



MARA Vegetation Database: Monitoring Alien species along mountain Roads in the central Apennines*

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Abstract

The MARA (Monitoring Alien species along mountain Roads in the central Apennines) database was developed to monitor the distribution of vascular plant species along mountain roads in the Central Apennines, Italy, focusing on alien (i.e. neophytes) and thermophilous plant species. Data were gathered in 2022 from 118 plots spanning an elevation range from 420 to 2125 meters a.s.l. along 3 main road corridors on three massifs (Gran Sasso, Maiella and Terminillo), following the MIREN road survey protocol. The database comprises 810 taxa (species and subspecies), of which 16 are identified as alien taxa. Major plant families in frequency are Asteraceae, Poaceae, and Fabaceae. MARA captures detailed information on species cover, taxonomy, and ecological traits, such as life forms and Ecological Indicator Values for Europe (EIVE) related to temperature. Notably, 53% of the alien species recorded were thermophilous, thriving in warmer environments, and predominantly concentrated below 1200 meters, though a few species extend to higher elevations. This suggests that rising temperatures due to climate change may facilitate the upward movement of these species, potentially disrupting native vegetation. For such reasons, the MARA database is a valuable resource for long-term ecological monitoring, providing valuable data for both national and international research networks.

Keywords

Alien taxa, MIREN sampling method, thermophilous taxa, vegetation database

Introduction

Mountain ecosystems are recognized for their ecological significance and biodiversity richness, characterized by steep environmental gradients that create distinct vegetation zones (Theurillat et al. 2007; Lazarina et al. 2019; Di Biase et al. 2021). The Central Apennines in Italy, including the Gran Sasso and Monti della Laga National Park, Maiella National Park, and Mount Terminillo, are renowned for their unique topography, geological formations (Cosentino

et al. 2010), and vascular flora richness (Ciaschetti et al. 2015; Conti and Bartolucci 2016; Piacentini et al. 2017; Conti et al. 2019, 2022). These areas serve as natural laboratories for studying changes in vegetation composition with elevation and the effects of global change on mountain habitats (Barni et al. 2012; Frate et al. 2018; Vitali et al. 2018; Guarino et al. 2021). Nowadays, alien taxa are becoming an emergent threat also in mountain zones around the world, even in high elevation protected areas and in isolated mountain landscapes (McDougall et al. 2011; Alexander et

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al. 2016; Pauchard et al. 2016; Pathak et al. 2019; Pyšek et al. 2020; Canavan et al. 2021). In this context, mountain roads often facilitate the movement of alien plant species and contribute to habitat fragmentation (Forman and Alexander 1998; Haider et al. 2018; McDougall et al. 2018). Previous research has highlighted the role of roads in altering native species composition and introducing disturbance-adapted taxa, which can lead to shifts in ecosystem dynamics, especially in sensitive high-elevation environments (Alexander et al. 2009; Okimura et al. 2016; Follak et al. 2018; Lázaro-Lobo and Ervin 2019; Corcos et al. 2020; Barros et al. 2022; Dostálek and Frantík 2024; Santoianni et al. 2024).

In the summer of 2022, the first Italian and Mediterranean site of the Mountain Invasion Research Network (MIREN) (Kueffer et al. 2014; Haider et al. 2022) was established in the Central Apennines. MIREN aims to understand the effects of global changes on species distribution and biodiversity in mountainous regions. Its scope is to study mountain species (re)distribution broadly, considering various drivers of global change, including biological invasions, climate change, and land-use change. In this context, monitoring alien (i.e. neophytes) and thermophilous species is particularly important to evaluate future scenarios for alien plant species and the upward shift of thermophilous plants (Dostálek and Frantík 2024). This phenomenon, known as the thermophilization of mountains, could have significant implications for biodiversity and ecological balance in mountain environments that are sensitive to climate change (Gottfried et al. 2012; Sekar et al. 2024). In this context, a database can support biodiversity management and protection entities at both regional and national levels, including national parks, nature reserves, and research centers (Costello et al. 2015; Viciani et al. 2018).

