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Prioritizing conservation of terrestrial orchids: A gap analysis for Italy

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ABSTRACT

Protected areas (PAs) are a strategic tool for biodiversity conservation, and conservation planning approaches are used to optimize PAs capacity to preserve specific target groups. Orchidaceae is one of the most threatened plant families, as most species are vulnerable to habitat changes because of their strong ecological specialization. Italy plays a key role in biogeography as a result of its geographical position and hosts one of the most diverse orchid floras in the Mediterranean Basin. The aim of this work is to depict the degree of protection granted to orchids by the current network of PAs across the entire Italian country, testing whether distributional and ecological features affect species' conservation representativeness, and identifying a priority list of species to be further protected. We compiled a dataset comprising 71,693 occurrence records, the spatial conservation representativeness was calculated as the percent of occurrences falling within the borders of PAs. Generalized Linear Models were run to assess differences in the spatial conservation representativeness among species according to the preferred habitat, endemicity, chorology, and protection by the Habitats Directive. We produced a list of species to be used for prioritizing conservation planning. Our findings show that emphasis is needed on adopting orchid species linked to primary or well mature habitats to select additional PAs with high conservation significance. Our findings reiterate the urgency of targeted conservation actions that can protect orchids and prevent their decline.

1. Introduction

Biodiversity conservation is one of the main challenges Humanity has faced in the last decades. Several plans for the conservation of biodiversity have focused on the importance of expanding protected areas (PAs, hereafter) and identifying target species as key objectives for slowing the loss of biodiversity. Among these, the Strategic Plan for Biodiversity 2011–2020, with 20 Aichi Biodiversity targets, specifically recommends increasing the protection and management of areas important for biodiversity (target 11) as well as improving the conservation status of endangered species and lowering the risk of their extinction (target 12) (SCBD, 2011). The establishment of portions of land area specifically dedicated to the protection of biodiversity is crucial for slowing down the loss of biodiversity (Watson et al., 2014). PAs are defined as regions of land or sea that are designated and managed for the long-term conservation of nature and associated ecosystem services (Gaston et al., 2008; Hannah et al., 2007; Pressey et al., 2007). PAs are an important asset in biological conservation

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because they provide a safe refuge for biodiversity while also buffering the effects of human activities on ecosystems (Foxcroft et al., 2017). According to Watson et al. (2014), PAs promote species persistence and abundance, minimize the risk of extinction and facilitate ecosystems regeneration. PAs can also provide refuge for species threatened by climate change (Heller and Zavaleta, 2009) and preserve fundamental ecosystem services, which are critical for human livelihoods. A recent global assessment estimated that protecting 30 % of the planet's terrestrial and marine ecosystems by 2030 could provide significant benefits for both biodiversity and human well-being (IPBES, 2019). The efficiency of PAs in fulfilling conservation objectives is not to be taken for granted, since factors such as inadequate management, lack of funding, and fragmentation can undermine their effect on biodiversity conservation (Cao et al., 2013; Elsen et al., 2020; Leverington et al., 2010; Watson et al., 2014). Climate change also presents a significant challenge to PAs, as many species and ecosystems will need to adapt to changing conditions (Heller and Zavaleta, 2009; Hoffmann et al., 2019).

Conservation planning efforts typically begin with a pre-existing network of PAs, acting as a starting point for identifying gaps and identifying additional sites for enlarging the conservation area network. In this respect, gap analysis is an effective tool to formulate conservation strategies for biodiversity and ecosystems (Santini et al., 2016). Gap analysis has been used to identify targets of high conservation value that are not fully protected to prioritize them in further conservation measures. Gap analysis focuses on how effectively PA networks overlap with species distributions and occurrence (Jennings, 2000) and it has primarily been performed in terms of species distribution and abundance in PAs as a proxy for the creation of habitat suitability maps, considering terrestrial mammals (Maiorano et al., 2006; Santini et al., 2016). Until recently, plant conservation in terms of identification of plant diversity hotspots has received comparatively little attention (Blasi et al., 2011; Carta et al., 2019, 2018; Marignani and Blasi, 2012). However, there have been recent papers exploring conservation gaps for plant species and habitats (Chiarucci et al., 2008; Moreno-Saiz et al., 2021; Qin et al., 2022; Rosati et al., 2008; Spiliopoulou et al., 2023).

Italy, in the middle of the Mediterranean biodiversity hotspot, is characterized by high biodiversity and strong biogeographical gradients (see e.g., Blasi et al., 2011; Chiarucci et al., 2019) and has a significant amount of PAs (UNEP-WCMC, 2003). The main categories of PAs in Italy are National and Regional Parks, Nature Reserves, Natural Monuments, Marine Protected Areas, and Regional Nature Parks. Only partially overlapping to these, a rich network of Natura 2000 Sites of Community Importance (SCIs) and Special Areas of Conservation (SACs), together with the Special Protection Areas (SPA), adds to the overall protected surface in Italy, summing to ca. the 21.6 % of the national land territory and 10.6 % of the marine (UNEP-WCMC, 2003). Given the heterogeneity of PA categories, they vary in terms of management strategies, legislation and governing bodies.

