main gradient isolates group 3 (large islands enriched with Eurasian and introduced species and with a high density of gulls) from groups 1 and 2 (smaller islands with a higher proportion of Mediterranean species).

On the other hand, the separation of sites along the second canonical axis is driven by their geographical location (longitude and latitude), irrespective to the main gradient separating the three groups. Interestingly, endemic, entomogamous, and autochorous or hydrochorous species occur mainly in the western and northern part of the study area (lower longitude East, higher latitude North), particularly in four islands (Sbiaat, Mokreum, Petite Habibas, and Île aux Rats).

DISCUSSION

Physiography of the Algerian islands

The classification of the 30 Algerian islands and islets through the PCA highlighted the importance of physiographic variables: in western Algeria, islands are represented by the Habibas, Rachgoun, Mokreum, and Sbiaat islands, and are characterised by fairly large surfaces

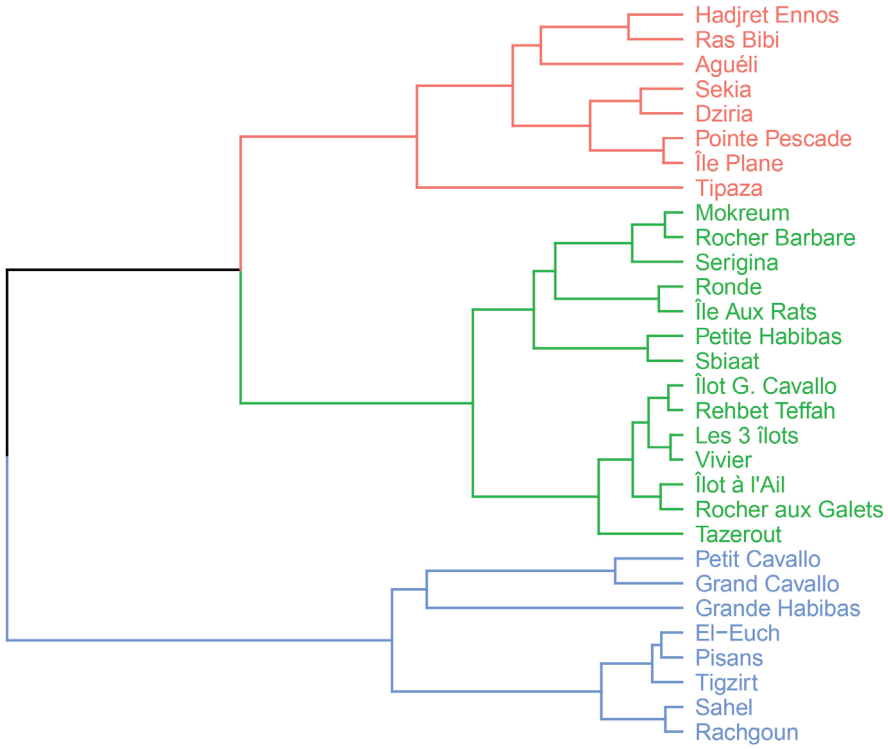

Figure 5. Dendrogram of the 30 islands and islets of Algeria classified according to flora descriptors.

and marked isolation compared to the other islands and islets, a specificity associated with a biogeographical pattern characteristic of the Oranese sector, the Baetic-Rifan arc, and the Iberian-Mauritanian ensemble (Véla et al. 2013). In contrast, the majority of the islets or rocks located on the Central and Eastern coasts of Algeria are very close to the continent and they are characterized by a biogeography influenced by the Kabyle sector, the Algerian-Constantinian Tell, and the Tyrrhenian microplate complex. The same phenomenon occurs in the far east, according to a preliminary analysis of recent data by Hamel et al. (2023).