This study aims to establish a database for Monitoring Alien species along mountain Roads in the central Apennines (MARA) to address gaps in knowledge regarding the distribution of alien and thermophilous taxa in the Central Apennines and examines the plant taxa composition, distribution and ecology along mountain roads across an elevation gradient in three mountain sites in Central Italy. The findings may contribute to establishing long-term ecological monitoring of the native and alien

plant taxa upshifting and inform conservation strategies for maintaining the integrity of these ecosystems.

Methods

Study area

The vegetation sampling was conducted along three mountain roads in the Central Apennines (Italy), within two protected areas, Gran Sasso and Monti della Laga National Park and the Maiella National Park, and Mount Terminillo. The sampling covered an elevation gradient range from 420 m to 2125 m above sea level (a.s.l.) (Fig. 1). These mountain sites are characterized by prominent limestone formations, deep glacial valleys, river valleys, and karst phenomena (Piacentini et al. 2017). The study area encompasses a range of hilly and mountainous terrains, each supporting distinct vegetation types (Gigante et al. 2024). At lower elevations, the landscape is characterized by the following plant communities, according to the EUNIS Habitat Classification (Chytrý et al. 2020, 2024): semi-dry perennial calcareous grasslands (R1A), thermophilous forest fringes on base-rich soils (R51), and trampled xeric grasslands with annuals (V34). In the hilly and mountain belts Mediterranean thermophilous deciduous forests (T1A), temperate and submediterranean thermophilous deciduous forests (T19), and *Fagus* forests on non-acid soils (T17) occur. Beyond the treeline at higher elevations, habitats are dominated by perennial rocky grasslands of the Italian Peninsula (R14) and perennial rocky calcareous grasslands of subatlantic-submediterranean Europe (R18) (Table 1) (Santoianni et al. 2024).

Data collection

Vegetation sampling took place during the summer of 2022, following the MIREN road survey protocol (Haider et al. 2022). Sampling locations were established by dividing the total elevation range of the roads into 19 elevational bands (of ~ 100 m in elevation), giving a total of 20 sample sites (Fig. 1). Sampling in each site was

Table 1. The table lists EUNIS habitat codes, their full names, diagnostic, dominant, and constant species (Chytrý et al. 2020, 2024) recorded in the study area, along with the elevation range (m a.s.l.) for each habitat. A cluster analysis was performed, identifying 8 groups. Diagnostic species for each group were determined using the ‘Indicator Species’ function in PAST (Hammer et al. 2001) and compared with EUNIS habitat diagnostic, dominant and constant species (Chytrý et al. 2020, 2024; Santoianni et al. 2024).

EUNIS habitat code	EUNIS habitat name	Diagnostic, dominant and constant taxa	Elevation range (m a.s.l.)
R1A/R51/V34	Semi-dry perennial calcareous grassland (meadow steppe) / Thermophilous forest fringe of base-rich soils / Trampled xeric grassland with annuals	<i>Anthoxanthum odoratum</i> , <i>Anthyllis vulneraria</i> , <i>Acer campestre</i> , <i>Rubus ulmifolius</i> , <i>Lolium perenne</i> , <i>Plantago lanceolata</i> , <i>Convolvulus arvensis</i>	419–1429
T1A/T19/T17	Mediterranean thermophilous deciduous forest / Temperate and submediterranean thermophilous deciduous forest / <i>Fagus</i> Forest on non-acid soils	<i>Quercus pubescens</i> , <i>Emerus major</i> , <i>Quercus cerris</i> , <i>Acer opalus</i> subsp. <i>obtusatum</i> , <i>Fagus sylvatica</i> , <i>Cardamine bulbifera</i>	533–1386
R14/R18	Perennial rocky grassland of the Italian Peninsula / Perennial rocky calcareous grassland of subatlantic-submediterranean Europe	<i>Bromopsis erecta</i> , <i>Festuca inops</i> , <i>Globularia bisnagarica</i> , <i>Helianthemum oelandicum</i> subsp. <i>incanum</i> , <i>Teucrium chamaedrys</i>	906–2125

