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Global and regional conservation status of vascular wetland plants in Mediterranean islands: a collaborative network to improve knowledge and awareness

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ABSTRACT

Mediterranean wetlands are highly sensitive ecosystems, particularly vulnerable to human pressure and shifts in precipitation and temperature regimes. Wetland plants can be particularly threatened in Mediterranean insular

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contexts, where such habitats are naturally smaller and more fragmented than in their continental counterparts. This study investigated 275 species of vascular wetland plants that were considered to be at least regionally threatened across 2217 islands and islets in the Mediterranean. We provided both global and local IUCN conservation assessments (summarized in a ‘conservation concern’ index) and ‘assessment completion’ (i.e. knowledge level) for each taxon as well as a geographic distribution among islands, wetland types, and life forms. Most of wetland plants were threatened at the regional level, although assessment completion was generally low, except for endemics. Inland and endemic wetland plants were more threatened than the rest. A phylogenetic signal was detected, highlighting that Orchidaceae and Apiaceae were of particularly high conservation concern, while other families, especially Amaranthaceae, exhibited low levels of assessment completion. No geographical patterns were found in terms of conservation concern and assessment completion. Our findings provide critical insights into biodiversity patterns, identify conservation gaps and priorities and contribute to the development of targeted strategies for the protection of wetland plants, which are crucial indicators of the entire natural capital of Mediterranean island ecosystems.

1. Introduction

The Mediterranean Basin is one of the world’s most biodiverse regions, home to a wide variety of fauna and flora (Médail and Quézel, 1997; Cuttelod et al., 2009). In particular, islands represent important areas of the Mediterranean Basin, often acting as putative refuges of high conservation priority for long-term species persistence and genetic diversity (Médail and Diadema, 2009; Médail, 2017). In this context, plants are among the most representative species groups, with higher percentages of endemic and threatened species than their continental counterparts (Médail, 2017). Threats to plants on Mediterranean islands are exacerbated in marginal and small-scale ecosystems, such as mountain tops, islets, and wetlands (Médail, 2017; Haase et al., 2023). In particular, the fragmentation of wetland ecosystems is generally higher on islands than in continental areas, being more fragile and often overlooked in conservation efforts (Médail, 2017). Moreover, due to the scarcity of freshwater for geographical and climatic reasons, wetlands on islands, even on the smallest ones, have been over-impacted (Médail and Pasta, 2024) and – especially if they are seasonally inundated and/or at low elevations – climate change may further negatively affect their biota, leading to a further loss of plant diversity (Bagella and Podani, 2017; Lefebvre et al., 2019; Saatkamp et al., 2023).

In this framework, improving the knowledge of island wetland plants is a crucial aim but one that is far from being satisfactorily achieved. For example, the taxonomy of certain genera, such as *Isoetes* L., *Elatine* L. and *Ranunculus* L. section *Batrachium* DC. remains partially unresolved, and recent advances have yet to offer a complete understanding of their diversity, distribution and conservation status (Wiegleb et al., 2017; Brunton and Troia, 2018; Brullo et al., 2022). Inter- and intraspecific interactions are also poorly understood, although they are believed to be intense due to the high complexity and biodiversity concentrated in wetlands (Manzano et al., 2019; Fois et al., 2021). For these reasons, several policy and management shortcomings negatively affect their conservation and restoration. Indeed, even though many freshwater habitats and species are legally recognized and protected at different levels, several authors have highlighted the need to improve policies and practical efforts for their conservation (e.g. Maasri et al., 2021; Bagella, 2023; Spiliopoulou et al., 2023).

The IUCN Red List of Threatened Species is a central tool for biodiversity conservation, guiding policy implementation and biodiversity monitoring at global and regional scales (Rodrigues et al., 2006; Moreno et al., 2015; Bachman et al., 2019). The first assessments were produced in the 1970s, based on subjective expert opinion (Maes et al., 2015). In the 1990s, a standardized set of quantitative criteria was defined for assessing species conservation status and threats and subsequently have been widely used to implement ‘Red Lists’ at the global, national and regional administrative levels (Gärdenfors et al., 2008; Maes et al., 2015). According to such criteria, a species can be assessed as Extinct (Ex), Extinct in the wild (Ew), Regionally Extinct (RE) or threatened at different levels: Critically endangered - Possibly Extinct, CR(PE), Critically endangered (CR), Endangered (EN) or Vulnerable (VU) (IUCN, 2024). Unfortunately, decades of insufficient funding have dramatically limited risk assessment and reassessment rates (Cazalis et al., 2023). For instance, only about 7 % of plant species are currently included on the IUCN Red List and, among them, around 14 % were listed as Data Deficient (DD) (Bachman et al., 2019; Cazalis et al., 2023). Some efforts have been made in the Mediterranean Basin to improve the limited knowledge available. For example, the IUCN SSC Mediterranean Plant Specialist Group has supported reports (e.g., Pasta et al., 2017) and conservation projects (e.g. Fenu et al., 2017), and the IUCN SSC Freshwater Plant Specialist Group has produced a baseline for a Red List Index of Mediterranean wetland-dependent plants, in collaboration with the Mediterranean Wetland Observatory. Comprehensive contributions for islands covered the ‘Top 50’ most threatened plants (Pasta et al., 2017), while for wetlands, the IUCN prepared assessments for species from the eastern Mediterranean (Smith et al., 2014) and northern Africa (García et al., 2010). Furthermore, some Mediterranean countries have published relatively recent Red Lists at the national level (e.g. Orsenigo et al., 2021; Natural Environment and Climate Change Agency (NECCA), 2024) or even at the regional administrative level (e.g. Delage and Hugot, 2015; Sáez et al., 2017). Considering that around 60 % of Mediterranean plants are either endemic to the region or restricted to narrower areas (Médail, 2017), such local assessments often also provide information at the global level. For the remaining regional assessments, which are generally conducted at the national level, a lack of homogeneity in the assessment was found due to differences in effort, timing and application of IUCN regional criteria. This has led to recommendations for increased communication and information exchange between countries, regions and between regional and global assessors (Miller et al., 2007; Glasnović et al., 2024).

