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Detecting Phytogeographic Units Based on Native Woody Flora: A Case Study in Central Peninsular Italy

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Abstract We present a statistically derived phytogeographic regionalization based on the spatial distribution of native woody flora, investigating environmental correlates and assessing congruence between the spatial patterns of species, genera, and families. A sector of central peninsular Italy (Lazio and Abruzzo regions) was selected as a case study. A rich georeferenced floristic database was compiled, including information from different sources. A total of 43,968 occurrence data, 290 10 × 10 km cells, 224 species, 103 genera, and 80 families was used; Ward's clustering was performed to identify phytogeographic units. Three well-defined and relatively spatially coherent units were identified at the species, genus, and family levels: a Mediterranean unit, a Transition unit, and a Eurosiberian one. Congruence between taxonomic levels was well supported. Further divisions in subunits were detected using species data. The main environmental descriptors of the clusters were distance from the sea, elevation, temperature, and lithology.

Keywords Biogeographic regionalization · βsim index · Floristic database · Higher-taxon approach · Indicator species analysis · Transition zone

Introduction

Biogeographic regionalizations represent fundamental abstractions of the geographic organization of life on Earth in response to past or current physical and biological forces, and are central to many basic and applied questions in biogeography, ecology, evolution, and conservation (Kreft & Jetz, 2010; Whittaker et al., 2013; Lomolino et al., 2010). Since biogeographic regionalizations are traditionally developed by experts and are based on qualitative evidence, the lack of transparency and quantitative support has set constraints on their utility (Kreft & Jetz, 2010). In fact, these kinds of regionalizations have not always been based on detailed species distribution data, while accurate distribution mapping is the

basis for detecting biogeographic patterns and processes (Riddle et al., 2011). The recent availability of multivariate techniques, enhanced computational power, and information on species distribution now enable a quantitative scrutiny and expansion of biogeographic regionalizations that will facilitate new and more rigorous uses (Kreft & Jetz, 2010). Different quantitative methods have been applied to define statistically derived biogeographic regionalizations: cluster analysis (Márquez et al., 2001; Kreft & Jetz, 2010; Rueda et al., 2010; Heikinheimo et al., 2012; Linder et al., 2012; Mateo et al., 2013; Abbate et al., 2016; Divíšek et al., 2016), the network approach (Vilhena & Antonelli, 2015), and fuzzy logic (Olivero et al., 2013). All these methods provide objective approaches for classifying biota, because they use quantitative measures of similarity between areas to reveal natural patterns of distribution. Furthermore, both Olivero et al. (2013) and Vilhena and Antonelli (2015) have remarked that in a biogeographic regionalization it is important to combine sharp and precise boundaries with gradual transition zones.

In terms of its biogeographic features, Italy is a very interesting country, belonging to both the Eurosiberian and Mediterranean Regions. Italy is of particular interest due to its latitudinal extension, great environmental and climatic heterogeneity, richness in vascular flora (it contains approximately half of the number of species found in Europe), richness in vegetation types, and its position in the Mediterranean Basin (see Abbate et al., 2015, and references therein). The ecoregional classification of Italy composed by Blasi et al. (2014) reflects this complexity, providing 7 provinces, 11 sectors, and 33 subsectors. Italy's countryside is characterised by a rich diversity of cultural landscapes, shaped by traditional land-uses (Plieninger et al., 2006). Moreover, the Italian peninsula provided refuge areas for flora during the glacial period (Svenning et al., 2008); the modern heterogeneity of vegetation was also observed in the Holocene history of trees (Magri et al., 2015).

Despite different studies being conducted over the last 60 years (Giacomini, 1958; Takhtajan, 1986; Rivas-Martinez et al., 2004; Blasi et al., 2007; Abbate et al., 2016), the phytogeographic regionalization of peninsular Italy, in particular with regard to the central sector, is not completely well defined. In fact, the extension, boundaries, names, and the inner delimitation of the Eurosiberian and Mediterranean regions have repeatedly changed over time. Following the regionalization by Rivas-Martinez et al. (2004), inland areas of central Italy belong to the Apennine sector of the Eurosiberian Region; coastal areas of the western Tyrrhenian side and of the eastern Adriatic one both belong to the Mediterranean Region and can be referred to the "Settore Italico of Provincia Tirrenica" and the "Settore Apulo of Provincia Adriatica", respectively. However, the regionalizations by Rivas-Martinez et al. (2004), and previously those by Giacomini (1958) and Takhtajan (1986), are expert-based and not statistically derived like the regionalizations by Blasi et al. (2007) and by Abbate et al. (2016). Particularly, the recent regionalization by Abbate et al. (2016), based on native woody flora and on the higher-taxon approach, has contributed to describe the phytogeographic structure of Italy at the scale of administrative regions; in central Italy, a Tyrrhenian Apennine sector and an Adriatic Apennine sector have each been described. Unfortunately, the database used did not allow for further distinction at a more detailed spatial scale within the Mediterranean and the Temperate Regions.

The choice to analyse woody plants (including trees, shrubs, and lianas) was made because they are important biodiversity surrogates for highly heterogeneous areas. In Italy, the richness of native woody plants has been shown to be a good predictor of the overall

native vascular flora richness at a medium spatial scale (corresponding to administrative regions) (Abbate et al., 2015). Moreover, woody plants represent one of the best groups of organisms for examining the role of climate in shaping the geographic variation of species richness (Qian, 2013). As concerns forest ecosystems, data on woody plant species are also valid predictors of both beta and gamma diversity of all plant species (Giorgini et al., 2015); despite this, evidences also occurred that this is not always true: for instance, in recent studies tree species diversity appeared not to be among the drivers of the overall species diversity relatively to the understorey of European forests (Ampoorter et al., 2016). Woody flora and trees, providing habitat structure and therefore being biotic drivers of animal distribution, also have a strong influence on the biogeographic structure of many animal groups (Rueda et al., 2010; Heikinheimo et al., 2012). Therefore, for phytogeographic regionalization, using suitable surrogate groups, for which taxonomic and distributional data are more easily available, can be considered a useful approach, especially for highly biodiverse territories.

In this framework, the use of an higher-taxon approach also represents a good tool; in fact, reduction in taxonomic resolution is desirable because it could allow for more rapid acquisition of knowledge while requiring less effort, if only some information is lost (Landeiro et al., 2012). The higher-taxon approach has been largely tested as a surrogate for species richness for a number of taxa, including woody plants (e.g. Balmford et al., 1996; La Ferla et al., 2002; Prinzing et al., 2003; Villaseñor et al., 2005; Mandelik et al., 2007; Landeiro et al., 2012; Alves et al., 2016); some studies have also tested the usefulness of the higher-taxon approach to describe patterns in the compositional turnover of species (e.g. Prinzing et al., 2003; Bergamini et al., 2005; Heino & Soininen, 2007; Mandelik et al., 2007; Landeiro et al., 2012; Alves et al., 2016; Abbate et al., 2016; Latini et al., in prep.).

Nowadays, the importance of rich datasets covering various components of biodiversity and comprising data from different sources is emphasized. For the last 200 years, information on species distribution has mostly been scattered in natural history collections and scientific publications or monographs. Now, this information is increasingly available in digital formats: databasing of plant diversity data became one of the major objectives in biodiversity informatics, and floristic records provide baseline data for several studies (Lavoie, 2013; Bedini et al., 2016). In the last few years, several georeferenced floristic databases have been created for central Italy (Conti et al., 2010; Latini et al., 2014; Peruzzi & Bedini, 2015).

In this study, we selected an area in central peninsular Italy and used rich georeferenced floristic databases. We aimed to (1) develop a statistically derived biogeographic regionalization based on native woody flora, investigating environmental correlates, and (2) assess congruence between the biogeographic patterns of native woody species, genera, and families.

Materials and Methods

Study Area

The study area is located in central Italy and includes two administrative regions (Lazio and Abruzzo) (Fig. 1). It has a surface area of ca. 28,040 km^2 (ISTAT, 2016a). A

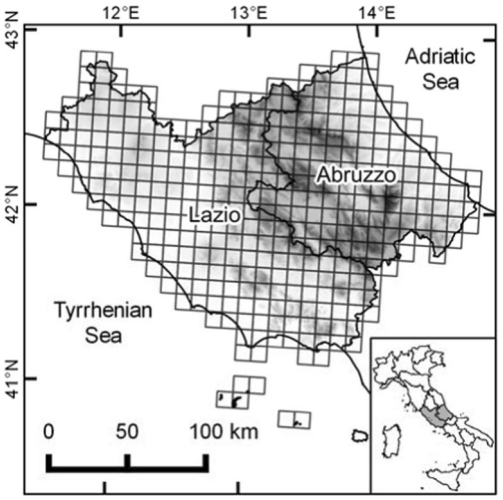

Fig. 1 Study area (Lazio and Abruzzo administrative regions, central Italy) with the used 10 × 10 km grid cells (colours from white to black correspond to the increasing elevation; geographic coordinates in WGS84)

continuous mountain ridge (the Central Apennines) separates the western Tyrrhenian slope from the eastern Adriatic one, with an altitudinal range of 2912 m from the coast to the highest peak of the entire Apennines; in the western slope, the Anti-Apennine mountains and volcanoes are present. Six small islands in the Tyrrhenian Sea are included. The Tyrrhenian coast is ca. 375 km long, and the Adriatic one is ca. 140 km. The percentage cover of the three standard elevation belts (ISTAT, 2011) is 10% plains, 44% hills, and 46% mountains. The climate is characterised by four climatic regions (Temperate, Mediterranean and two transitional regions) and six bioclimates (Blasi & Michetti, 2007). The most widespread lithotypes are limestones and dolomites (34%), alluvial sediments and clays (22%), volcanic rocks (18%), and flysch deposits and arenaceous assemblages (17%) (Geoportale Nazionale, 2016). Thus, a clear west-to-east gradient is present in terms of topography, climate, and lithology, producing high environmental diversification. According to the Coordination of Information on the Environment (CORINE) Land Cover 2012 classification (ISPRA, 2012), agricultural areas cover 52% of the area, forests cover 27%, scrub and herbaceous vegetation covers 14%, and artificial surfaces cover 5%. In terms of vegetation, 34 series and seven geosygmeta have been described (Blasi, 2010), mostly including deciduous *Quercus-Fagus* forests and secondarily sclerophyllous ones. The 7,200,000 inhabitants are mostly concentrated in coastal areas, especially in the cities of Roma and Pescara (ISTAT, 2016b).