Orchidaceae is one of the most endangered plant families, as most species are vulnerable to habitat changes because of their strong ecological specialization (Cribb et al., 2003; Givnish et al., 2016). Orchids also represent a typical target for developing and adopting conservation strategies (Pillon and Chase, 2007). This plant family includes >28.000 taxa and is globally distributed and is distinguished by extreme adaptability to local ecological factors (Givnish et al., 2016; Skotnicki et al., 2009). Nonetheless, many species are threatened by land use, climate change, overexploitation, or their natural rarity due to the high rates of endemism that characterize the family. Thus, orchids are an excellent model group for assessing the effectiveness of current strategies for plant conservation to address and develop key biodiversity areas (Pillon and Chase, 2007; Tsiftsis et al., 2009; Tsiftsis and Tsiripidis, 2020) but the only a study measures the role of Nature 2000 network in protecting orchids showing a limited overlap between orchids' occurrence and PAs (Tsiftsis, 2021). Italy has one of the most diverse orchid floras in the area. Up to now, few studies have focused on examining the conservation needs of a specific taxon (Blasi et al., 2011; Lin et al., 2021).

In this study, we aim at evaluating the efficiency of the existing conservation network in protecting the orchid flora of Italy. Specifically, we aim at: i) assessing how much protection is provided to orchids by the current network of PAs; ii) testing whether species' conservation representativeness is influenced by distributional (chorology, endemicity) and ecological (habitat preferences) species features; and iii) identifying a priority list of taxa for conservation.

2. Materials and methods

2.1. Study area

Italian territory falls within the Mediterranean, Alpine and Continental biogeographic regions (Cervellini et al., 2020). The territory has a surface of ca. 302,000 km^2 and is characterized by high altitudinal ranges throughout its length. Besides the peninsular portion, Italian geography is characterized by a high number of islands and archipelagos, including the largest ones in the Mediterranean Basin (Sardinia and Sicily), as well as volcanic archipelagos such as the Aeolian Islands, all of which have contributed to a remarkable plant diversity. As such, Italy shows the highest plant species richness in Europe (Bartolucci et al., 2018), hosting 8195 species and subspecies of native plants (afterward referred to as species), grouped in 152 families and 1092 genera. This richness results from the combined effects of large elevational gradients, unique climatic and geological variation, and a diversified biogeographic context (Chiarucci et al., 2019), in which human presence over time has profoundly shaped the landscape (Blasi et al., 2014; Capotorti et al., 2012; Smiraglia et al., 2013). The World Database on Protected Areas (UNEP-WCMC, 2003) lists 3948 PAs that make up the Italian PAs network, including national and regional parks, natural reserves, biotopes and natural monuments, as well as 79 Sites of Community Importance (SCIs) and 2278 Special Areas of Conservation (SACs) (UNEP-WCMC, 2003) making up the Natura 2000 network (N2000) proposed under the European Birds and Habitats Directives.

2.2. Target species

The family Orchidaceae, with ca. >28.000 species, is the richest in the plant kingdom (Chase et al., 2015). It has a cosmopolitan distribution, ranging from the tropics, where it is highly diversified, to the poles, and from sea level to the highest mountains (Dressler, 1993). Since orchids' life cycle is inextricably linked to other organisms, such as fungi for the germination of their seeds and animals for pollination, they are recognized as indicators of ecosystem health (Fay, 2018). According to Bartolucci et al. (2018), Italy hosts 237 orchids species and subspecies. In order to account for the complexity of orchid taxonomy and prevent taxonomic inflation from leading to conservation bias (Pillon and Chase, 2007), we considered the species ranks only. Due to the intricacy of the species concept in orchids (Bateman and Rudall, 2023; Chase et al., 2015), nomenclature was standardized following Bartolucci et al. (2018) and then harmonized according to the *Plants of the World Online* (https://powo.science.kew.org/). Italian orchids face numerous threats, including habitat loss and fragmentation, overgrazing, overcollection and climate change (Pellegrino and Bellusci, 2014; Swarts and Dixon, 2009). As for other nature management regulations, orchid conservation is delegated to Regions and Autonomous Provinces, leading to uneven and fragmented protection practices and regulations. However, Italy has adopted the European Habitats Directive 92/43/EEC, which lists four orchid species in Annex II: *Cypripedium calceolus*, *Himantoglossum adriaticum*, *Liparis loeselii*, and *Ophrys lunulata*.

2.3. Species distribution data

We selected georeferenced records of all the taxa of the family Orchidaceae occurring within the political borders of Italy. Orchid occurrences were obtained from GBIF (https://www.gbif.org/; https://www.gbif.org/occurrence/download/0271235-220831081235567), iNaturalist (www.inaturalist.org) and Wikiplantbase #Italy (http://bot.biologia.unipi.it/wpb/italia), a collaborative online database of Italian vascular plants which is managed by Società Botanica Italiana and University of Pisa. Duplicates, as well as records with low spatial resolution (<4 degrees decimals of coordinates), were discarded; records collected before the year 1945 were excluded as well, in order to lower the risk of false occurrences for the present time. In the cases of two or more records of the same species occurring at a distance < 100 m, we only took into account the most recent one, in order to avoid counting the same individual twice, or more. As far as quantitative analyses are concerned (see below), we included in the analyses only species with >5 records, since the apparent rarity of species with fewer records may derive from a lack of exploration, as a consequence of recent taxonomic delimitations, instead of reflecting an actual small range or population size. All species were also grouped according to ecosystem type (classified as either forest, wetland or grassland habitats), endemicity (Italian endemic or not), chorology (following GIROS, 2016; Kühn et al., 2019), and inclusion in the Annex II of the Habitats Directive (HD).

