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The Italian endemic forest plants: an annotated inventory and synthesis of knowledge

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Abstract

Forests are among the most threatened ecosystems at the global scale, and endemic plants are often a vulnerable component of the flora of a given territory. So far, however, European forest endemic taxa have been scarcely investigated, especially those of the understory of the southern regions. Italy has a significant incidence of plant endemism and a broad diversity of forest types, but the endemic taxa typical of these habitats are still poorly known and not even inventoried. Accordingly, we elaborated a list of species and subspecies restricted to Italian forests using available information to refer each taxon to one of two categories of European forest specialist plants. This resulted in a list of 132 taxa (96 species and 36 subspecies), mostly linked to forest interior habitats. However, uncertainties about the taxonomic and endemic status affected a significant proportion of the taxa, and even trees. Available information about taxonomy, regional distribution, ecology, biology, functional traits and conservation status was included for each taxon. This resulted in a datasheet that allowed baseline statistics to be calculated. The rate of forest endemism, especially local, increased with decreasing latitude and was highest in Sicily and Calabria, where paleoendemic mono- or oligotypic genera were also present. Phanerophytes represented a considerable proportion, especially on islands. Beech and deciduous oak forests were the most important habitats, suggesting

the role of glacial refugia of the southern mountain massifs. Hygrophilous woodlands resulted also home of stenoecious local endemics. Overall, however, the ecology, biology, and functional traits of the forest endemic taxa are still poorly known. About 20% of the taxa resulted “Critically Endangered”, “Endangered” or Vulnerable”, while over 50% were flagged as “Data Deficient”. Fire was the most recurrent threat. More knowledge is needed about these globally rare taxa, to support their conservation in changing forest landscapes.

Key words

Endemic plants, forest biodiversity, Italian flora, understorey vegetation

Introduction

Endemic species represent the most valuable component of the biota of a given territory, often including very local taxa that are vulnerable to extinction for a variety of natural factors and/or anthropogenic pressures (Malcom et al. 2006). According to Manes et al. (2021) extinction risk of endemic species at the global scale is three times higher than that of native species, while Hobohm et al. (2014) mention endemism as a pre-extinction stage. Endemic plants are therefore the target of conservation programs in many regions of the world, primarily *in-situ* through the institution of protected areas, but also *ex-situ* through cultivation in gardens, cryo-conservation in seed banks and biotechnological approaches (Coelho et al. 2020; Frankel et al. 1995). Plant endemism is a key biodiversity indicator (Bruchmann 2014), one of the main criteria for biogeographical assessments (Hobohm et al. 2014), for identifying macro- and micro-floristic hotspots at various spatial scales, and for setting nature conservation priorities (Cañadas et al. 2014; Hobohm 2003; Kougioumoutzis et al. 2021; Wulff et al. 2013). Acquiring information about the distribution, ecology, population trends, reproductive biology, traits and genetics of endemic species is necessary to implement effective strategies for their *in-situ* conservation in the face of potential threats and changes to their habitat. Hence, hundreds of studies have been dedicated to these plants worldwide. In Europe, it is well documented that the highest concentration of endemic plant taxa is found in the southern countries included in the Mediterranean region (Hobohm 2008, 2003; Médail & Quezel 1997; Thompson 2005, 2020) which is one of the 35 biodiversity hotspots identified at the global scale (Myers et al. 2000; Mittermeier et al. 2011). It is also well known that most plant endemics in this region and other parts of Europe are found in open habitats, such as rocky outcrops, coastal cliffs, mountain grasslands, screes, and others (Thompson 2005, 2020), while a much smaller proportion is linked to forest communities (Bruchmann 2011). This is possibly one of the reasons for the few studies dedicated so far to forest endemics in Europe, in particular to the ecology and biology of the

herbaceous ones of the understorey. However, forest biomes host a disproportionate number of threatened species, due to direct or indirect anthropogenic disturbances such as human exploitation, fragmentation, fire, invasive species, increasing herbivore pressure, pollution and climate extremes (Roberts et al. 2021). Most of these disturbances have lasted for centuries and are increasingly impacting especially in the Mediterranean region (Médail et al. 2019; Peñuelas & Sardans, 2021). Their effects on forest understorey species and endemics are largely unknown, though these plants are often stenoecious and sensitive to global changes (Gilliam 2007; Iacopetti et al. 2021; Landuyt et al. 2019). Threats to forest biodiversity are thus mostly a function of threats to herb-layer species, explaining why maintaining the integrity of the understorey is acknowledged as a major goal in sustainable forest management and biodiversity conservation in Europe (Blondeel et al. 2021; Canullo et al. 2016).

Italian forests, currently covering ca. 11.4 million hectares (nearly 40% of the national surface), according to FAO (2020) are home of a still undetermined number of endemic plants. However, this ecological group of the rich national endemic flora (over 1400 taxa, Peruzzi et al. (2014, 2015); is still poorly known and not even inventoried and quantified. This gap does not help to implement the current EU and Italian national biodiversity strategies for 2030, the EU Forest Strategy for 2030 and to meet the sustainable forest management criteria advocated in the “Testo Unico Forestale” published by the Italian government in 2018 (DLvo 03/04/2018 n. 34). Moreover, it is also one of the causes for the persistent scarcity and fragmentation of information about the European threatened forest plants that was highlighted in the last Forest Europe report (ForestEurope 2020). Accordingly, we elaborated a first inventory of the Italian endemic forest plants, assembling available information about taxonomy, distribution, ecology, biology and conservation status and including our unpublished field data and observations. This allowed us to identify knowledge gaps but also to calculate baseline statistics which suggested previously undetected taxonomical, biogeographical and ecological patterns. In perspective, this work may thus contribute to implement the recently developed European forest plant species list (EuForPlant; Heinken et al. 2022), so far limited to the central and northern regions of the continent, and serve as a basis for conservation and further research on a unique biological heritage.