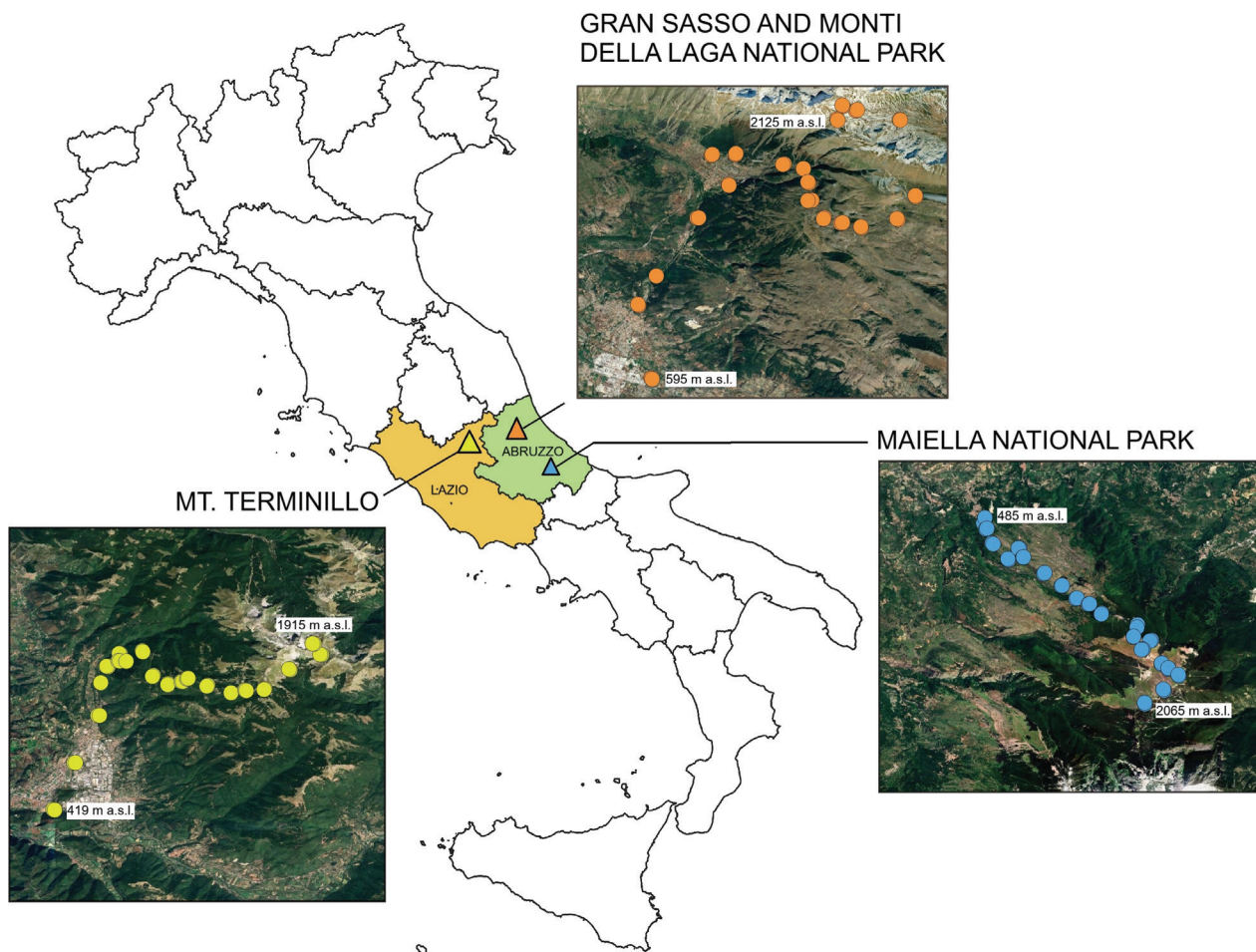


Figure 1. Location of the three study areas in the Central Apennines (Italy). The detailed map shows the location of the plots along the elevation gradient (scale 1:150000) within the Gran Sasso and Monti della Laga National Park (orange), the Maiella National Park (blue), and along Mount Terminillo (yellow). For each study area, the initial and final elevations of the investigated road are indicated. Google Earth. Retrieved November 29, 2024, from <https://www.google.com/earth>.

carried out on a transect designed in a T-shape configuration and consisted of two plots, each measuring 50 m in length and 2 m in width. The roadside plot was positioned parallel to the road, while the inland plot was situated perpendicular to the center of the roadside plot, forming a 90° angle. The distance between the two plots was 50 m.