2.4. Data analyses

For each species, we calculated the spatial conservation representativeness as the percent of occurrences falling within the borders of the entire network of Italian PAs. Extinction risk was assessed by consulting the IUCN Red List of Threatened Species databases (Orsenigo et al., 2018). We ran a Generalized Linear Model to assess differences in the spatial conservation representativeness among species according to the preferred habitat (categorized as either "forest", "grassland", "wetland", as specified above (Kühn et al., 2019)), endemicity (binary variable: endemic to Italy = 1, non-endemic to Italy = 0), chorology (categorized according to the 15 classes described by Kühn et al., 2019), and protection by the HD as assessed by the species being included in any Annex of the HD (binary variable: listed = 1, non-listed = 0). We also included the number of records as a covariate in order to verify any effect of different sampling efforts and/or spatial spread. In case of significant effects (variable effect size $p < 0.05$), we ran a Tukey's post-hoc test for calculating class contribution to significance, using a Bonferroni correction for multiple comparisons. To define a list of species to prioritize for conservation, linear regression was initially used to define the relationship between the percentage of occurrences within PAs and the total number of occurrences. Additionally, we fit an inverse logistic function to meet our theoretical expectation to assess which species should be preferred in conservation efforts. Indeed, we assumed that the protection cover should range from 30 % for very common species (>1000 occurrences) to 80 % for rare species (<10 occurrences). This was assessed in line with the objective of the EU Biodiversity Strategy 2030, namely to produce a species list that could reap major benefits if taken into account while planning for the next extension of Natura 2000 areas. Therefore, a logistic fit can elucidate how many and which species are only marginally impacted by the protection provided by the network of PAs in Italy. We were able to identify species that are currently not appropriately protected by computing the residuals for each species and determining their effective protection status. Record filtering, calculation of conservation representativeness, and maps were performed using QGIS version 3.16 (QGIS Development Team, 2020), while all other statistical analyses and figures were produced using R Studio version 4.1.2 (R Core Team, 2022).

3. Results

We collected 74,762 records for 195 species of orchids occurring in Italy (Fig. 1), which were reduced to 71,693 after data cleaning; number of records per species ranged from 1 (for the endemic *Ophrys gravinensis*) to 3163 (*Dactylorhiza maculata*), averaging 385 records per species (95 % confidence interval: 297–474) (Appendix B, Table 1). Full details of species occurrences and their IUCN assessment are provided in Appendix A.

Out of the 195 species, 70 are endemic to Italy (36 %), and 4 (2 %) are listed within Annex II of the Habitats Directive. Nine species (4.6 %) are classified as threatened (either VU or EN) by the IUCN European Red List, 11 as Near Threatened (5.6 %), 3 as Data Deficient (1.5 %), 76 as Least Concern (39.0 %), and 95 not assessed (48.7 %) (Appendix B, Table 1). Overall, orchid species showed on average 47.7 % ± 24.0 % of records within PAs (95 % confidence interval: 43.4 %–51.1 %), with thirteen species having all their occurrences within the PA network and thirteen species completely unprotected (Appendix B, Table 1).

A total of 32 species showed <5 independent recent records. Thus, 163 species were used for quantitative analyses. Among the tested predictors, only the species' preferred habitat showed a significant effect on the value of species' spatial conservation representativeness ($F_{2,155} = 4.38$, $p = 0.014$), with significant differences occurring between species linked to grasslands and forests (padj = 0.046), and between those linked to wetlands and forests (padj = 0.042); namely, wetland species (n = 5) featured on average 30.2 % of protected occurrences, grassland species (n = 129) 46.2 %, and forest species (n = 29) 57.6 %. In fact, orchid genera with lower representativeness in our analysis mostly comprised taxa occurring in wetlands and either wet or dry grasslands (e.g., genera *Dactylorhiza*, *Himantoglossum*, *Platanthera* and *Orchis*), with the exception of the genus *Cephalanthera*, which was the only forest specialist group of species with low conservation representativeness values (Fig. 2). No significant effect of HD protection, number of records, or endemicity was found (all $p > 0.05$), i.e., this indicates that the value of conservation representativeness was not influenced by being included in the HD Annexes, or by being more frequently recorded and distributed, or by being limited to the Italian region.

Chorology did not show any significant effect on the conservation representativeness. Ninety-two species revealed a negative difference between expected and observed residuals (16 within −80 and −50, 21 within −50 and −25, and 55 within −25 and 0). A positive difference was observed for 102 species, of which 65 were between 0 and 25, 32 between 25 and 50 and 5 > 50 (Fig. 3).

Sixteen species have been identified as high priority species (difference between residuals < −50, Fig. 4). 62 % of these are Italian endemic, with 40 % belonging to the genus *Epipactis* (N = 4), 40 % to *Ophrys* (N = 4), and 10 % to the *Limodorum* and *Serapias* (N = 1 each). The remaining 38 % belongs to the genus *Liparis* (N = 2), *Ophrys* (N = 2), *Epipactis*, and *Platanthera* (N = 1 each) (Fig. 5).