Methods

Checklist preparation

The inventory started from the most recent and continuously updated list of the vascular plant species and subspecies endemic to Italy (Peruzzi et al. 2015, 2014; link in reference list). The term “endemic” is here used for those taxa that are native to the Italian national territory or to Italy and

Corsica (France), as reported in the most recent checklist of the native Italian flora (Bartolucci et al., 2018). All taxa were checked in Euro+Med PlantBase for name, taxonomic status and distribution (Euro+Med, 2006).

Identification of the taxa that find their primary habitat in forest communities of natural origin (excluding tree plantations) was then based on the following sources: 1) Information about the type locality ("*locus classicus"*) reported in the prologue (original description) of each taxon, based on Peruzzi et al. (2015). The analysis of *loci classici* is an important source of information to implement strategies of conservation of endemic plants and their habitat (Brundu et al. 2017; Domina et al. 2012). Any reference to forest habitats in the protologue of a given taxon was assumed to be a first and unequivocal indication that the taxon is primarily found in woodlands; 2) Information from the literature, especially *Flora d'Italia* 2n edn. (Pignatti et al. 2017-2019), relevant books about Italian forests and vegetation (Blasi 2010; Pignatti 1998), papers on single or small groups of taxa, and various web sources; 3) Herbarium collections in FI (*Herbarium Centrale Italicum*, Firenze), which were conducted for over 100 taxa to extract information on the type of habitat where specimen collection was done (forest vs. non forest); 4) Hundreds of vegetation plots by the authors, both published and unpublished, which were used to infer occurrence data of the taxa in forest habitats; 5) Personal knowledge by the authors based on years of field work and observations across the Italian woodlands. *Ad-hoc* field surveys were also carried out for some taxa in the south and central regions of the Italian peninsula.

Based on evidence retrieved, we included in the list only two categories of taxa: 1) those strictly or mainly found in forest communities, regardless of type, dynamic stage, structural features, and conservation status, and 2) those occurring in forests as well as at their margins, gaps and clearings. These two groups roughly correspond to the categories 1.1 and 1.2 of the system recently developed for central and northern Europe by Heinken et al. (2022), and collectively form the group of the so-called "forest specialists". In addition, all endemic tree taxa forming or found in forests were included in the list (category 1.1), as well as taxa that grow in wet riparian communities of mountain streams and rivulets mostly in shady forest habitats (e.g. *Cryptotaenia thomasii* and *Petagnaea gussonei*).

Data collection and analysis

For each taxon, information was collected regarding five major fields to build a spreadsheet database similar to the EvaPlantE database (Endemic Vascular Plants in Europe; based on Bruchmann (2011): taxonomy, distribution and ecology (habitat), biology, functional traits, and conservation. For each field, the following information was recorded.

Taxonomy: 1) presence of a validly designated type specimen (holo-, lecto- or neo-type), mainly after Peruzzi et al. (2015); 2) family; 3) order; 4) major clade following APG IV 2016 (for angiosperms); 5) taxonomic level, as this is relevant when quantifying endemism (Bruchmann 2011); to this purpose we used the following levels: monotypic genus (a single species), oligotypic genus (including ≤ 5 species worldwide, after Mabberley 2017), species, subspecies and micro-species. The latter refers to those taxa described and currently accepted at the species level in the national lists above, but belonging to critical taxonomic groups with strong incidence of apomictic reproduction (e.g. *Hieracium, Ranunculus*) and very weakly differentiated on morphological grounds. Moreover, we also indicated the taxa for which doubts about their taxonomic status still exist, based on Bartolucci et al. (2018), the Portal to the Flora of Italy (link in the reference list) and the national open source ActaPlantarum (link in the reference list).

Distribution and ecology: 1) country-level distribution in the Euro-Mediterranean region based on Euro+Med PlantBase; this was done to check for discrepancies with respect to endemic taxa in our list (see above); 2) presence across the twenty Italian administrative regions, after Bartolucci et al., (2018) , the portal to the Flora of Italy and ActaPlantarum (references above), and across the five Italian geographic sectors, according to Nomenclatura delle Unità Territoriali Statistiche (NUTS, link in the reference list) e.g. North-West, North-East, Center, South, and Islands. Regions were scored for relative endemic richness and density using, respectively, *z*-values (Malyshev, 1991) and ratio no. forest endemics: regional area in km^2 (E/A; Hobohm 2003); the Regional richness in forest endemic taxa (E) was then related to the following variables: regional area (A, using log function), regional forest area from Inventario Forestale Nazionale (INFC, link in the reference list) (ha, log function), total number of endemic taxa, native species richness of the region (S), and latitude of the central regional point (UTM system), using Spearman rank correlation coefficients; the ratio E/S was considered as a simple measure of regional endemism rate (Bruchmann 2011); 3) altitudinal range based on Pignatti (2017-2019), ActaPlantarum and personal knowledge; 4) the dominant or more frequent tree species in the forest type(s) inhabited by each endemic taxon; 5) major reference phytosociological *syntaxa* (orders or alliances), based on literature, and for the available taxa, “Prodromo della Vegetazione Italiana” (link in the reference list); 6) habitat type(s) according to the EUNIS classification system (link in the reference list), using both 2012 and 2021 codes; 7) habitat type(s) according to the EEC Directive 92/43 Annex I; 8) ecological group after Heinken et al., (2022), e.g. whether 1.1 or 1.2 as explained above; 9) type of preferred substrate (indifferent, siliceous, calcareous, basalt), when known; 10) Ellenberg ecological indices (L,T, C, H, R, N), after Guarino et al. (2012) and Pignatti et al. (2005), when available.