The cover of all vascular plant taxa was visually estimated and recorded using a metric of cover based on eight classes (1 = <0.1%, 2 = 0.1–1%, 3 = 2–5%, 4 = 6–10%, 5 = 11–25%, 6 = 26–50%, 7 = 51–75%, 8 = 76–100%) (Haider et al. 2022). Taxonomy and nomenclature followed Bartolucci et al. (2024). Species were categorized as either native (autochthonous taxa and archaeophytes, alien taxa introduced before 1492) or alien (taxa introduced after 1492, i.e., neophytes) (Galasso et al. 2018, 2024).

Structure and content of the dataset

We compiled a comprehensive floristic database encompassing general and road/environmental information about plots and all taxa recorded across the mountain sites within the study area. The database was created using the

data management system PostgreSQL (PostgreSQL Global Development Group 2024). The road/environmental information includes plot code, region, road (Gran Sasso, Maiella, or Terminillo), plot type (roadside or inland), latitude, longitude, elevation, observers, and sampling date. The geographic locations of the plots were recorded in the field according to the World Geodetic System 1984 (WGS84 - EPSG:4326). Subsequently, the following road-related information is included: traffic intensity (referring to the volume of vehicles traveling on the road segment during the year; low = 1, intermediate = 2, high = 3), road opening period (number of months the road is open to traffic), road type (type of road surface, e.g., asphalt, gravel), rock cover (in percentage), bare ground (percentage of the plot without vegetation foliage, excluding rock and litter), litter (percentage of the plot without vegetation foliage but covered with dead and decaying plant material such as leaves, bark, needles, and twigs), tree cover (percentage of the plot covered by trees taller than 3 m), shrub cover (percentage), herb/cryptogam cover (percentage), and wetland/riparian habitat presence (percentage).

The dataset contains all taxa, including information on family, genus, species, subspecies, and authority, all arranged alphabetically (Bartolucci et al. 2024). For each

taxon, the following information is provided: i) locality of occurrence (specific plot sites where the taxon was found), ii) cover (percentage of the taxon's coverage within each plot), iii) status: general categorization indicating whether the taxon is native (incl. archaeophytes) or alien according to Galasso et al. (2018, 2024), iv) life form: classification according to the Raunkiaer system (Raunkiaer 1934), v) growth form: categorization following the system proposed by Díaz et al. (2022), vi) Ecological Indicator Values for Europe (EIVE) Temperature: data provided according to Dengler et al. (2023).

Data analysis

To describe the dataset in terms of taxa composition, we calculated the total cover of each taxonomic family by summing taxa cover values across all plots and we used their percentage on total coverage, grouping families with less than 4% cover as “Others.” This approach was also applied to alien taxa. We also assessed the cover of different life forms and their distribution among alien species. Next, plant taxa were categorized based on their occurrence across the three mountain sites and expressed as percentages, classifying them into: (i) common to all three sites, (ii) common to two sites, and (iii) present in only one site (Suppl. material 1). To explore the relationship between taxa richness, elevation, and plot type (roadside vs. inland), the dataset was divided into two elevation groups: below and above 1200 meters a.s.l., as this altitude is considered the upper limit for the most common alien taxa (Haider et al. 2018; Vorstenbosch et al. 2020; Santoianni et al. 2024). Within each elevation group, data were further categorized by plot type (roadside vs. inland). Taxa richness was calculated (Gotelli and Colwell 2001) and compared using four independent Student's t-tests (Kalpić et al. 2011) to assess differences between plot types and elevations. Additionally, the distribution of EIVE Temperature (EIVE T) (Dengler et al. 2023) indicators was examined. The EIVE database was utilized to facilitate future comparisons of our dataset with other MIREN sites throughout Europe (i.e. Swiss Alps, French Alps, El Teide). We calculated the 25th and 75th percentiles to identify taxa with particularly low or high EIVE T values, categorizing species above the 75th percentile as “thermophilous” (Gottfried et al. 2012; Varricchio et al. 2021). A density plot was created to visualize the distribution of EIVE T values (Saatkamp et al. 2023). For alien plant taxa, cover data across elevations were organized using the “tidyr” package (Wickham et al. 2024). EIVE T values were classified into temperature ranges, and taxa were visualized according to these classes. All analyses were conducted using R Statistical Software (v4.3.0; R Core Team 2023), with plots generated using the “ggplot2” package (Wickham 2016).

