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RESEARCH ARTICLE

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

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Abstract

Background and aims – Forests are among the most threatened ecosystems worldwide, and endemic plants are often a vulnerable component of the flora of a given territory. So far, however, understory forest endemics of southern Europe have received little attention and are poorly known for several aspects.
Material and methods – We developed the first list of native vascular plants that are restricted to Italian forests. Available information on taxonomy, regional distribution, ecology, biology, functional traits, and conservation status was collected for each taxon, allowing to identify major knowledge gaps and calculate baseline statistics.
Key results – The list includes 134 taxa, most of which are linked to closed-canopy forest habitats, while the others are also found in margins and gaps. The forest and non-forest Italian endemic flora differed in terms of taxonomic and life-form distribution. The rate and density of forest endemism increased with decreasing latitude and were highest in Sicily, Calabria, and Basilicata, where paleoendemic mono- or oligotypic genera also occur. Endemic phanerophytes were especially numerous on islands. Beech and deciduous oak forests were the most important habitats, but hygrophilous woodlands also host numerous endemics. Overall, the ecology, biology, and functional traits of the forest endemic taxa are still poorly known. The ratio diploids/polyploids was highest in the south and on the islands. Almost 24% of the taxa were assessed as “Critically Endangered”, “Endangered”, or “Vulnerable”, and 24% were categorized as “Data Deficient”, based on the IUCN system. Increasing frequency and intensity of fires was the most frequent threat.
Conclusions – This work can contribute to implement the European forest plant species list and serve as a basis for further research on a unique biological heritage of the continent. However, more knowledge about these globally rare taxa is needed, to support their conservation in changing forest landscapes.

Keywords

endemic plants, forest biodiversity, Italian flora, Mediterranean, 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), the extinction risk of endemic species at the global scale is three times

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higher than that of other native species, while Hobohm et al. (2013) mention endemism as a pre-extinction stage. Endemic plants are the target of conservation programs in many regions of the world, primarily in situ in protected areas, but also ex situ through cultivation in gardens, cryo-conservation in seed banks, and biotechnological approaches (Frankel et al. 1995; Coelho et al. 2020). Plant endemism is a key biodiversity indicator (Bruchmann 2014), one of the main criteria for biogeographical assessments (Hobohm et al. 2013), for identifying macro- and microfloristic hotspots at various spatial scales, and for setting nature conservation priorities (Hobohm 2003; Wulff et al. 2013; Cañadas et al. 2014; Kougioumoutzis et al. 2021).

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 in their habitat. Hence, hundreds of studies have been dedicated to these plants worldwide. In Europe, the highest concentration of endemic plant taxa is found in the southern countries included in the Mediterranean region (Médail and Quézel 1997; Hobohm 2003, 2008; Thompson 2005, 2020), which is one of the 35 biodiversity hotspots at the global scale (Myers et al. 2000; Mittermeier et al. 2011).

It is also well known that most plants endemic to 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 why relatively few studies have been dedicated so far to forest endemics in Europe, especially to understorey herbaceous species. However, forest biomes host a disproportionately high 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 and Sardans 2021). Their effects on forest understorey species and endemics are largely unknown, though these plants are often stenoecious and susceptible to global changes (Gilliam 2007; Landuyt et al. 2019; Iacopetti et al. 2021). Conserving the diversity and integrity of the understorey is thus a major goal in sustainable forest management in Europe (Canullo et al. 2016; Blondeel et al. 2021).

Italian forests and wooded land, currently covering ca 114,320 km^2 (ca 38.9% of the national land surface, according to FAO 2020), are home to a still undetermined number of endemic plants. However, this ecological group of rich national endemic flora (more than 1400 taxa; Peruzzi et al. 2014, 2015) is still poorly known and has not even been 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. 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 (Forest Europe 2020). Therefore, we developed the first inventory and baseline statistics of the Italian forest endemics after assembling available information about their taxonomy, distribution, ecology, and conservation status, also based on our unpublished field data and observations. Therefore, this work may contribute to the implementation of the recently developed European forest plant species list (EuForPlant; Heinken et al. 2022), so far limited to the central and northern regions, and serve as a basis for conservation actions and further research on a unique biological heritage of the continent.

MATERIAL AND 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. 2014, 2015). 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 also checked in Euro+Med PlantBase for name, taxonomic status, and distribution (Euro+Med 2006).

In line with Heinken et al. (2022), we define forest as a "tree-covered areas with normally at least 30% canopy cover (but including, for example, pine forests on sand dunes and bogs, forests on dry rocky slopes, and pasture woods). In the case of completely closed canopies, the area of a stand should be at least a circle with the radius of the maximal height of its tree layer. In the case of an open canopy, the minimum area increases proportionally with the decrease in overhead shading". The forest habitat includes clear-cuts or temporarily open areas such as forest gaps; stands in the regeneration phase or with shoots from stumps after coppicing; forest edges, including edges of forest tracks. All forest types considered in this work are among those listed in the EUNIS habitat classification system (as "forest and other wooded land", code T; EEA 2021). Identification of the taxa that are primarily found in forest habitats as defined above was then based on the following sources: 1) Information about the type locality ("locus classicus") reported in the protologue (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 (Domina et al. 2012; Brundu et al. 2017). 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 forests; 2) Information from the literature, especially Flora d'Italia Second Edition (Pignatti et al. 2017–2019), relevant books about Italian forests and vegetation (Pignatti 1998; Blasi 2010), papers on single taxa or small groups of taxa, and various web sources; 3) Herbarium collections in FI (Herbarium Centrale Italicum, Firenze), which were used to extract information from over 100 taxa on the type of habitat where 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 (available from the authors upon request); 5) Personal knowledge by the authors based on years of field work and ad hoc field surveys and observations across the Italian woodlands. Expert assessments are invaluable and are still gaining importance in ecological applications and decision-making in biodiversity conservation (Kuhnert et al. 2010; Heinken et al. 2022).

We included in our list only two categories of taxa: 1) those mainly found in closed-canopy forests, regardless of their type, dynamic stage, structural features, and conservation status, and 2) those occurring in forests as well as in their margins, gaps, and clearings. These two groups largely correspond to the categories 1.1 and 1.2 of the classification 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 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 in shady forest habitats (e.g. *Cryptotaenia thomasii* and *Petagnaea gussonei*). In the most recent EUNIS habitat classification system (EEA 2021), these communities are classified in the category "Grasslands and lands dominated by forbs, mosses or lichens" (code R).

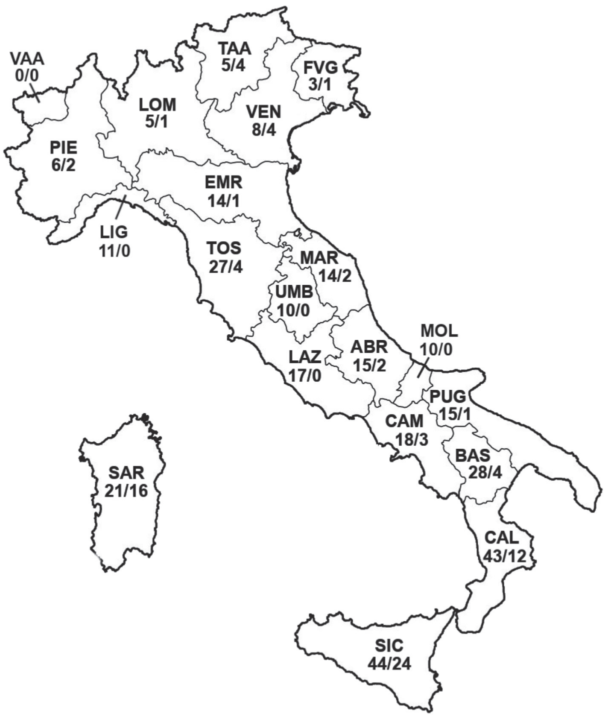

Figure 1. Forest endemic taxa (species and subspecies) across the 20 Italian regions (for region codes see Table 1). The map shows the total number of Italian forest endemics and the number of forest endemics exclusive to the region (XX/XX).