Data Collection

For our study, we selected all native woody taxa at present certainly occurring in the Lazio and/or Abruzzo administrative regions (Bartolucci et al., in prep.; see Bartolucci et al., 2016). All taxa belonging to phanerophyte and nano-phanerophyte life-forms sensu Raunkiaer (Pignatti, 1982) were considered, including some taxa being phanerophytes or nano-phanerophytes only secondarily (namely *Asparagus acutifolius*,

Atriplex halimus, and *Santolina etrusca*). We excluded from the analysis groups of species and hybrids. Alien taxa (national and/or regional) were generally not considered; however, *Abies alba* (doubtfully native for Lazio), *Olea europaea,* and *Cercis siliquastrum* (both naturalized to Abruzzo), were considered in both regions. *Periploca graeca* (doubtfully native to Abruzzo) was not considered. There were 229 selected species belonging to 106 genera and 51 families.

Taxa distribution data were compiled from various sources including herbarium specimens as well as published and unpublished data; data were stored in the georeferenced floristic databases of Lazio and Abruzzo regions (Conti et al., 2010; Latini et al., 2014). The basic herbarium collection data were provided by RO, APP, and UTV (acronyms follow Thiers, 2016). Published data included mainly floristic and phytosociological papers. Unpublished data included field observations we recently collected in central Italy. Only data identified to the species level were considered in this study. We excluded doubtfully identified taxa. Only data collected after 1950 were considered; this threshold was chosen following botanical and floristic literature, in which records collected after this year are considered recent (Scoppola & Magrini 2005; Celesti-Grapow et al., 2009; Conti et al., 2010). Cultivated and naturalized taxa were excluded. Although herbarium and published records did not usually provide latitudinal and longitudinal information, we were able to georeference many of these records based on the original location descriptions. An accuracy value, according to Conti et al. (2010), was used to express spatial resolution of the georeferenced data. Only georeferenced data with accuracy values of 1 (originally georeferenced data or point site), 2 (corresponding to an area of nearly 1 km^2 around the reference point) or 3 (roughly corresponding to a municipality area) were considered. Data with an accuracy value of 4 (wide geographic range) or 5 (regional presence) were not considered. Nomenclature follows Bartolucci et al. (in prep.; see Bartolucci et al., 2016). The resulting dataset included a total of 43,968 taxa occurrence data.

A 10 km × 10 km equal-area grid (European Environmental Agency, 2016) was chosen to appropriately reflect the spatial accuracy of the distribution data, and in accordance with the study goal (Kreft & Jetz, 2010); this spatial resolution (analysis grain) was chosen because a higher resolution was not possible due to the spatial error in the geo-referenced data. The 10 × 10 km grid was superimposed on the map of the Lazio and Abruzzo administrative regions (ISTAT, 2016a). All the cells and portions of cells were initially considered, the correlations between cell surface and number of species being weak (Pearson $r = 0.33$). The resulting grid included a total of 344 cells (201 for Lazio, 112 for Abruzzo, and 31 at the boundaries between the two regions) (Fig. 1).

Subsequently, the 10 × 10 km grid was superimposed onto taxa distribution data. Three incidence matrices (for species, genera, and families) were created, containing species, genera, and families presence-absence data, respectively, within each grid cell. Cells with five or fewer species, showing also a low sampling intensity, were removed from the analysis (Fig. 2). The final dataset comprises 290 cells, 224 species, 103 genera, and 80 families, with in all 11,682 species presence data, 8194 genera presence data, and 5342 families presence data.

For each grid cell or portion of a grid cell, a set of environmental variables was recorded. Coordinates (X and Y, WGS84 UTM 33 T) and distance from the sea (DIST_SEA, km) were calculated, considering centroids. Minimum, mean, maximum

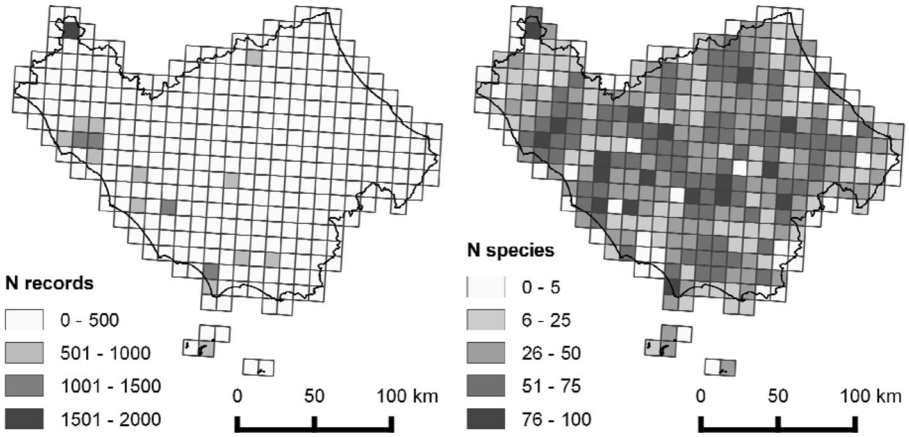

Fig. 2 Number of records and number of species per grid cells

and range values for elevation (ELEV_MIN, ELEV_MEAN, ELEV_MAX, ELEV_RANGE, m a.s.l.) were calculated using a 20 m DEM (ISPRA, 2016). The mean values of the following bioclimatic variables were obtained from WorldClim (Hijmans et al. 2005; WorldClim, 2016): annual mean temperature (T_MEAN, °C), maximum temperature of the warmest month (T_MAX, °C), minimum temperature of the coldest month (T_MIN, °C), annual temperature range (T_RANGE, °C), annual precipitation (P_ANN, mm), precipitation of the wettest month (P_WET, mm), and precipitation of the driest month (P_DRY, mm). Surface covered by each geolithological type was obtained using geolithological map from the Geoportale Nazionale (2016), with the types abbreviated as follows: limestones, dolomites, marls, travertines, and glacial deposits (LIT_LIM), alluvial sediments and clays (LIT_ALL), volcanic rocks (LIT_VOL), arenaceous assemblages and flysch deposits (LIT_ARE), sands, conglomerates, and aeolian deposits (LIT_SAN), lakes and glaciers (LIT_LAK), and gypsum and evaporite deposits (LIT_EVA). Surface covered by each CORINE Land Cover category was obtained using CORINE Land Cover 2012 map (ISPRA, 2012), with the category abbreviated as follows: artificial surfaces (CLC_1), agricultural areas (CLC_2), forests and seminatural areas (CLC_3), wetlands (CLC_4), water bodies (CLC_5).

All the analyses were performed using the software QGIS version 2.6.1 (QGIS Development Team, 2014).

Data Analysis

To quantitatively delineate phytogeographical regions of central Italy based on native woody flora, we used multivariate techniques, as recommended by Kreft & Jetz (2010).

Analyses were performed at species, genus, and family taxonomic levels.

Using the βsim index between cells based on presence-absence data of species, genera, and families respectively, dissimilarity matrices for species, genera, and families were created. Values of βsim varied from 0, for the identical taxa composition of two grid cells, to 1 for grid cells that do not share any taxon. Bsim does not take shared absences (zero values) into account: for biogeographic regionalizations, presence-only

measures are important because areas which lack many species and share none should not to be found similar purely due to shared absence (Linder et al., 2012). The advantage of βsim over other distance metrics is its independence of species richness gradients in the study area, since it is not sensitive to major differences in species richness (Koleff et al., 2003; Kreft & Jetz, 2010; Leprieur & Oikonomou, 2014).

To extract the discontinuity sets in native woody flora composition, each dissimilarity matrix was submitted to the clustering procedure using Ward's minimum variance method (Ward, 1963). Hierarchical algorithms, which construct a hierarchy of clusters, are particularly useful in biogeographical analysis, because biogeographical regions are hierarchically arranged (Kreft & Jetz, 2010; Vilhena & Antonelli, 2015). Ward's method minimizes the sum of the within-group sums of squares merging the clusters only if they increase the within-cluster variation the least; therefore, it was chosen because it is recommended when within-cluster homogeneity is desired (Legendre & Legendre, 1998; Ramette, 2007). Since Ward's method works in Euclidean space, but the βsim index produces a non-Euclidean dissimilarity matrix (Legendre & Legendre, 1998), we used a βsim matrix corrected by using the correction by Cailliez (1983), which computes the smallest positive number and adds it to each dissimilarity value. This procedure was successfully applied by Divíšek et al. (2014). We did not include spatial constraints during clustering; cells were clustered based on their taxa composition without regard to their spatial proximity so as to not force cohesion of clusters not justified by the actual distributions of taxa.