In this article, we compiled all the available information on wetland vascular plants found on at least one of the 2217 islands and islets in the Mediterranean (Santi et al., 2024). As previously mentioned, we assumed that the conservation status of many of these species is either poorly understood or threatened, at least at a regional scale. Accordingly, we provide and discuss an updated checklist of vascular wetland plant species of conservation concern, including those that are extinct, threatened, data deficient or not evaluated at global and regional levels. We review these in terms of conservation concern and assessment completion, and evaluate differences among taxonomic groups, moisture values, life-forms, chorology, distribution across islands, and habitat preferences in terms of inland vs. coastal and temporary/seasonal vs. permanent wetlands. The information presented here is intended to serve as a reference for planning conservation actions and raising public awareness of plant diversity in Mediterranean island wetlands.

2. Material and methods

2.1. Study area

The preliminary study area includes all the 2217 islands and islets with a surface area > 1 ha – excluding estuarine islands – in the Mediterranean Basin, here defined as the Sea Basin bounded by Gibraltar and the Bosphorus Strait (Santi et al., 2024). This biogeographical region includes islands with a wide range of sizes (from the largest island of Sicily with 25,456 km^2 to small islets of a few tens of square metres) and elevation (from Mt. Etna, 3403 m a.s.l. to almost flat islets) (Médail, 2022). Most of the islands are located in the Ionian and Aegean Seas (mainly the Greek islands) and in the Adriatic Sea (mainly the Croatian islands). In contrast, the majority of the largest islands are located in the western-central Mediterranean, with the Italian islands of Sicily and Sardinia (23,799 km^2), followed by Cyprus (9262 km^2), Corsica (8726 km^2) and Crete (8336 km^2). Due to their high number and complexity, the islands were grouped from west to east as follows: (i) Baleares, (ii) Southern France (henceforth, S France), (iii) Corsica (including its surrounding islands), (iv) Ligurian and Tuscan Archipelago (henceforth, Liguria and Tuscany), (v) Sardinia (including its surrounding islands), (vi) Tyrrhenian S. Italy, (vii) Tunisian islands (henceforth, Tunisia), (viii) Maltese islands (henceforth, Malta), (ix) Sicily (including its surrounding islands), (x) Croatia, (xi) Adriatic S. Italy, (xii) Ionian Greece, (xiii) Aegean Greece, (xiv) Crete and Karpathos, (xv) Turkish islands (henceforth, Turkey), and (xvi) Cyprus. Other minor island territories, such as the Columbretes Archipelago, and the islands of Israel/Palestine, Morocco, Algeria, Libya, Egypt, Lebanon, Slovenia, Albania and Montenegro were excluded after confirming, with the advice of local experts (see Acknowledgements for details), that these islands do not host any wetland plants of conservation concern. The island grouping considered both biogeographical (e.g., the presence of endemics in that given territory) and political (e.g., administrative boundaries) reasons.

2.2. Selection of species and data collection

We considered all plants (at the species taxonomic level) living exclusively in permanent and temporary wetlands, at least on the Mediterranean islands. To do so, we first retained all wetland plant species native to at least one Mediterranean island that were listed with Ellenberg-type moisture indicator values ≥8 reported in the European vascular flora (Tichý et al., 2023). According to the definitions reported by Ellenberg and Leuschner (2010), our list includes all aquatic plants (Ellenberg moisture values ≥9) but also 'amphibious' plants (Ellenberg moisture values =8), which live in conditions between well-moistened and often soaked soils. Further species that are considered to be adapted to drier conditions, but which are known as typical for the target area or exclusive to wetlands, have been included alongside such aquatic and amphibious plants. The rationales underpinning these inclusions are elucidated in the annotations provided in the supplementary material (see Appendix A). The list was then subjected to further analysis based on expert revision, the literature – including the recent description of new taxa (e.g., Brullo et al., 2023; Jopek et al., 2023) and its taxonomy standardized according to the Euro+Med PlantBase (http://europlusmed.org). In this regard, only few exceptions were accepted, as in the case of *Elatine campylosperma* Seub., which is generally reduced to the synonymy of *Elatine macropoda* Guss. (Uotila, 2009) but reconfirmed by recent morphological, phylogenetic and karyological studies (Sramkó et al., 2016; Takács et al., 2018). For all these species, we reviewed available information on the conservation status at global, European and Mediterranean levels on the IUCN website (https://www.iucnredlist.org/) and we retained all those listed as Ex, Ew, CR(PE), CR, EN, VU and DD. In addition, we included wetland plants reported in red lists at national and regional administrative levels as RE or as the same categories mentioned above (Lončarević et al., 2024; and others in Appendix B: S1). In the case of obsolete or missing national red lists, regional assessments according to the IUCN guidelines for plants of special interest have been produced for the first time in this work. The authors' final additions were made for those plants believed to be threatened but not yet assessed at any level. We reviewed all available regional and global assessment information by assigning each wetland plant to the following general categories: (i) globally threatened, if so assessed at the global level or in all clusters where it is exclusive to, (ii) regionally threatened, if not threatened globally but at least in one island cluster, and (iii) insufficiently known, if not evaluated in most of clusters or DD at global or lower levels. The main plant life-forms described by Stefanaki et al. (2015) (i.e., annual herb, perennial herb, geophyte, perennial woody) were critically reported after consulting several references works, mostly concerning the national vascular floras of Italy (Pignatti et al., 2005, 2017–2019) and Greece (Dimopoulos et al., 2024). From the same sources, a simplified chorology of each species was attributed as follows: (i) endemic, i.e. exclusive to only one island or archipelago, (ii) Mediterranean, and (iii) widespread for the rest. To verify the presence/absence within each of the island groups listed above, we first used the geographic range reported – when available – in the IUCN assessments (https://www.iucnredlist.org/). This information was integrated with data from national and regional literature sources (see Appendix B: S1), expert revision and field data. The habitat preference of each species was summarized by two parameters obtained by inspecting all available information and on expert knowledge: (i) location: i.e. if a plant is exclusive to coastal, inland or any environments and (ii) hydroperiod: if a plant is exclusive to temporary, permanent or any type of wetland hydroperiod. All of the above information, including that of experts, was used to assign each species a preferred ecological need for coastal or inland and temporary or permanent wetlands.

2.3. Factor analysis

To evaluate the level of vulnerability of each wetland plant, a 'conservation concern index' was calculated by assigning a decreasing value ranging from Ex/Ew (1) to alien (−0.2), and dividing this by the total number of island clusters in which each taxon is present (see Appendix B: S2 for details). High values of threat index were thus attributed to taxa assigned to high-risk categories in most island clusters, whereas lower values were attributed to species that are threatened in only a few clusters and generally listed as Least Concern (LC) or even considered alien. An 'assessment completion' of each taxon was measured by calculating the ratio between the number of regional assessments and the total number of island clusters in which each taxon is present. In this way, ratios equal or close to 1 indicate a high level of knowledge of the taxa, as opposed to values close to or equal to 0. The number of species, and the averages of conservation concern and assessment completion indexes were represented for every genus using a circular cladogram built using the R package U.Phylomaker (Jin and Qian, 2023).