Results

The MARA database encompasses a total of 810 plant taxa from 118 plots (60 roadside and 58 inland), comprising 646 species and 164 subspecies, including

both native and alien plants. Among these, 16 taxa are classified as alien plant taxa (APT), including 12 species and 4 subspecies. The recorded taxa are distributed across 75 distinct taxonomic families. The most frequent families are Asteraceae (15%), Poaceae (10%), and Fabaceae (10%). Conversely, the families with the highest coverage in the study area are Poaceae (22%), Fagaceae (16%), and Fabaceae (8%) (Fig. 2A). In terms of life form distribution according to Raunkiaer's classification, the most abundant life forms are Phanerophytes (41%), Hemicryptophytes (36%), and Therophytes (8%) (Fig. 2B). The alien plant taxa are represented across 9 taxonomic families. The most common families of alien plants are Asteraceae (44%) and Poaceae (13%). However, the families with the highest cover are Simaroubaceae (41%), Sapindaceae (29%), and Fabaceae (14%) (Fig. 2C). Regarding alien plants life forms according to Raunkiaer's classification, the most abundant are Phanerophytes (88%), Therophytes (7%), and Hemicryptophytes (5%) (Fig. 2D).

Considering the taxa's occurrence across the three mountain sites of the study area (Gran Sasso Massif, Maiella Massif, and Mt. Terminillo) we observed that 23% of taxa are common to all three sites (Suppl. material 1). The most abundant taxa in this category are: *Fagus sylvatica*, *Brachypodium rupestre* and *Fraxinus ornus*. 27% of taxa are common to two sites, with the most abundant species *Pteridium aquilinum* subsp. *aquilinum*, *Rubus idaeus* subsp. *idaeus*, and *Abies alba*. 50% of taxa have been only recorded in one site. Among them, *Anthemis cretica* subsp. *columnae* is found in Gran Sasso, *Pinus mugo* subsp. *mugo* in Maiella, and *Patzkea paniculata* subsp. *paniculata* in Terminillo.

The boxplot analysis of taxa richness reveals differences between roadside and inland plots, both below and above 1200 m a.s.l. Below 1200 m a.s.l. the taxa richness is significantly higher in roadside plots compared to inland plots (p-value < 0.001) (Fig. 3). A similar trend is observed above 1200 m a.s.l., with roadside plots exhibiting higher taxa richness than inland plots (p-value = 0.018). Moreover, roadside plots richness significantly differs between the two elevation ranges (p-value < 0.001).

The analysis of the EIVE Temperature data, associated with each species in the MARA database, reveals that the taxa with EIVE T between EIVE T = 4 and EIVE T = 5.55 are the most common in our dataset (Fig. 4A). This species group is mainly represented by the typical species of deciduous forests, especially of the mountain *Fagus* forest, such as *Fagus sylvatica*, *Acer pseudoplatanus*, *Viola reichenbachiana*, *Cornus sanguinea*. Below the 25th percentile (EIVE T < 4), we mainly find taxa occurring in subalpine grasslands, such as *Festuca circummediterranea*, *Leucopoa dimorpha*, *Juniperus communis*, *Pilosella officinarum*. Above the 75th percentile (EIVE T > 5.55), the thermophilous species group occurs. These taxa are common at low elevations, in Mediterranean grassland and mixed thermophilous woodland, such as *Carthamus lanatus*, *Sesleria nitida*, *Avena sterilis*, *Fraxinus ornus* and *Quercus pubescens*.