Data collection and analysis

For each taxon, information was collected about five major aspects 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 aspect, the following information was recorded.

Taxonomy: 1) existence of a validly designated type specimen (holo-, lecto-, or neotype), mainly after Peruzzi et al. (2015), and later papers; 2) family; 3) order; 4) major clade according to APG IV (for angiosperms) (Angiosperm Phylogeny Group 2016); 5) taxonomic level, as this is relevant when quantifying endemism (Bruchmann 2011): monotypic genus (a single species worldwide, after Mabberley 2017), oligotypic genus (≤ 5 species), species, subspecies, and microspecies. 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*) 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 (https://dryades.units.it/floritaly), and the Acta Plantarum project (https://www.actaplantarum.org).

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 20 Italian administrative regions (shown in Fig. 1 and listed in Table 1), after Bartolucci et al. (2018), the Portal to the Flora of Italy, and Acta Plantarum; and across the five Italian geographic sectors, according to the Nomenclature of territorial units for statistics (NUTS, https://ec.europa.eu/eurostat/web/regions-and-cities/overview), i.e. northwest, northeast, centre, south, and islands. For each administrative region we determined: i) forest endemic species richness (E), as the number of regional (restricted to the region) and national endemics (found in more regions), ii) endemism density in relation to the total regional area (A, km^2) and to the forest regional area (F, km^2, based on Inventario Forestale Nazionale, INFC, https://www.inventarioforestale.org), as ratio E/A and E/F, respectively; the α-index of Hobohm (2003), based on the species-area relationship, was also determined to compare forest endemism density across regions, accounting for their different size; iii) endemism

Table 1. Forest endemism rate (E/S, ratio total number of forest endemics:total regional species richness, percent), E/A density (ratio total no. of forest endemics:regional area km^2, percent), E/F density (ratio total no. of forest endemics:regional forest surface km^2, percent) and α-index (after Hobohm 2003) across the twenty Italian regions, ordered by geographic sector (NW: northwest; NE: northeast; C: centre; S: south; I: islands).

Sector	Region	E/S endemism rate%	E/A density %	E/F density %	α-index
NW	Val d'Aosta - VAA	0.00	0.000	0.000	0.00
NW	Piedmont - PIE	0.17	0.024	0.062	0.45
NW	Lombardy - LOM	0.15	0.021	0.072	0.37
NW	Liguria - LIG	0.37	0.203	0.284	0.83
NE	Trentino-A. Adige - TAA	0.16	0.037	0.064	0.42
NE	Veneto - VEN	0.25	0.044	0.170	0.60
NE	Friuli V. Giulia - FVG	0.10	0.038	0.080	0.24
NE	Emilia-Romagna - EMR	0.50	0.062	0.219	0.82
C	Tuscany - TOS	0.80	0.117	0.227	1.11
C	Latium - LAZ	0.57	0.099	0.262	0.93
C	Umbria - UMB	0.42	0.118	0.242	0.76
C	Marche - MAR	0.56	0.149	0.447	0.89
S	Abruzzo - ABR	0.47	0.138	0.316	0.91
S	Molise - MOL	0.43	0.224	0.577	0.81
S	Campania - CAM	0.64	0.132	0.366	0.97
S	Apulia - PUG	0.59	0.077	0.782	0.87
S	Basilicata - BAS	1.08	0.278	0.714	1.19
S	Calabria - CAL	1.55	0.283	0.661	1.34
I	Sicily - SIC	1.59	0.170	1.136	1.31
I	Sardinia - SAR	0.91	0.087	0.161	0.99

rate as ratio E/S, where S is the regional richness in native species. Next, we used a GLM regression analysis to examine the relationships between regional forest endemic richness (E) and regional area (A, using log function), regional forest area (F, log function), and latitude of the central point of the region (UTM system); 3) altitudinal range based on Pignatti et al. (2017–2019), Acta Plantarum, and personal observations; 4) the dominant or more frequent tree species in the forest type(s) inhabited by each Italian endemic taxon; 5) major reference phytosociological syntaxa (orders or alliances), based on literature, and for the available taxa, Prodromo della Vegetazione Italiana (https://www.prodromo-vegetazione-italia.org); 6) habitat type(s) according to the EUNIS habitat classification system (EEA 2021), 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 also from our field observations; 10) Ellenberg ecological indices (L,T, C, H, R, N), after Pignatti et al. (2005) and Guarino et al. (2012), when available.

Biology: 1) Raunkiaer life-form after Pignatti et al. (2017–2019); 2) chromosome number (2n), when known/available from the Chromosome Counts Database (CCDB version 1.63) (Rice et al. 2015) or Chrobase.it (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), and the data in the updated list of the Italian endemics mentioned above (Peruzzi et al. 2015). We also took into account the presumed ancestral chromosome number of the most recent common ancestor of the family for each angiosperm taxon as reported in Carta et al. (2020); 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) currently available trait data were checked for each taxon using the TRY database (Kattge et al. 2020).

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

RESULTS

Taxonomy

The list of forest vascular plants endemic to Italy with their respective category is provided in Table 2, while the associated information is given in Supplementary material 1. This list includes 96 species and 38 subspecies

Table 2. List of vascular plant species and subspecies endemic to the Italian forests (in alphabetical order), with family and forest category based on Heinken et al. (2022).