We used the Random Forests (RF) machine learning algorithm (Breiman, 2001) to build predictive models and identify variables (i.e. family, life-form, simplified chorology, location, hydroperiod, moisture value) that are important predictors of level of conservation concern in Mediterranean islands wetland plants. RF uses independent variables to create many individual decision trees that act as an ensemble to predict a response. Each decision tree in the RF uses a subset of the independent variables and returns a response, and variable importance is determined based on the increase in model error when that variable is not included (Amador et al., 2024). RF regression models were created using the *randomForest* function in the randomForest R package (Liaw and Wiener, 2002), with 500 trees and 100 permutations. We made predictions on the training and test (unseen data values in the models) data sets that were evaluated with the mean squared error and R^2 metrics in the RF regression analysis and with the confusion matrix in RF classification analyses. Relative importance for each independent variable was measured and printed using the *importance* function in the randomForest package. The output from the *importance* function in RF model provides two metrics for each predictor variable: (i) percentage increase in Mean Squared Error (%IncMSE), where higher values suggest that the variable has a larger effect on model performance; Increase in Node Purity, where higher values indicate that the variable is more effective in splitting the data and creating homogeneous subgroups. The Kruskal-Wallis test was used to corroborate the statistical significance of conservation concern comparisons between variables and island clusters (used as categories). Pairwise comparisons between groups were performed with the Wilcoxon test with Bonferroni correction. We used adjusted *p* values (P_{adj}) to find possible significant differences among groups. This test was chosen because the assumption of normality required for parametric ANOVA was not met.

3. Results

We retained a list of 275 vascular plant species, belonging to 124 genera and 59 families. The full list with the respective attributes is available in Appendix A. The most represented families were Cyperaceae (48 species) and Ranunculaceae (22 species). *Carex* L. and *Ranunculus* were the richest genera, with 22 and 19 species, respectively; 18 families and 74 genera were represented by a single species. In terms of life-forms, the most abundant were perennial herbs (127 taxa), followed by annual herbs (75 taxa) and geophytes (57 taxa) (Fig. 1a). The most frequent species (featuring in 12 clusters each) were again two Cyperaceae (*Carex extensa* C.A.Mey. and *Eleocharis palustris* (L.) Roem. & Schult.) and one Caryophyllaceae (*Corrigiola litoralis* L.).

The distribution in simplified chorotypes showed that most of the threatened taxa in island wetlands were widespread (142 taxa) (Fig. 1b). Among widespread species, *Crypsis aculeata* (L.) Aiton, *Cyperus serotinus* Rottb., *Elatine hexandra* (Lapierre) DC., *Ipomoea sagittata* Poir. and *Phyla nodiflora* (L.) Greene were under a threat category in some clusters and cryptogenic or alien in others.

The distribution across habitat preferences (Fig. 1c) showed that most of the threatened plants live in temporary inland wetlands, but other wetland types were also represented, such as inland permanent wetlands or temporary coastal ones. These habitat preferences were not evenly distributed among life forms and distribution. In particular, the frequency of annual grasses was higher in temporary wetlands, showing no clear preference between coastal and inland contexts. In temporary inland wetlands, all life forms were well represented except woody perennials, which preferred coastal wetlands instead. Most of the plants found in permanent wetlands were widespread, while endemics were mainly found in temporary wetlands (Fig. 1).

Overall, 684 assessments at the island cluster level were reported, of which 106 were previously unpublished (Appendix A). Most of the taxa included in this checklist were threatened at a regional level (195 taxa), while 56 of them were threatened at a global level. Moreover, 24 taxa were classified as insufficiently known. The globally threatened taxa showed higher average values of assessment completion (0.89) and conservation concern (0.55) compared to the regionally threatened ones (assessment completion = 0.73; conservation concern = 0.33). Taxa classified as insufficiently known, without assessments in most of the clusters or DD at a global level, showed low average values of assessment completion (0.32) and low conservation concern (0.17).

3.1. Factor analysis

The most important variables for predicting conservation concern were distribution, family, and location, based on both %IncMSE and IncNodePurity. The moisture value and life-form were moderately important, while hydroperiod seemed to have minimal impact on the model's predictions (Appendix B: S3–4). Specifically, wetland plants living in inland wetlands had significant higher conservation concern than those living in coastal or in all environments; endemics had a significantly higher conservation concern than Mediterranean and widespread plants (Fig. 2). No significant differences were detected for the assessment completion, apart from family and distribution, with significantly higher values for endemics compared to the rest of categories (Appendix B: S5–6).

The high importance of the family as explicative factor confirmed a phylogenetic signal (Fig. 3). Within the class Lycopodiopsida, the genus *Isoetes* was well represented, counting by eight species. However, the conservation concern values concerning quillworts were not particularly high, as species like *Isoetes haussknechtii* Troia & Greuter or *I. todaroana* Troia & Raimondo were less regionally threatened in the investigated study area than globally. Among the rest of the seedless vascular plants (class Polypodiopsida), *Woodwardia radicans* (L.) Sm. and *Pilularia minuta* Durieu appeared to be the species with the highest conservation concern. Within the Liliopsida class, generally high conservation concern was detected for the well-represented family of Orchidaceae (five genera). Within the major branch of the class Magnoliopsida, besides scattered species such as *Trapa natans* L. and *Ludwigia palustris* (L.) Elliott of the order Myrtales, the high conservation concern of Apiaceae within the Asterids clade was noted. Regarding the assessment completion, a similar, though less evident pattern was observed compared to the conservation concern index. However, some patterns were found among the inconspicuous - and possibly cryptic - flowering plant families of the Amaranthaceae or other minor taxonomic groups (e.g., Ruppiaceae and Potamogetonaceae).