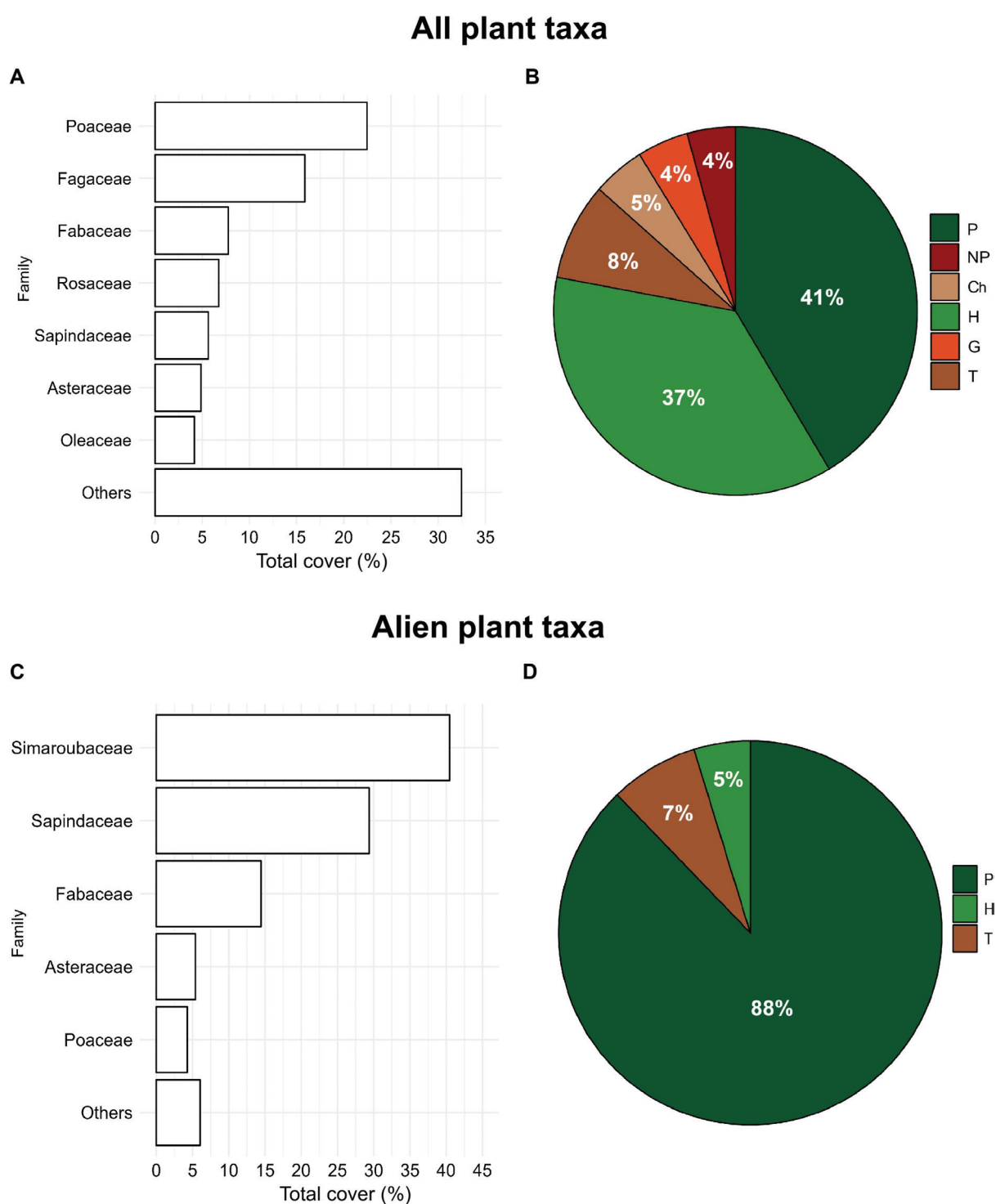


Figure 2. The first bar plot shows the percentage of total cover for each taxonomic family in the MARA database. Families contributing less than 4% cover are grouped under 'Others' (68 families) (A). The pie chart illustrates the percentage of total cover for each life form according to the Raunkiaer classification in the MARA database (P = Phanerophyte, NP = Nanophanerophytes, Ch = Chamaephyte, H = Hemicryptophyte, G = Geophyte, T = Therophyte) (B). The latter bar plot shows the cover percentage of alien plant taxa (APT) for each taxonomic family in the MARA database. Families contributing less than 4% of cover are grouped under 'Others' (9 families) (C). The pie chart illustrates the percentage cover of alien plant taxa (APT) for each life form according to the Raunkiaer classification in the MARA database (P = Phanerophyte, H = Hemicryptophyte, T = Therophyte) (D).