Biology: 1) Raunkiaer life-form after Pignatti (2017-2019); 2) chromosome number (2*n*), when known/available from the Chromosome Counts Database (CCDB version 1.63) (Rice et al. 2015) or Chrobase (Bedini et al. 2021); the incidence of polyploidy was estimated by considering as taxa of likely polyploid origin those with chromosome number ≥ 24 divisible by four or more (Coppi et al. 2022); 3) main presumed reproductive system, e.g., whether prevalently gamous or agamous; 4) main pollen vector (wind vs. insects); 5) main fruit type; seed dispersal modes were not indicated since documented information about this aspect is at present almost completely missing for the taxa in our list, though partly inferable from the fruit traits and data about related taxa in the same genera.

Functional traits: 1) Current availability of trait data was checked for each taxon based on Try (Kattge et al. 2020).

Conservation: 1) IUCN Red list status according to the IUCN categories, assessment criteria and threats (IUCN 2012), after Orsenigo et al. (2018, 2021).

Results

Taxonomy

The list of the 132 forest specialist plants endemic to Italy (96 species and 36 subspecies, including 16 doubtful taxa) is provided in Supplementary Table 1, with associated information included in the database. Discrepancies between our list and Euro+Med PlantBase consisted in 12 taxa that were missing in the latter, four that were categorized as doubtful (not corresponding to those categorized as doubtful in the portal to the flora of Italy), and nine that were reported as synonyms of other taxa not endemic to Italy. Taxonomic distribution across higher taxonomic ranks and the 37 represented families was highly uneven. Asterids, Rosids, Monocots and Ranunculales were, in the order, the most represented clades, with Asteraceae, Ranunculaceae and Orchidaceae as most represented families; Boraginaceae, Salicaceae and Rosaceae were also significantly present. Concerning nomenclatural types, 25% of the taxa resulted without a designated type, while 55% were typified by a holotype and the rest mainly by a lectotype. As many as seven genera were oligotypic, among which *Aegonychon, Limodorum, Cryptotaenia* and *Zelkova*, and one was monotypic, *Petagnaea* (Fig. 1). On the other hand, the incidence of microspecies in large genera such as *Hieracium, Epipactis* and *Ranunculus* was also significant (35, 26.5%).

Distribution

As many as 77 taxa (58.3%) were restricted to only one Italian region (narrow-ranged endemics), and several of these to only a single or a few localities in it (local endemics), such as *Abies nebrodensis, Petagnaea gussonei, Ranunculus abbaianus* and others. On the other hand, 4.5% of the taxa were found in ten regions or more, and a few over most of the peninsula, such as *Melampyrum italicum, Digitalis micrantha, Echinops siculus, Helleborus viridis* subsp. *bocconei* and others. Distribution across regions was highly uneven (mean number of taxa per region =16±11.5), ranging from 0 (VAA) to 42 taxa (CAL); z-scores ranged from 2.1 (CAL and SIC) to -1.2 (FVG), while forest endemism density (E/A) was highest in BAS (0.00288) and lowest in LOM (0.00021; Table 1). Regional forest endemism was strongly related to total Italian endemism (Spearman R_s = 0.92; Fig. 2a), but not to regional species richness, regional area and regional forest area. Overall, forest endemism richness increased significantly with decreasing latitude (R_s = 0.86; Fig. 2b), as confirmed by the steeply decreasing South-to-North gradient along sectors: the insular (Sardinia and Sicily) and the southern sector hosted both 43% of the taxa, the central 28.8% and the northern ones 20% and 11.4 % (North-East and North-West, respectively). The southern regions (CAL, SIC and BAS) also had the highest proportion of forest endemism with respect to the regional species richness (E/S values > 0.01).

According to EuroMed+PlantBase, seven taxa (5.3%) are also native to countries other than Italy, and France (Corsica), and thus not endemic, among which the two trees *Alnus cordata* and *Acer cappadocicum* subsp. *lobelii*, recorded also from Albania and former Yugoslavian countries, respectively.

Habitat and ecology

Concerning the two categories of forest specialists, most of the taxa (60%) resulted mainly restricted to the forest interiors (1.1), the others (40%) being found also along margins, in gaps and clearings (1.2). The highest concentration of forest endemics was found in the altitudinal ranges 800-1200 m and 1200-1600 m a.s.l., but a significant proportion of taxa also occurred at elevations < 800 m a.s.l. (Fig. 3). About 40 wide-ranged tree species were found to provide forest habitat to endemics, among which beech was the most important (57 taxa, 43.2%). Oaks (*Quercus cerris, Q. pubescens* s. l. and *Q. ilex*) were also key habitat species (in total 53%), and the role *of Alnus glutinosa* was also not negligible (9.8%). Syntaxonomically, the order *Fagetalia* was consistently the most important habitat (53%; Fig. 4a), especially the southern communities of the alliance *Geranio versicoloris-Fagion*; the forests of *Quercetalia pubescentis-petraeae* were also home for a large proportion of endemics (46%), in particular the southern ones of the alliance *Pino calabricae-Quercion congestae*. Remarkably, hygrophilous forest communities of *Populetalia albae*, with