3.2. Geographic overview among island clusters

Among the 16 island clusters, the high variability in terms of the number of islands and total surface area was reflected in the number of

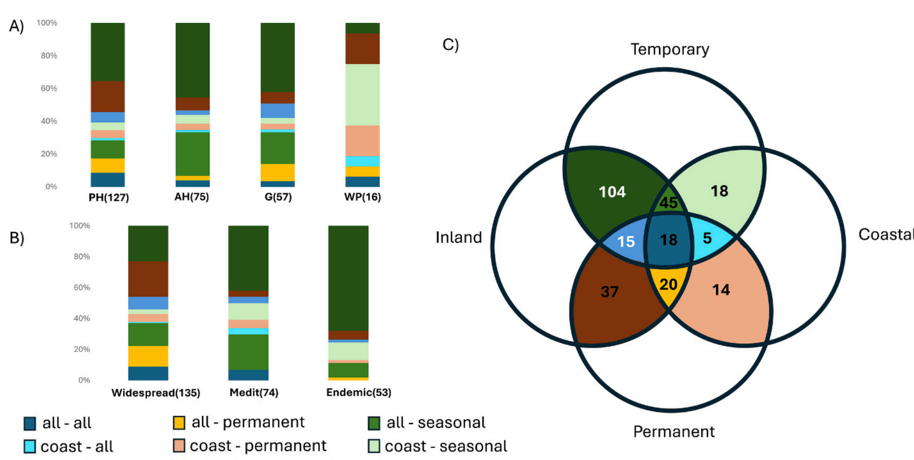

Fig. 1. Distribution of wetland species among (A) life forms, (B) simplified chorology and (C) habitat preferences. Colours in a-b refer to habitat preferences. Life-form abbreviations: Perennial Herb (PH), Annual Herb (AH), Geophyte (G), Woody Perennial (WP).

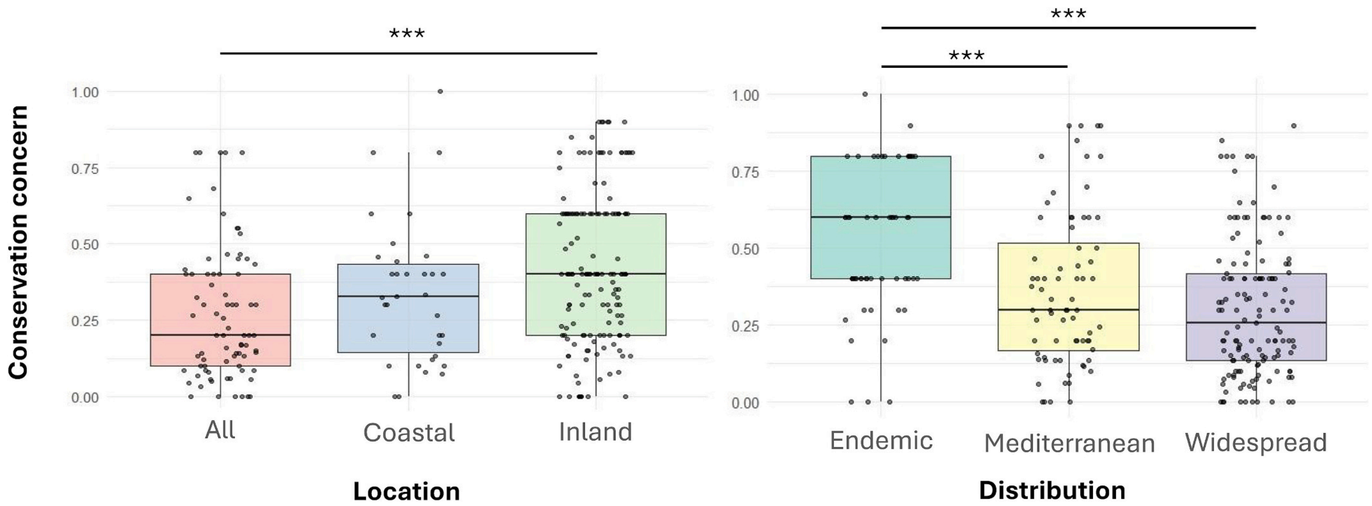

Fig. 2. Boxplots of plant species conservation concern indicating differences among locations (Coastal, Inland, All of them) and distribution (Endemic, Mediterranean, Widespread). The y-axes report values between 0 and 1 of the Conservation concern index (see methods for further details).