Family	Taxon	Forest category
Pinaceae	*Abies nebrodensis* (Lojac.) Mattei	1.1
Sapindaceae	*Acer cappadocicum* Gled. subsp. *lobelii* (Ten.) A.E.Murray	1.1
Fabaceae	*Adenocarpus complicatus* (L.) J.Gay subsp. *bivonae* (C.Presl) Peruzzi	1.2
Asteraceae	*Adenostyles alpina* (L.) Bluff & Fingerh. subsp. *nebrodensis* (Wagenitz & I.Müll.) Greuter	1.1
Adoxaceae	*Adoxa moschatellina* L. subsp. *cescae* Peruzzi & N.G.Passal.	1.1
Boraginaceae	*Aegonychon calabrum* (Ten.) Holub	1.2
Amaryllidaceae	*Allium anzalonei* Brullo, Pavone & Salmeri	1.2
Amaryllidaceae	*Allium julianum* Brullo, Gangale & Uzunov	1.1
Betulaceae	*Alnus cordata* (Loisel.) Duby	1.1
Ranunculaceae	*Anemonoides trifolia* (L.) Holub subsp. *brevidentata* (Ubaldi & Puppi) Galasso, Banfi & Soldano	1.1
Ranunculaceae	*Aquilegia barbaricina* Arrigoni & E.Nardi	1.2
Ranunculaceae	*Aquilegia nugorensis* Arrigoni & E.Nardi	1.1
Ranunculaceae	*Aquilegia sicula* (Strobl) E.Nardi	1.1
Aristolochiaceae	*Aristolochia sicula* Tineo	1.2
Aristolochiaceae	*Aristolochia tyrrhena* E.Nardi & Arrigoni	1.2
Araceae	*Arum apulum* (Carano) P.C.Boyce	1.2
Campanulaceae	*Asyneuma trichocalycinum* (Ten.) K.Malý	1.1
Betulaceae	*Betula aetnensis* Raf.	1.2
Cucurbitaceae	*Bryonia marmorata* E.Petit	1.2
Brassicaceae	*Cardamine battagliae* Cesca & Peruzzi	1.1
Cyperaceae	*Carex microcarpa* Bertol. ex Moris	1.1
Cannabaceae	*Celtis tournefortii* Lam. subsp. *aetnensis* (Tornab.) Raimondo & Schicchi	1.2
Cannabaceae	*Celtis tournefortii* Lam. subsp. *asperrima* (Lojac.) Raimondo & Schicchi	1.2
Asteraceae	*Cirsium lacaitae* Petr.	1.2
Ranunculaceae	*Clematis rigoi* W.T.Wang	1.1
Papaveraceae	*Corydalis densiflora* C.Presl subsp. *densiflora*	1.1
Rosaceae	*Crataegus insegnae* (Tineo) Bertol.	1.2
Iridaceae	*Crocus etruscus* Parl.	1.2
Iridaceae	*Crocus ilvensis* Peruzzi & Carta	1.2
Apiaceae	*Cryptotaenia thomasii* (Ten.) DC.	1.1
Plantaginaceae	*Digitalis micrantha* Roth ex Schweigg.	1.2
Asteraceae	*Echinops siculus* Strobl	1.2
Orchidaceae	*Epipactis aspromontana* Bartolo, Pulv. & Robatsch	1.1
Orchidaceae	*Epipactis autumnalis* Doro	1.1
Orchidaceae	*Epipactis calabrica* U.Grabner, S.Hertel & Presser	1.1
Orchidaceae	*Epipactis cupaniana* C.Brullo, D'Emerico & Pulv.	1.1
Orchidaceae	*Epipactis etrusca* Presser & S.Hertel	1.1
Orchidaceae	*Epipactis ioessa* Bongiorni, De Vivo, Fori & Romolini	1.1
Orchidaceae	*Epipactis lucana* Presser, S.Hertel & V.A.Romano	1.1
Orchidaceae	*Epipactis maricae* (Croce, Bongiorni, De Vivo & Fori) Presser & S.Hertel	1.1
Orchidaceae	*Epipactis meridionalis* H.Baumann & R.Lorenz	1.1
Orchidaceae	*Epipactis sanguinea* S.Hertel & H.Presser	1.1
Orchidaceae	*Epipactis schubertiorum* Bartolo, Pulv. & Robatsch	1.1
Orchidaceae	*Epipactis thesaurensis* Agrezzi, Ovatoli & Bongiorni	1.1
Euphorbiaceae	*Euphorbia ceratocarpa* Ten.	1.2

Table 2 (continued). List of vascular plant species and subspecies endemic to the Italian forests (in alphabetical order), with family and forest category based on Heinken et al. (2022).

Family	Taxon	Forest category
Euphorbiaceae	*Euphorbia corallioides* L.	1.1
Euphorbiaceae	*Euphorbia hyberna* L. subsp. *insularis* (Boiss.) Briq.	1.2
Euphorbiaceae	*Euphorbia meuselii* Geltman	1.1
Euphorbiaceae	*Euphorbia semiperfoliata* Viv.	1.2
Oleaceae	*Fraxinus excelsior* L. subsp. *siciliensis* Ilardi & Raimondo	1.1
Liliaceae	*Gagea chrysantha* Schult. & Schult.f.	1.2
Liliaceae	*Gagea sicula* Lojac.	1.2
Lamiaceae	*Glechoma sardoa* (Bég.) Bég.	1.2
Berberidaceae	*Gymnospermium scipetarum* Paparisto & Qosja ex E. Mayer & Pulević subsp. *eddae* Rosati, Farris, Fascetti & Selvi	1.1
Ranunculaceae	*Helleborus lividus* Aiton subsp. *corsicus* (Briq.) P.Fourn.	1.1
Ranunculaceae	*Helleborus viridis* L. subsp. *bocconei* (Ten.) Peruzzi	1.2
Ranunculaceae	*Helleborus viridis* L. subsp. *liguricus* (M.Thomsen, McLewin & B.Mathew) Bartolucci, F.Conti & Peruzzi	1.2
Apiaceae	*Heptaptera angustifolia* (Bertol.) Tutin	1.1
Asteraceae	*Hieracium bernardii* Rouy subsp. *gallurense* (Arrigoni) Greuter	1.1
Asteraceae	*Hieracium boreoappenninum* Gottschl.	1.2
Asteraceae	*Hieracium grovesianum* Arv.-Touv. ex Belli	1.1
Asteraceae	*Hieracium insubricum* Gottschl.	1.1
Asteraceae	*Hieracium macrogrovesianum* Gottschl.	1.1
Asteraceae	*Hieracium niveobarbatum* Arv.-Touv. ex Gottschl.	1.1
Asteraceae	*Hieracium picenorum* Gottschl. subsp. *falsobifidum* Gottschl.	1.1
Asteraceae	*Hieracium picenorum* Gottschl. subsp. *picenorum*	1.1
Asteraceae	*Hieracium pratorum-tivi* Gottschl.	1.1
Asteraceae	*Hieracium pseudaustrale* Gottschl.	1.1
Asteraceae	*Hieracium pseudogrovesianum* Gottschl.	1.1
Asteraceae	*Hieracium pseudopallidum* Gottschl.	1.2
Asteraceae	*Hieracium squarrosofurcatum* Gottschl.	1.1
Asteraceae	*Hieracium symphytifolium* Froel.	1.1
Asteraceae	*Hieracium tonalense* Gottschl.	1.1
Asteraceae	*Hieracium toscoemilianum* Gottschl.	1.2
Asteraceae	*Hieracium truttae* Gottschl.	1.1
Asteraceae	*Hieracium umbrosoides* Gottschl.	1.1
Hypericaceae	*Hypericum hircinum* L. subsp. *hircinum*	1.1
Asteraceae	*Klasea flavescens* (L.) Holub subsp. *cichoracea* (L.) Greuter & Wagenitz	1.2
Dipsacaceae	*Knautia gussonei* Szabó	1.2
Dipsacaceae	*Knautia lucana* Lacaita & Szabó	1.2
Fabaceae	*Lathyrus jordanii* (Ten.) Ces., Pass. & Gibelli	1.1
Orchidaceae	*Limodorum brulloi* Bartolo & Pulv.	1.2
Juncaceae	*Luzula sylvatica* (Huds.) Gaudin subsp. *sicula* (Parl.) K.Richt.	1.1
Rosaceae	*Malus crescimannoi* Raimondo	1.2
Orobanchaceae	*Melampyrum italicum* (Beauverd) Soó	1.1
Boraginaceae	*Myosotis decumbens* Host subsp. *florentina* Grau	1.2
Boraginaceae	*Myosotis sylvatica* Hoffm. subsp. *elongata* (Strobl) Grau	1.2
Asparagaceae	*Ornithogalum etruscum* Parl. subsp. *umbratile* (Tornad. & Garbari) Peruzzi & Bartolucci	1.1
Paeoniaceae	*Paeonia mascula* (L.) Mill. subsp. *russoi* (Biv.) Cullen & Heywood	1.2

Table 2 (continued). List of vascular plant species and subspecies endemic to the Italian forests (in alphabetical order), with family and forest category based on Heinken et al. (2022).

