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Endemic and alien vascular plant diversity in the small Mediterranean islands of Sardinia: ~~d~~Drivers and implications for their conservation

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Mauro Fois Writing - original draft Data curation Investigation Formal analysis Methodology Conceptualization [a], Lina Podda Writing - review & editing Data curation Conceptualization [a,*] lina.podda@gmail.com, Frédéric Médail Supervision Writing - review & editing [b], Gianluigi Bacchetta Supervision Writing - review & editing Data curation Conceptualization [a,c]

[a]Centro Conservazione Biodiversità (CCB), Dipartimento di Scienze della Vita e dell'Ambiente (DISVA), Università degli Studi di Cagliari, V.le S. Ignazio da Laconi 13, 09123 Cagliari, Italy

[b]~~Aix Marseille Univ, Avignon Univ, CNRS, IRD, IMBE, Technopôle de l'Arbois-Méditerranée, BP 80, 13545 Aix-en-Provence Cedex 4, France~~Institut Méditerranéen de Biodiversité et d'Ecologie marine et continentale (IMBE), Aix Marseille Univ, Avignon Université, CNRS, IRD. Technopôle de l'Arbois-Méditerranée, BP 80, 13545 Aix-en-Provence Cedex 4, France

[c]Hortus Botanicus Karalitanus (HBK), Università degli Studi di Cagliari, V.le S. Ignazio da Laconi 9-11, 09123 Cagliari, Italy

*Corresponding author at: Centro Conservazione Biodiversità (CCB), Dipartimento di Scienze della Vita e dell'Ambiente, Università degli Studi di Cagliari, V.le S. Ignazio da Laconi 13, 09123, Cagliari, Italy.

Abstract

Islands are of high interest for conservationists, due to their great biodiversity within discrete territories. Nonetheless, several mechanisms of plant diversity patterns are unknown, especially for continental islands. In this paper, we explored how endemic and alien vascular plant species richness and the compositional dissimilarity of small Mediterranean continental islands vary according to factors related to human activities, geography/landscape, and climate. Actions for endemic plant conservation were also prioritised according to both endemic and alien components. To this aim, data of endemic and alien plant species for forty islands of Sardinia were considered.

Species-area residuals, which express the actual species composition free of area-effects, were modelled using 19 variables related to anthropogenic, geographic/landscape and climatic domains (group of factors). The geographic/landscape domain appeared to be important for both endemic and alien species richness and compositional dissimilarity, while the climatic one was especially relevant for alien species richness. The anthropogenic domain was mostly important for the compositional dissimilarity of aliens and for the endemic species richness. Actions for endemic plant conservation were of high priority for 14 islands; 11 of which are located off the northwest coast of Sardinia. Our research confirms that the Mediterranean small islands of Sardinia are plant endemism hotspots prone to alien invasion. Our findings suggest that removing anthropogenic disturbances is not sufficient to prevent plant invasions. Other factors related to climatic and geographic/landscape domains are as or more important in determining endemic and alien plant composition.

1 Introduction

Due to their great biodiversity within apparently simple and discrete territories, islands are of particular interest for studies in ecology, biogeography and evolution (Whittaker et al., 2017). Islands count for just 3.5% of Earth's land area but host 15–20% of all terrestrial species and are key areas for the conservation of biodiversity (Médail, 2017; Whittaker et al., 2017). Having been adapted to or even evolved in isolation, island native plant species often occur in small geographical ranges, tend to be habitat specialists and are consequently more vulnerable to the introduction of non-native competitors (Terzopoulou et al., 2015). It is not therefore surprising that island biotas have provided the majority of recorded global plant species extinctions since 1600 CE because of extensive deforestation, transformation of natural habitats and introduction of non-native species (Fois et al., 2018a; Terzopoulou et al., 2015). Of particular interest are mechanisms of invasibility in islands and the pattern of native/exotic richness relationships. Despite much research, the mechanisms promoting plant invasions have yet to be resolved (Burns, 2016) because they are dependent on other specific variables, such as the scale of the study and the biogeographical and bioclimatic contexts, as well as other factors, mainly related to human activities (Bjarnason et al., 2017; Burns, 2016). In this sense, a comparative approach to the distribution pattern of invaders and threatened species may be useful for conservation purposes. For instance, if consistent differences in terms of adaptation and colonisation abilities can be identified between invasive and native taxa, these differences might help explain why an invader has become so successful (Daehler, 2003). Furthermore, such a comparison might be used for the prioritisation of actions aimed at the control of alien species in insular areas of particular conservation interest (Carli et al., 2018; Valli et al., 2019).

In the context of island plant diversity, Mediterranean islands represent important areas of the Mediterranean basin (Médail, 2013) due to their exceptional number of endangered and endemic plants. In particular, the numerous (>10,000 islands and islets) Mediterranean islands host even a higher concentration of endemic and

range-restricted plant species (Médail, 2017), and they often act as putative refugia with a high conservation priority for the long-term persistence of species and genetic diversity (Médail and Diadema, 2009). Compared to other contexts, the proportion of non-native plant species in the Mediterranean context is not exceptional; nonetheless, several authors (e.g. Celesti-Grapow et al., 2016; Mayoral et al., 2017; Pretto et al., 2012) have demonstrated that the negative consequences of plant invasions on native communities are also relevant in Mediterranean islands.

A recent study devoted to the island of Crete and 49 surrounding islets tested four hypotheses of plant invasibility (Bjarnason et al., 2017). Results showed that areas of high plant species richness have greater invasibility, while areas with a high number of alien plant species were generally poor in endemic species. Such negative correlation between alien and endemic plants appears to be driven by elevation, especially by its role as an environmental filter. Other studies on non-native plant species richness across Mediterranean islands indicated that tourism and the increase of anthropogenic habitats are other important factors in favouring the establishment of alien vascular species (Pretto et al., 2012) and act to the detriment of endemic ones (Fois et al., 2016). In general, both human-related and environmental factors, which are sometimes even correlated with one another (e.g. human presence is commonly inversely correlated with elevation), are often co-determinants of alien and endemic distribution patterns.

Besides species richness, islands can also importantly differ in terms of species composition. Studies of differences between island compositional dissimilarity (sensu Podani and Schmera, 2011) can inform the prioritisation of protected areas and the management of biological invasions (Socolar et al., 2016). For instance, it is assumed that compositional dissimilarity of island species assemblages varies according to species dispersal and colonisation ability and, therefore, depends on the degree of isolation and on other environmental variables, such as elevation and climate of the island (Aranda et al., 2013; Moody, 2000; Panitsa et al., 2008). A recent meta-analysis suggests even that island species diversity patterns are shaped by intra-archipelago processes more strongly than by isolation from mainland source pools (Matthews et al., 2019). Nonetheless, in the Anthropocene, humans are strongly influencing the compositional dissimilarity among islands leading to biological homogenisation, mainly due to the introduction of alien species, the artificialisation of ecosystems and the intensification of fires (Capinha et al., 2015; Panitsa et al., 2008).

Most of the Mediterranean islands and islets are of continental origin (Fois et al., 2016; Médail, 2017), and the relationship between alien and endemic taxa is poorly known for continental islands (Meiri, 2017). Among the larger Mediterranean islands, Sardinia has the sad reputation of hosting one the highest percentages of alien plants (ca. 18% of its total flora; Puddu et al., 2016) while, at the same time, it harbours a high rate of plant endemism (294 endemics out of 2,301 native taxa, ca. 12.7%; Fois et al., 2017). The Sardinian offshore coasts also account for numerous small satellite islands and islets, i.e. 399 of the 1,100 islands of Western Mediterranean Basin, hosting 105 endemic species (Fois et al., 2016). This implies a high conservation importance of these insular areas as 'nano-hotspots' (sensu Cañadas et al., 2014) within the Mediterranean Basin regional hotspot (Médail and Quézel, 1997) or 'mega-hotspot' of biodiversity (Fois et al., 2018b). The impact of non-native flora, often outscores the influence of human presence and land-use changes are important facilitators for their colonisation and establishment (Pretto et al., 2012); such plant invasion phenomena have been alarmingly increasing in recent years (Celesti-Grapow et al., 2016).

Several questions concerning the key factors that affect the occurrence of non-native and endemic plant species in islands and especially in the smaller ones were, to our knowledge, not already addressed for the continental islands. In particular, we used a representative set of satellite small islands and islets of the Western Mediterranean (Sardinia) to answer the following questions: 1) Are there differences among the main drivers of endemic and alien plant species richness and compositional dissimilarities? 2) How does each component of plant diversity vary in relation to factors related to anthropogenic, geographic/landscape, and climatic domains? 3) Can we prioritise these islands for plant conservation, according to both endemic and alien species richness and compositional dissimilarity?

~~2.~~2 Material and ~~M~~methods

~~2.1.~~2.1 Study area

Sardinia is situated in the Western Mediterranean Basin, between 38' 52" and 41' 16" north and 8' 8" and 9' 50" east (Fig. 1). Around the about 1900 km of coast (De Falco et al., 2008), Sardinia has 399 satellite islands and small islets, mostly belonging to the four main archipelagos of Asinara, La Maddalena and Tavolara in the northern part, and of Sulcis and Fiori in the offshore coast of southern Sardinia (Fois et al., 2016). Geologically and biogeographically, they are all included as continental islands because they were originated from the split of the Sardo-Corsican microplate from the Ibero-Provencal sector ca. 30 Ma (Alvarez et al., 1974; Rosenbaum et al., 2002) and for the subsequent eustatic sea-level rise. This is demonstrated by the floristic uniqueness of the Sardo-Corsican flora (Bacchetta et al., 2012) and by the presence of common lineages or taxa shared with the Iberian, Provencal, Balearic and Calabro-Peloritan territories (e.g. Bobo-Pinilla et al., 2016; Mansion et al., 2008; Salvo et al., 2010).