4. Discussion

Here, we developed a prioritization exercise for the entire territory of Italy by focusing on orchids, a cosmopolitan plant taxon highly indicative of ecological quality that may serve as a blueprint protocol for planning the expansion of PAs while safeguarding all biotic and abiotic networks linked to it. A well-defined species prioritization list, such as the one proposed here, is a crucial tool for identifying conservation goals, defining new PAs or expanding those that already exist.

Similarly to the finding for East Macedonia (Tsiftsis, 2021), our results clearly highlight how poorly orchids are effectively protected by the network of Italian PAs and how an enlargement of the protected area network is needed to ensure its representativeness for this taxon. This is not surprising, given that PAs were not specifically designed to take orchids into account and that their historical setting was not based on a systematic planning approach. By compiling a comprehensive database of orchid occurrences in the Italian territory and testing the influence of habitat preferences, protection regimes, and biogeographical traits upon the conservation representativeness of 163 taxa, we highlight the relevance of habitats for orchids' conservation, showing a significantly lower protected area representativeness for species associated to wetlands and grasslands. As a result of our investigation, wetlands and

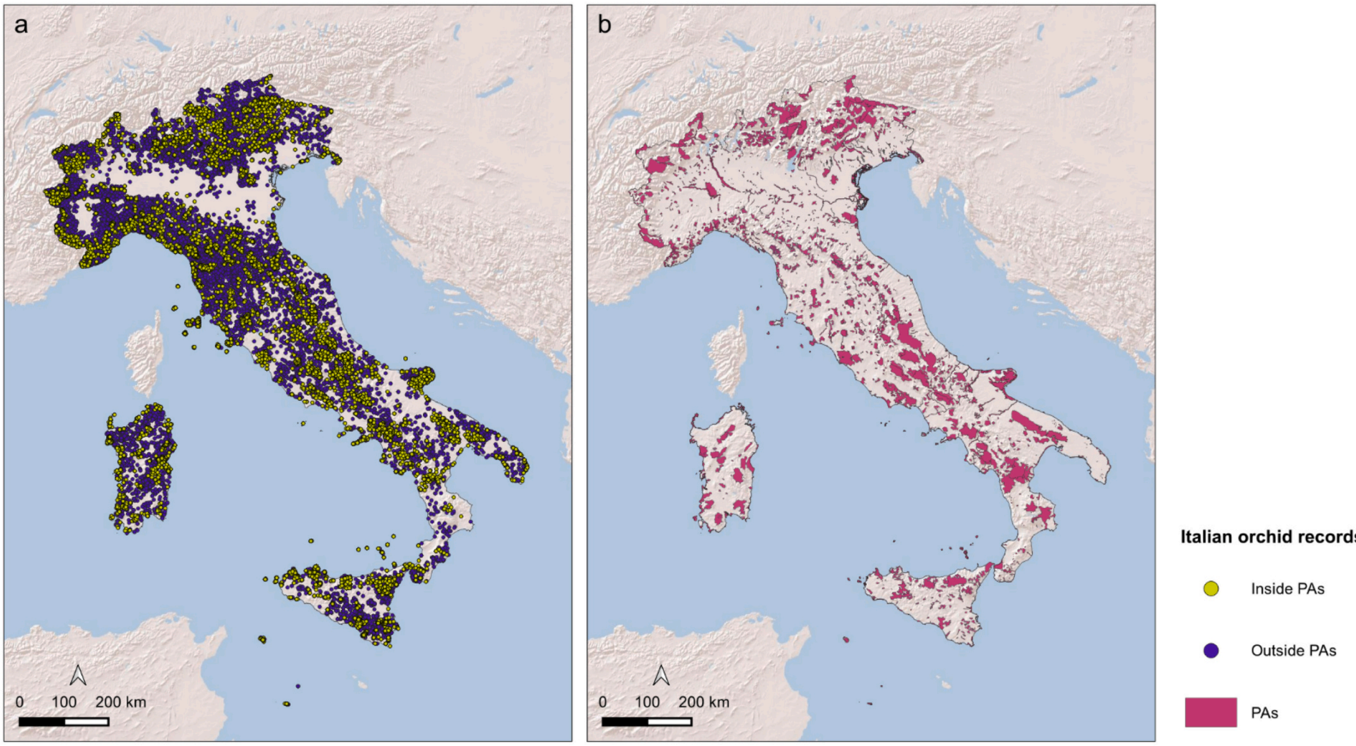

Fig. 1. Distribution of occurrences of orchid species (a) and surface of protected areas (b) in Italy.