The morphology and the elevation of the studied islands are not very important factors for the islands' classification; the majority of them are characterised by a more or less flat shape and low elevations. As a result, the physiognomy of the Algerian islands is quite peculiar compared to the small islands of Sardinia, for which Fois et al. (2016) demonstrated the importance of the elevation and the SI factor, which strongly contributed to the floristic structuration of these small islands. Indeed, Fois et al. (2016) refer to islands with much larger dimensions and elevations above 500 m a.s.l. The Algerian coast is characterised by a scarcity of islands and islets, compared to the other Mediterranean countries (Médail 2022), and in addition to their rarity, the few existing insular entities are in great majority very small islets of less than one hectare. In fact, when considering the physiographic

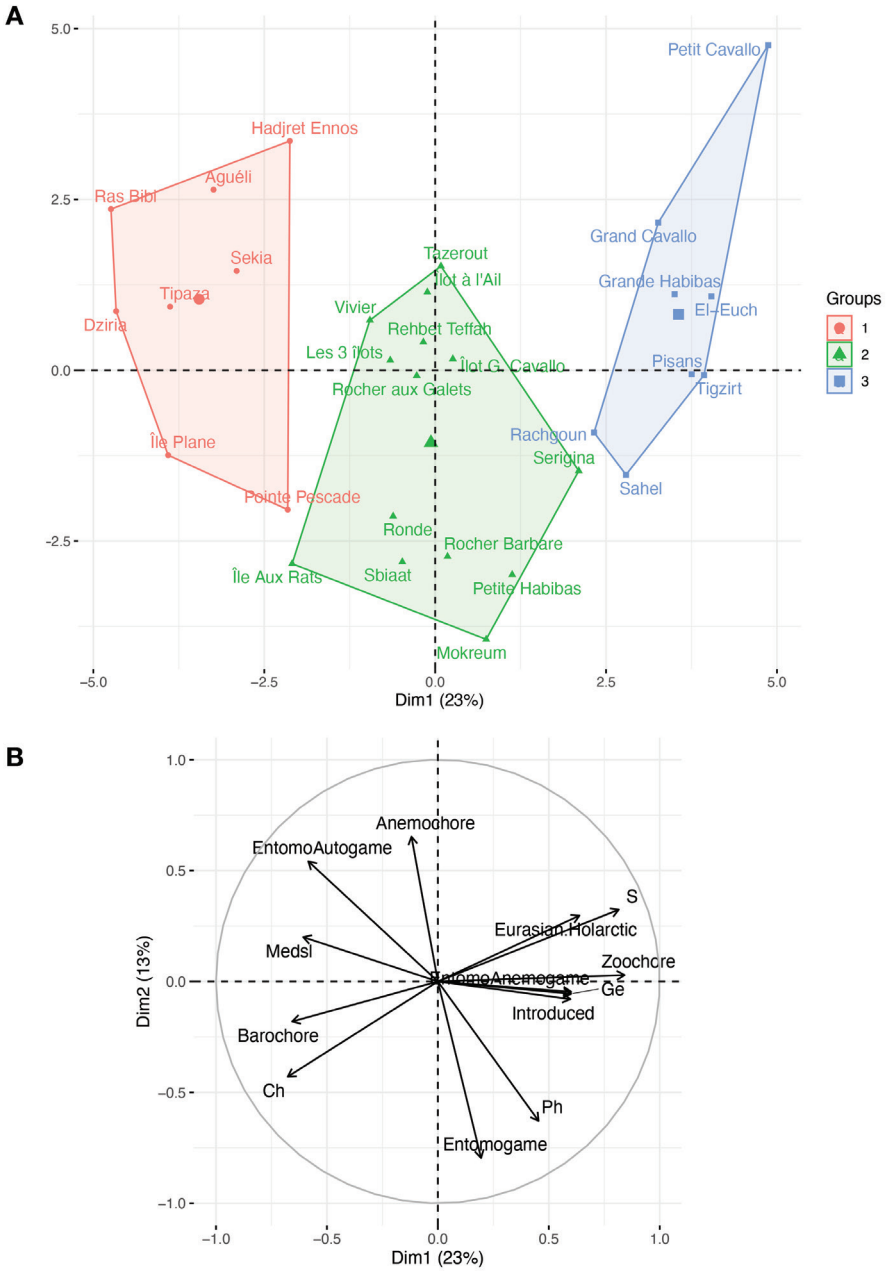

Figure 6. PCA ordination of the 30 islands and islets of Algeria (**A**) according to flora descriptors (**B**). Only variables that contribute most to the first two PCA axes are drawn.

variables and beside a longitudinal gradient, surface area and isolation (distance from the mainland) resulted to be the two most important determinants of the floristic composition of the Algerian islands.