Regarding the distribution of alien plant taxa along the elevation gradient (Fig. 4B), 88% of plant taxa are concentrated below 1200 m a.s.l. Only a few species, such as *Ceratochloa cathartica*, *Crepis sancta* subsp. *nemausensis*, *Erigeron sumatrensis*, and *Matricaria discoidea* subsp.

discoidea, reach higher elevations (until 1659 m a.s.l.). Alien taxa EIVE T values show that thermophilous taxa prevail (53%), meaning they exceed EIVE T>5.5. Specifically, *Erigeron sumatrensis*, with EIVE T=6.54, reaches the maximum altitude of 1610 m a.s.l.

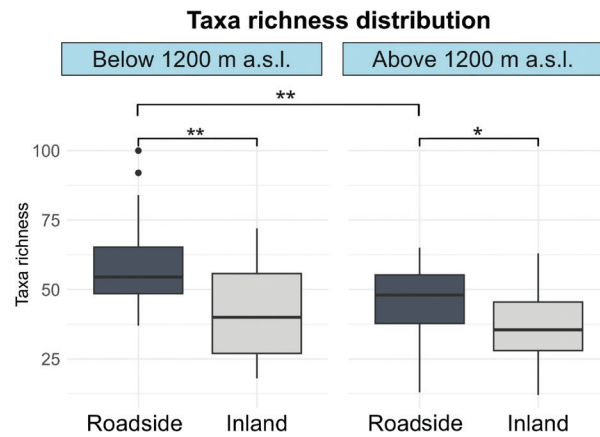


Figure 3. The boxplots show the taxa richness across the two plot types (roadside and inland plots) and elevation ranges (below 1200 m and above 1200 m a.s.l.). Significant differences between box-plots are highlighted using statistical significance markers (*) according to the Student's t-test (* $p < 0.05$, ** $p < 0.01$).