Family	Taxon	Forest category
Paeoniaceae	*Paeonia morisii* Cesca, Bernardo & N.G.Passal.	1.1
Paeoniaceae	*Paeonia sandrae* Camarda	1.1
Apiaceae	*Petagnaea gussonei* (Spreng.) Rausch.	1.1
Campanulaceae	*Phyteuma ovatum* Honck. subsp. *pseudospicatum* Pignatti	1.1
Pinaceae	*Pinus nigra* J.F.Arnold subsp. *laricio* Palib. ex Maire	1.1
Boraginaceae	*Pulmonaria officinalis* L. subsp. *marzolae* G.Astuti, Peruzzi, Cristof. & Pupillo	1.1
Fagaceae	*Quercus ichnusae* Mossa	1.1
Fagaceae	*Quercus leptobalana* Guss.	1.1
Fagaceae	*Quercus petraea* (Matt.) Liebl. subsp. *austrotyrrhenica* Brullo, Guarino & Siracusa	1.1
Ranunculaceae	*Ranunculus abbaianus* Dunkel	1.1
Ranunculaceae	*Ranunculus monspeliacus* L. subsp. *aspromontanus* (Huter) Peruzzi & N.G.Passalacqua	1.2
Ranunculaceae	*Ranunculus baldensis* Dunkel	1.1
Ranunculaceae	*Ranunculus gortanii* Pignatti	1.1
Ranunculaceae	*Ranunculus hostiliensis* Pignatti	1.1
Ranunculaceae	*Ranunculus mutinensis* Pignatti	1.1
Ranunculaceae	*Ranunculus pedemontanus* Dunkel	1.1
Ranunculaceae	*Ranunculus prosseri* Dunkel	1.1
Rhamnaceae	*Rhamnus lojaconoi* Raimondo	1.1
Rhamnaceae	*Rhamnus persicifolia* Moris	1.1
Asteraceae	*Rhaponticoides centaurium* (L.) M.V.Agab. & Greuter	1.1
Grossulariaceae	*Ribes multiflorum* Kit. ex Roem. & Schult. subsp. *sandalioticum* Arrigoni	1.1
Rosaceae	*Rubus arrigonii* Camarda	1.1
Salicaceae	*Salix arrigonii* Brullo	1.2
Salicaceae	*Salix brutia* Brullo & Spamp.	1.2
Salicaceae	*Salix gussonei* Brullo & Spamp.	1.2
Salicaceae	*Salix ionica* Brullo, Scelsi & Spamp.	1.2
Salicaceae	*Salix oropotamica* Brullo, Scelsi & Spamp.	1.2
Salicaceae	*Salix purpurea* L. subsp. *eburnea* (Borzì) Cif. & Giacom. ex Pignatti	1.2
Salicaceae	*Salix tyrrhenica* Brullo, Scelsi & Spamp.	1.2
Lamiaceae	*Scutellaria columnae* All. subsp. *gussonei* (Ten.) Arcang.	1.2
Asteraceae	*Senecio nemorensis* L. subsp. *apuanus* (Tausch) Greuter	1.2
Asteraceae	*Senecio ovatus* (G.Gaertn., B.Mey. & Scherb.) Willd. subsp. *stabianus* (Lacaita) Greuter	1.2
Primulaceae	*Soldanella calabrella* Kress	1.1
Rosaceae	*Sorbus aucuparia* L. subsp. *praemorsa* (Guss.) Nyman	1.1
Rosaceae	*Sorbus busambarensis* G.Castellano, P.Marino, Raimondo & Spadaro	1.2
Rosaceae	*Sorbus madoniensis* Raimondo, G.Castellano, Bazan & Schicchi	1.2
Boraginaceae	*Symphytum gussonei* F.W.Schultz	1.1
Asteraceae	*Tephroseris italica* Holub	1.2
Lamiaceae	*Teucrium siculum* (Raf.) Guss. subsp. *euganeum* (Vis.) Tornad.	1.2
Ranunculaceae	*Thalictrum calabricum* Spreng.	1.2
Fabaceae	*Vicia brulloi* Sciandr., Giusso, Salmeri & Miniss.	1.1
Fabaceae	*Vicia ochroleuca* Ten.	1.2
Fabaceae	*Vicia tenuifolia* Roth subsp. *elegans* (Guss.) Nyman	1.2
Apocynaceae	*Vinca difformis* Pourr. subsp. *sardoa* Stern	1.2
Ulmaceae	*Zelkova sicula* Di Pasq., Garfì & Quézel	1.2