Biogeographical and conservation interest

As already pointed out by Benhamiche-Hanifi and Moulaï (2012), the flora of Mediterranean origin is dominant on the islands of Jijel and Bejaia, and this pattern was observed on all the studied islands, where the flora is largely dominated by the Mediterranean species (Supplementary material 2). The same characteristics were observed by Hamel et al. (2023) for the islands at the extreme east of the country. However, there is a west-east difference, with the Oranese islands being influenced by the western Mediterranean sub-domain, including the Ibero-Maghrebian complex, whereas the Kabyle and Numidian islands are influenced by the central Mediterranean sub-domain, including the Tyrrhenian complex (Véla and Pavon 2013; Hamel et al. 2023).

In the case of the Algerian and Tunisian islands, Véla and Pavon (2013) showed that a larger surface area does not necessarily mean higher richness, nor does reduced

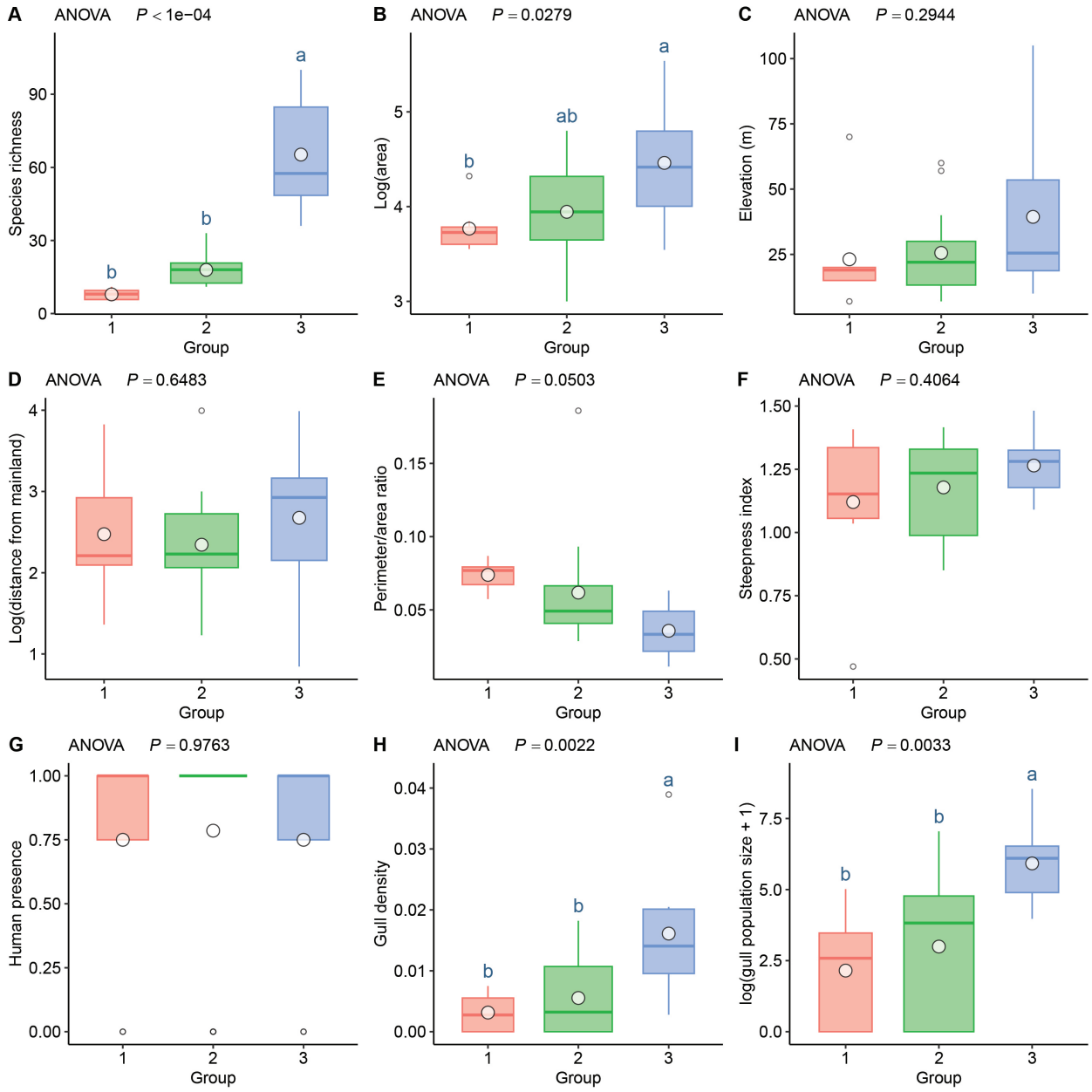

Figure 7. Main characteristics of the three groups of Algerian islands and islets derived from the flora descriptors. **A**. Species richness. **B**. Log_{10}-transformed area (m). **C**. Elevation (m a.s.l.). **D**. Perimeter/area ratio. **E**. Steepness index. **F**. Log_{10}-transformed isolation (distance in m from the mainland). **G**. Gull density. **H**. Gull population size. Mean values are added as white circles on the boxplots. Differences between group means were tested by ANOVA (p value) and Tukey post-hoc tests: different letters indicate significant differences, in decreasing order.