Indicator species analysis (ISA) (Dufrêne & Legendre, 1997) was used to identify taxa (species, genera, and families) associated with each cluster or with the combination of clusters (De Cáceres et al., 2010). The indicator value index (IndVal) resulting from the analysis is the product of two components (A and B); component A (specificity), in the case of presence/absence data (Bakker, 2008), is the ratio between the number of cells in a cluster occupied by the taxon and the total number of cells occupied by the taxon; component B (frequency) is the ratio between the number of cells in a cluster occupied by the taxon and the total number of cells in the cluster. Values of IndVal varied from 0 for a species that is absent from a cluster and 1 for species that occurs in all samples within a cluster and does not occur in other clusters. For each cluster or combination of clusters, indicator taxa were those with an IndVal higher than 0.25, as suggested by Dufrêne and Legendre (1997), and for $p < 0.05$. ISA was successfully used by Mateo et al. (2013) to identify species associated to biogeographic units.

To look for interpretable clusters to retain, we based on the visual inspection of the dendrograms and on the taxa-based maps, and on the ISA results.

In order to analyse the relationships between clusters and environmental variables, basic statistics for environmental variables were obtained and visually examined using boxplots and barplots.

In order to assess congruence among the taxonomic levels, woody flora patterns at the species, genus, and family levels were compared to each other. Dissimilarity matrices were compared using a Mantel test based on Pearson's product-moment correlation (Mantel, 1967; Legendre & Legendre, 1998); the significance of the resulting Mantel statistics was evaluated by a permutation test (999 permutations). Species and genera site topology resulting from cluster analysis was compared by applying Pearson's chi-square test (with simulated p value based on 2000 replicates) on a contingency table.

All analyses were performed in R software (R Core Team, 2015) using 'vegan' (Oksanen et al., 2016) and 'indicspecies' (De Cáceres & Legendre, 2009) packages.

Results

At all the considered taxonomic levels, the dendrograms (Fig. 3), the mapping of the clusters (Fig. 4), and the ISA results suggest the presence of three well-defined clusters (named S1, S2, and S3 at the species level; G1, G2, and G3 at the genus level; and F1, F2, and F3 at the family level). Although we did not include spatial constraints to influence the clustering of neighbouring cells, phytogeographic regions for native woody flora were quite spatially cohesive, especially at the species level. Further interpretable subclusters can be identified at the species level (Figs. 5, 6).

Results obtained across different taxonomic levels are congruent with each other. In fact, Mantel tests show a strong correlation between dissimilarity matrices of species and genera (r = 0.8784, p = 0.001), between genera and families (r = 0.8368, p = 0.001), and between species and families (r = 0.7286, p = 0.001); chi-square tests calculated on contingency tables reveal that site topologies are also congruent with each other for both the two-cluster and the three-cluster solutions (Table 1). However, the hierarchical relationships between clusters present some differences between taxonomic levels. In fact, the highest dendrogram division separates clusters S1 and S2 from S3 at the species level, clusters G1 and G2 from G3 at the genus level, while at the family level, the first division separates cluster F1 from F2 and F3.

Hereafter, we report the most important features of the clusters to highlight affinities and differences between taxonomic levels. Moreover, features of the subclusters identified at the species level are also reported. For the three-cluster solutions, dendrograms are in Fig. 3 and maps are in Fig. 4; boxplots for the most important environmental variables are in Fig. 7; ISA results are in Table 2; extended results of numbers of cells, taxa and basic statistics for environmental variables are in Appendix, Tables 3, 4, and 5; extended results of ISA are in Appendix, Tables 6, 7, and 8. For the six-cluster solution, dendrogram is in Fig. 5 and map is in Fig. 6; other results are available under request.

Clusters S1, G1, and F1 can all be identified as a Mediterranean unit. They are characterized by the lowest number of cells and number of taxa per cluster; they are

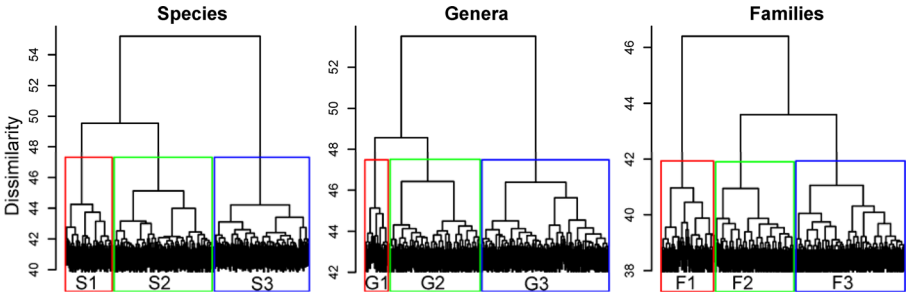

Fig. 3 Dendrograms and phytogeographic units resulting from the cluster analysis (Ward method on βsim dissimilarity with Cailliez correction) conducted on the occurrence data of native woody flora in the 10 × 10 km grid cells at species, genus, and family levels

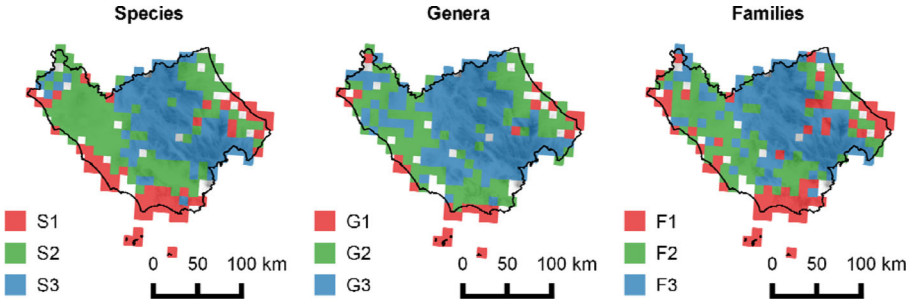

Fig. 4 The three phytogeographic units of Lazio and Abruzzo resulting from the cluster analysis (Ward method on βsim dissimilarity with Cailliez correction) conducted on the occurrence data of native woody flora in the 10 × 10 km grid cells at species, genus, and family levels

located in the low-elevation coastal areas of both the Tyrrhenian and Adriatic slopes and have the highest annual mean temperature values and the lowest annual precipitation values. Alluvial sediments (i.e. LIT_ALL), limestones (i.e. LIT_LIM), and sands (i.e. LIT_SAN) prevail for lithotypes, and agricultural areas prevail for the CORINE Land Cover classification. In the ISA results 32 indicator species were identified for S1 (e.g. *Pistacia lentiscus*, *Myrtus communis*, and *Lonicera implexa*), of which six are exclusive (e.g. *Juniperus turbinata* and *Euphorbia dendroides*); 17 indicator genera were identified for G1 (e.g. *Myrtus*, *Ceratonia*, and *Rosmarinus*), of which three are exclusive (e.g *Anthyllis* and *Medicago*); 6 indicator families were identified for F1 (e.g. Myrtaceae, Cistaceae, and Lamiaceae), of which one is exclusive (Arecaceae).

Clusters S2, G2, and F2 can all be identified as a transition unit between the Mediterranean and Eurosiberian units. For cluster S2, the number of cells and taxa is the highest among species-level clusters (i.e. 190 species in S2); for clusters G2 and F2, the numbers of taxa are the highest among genera- and family-level clusters (i.e. 98

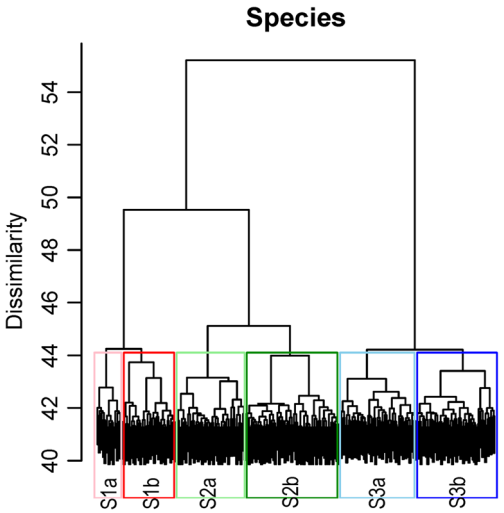

Fig. 5 Dendrograms and phytogeographic subunits resulting from the cluster analysis (Ward method on βsim dissimilarity with Cailliez correction) conducted on the occurrence data of native woody flora in the 10 × 10 km grid cells at species level

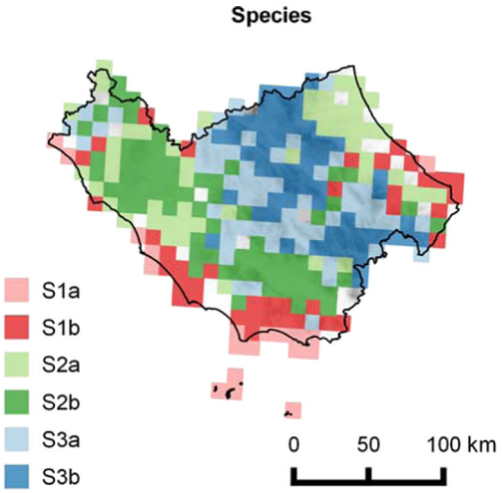

Fig. 6 The six phytogeographic subunits of Lazio and Abruzzo resulting from the cluster analysis (Ward method on βsim dissimilarity with Cailliez correction) conducted on the occurrence data of native woody flora in the 10 × 10 km grid cells at species level

genera in G2 and 49 families in F2). Clusters S2, G2, and F2 are located in middle-elevation inland areas of both Tyrrhenian and Adriatic slopes. Alluvial sediments (i.e. LIT_ALL) and volcanic rocks prevail for the lithotypes in these areas, and agricultural areas prevail for the CORINE Land Cover classification. Only one species was identified as an indicator of S2 (*Adenocarpus complicatus*), one family was identified as an indicator of F2 (Staphyleaceae), and no indicator genus was detected for G2.