alliances *Salicion albae* and *Platanion orientalis* were found to provide the habitat to a significant number of understorey endemics (19.7%). As many as 34 Eunis habitats of third or fourth level were home for endemics, among which "Southern Italian *Fagus* forests" (T176, 33 taxa, 25%), "southern medio-European *Fagus* forests" (T175, 18 taxa, 13.6%), "southeastern sub-thermophilous *Quercus* forests" (T195, 23 taxa, 17.4%) and "Eastern *Quercus pubescens* forests" (T193, 12%) were most important. Hygrophilous forests with *Salix* (T141, 6.8%) and mesophilous forests with *Castanea* (T19C, 6.1%) were also relevant habitats. Concerning the Natura 2000 system, as many as nine priority habitats were inhabited by forest endemics (Fig. 4b). In line with previous data, the most important were "Apennine beech forests with *Abies alba* and beech forests with *Abies nebrodensis*" (9220*) and "Pannonian-Balkanic turkey oak-sessile oak forests" (91M0); xerophilous *Quercus pubescens* forests (91AA*), and "alluvial *Alnus-Fraxinus* forests" (91E0*), both priority habitats, were also significantly represented.

Edaphic preferences have been estimated for ca. 61% of the Italian forest endemics. About half of these can apparently be found on different soil types, while among the most selective ones, those linked to siliceous soils (acidophilous or calcifugous) resulted significantly prevalent over calciphilous taxa mainly growing on limestone (37% vs. 9.9%).

Ellenberg indicator values of endemics are still incomplete, being available for nearly 40% of the taxa. Based on these data, mean values for most factors changed with geographic sector (Table 2). While L did not change, T values were significantly lower in the northern sectors and highest on islands, and vice-versa for C values; H tended to decrease with latitude but not significantly. Southern and insular forest endemics showed a more acidophilous trend and a stronger association with nutrient-poor soils, compared to central and northern endemics.

Biology and traits

Most of the Italian forest endemic plants are perennial herbs (ca. 73%). Of these, hemicryptophytes (ca. 42%) are prevalent over geophytes (ca. 31%), though the relative proportions of these two forms depended on habitat. Endemic geophytes, for example, were significantly more represented than hemicryptophytes in habitat T1941 (Northern Italian *Quercus cerris* forests). The overall proportion of phanerophytes was also remarkable (23.5%), of which nearly half (11.4%) were trees of the upper or intermediate forest layers. Endemic phanerophytes were especially important in the Eunis habitats T1411 (Mediterranean tall *Salix* galleries) and T2121A (Southern Italian holm-oak forests). Sicily and Sardinia hosted the highest proportion of the Italian endemic phanerophytes (66.7%), as woody species represented 44% of the total forest endemism in the insular sector. In the southern sector woody endemics were also important (nearly 20% of the total). Chromosome

numbers have been reported for 60 endemic taxa (c. 45%). Based on these still incomplete data, the frequency of taxa of likely polyploid origin was remarkable and in the range 40-43% vs. 57-60 % of diploids. Overall the diploid/polyploid ratio was considerably higher in the southern (ca. 1.16) and, even more, the insular sector (1.53), when compared to the north-western and central sectors (ca. 0.80). At present, specific data about pollen vectors for Italian forest endemics are very scarce. The great majority of understorey taxa belong to entomophilous genera and families, while anemophily is prevalent in the tree species, such as the conifers *Abies nebrodensis* and *Pinus nigra* subsp. *laricio*, and the broadleaf *Alnus cordata, Betula etnensis, Fraxinus excelsior* subsp. *siciliensis*, *Zelkova sicula* and *Quercus* sp. pl. Among the herbaceous species, anemophily was only present in the monocots *Carex microcarpa* and *Luzula sicula*. Dry fruits are prevalent among forest endemics, with capsule, achene and follicle being the most frequent fruit types, followed by the wind-dispersed cypsela of Asteraceae. Fleshy fruits (and false fruits) such as berry, drupe and pome are found in ca. 10% of the taxa, which are typically endozoochorous, as for the taxa in the Rosaceae. Availability of data about functional traits in TRY and other databases is currently very low; only 13% of the taxa are listed for at least one trait. Available traits concern mostly the whole plant (plant height), leaf (leaf area and specific leaf area), and seed mass.

Conservation

Most of the Italian forest endemics have been assessed for IUCN category (13 taxa not assessed, 9.8%; Fig. 5a), but ca. 27% are currently evaluated as DD (data deficient). Most assessed taxa are flagged as LC (least concern) but a significant proportion (25 taxa, ca. 21 %) is included in the two categories of highest threat, CR (critically endangered, 9 taxa; 7.5%) and EN (endangered, 11 taxa, 9.2%) and VU (5 taxa). Most of the CR taxa are restricted to Sicily, such as *Abies nebrodensis*, *Petagnaea gussonei*, *Rhamnus lojaconoi*, *Sorbus busambarensis* and *Zelkova sicula*. CR, EN and VU taxa were mostly flagged with Criteria D (very small populations, < 50 mature individuals), B1 or B2, based on restricted range size. Remarkably two species of hygrophilous forests of the Po plain in Veneto and Emilia-Romagna, *Ranunculus hostiliensis* and *R. mutinensis*, are apparently extinct in the wild (category EX). As many as 28 threats were found to affect the Italian forest endemics (Fig. 5b). The most frequent one was increasing frequency and/or intensity of fires (7.1), affecting nearly 23.5% of the assessed taxa. “Livestock farming and ranching” (threat 2.3; 15%) and “other ecosystem modifications” (7.3; 14.2%) were also significant. Threats resulted not identified for 63 taxa, mostly in the categories DD and LC (Least Concern).