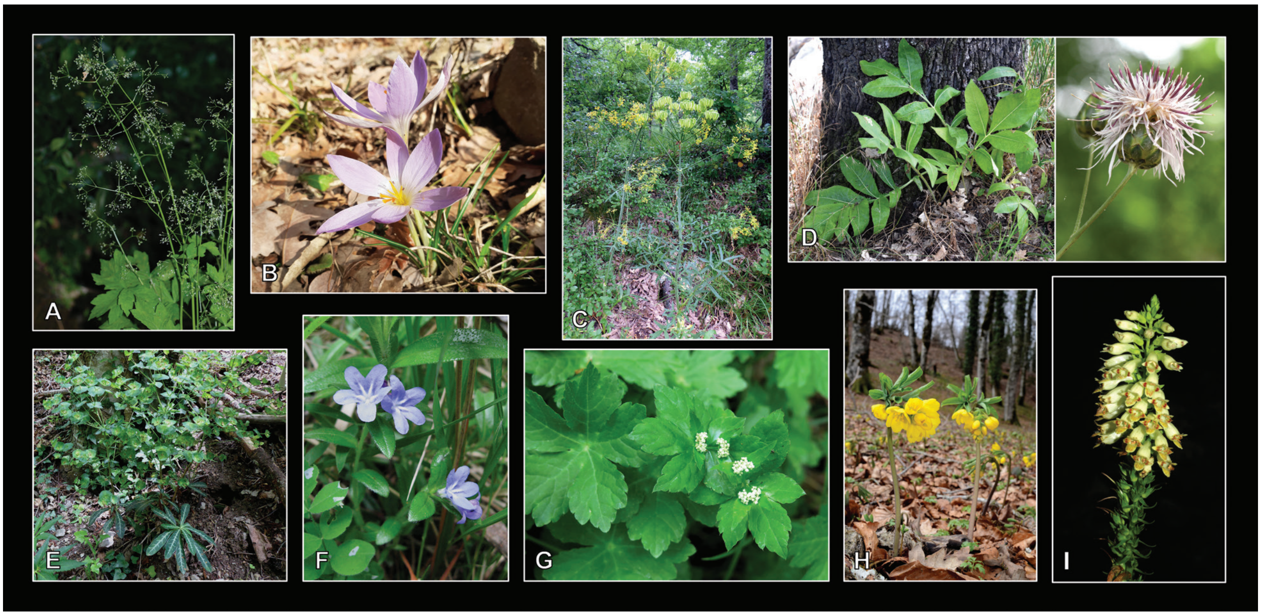

Figure 2. Field photographs of Italian forest endemics in their natural habitat. **A**. *Cryptotaenia thomasii* (Calabria). **B**. *Crocus etruscus* (Tuscany). **C**. *Heptaptera angustifolia* (Basilicata). **D**. *Rhaponticoides centaurium*, basal leaf (left) and capitulum (Basilicata). **E**. *Euphorbia meuselii* (Calabria). **F**. *Aegonychon calabrum* (Calabria). **G**. *Petagnaea gussonei* (Sicily). **H**. *Gymnospermium scipetarum* subsp. *eddae* (Campania). **I**. *Digitalis micrantha* (Umbria). Photos by Federico Selvi (A–C, E, I), Leonardo Rosati (H), Lorenzo Cecchi (D, F), and Salvatore Cambria (G).

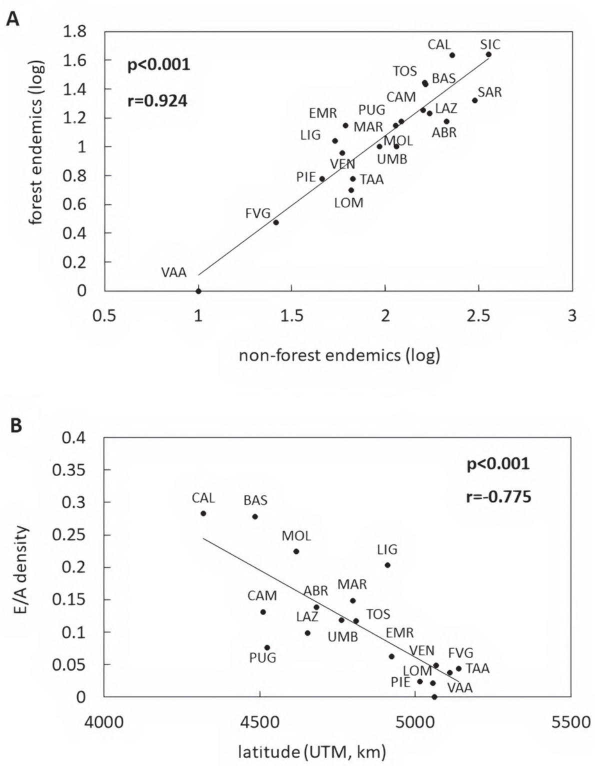

Figure 3. Relationships between (**A**): total number of endemic forest taxa (regional and national endemic species and subspecies) and non-forest Italian endemics in the 20 administrative regions (log function); and (**B**): density of regional forest endemics and latitude of the region (central point according to UTM system; excluding insular regions). P-values of the GLM (p) and Pearson correlation coefficient (r) are indicated.

(of which 14 doubtful), belonging to 40 families (31 dicots, 8 monocots, 1 gymnosperm). Our results are different from Euro+Med PlantBase for 10 taxa (7.5%), which were missing in the latter, 4 (3%) that were categorized as doubtful, and 9 (6.7%) that were reported as synonyms of other taxa also occurring outside Italy. Taxonomic distribution across higher taxonomic ranks was highly uneven. Asterids, Rosids, monocots, and Ranunculales were, in decreasing order, the most represented major clades, with Asteraceae, Ranunculaceae, and Orchidaceae as most represented families; Boraginaceae, Salicaceae, and Rosaceae were also present in high numbers. As many as seven genera were oligotypic, among which *Aegonychon*, *Limodorum*, *Cryptotaenia*, and *Zelkova*, and one was monotypic, *Petagnaea* (Fig. 2). On the other hand, the incidence of microspecies in large genera such as *Hieracium*, *Epipactis*, and *Ranunculus* was also significant (26%).

Distribution

As many as 81 taxa (60%) were restricted to only one Italian region, while only 3.8% occurred in at least 50% of the regions, and a few others were found over most of the Italian peninsula. The number of endemic taxa per region ranged from 0 (Val d'Aosta) to 44 taxa (Sicily) (Fig. 1). Forest endemism density (E/A) was highest in Calabria and Basilicata and lowest in Lombardy, a large northern region poor in forest endemics (Table 1). Values of the α-index showed considerable variation, being over three times higher in Sicily, Calabria, and Basilicata than in Lombardy (Table 1). Density related to the regional forest surface (E/F) was also highest in Sicily and lowest in Piedmont and Lombardy, also due to the larger forest surface of the latter two regions. The southern and insular regions (Calabria, Sicily, and Basilicata) also had the highest forest endemism rates with respect to the regional species richness (E/S values > 1; Table 1). The rates of forest and non-forest Italian endemism were positively related ($p < 0.001$; Fig. 3A), though some regions with a similar rate of non-forest endemics showed different rates of forest endemics, for example Lombardy vs Emilia-Romagna. Forest endemism did not depend on regional species richness ($p > 0.05$) and regional area ($p > 0.05$) but was weakly related to regional forest area ($p = 0.025$; Pearson $r = 0.49$, data not shown). Instead, endemic richness and density increased significantly with decreasing latitude ($p < 0.001$; Fig. 3B); in fact, the southern and insular sectors hosted both ca 43% of the taxa, the central the 27.4% and the northern ones 18.5 and 9.6 % (northeast and northwest, respectively).

The status of Italian endemics of *Alnus cordata* and *Acer cappadocicum* subsp. *lobelii* needs to be confirmed since the records of these taxa from respectively Albania and former Yugoslavia, which appear in Euro+Med PlantBase, are most likely due to errors (see Barina et al. 2018 and Crowley 2020).

Habitat and ecology

Most of the taxa in our list (58.5%) were linked to closed-canopy forest habitats (category 1.1), while the others were found also in margins, gaps, and clearings (category 1.2). The highest concentration of forest endemics was in the altitudinal range 800–1200 m a.s.l., but a significant proportion also occurred below 800 m (Fig. 4A). About 40 tree species with wide distribution range were found to form the forest habitat of endemics, among which beech was the most important (ca 42.2% of the taxa are associated with this species). Oaks (*Quercus cerris*, *Q. ilex*, and *Q. pubescens*) were other key habitat species (in total 48.9%), and the role of *Castanea sativa* was also not negligible (8.1%). In terms of syntaxonomical units, the order *Fagetalia* hosted the largest number of endemics (55.5%; Fig. 5A), especially the southern communities of the alliance *Geranio versicoloris-Fagion*; the forests of *Quercetalia pubescentis-petraeae* were also home to a large proportion of endemics (37%), 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 host a significant number of understorey endemics (14.8%). As many