richness mean lower conservation interest, as in the case for Rachgoun Island (large but poor although of high conservation interest), and for the Islets of Garlic and Sahel (small but of high conservation interest). This dissymmetry between surface area, richness, and conservation interest is also confirmed at the extreme east of the country by Hamel et al. (2023). Due to their small surface area, the Algerian islands are not considered as regional hotspots; this is mainly due to the fact that the small surface area is insufficient to allow in situ speciation (Lomolino and Weiser 2001), and consequently these sites are very poor in exclusive endemics (Triantis et al. 2008). The Oranese islands belong to the regional hotspot of the Baetic-Rifan Arc and the islands of the coast east of Algiers belong to the regional hotspot Kabylie-Numidie-Kroumirie (Véla and Benhouhou 2007). Nevertheless, for the Habibas archipelago, plant endemics are shared with at least one site on the mainland (Africa and/or Europe) or with other archipelagos in the Alboran Sea or the Algerian-Provençal basin (Véla et al. 2013). Furthermore, a relatively small area sometimes harbours a relatively high level of species richness, such as the archipelago of El Aouana on the Jijel west coast, classified as an Important Plant Area (Véla and Pavon 2013). Finally, the random sharing of a number of endemic and/or threatened species in common with the nearby mainland makes these islands and archipelagos to belong to a mainland IPA: Rachgoun to the Trara Mounts IPA, Sekia and Dziria to the Cap Ténès IPA, Islet à l'Ail and Islet Sahel to the Gouraya National Park IPA, Islet and Islet Grand Cavallo and Petit Cavallo to the El Aouana coastal IPA (Benhouhou et al. 2018), Pain de Sucre, Fontaine Romaine, Gargamiz, Kef Amor, Akacha and Toughnechet in the Edough Peninsula IPA, Boutribicha, Callisar and Hennaya (Lehnaya) in the El Kala-1 IPA (Hamel et al. 2023).

At this stage, the island of Serigina, which also hosts some endemic plants (Véla 2008), is not part of an existing IPA on the continent. However, the process of identifying