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~~Figure 1.~~Fig. 1

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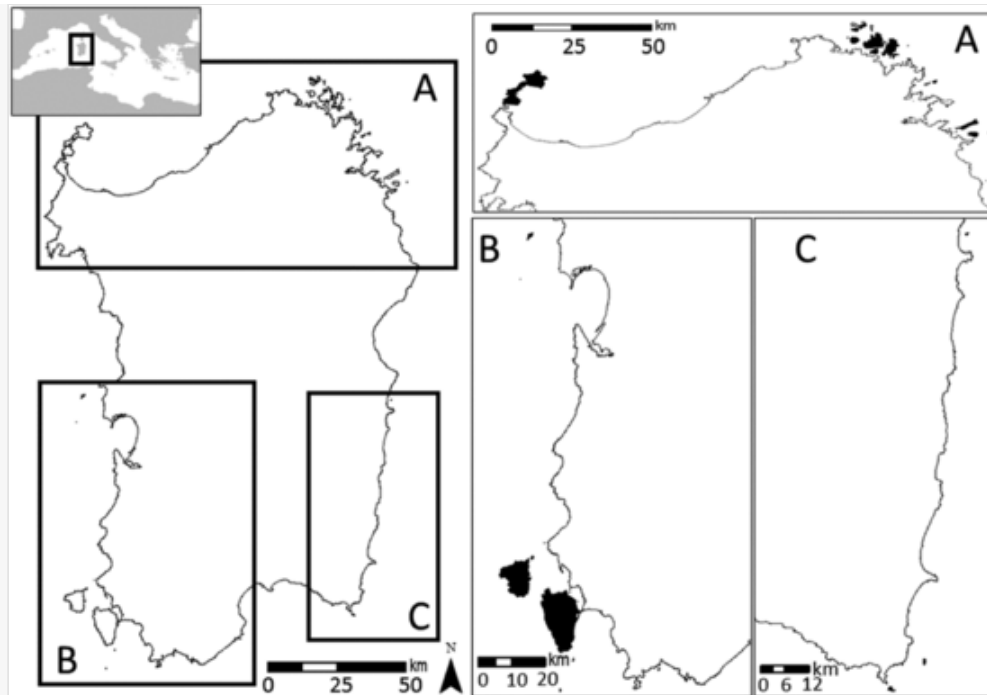
Location of the 40 small Sardinian islands analysed in this study, clustered into four areas.

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This study focuses on the available data concerning 40 Sardinian satellite islands, which belong to all the four above-mentioned archipelagos. The selection was based on the presence of at least one endemic and alien species. All of them can be defined as 'small islands' according to Hess (1990), being smaller than 10 000 km^2 in size and having a resident population of ~~less than~~ $\leq$500 000 inhabitants. Nonetheless, such classification is relative, so that a 'large island' was defined in the Mediterranean context when its surface area exceeded 100 km^2 and a 'small island' was defined when it was ~~less than~~ $\leq$10 km^2 (Médail, 2017). In particular, our set of 'large', 'medium', 'small' and 'very small' islands (islands, hereafter) was composed by islands ranging from 109 km^2 (Sant'Antioco) to 0.005 km^2 (Coltellazzo) and from a resident population of ca. 11 000 inhabitants (La Maddalena and Sant'Antioco) to totally uninhabited islands or islets (the large majority, i.e. 36 over the 40 studied islands). However, these latter islands are prone to the direct and indirect effect of human activities, such as the introduction of non-native species or a rather high frequency of impacts due to tourists' visits (e.g. Bocchieri, 1998; Fois et al., 2016; Ruffino et al., 2009).

~~2.2.~~2.2 Explanatory variables

For each island, we took into consideration 19 explanatory variables framed into three conceptual-methodological domains or groups of factors (sensu Sperandii et al., 2019): (1) four variables related to the anthropogenic domain, (2) eight variables related to the geographic/landscape domain and (3) seven variables related to the climatic domain (Table 1).

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Description and abbreviations of the 19 explanatory variables framed into three main domains: anthropogenic (A), geographic/landscape (G), and climatic (C). QGIS in the column 'Source', describes variables that were derived by means of a Geographycal Information System (QGIS Development Team 2014) from the shapefiles available from the official Sardinian geo-portal (http://www.sardegnageoportale.it). Conc. artif. and N.Habitats were revised through photointerpretation of most recent available Google Earth images (approx. 2016–2017).

Abbreviation	Description	Domain	Source
Conc.artif	Concentration of human-built structures per hectare	A	From the database of the official Sardinian geo-portal (http://www.sardegnageoportale.it), Google Earth
%Artificial	Percentage of the island surface covered by artificial and agricultural areas	A	From land use (Regione Autonoma della Sardegna, 2003)
D.port	Distance from the nearest port (m)	A	Di Gregorio et al., 2000
N.Moorings	Number of moorings (within a radius of 1 km from the island)	A	Di Gregorio et al., 2000
Latitude	Latitude	G	QGIS
Longitude	Longitude	G	QGIS
Dist.SA	Distance from Sardinia (m)	G	QGIS
Dist.is	Distance from the nearest island (m)	G	QGIS
A	Area (ha)	G	QGIS
P	Perimeter (m)	G	QGIS
Elev.	Maximum elevation (m a.s.l.)	G	1:25,000 Military Geographic Institute (IGM) maps (https://www.igmi.org)
N.Habitats	Habitat heterogeneity	G	From land use classification (Smiraglia et al., 2013), Google Earth
ic	Simple continentality index (i.e. the ratio of the mean temperature of the warmest month and the mean temperature of the coldest month)	C	Pesaresi et al., 2014
io	Annual ombrothermic index (i.e. the ratio of the annual positive precipitation and yearly positive temperatures)	C	Pesaresi et al., 2014

pp	The total average precipitation of months with an average temperature higher than 0 °C (i.e. annual positive) precipitation	C	Pesaresi et al., 2014
it	Thermicity index, i.e. the sum of mean annual temperatures plus the average of the minimum temperatures of the coldest month and the average of the maximum temperatures of the coldest month	C	Pesaresi et al., 2014
Bio1	Annual mean temperature (°C) × 100	C	Hijmans et al., 2005
Bio12	Annual precipitation (mm)	C	Hijmans et al., 2005
AET	Annual actual evapotranspiration	C	Trabucco and Zomer, 2010

We checked for weak co-linearity among the initial set of 19 variables by applying a stepwise trait selection, based on variance inflation factors (VIF) by means of function 'vifstep' in the *usdm* R package (Naimi, 2015). In order to reduce heteroscedastic biases and improve the linearity of the relationships in the regression models, variables were log10-transformed to normalise their distribution so that they could be compared with bivariate and multivariate regression methods (Valli et al., 2019). The Shapiro-Wilk test, with 95% level of confidence, was used to check the normality of each transformed variable.

~~2.3.~~2.3 Response variables

We compiled two presence/absence island-plant matrices, one for endemic plant taxa and one for alien plant taxa. Alien taxa included all of the non-native vascular plants occurring in Sardinia and listed in the national inventory of Galasso et al. (2018); we included not only invasive and naturalised but also casual species as a precautionary approach, since these last ones might be potentially future invaders (Gassó et al., 2010). Endemic taxa were defined according to Fois et al. (2016, 2017). Plant distributional data were retrieved from a geodatabase already developed by these authors for the entire Sardinian territory and constantly implemented since 2002. The database includes the localities reported in seven Italian herbarium collections (CAG, CAT, FI, RO, SASSA, SS, TO; herbaria codes according to Thiers, 2019), the available literature concerning the Sardinian vascular flora (e.g. Arrigoni et al., 1976–1991; Bocchieri, 1992, 1998) and many unpublished data issuing from the field surveys carried out by the authors.

Matrices were first used to calculate the number of endemic and alien species per island (i.e. species richness). As a second step, we used the same matrices to measure the endemic and alien compositional dissimilarities based on all possible pairs of sites. This index was calculated as the 1-complement of the Jaccard index, and it is referred to as relativized beta diversity by Podani and Schmera (2011) and as compositional dissimilarity by Tuomisto (2010) and Pitta et al. (2014). Compositional dissimilarity was defined as $1 - a / (a + b + c)$, where a is the number of species present in both islands being compared, b is the number of species present only in the first one and c is the number of species present only in the second island. To obtain a measure of compositional dissimilarity for each island, we averaged all dissimilarities in a matrix by summing up all pairwise values and then dividing this sum by $(m^2 - m)/2$, where m is the number of islands (Pitta et al., 2014; Podani and Schmera, 2011). To calculate compositional dissimilarity we used the 'vegdist' function of the 'vegan' package (Oksanen et al., 2013).

In order to account for species-area relationships, the four response variables (endemic/alien species richness and endemic/alien compositional dissimilarity) for each island were regressed to the log-island area. The island species-area relationships (ISARs) were investigated for the Sardinian islands by fitting the logarithmic transformation of the Arrhenius (1921) power model, $Log(S) = c + z \times Log(A)$, where S is the value of each of the four species metrics, A is the island area, c is the intercept and z is the slope. Positive and negative values of Pearson's standardised residuals refer to areas with species diversity components above and below average, respectively (Hobohm, 2003). We used residuals, instead of simple species richness and compositional dissimilarity, because this is a measure of island species diversity that does not reflect the influence of island area (Hobohm, 2003; Moody, 2000; Valli et al., 2019). Such an approach was conceptually conceived to go beyond the common direct correlation between species richness and island area; however, this has been recently applied to other species diversity components, such as compositional dissimilarity, that were clearly correlated with the island size or distance (e.g. Penone et al., 2016; Valli et al., 2019). Summarising, the final four response variables used for regression analyses were the power model residuals of endemic/alien species richness (α-Endemic and α-Alien, hereinafter) and endemic/alien compositional dissimilarity (β-Endemic and β-Alien, hereinafter).