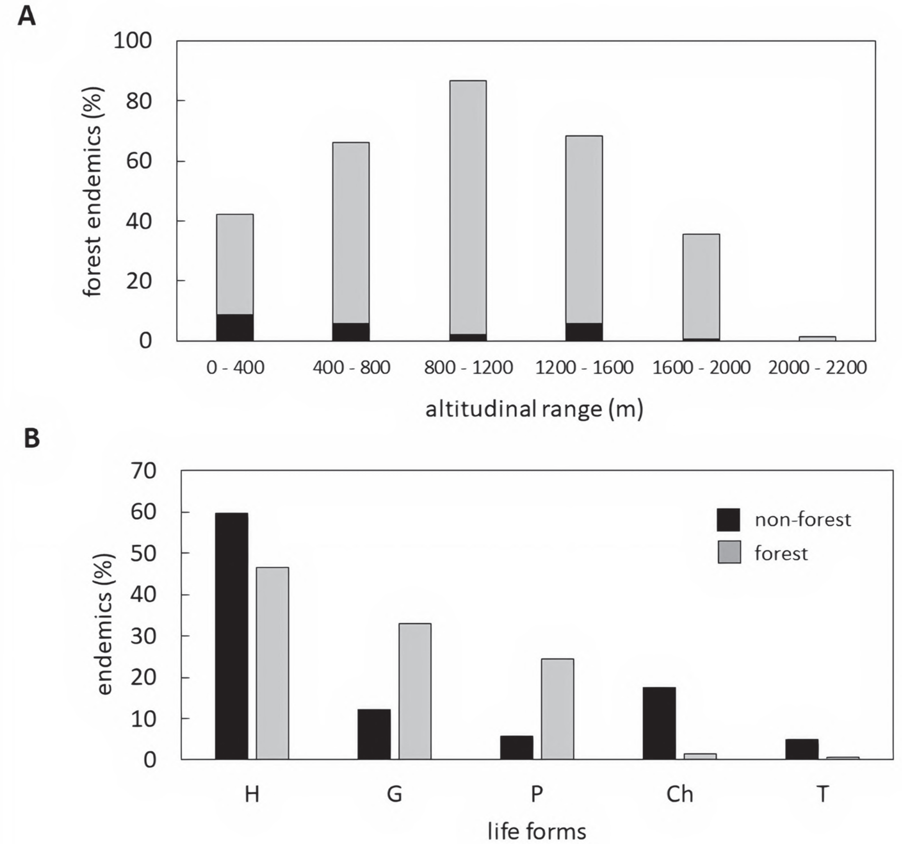

Figure 4. A. Frequency of Italian forest endemic plant species across altitudinal belts from 0 to 2200 m; black bars show the proportion of taxa exclusively found in each belt, grey bars the proportion of species also found in other altitudinal belts. **B**. Distribution of Raunkiaer life-forms across the forest (grey bars) and the non-forest (black bars) Italian endemic flora inventoried at present; H: hemicryptophytes, G: geophytes, P: phanerophytes, Ch: chamaephytes, T: therophytes.

as 34 EUNIS forest types of third or fourth level were habitats for endemics. Of these, "Southern Italian *Fagus* forests" (T176, 34 taxa, 25%), "Southern medio-European *Fagus* forests" (T175, 16 taxa, 12%), "Southeastern sub-thermophilous *Quercus* forests" (T195, 23 taxa, 17%), and "Eastern *Quercus pubescens* forests" (T193, 14%) were the most important. Hygrophilous forests with *Salix* (T141, 6.7%) and mesophilous forests with *Castanea* (T19C, 6.7%) were also relevant habitats.

In relation to the Natura2000 system, forest endemics were recorded in 25 habitats, of which nine are with priority (Fig. 5B). 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*) were also significantly represented. Contrastingly, the typical Mediterranean forests dominated by evergreen sclerophylls were comparatively less important habitat for the endemics.

Edaphic preferences have been estimated for ca 64% of the Italian forest endemics. About 40% of these can be found on different soil types, while among the most selective ones, those linked to siliceous soils (acidophilous and/or calcifugous) were significantly prevalent over calciphilous and basophilous taxa mainly growing on limestone or similar calcareous substrates (34.4% vs 11.4%).

Ellenberg indicator values of endemics are still largely incomplete, being available for 44.8% of the taxa in our list. In relation to the light factor, the endemics placed in category 1.1 (closed-canopy forests) were linked to more shaded conditions than those of category 1.2 (also found in margins and gaps), with mean L values of 4.4 and 6.5 (on a 1–12 scale; Pignatti et al. 2005), respectively. As expected, T values were significantly lower in the northern sectors and highest on islands, and vice-versa for C values (Supplementary material 2). Concerning the edaphic factors, southern and insular forest endemics

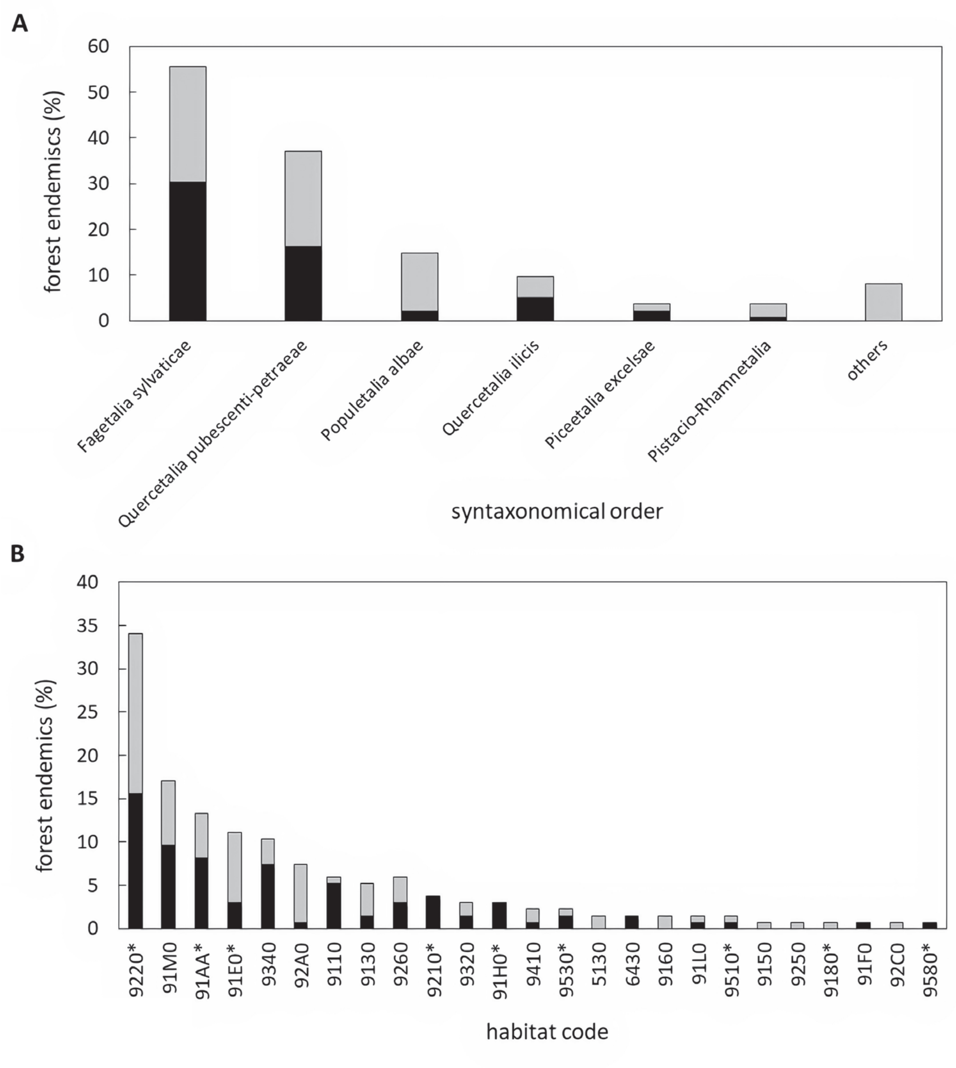

Figure 5. Frequency of forest endemic plant species across: (**A**) major phytosociological orders, showing the proportion of taxa exclusive to a single order (black), and those shared with other orders (grey); (**B**) Natura2000 habitat type(s) according to the EEC Directive 92/43; showing the proportion of taxa exclusive to a single habitat (black), and those shared with other habitats (grey).

showed a stronger association with acidic and nutrient-poor soils, compared to central and northern endemics.