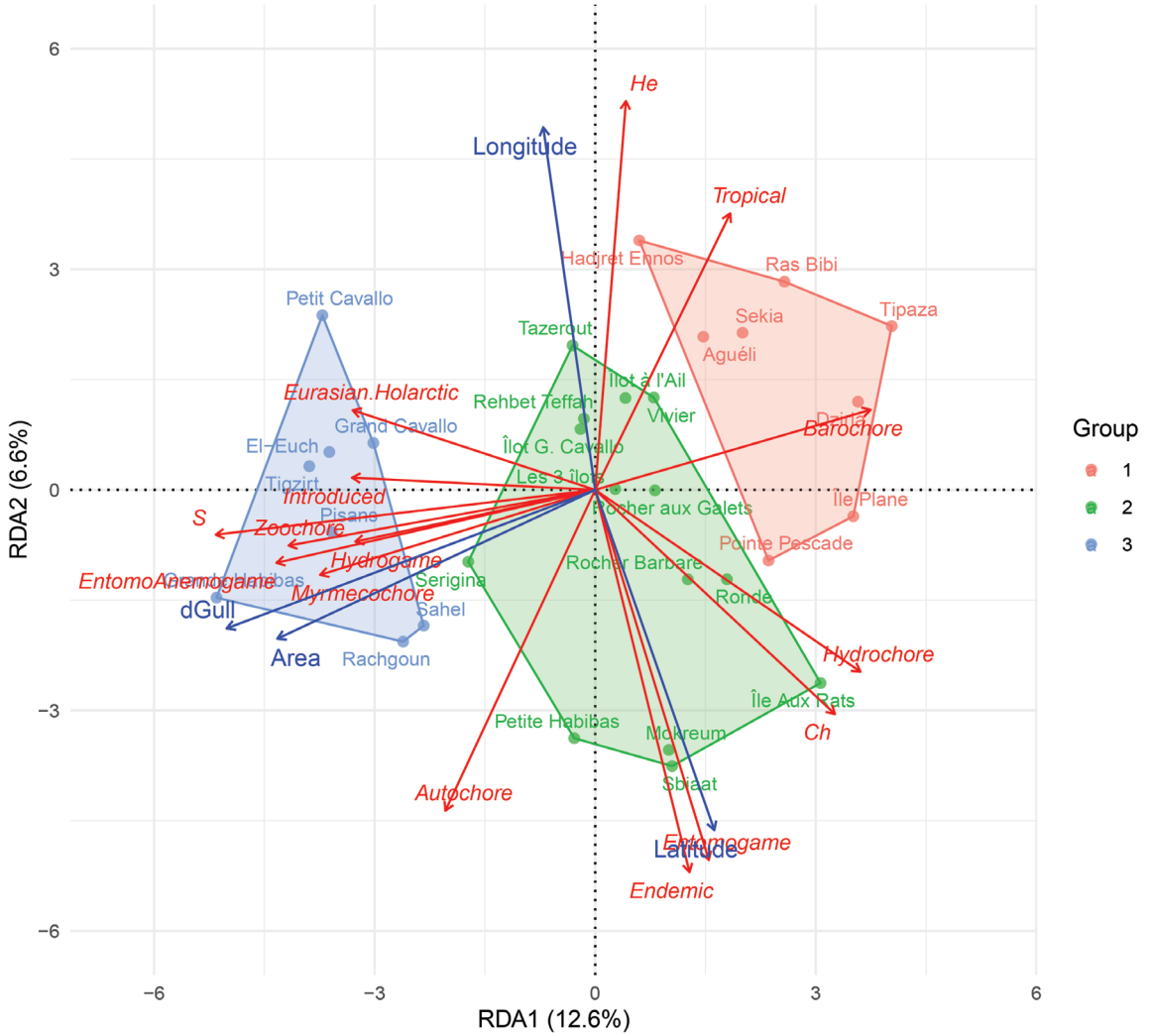

Figure 8. RDA triplot of the parsimonious model that explain flora descriptors (red arrows) by four quantitative variables (blue arrows). Only flora descriptors that contribute most to the first two RDA axes are drawn. Colours and convex hulls identify the three groups of sites defined by the HCPC of flora descriptors.

Table 4. Vascular plant species with a patrimonial interest, occurring on the small islands and islets of Algeria. Law 2012: Executive decree nº. 12-03 of 10 Safar 1433 corresponding to January 4, 2012 establishing the list of protected non-cultivated plant species (JORA 2012). Biogeographic divisions are explained in Fig. 1. C: Common ; AC: fairly common; R: Rare ; RR: Very rare ; LC: Least Concern; V: Vulnerable.