Discussion

Based on our analysis, Italian forest endemic plants represent 1.6% of the native national flora as inventoried in Bartolucci et al. (2018) and ca. 9% of the total endemic component currently known for the country (Peruzzi et al. 2015). Though representing a tiny fraction of the European endemic pool (ca. 2.2%), this proportion is not negligible when considering that the continent forests are endemism-poor when compared to open habitats (Bruchmann et al. 2011), and that we here focused only on forest specialists (categories 1.1 and 1.2 in Heinken et al. 2022). However, the still significant proportion of doubtful taxa (12.1%) and the discrepancies with respect to European sources such as Euro+MedPlantBase (16% of the taxa missing or considered as synonyms of other non-Italian endemic taxa) show that percentages and statistics can be affected by varying taxonomic knowledge and species concepts adopted by authors in given plant groups, both determining, in turn, the delimitation of the distribution ranges of the taxa. Emblematic cases are those of the trees *Betula etnensis*, synonymized to the widespread *B. pubescens* Ehrh. in Euro+Med PlantBase, and *Acer cappadocicum* subsp. *lobelii*, considered as separate species (*A. lobelii* Ten.) but also native to former Yugoslavia, thus not endemic to Italy. This supports that taxonomic resolution or uncertainty poses an important problem in biodiversity research (Bozzuto & Blanckenhorn 2017) and calls for more studies to address the inconsistency in interpretation of endemic plants which still persists in Europe (Bruchmann et al., 2011).

Despite this, Italian forest endemics remain a diverse group with respect to phylogeny and taxonomy, representing conifers, all major mesangiosperm clades and one third of the families of endemic plants in Europe (110, according to Bruchmann et al. 2011). The presence of one mono- and seven oligo-typic endemic genera greatly contributes the biogeographical and conservation value of this floristic component, being these taxa of ancient origin and phylogenetically isolated, thus mostly paleoendemics *sensu* (Heywood 1995) and stenoecious (Coppi et al. 2014). On the other hand, the significant proportions of neoendemic subspecies and microspecies in mainly agamospermous groups such as *Hieracium* and *Ranunculus* suggest the role of Italian forests as centers of recent micro-evolutionary processes.

Geographic distribution of forest endemism across Italian regions is well known, highlighting the crucial role played by the southern and insular regions. The observed North-to-South increasing rate is in line with the trend detected at the continental scale for European endemic plants, demonstrating the biogeographical importance of mountainous and spatially isolated regions of the southern parts of the continent (Bruchmann et al. 2011). Forest endemism in south and insular Italian regions is mainly local and concentrated on mountains, especially beech forests and some

types of oak-dominated deciduous woodlands of the southern Apennines and Sicily, while low-altitude sclerophyllous woodlands of evergreen oaks come behind. This supports the role of southern Italy as a glacial refuge area for beech and associated understory species, whose limited post-glacial dispersal may have led to the current condition of local endemic (Willner et al. 2009). We therefore support that habitat continuity, intended as persistence of forest communities through the Quaternary glaciations, is likely an additional driver of endemism in South Italy (Bruchmann et al. 2011). The significant incidence of woody endemic taxa, mainly phanerophytes, restricted to the southern and insular sectors further corroborates the role of isolation and habitat continuity as factors for the origin or conservation of also long-lived plants such as trees, like in other Mediterranean areas (Médail et al. 2019). In addition, the remarkable number of forest types hosting endemic plants in Italy, including hygrophilous woodlands, supports that habitat diversity is an additional key explanatory variable accounting for patterns of endemism at the local scale (Bruchmann et al. 2011). Instead, the lack of correlation with regional floristic richness was not in line with the assumption that the rate of endemism increases with the size of the species pool of a territory ("the more species, the more endemics"; Hobohm 2003). Since deviations from this general pattern usually apply to islands, there is evidence for the somewhat insular biogeographical character of the Italian peninsular regions, especially the southern ones.

Overall, available information about the ecology of forest endemics is still poor, as supported by the large proportion of taxa not assessed for Ellenberg indicator values and without syntaxonomical placement in "Prodromo della Vegetazione Italiana". However, analysis of available Ellenberg data supported consistent ecological variation from the northern to the southern and insular sectors, such as increasing T, decreasing C, and less expectedly, stronger association with acid and nutrient-poor soils. Only a few studies focused so far on the ecology, biology and phylogenetic relationships (including genetics) of Italian forest endemics, such as those on *Petagnaea gussonei* (De Castro et al. 2015, 2009; Gianguzzi 2002; Gianguzzi & La Mantia, 2004), Sardinian *Aquilegia* (Garrido et al. 2012; Mattana et al. 2012), and *Gymnospermium scipetarum* (Marzario et al. 2022; Rosati et al. 2019a, 2019b). Overall, therefore, the biological features of most Italian forest endemics remain incompletely known, starting from chromosome number and especially regarding mating systems, reproductive strategies, clonal growth, and seed dispersal mechanisms. Interestingly, available data about chromosome number suggested that the ratio diploids:polyploids tends to be higher in the southern and insular regions, especially compared to the north-west. Most of the diploids have low numbers and are thus patro- or schizo-endemics *sensu* (Favarger & Contandriopoulos 1961), of likely ancient origin. Sicily is also home of two paleo-endemics with $2n=42$, *Zelkova sicula* and *P. gussonei*. This number has been reported as of triploid origin for the former (Nakagawa et al. 1998),

and is likely associated with the inability for sexual reproduction in both taxa, which mostly adopt strategies of vegetative growth and spread. However, *P. gussonei* has been reported to be occasionally able to produce seeds (De Castro et al. 2015), suggesting that it can also behave as a functional diploid via formation of regular gametes with *n*=21.