Clusters S3, G3, and F3 can all be identified as a Eurosiberian unit. For clusters G3 and F3, the numbers of cells are the highest among genus and family clusters, while the numbers of taxa in these clusters are the lowest among genus and family clusters. These clusters are located in the inland high-elevation areas; they have the lowest annual mean temperature values and the highest annual precipitation values. Limestones (i.e. LIT_LIM) and arenaceous assemblages (i.e. LIT_ARE) prevail for lithotypes of these areas, and forests and seminatural areas dominate for the CORINE Land Cover classification. Overall, 40 species are indicators of S3 (e.g. *Fagus sylvatica*, *Sorbus aria*, and *Laburnum anagyroides*), five of which are exclusive (e.g. *Oreoherzogia*

Table 1 Contingency tables for phytogeographic units at species (S1, S2, S3), genus (G1, G2, G3), and family (F1, F2, F3) levels and Pearson's Chi-squared test with simulated *p*-value (based on 2000 replicates): a) species/genera contingency table: X-squared = 203.14, *p*-value <0.001; b) genera/families contingency table: X-squared = 128, *p*-value <0.001. c) genera/families contingency table: X-squared = 179.76, *p*-value <0.001

a) Species/genera				b) Genera/families				c) Species/families			
	G1	G2	G3		F1	F2	F3		F1	F2	F3
S1	25	31	2	**G1**	26	3	0	**S1**	43	14	1
S2	2	73	44	**G2**	29	51	29	**S2**	12	67	40
S3	2	5	106	**G3**	9	42	101	**S3**	9	15	89

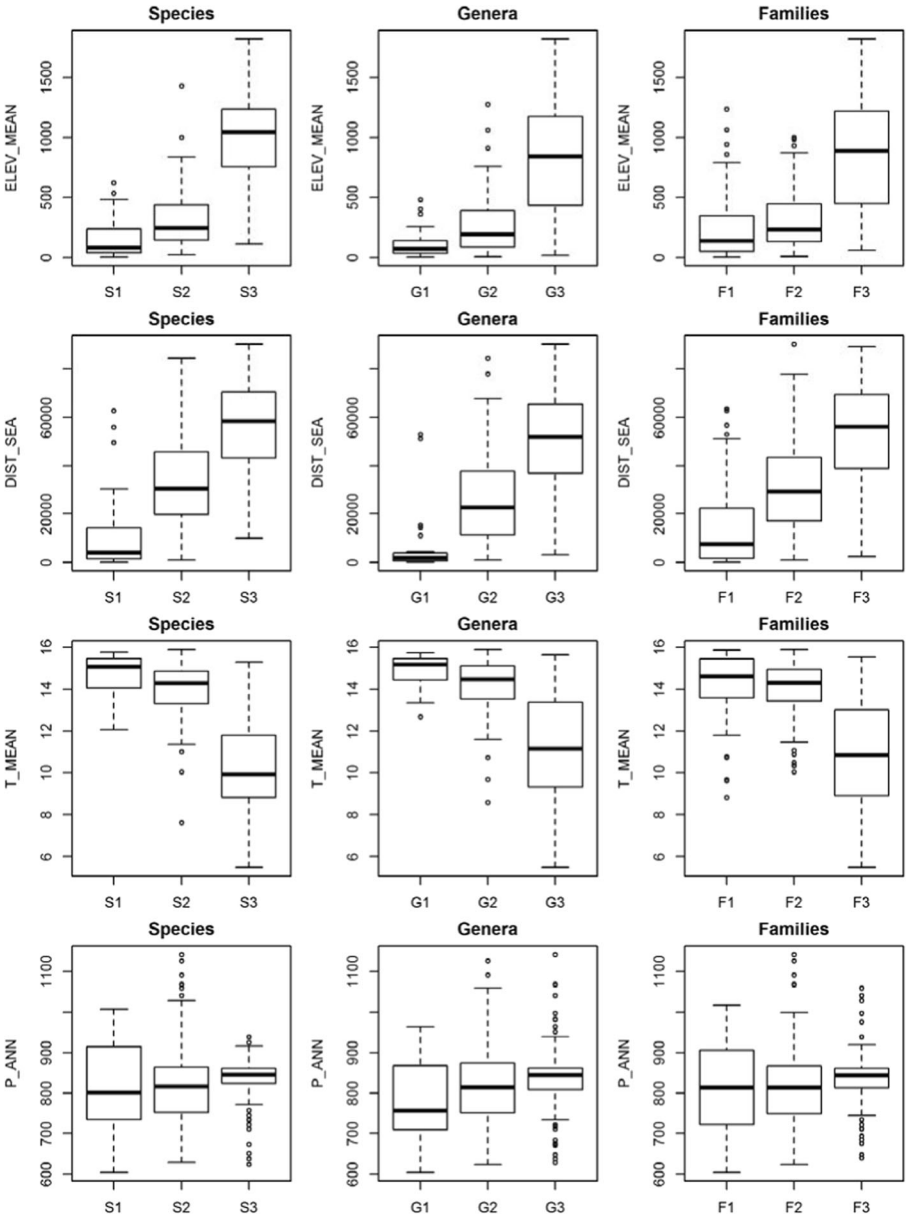

Fig. 7 Boxplot for the most important environmental variables for the three phytogeographic units resulting from the cluster analysis (Ward method on βsim dissimilarity with Cailliez correction) conducted on the occurrence data of native woody flora in the 10 × 10 km grid cells at species, genus, and family levels

fallax and *Ribes uva-crispa*); seven genera are indicators of G3 (e.g. *Fagus*, *Laburnum*, and *Amelanchier*); two families are indicator of F3 (i.e. Taxaceae and Grossulariaceae).

The shared indicator taxa between clusters are also noteworthy. There were 27 species indicators of S1-S2 (e.g. *Rubia peregrina*, *Rosa sempervirens*, and *Smilax aspera*), 17 genus indicators of G1-G2 (e.g. *Rubia*, *Smilax*, and *Asparagus*), and nine family indicators of F1-F2 (e.g. Rubiaceae, Asparagaceae, Smilacaceae). There were

Table 2 Indicator Species Analysis results: indicator taxa and indicator values (IndVal) for each native woody flora phytogeographic unit or combination of units at species (S1, S2, S3), genus (G1, G2, G3), and family (F1, F2, F3) levels

Species		Genera		Families	
S1	**IndVal**	**G1**	**IndVal**	**F1**	**IndVal**
Pistacia lentiscus L.	0.778	*Myrtus*	0.703	Myrtaceae	0.659
Myrtus communis L.	0.759	*Ceratonia*	0.572	Cistaceae	0.643
Lonicera implexa Aiton	0.656	*Rosmarinus*	0.551	Lamiaceae	0.561
Clematis flammula L.	0.636	*Anthyllis*	0.525	Chenopodiaceae	0.381
Rhamnus alaternus L.	0.579	*Atriplex*	0.498	Arecaceae	0.306
Daphne gnidium L.	0.567	*Tamarix*	0.484	Asteraceae	0.295
Cistus monspeliensis L.	0.529	*Coronilla*	0.474		
Erica multiflora L.	0.526	*Thymelaea*	0.474		
Quercus suber L.	0.526	*Artemisia*	0.448		
Cistus salviifolius L.	0.524	*Chamaerops*	0.405		
S2	**IndVal**			**F2**	**IndVal**
Adenocarpus complicatus (L.) J.Gay	0.31			Staphyleaceae	0.284
S3	**IndVal**	**G3**	**IndVal**	**F3**	**IndVal**
Fagus sylvatica L.	0.753	*Fagus*	0.760	Taxaceae	0.510
Sorbus aria (L.) Crantz	0.733	*Laburnum*	0.655	Grossulariaceae	0.388
Laburnum anagyroides Medik.	0.657	*Amelanchier*	0.504		
Juniperus communis L.	0.655	*Taxus*	0.495		
Acer pseudoplatanus L.	0.638	*Oreoherzogia*	0.469		
Daphne oleoides Schreb.	0.601	*Ribes*	0.378		
Juniperus deltoides R.P.Adams	0.593	*Betula*	0.320		
Amelanchier ovalis Medik.	0.574				
Viburnum lantana L.	0.557				
Rubus idaeus L.	0.549				
S1-S2	**IndVal**	**G1-G2**	**IndVal**	**F1-F2**	**IndVal**
Rubia peregrina L.	0.795	*Rubia*	0.743	Rubiaceae	0.727
Rosa sempervirens L.	0.770	*Smilax*	0.738	Asparagaceae	0.722
Smilax aspera L.	0.759	*Asparagus*	0.734	Smilacaceae	0.695
Asparagus acutifolius L.	0.751	*Pistacia*	0.724	Anacardiaceae	0.627
Rubus ulmifolius Schott	0.749	*Cistus*	0.695	Cannabaceae	0.604
Ulmus minor Mill.	0.728	*Phillyrea*	0.671	Lauraceae	0.587
Hedera helix L.	0.706	*Arbutus*	0.573	Ericaceae	0.581
Quercus ilex L.	0.705	*Laurus*	0.567	Euphorbiaceae	0.461
Phillyrea latifolia L.	0.666	*Olea*	0.554	Tamaricaceae	0.414
Sorbus domestica L.	0.625	*Euphorbia*	0.541		
S1-S3	**IndVal**	**G1-G3**	**IndVal**	**F1-F3**	**IndVal**
Tilia cordata Mill.	0.359	*Juniperus*	0.715	Thymelaeaceae	0.745
Rosa spinosissima L.	0.278	*Daphne*	0.709	Cupressaceae	0.737
		Ilex	0.507	Rhamnaceae	0.651
		Genista	0.404	Malvaceae	0.497