2.4.2.4 Data analyses

Four regression analyses were repeated separately for each of the above-explained response variables. For model selection among all possible combinations of predictor variables, we used the 'dredge' function (R package *MuMln*, Bartoń, 2019). Due to the limited sample size, interactions were not considered. Akaike's information criterion corrected for small samples (AICc), and ΔAICc, the difference between the given model's AICc values, were computed for each model. Averaged parameter estimates from top-ranked models within ΔAICc <−2 (Burnham and Anderson, 2004; Zhang et al., 2017) were then produced using the 'model.avg' function. The 'sw' function was then used to calculate the relative variable importance (RI) of each explanatory variable as the sum of the relative evidence weights of the candidate models in which the predictor appeared. In order to obtain the relative importance of each domain, we summed up the rescaled in percentage term RI values of each respective predictor (Sperandii et al., 2019).

Tests using the *ncf* R package (Bjornstad, 2016) revealed that there was no statistically significant spatial autocorrelation in model residuals (see Appendix A; Fig. A1). All analyses were carried out in R 3.6.2 (R Development Core Team).

2.5.2.5 Island prioritisation on the basis of endemic vs. alien species richness and compositional dissimilarity

The overall risk-ranking method prioritised islands using endemic vs. alien components. The principle was to weight islands according to the four response variables related to both endemic and alien components. To do that, the values of the residuals from the ISAR models of endemic and alien plant species richness (α-Endemic and α-Alien) and compositional dissimilarity (β-Endemic and β-Alien) metrics were plotted in a two-dimensional Cartesian system in order to classify islands according to the sensitivity of endemic flora to plant invasion. An island with both α-indexes >0 was assumed as more sensitive than another with an α-index <0 of at least one of the two richness parameters, because of the exceptional number of endemics potentially

threatened by a high abundance of alien plants. The same was assumed for β-metrics; we ranked as higher conservation priority those islands that particularly contributed to the difference in terms of endemic species composition from other islands, and had a high degree of dissimilarity in alien species (i.e. high β-Endemic and β-Alien). The two plots were divided in four quadrants and a value from 0.25 to 1 per plot was attributed to each island. In each plot, a minimum score of 0.25 was attributed to islands with both numerical coordinates <0 and a maximum score of 1 to islands with both numerical coordinates >0 (Fig. 2). A total score, ranging from 0.5 to 2, was attributed to each island by summing the two partial scores derived from the two plots.

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Figure 2.Fig. 2

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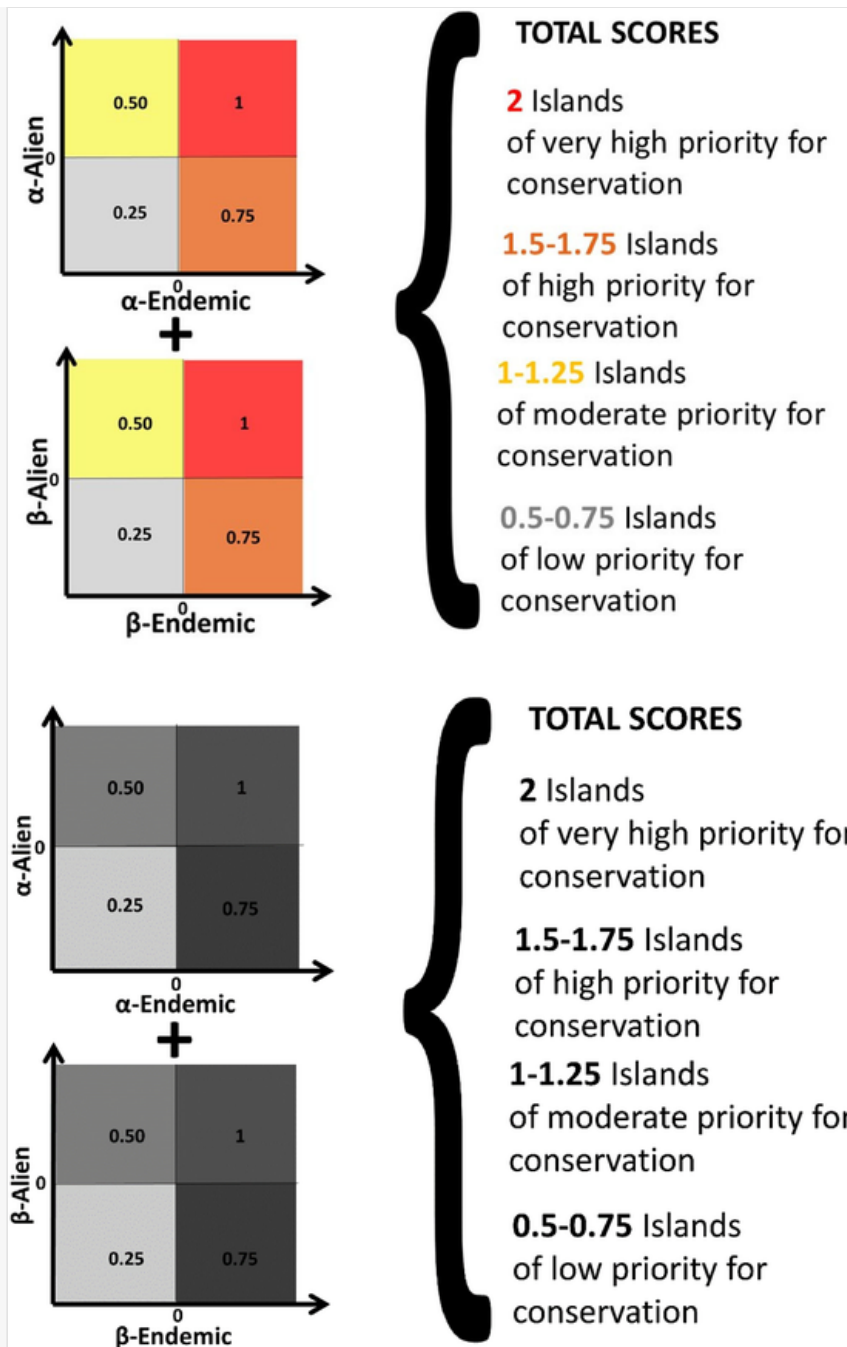
Conceptual framework for ranking the conservation of insular vascular plants, on the base of endemic/alien species richness and endemic/alien compositional dissimilarity. The total score was obtained by the sum of the two partial scores obtained from the two Cartesian plots with α- and β-numerical coordinates. Lowest total scores (0.5) were attributed to islands showing all numerical coordinates <0, while the highest total scores (2) to islands showing all numerical coordinates >0 (see online version for colours).

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3.3 Results

We recorded 168 alien plant taxa on the 40 islands analysed, representing about 35% of the 481 alien taxa of the entire Sardinian territory. A similar percentage (36%) was found for the endemic component, with 105 out the 294 taxa endemic to Sardinia. Strong and significant positive correlations between endemic and alien species richness and island area were found ($R^2 \geq 0.69$; $P < 0.001$; Appendix A; Fig. A.2). Such correlation was less strong for the compositional dissimilarity of endemic ($R^2 = 0.36$) and alien ($R^2 = 0.66$) plant species, even though significant ($P < 0.001$) in both groups (Appendix A, Fig. A.3).

Six variables from the 19 input variables were excluded due to collinearity problems; these were pp, io, it, Bio12, P, and Latitude. After excluding these variables, VIFs were <10 for the rest of parameters, ranging from 5.3 (N.Habitats) to 1.5 (ic). The minimum correlation was found between ic and Conc.artif (r = 0.00), while the maximum one was between N.Moorings and Longitude (r = 0.68).
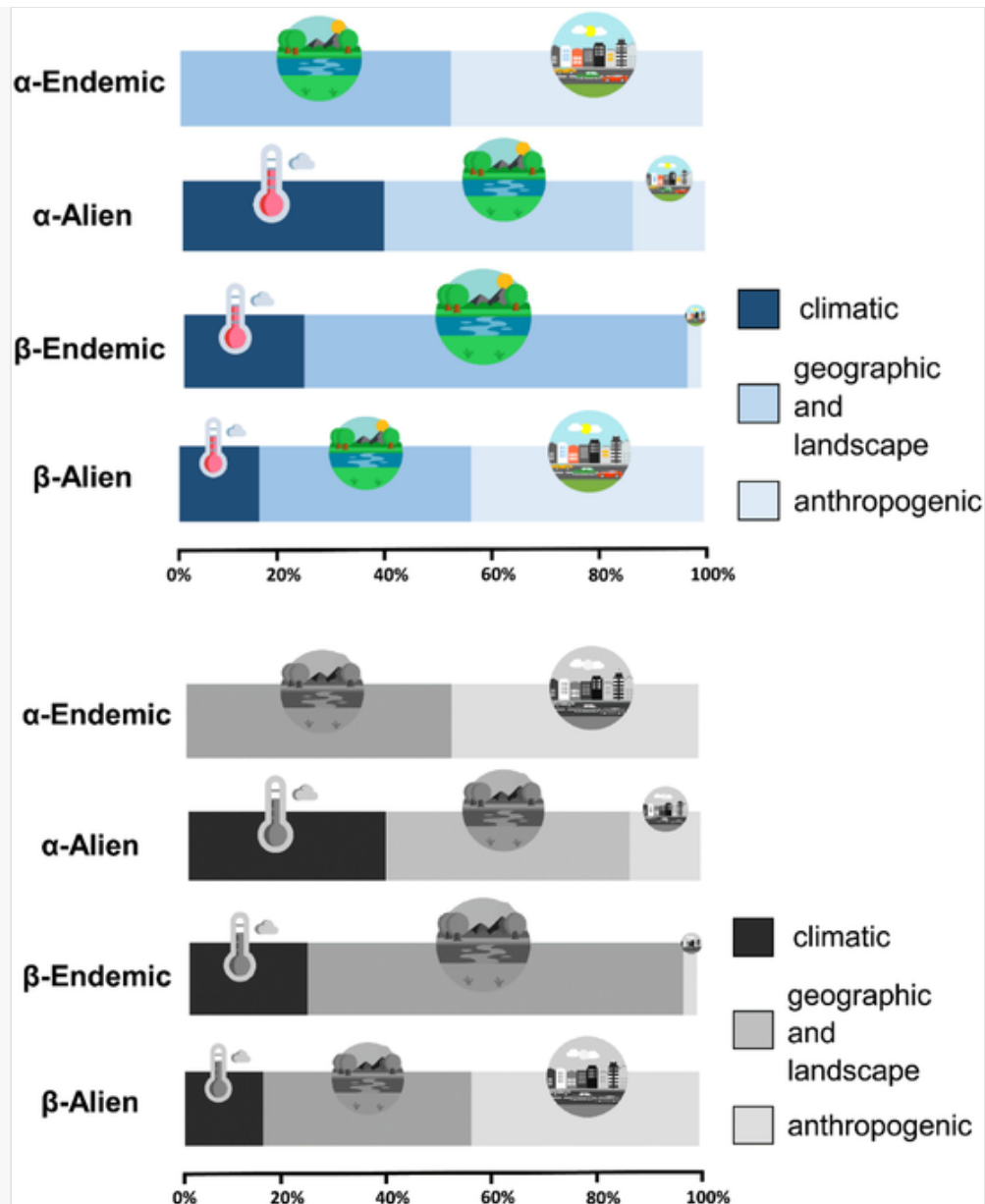
3.1. 3.1 Drivers of endemic and alien plant species richness and compositional dissimilarities