Biology and traits

Hemicryptophytes (ca 44%), geophytes (ca 31%), and phanerophytes (23%) were the most important life-forms (Fig. 4B), while chamaephytes and therophytes were uncommon (1.5 and 0.8, respectively). Among the endemic phanerophytes, nearly half (11.1%) were trees of the upper or intermediate forest layers. This life-form was especially important in the EUNIS habitats T1411 (Mediterranean tall *Salix* galleries) and T2121A (Southern Italian holm-oak forests). Sicily and Sardinia contain the highest proportion of endemic phanerophytes (51.6%), which represented 44% of the total forest endemism in the insular sector. This form was also important in the southern sector (nearly 20% of the total).

Data about chromosome number are currently available for 51% of the forest endemics, a lower proportion compared to the entire Italian endemic flora (currently ca 63%). Based on these still incomplete data, the range of chromosome numbers was 2n = 10–96 (*Paeonia morisii*-*Symphytum gussonei*, respectively), and the frequency of taxa of likely polyploid origin was in the range 40–43% vs 57–60% of diploids. Overall, the diploids/polyploids ratio was considerably higher in the southern (ca 1.5) and even more in the insular sector (2.18), compared to the north-western and central sectors (ca 0.80).

Most understorey endemic taxa are entomophilous, but information about relationships with pollinating insects is currently very scarce. Dry fruits are prevalent, 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 the TRY database is currently very low. Only 12% of the taxa have been analysed for at least one trait, most often plant height and/or leaf area.

Conservation

Most of the Italian forest endemics have been assessed for IUCN category (only four taxa not assessed; Fig. 6A), but 23.9% are currently evaluated as DD (data deficient). Most assessed taxa are flagged as LC (least concern) but a significant proportion (31 taxa, 23.7%) is included in the three categories of highest threat, CR (critically endangered, 9 taxa, 6.9%), EN (endangered, 16 taxa, 12.2%), and VU (6 taxa). CR, EN, and VU taxa were mostly

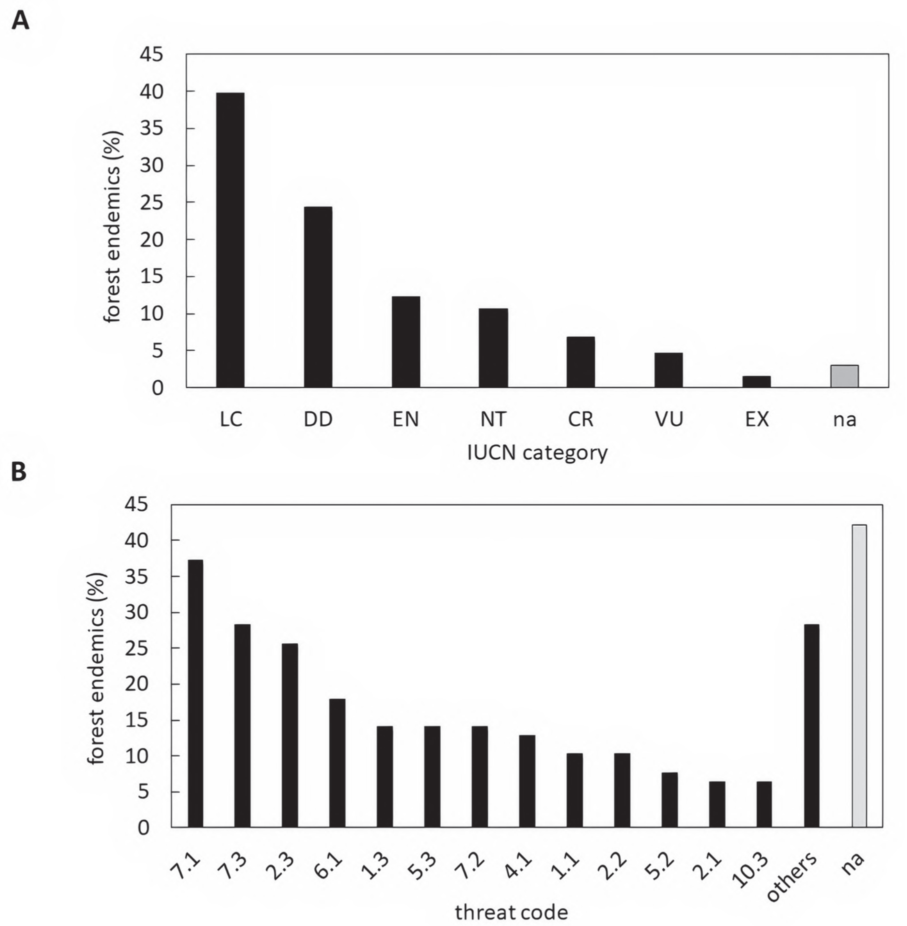

Figure 6. Proportion of Italian forest endemic taxa across: (**A**) IUCN Red list categories; (**B**) IUCN threat types (IUCN 2022).

assessed based on 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 considered extinct in the wild (category EX). As many as 29 types of threat were found to affect the Italian forest endemics (Fig. 6B); the most important was the increasing frequency and/or intensity of fires (7.1), affecting over 37% of the assessed taxa. "Livestock farming and ranching" (threat 2.3; 25.6%) and "other ecosystem modifications" (7.3; 28.2%) were also recurrent threats.

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 inventoried at present. Though representing a tiny fraction of the European endemic pool (ca 2.2%), this proportion is not negligible when considering that the continental forests are endemism-poor compared to open habitats (Bruchmann 2011), and that we focused only on forest specialists (categories 1.1 and 1.2 in Heinken et al. 2022). However, the still significant proportion of taxonomically doubtful taxa and the discrepancies with other sources such as Euro+Med PlantBase show that statistics can be affected by variable taxonomic knowledge and species concepts adopted by authors. In turn, this affects the range limits of the taxa and thus their endemic or non-endemic status. Emblematic cases are those of the trees *Betula aetnensis*, synonymized to the widespread *B. pendula* in Euro+Med PlantBase, *Quercus leptobalana*, reported as synonym of *Q. congesta*, and of the orchids *Limodorum brulloi* and *Epipactis thesaurensis*, both considered as synonyms of the widespread *L. abortivum* and *E. leptochila*, respectively. This supports that taxonomic resolution or uncertainty represents an important issue in biodiversity research (Bozzuto and Blanckenhorn 2017), and highlights that more taxonomic work is still needed on the European flora (Bruchmann 2011).