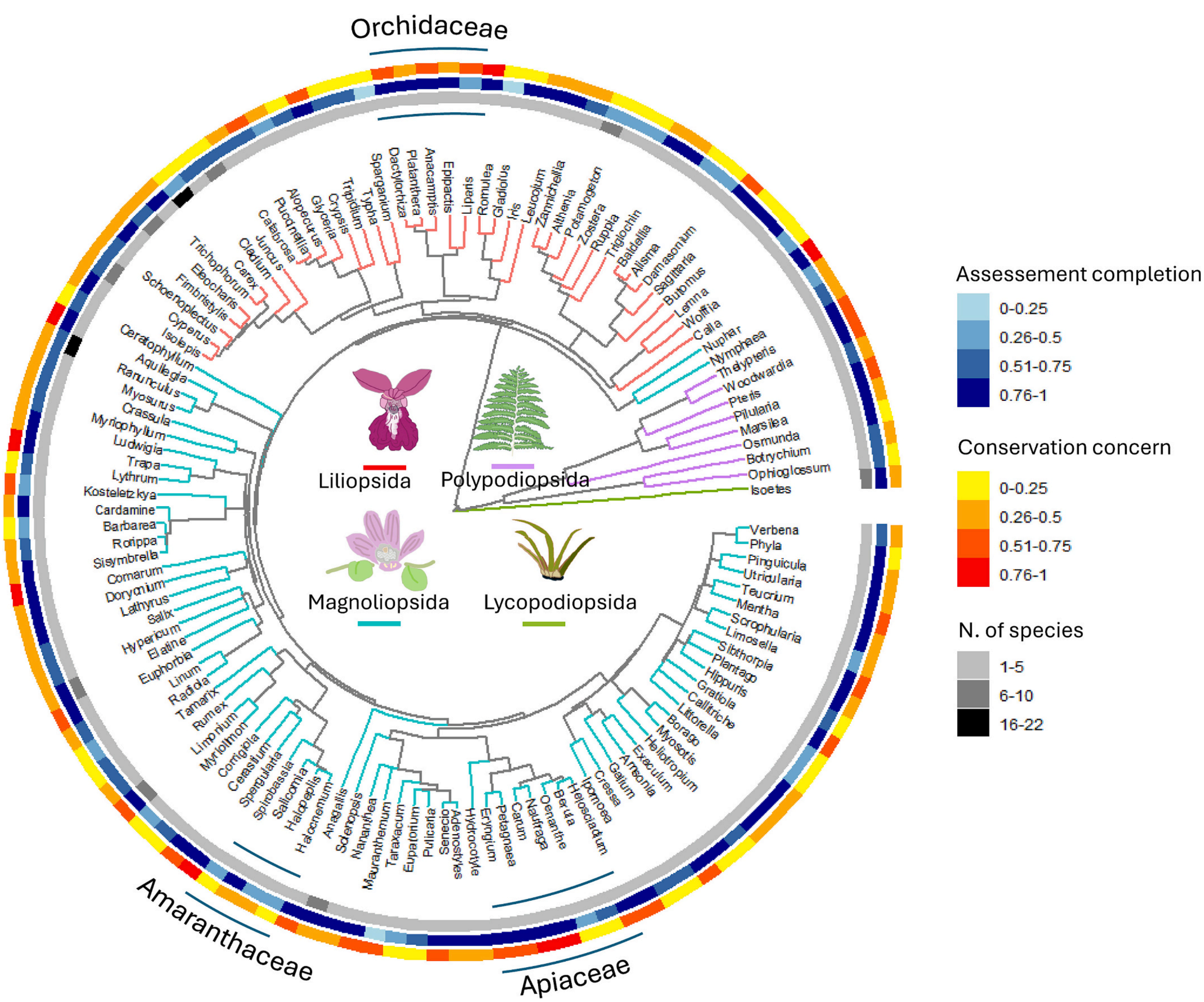

Fig. 3. Phylogenetic relationships of wetland plants and corresponding values concerning the number of species, the conservation concern and the assessment completion by genus. External lines highlight families for which a phylogenetic signal has been detected in terms of assessment completion and conservation concern.

species retained (see Appendix B: S7). Only two regionally endangered species (*Carex extensa* Gooden. and *Zostera marina* L.) were retained for the Italian cluster of the Adriatic Italian islands, while 151 and 154 species were retained for the two major clusters of Sardinia and Sicily, respectively (Fig. 4a). However, there were no significant differences ($P._{adj} > 0.05$) in conservation concern and assessment completion values between clusters when compared pairwise (Fig. 4b, c).

3.3. The top-most threatened wetland plants on Mediterranean islands

The most threatened wetland plants on Mediterranean islands (i.e. those showing higher conservation concern index values) were mostly Mediterranean plants, followed by two endemics and two widespread plant taxa. These included two endemic Ex/Ew taxa and other regionally RE or CR taxa that were not evaluated or not threatened at global level. The main habitat preference of such top-most threatened plants was mainly related to inland seasonal wetlands (Table 1).

4. Discussion

The present list comprises a very diverse assemblage of vascular plants, despite the prevalence of certain families, such as Cyperaceae and Ranunculaceae. These two families rank among the largest angiosperm families in the world, with approximately 6000 and 3700 accepted species, respectively (POWO, 2024). Both have been the subject of studies related to their cryptic taxonomy (Wiegleb et al., 2017; Miguez et al., 2021). The presence of some threatened species of Cyperaceae and Ranunculaceae may be related to their diversification patterns in the Mediterranean, which seems to have been historically promoted by global cooling periods but rendered them threatened during warmer phases, such as interglacial periods (Paun et al., 2005; Martín-Bravo et al., 2019). In terms of life forms, we did not find any surprising results. Perennial herbs, such as many species of *Carex* and *Ranunculus,* are the group with the largest number of species in European vegetation (Midolo et al., 2023) and are also well represented among the most common genera of wetland plants. Indeed, the