Results from the full model revealed how the three domains (i.e. geographic, climatic and landscape) were differently related to the four components of alien and endemic species diversity (Fig. 3). In particular, the geographic and landscape domain appeared to be important for all α and β components, especially for β-Endemic. The climatic domain appeared to be especially relevant for α-Alien and, secondly, for β-Endemic. The anthropogenic domain had the most importantance for α-Endemic and β-Alien.

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Figure 3. Fig. 3

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Relative variable importance of each domain. The relative importance of each factor was rescaled in percentage and summed to the total importance of the three climatic, geographic and landscape and anthropogenic domains. See Table 1 for further details. Icons are made by Freepik and Nikita Golubev, from www.flaticon.com (see online version for colours).

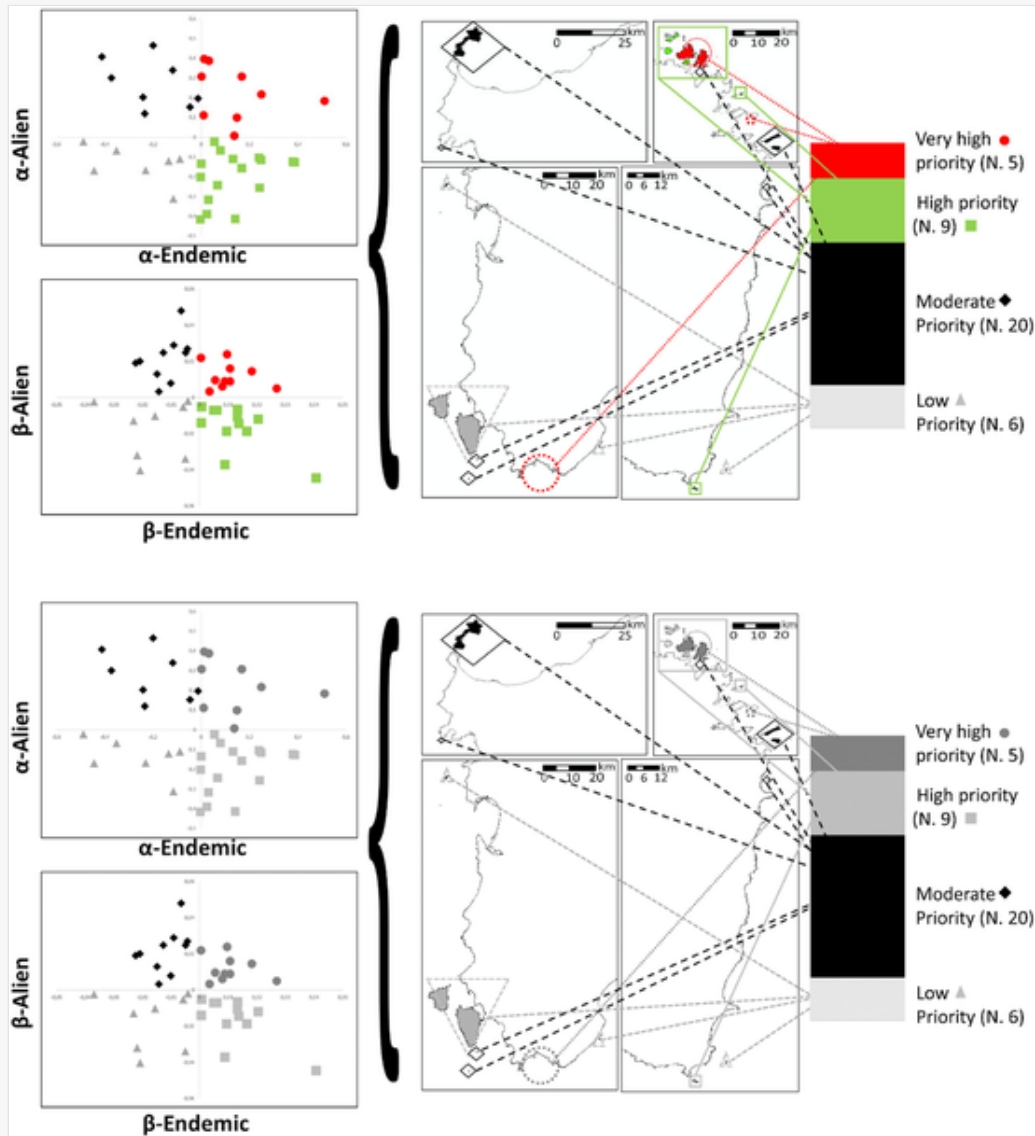alt-text: Fig. 4

~~Figure 4.~~Fig. 4

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Location and priority rankings for the conservation of insular vascular plants, on the base of endemic vs. alien species richness and endemic vs. alien compositional dissimilarities (see Appendix C for details and online version for colours).

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~~Table 2.~~ Table 2

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Model-averaged estimates, standard errors, and P values of the top-ranked models (with ΔAICc < 2) for endemic and alien vascular plant species, regarding α- and β-diversity indices. The relative importance (RI) of each predictor is the sum of the Akaike weights over all top-ranked models. Only variables with RI > 0.2 are shown. Abbreviations are the same reported in Table 1.

Predictor	Standardised coefficient	Adj. SE	z	P	RI
α-Endemic					
Intercept	−76.004	17.481	4.348	0.000	
N.Moorings	−1.333	0.247	5.402	0.000	1
%Artificial	−4.765	0.835	5.703	0.000	1
Longitude	14.229	3.005	4.736	0.000	1
Dist.is	−0.795	0.218	3.638	0.000	1
Dist.SA	−0.247	0.170	1.449	0.147	0.38
D.port	0.486	0.372	1.306	0.191	0.33
α-Alien					
Intercept	−52.561	37.251	1.411	0.158	
Bio1	28.157	14.420	1.953	0.051	0.84
Dist.SA	−0.364	0.237	1.538	0.124	0.50
Elev	0.521	0.372	1.397	0.162	0.33
%Artificial	1.589	1.250	1.271	0.204	0.24
N.Habitats	0.515	0.370	1.391	0.164	0.21
β-Endemic					
Intercept	−10.734	5.672	1.893	0.058	
AET	5.463	2.061	2.651	0.008	1
N.Moorings	−0.739	0.315	2.348	0.018	1
%Artificial	−3.125	1.157	2.700	0.007	1
D.port	−0.679	0.402	1.688	0.091	0.61
Conc.artif	−0.246	0.149	1.645	0.099	0.59
β-Alien					

Intercept	-39.922	44.925	0.889	0.374	
%Artificial	2.567	1.193	2.151	0.031	0.79
N.moorings	0.702	0.328	2.142	0.032	0.76
Longitude	10.105	5.322	1.899	0.057	0.73
Dist.SA	0.463	0.254	1.827	0.067	0.54
Dist.is	-0.488	0.282	1.731	0.083	0.36
AET	4.655	3.242	1.436	0.151	0.35
D.port	-0.862	0.467	1.847	0.065	0.30

Results of the four most parsimonious models confirmed that the influence of each driver considerably differed between endemic and alien species, as well as between the α and β components of biodiversity (Table 2). Specifically, models revealed that α-Endemic mostly decreased with Dist.is and Longitude and, as regards the anthropogenic-related factors, by N.Moorings and percentage of the island surface covered by artificial areas (%Artificial). β-Endemic was at the same time influenced by AET and by %Artificial and N.Moorings. As regards the alien component, α-Alien mostly increased at higher mean temperatures (Bio1), while β-Alien increased with %Artificial. All drivers, as well as the presence–absence matrices, are reported in Appendix B.

3.2. 3.2 Island prioritisation on the basis of endemic vs. alien species richness and compositional dissimilarity

Plots of residuals of endemics versus alien species richness and compositional dissimilarity permitted the ranking of the islands according to positive or negative residuals in the four ISAR curves of endemic composition (i.e. α- and β-Endemic) and alien composition (α- and β-Alien) (Fig. 4). Such scores identify areas where the endemic component is likely endangered by competition from the alien component, with highest priority of conservation actions for those islands with residuals that resulted positive in all ISAR curves. Accordingly, islands were subdivided into 14 of very high and high priority, and 26 of moderate and low priority. Three of five islands of very high priority (Figarolo, Rossa di Teulada and Campionna) are relatively small islands (from 0.22 km^2 of Figarolo to 0.006 km^2 of Campionna), while, among the five largest islands, these were subdivided into two of very high priority (La Maddalena and Caprera) and three of moderate and low priority (S. Pietro, S. Antioco and Asinara). A clear geographic pattern was not found, even though 11 over the 14 islands of very high and high priority were located off the north-west coast of Sardinia. For rankings, specific to each island, see Appendix C.