Italian forest endemics are a diverse group with respect to phylogeny and taxonomy, representing conifers, all major mesangiosperm clades and about one third of the families of the European endemic plants (110 according to Bruchmann 2011). The forest endemics are distributed across 56% of the families represented in the entire Italian endemic flora. Ranunculaceae and Orchidaceae were more represented in the forest than in the entire endemic flora (ca 12% vs 4% and 9.5% vs 6.2%), while the endemism-rich families Plumbaginaceae, Caryophyllaceae, and Saxifragaceae were missing. The presence of one mono- and seven oligotypic endemic genera greatly contributes the biogeographical and conservation value of the Italian forest endemic flora, being these taxa of ancient origin and phylogenetically isolated, thus mostly paleoendemics sensu UNEP (1995) (see also Siljak-Yakovlev and Peruzzi 2012) 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 that Italian forests are also centres of more recent microevolutionary processes.

The distribution of forest endemics across Italian regions is currently well known, while less information exists about the detailed distribution and extent of most taxa within regions. At the regional level, there was a clear north-to-south increasing proportion of forest endemism, in line with the trend known at the continental scale for the European endemic flora (Bruchmann 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 (see Fig. 4A). This supports the role of southern Italy as a glacial refugium area for beech and associated understory species, some of which may have been subject to limited post-glacial dispersal (Willner et al. 2009). 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 in the origin and/or conservation of also long-lived plants such as trees, like in other Mediterranean areas (Médail et al. 2019). In addition, the relatively large number of forest types (34 EUNIS habitats of third and fourth level and 25 habitats of Natura2000) hosting endemic plants in Italy, including hygrophilous woodlands, suggests that habitat diversity is another variable accounting for patterns of endemism at the local scale. The observed lack of correlation between regional forest endemism and floristic richness does not support the assumption that rate of endemism increases with the size of the species pool of a territory ("the more species, the more endemics"). On average, the central, southern and insular Italian regions showed higher endemism density (E/A and α-index values) than the northern ones (Table 1), likely due to the effect of latitude and insularity for Sicily and Sardinia. In general, islands tend to have lower floristic richness vs higher rates and densities of endemism than continental areas (Kier et al. 2009), suggesting that the high E/S, E/A, and α-index values of Calabria and Basilicata may reflect a certain degree of biogeographical insularity even in these peninsular regions. Insularity may help to explain the relatively high forest endemism density of a more northern region like Tuscany, that includes islands (the Tuscan archipelago) inhabited by forest endemics such as *Hypericum hircinum*, *Carex microcarpa*, and *Crocus ilvensis*. Noteworthy, the α-index of the latter region is almost the same of that reported for the Mediterranean basin (1.33; Hobohm 2003), also due to the significant presence of thermophilous forest habitats of the Tyrrhenian ecoregion with a typical Mediterranean climate (Blasi et al. 2014).

Bioclimate, latitude and geomorphology also account for the different proportion of forest endemics in regions with similar proportions of total Italian endemics, as in the case of Emilia-Romagna vs Lombardy and Trentino Alto-Adige. While the latter two are largely included in the Alpine ecoregion and many of their endemic plants are found in non-forest areas at high elevation a.s.l., the former largely belong to the Apennine ecoregion (Blasi et al. 2014), with a larger proportion and diversity of lower altitude forest habitats hosting peninsular endemic taxa.

Overall, available information about the ecology of forest endemics is still poor, with a large proportion of taxa not assessed for Ellenberg indicator values and without syntaxonomical placement in "Prodromo della Vegetazione Italiana". 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. Most of the endemic taxa in our list, especially those typical of forest interiors and more adapted to shade (category 1.1), are likely to fit into the concept of "ancient forest species" as defined by Peterken (1974) and Hermy et al. (1999), i.e. forests with long temporal continuity (usually two centuries at least). However, mores studies on the biology and ecology of these taxa and on the forest sites that they inhabit are needed to support this hypothesis and to identify the ancient forest Italian endemics.

So far, the biology and phylogenetic relationships have been investigated in only a few taxa, among which *Petagnaea gussonei* (Gianguzzi 2002; Gianguzzi and La Mantia 2004; De Castro et al. 2009, 2015), Sardinian *Aquilegia* (Garrido et al. 2012; Mattana et al. 2012), *Gymnospermium scipetarum* subsp. *eddae* (Rosati et al. 2019a, 2019b; Marzario et al. 2022), and *Crocus etruscus* (Carta et al. 2014, 2015, 2016; Harpke et al. 2015). Based on available karyological data, the mean chromosome number is 32.1 (± 22.5), similarly to the whole Italian endemic flora (30.7 according to Bedini et al. 2012). The incidence of polyploids in forest endemics resulted slightly higher than in the entire Italian endemic flora (40–43% vs 35–37%) and the diploids/polyploids ratio of the forest endemics tended to be larger in the southern and insular regions, especially compared to the northwest. Most of the diploids have low numbers and are thus patro- or schizoendemics (sensu Favarger and Contandriopoulos 1961; Siljak-Yakovlev and Peruzzi 2012), likely of ancient origin. Sicily is also home of two narrow-ranged paleoendemics with 2n = 42, *Zelkova sicula* and *P. gussonei*. This number has been reported as of triploid origin for the former (base number x = 18; 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.

In terms of life-forms and functional groups, the endemic forest flora resulted almost exclusively composed of perennial plants, mainly herbaceous. Major differences with respect to the non-forest Italian endemic flora were the much lower proportion of chamaephytes, versus higher proportions of geophytes and, even more, phanerophytes (Fig. 4B).

Concerning conservation, most of the taxa have been assessed for IUCN category (Orsenigo et al. 2018, 2021), but the significant proportion of endemics assessed as "Data Deficient" and those for which threats are not known (42%) shows the need for further assessment work. Overall, the numerous taxa in the CR, EN, and VU (ca 24%) 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 wildfires (Di Virgilio et al. 2019; Carrari et al. 2022), which in fact resulted as the most recurrent threat to forest endemics, especially in the southern and insular sectors. Fire prevention is therefore crucial for the conservation of forest endemics, as well as the limitation of livestock farming and other recurrent types of disturbance that can cause ecosystem alterations, including forest fragmentation and extensive cuts for wood production.

Both the list of taxa and the associated information provided for the first time in this work will be updated and integrated with the new data that may become available in the future to support and inform further research and conservation actions targeted at the endemic flora and forest biodiversity in Europe.

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SUPPLEMENTARY MATERIALS

Supplementary material 1

Checklist of the Italian forest endemic species and subspecies, with associated available information about taxonomy, distribution, ecology, biology, and conservation status.
Link: https://doi.org/10.5091/plecevo.95929.suppl1

Supplementary material 2

Average Ellenberg indicator values (Light, Temperature, Continentality, Humidity, soil Reaction, Nutrients) of Italian endemic forest plants across the five Italian geographical sectors (values are means ± standard deviation; for administrative regions belonging to each sector see Table 1). Significance of differences are based on non-parametric Kruskal-Wallis test followed by post-hoc Tukey test.
Link: https://doi.org/10.5091/plecevo.95929.suppl2