Table 2 (continued)

Species		Genera		Families	
		Pinus	0.308	Pinaceae	0.365
S2-S3	**IndVal**	**G2-G3**	**IndVal**	**F2-F3**	**IndVal**
Acer campestre L.	0.790	*Acer*	0.866	Sapindaceae	0.832
Quercus pubescens Willd.	0.785	*Rosa*	0.836	Betulaceae	0.824
Quercus cerris L.	0.763	*Crataegus*	0.795	Fagaceae	0.822
Ostrya carpinifolia Scop.	0.755	*Fraxinus*	0.795	Cornaceae	0.786
Corylus avellana L.	0.752	*Prunus*	0.794	Salicaceae	0.764
Clematis vitalba L.	0.725	*Cornus*	0.792	Celastraceae	0.708
Rosa canina L.	0.724	*Rubus*	0.779	Ulmaceae	0.708
Prunus spinosa L.	0.715	*Ostrya*	0.774	Solanaceae	0.487
Acer opalus Mill.	0.705	*Euonymus*	0.770	Aquifoliaceae	0.484
Cornus mas L.	0.685	*Carpinus*	0.745	Moraceae	0.473

Only the 10 taxa with the highest indicator values are given for each unit or combination of units

two species indicators of S1-S3 (i.e. *Tilia cordata* and *Rosa spinosissima*), five genus indicators of G1-G3 (e.g. *Juniperus*, *Daphne*, and *Ilex*), five family indicators of F1-F3 (e.g. Thymelaeaceae, Cupressaceae, and Rhamnaceae). There were 38 species indicators of S2-S3 (e.g. *Acer campestre* and *Quercus pubescens*), 20 genus indicators of G2-G3 (e.g. *Acer*, *Rosa*, and *Crataegus*), and 12 family indicators of S2-S3 (e.g. Sapindaceae, Betulaceae, and Fagaceae).

At the species level, it was possible to further divide the units in subunits; at genus and family levels, interpretable subunits cannot be clearly identified, being geographically scattered and not well supported by indicator taxa. First of all, within the Transition unit, a subcoastal subtype (S2a) and an inland one (S2b) can be identified; in particular, in the subcoastal subtype, elevation values are lower, alluvial sediments and clays prevail, and most indicator species are hygrophilous (e.g. *Populus nigra*, *Salix purpurea*, *Populus alba*, and *Salix triandra*). Secondly, the Mediterranean unit can be divided into an eurimediterranean subtype (S1a) and a stenomediterranean one (S1b). In the stenomediterranean subtype, including islands and cells close to the coast mostly located in the Tyrrhenian slope, stenomediterranean indicator species prevail (e.g. *Juniperus turbinata*, *Anthyllis barba-jovis*, and *Ceratonia siliqua*). Finally, within the Eurosiberian unit, we can recognize two subtypes corresponding to the average elevation: a mountain subtype (S3a) and a subalpine one (S3b).

Discussion

The proposed phytogeographic regionalization of the analysed sector of peninsular Italy based on native woody flora shows the presence of three well-defined and spatially coherent units. These units can be clearly identified at all the taxonomic levels considered. Further divisions in subunits can be detected only at the species level.

Congruence, at the adopted scale, between native woody flora patterns at the species, genus, and family levels is evident from the visual comparison of the species-, genera-, and families-based maps and is well supported by the Mantel and chi-squared tests. These results are consistent with previous findings by Abbate et al. (2016) and by Latini et al. (in prep.). Moreover, most of the indicator taxa for each unit are taxonomically linked to each other, especially for the Mediterranean unit, and secondly for the Eurosiberian unit. Obviously, the correspondence is particularly good in the case of monotypic genera and families. Contrarily, for genera and families including species with very different ecological preferences (e.g. *Daphne gnidium*, *D. sericea*, *Juniperus macrocarpa*, and *J. turbinata*, indicator of S1; *D. mezereum*, *D. alpina*, *J. communis* and *J. sabina*, indicator of S3) this correspondence is lower, since the species can work as an indicator while the genus and family cannot.

At each considered taxonomic level, the low-elevation coastal unit and the high-elevation inland unit can be identified as Mediterranean and Eurosiberian units, respectively, which are already identified in previously existing phytogeographic regionalizations by Giacomini (1958), Takhtajan (1986), and Rivas-Martinez et al. (2004). Moreover, a middle-elevation inland unit highly biodiverse was identified, representing a Transition unit between them. Compared with the above-cited regionalizations, our findings further reduce the spatial extension of the Mediterranean unit, moving it towards the coast. In addition, the extension of the Eurosiberian unit was reduced, being partially replaced by the Transition unit. An analysis by Latini et al. (in prep.) of the woody flora distribution patterns along a west-east transect in Lazio and Abruzzo made it evident that three woody flora types (i.e. low-elevation coastal type, middle-elevation inland type, and high-elevation inland one) are present; these three types describe well the phytogeographic units here detected for the whole of Lazio and Abruzzo.

The Mediterranean unit, geographically restricted to coastal areas and islands, is characterized by the lowest number of cells and taxa, but by the strongest floristic identity. This identity is supported at the family level by the dendrogram divisions and by possessing the highest number of indicator families. At the genus level, we observed the highest number of indicator genera; at the species level the presence of many exclusive indicator taxa was detected, mostly Mediterranean ones. Such floristic identity at the family level, and to a small extent at the genus and species levels, is arguably linked to the fact that many families and genera, especially those that are monotypic or paucitypic (at least for Italian woody flora), are geographically restricted to coastal areas characterized by a Mediterranean climate (Blasi & Michetti, 2007). Particularly in this unit, indicator taxa are taxonomically linked. For example, the species *Myrtus communis* is an indicator of S1, the genus *Myrtus* is an indicator of G1, and the family *Myrtaceae* is an indicator of F1. The Mediterranean area was already identified as a well-circumscribed region also in regionalizations based on bryophyte (Mateo et al., 2013) and on vascular plants (Heikinheimo et al., 2012), given the presences of species that are specific to it and are largely distributed across the region. It is noteworthy the good match between the detected Mediterranean unit and the vegetation series assigned by Blasi (2010) to the Mediterranean Bioclimatic Region.

The Eurosiberian unit results to be very wide (it comprises the highest number of cells), particularly when detecting at the genus and family levels. This unit shows its maximum floristic identity especially at the species level, as indicated by the dendrogram and the fact that it possesses the highest number of indicator species, mostly

Eurosiberian ones. This result is consistent with the strong floristic identity highlighted by Latini et al. (in prep.) for high-elevation inland areas of the Abruzzo Apennine mountains. Here, species associated with the inland high-elevation type were mostly mesophilous Eurasiatic/Atlantic or microthermal ones (some of which were conifers), with boreal or high mountainous distributions. Also in this unit, a clear taxonomic linkage between indicator taxa was assessed: e.g. *Taxus baccata*, *Ribes uva-crispa*, and *R. alpinum* are indicators at the species level, *Taxus* and *Ribes* at genera level, and *Taxaceae* and *Grossulariaceae* are indicators at family one.

The identification of the middle-elevation inland unit as a Transition unit was supported by many results: it is spatially located between the Mediterranean and Eurosiberian units, its floristic identity is the lowest among units, and the relationships with other units are not completely well defined. For example, the transition unit is characterized by the lowest number of indicator taxa (i.e. only one species and one family, and no genera). It is interesting how, the richness in the total number of taxa notwithstanding, there are only few indicator taxa. In fact, the highest number of taxa was detected in this unit, at all taxonomic levels (i.e. 190 at the species level, 98 at the genus level, and 49 at the family level). At the species level, the highest number of species corresponds to the highest number of cells. This floristic richness of middle-elevation areas is consistent with previous findings by Abbate et al. (2016), who noted a high level of plant diversity for the hilly belt in the administrative regions of Italy. Noteworthy is the richness of native woody taxa in areas with a strong presence of agricultural and seminatural areas. As stated above, hierarchic relationships between the Transition unit and the other units are not completely clear, as testified by some discordant results obtained: the Transition unit is more similar to the Mediterranean unit in some respects, and is more similar to the Eurosiberian unit in other respects, confirming its transitional nature. In fact, as shown by dendrograms, the Transition unit is closely related to the Mediterranean one at the species and genus levels, and to the Eurosiberian unit at the family level. Conversely, at all taxonomic levels, ISA results point to a higher affinity of the Transition unit with the Eurosiberian unit, as testified by the highest number of shared indicator taxa. Therefore, we retain the identification of a Transition unit as being particularly advisable and appropriate. Moreover, the identified Transition unit is exactly located in a zone previously ascribed to the Mediterranean Region by Giacomini (1958) and by Takhtajan (1986), but to the Eurosiberian one by Rivas-Martinez et al. (2004). This historic doubt behind the location of the boundaries between the Mediterranean and Eurosiberian regions can be resolved by identifying a Transition zone between them. Other transition zones in correspondence of historically debated biogeographic boundaries were also recently identified by Olivero et al. (2013).