4. 4 Discussion

4.1. 4.1 Determinants of species richness and species richness of alien vs. endemic plants

Our analyses confirmed that these small Mediterranean islands are 'nano-hotspots' or centres of plant endemism, which are, at the same time, prone to the invasion of several alien plants, the most frequent of

which are *Erigeron bonariensis* L., *Opuntia ficus-indica* (L.) Mill. and *Oxalis pes-caprae* L. Besides several interconnected variables, including, among others, climate, degree of isolation and historical human presence, this pattern is strongly influenced by the geological origin of Mediterranean islands, which are mostly continental-shelf islands that harbour relatively saturated biota (Whittaker et al., 2008). Considering the small extent of the investigated territory (approximately 1% of the total Sardinian surface), we found a high representativeness of both alien (35%) and endemic (36%) plants. Such results are not surprising, being similar of those found in other Mediterranean island groups (e.g. Nikolić et al., 2008; Pretto et al., 2012; Valli et al., 2019) and confirming the need of urgent actions for a more effective conservation of the Mediterranean island ecosystems (Médail, 2013).

To maximise returns on conservation efforts on specific islands or archipelagos, it is therefore crucial to consider all the factors that could affect the different components of biodiversity, including the compositional differences between local species assemblages (Socolar et al., 2016). As one of the most general models in ecology, power models are mostly applied for investigations regarding species richness or number of species in a given sample (Lomolino and Weiser, 2001). However, compositional dissimilarity patterns among assemblages of various species groups in different types of insular systems were found to be correlated to island size (e.g. Pitta et al., 2014; Valli et al., 2019) or both to island size and degree of isolation (e.g. Fattorini, 2010). In the present study, area was significantly correlated with all the diversity metrics used, namely endemic and alien species richness and compositional dissimilarities. This enables the use of power function residuals (i.e. α- and β-indexes) for comparisons of species richness and dissimilarities among islands of a relatively wide size range, which allows going beyond the island-size effect (Hobohm, 2003).

Our findings confirm the hypothesis that no single factor or factors related to one single domain explain the patterns of endemic and alien species diversity. Even with different proportions, all three factor domains were important to α and β components of alien and endemic species. Human-related factors play a predominant role on β-Alien and, to a lesser extent, on both α- and β-Endemic. Such a trend is particularly clear in oceanic islands, because of the above-mentioned unsaturated biota (Whittaker et al., 2008). Otherwise, the few studies that have examined factors related to plant compositional dissimilarity between Mediterranean continental islands have shown a high influence of humans, often finding a floristic homogenisation because of human-induced habitat modifications and introductions of non-native species (e.g. Castro and Jaksic, 2008; Pretto et al., 2012). In our case, %Artificial negatively affected both α- and β-Endemic while α- and especially β-Alien increased with it. Our results confirm that alien components increase even with low-intensity disturbances resulting just from human access, such as N.moorings, to the islands, such as intentional and unintentional introductions (Pretto et al., 2010) or the creation of suitable environments for alien species with waste deposits, and flattened and altered soils caused by agricultural practices or human trampling (Hulme et al., 2008; Pinna et al., 2019). On the other side, studies on rare and endangered plants in the Mediterranean context have reported human-related factors a determinant of local extinctions (Fois et al., 2018a; Lavergne et al., 2005), suggesting that our decrease of the endemic components with human-related factors (i.e. N.Moorings and %Artificial) might be caused by the disappearance of local populations threatened by humans. Moreover, it has been found that both the richness and compositional dissimilarity of endemic species might decrease with alien plants (e.g. Bjarnason et al., 2017; Castro and Jaksic, 2008; Marini et al., 2013), so that all human-

related disturbances can directly or indirectly have a negative ~~affect~~ effect on the local persistence of endemic plant species.

However, anthropogenic factors played a little role in shaping α-Alien. These results are not surprising, for several reasons. First, studies in similar insular environments (e.g. Carboni et al., 2010; Valli et al., 2019) have found that other factors related to climatic and geographical domains have important roles for determining the endemic and alien plant richness. This trend is clearer for endemics; for instance, elevation was found as a key factor in species richness of Provencal (Médail and Vidal, 1998), Sardinian (Fois et al., 2016), Sicilian (Bonanno and Veneziano, 2016) and Eastern Mediterranean islands (Steinbauer et al., 2013; Valli et al., 2019). Although anthropogenic disturbances were found to be the main determinants of alien species richness of Mediterranean islands (Pretto et al., 2012), elevation and climatic variables were the most important drivers on Mediterranean coasts (Carboni et al., 2010). This suggests that the trend in the Mediterranean continental islands is similar to those found in oceanic islands, in which both environmental and anthropogenic factors were roughly equally important (Arévalo et al., 2005; Blackburn et al., 2016). Moreover, α-Alien was explained by few and poorly significant variables, so that, especially in this case, further studies are needed. For instance, more specific variables can be extrapolated in order to evaluate the effects of human presence. As regards the geographic and landscape domain, α-Endemic and α-Alien decrease with the level of isolation. While Dist.is plays a major role in driving α-Endemic, Dist.SA was most important for α-Alien. This suggests the role of minor islands as stepping stones for endemic dispersion and colonisation, while the main island appears to be the main source of alien plants that, supposedly facilitated by humans, are less dependent to other stepping-stone islands for their dispersion. The first result matches very well with those concerning other Mediterranean islands (e.g. Fois et al., 2016; Georghiou and Delipetrou, 2010; Steinbauer et al., 2013), where it was found that the endemism rates on satellite continental islands were more associated to the capacity of populations persistence or recolonisation, rather than to speciation processes. Even more common is our trend with α-Alien, as the degree of isolation often decreases with alien colonisation success, which is favoured by natural spreading processes, such as zoochory, but especially by human-aided spreading processes (e.g. Médail and Vidal, 1998; Pretto et al., 2012).

The climatic domain primarily influenced α-Alien and, secondarily, β-Endemic. Specifically, AET was a significant driver of β-Endemic. Although AET, a measure of the joint availability of energy and water in the environment, has already been proven a determinant for both α and β components (e.g. Wylie and Currie, 1993 ; Yan et al., 2013), the interpretation of such correlations were often problematic. Indeed, besides simple species distribution or colonisation patterns, AET is considered influential for complex species dynamics, such as intra- and interspecies interactions or for indirect effects related, for instance, to fire frequencies and soil fertility (Stephenson, 1998). The fact that alien plant species diversity increases along with temperature, in our case along with Bio1, was often found across islands (Blackburn et al., 2016; Valli et al., 2019). From a conservation point of view, these results are alarming and suggest that a pool of species may potentially invade colder environments after a climatic pre-adaptation (Marini et al., 2013; McDougall et al., 2018) or find more climatically suitable conditions because of global warming (Cerasoli et al., 2019; Gallardo et al., 2017; Podda et al., 2018).

4.2. 4.2 Islands prioritisation on the base of alien vs. endemic species richness and compositional dissimilarity

Once factors affecting both endemic and alien species richness and composition dissimilarity have been determined and compared, a further step is to set conservation priorities in biodiversity hotspots (Bacchetta et al., 2012; Gauthier et al., 2010; Le Berre et al., 2018). The development of global criteria for the prioritisation of both species and habitats has provided comprehensive information that allows informed decisions for conservation planning (Rodrigues et al., 2006). Our approach provides an alternative to most common ones that generally prioritise areas that are in good condition or where protection would have the lowest cost (Manhães et al., 2018). Moreover, this study's objective was to prioritise local conservation actions against the increasing alien colonisation of islands, providing guidance to managers on where the extinction risk of endemic species would increase without an intervention. To do this, local multicriteria assessments are specifically needed for effective conservation management of biodiversity hotspots, such as the Mediterranean islands and islets (Bonanno, 2013; Fois et al., 2018b; Gauthier et al., 2010). In this study, we provided a simple reproducible framework for island conservation, which included four of the most important factors that could help planners choose among alternative islands for the conservation of the endemic flora. On one side, endemic richness has become an increasingly common surrogate for identifying keystone protected areas (e.g. Abdelaal et al., 2018; Bonanno, 2013; Cañadas et al., 2014; Orsenigo et al., 2018). Endemic plant species are potentially threatened because of their often narrow distribution ranges and habitat specificity, and because areas rich in endemism are often rich in other species or unique evolutionary units that are the concern for conservation (Crisp et al., 2001; Fois et al., 2018b; Médail and Diadema, 2009). Yet, most conservation plans initiated in island systems have often focused on static patterns only, such as species abundance distributions, while ignoring dynamic biodiversity processes (Lagabrielle et al., 2009).

Furthermore, the conservation of biodiversity is often performed through the implementation of policy with only limited resources and, therefore, effective conservation must pass through the consideration of further criteria (Fernandes et al., 2015; Gauthier et al., 2010). In our case, both α- and β-Alien were informative parameters to detect which islands are under pressure. Indeed, what is critical is not only finding the islands with the highest number of alien species but also how their compositional dissimilarity was distributed. This last information may elucidate the assembly mechanisms of alien plant communities, and suggest prioritising places where the number of aliens is low. However, according to the high β-Alien index, these species presumably have either the broadest environmental tolerance or the greatest capacity to adapt to novel conditions (Marini et al., 2013). In our particular case, the low correspondence among the four scores considered for ranking the conservation of insular vascular plants suggests that the omission of different aspects might lead to truncated results, which would not be relevant for a good prioritisation of conservation issues. If, for instance, only islands with high α-indexes were selected, the risk would be to underrate irreplaceable places or islands with alien species most likely to adapt to new environments.