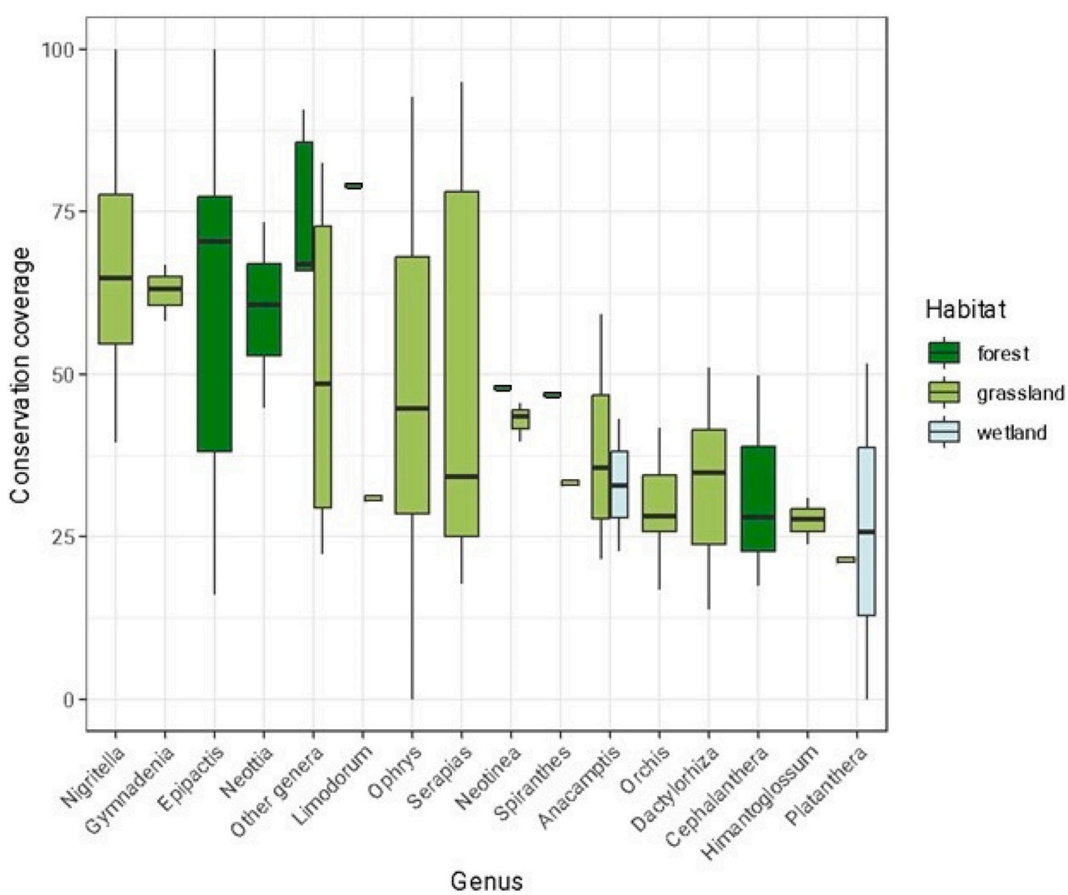

Fig. 2. Boxplots showing the variability in spatial conservation representativeness (as percent of occurrences falling within PAs) for 163 species of orchids in Italy, grouped by genus and preferred habitat and organized in decreasing order according to mean.