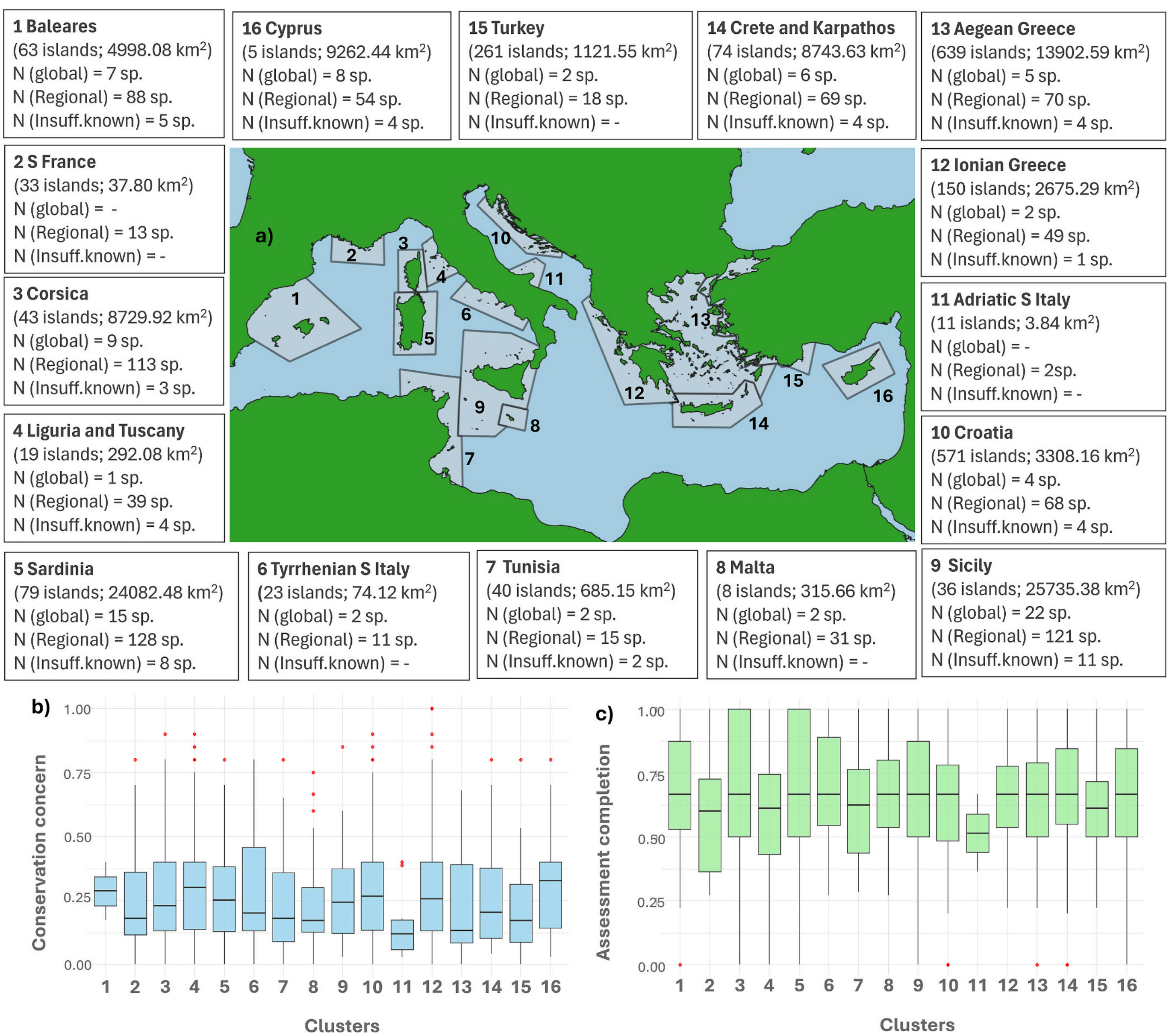

Fig. 4. (a) Distribution of the 16 island clusters with basic information concerning the number of islands, the total surface, the number of taxa with a risk category at the global or regional level and species insufficiently known. Boxplots of (b) Conservation concern and (c) Assessment completion among clusters (numbers are referred to those reported in the map).

Table 1
List of the eight most threatened species in the Mediterranean islands: their distribution is simplified as endemic (End), Mediterranean (Med) and widespread (Wides); location (Loc.) in inland (inl) or coastal (coast), hydroperiod in seasonal, permanent (perm) or all, and moisture values (M) refer to those revised for the Mediterranean. Acronyms referring to IUCN assessments at global and Mediterranean levels are according to guidelines (IUCN, 2024): Critically endangered (CR), Near Threatened (NT), Not Evaluated (NE), Least Concern (LC). See methods for the Conservation Concern index (CC).

Species	Distrib.	Loc.	Hydr.	M	IUCN global	IUCN Med	CC	Notes
Limonium intermedium (Guss.) Brullo	End	coast	seasonal	8	NE	NE	1	Endemic to Sicily, considered Extinct in the wild (Pasta, 2001a; Orsenigo et al., 2021; Domina et al., 2025).
Puccinellia gussonei Parl.	End	inl	seasonal	8	CR	CR	1	Endemic to Sicily, considered Extinct in the wild (Brullo and Siracusa, 2000; Pasta, 2001b; Di Gristina et al., 2022). Some authors consider it a synonym of *P. festuciformis* (Host) Parl. subsp. *lagascana* M.A.Juliá & J.M.Monts. (Banfi, 2017).
Anagallis crassifolia Thore	Medit	inl	seasonal	8	NT	NT	0.9	Among Mediterranean islands, it has been reported only for Sardinia (Martinoli, 1959), where recent field surveys have led to its provisional assessment as Regionally Extinct (Domina et al., 2025).
Carum verticillatum (L.) W.D.J.Koch	Medit	inl	seasonal	8	LC	NE	0.9	Among Mediterranean islands, it has been reported only for Corsica, where recent field surveys have led to its provisional assessment as Regionally Extinct (Delage and Hugot, 2015).
Senecio altissimus Mill.	Medit	inl	all	9	NE	NE	0.9	Among Mediterranean islands, it has been reported only for Sicily, where the most recent reports date back to the XIX century.
Trapa natans L.	Wides	inl	perm.	11	LC	NE	0.9	Among Mediterranean islands, it has been reported only for Mallorca (Balearic archipelago), where it was assessed Regionally Extinct (Aedo et al., 2015).
Dactylorhiza elata (Poir.) Soó	Medit	inl	seasonal	8	NT	NT	0.85	It has been reported only for Corsica (not recorded since 1885; Jeanmonod and Gamisans, 2013). The subsp. *sesquipedalis* (Willd.) Soó is found at only one site and in decline, even possibly extinct, in Sardinia (Lussu et al., 2025).
Eleocharis ovata (Roth) Roem. & Schult.	Wides	inl	seasonal	9	NE	NE	0.85	It has been reported only for Sicily (Regionally Extinct), and Malta, where it is restricted to only one location and assessed as CR.

vegetative strategy of perennial herbs allows them to cope with other stresses or disturbances, such as long-lasting snow cover or mowing and grazing. Perennial herbs are a very diverse group and constitute the most widespread life form in stable systems with high humidity and productivity, which are generally typical to temperate climates (Midolo et al., 2023). In the Mediterranean islands, they find such conditions especially in wetlands, with no clear preference between coastal and inland areas. The second and third most common life forms are annual herbs and geophytes, which appear to be common in both coastal and inland temporary wetlands. This suggests that they have adapted to dry conditions for at least part of their life cycle (Osland et al., 2019; Mofutsanyana et al., 2020). The less common woody plants are more frequent in coastal environments, e.g. several species belonging to the genera *Limonium* Mill. and *Tamarix* L., as well as members of the family Amaranthaceae, which have evolved mechanisms of adaptation to salt water (Grigore and Toma, 2020).

Our synthesis also confirms that wetland plant endemism is lower than in other environments, such as rocky habitats (e.g. De Candolle, 1855; Hobohm and Bruchmann, 2011; Fois et al., 2024). This is particularly true for many coastal wetland species, while endemicity increases in inland areas and especially in inland temporary wetlands. In coastal areas, wetlands are subject to regular mixing of freshwater and saline conditions, offering a wide availability of habitats and niches favouring species with a large ecological niche (Santamaría, 2002; Dalla Vecchia et al., 2020). More generally, this pattern may also be influenced by the capacity for clonal propagation (Santamaría, 2002) and long-distance dispersal, especially through water (i.e. hydrochory; Cuena-Lombraña et al., 2024), or through close interaction with birds (i.e. ornithochory; Green and Wilkinson, 2024). Likewise, they are likely to be more generalist in reproduction, e.g. through anemophily and hydrophily, thus overcoming reproductive barriers represented by specialized interspecific interactions (Schulze-Albuquerque et al., 2024).