No qualitative differences between the western Tyrrhenian and the eastern Adriatic slope have been detected, since the three identified phytogeographic units are present in both slopes; conversely, a strong difference in the spatial extension of these units—the units are wider in the Tyrrhenian slope—is present. It is the difference in physiography of the Tyrrhenian slope and of the Adriatic one that arguably plays an important role in determining these extensions, together with the climatic features. Previous findings by Giacomini (1958), Takhtajan (1986), Rivas-Marinez et al. (2004), Blasi et al. (2007), Abbate et al. (2016), and Latini et al. (in prep.) have reported differences between the two peninsulas' slopes. Particularly, neither the division of the Mediterranean Region

into Tyrrhenian and Adriatic sectors, as carried out by Giacomini (1958), Takhtajan (1986), and Rivas-Martinez et al. (2004), nor the differences between the Tyrrhenian and Adriatic subtypes within high-elevation inland types evidenced by Latini et al. (in prep.), are confirmed by our findings. The supposed floristic identity of an Adriatic Mediterranean subunit was not successfully delineated, we argue, due to the small areas occupied by this unit in the eastern portion of territory here considered; the small extension of the Mediterranean Region, located in the southern coastal sector, has been already highlighted by Conti (2004) in a previous phytogeographic regionalization of Abruzzo. The floristic differences within the high-elevation inland type were probably not detected due to the here adopted spatial scale.

Environmental features like lithology, distance from the sea, and elevation play important roles in defining subunits at species levels. However, the 10 × 10 km grid we used, especially in highly heterogeneous areas like the considered one, was not fine enough to satisfactorily delineate the boundaries of subunits.

In conclusion, the obtained regionalization based on native woody flora contributes to the knowledge of the phytogeographic structure of central Italy, identifying environmental correlates of the units. Further research, once data will be available, will be aimed at comparing the observed spatial patterns of native woody flora to those of the whole vascular flora or to other taxonomic/functional groups, to highlight congruences and differences between the obtained phytogeographic regionalizations.

The higher taxon-approach has proven to be useful for detecting native woody flora patterns and for providing phytogeographical regionalization at a fine scale. In particular, genus and family levels are especially suitable for coarse/medium-scale regionalizations, while species data are needed to provide fine-scale regionalizations.

Furthermore, if provided for wider study area, for example the whole Italy, such a statistically derived phytogeographic regionalization could be useful for many basic and applied purposes, e.g. to contextualize national conservation actions according to biogeographic boundaries. In particular, the identification of the boundaries of the Transion unit along the whole peninsular Italy could be very interesting, because it is a very highly biodiverse and heterogeneous unit, where agricultural systems and high nature-value rural landscapes are prevailing.

Literature Cited

Abbate, G., Bonacquisti, S., Burrascano, S., Giovi, E., Giuliani, A., Pretto, F., & Scassellati, E. 2015. Woody flora as a predictor of vascular plant richness: An insight in Italy. Plant Biosystems 149: 565–573.

———, Scassellati, E., Bonacquisti, S., Iberite, M., Latini, M., & Giuliani, A. 2016. Using woody genera for phytogeographic regionalization at a medium scale: A case study of Italy. Botany 94: 533–542.

Alves, C., Vieira, C., Almeida, R., & Hespanhol, H. 2016. Genera as surrogates of bryophyte species richness and composition. Ecological Indicators 63: 82–88.

Ampoorter, E., Selvi, F., Auge, H., Baeten, L., Berger, S., Carrari, E., Coppi, A., Fotelli, M., Radoglou, K., Setiawan, N. N., Vanhellemont, M., & Verheyen K. 2016. Driving mechanisms of overstorey–understorey diversity relationships in European forests. Perspectives in Plant Ecology, Evolution and Systematics 19: 21–29.

Bakker, J. D. 2008. Increasing the utility of indicator species analysis. Journal of Applied Ecology 45: 1829–1835.

Balmford, A., Jayasuriaya, A. H. M., & Green, M. J. B. 1996. Using higher-taxon richness as a surrogate for species richness: II. Local applications. Proceedings of the Royal Society B 263: 1571–1575.

Bartolucci, F., Peruzzi, L., Galasso, G. & Conti, F. 2016. Checklist aggiornata della flora vascolare autoctona d'Italia. Notiziario della Società Botanica Italiana 0: 5–6.

Bedini, G., Pierini, B., Roma-Marzio, F., Caparelli, K. F., Bonari, G., Dolci, D., Gestri, G., D'Antraccoli, M., & Peruzzi, L. 2016. Wikiplantbase #Toscana, breaking the dormancy of floristic data. Plant Biosystems 150: 601–610.

Bergamini, A., Scheidegger, C., Stofer, S., Carvalho, P., Davey, S., Dietrich, M., Dubs, F., Farkas, E., Groner, U., Kärkkäinen, K., Keller, C., Lökös, L., Lommi, S., Máguas, C., Mitchell, R., Pinho, P., Rico, V. J., Aragón, G., Truscott, A.-M., Wolseley, P., & Watt, A. 2005. Performance of Macrolichens and lichen genera as indicators of lichen species richness and composition. Conservation Biology 19: 1051–1062.

Blasi, C. (ed.). 2010. La Vegetazione d'Italia Con Carta delle Serie di Vegetazione in scala 1:500000. Palombi Editori, Roma.

———, & Michetti, L. 2007. Biodiversity and climate. *In:* C. Blasi, L. Boitani, S. La Posta, F. Manes, & M. Marchetti (eds.), Biodiversity in Italy. Contribution to the National Biodiversity Strategy (pp. 57–66). Palombi Editori, Roma.

———, Capotorti, G., Copiz, R., Guida, D., Mollo, B., Smiraglia, D., & Zavattero, L. 2014. Classification and mapping of the ecoregions of Italy. Plant Biosystems 148: 1255–1345.

———, Filibeck, G., Burrascano, S., Copiz, R., Di Pietro, R., Ercole, S., Lattanzi, E., Rosati, L., & Tilia, A. 2007. Primi risultati per una nuova regionalizzazione fitogeografica del territorio italiano. Biogeographia 28: 9–23.

Cailliez, F. 1983. The analytical solution of the additive constant problem. Psychometrika 48: 305–308.

Celesti-Grapow, L., Alessandrini, A., Arrigoni, P.V, Banfi, E., Bernardo, L., Bovio, M., Brundu, G., Cagiotti, M.R., Camarda, I., Carli, E., Conti, F., Fascetti, S., Galasso, G., Gubellini, L., La Valva, V., Lucchese, F., Marchiori, S., Mazzola, P., Peccenini, S., Poldini, L., Pretto, F., Prosser, F., Siniscalco, C., Villani, M.C., Viegi, L., Wilhalm, T., & Blasi, C. 2009. Inventory of the non-native flora of Italy. Plant Biosystems 143: 386–430.

Conti, F. 2004. Suddivisioni fitogeografiche della regione Abruzzo. Colloques Phytosociologique 28: 731–745.

———, Tinti, D., Bartolucci, F., Scassellati, E., Di Santo, D., Fanelli, C., Iocchi, M., Meister, J., Pavoni, P., & Torcoletti, S. 2010. Banca dati della flora vascolare d'Abruzzo: lo stato dell'arte. Annali di Botanica (Roma), Quaderni (suppl. 2009), 85–94.

De Cáceres, M., & Legendre, P. 2009. Associations between species and groups of sites: Indices and statistical inference. Retrieved September, 5, 2016 from http://sites.google.com/site/miqueldecaceres/

———, ———, & Moretti, M. 2010. Improving indicator species analysis by combining groups of sites. Oikos 119: 1674–1684.

Divíšek, J., Chytrý, M., Grulich, V., & Poláková, L. 2014. Landscape classification of the Czech Republic based on the distribution of natural habitats. Preslia 86: 209–231.

———, Storch, D., Zelený, D., & Culek, M. 2016. Towards the spatial coherence of biogeographical regionalizations at subcontinental and landscape scales. Journal of Biogeography 43: 2489–2501.

Dufrêne, M., & Legendre, P. 1997. Species assemblages and indicator species: The need for a flexible asymmetrical approach. Ecological Monographs 67: 345–366.

European Environmental Agency 2016. EEA reference grid, Italy shapefile. Retrieved September, 5, 2016 from http://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2.

Geoportale Nazionale 2016. Carta geolitologica d'Italia. URL: http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/Carta_geolitologica.map. Retrieved September, 5, 2016 from http://www.pcn.minambiente.it/GN/accesso-ai-servizi/servizi-di-download/wfs.

Giacomini, V. 1958. Conosci l'Italia: La Flora. Touring Club Italiano, Milano.

Giorgini, D., Giordani, P., Casazza, G., Amici, V., Mariotti, M. G., & Chiarucci, A. 2015. Woody species diversity as predictor of vascular plant species diversity in forest ecosystems. Forest Ecology and Management 345: 50–55.

Heikinheimo, H., Eronen, J. T., Sennikov, A., Preston, C. D., Oikarinen, E., Uotila, P., Mannila, H., & Fortelius, M. 2012. Convergence in the distribution patterns of Europe's plants and mammals is due to environmental forcing. Journal of Biogeography 39: 1633–1644.

Heino, J., & Soininen, J. 2007. Are higher taxa adequate surrogates for species-level assemblage patterns and species richness in stream organisms? Biological Conservation 137: 78–89.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965–1978.

ISPRA 2012. Corine land cover 2012 IV livello. Retrieved September, 5, 2016 from http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/corine-land-cover/corine-land-cover-2012-iv-livello/view.