5. 5 Conclusions

The present study proposes several new aspects crucial to plan an effective conservation strategy of the endangered vascular flora of small islands and islets. First, the determination of factors related to

anthropogenic, geographic/landscape and climatic domains has underscored how the composition of alien and endemic plants are driven differently. Our results highlight the need of a multivariate approach that includes these two key components and the different aspects that influence their patterns. Considering the high biological value of most of the Mediterranean islands, it is difficult to choose which need priority protection. Nonetheless, limited resources force a focus of attention on the most compelling necessities. Our research did not give priority to the islands usually considered most important, which are the most diverse, but it highlighted the importance of other smaller islands where other aspects of plant diversity, besides species richness, are under threat. As our research was only aimed at the conservation of endemic plants, which are threatened by aliens, we encourage similar multicriteria studies to pursue the conservation of different species groups and/or those affected by other threats.

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CRediT authorship contribution statement

Mauro [Instruction: Please, insert a space after colons]**Fois:**Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft[Instruction: Please, insert a space after periods].**Lina Podda**[Instruction: Please, insert a space after colons]**:**Conceptualization, Data curation, Writing - review & editing[Instruction: Please, insert a space after periods].**Frédéric Médail**[Instruction: Please, insert a space after colons]**:**Writing - review & editing, Supervision[Instruction: Please, insert a space after periods].**Gianluigi Bacchetta**[Instruction: Please, insert a space after colons]**:**Conceptualization, Data curation, Writing - review & editing, Supervision.

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Declaration of competing interest

The authors of this study declare that they have no conflict of interest to report.

References

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Abdelaal, M., Fois, M., Fenu, G., Bacchetta, G., 2018. Critical checklist of the endemic vascular plants of Egypt. Phytotaxa 360, 19–34. doi:10.11646/phytotaxa.360.1.2.

Alvarez, W., Cocozza, T., Wezel, F.C., 1974. Fragmentation of Alpine orogenic belt by microplate dispersal. Nature 248, 309–314. doi:10.1038/248309a0.

Aranda, S.C., Gabriel, R., Borges, P.A.V., Santos, A.M.C., Hortal, J., Baselga, A., Lobo, J.M., 2013. How do different dispersal modes shape the species–area relationship? Evidence for between group coherence in the Macaronesian flora. Glob. Ecol. Biogeogr. 22, 483–493. doi:10.1111/geb.12008.

Arévalo, J.R., Delgado, J.D., Otto, R., Naranjo, A., Salas, M., Fernández-Palacios, J.M., 2005. Distribution of alien vs. native plant species in roadside communities along an altitudinal gradient in Tenerife and Gran Canaria (Canary Islands). Perspect. Plant Ecol. Evol. Syst. 7, 185–202. doi:10.1016/j.ppees.2005.09.003.

Arrhenius, O., 1921. Species and area. J. Ecol. 9, 95–99. doi:10.2307/2255763.

Arrigoni, P.V., Camarda, I., Corrias, B., Diana Corrias, S., Nardi, E., Raffaelli, M., Valsecchi, F., 1976–1991. Le Piante endemiche della Sardegna. Boll. Soc. Sarda Sci. Nat. 16–28, 1–202.

Bacchetta, G., Farris, E., Pontecorvo, C., 2012. A new method to set conservation priorities in biodiversity hotspots. Plant Biosyst 146, 638–648. doi:10.1080/11263504.2011.642417.

Bartoń, K., 2019. MuMIn: Multi-Model Inference. R Package Version 1.43.15. Available at http://cran.rproject.org/package=MuMIn, 2019.

Bjarnason, A., Katsanevakis, S., Galanidis, A., Vogiatzakis, I.N., Moustakas, A., 2017. Evaluating hypotheses of plant species invasions on Mediterranean islands: inverse patterns between alien and endemic species. Front. Ecol. Evol. 5, 91. doi:10.3389/fevo.2017.00091.

Bjornstad, O.N., 2016. ncf: spatial nonparametric covariance functions. R package version 1.1-7 https://CRAN.R-project.org/package=ncf.

Blackburn, T.M., Delean, S., Pyšek, P., Cassey, P., 2016. On the island biogeography of aliens: a global analysis of the richness of plant and bird species on oceanic islands. Glob. Ecol. Biogeogr. 25, 859–868. doi:10.1111/geb.12339.

Bobo-Pinilla, J., de León, S.B.B., Colomar, J.S., Fenu, G., Bacchetta, G., de Giles, J.P., Martínez-Ortega, M.M., 2016. Phylogeography of *Arenaria balearica* L. (Caryophyllaceae): evolutionary history of a disjunct endemic from the Western Mediterranean continental islands. PeerJ 4, e2618. doi:10.7717/peerj.2618.

Bocchieri, E., 1992. Flora of the small

islands of the archipelago of Maddalena (north-eastern Sardinia) and floristic contributions regarding some of the main islands of the archipelago. Flora Mediterranea 2, 33–64. http://www.herbmedit.org/flora/2-033.pdf.

Bocchieri, E., 1998. On the failure to find plants on some minor islands of Sardinia. Flora Mediterranea 8, 197–212. http://www.herbmedit.org/flora/8-197.pdf.

Bonanno, ~~G~~G., 2013. Adaptive management as a tool to improve the conservation of endemic floras: the case of Sicily, Malta and their satellite islands. Biodivers. Conserv. 22, 1317–1354. doi:10.1007/s10531-013-0473-9.

Bonanno, G., Veneziano, V., 2016. ~~New insights into the distribution patterns of Mediterranean insular endemic plants: The Sicilian islands' group~~New insights into the distribution patterns of Mediterranean insular endemic plants: the Sicilian islands' group. Flora 224, 230–243. doi:10.1016/j.flora.2016.09.001.

Burnham, K.P., Anderson, D.R., 2004. Multimodel inference understanding AIC and BIC in model selection. Sociol. Methods Res. 33, 261–304. doi:10.1177/0049124104268644.

Burns, K.C., 2016. Native–exotic richness relationships: a biogeographic approach using turnover in island plant populations. Ecology 97 (11), 2932–2938. doi:10.1002/ecy.1579.

Cañadas, ~~E. M.~~E.M., Fenu, G., Peñas, J., Lorite, J., Mattana, E., Bacchetta, G., 2014. ~~Hotspots within hotspots: Endemic plant richness, environmental drivers, and implications for conservation~~Hotspots within hotspots: endemic plant richness, environmental drivers, and implications for conservation. Biol. Conserv. 170, 282–291. doi:10.1016/j.biocon.2013.12.007.

Capinha, C., Essl, F., Seebens, H., Moser, D., Pereira, H.M., 2015. The dispersal of alien species redefines biogeography in the Anthropocene. Science 348, 1248–1251. doi:10.1126/science.aaa8913.

Carboni, M., Thuiller, W., Izzi, F., Acosta, A., 2010. Disentangling the relative effects of environmental versus human factors on the abundance of native and alien plant species in Mediterranean sandy shores. Divers. Distrib. 16, 537–546. doi:10.1111/j.1472-4642.2010.00677.x.

E. Carli R. Frondoni M.S. Pinna G. Bacchetta G. Fenu M. Fois ... C. Blasi Spatially assessing plant diversity for conservation: A Mediterranean case study J. Nat. Conserv. 41 2018 35 43 10.1016/j.jnc.2017.11.003

Castro, S.A., Jaksic, F.M., 2008. Role of non-established plants in determining biotic homogenization patterns in Pacific Oceanic Islands. Biol. Invasions 10, 1299–1309. doi:10.1007/s10530-007-9204-z.

L. Celesti-Grapow L. Bassi G. Brundu I. Camarda E. Carli G. D'Auria ... L. Lazzaro Plant invasions on small Mediterranean islands: An overview Plant Biosyst 150 2016 1119 1133 10.1080/11263504.2016.1218974

Cerasoli, F., Iannella, M., Biondi, M., 2019. Between the hammer and the anvil: how the combined effect of global warming and the non-native common slider could threaten the European pond turtle.

Management of Biol. Invasions 10, 428–448. doi:10.3391/mbi.

Crisp, M.D., Laffan, S., Linder, ~~H.P~~H.P., Monro, A., 2001. Endemism in the Australian flora. J. Biogeogr. 28, 183–198. doi:10.1046/j.1365-2699.2001.00524.x.

Daehler, C.C., 2003. Performance comparisons of co-occurring native and alien invasive plants: implications for conservation and restoration. Annu. Rev. Ecol. Evol. Syst. 34, 183–211. doi:10.1146/annurev.ecolsys.34.011802.132403.

De Falco, G., Simeone, S., Baroli, M., 2008. Management of beach-cast *Posidonia oceanica* seagrass on the island of Sardinia (Italy, Western Mediterranean). ~~J. Coast. Res~~J. Coast. Res. 24, 69–75. doi:10.2112/06-0800.1.

Di Gregorio, F., Federici, P.R., Fierro, G., Ginesu, S., 2000. Atlante delle spiagge della Sardegna. SELCA, Firenze.

Fattorini, S., 2010. The influence of geographical and ecological factors on island beta diversity patterns. J. Biogeogr. 37, 1061–1070. doi:10.1111/j.1365-2699.2009.02252.x.

Fernandes, J.P., Guiomar, N., Gil, A., 2015. Strategies for conservation planning and management of terrestrial ecosystems in small islands (exemplified for the Macaronesian islands). ~~Environ. Sci. Policy~~Environ. Sci. Pol. 51, 1–22. doi:10.1016/j.envsci.2015.03.006.

Fois, M., Fenu, G., Bacchetta, G., 2016. Global analyses underrate part of the story: finding applicable results for the conservation planning of small Sardinian islets' flora. Biodivers. Conserv. 25, 1091–1106. doi:10.1007/s10531-016-1110-1.

Fois, M., Fenu, G., Cañadas, E.M., Bacchetta, G., 2017. Disentangling the influence of environmental and anthropogenic factors on the distribution of endemic vascular plants in Sardinia. PLoS One 12, e0182539. doi:10.1371/journal.pone.0182539.