The inherent wide distribution of many wetland plants leads to a possible underestimation of the importance and urgency of their conservation. While globally threatened species are, by definition, at higher risk of extinction, locally or regionally threatened species also deserve attention. Furthermore, as noted by our index of assessment completion, the conservation status of regionally threatened plants is insufficiently known, which again leads to a possible underestimation of their conservation priority. For instance, although the widespread species *Carex extensa* and *Corrigiola litoralis* are LC at the global level, they both suffered regional extinctions in Cyprus and in the Tremiti archipelago (Adriatic S Italian cluster) respectively, thus deserving high conservation priority, at least locally. The same applies to the case of the extinctions of *Eleocharis palustris*, *Ranunculus peltatus* subsp. *baudotii* (Godr.) C.D.K. Cook and *Baldellia ranunculoides* (L.) Parl. from the entire Tuscan Archipelago (Foggi et al., 2014). The most extreme example of the difficulties in interpreting and thus prioritizing the conservation of widespread species is represented by those that are considered to be introduced by humans on some Mediterranean islands, while in others they are threatened. For example, *Ipomoea sagittata* is present in America and Europe, considered CR in Corsica and Cyprus, while it is reported as cryptogenic in Italy. Wood et al. (2020) theorized that it has been present in Europe since at least prehistoric times, which is explained by its ability to naturally disperse over long distances through ocean currents. In contrast, Austin (2014) considers *I. sagittata* to be native to the circum-Caribbean region of the Americas, therefore, to be considered an alien species and not to be protected in Europe. The whole reasoning is compounded with the insufficiently known species, which show the lowest assessment completion and, at the current state of knowledge, the lowest conservation concern as well.

4.1. Factor analysis

Contrary to what may be expected, moisture values and wetland hydroperiod species preferences were not strong drivers of the conservation concern index. It is indeed widely accepted that most of threatened wetland plants in the Mediterranean are amphibious living in the so-called 'Mediterranean temporary ponds' (e.g. Daoud-Bouattour et al., 2011; Fernández-Zamudio et al., 2016; Hammana et al., 2024), a priority habitat (code 3170) for conservation under the 'Habitat' Directive 92/43/EEC. Differently, species of conservation concern are likely to be more influenced by their distribution (i.e. endemics are of greater conservation concern) and location (i.e. plants living in inland wetlands are of greater conservation concern). Plants of conservation concern live in several inland Mediterranean temporary ponds but are not exclusive to them: many other ecosystems, such as permanent or intermittent rivers, streams, lakes, pools or springs, appear to be equally important for plant conservation on Mediterranean islands. In light of the prevailing consensus that current international legislative frameworks are inadequate for the purpose of safeguarding all categories of wetlands, with a particular emphasis on small and isolated water bodies, a distinctive convention was proposed as a means of addressing the imperative for the comprehensive protection of wetlands on a global scale (Stanković et al., 2023). In line with this reasoning, we extended the selection beyond vascular plants considered as 'aquatic macrophytes' (i.e. Ellenberg moisture index ≥9) to include 'amphibious' species (i.e. Ellenberg moisture index =8), and even others that are not considered physiologically dependent on wet habitats but are nevertheless characteristic of such habitats in the context of the Mediterranean islands, especially in small and ephemeral wetlands. This is the case of the characteristic "dwarf flora" of the Mediterranean temporary pools. Among them, there are several annuals, like *Radiola linoides* Roth or *Exaculum pusillum* (Lam.) Caruel, which show several structural adaptations to the ephemeroid life form, such as the ability to germinate in an opportunistic manner from a permanent seed bank, to flower with a very small vegetative apparatus and to fructify within a few weeks after germination (Bagella and Caria, 2012). To improve current legislative frameworks, further supporting knowledge is needed. It is important to encourage new observations of habitat preferences since the traditional distinction between aquatic, amphibious and terrestrial habitats, as well as between halophilous and hygro-hydrophilous habitats, is not always clear. This distinction is mostly inferred from non-experimental data and is sometimes limited to locations reported on herbarium labels (Troia and Greuter, 2015). The physiology is particularly unclear for many annual plants characteristic of ephemeral wetlands, although they are exclusive to these areas they complete their life cycle in dry conditions. Similar ecophysiological experiments could be carried out on other plants such as *Limonium* spp., which live in flooded environments but also show clear adaptations to hypersalinity (Baumberger et al., 2012). The fact that the assessment completion of widespread plants is lower than that for endemics confirms limitations in investigating their entire populations and suggests that they receive less research and conservation effort due to their lower charisma at the regional level. This may result in an underestimation of the conservation concern for widespread species and associated habitats, such as coastal habitats. The finding that coastal species are less at risk than those living inland was unexpected. This was surprising given the high level of human activities and urbanisation along the Mediterranean coast. As regards the phylogenetic signal for both conservation concern and assessment completion, results are mostly explainable. Orchids, for instance, are a well-studied group, which is widely considered as a target group for conservation (e.g. Vogt-Schilb et al., 2016; Lussu et al., 2020, 2024). Despite the general flowering attractiveness of Orchidaceae, the remaining families of high conservation concern and assessment completion do not fully confirm the hypothesis that conservation efforts are influenced by their popularity (Adamo et al., 2022). In fact, several Lycopodiopsida and Polypodiopsida, such as *Pilularia minuta* or *Marsilea* spp., green-flowering Liliopsida, like Cyperaceae, or small white-flowering Magnoliopsida, such as Apiaceae also show high assessment completion. However, among the families with low completion of the assessment, we found many Amaranthaceae and other cryptic species of Ruppiaceae and Potamogetonaceae, suggesting an influence of floral attractiveness, especially in coastal and transitional environments, where these two families are well represented. The relatively high number of Apiaceae among wetland species of conservation concern may be simply related to their high representativeness in the Mediterranean flora (Vargas et al., 2018). Two of the three endemic Mediterranean island genera linked to wet habitats belong to the Apiaceae family: *Naufraga* Costance & Cannon and *Petagnaea* Caruel. The other one, *Nananthea* DC., belongs to Asteraceae. The centre of diversity of the several Old-World clades of both families is located in the West Mediterranean since around 3–4 Mya, falling into a period of increasing aridification across Eurasia (Coleman et al., 2003; Kadereit et al., 2008; Bengtson and Anderberg, 2018), thus many species are widespread as they currently find favorable conditions. However, within these large clades, some taxa, as annual *Eryngium* L. species (e.g. *E. corniculatum* Lam., *E. pusillum* L.), or *Petagnaea gussonei* (Spreng.) Rauschert, are sisters to the remainder of the New World clade (Kadereit et al., 2008).