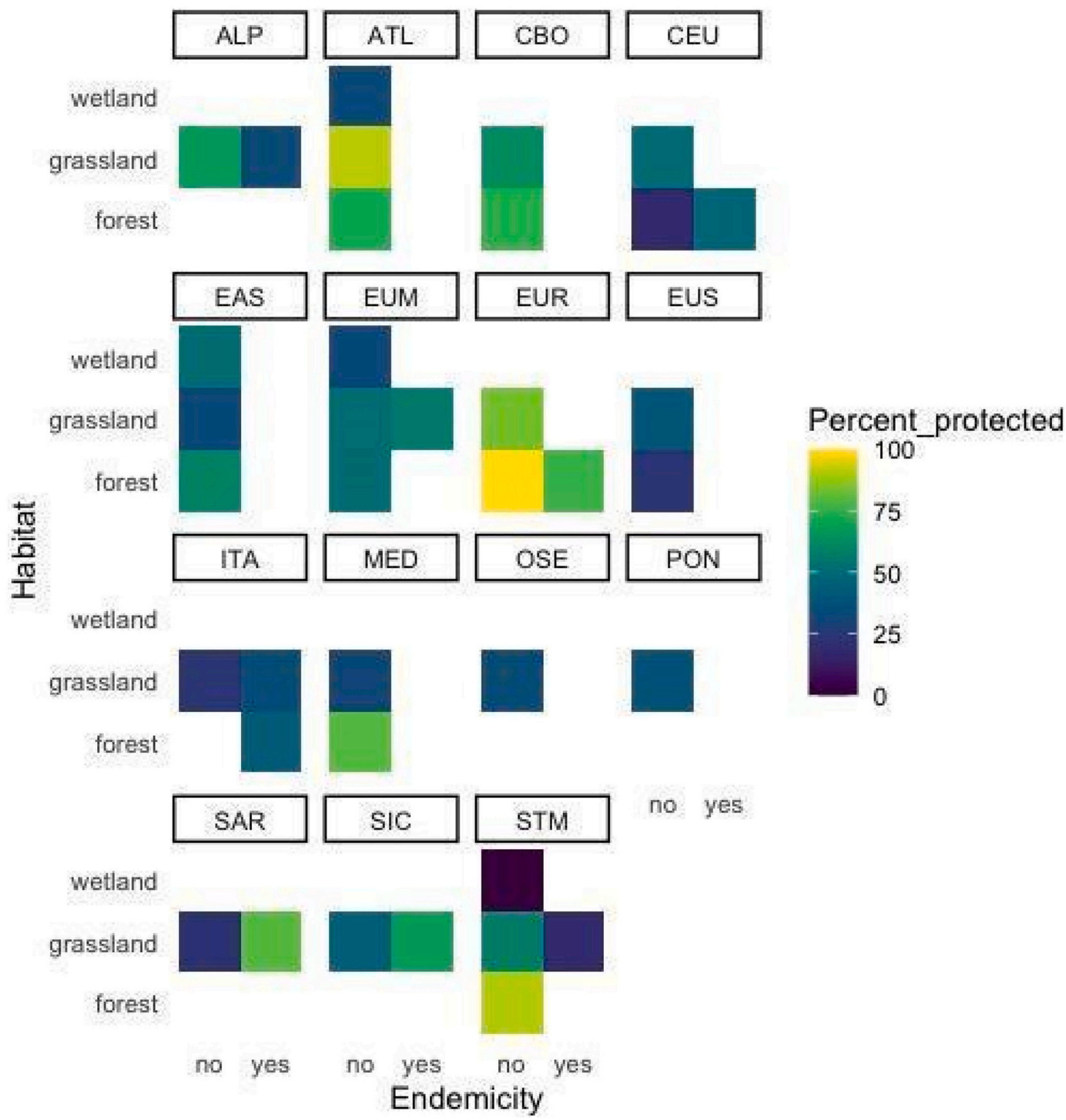

Fig. 3. Heatmap of conservation representativeness of orchid species (n = 163) in Italy, separately for habitats (wetland, grassland and forest) and chorology. EUR = European, ATL = Atlantic, ITA = Italic; ALP = Artic-Alpine, CBO = Circum-Boreal; SIC = Sicilian; OSE = South European Orophyte; EAS = Eurasiatic, CEU = Central European, MED = Mediterranean, EUM = Eurimediterranean, STM = Stenomediterranean, SARD = Sardo-Corsican, PON = Pontic. (Full definitions of chorological categories used are provided in Appendix B, Table 2).

grasslands are key habitats on which expand PAs for orchid conservation. Based on the occurrences of these species, we can also identify that a potential enlargement of PAs network might be designed providing importance to these habitats. Wetlands, including marshes, ponds, and riverine ecosystems are well known to be particularly affected by anthropic transformation at several scales, ranging from local - such as water collection and land reclamation for agriculture - to global factors like climate change and its associated events (e.g., droughts), with accumulated negative effects on the most specialized flora (Bolpagni et al., 2018; Montanari et al., 2020). In Italy, the status of wetland ecosystem is negatively affected by human transformation, with reduction of the amount of natural wetlands, water level fluctuation, impact of agriculture and urbanization playing a pivotal role in this process. The result is that many species closely related to this habitat, such as *Anacamptis palustris* and *Malaxis paludosa*, are already declining at a rapid and progressive rate. As Bolpagni et al. (2018) pointed out, historical drainage and reclamation of most of the national wetlands, lead to significant reduction or even the extinction of many wetlands specialized plants and the elaboration of large-scale strategies to ensure the survival of aquatic plants is urgent, also in the light of the predicted climatic changes. On the other hand, in hyper-exploited landscapes such as those of many Italian landscapes, in which plant communities are driven more by human management than ecological factors (Bolpagni et al., 2018; Montanari et al., 2022, 2020) man-made water bodies can contribute to achieve some basic conservation targets. The debate on the restoration and rewilding of riverine and other wetland ecosystems which is presently ongoing in Europe (see e.g., Brown et al., 2018; Willby et al., 2018) can benefit from having established specific conservation targets as prioritized species lists for orchids as those here provided.

On the other hand, most of the dry grasslands and meadows, including garrigues and pastures, are intimately related to traditional human activities and these are likely to be subjected to the ongoing process of naturalization due the abandonment on traditional agricultural practices in many remote areas. According to Pierce et al. (2014) preservation of species-rich habitats in semi-natural dry grasslands is crucial for the conservation of Italian endemic orchid taxa, which are particularly susceptible to pedomorphological changes and replacement by species with faster growth rates. Habitat protection is undoubtedly the cornerstone of orchid conservation (Cribb et al., 2003; Hágsater