Detailed information about pollination is very scarce but entomophily appears as the most important general mechanism, especially among the understorey endemics, which supports their importance for the life and diversity of forest insects. Providing habitat and food to pollinators is in fact a key ecosystem service of temperate understory plants (Landuyt et al. 2019). Dry fruits, either dehiscent or indehiscent, resulted largely prevalent over fleshy ones, implying seed dispersal mechanisms especially based on anemochory and myrmecochory in the several taxa with capsules releasing small seeds to the ground. Coupled with the still significant proportion of endozoochorous taxa with fleshy diaspores, mostly phanerophytes, this shows again the relevant role of endemics for the forest wildlife. Functional trait data are completely missing for most taxa, and when available, mostly limited to plant acquisitive traits such as plant height and leaf area. Besides acquiring additional data on traits, it is especially important to investigate intraspecific trait variability since phenotypic plasticity is a major component of the species adaptive capacity to changes in habitat and site conditions (Albert et al. 2011; Garnier et al. 2015). Trait variability is thus crucial for conservation.

Most of the taxa have been assessed for IUCN category (Orsenigo et al. 2018), but the significant proportion of endemics flagged as “Data Deficient” and those for which threats are not known (> 50%) shows again the need of further assessment work. Overall, the numerous taxa in the CR, EN and VU (ca. 21%) supports that the Mediterranean Basin is among the most vulnerable global hotspots for endemic species, because many of them are narrow-ranged, stenoecious and consist of small populations, thus strongly exposed to the direct and indirect effects of global warming (Malcom et al. 2006). One of these effects is doubtlessly the increasing frequency and intensity of fires (Di Virgilio et al. 2019), which in fact resulted as the most recurrent threat to forest endemics, especially in the southern and insular sectors.

Both the list of taxa and the associated data provided in this work will be periodically updated and integrated with new evidence and information that may become available in the next future. It is therefore a work in progress that is hoped to serve as a starting point and reference for more research on the biogeography and conservation of forest biodiversity and endemic flora in Europe.

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Table 1. Forest endemism across the twenty Italian regions, ordered by geographic sector (NW: northwest; NE: northeast; C: center; S: south; I: islands), showing: total number of forest endemic species and subspecies (tot. no. end), number of exclusive regional endemics (no. reg. end), *z*-values based on number of total forest endemics; forest endemism density (E/A, ratio total no: regional surface km^2), and forest endemism rate (E/S, ratio tot forest endemics:total regional species richness).

Sector	Region	tot no. end	no. reg. end	*Z*-values	density	rate
NW	Val d'Aosta - VAA	0	0	-1.443	0.00000	0.0000
NW	Piemonte - PIE	7	2	-0.836	0.00028	0.0020
NW	Lombardia - LOM	5	1	-1.009	0.00021	0.0015
NW	Liguria - LIG	13	0	-0.316	0.00240	0.0043
NE	Trentino A. Adige - TAA	6	4	-0.923	0.00044	0.0019
NE	Veneto - VEN	7	4	-0.836	0.00038	0.0022
NE	Friuli V. Giulia - FVG	3	1	-1.183	0.00038	0.0010
NE	Emilia-Romagna - EMR	15	1	-0.143	0.00067	0.0054
C	Toscana - TOS	28	3	0.983	0.00122	0.0083
C	Lazio - LAZ	19	0	0.204	0.00110	0.0063
C	Umbria - UMB	12	0	-0.403	0.00142	0.0051
C	Marche - MAR	16	2	-0.056	0.00170	0.0064
S	Abruzzo - ABR	17	2	0.030	0.00157	0.0053
S	Molise - MOL	11	0	-0.490	0.00247	0.0048
S	Campania - CAM	20	2	0.290	0.00146	0.0071
S	Puglia - PUG	16	1	-0.056	0.00082	0.0063
S	Basilicata - BAS	29	4	1.070	0.00288	0.0112
S	Calabria - CAL	42	11	2.196	0.00276	0.0152
I	Sicilia - SIC	41	22	2.110	0.00159	0.0148
I	Sardegna - SAR	22	16	0.464	0.00091	0.0096

Table 2 Variation of Ellenberg ecological indices (L,T,C, H, R, N) of Italian endemic forest plants across the Italian geographical sectors (means ±standard deviation). Significance of differences are based on non-parametric Kruskal-Wallis test.

	North-West	North-East	Central	South	Islands	p-value	tot average
L	5.5±2.1	5.3±1.6	5.6±1.4	4.9±1.9	5.3±1.6	ns	**5.3±1.6**
T	4.0±1.41	4.8±1.0	5.6±1.3	5.3±2.3	6.3±1.7	0.033	**5.9±1.7**
C	6.0±1.41	4.5±0.5	4.4±0.5	3.9±1.3	3.8±0.9	0.02	**4.0±1.0**
H	6.0±0.0	5.3±1.2	4.9±1.9	4.3±1.8	4.4±1.7	ns	**4.6±1.7**
R	6.0±0.0	6.7±0.8	6.4±1.3	5.4±2.2	4.6±1.6	0.002	**5.1±1.7**
N	7.5±0.7	5.7±1.5	5.0±1.7	4.4±1.9	4.2±1.8	0.05	**4.4±19**