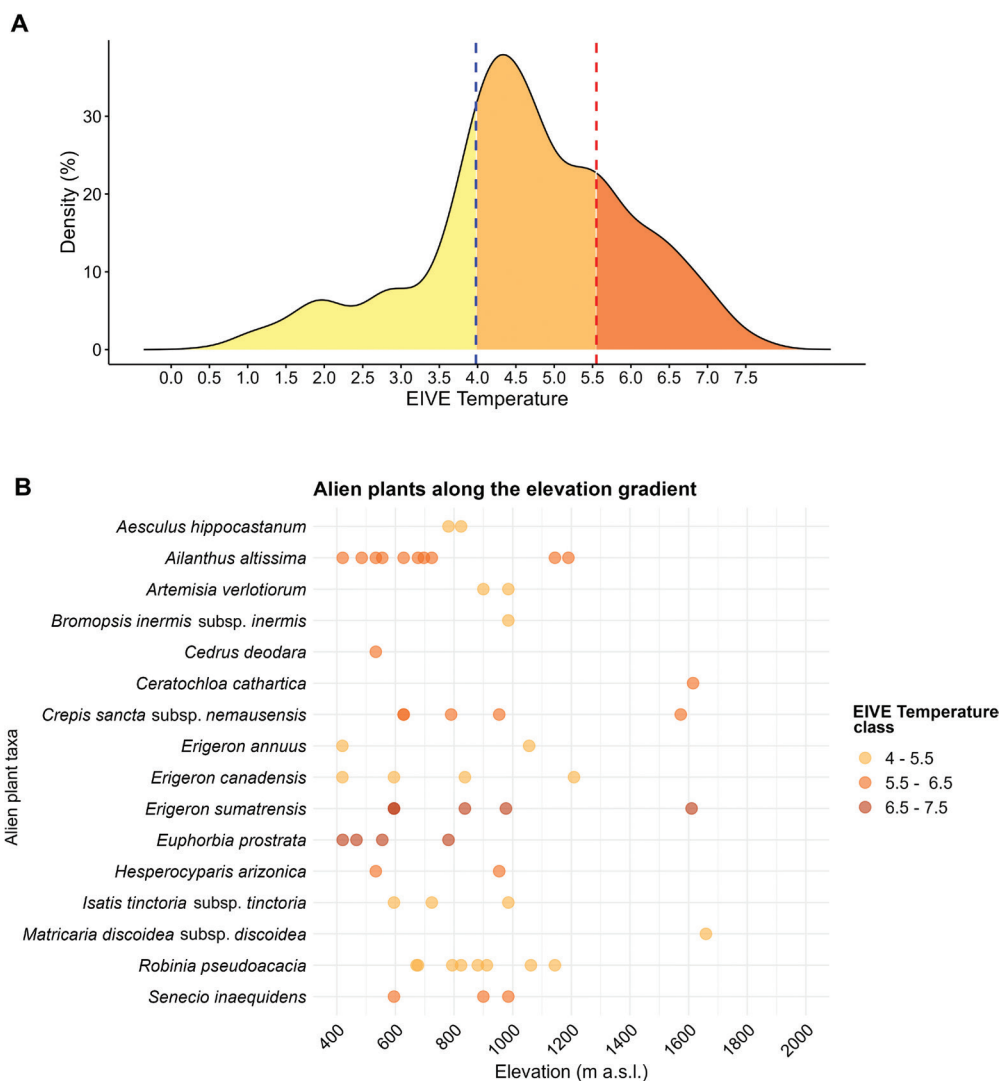


Figure 4. Density plot of the EIVE Temperature distribution with highlighted sectors based on percentile thresholds. The graph illustrates temperature density as a percentage, with the 25th percentile (blue dashed line) and 75th percentile (red dashed line) demarcating the lower, middle, and upper temperature ranges. The shaded areas represent the proportion of EIVE T falling within these ranges, with colors indicating different density levels: light yellow for EIVE T below the 25th percentile, orange for EIVE T between the 25th and 75th percentiles, and dark orange for EIVE T above the 75th percentile (A). The point chart shows the distribution of alien plant taxa along the elevation gradient, using EIVE T data for ecological classification. Each colored dot represents the elevation at which the alien plant taxon was recorded, with each color corresponding to a specific EIVE T class (B).

Conclusions and future perspectives

The MARA database was developed through extensive data collection, careful identification of plant specimens, taxonomic revision, and organized digitization and structuring of the data. Its organizational framework allows for scalability and integration into existing vegetation databases. Specifically, MARA represents a national and regional adaptation of data shared within the international MIREN framework (Seipel et al. 2022). The database will be updated by resampling the established plots every five years, with the next global monitoring survey scheduled for 2027.

Additionally, due to the layout (arranged along the elevation gradient) and the standard size of the monitoring plots, they could potentially be integrated into the Italian Long-term Ecosystem Research Network (LTER-IT), as some of the vegetation plots are already located within two LTER Sites: IT01-001-T Central-southern Apennine Majella-Matese, and IT01-003-T central Apennine: Gran Sasso d'Italia (Capotondi et al. 2021) and the Dynamic Ecological Information Management System - Site and Dataset Registry (DEIMS-SDR). DEIMS-SDR provides access to an increasing number of datasets and data products associated with LTER sites. Furthermore, as the plots are permanent, they will be revisited every five years and could be integrated into the 'ReSurveyEurope' network (Knollová et al. 2024), an initiative within the European Vegetation Archive (EVA) (Chytrý et al. 2016).

A particularly striking finding is that 53% of alien plant taxa are classified as thermophilous species, meaning they thrive in warmer environments and could potentially disrupt native ecosystems (Carboni et al. 2018). This is significant because, as temperatures rise due to climate change, these taxa might have greater opportunities to expand their range along elevation gradients. The warming climate is giving these thermophilous species a further advantage, allowing them to establish in habitats where they previously could not survive (Di Nuzzo et al. 2021).

In conclusion, our study and the MARA database highlight the importance of monitoring alien taxa in mountain environments and protected areas, especially in the current context of global warming. Understanding these dynamics will help guide future conservation strategies aimed at preserving Mediterranean native biodiversity and mitigating the impact of biological invasions.

Data accessibility

MARA database can be obtained by contacting the dataset custodians directly (Angela Stanisci stanisci@unimol.it; Lucia Antonietta Santoianni luciasantoian-ni@gmail.com).

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Supplementary material 1

Bar chart illustrating the percentage of taxa classified by their occurrence across the three sites

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Data type: png

Explanation note: The categories include species occurring in the plots of all three sites, in the plots of two sites, and those occurring only in the plots of one single site.

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