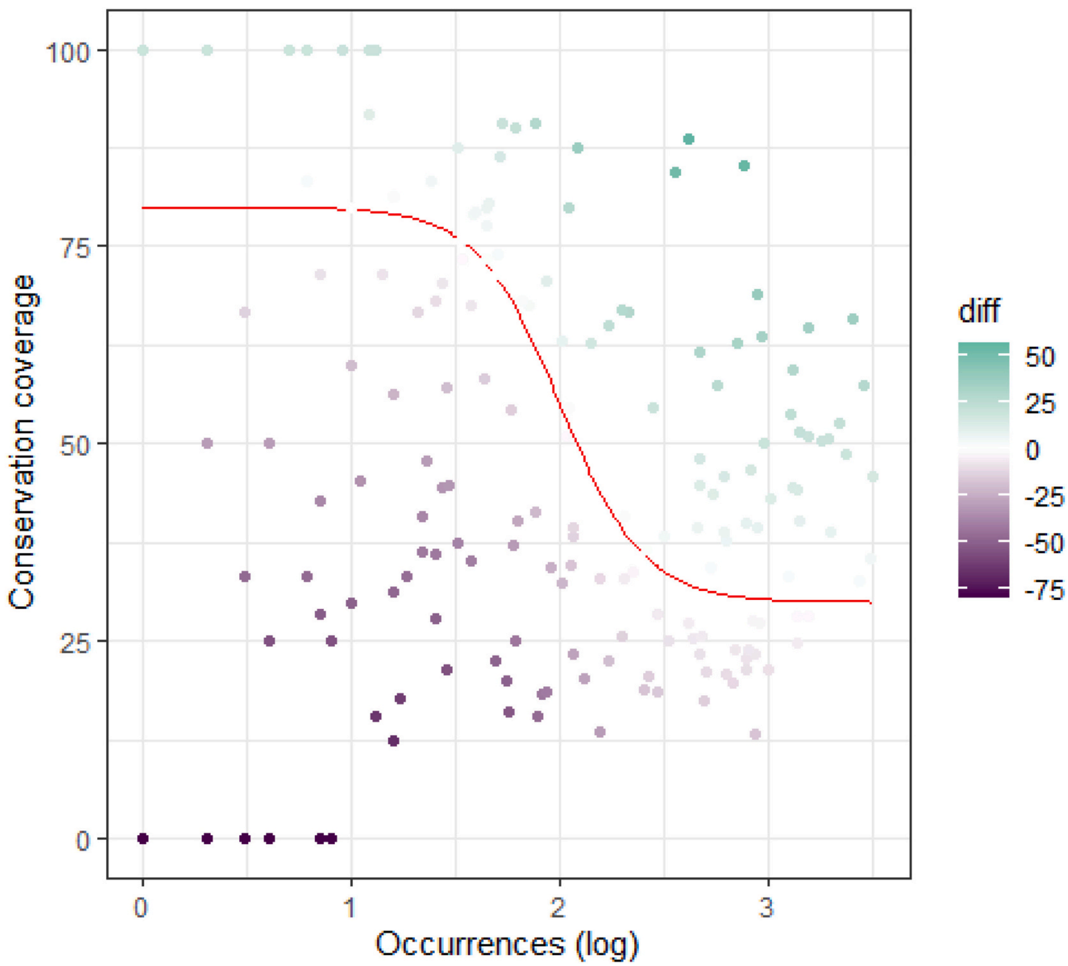

Fig. 4. Relationship between the percentage of occurrences falling within PAs and the log transformed number of occurrences for 195 orchid species in Italy. The expected inverse logistic function is shown in red. Negative differences between residuals are shown in purple, while positive differences are shown in green. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

et al., 1996), however, the conservation of static cultural landscapes is not realistic with the ongoing process of population urbanization and depopulation trends in mountain areas and the abandonment of traditional grazing practices. Orchid protection per se can only reach successful conservation effects if combined with plant-pollinator interactions (Djordjević et al., 2022, 2020; Hutchings et al., 2018; Vereecken et al., 2010). When planning the extension of potential PAs, not considering the pollinator-plant relationship will lead to ephemeral conservation effort. In contrast, Alpine grasslands are less directly affected by direct human impact, as they are usually located beyond 2500 m, i.e., at more remote locations. The symmetric overall higher spatial conservation representativeness of forest species we found may be due to at least two factors: i) PAs are spatially biased towards forest areas (Rosati et al., 2008), mostly due to their lower suitability to agriculture, and accessibility (Venter et al., 2018; Wade et al., 2020), and ii) forests are expanding throughout Europe, after the abandonment of agricultural and pastoral practices in many mountain areas (Amici et al., 2013; Geri et al., 2010). Both of these phenomena probably contribute to making forest orchids less susceptible to extinction and better covered by the existing network of PAs, at least in Italy. Hence, for the orchid species traditionally linked to cultural mountain landscapes simulation and modeling analyses are needed to understand the future potential distribution range shift with the ongoing re-naturalization processes, which are inevitable and also contribute to improve the nature contribution to people. New rewilding scenario, including the reintroduction of large wild herbivores, could be considered to restore grazing where herbivory functions are missing due extensive livestock farming abandonment and/or the depletion of functional wild herbivore populations (see e.g., Bonavent et al., 2023; Saavedra et al., 2023).

Promoting the expansion of PAs to include these taxa is critical for increasing the protection of functional diversity, besides the taxonomic uniqueness found within the Mediterranean biodiversity hotspots and especially in the Italian peninsula. This is particularly relevant at European scale since Sardinia and Sicily show remarkable values of endemicity (Lussu et al., 2020). Our final list includes species showing a very narrow distribution, the majority of which are Italian endemics occurring in grasslands. This result is not surprising, given that the majority of Italian orchids grow in this habitat. However, many of the studied species have received little attention by taxonomists and conservationists so far, and accurate knowledge about their systematic position and their biology is still lacking. This is a critical flaw, especially for genera such as *Ophrys* that have very specialized pollination strategies, and may thus be more at risk in case of local or global extinction of the pollinator(s) they specialized upon (Tsiftsis and Djordjević, 2020). In recent decades, more than any other continent, Europe has seen an exponential increase in the number of described orchid species, subspecies or local entities, that are rarely supported by clear systematic and taxonomic studies (Bateman and Rudall, 2023; Pillon and Chase, 2007). In Italy, this taxonomic inflation towards certain groups such as *Ophrys* contributes negatively to the effectiveness of conservation programs making it complex to define a taxonomically uniform list of species. The high percentage of Italian endemics in our priority list is