Fois, M., Bacchetta, G., Cuena-Lombrana, A., Cogoni, D., Pinna, M.S., Sulis, E., Fenu, G., 2018. Using extinctions in species distribution models to evaluate and predict threats: a contribution to plant conservation planning on the island of Sardinia. Environ. Conserv. 45, 11–19. doi:10.1017/S0376892917000108.

Fois, M., Fenu, G., Bacchetta, G., 2018. Identifying and assessing the efficiency of different networks of a fine-scale hierarchy of biodiversity hotspots. Plant. Ecol. Divers. 11, 121–132. doi:10.1080/17550874.2018.1474281.

G. Galasso F. Conti L. Peruzzi N.M.G. Ardenghi E. Banfi L. Celesti-Grapow ... F. Bartolucci An updated checklist of the vascular flora alien to Italy Plant Biosyst 152 2018 556 592 10.1080/11263504.2018.1441197

B. Gallardo D.C. Aldridge P. González-Moreno J. Pergl M. Pizarro P. Pyšek ... M. Vilà Protected areas offer refuge from invasive species spreading under climate change Global Change Biol 23 2017 5331

5343 10.1111/gcb.13798

Gassó, N., Basnou, C., Vilà, M., 2010. Predicting plant invaders in the Mediterranean through a weed risk assessment system. Biol. Invasions 12, 463–476. doi:10.1007/s10530-009-9451-2.

Gauthier, P., Debussche, M., Thompson, J.D., 2010. Regional priority setting for rare species based on a method combining three criteria. Biol. Conserv. 143, 1501–1509. doi:10.1016/j.biocon.2010.03.032.

Georghiou, K., Delipetrou, P., 2010. Patterns and traits of the endemic plants of Greece. Bot. J. Linn. Soc. 162, 130–153. doi:10.1111/j.1095-8339.2010.01025.x.

Hess, A.L., 1990. Overview: sustainable development and environmental management of small islands. In: Beller, W., d'Ayala, P., Hein, P. (Eds.), ~~Man and the biosphere 5: sustainable development and environmental management of small islands~~ Man and the Biosphere 5: Sustainable Development and Environmental Management of Small Islands. UNESCO, Paris, pp. 3–14. http://portal.unesco.org/en/ev.php-URL_ID=12824&URL_DO=DO_TOPIC&URL_SECTION=201.html.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25, 1965–1978. doi:10.1002/joc.1276.

Hobohm, C., 2003. Characterization and ranking of biodiversity hotspots: centers of species richness and endemism. Biodivers. Conserv. 12, 279–287. doi:10.1023/A:1021934910722.

P.E. Hulme G. Brundu I. Camarda P. Dalias P. Lambdon F. Lloret ... M. Vilà Assessing the risks to Mediterranean islands ecosystems from alien plant introductions B. Tokarska-Guzik J.H. Brock G. Brundu L. Child C.C Daehler P. Pyšek Plant invasions: human perception, ecological impacts and management 2008 Backhuys Publishers Leiden 39 56

E. Lagabrielle M. Rouget K. Payet N. Wistebaar L. Durieux S. Baret ... D. Strasberg Identifying and mapping biodiversity processes for conservation planning in islands: A case study in Réunion Island (Western Indian Ocean) Biol. Conserv. 142 2009 1523 1535 10.1016/j.biocon.2009.02.022

Lavergne, S., Thuiller, W., Molina, J., Debussche, M., 2005. Environmental and human factors influencing rare plant local occurrence, extinction and persistence: a 115-year study in the Mediterranean region. J. Biogeogr. 32, 799–811. doi:10.1111/j.1365-2699.2005.01207.x.

Le Berre, M., Noble, V., Pires, M., Casazza, G., Minuto, L., Mariotti, M., Diadema, K., 2018. Applying a hierarchisation method to a biodiversity hotspot: challenges and perspectives in the South-Western Alps flora. J. Nat. Conserv. 42, 19–27. doi:10.1016/j.jnc.2018.01.007[Instruction: This article has more than seven authors and should be cited as: Le Berre, M., Noble, V., Pires, M., Casazza, G., Minuto, L., Mariotti, M., … Diadema, K., 2018. Applying a hierarchisation method to a biodiversity hotspot: challenges and perspectives in the South-Western Alps flora. J. Nat. Conserv. 42, 19–27. https://doi.org/10.1016/j.jnc.2018.01.007].

Lomolino, M.V., Weiser, M.D., 2001. Towards a more general species-area relationship: diversity on all islands, great and small. J. Biogeogr. 431–445. doi:10.1046/j.1365-2699.2000.00185.x.

Manhães, A.P., Loyola, R., Mazzochini, G.G., Ganade, G., Oliveira-Filho, A.T., Carvalho, A.R., 2018. Low-cost strategies for protecting ecosystem services and biodiversity. Biol. Conserv. 217, 187–194. doi:10.1016/j.biocon.2017.11.009.

Mansion, G., Rosenbaum, G., Schoenenberger, N., Bacchetta, G., Rosselló, J.A., Conti, E., 2008. Phylogenetic analysis informed by geological history supports multiple, sequential invasions of the Mediterranean Basin by the angiosperm family Araceae. Syst. Biol. 57, 269–285. doi:10.1080/10635150802044029.

Marini, L., Bertolli, A., Bona, E., Federici, G., Martini, F., Prosser, F., Bommarco, R., 2013. Beta-diversity patterns elucidate mechanisms of alien plant invasion in mountains. ~~Global Ecol. Biogeogr.~~Glob. Ecol. Biogeogr. 22, 450–460. doi:10.1111/geb.12006.

Matthews, T.J., Rigal, F., Triantis, K.A., Whittaker, R.J., 2019. A global model of island species–area relationships. PNAS 116, 12337–12342. doi:10.1073/pnas.1818190116.

O. Mayoral F. Mascia L. Podda E. Laguna P. Fraga J. Rita … G. Bacchetta Alien plant diversity in Mediterranean wetlands: a comparative study within Valencian, Balearic and Sardinian floras Not. Bot. Horti Agrobot. Cluj-Na. 46 2017 317 326 10.15835/nbha46210470

K.L. McDougall J. Lembrechts L.J. Rew S. Haider L.A. Cavieres C. Kueffer … T. Seipel Running off the road: roadside non-native plants invading mountain vegetation Biol. Invasions 20 2018 3461 3473 10.1007/s10530-018-1787-z

Médail, F., 2013. The unique nature of Mediterranean island floras and the future of plant conservation. In: Cardona Pons, E., Estaún Clarisó, I., Comas Casademont, M., Fraga i Arguimbau, P. (Eds.), ~~Islands and plants: preservation and understanding of flora on Mediterranean islands~~Islands and Plants: Preservation and Understanding of Flora on Mediterranean Islands. In: 2nd Botanical Conference in Menorca. Recerca 20. Consell Insular de Menorca. Institut Menorquí d'Estudis, Maó, Menorca, pp. 325–350. https://www.academia.edu/9800704/Islands_and_plants_preservation_and_understanding_of_flora_on_Mediterranean_islands_THE_UNIQUE_NATURE_OF_MEDITERRANEAN_ISLAND_FLORAS_AND_THE_FUTURE_OF_PLANT_CONSERVATION?auto=download.

Médail, ~~F~~F., 2017. The specific vulnerability of plant biodiversity and vegetation on Mediterranean islands in the face of global change. ~~Reg. Environ. Change~~Reg. Environ. Chang. 17, 1775–1790. doi:10.1007/s10113-017-1123-7.

Médail, F., Diadema, K., 2009. Glacial refugia influence plant diversity patterns in the Mediterranean Basin. J. Biogeogr. 36, 1333–1345. doi:10.1111/j.1365-2699.2008.02051.x.

Médail, F., Quézel, P., 1997. Hot-spots analysis for conservation of plant biodiversity in the Mediterranean Basin. Ann. Mo. Bot. Gard. 84, 112–127. doi:10.2307/2399957.

Médail, F., Vidal, E., 1998. Organisation de la richesse et de la composition floristique d'îles de la Méditerranée occidentale (sud-est de la France). Can. J. Bot. 76, 321–331. doi:10.1139/b97-135.

Meiri, S., 2017. Oceanic island biogeography: nomothetic science of the anecdotal. Front. Biogeogr. 9, e32081. doi:10.21425/F59132081.

Moody, A., 2000. Analysis of plant species diversity with respect to island characteristics on the Channel Islands, California. J. Biogeogr. 27, 711–723. doi:10.1046/j.1365-2699.2000.00435.x.

B. Naimi. Usdm: uncertainty analy[Instruction: Naimi (2015) should be cited as following: Naimi, B., 2015. Usdm: uncertainty analysis for species distribution models. R package version 1.1– 15. http://CRAN.R-project.org/package=usdm]sis for species distribution models. R package version 1.1– 15 http://CRAN.R-project.org/package=usdm, 2015.

Nikolić, T., Antonić, O., Alegro, A.L., Dobrović, I., Bogdanović, S., Liber, Z., Rešetnik, I., 2008. Plant species diversity of Adriatic islands: an introductory survey. Plant Biosyst 142, 435–445. doi:10.1080/11263500802410769.

J. Oksanen , F.G. Blanchet , R. Kindt , P. Legendre , P.R. Minchin , R.B. O'Hara , ... H. WagnerO . Vegan: community ecology package . R package version 2.0-1 http://cran.r-project.org/web/packages/vkegan/index.html, 2013 . sanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O''Hara, R.B., … Wagner, H., 2013. Vegan: community ecology package. R package version 2.0-1. http://cran.r-project.org/web/packages/vegan/index.html.