CAPTIONS OF FIGURES

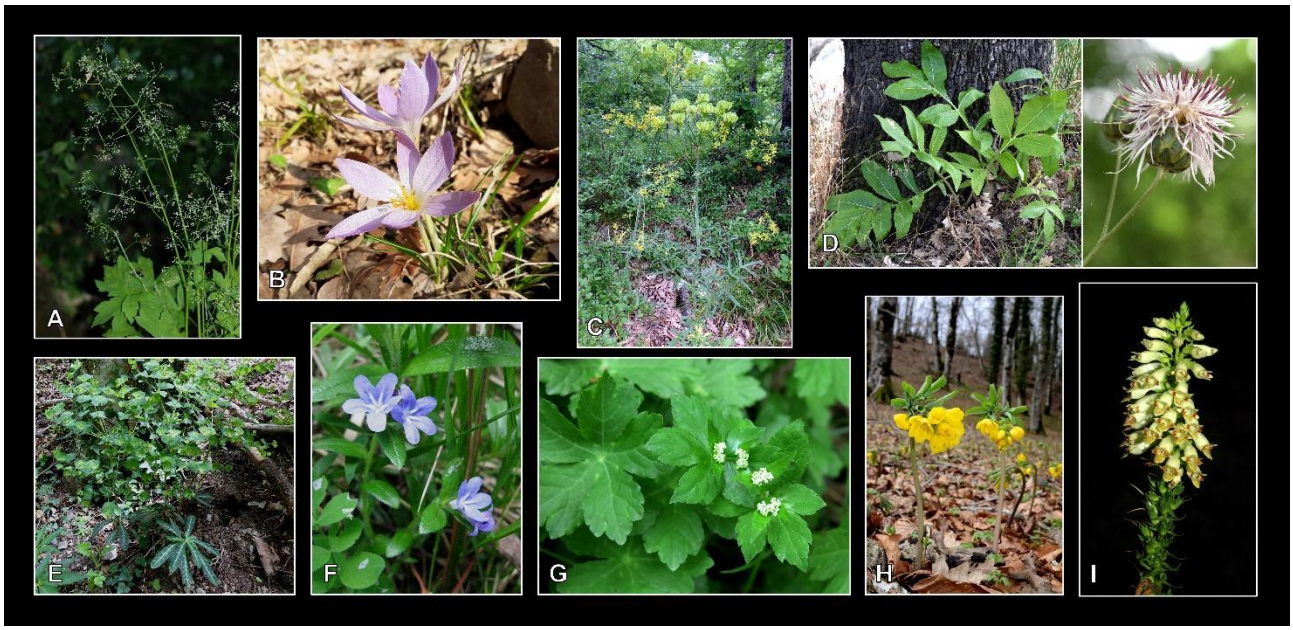

Figure 1. Field photographs of Italian forest endemics in their natural habitat. A, *Cryptotaenia thomasii* (Calabria); B, *Crocus etruscus* (Tuscany); C, *Heptaptera angustifolia* (Basilicata); D, *Rhaponticoides centaurium*, basal leaf (left) and capitulum (Basilicata); E, *Euphorbia meuselii* (Calabria); F, *Aegonychon calabrum* (Calabria); G, *Petagnaea gussonei* (Sicily); H, *Gymnospermium scipetarum* subsp. *eddae* (Campania); I, *Digitalis micrantha* (Umbria). Photos by FS (A,B,C,E,I), LR (H), Lorenzo Cecchi (D,F) and Salvatore Cambria (G).

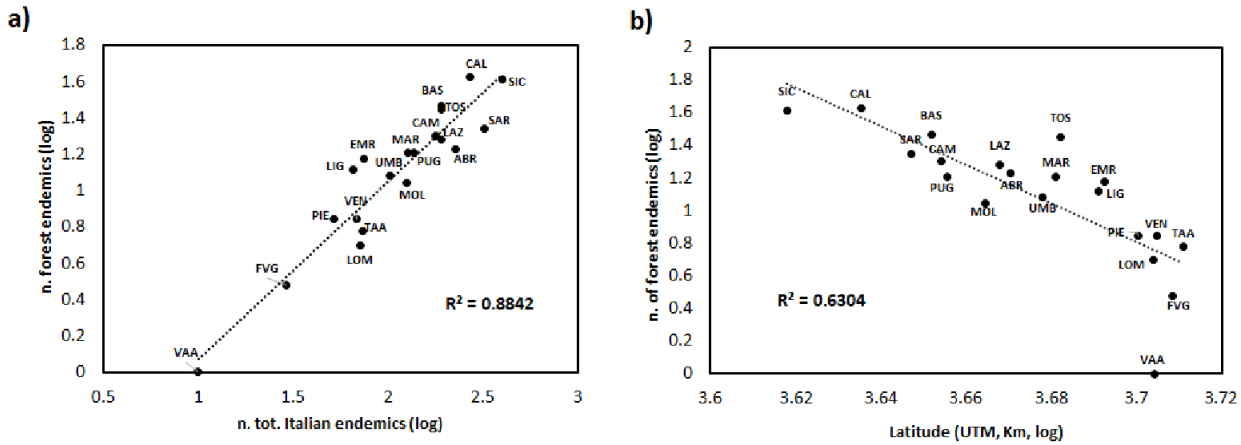

Figure 2. Relationship between number of Italian endemic forest plants (species and subspecies) in the twenty Italian regions and **a)** total number of Italian endemic species per region, and **b)** latitude of the region (central point according to UTM system).