——— 2016. DEM20. Retrieved September, 5, 2016 from http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/dem20/view.
ISTAT 2011. Annuario Statistico Italiano 2011 (p. 19). Istituto nazionale di statistica, Roma.
——— 2016a. Confini delle unità amministrative a fini statistici, Versione non generalizzata, WGS84 UTM 32N Anno 2016. Retrieved September, 5, 2016 from http://www.istat.it/it/archivio/124086.
——— 2016b. Popolazione residente al 1° gennaio. Retrieved September, 5, 2016 from http://dati.istat.it/Index.aspx?DataSetCode=DCIS_POPRES1.
Koleff, P., Gaston, K. J., & Lennon, J. J. 2003. Measuring beta diversity for presence-absence data. Journal of Animal Ecology 72: 367–382.
Kreft, H., & Jetz, W. 2010. A framework for delineating biogeographical regions based on species distributions. Journal of Biogeography 37: 2029–2053.
La Ferla, B., Taplin, J., Ockwell, D., & Lovett, J. C. 2002. Continental scale patterns of biodiversity: Can higher taxa accurately predict African plant distributions? Botanical Journal of the Linnean Society 138: 225–235.
Landeiro, V. L., Bini, L. M., Costa, F. R. C., Franklin, E., Nogueira, A., De Souza, J. L. P., Moraes, J., & Magnusson, W. E. 2012. How far can we go in simplifying biomonitoring assessments? An integrated analysis of taxonomic surrogacy, taxonomic sufficiency and numerical resolution in a megadiverse region. Ecological Indicators 23: 366–373.
Latini, M., Abbate, G., & Iberite, M. 2014. La flora legnosa del Lazio: allestimento di una banca dati geografica. *In:* L. Peruzzi, & G. Domina (eds.), Società Botanica Italiana, Gruppo per la Floristica, Sistematica ed Evoluzione "Floristica, Sistematica ed Evoluzione" (pp. 11–12). Tipolitografia Euroservice Punto Grafica, via Toselli Pietro Maggiore, 8 - Palermo.
Lavoie, C. 2013. Biological collections in an ever changing world: Herbaria as tools for biogeographical and environmental studies. Perspectives in Plant Ecology, Evolution and Systematics 2013: 68–76.
Legendre, P., & Legendre, L. 1998. Numerical ecology. Numerical ecology second English edition (2nd edn). Elsevier, Amsterdam.
Leprieur, F., & Oikonomou, A. 2014. The need for richness-independent measures of turnover when delineating biogeographical regions. Journal of Biogeography 41: 417–420.
Linder, H. P., de Klerk, H. M., Born, J., Burgess, N. D., Fjeldså, J., & Rahbek, C. 2012. The partitioning of Africa: Statistically defined biogeographical regions in sub-Saharan Africa. Journal of Biogeography 39: 1189–1205.
Lomolino, M.V, Riddle, B. R., Whittaker, R. J., & Brown, J. H. 2010. Biogeography (4th edn). Sinauer, Sunderland.
Magri, D., Agrillo, E., Di Rita, F., Furlanetto, G., Pini, R., Ravazzi, C., & Spada, F. 2015. Holocene dynamics of tree taxa populations in Italy. Review of Palaeobotany and Palynology 218: 267–284.
Mandelik, Y., Dayan, T., Chikatunov, V., & Kravchenko, V. 2007. Reliability of a higher-taxon approach to richness, rarity, and composition assessments at the local scale. Conservation Biology 21: 1506–1515.
Mantel, N. 1967. The detection of disease clustering and a generalized regression approach. Cancer Research 27: 209–220.
Márquez, A. L., Real, R., & Vargas, J. M. 2001. Methods for comparison of biotic regionalizations: The case of pteridophytes in the Iberian peninsula. Ecography 24: 659–670.
Mateo, R. G., Vanderpoorten, A., Muñoz, J., Laenen, B., & Désamoré, A. 2013. Modeling species distributions from heterogeneous data for the biogeographic regionalization of the European bryophyte Flora. PLoS ONE 8: e55648.
Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Szoecs, E., & Wagner, H. 2016. Vegan: Community ecology package. R package version 2.4-1. Retrieved September, 5, 2016 from https://cran.r-project.org/package=vegan.
Olivero, J., Márquez, A. L., & Real, R. 2013. Integrating fuzzy logic and statistics to improve the reliable delimitation of biogeographic regions and transition zones. Systematic Biology 62: 1–21.
Peruzzi, L., & Bedini, G. 2015. Wikiplantbase #Toscana v2.1. Retrieved September, 5, 2016 from http://bot.biologia.unipi.it/wpb/toscana/index.html
Pignatti, S. 1982. Flora d'Italia. Edagricole, Bologna.
Plieninger, T., Höchtl, F., & Spek, T. 2006. Traditional land-use and nature conservation in European rural landscapes. Environmental Science and Policy 9: 317–321.
Prinzing, A., Klotz, S., Stadler, J., & Brandl, R. 2003. Woody plants in Kenya: Expanding the higher-taxon approach. Biological Conservation 110: 307–314.
QGIS Development Team 2014. QGIS geographic information system. Open source geospatial foundation project. Retrieved from http://www.qgis.org/

Qian, H. 2013. Environmental determinants of Woody Plant diversity at a regional scale in China. PLoS ONE 8: e75832.
R Core Team 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from https://www.r-project.org/
Ramette, A. 2007. Multivariate analyses in microbial ecology. FEMS Microbiology Ecology 62: 142–160.
Riddle, B. R., Ladle, R. J., Lourie, S. A., & Whittaker, R. J. 2011. Basic biogeography: Estimating biodiversity and mapping nature. *In:* R. J. Ladle, & R. J. Whittaker (eds.), Conservation biogeography (pp. 47–92). Wiley-Blackwell, Chichester.
Rivas-Martinez, S., Penas, A., & Diaz, T. E. 2004. Biogeographic maps of Europe. Retrieved July 8, 2016, from http://www.globalbioclimatics.org/form/bg_med.htm
Rueda, M., Rodríguez, M. Á., & Hawkins, B. A. 2010. Towards a biogeographic regionalization of the European biota. Journal of Biogeography 37: 2067–2076.
Scoppola, A., & Magrini, S. 2005. Bibliografia floristica per gli anni 1950–2005. *In:* A. Scoppola & C. Blasi (eds.), Stato delle conoscenze sulla flora Vascolare d'Italia (pp. 217–224). Palombi Editori, Roma.
Svenning, J. C., Normand, S., & Kageyama, M. 2008. Glacial refugia of temperate trees in Europe: Insights from species distribution modelling. Journal of Ecology 96: 1117–1127.
Takhtajan, A. L. 1986. Floristic regions of the world. University of California Press, Berkley.
Thiers, B. 2016. Index Herbariorum: A global directory of public herbaria and associated staff. New York botanical Garden's virtual herbarium. Retrieved November 14, 2016, from http://sweetgum.nybg.org/science/ih/
Vilhena, D. A., & Antonelli, A. 2015. A network approach for identifying and delimiting biogeographical regions. Nature Communications 6: 1–9.
Villaseñor, J. L., Ibarra-Manríquez, G., Meave, J. A., & Ortíz, E. 2005. Higher taxa as surrogates of plant biodiversity in a megadiverse country. Conservation Biology 19: 232–238.
Ward, J. H. 1963. Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association 58: 236–244.
Whittaker, R. J., Riddle, B. R., Hawkins, B. A., & Ladle, R. J. 2013. The geographical distribution of life and the problem of regionalization: 100 years after Alfred Russel Wallace. Journal of Biogeography 40: 2209–2214.
WorldClim 2016. WorldClim 1.4: Current conditions (~1960–1990), Bioclimatic variables, 30 arc-reconds resolution (~ 1km), Zone 16. Retrieved September, 5, 2016 from http://www.worldclim.org/tiles.php?Zone=16.

Appendix

Table 3 Number of cells, number of taxa, and basic statistics of environmental variables for native woody flora phytogeographic units at species level (S1, S2, S3). The acronyms are defined in the text

	S1	S2	S3
No. CELLS	58	119	113
No. TAXA	164	190	187
Coordinates (WGS84 UTM 33 T; mean ± SD (min–max))			
X	353,007.79 ± 70,082.40 (213,208–476,167)	330,094.89 ± 64,734.76 (224,011–469,476)	368,817.62 ± 46,182.70 (223,784–458,310)
Y	4,618,010.93 ± 51,870.82 (4,516,908–4,715,885)	4,666,675.34 ± 40,653.5 (4,587,953–4,745,132)	4,668,660.14 ± 34,918.63 (4>,578,576–4,738,187)
Elevation (m a.s.l.; mean ± SD (min–max))			
ELEV_MIN	25.41 ± 51.18 (0–225)	120.55 ± 121.07 (0–649)	492.34 ± 254.68 (4–1199)
ELEV_MAX	441.12 ± 392.21 (14–1313)	718.78 ± 438.90 (80–2228)	1740.22 ± 534.96 (195–2908)
ELEV_MEAN	150.64 ± 153.72	319.73 ± 237.25	988.77 ± 370.77

Table 3 (continued)