S. Orsenigo C. Montagnani G. Fenu D. Gargano L. Peruzzi T. Abeli ... C. Brullo Red Listing plants under full national responsibility: extinction risk and threats in the vascular flora endemic to Italy Biol. Conserv. 224 2018 213 222 10.1016/j.biocon.2018.05.030

Panitsa, M., Tzanoudakis, D., Sfenthourakis, S., 2008. Turnover of plants on small islets of the eastern Aegean Sea within two decades. J. Biogeogr. 35, 1049–1061. doi:10.1111/j.1365-2699.2007.01846.x.

C. Penone B.G. Weinstein C.H. Graham T.M. Brooks C. Rondinini S.B. Hedges ... G.C. Costa Global mammal beta diversity shows parallel assemblage structure in similar but isolated environments Proc. R. Soc. B. 283 2016 20161028 10.1098/rspb.2016.1028

Pesaresi, S., Galdenzi, D., Biondi, E., Casavecchia, S., 2014. Bioclimate of Italy: application of the worldwide bioclimatic classification system. J. Maps 10, 538–553. doi:10.1080/17445647.2014.891472.

Pinna, M.S., Bacchetta, G., Cogoni, D., Fenu, G., 2019. Is vegetation an indicator for evaluating the impact of tourism on the conservation status of Mediterranean coastal dunes?. Sci. Total Environ. 674, 255–263. doi:10.1016/j.scitotenv.2019.04.120.

Pitta, E., Kassara, C., Tzanatos, E., Giokas, S., Sfenthourakis, S., 2014. Between-island compositional dissimilarity of avian communities. Ecol. Res. 29, 835–841. doi:10.1007/s11284-014-1170-1.

Podani, J., Schmera, D., 2011. A new conceptual and methodological framework for exploring and explaining pattern in presence—absence data. Oikos 120, 1625–1638. doi:10.1111/j.1600-0706.2011.19451.x.

Podda, L., Santo, A., Mattana, E., Mayoral, O., Bacchetta, G., 2018. Inter-and intra-variability of seed germination traits of *Carpobrotus edulis* NE Br. and its hybrid *C*. affine *acinaciformis*. Plant Biol. 20, 1059–1067. doi:10.1111/plb.12867.

Pretto, F., Celesti-Grapow, L., Carli, E., Blasi, C., 2010. Influence of past land use and current human disturbance on non-native plant species on small Italian islands. Plant Ecol. 210, 225–239. doi:10.1007/s11258-010-9751-8.

Pretto, F., Celesti-Grapow, L., Carli, E., Brundu, G., Blasi, C., 2012. Determinants of non-native plant species richness and composition across small Mediterranean islands. Biol. Invasions 14, 2559–2572. doi:10.1080/11263504.2016.1218974.

Puddu, S., Podda, L., Mayoral, O., Delage, A., Hugot, L., Petit, Y., Bacchetta, G., 2016. Comparative analysis of the alien vascular flora of Sardinia and Corsica. Not. Bot. Horti Agrobot. Cluj-Na. 44, 337–346. doi:10.15835/nbha44210491.

Regione Autonoma della Sardegna, 2003. Carta dell'Uso del Suolo (Scala 1:25.000). Note illustrative. Roma: Assessorato agli Enti Locali, Finanze ed Urbanistica. http://dati.regione.sardegna.it/dataset/carta-delluso-del-suolo-in-scala-1-25-000-2003.

Rodrigues, A.S.L., Pilgrim, J.D., Lamoreux, J.F., Hoffmann, M., Brooks, T.M., 2006. The value of the IUCN red list for conservation. Trends Ecol. Evol. 21, 71–76. doi:10.1016/j.tree.2005.10.010.

Rosenbaum, G., Lister, G.S., Duboz, C., 2002. Reconstruction of the tectonic evolution of the western Mediterranean since the Oligocene. J. Virt. Ex. 8, 107–126. doi:10.3809/jvirtex.2002.00053.

Ruffino, L., Bourgeois, K., Vidal, E., Duhem, C., Paracuellos, M., Escribano, F., Oro, D., 2009. Invasive rats and seabirds after 2,000 years of an unwanted coexistence on Mediterranean islands. Biol. Invasions 11, 1631–1651. doi:10.1007/s10530-008-9394-z.

Salvo, G., Ho, S.Y., Rosenbaum, G., Ree, R., Conti, E., 2010. Tracing the temporal and spatial origins of island endemics in the Mediterranean region: a case study from the citrus family (*Ruta* L., Rutaceae). Syst. Biol. 59, 705–722. doi:10.1093/sysbio/syq046.

Smiraglia, D., Capotorti, G., Guida, D., Mollo, B., Siervo, V., Blasi, C., 2013. Land units map of Italy. J. Maps 9, 239–244. doi:10.1080/17445647.2013.771290.

Socolar, J.B., Gilroy, J.J., Kunin, W.E., Edwards, D.P., 2016. How should beta-diversity inform biodiversity conservation?. Trends Ecol. Evol. 31, 67–80. doi:10.1016/j.tree.2015.11.005.

Sperandii, M.G., Bazzichetto, M., Acosta, A.T.R., Barták, V., Malavasi, M., 2019. Multiple drivers of plant diversity in coastal dunes: a Mediterranean experience. Sci. Total Environ. 652, 1435–1444. doi:10.1016/j.scitotenv.2018.10.299.

Steinbauer, M.J., Irl, S.D., Beierkuhnlein, C., 2013. Elevation-driven ecological isolation promotes diversification on Mediterranean islands. Acta Oecol. 47, 52–56. doi:10.1016/j.actao.2012.11.004.

Stephenson, N.L., 1998. Actual evapotranspiration and deficit: biologically meaningful correlates of vegetation distribution across spatial scales. J. Biogeogr. 25, 855–870. doi:10.1046/j.1365-2699.1998.00233.x.

Terzopoulou, S., Rigal, F., Whittaker, R.J., Borges, P.A., Triantis, K.A., 2015. Drivers of extinction: the case of Azorean beetles. Biol. Lett. 11, 20150273. doi:10.1098/rsbl.2015.0273.

Thiers B., 2019 [continuously updated]. *Index Herbariorum*: a global directory of public herbaria and associated staff. New York Bot Garden's Virtual Herbarium. http://sweetgum.nybg.org/science/ih/ (accessed 20 December 2019).

Trabucco, A., Zomer, R.J., 2010. Global soil water balance geospatial database. In: CGIAR Consortium for Spatial Information. http://www.cgiar-csi.org. (Accessed 18 January 2019).

Tuomisto, H., 2010. A diversity of beta diversities: straightening up a concept gone awry. Part 1. Defining beta diversity as a function of alpha and gamma diversity. Ecography 33, 2–22. doi:10.1111/j.1600-0587.2009.05880.x.

Valli, A.T., Kougioumoutzis, K., Iliadou, E., Panitsa, M., Trigas, P., 2019. Determinants of alpha and beta vascular plant diversity in Mediterranean island systems: the Ionian islands, Greece. Nord. J. Bot. 37, e02156. doi:10.1111/njb.02156.

Whittaker, R.J., Triantis, K.A., Ladle, R.J., 2008. A general dynamic theory of oceanic island biogeography. J. Biogeogr. 35, 977–994. doi:10.1111/j.1365-2699.2008.01892.x.

Whittaker, R.J., Fernández-Palacios, J.M., Matthews, T.J., Borregaard, M.K., Triantis, K.A., 2017. Island biogeography: taking the long view of nature's laboratories. Science 357, 8326. doi:10.1126/science.aam8326.

Wylie, J.L., Currie, D.J., 1993. Species-energy theory and patterns of species richness: I. patterns of bird, angiosperm, and mammal species richness on islands. Biol. Conserv. 63, 137–144. doi:10.1016/0006-3207(93)90501-Q.

Yan, Y., Yang, X., Tang, Z., 2013. Patterns of species diversity and phylogenetic structure of vascular plants on the Qinghai-Tibetan Plateau. Ecol. Evol. 3, 4584–4595. doi:10.1002/ece3.847.

Zhang, M., Chang, C., Quan, R., 2017. Natural forest at landscape scale is most important for bird conservation in rubber plantation. Biol. Conserv. 210, 243–252. doi:10.1016/j.biocon.2017.04.026.

Graphical abstract
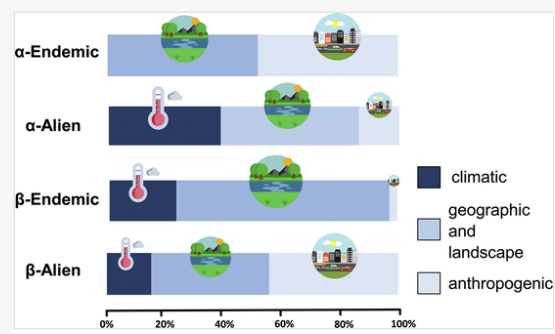
Highlights

- Small islands are areas of plant endemism and invasibility.
- Endemic and alien species richness and compositional dissimilarities are investigated.
- Anthropogenic factors appear to impact only endemic compositional dissimilarities.
- Climate and geographic/landscape drivers must be taken into account.
- Multi-criteria analyses contribute to perform more efficient conservation plans.

Tests using the *ncf* R package (Bjornstad, 2016) revealed that there was no statistically significant spatial autocorrelation in model residuals (see *Appendix A*; Fig. A1). All analyses were carried out in R 3.6.2 (R Development Core Team). We recorded 168 alien plant taxa on the 40 islands analysed, representing about 35% of the 481 alien taxa of the entire Sardinian territory. A similar percentage (36%) was found for the endemic component, with 105 out the 294 taxa endemic to Sardinia. Strong and significant positive correlations between endemic and alien species richness and island area were found ($R^2 \geq 0.69$; $P < 0.001$; *Appendix A*; Fig. A.2). Such correlation was less strong for the compositional dissimilarity of endemic ($R^2 = 0.36$) and alien ($R^2 = 0.66$) plant species, even though significant ($P < 0.001$) in both groups (*Appendix A*, Fig. A.3).