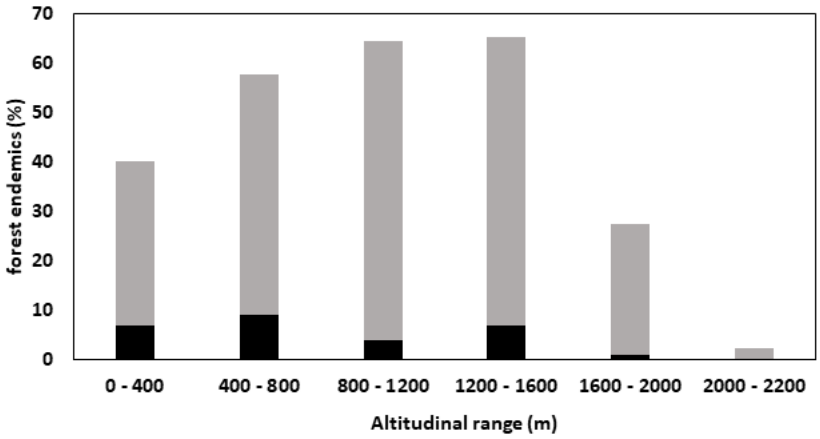

Figure 3. Frequency of Italian forest endemic plant species across altitudinal belts from 0 to 2200 m. Black bars show the proportion of taxa exclusively found in each belt, grey bars the proportion of species also found in other altitudinal belts.

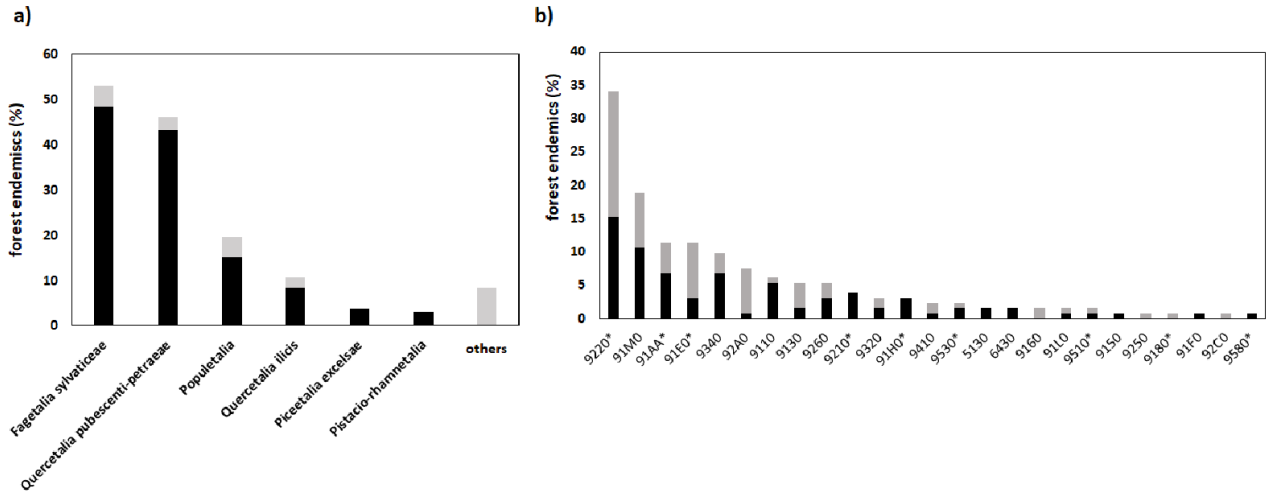

Figure 4. Frequency of forest endemic plant species across: **a)** major phytosociological syntaxa (Orders), showing the proportion of taxa exclusive to a single order (black), and those shared with other orders (grey); **b)** by habitat type(s) according to the EEC Directive 92/43 (Natura 2000); showing the proportion of taxa exclusive to a single habitat (black), and those shared with other habitats (grey).

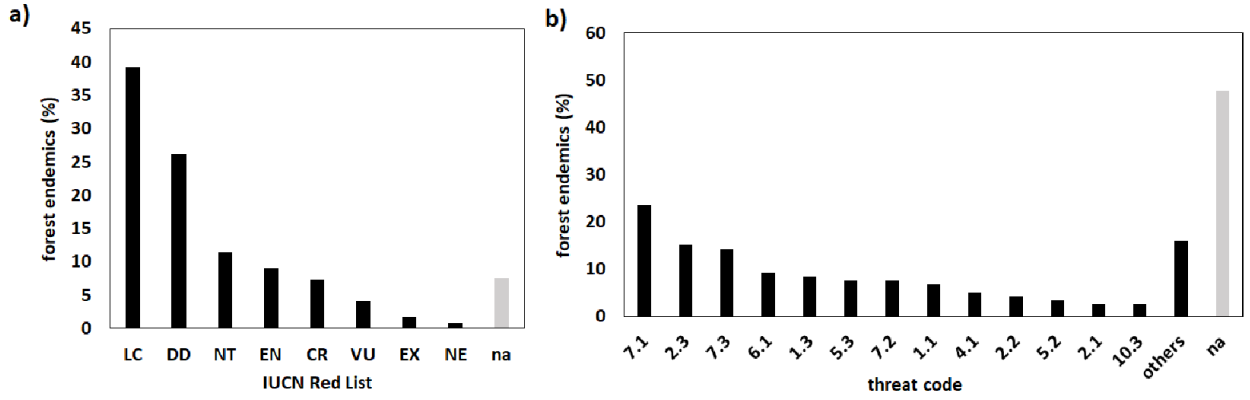

Figure 5. a) Frequency of the Italian forest endemic taxa across IUCN Red list categories, **b)** frequency of IUCN threats to the endemics.