Family	Plant species	Biogeography	Law 2012	Quézel and Santa (1962, 1963) or Maire (1952–1987) [or more recent bibliography]	IUCN Red List 1997/2022
Amaryllidaceae	*Allium commutatum* Guss.	Mediterranean	–	[RR]	–/LC
	Allium multiflorum Desf.	Endemic Morroco-Algeria	–	[AC]	–/LC
	Pancratium foetidum Pomel s.s.	Endemic Morroco-Algeria	–	AR: K2, O1-3	–/LC
Apiaceae	*Ferula tingitana* L.	SW-Mediterranean?	–	R: O1	–/–
Aspleniaceae	*Asplenium marinum* L.	Mediterranean-Atlantic	–	RR: K3 (El Kala) [+ O1 (Habibas)]	–/–
Asteraceae	*Anthemis chrysantha* J.Gay subsp. *chrysantha*	Alboran Sea endemic [subsp.: endemic NW-Algeria]	+	C: O1	–/–
	Sonchus tenerrimus subsp. *amicus* (Faure, Maire & Wilczek) Véla	Endemic NW-Algeria	–	[RR: O1: Habibas islands]	–/–
	Galactites mutabilis Durieu	Endemic Algeria-Tunisia	–	AR: A2, K1-2-3	–/–
Brassicaceae	*Brassica spinescens* Pomel	Endemic NW-Algeria (Habibas islands + Cap Falcon)	+	RR: O1	V/–
Caryophyllaceae	*Arenaria cerastioides* Poir. [var. *oranensis* Batt.]	SW-Mediterranean [var.: endemic NW-Algeria?]	–	C on the Oranese coastline	–/–
	Spergularia pycnorrhiza Foucaud ex Batt.	Endemic NW-Algeria	+	RR: O1: Habibas islands, Aïn Franin	R/–
Crassulaceae	*Sedum multiceps* Coss. & Durieu	Endemic NE-Algeria	+	R: K2, C2 around Constantine	–/–
	Sedum pubescens Vahl	Endemic Algeria-Tunisia	–	AC: K1-2-3, C1, A1-2	–/–
Fabaceae	*Genista numidica* Spach subsp. *numidica*	Endemic NE-Algeria	–	C: K2-3	–/–
Malvaceae	*Malva arborea* (L.) Webb & Berthel.	Mediterranean-Atlantic	–	[R: O1, A1, K1-2-3]	–/–
Papaveraceae	*Fumaria munbyi* Boiss. & Reut.	SW-Mediterranean	+	R: Coastline from Mostaganem to Ghazaouet	–/–
Plumbaginaceae	*Limonium cyrtostachyum* (Girard) Brullo	Endemic Algeria	–	C: O1, R: A2 (Cap Ténès)	–/–
	Limonium letourneuxii (Coss. ex Batt.) Greuter & Burdet	Endemic Algeria	+	R: A1 (Cap Ténès)	R/–
	Limonium gougetianum (Girard) Kuntze	Endemic Algeria-Tunisia	–	C: A1, K1-2; R: O1 (Dahra)	–/–
Poaceae	*Cynosurus polybracteatus* Poir.	Endemic Algeria-Tunisia	–	C in the Algerian-Constantinian Tell, R in Oran	–/–
	Rostraria balansae (Coss. & Durieu) Holub	Endemic Morroco-Algeria	+	O1: common in the east and west of Oran	–/–

IPAs is still incomplete, as the coastline between Skikda, Stora, and Oued Bibi hosts several endemic and/or threatened species, including *Lotus drepanocarpus* Durieu and especially *Anthemis maritima* subsp. *bolosii* Benedí & Molero (Véla 2008; Sakhraoui et al. 2020; present work), which by themselves justify classification as an IPA (Yahi et al. 2012). Therefore, we propose to denominate this new IPA "Corniche de Stora", which joins the forty or so IPAs already identified in Algeria (Benhouhou et al. 2018; Mostari et al. 2020). This is also the case for Sbiaat Island, where endemic and rare species presumed to be threatened as *Anthemis chrysantha* J.Gay subsp. *chrysantha* and *Sonchus tenerrimus* subsp. *amicus* (Faure, Maire & Wilczek) Véla (present work) have been recorded, justifying its classification as an IPA according to the criteria of Yahi et al. (2012) (Table 4). It is worth mentioning that this island belongs to a larger natural complex located on the mainland from Cape Figalo to

Cape Lindlès. Here, again, it seems important to name a new IPA "from Cap Figalo to Cap Lindlès", which extends westwards the IPA "the Oran hills" with a much more pronounced relief (Yahi et al. 2012; Benhouhou et al. 2018).