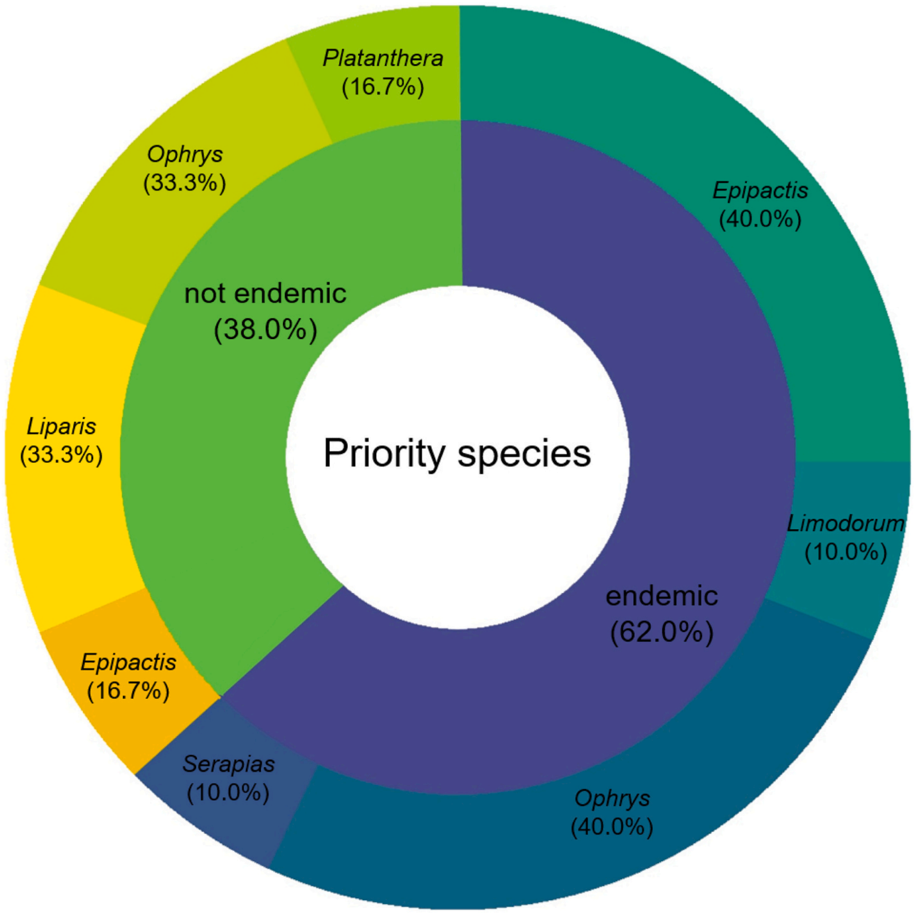

Fig. 5. Percentage of genera to which species with higher priority belong.

indicative of the need to increase the surface area of PAs at the country level. Since these species are the results of unique evolutionary processes and considerably contribute to genetic diversity, their conservation entails maintaining local biological and ecological processes as well as ecosystem functions and significant natural heritage. At the same time, our list underlines the need to develop conservation projects beyond the national borders for the protection of those taxa that, although not endemic and less charismatic, are declining (Urban et al., 2020). The Italian orchids species currently listed in protection inventories such as the Habitats Directive or the IUCN Red Lists is extremely low. Consequently, one of the first actions that should be carried out is to increase nation-wide monitoring campaigns in order to provide reliable species assessments.

A possible constraint of this work consists in the use of citizen science databases to calculate occurrences to establish protective representativeness within PAs. Indeed, it may cause an overestimation both inside and outside of PAs, or it may cause occurrences to be linked to infrastructure as roads (Fisher-Phelps et al., 2017; Jeliazkov et al., 2022; Yang et al., 2014). Hence, we suggest using prudence when incorporating occurrences for gap analysis, particularly when dealing with species that have a narrow biological range or are easily overlooked (Ancillotto and Labadessa, 2023; Carta et al., 2019; Herkt et al., 2017). As such, to minimize these biases we have used an easily recognizable plant family with a great diversity of ecological niches, the integrated use of databases followed by an accurate data cleaning on spatial, temporal and taxonomic basis (see Materials and Methods). Because the lack of distribution data severely restricts the development of red list assessments, the dataset we produced will serve as a starting point for distribution analyses. Indeed, one of the most ambitious goals of the European Union's Biodiversity Strategy for 2030 is to establish a trans-European network of PAs covering at least 30 % of the land and sea surface. Thus, since plants have been frequently under-represented in priority analyses, and since the goals of the Nature Restoration Law include the improvement and restoration of biodiversity and threatened species on a large scale, we emphasized the significance of orchids as flag species to guide future conservation management by acting as umbrella species in protecting all the biological networks to which they are ecologically associated. On a national and international level, our findings provide an essential basis for determining biodiversity conservation priorities, legislative options and identification of key biodiversity areas. Also, terrestrial orchids' conservation should increasingly focus on protection and management of individual species as well as habitats, contributing to the survival of orchids and their communities. We encourage scientists and stakeholders to incorporate our findings into conservation planning in order to maximize conservation efforts. For example, since the abovementioned EU Biodiversity strategy aims to strictly protect 10 % of the land, and this target is needed for preserving fundamental ecosystem processes but is still very far from achievement (Cazzolla Gatti et al., 2023), orchids linked to primary or well mature habitats can be used to select sites in which a strict level of conservation should be promoted. In order to prevent their extinction and the continued decline of orchid diversity, conservation actions cannot be further delayed, either legally or practically.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This research project was implemented under the National Recovery and Resilience Plan (NRRP), Project title

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Data availability

Data will be made available on request.

Appendices. Supplementary data

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