4.2. Geographic overview among island clusters

The number of threatened wetland plants in the clusters obviously varies according to their surface area. Larger clusters, such as Sicily and Sardinia, host a larger number of wetland plants and, consequently, a larger number of threatened plants. However, when accounting for the size of each island cluster, notable differences emerge that may reflect the paleobiogeographic history of the respective regions. In particular, the Balearic Archipelago, with an area of less than half that of the Greek Ionian islands, hosts a proportionally larger number of threatened wetland plants; Corsica and Cyprus have a similar surface area, but the former cluster hosts almost twice as many threatened wetland plants. Considering the role of glacial refugia played by the islands during the Quaternary period (Cronk, 1992; Médail and Diadema, 2009), the Balearic Archipelago and Corsica are thought to have allowed the persistence of some wetland plants related to the Tertiary subtropical flora (e.g. *Naufraga balearica* Costance & Cannon or *Woodwardia radicans*; Vargas et al., 2018; Médail, 2022). Such 'wetland refugia' can be approximately located within the mesomediterranean and supramediterranean humid bioclimatic belts, which are more widespread in the northern and western island clusters than in the southern and eastern ones (Médail and Diadema, 2009). This could also explain why the Greek Aegean islands and Cyprus show similar numbers to the Croatian islands, although the latter have a much smaller surface area.

Humans can obviously influence this pattern, as they may have a faster and heavier impact on wetland biodiversity in small islands, such as Malta or the Greek Aegean islands, than on continents or larger islands (Balbo et al., 2017; Médail and Pasta, 2024). However, no significant differences were detected in terms of conservation concern, suggesting that almost all Mediterranean island wetlands are presumed to be under equal pressures, despite the large disparity in size and human concentration. In contrast to previous findings (Miller et al., 2007; Glasnović et al., 2024), uneven engagement in regional assessments was not confirmed here, as no significant differences were detected in terms of assessment completion. This suggests similar efforts and expertise level of regional assessors, strongly supporting the idea of collective research and awareness-raising of a large group of local Mediterranean experts on the conservation of wetland plants.

4.3. The top-most threatened wetland plants on Mediterranean islands

The list of most threatened plants confirms that endemic taxa are less common in wetlands than elsewhere. Few cases of global extinctions have therefore been reported. However, limiting the study to the taxonomic level of species has made global extinctions at the subspecies level less evident. This is exemplified by *Adenostyles alpina* (L.) Bluff & Fingerth, which has two subspecies that are endemic to Corsica and Sicily and are facing different fates: *A. alpina* subsp. *briquetii* (Gamisans) Tutin is LC in Corsica, while *A. alpina* subsp. *nebrodensis* (Wagenitz & I. Müll.) Greuter has recently become extinct in its only known locality in the Madonie mountains in Sicily. The primary causes of this extinction are believed to be recurrent heatwaves and protracted drought, in combination with overgrazing (Scafidi, 2025). Regardless of whether they are regionally or globally threatened, this list presents explanatory examples from which to learn in order to prevent future extinctions, as they were generally the consequence of deplorable human actions, which have led to a loss of the natural capital of entire island systems. Land-use change is probably the main cause of local extinctions in wetland environments, such as the case of *Limonium intermedium*, which was exclusive to Lampedusa (Sicily), where it grew in a salt marsh near the harbour, now converted to a soccer field; only some individuals currently survive in the Botanical Garden of Catania, grown from seeds collected in nature about 50 years ago before the destruction of the only extant population (Pasta, 2001a; Domina et al., 2015, 2025). Regardless of its questionable taxonomic validity, a similar fate befell *Puccinellia gussonei*, once growing in few Sicilian permanent ponds close to mud volcanos (Guarino et al., 2021), namely near Adrano in the south-western flanks of Mt. Etna (Brullo and Siracusa, 2000) and at the Macalube near Aragona (Pasta, 2001b), and it was also the case of *Anagallis crassifolia*, last reported by Martinoli (1959), in a present-day wind farm of Portoscuso (Sardinia), or of *Trapa natans* in s'Albufereta (Mallorca) due to lake desiccation, extirpation by fishermen and habitat degradation (Aedo et al., 2015).

5. Conclusions

Wetland plants are widely recognized as a priority group for conservation (Reid et al., 2018; Cuena-Lombraña et al., 2021; Alahuhta et al., 2025). However, knowledge on their conservation status is far from complete. The underlying reasons are numerous, including the occurrence of cryptic or neglected species and the generally low charisma of many taxa, some of which are locally, but not globally, threatened. Although conservation status assessment is not a means of prioritizing conservation measures (IUCN, 2001), it continues to direct efforts towards those species that are recognized as globally threatened, thus rarely benefitting wetland plants (Fois et al., 2024). This need for their conservation is more evident in the Mediterranean islands, where widespread plants are confined to small and fragmented wetlands that are currently facing changes in precipitation and temperature regimes at an unprecedented rate (Herbert et al., 2015; Médail, 2017; Saatkamp et al., 2023). Furthermore, on small islands, human-induced changes to the wetlands are more likely to lead to local extinctions and thus to a major depletion of the natural capital of an entire cluster of islands.

Without underestimating the uncertainty inherent in the selection of the plants presented in this list, a process that required numerous discussions among the authors, it is relevant to underscore that the primary objective of our list of threatened wetland plants was not to shed light on their actual physiological requirements, but to highlight the growing need for attention to wetlands in the Mediterranean islands. Identifying and monitoring species at risk of extinction globally or locally would provide promising indicators of the health of the entire ecosystem, thereby supporting their restoration and protection. Our research is not a simple compilation of data from existing Red Lists. It required the participation of numerous local experts from the Mediterranean to improve knowledge and awareness. It has made it possible to include previously unpublished reports and to discuss in depth the ecology, distribution and conservation status of many plant species, often overlooked in previous research. Local experts will also ensure that conservation purposes are maintained. Indeed, sympathy, continuous monitoring and conservation efforts are more feasible and credible when carried out by people who live and study in the area around these wetland plants and who possibly have more direct contact with stakeholders. A major limitation of this research is related to the approach used for the selection of wetland plants. It was based on moisture indices previously reported on a different scale (usually national), often implemented on a non-experimental basis. Further research should therefore verify whether some plants –already reported or to be added in this list– physiologically need wet habitats and are under a real risk of extinction due to the disappearance of wetlands. Although we provided many new assessments, a further limitation was the large number of unassessed species that still remain for many islands. It is essential to fill these gaps by improving field monitoring of species with low level of assessment completion. Future research may include cooperation with experts on non-vascular plants and other groups, particularly neglected ones such as invertebrates.

CRediT authorship contribution statement

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Declaration of competing interest

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Supplementary data

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Data availability

All data are available in the Supplementary Material.

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