Diversity and ecological processes

The floristic factor analysis revealed that the most influential floristic attributes in the separation of the studied Algerian islands are total richness and the proportion of zoochorous species.

In accordance with the classic area-species model (Whittaker and Fernández-Palacios 2007), the total floristic richness is strongly correlated with the island area ($r = 0.581$, $p < 0.001$). This relationship was also highlighted, for example, by Médail and Vidal (1998), who stipulated that in the western Mediterranean, the surface area of island groups is the main variable involved in the organisation of the richness and composition of the vegetation on these islands, while its relationship with the distance from the coast (site isolation) is less obvious. Benhamiche-Hanifi and Moulaï (2012) highlighted also this relationship for Jijel and Bejaia islands, which is confirmed for the rest of the Algerian coastal islands through our results, which also reveal a negative correlation between the log-transformed island area and the PAR ($r = 0.800$, $p < 0.001$).

Regarding the dispersal syndromes of these island floras, the zoochorous and anemochorous syndromes have significant influence in the classification of the islands. The dominance of zoochorous taxa can be explained by the presence of seabirds, in particular colonies of yellow-legged gulls which spread seeds, either actively by eating seeds or fruits (endozoochory), or passively by plumage (epizoochory) (Calvino-Cancela 2011). According to Vidal et al. (1998), these birds could induce a functional link between some small island systems of continental origin close to feeding sites located on the mainland. Their location close to the shoreline has also favoured the settlement and presence of anemochorous taxa on islands which are exposed to onshore winds. The hydrochorous species are nearly present on all investigated islands, unlike the myrmecochorous and autochorous species. Almost all plant species recorded in our study are characterised by entomogamous or anemogamous pollination; favoured by the sea winds as well as the short distances or the weak isolation of almost all our island sites.

Threats and conservation issues

The RDA showed that the density of yellow-legged gulls, which is positively correlated with the island area, considerably affects the characteristics of the flora in the islands and islets.

For island flora conservation planning, some of these small islands can be considered "modern refuges" of terrestrial biodiversity from human pressures (Médail 2017, 2022); particularly in the context of Mediterranean ecosystems characterized by a quasi-permanent presence of humans in the various habitats, and notably along the coasts. But these islands themselves are increasingly attracting more curious tourists, and this in proportion to the phenomenon of recent development of seashore tourism (Véla and Pavon 2013; Boutarcha 2019).

The environmental features of these Algerian islands (small area and low slope) make them particularly susceptible to species extinction processes due to sea level rise and genetic drift. Some current estimates, stipulate that a global rise in sea level will need to reach at least 1 m by 2100, and de facto large parts of low-lying island ecosystems are at high risk of being submerged, leading to significant habitat loss (Bellard et al. 2014; Harradine et al. 2015).

CONCLUSION

The analysis of the Algerian island flora has brought to light a rather important floristic richness, consisting of 295 species and subspecies including several species of high biogeographical and conservation value. By explaining composition, ecological and biogeographical attributes of the flora by physiographic and biotic factors, we can identify the most reliable factors for the conservation planning of the island flora, especially since these small islands can be considered as "modern refuges" with regards to increasing human pressures.

This study also constitutes the first botanical synthesis undertaken on the majority of the islands and islets of the Algerian coast. This synthesis will certainly allow to get a global vision on the diversity and the status of the Algerian island plants, and we hope that this will allow to elaborate efficient strategies of conservation of these small fragile islands in order to preserve this unique biotic heritage.

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SUPPLEMENTARY MATERIALS

Supplementary material 1
List of species and their ecological attributes (chorology, life form, dispersal syndrome, pollination syndrome, and patrimonial status) inventoried at the 30 studied sites.
https://doi.org/10.5091/plecevo.117464.suppl1

Supplementary material 2
Richness and composition of each site, taking into account the different floristic attributes, as well as the number and density of seagulls.
https://doi.org/10.5091/plecevo.117464.suppl2

Supplementary material 3
Physiographic characteristics of each island and islet studied: latitude, longitude elevation, area, isolation, SI (steepness index) and PAR (perimeter/area ratio).
https://doi.org/10.5091/plecevo.117464.suppl3