	S1	S2	S3
	(3–623)	(24–1430)	(113–1821)
ELEV_RANGE	415.71 ± 368.87 (14–1292)	598.24 ± 369.10 (66–1819)	1247.88 ± 448.29 (162–2434)
Distance from the sea (km; mean ± SD (min–max))			
DIST_SEA	10,254.36 ± 13,598.03 (61–62,791)	32,573.14 ± 17,815.31 (915–84,357)	56,443.77 ± 18,771.66 (9950–90,213)
Temperature (°C; mean ± SD (min–max))			
T_MEAN	14.72 ± 0.91 (12.07–15.77)	13.94 ± 1.32 (7.6–15.9)	10.23 ± 2.14 (5.48–15.28)
T_MAX	28.41 ± 0.76 (26.68–30.48)	28.79 ± 1.38 (21.54–31.06)	24.83 ± 2.73 (18.08–29.83)
T_MIN	3.39 ± 1.23 (−0.27–5.48)	2.13 ± 1.50 (−2.52–5.25)	−1.10 ± 1.72 (−4.49–4.24)
T_RANGE	25.02 ± 1.24 (22.14–27.99)	26.66 ± 1.34 (23.05–28.81)	25.93 ± 1.42 (22.57–28.9)
Precipitation (mm; mean ± SD (min–max))			
P_ANN	819.92 ± 108.39 (603.93–1008.01)	824.17 ± 106.27 (628.53–1142.58)	833.22 ± 53.07 (623.39–939.12)
P_MAX	115.94 ± 22.39 (85.96–151.79)	109.70 ± 18.87 (85.79–164.31)	104.67 ± 8.61 (84.45–134.87)
P_MIN	23.44 ± 10.20 (10.83–42.93)	29.72 ± 9.81 (11.23–53.6)	43.06 ± 7.88 (14.8–53.03)
Lithotype (% cover)			
LIT_LIM	23.72	19.32	57.81
LIT_ALL	31.56	25.22	11.61
LIT_VOL	11.06	32.74	5.32
LIT_ARE	9.66	15.33	22.97
LIT_SAN	23.44	5.80	1.42
LIT_LAK	0.35	1.16	0.73
LIT_EVA	0.21	0.44	0.14
CORINE Land Cover I level (% cover)			
CLC_1	8.39	6.96	1.46
CLC_2	64.65	64.39	27.62
CLC_3	26.36	27.19	70.18
CLC_4	0.09	0.02	0.00
CLC_5	0.50	1.44	0.74

Table 4 Number of cells, number of taxa, and basic statistics of environmental variables for native woody flora phytogeographic units at genus level (G1, G2, G3). The acronyms are defined in the text

	G1	G2	G3
No. CELLS	29	109	152
No. TAXA	84	98	90
Coordinates (WGS84 UTM 33 T; mean ± SD (min–max))			
X	354,075.72 ± 77,560.81 (213,208–476,167)	342,534.01 ± 68,433.78 (223,784–469,476)	354,129.82 ± 52,591.19 (224,011–467,909)
Y	4,617,546.10 ± 63,694.97 (4,516,908–4,738,168)	4,658,689.11 ± 45,568.04 (4,572,339–4,745,132)	4,664,681.88 ± 37,055.64 (4,578,576–4,738,187)
Elevation (m a.s.l.; mean ± SD (min–max))			
ELEV_MIN	22.24 ± 65.83 (0–277)	88.46 ± 118.67 (0–655)	402.41 ± 272.07 (0–1199)
ELEV_MAX	359.97 ± 380.86 (14–1758)	655.75 ± 474.24 (66–2777)	1485.85 ± 650.86 (35–2908)
ELEV_MEAN	113.48 ± 122.33 (3–480)	266.94 ± 228.22 (5–1277)	829.80 ± 434.42 (16–1821)
ELEV_RANGE	337.72 ± 338.58 (14–1481)	567.29 ± 407.03 (66–2358)	1083.44 ± 495.02 (35–2434)
Distance from the sea (km; mean ± SD (min–max))			
DIST_SEA	6268.45 ± 13,274.40 (61–52,946)	26,316.37 ± 18,383.56 (915–84,357)	51,308.12 ± 20,200.75 (3115–90,213)
Temperature (°C; mean ± SD (min–max))			
T_MEAN	14.85 ± 0.81 (12.68–15.73)	14.17 ± 1.28 (8.58–15.9)	11.15 ± 2.5 (5.48–15.64)
T_MAX	28.24 ± 0.51 (27.22–29.13)	28.71 ± 1.32 (22.32–31.06)	25.85 ± 30 (18.08–30.66)
T_MIN	3.67 ± 1.15 (0.38–4.97)	2.41 ± 1.51 (−2.36–5.48)	−0.28 ± 2.18 (−4.49–5.06)
T_RANGE	24.56 ± 1.08 (23.17–27.25)	26.3 ± 1.40 (22.14–28.81)	26.13 ± 1.46 (22.57–28.9)
Precipitation (mm; mean ± SD (min–max))			
P_ANN	778.95 ± 104.65 (603.93–963.91)	821.43 ± 101.26 (623.39–1127.01)	837.98 ± 74.3 (628.53–1142.58)
P_MAX	108.19 ± 22.58 (85.79–145.79)	110.30 ± 19.88 (85.96–160.68)	107.84 ± 13.18 (84.45–164.31)
P_MIN	23.67 ± 11.01 (11.43–40.33)	28.83 ± 10.77 (10.83–51.21)	39.05 ± 10.43 (12.94–53.6)
Lithotype (% cover)			
LIT_LIM	16.34	19.40	49.03
LIT_ALL	42.38	29.78	12.20
LIT_VOL	8.35	25.33	14.11
LIT_ARE	6.02	15.09	20.47
LIT_SAN	25.84	9.63	2.78
LIT_LAK	0.45	0.27	1.30
LIT_EVA	0.61	0.49	0.10
CORINE Land Cover I level (% cover)			

Table 4 (continued)

	G1	G2	G3
CLC_1	12.27	7.48	2.45
CLC_2	65.71	67.11	35.38
CLC_3	21.19	24.88	60.77
CLC_4	0.14	0.04	0.00
CLC_5	0.68	0.49	1.40

Table 5 Number of cells, number of taxa, and basic statistics of environmental variables for native woody flora phytogeographic units at family level (F1, F2, F3). The acronyms are defined in the text

	F1	**F2**	**F3**
No. CELLS	64	96	130
No. TAXA	45	49	47
Coordinates (WGS84 UTM 33 T; mean ± SD (min–max))			
X	355,244.45 ± 72,188.58 (213,208–476,167)	332,286.1 ± 65,005.72 (223,784–467,909)	359,977.11 ± 50,304.41 (232,548–457,920)
Y	4,629,363.34 ± 57,410.86 (4,516,908–4,738,187)	4,659,199.17 ± 39,755.23 (4,589,231–4,729,401)	4,670,578.62 ± 36,142.21 (4,587,953–4,745,132)
Elevation (m a.s.l.; mean ± SD (min–max))			
ELEV_MIN	62.19 ± 115.45 (0–519)	120.86 ± 128.58 (0–774)	429.77 ± 281.6 (0–1199)
ELEV_MAX	641.91 ± 577.89 (14–2053)	698.02 ± 491.3 (68–2050)	1535.95 ± 651.31 (132–2908)
ELEV_MEAN	244.98 ± 286.09 (3–1238)	314.77 ± 248.28 (9–1000)	866.3 ± 443.87 (58–1821)
ELEV_RANGE	579.72 ± 497.55 (14–1828)	577.16 ± 395.75 (66–1754)	1106.18 ± 497.14 (114–2434)
Distance from the sea (km; mean ± SD (min–max))			
DIST_SEA	14,376.55 ± 16,862.48 (61–63,617)	30,720.69 ± 18,128.58 (915–90,213)	53,690.91 ± 20,097.85 (2493–89,360)
Temperature (°C; mean ± SD (min–max))			
T_MEAN	14.16 ± 1.65 (8.81–15.86)	13.99 ± 1.36 (10.04–15.9)	10.9 ± 2.5 (5.48–15.55)
T_MAX	27.99 ± 1.34 (22.91–30.27)	28.73 ± 1.4 (24.6–30.91)	25.59 ± 3.07 (18.08–31.06)
T_MIN	2.81 ± 1.89 (−2.54–5.48)	2.23 ± 1.52 (−1.46–5.06)	−0.56 ± 2.05 (−4.49–4.79)
T_RANGE	25.18 ± 1.31 (22.14–27.99)	26.5 ± 1.3 (23.05–28.64)	26.15 ± 1.51 (22.57–28.9)
Precipitation (mm; mean ± SD (min–max))			
P_ANN	815.35 ± 111.8 (603.93–1017.98)	823.58 ± 102.53 (623.39–1142.58)	834.67 ± 63.99 (640.55–1058.79)
P_MAX	112.43 ± 22.13 (85.93–151.79)	110.88 ± 18.71 (84.45–164.31)	105.71 ± 11.45 (86.96–153.37)

Table 5 (continued)

	F1	F2	F3
P_MIN	26.62 ± 11.79 (10.83–50.27)	28.7 ± 10.06 (12.48–53.6)	40.97 ± 9.28 (12.97–53.03)
Lithotype (% cover)			
LIT_LIM	31.25	18.74	50.52
LIT_ALL	30.44	24.00	14.23
LIT_VOL	9.41	34.22	9.40
LIT_ARE	12.00	15.68	21.24
LIT_SAN	16.37	7.08	2.61
LIT_LAK	0.32	0.28	1.50
LIT_EVA	0.22	0.00	0.51
CORINE Land Cover I level (% cover)			
CLC_1	5.87	7.82	2.34
CLC_2	59.10	64.63	33.95
CLC_3	34.49	27.02	62.11
CLC_4	0.08	0.02	0.01
CLC_5	0.46	0.51	1.59

Table 6 Indicator Species Analysis results: indicator species and indicator values (component A, component B, and IndVal) for each native woody flora phytogeographic unit or combination of units at species level (S1, S2, S3)

S1	A	B	IndVal	*p*-value	
Pistacia lentiscus L.	0.77922	0.77586	0.778	0.005	**
Myrtus communis L.	0.81491	0.70690	0.759	0.005	**
Lonicera implexa Aiton	0.73494	0.58621	0.656	0.005	**
Clematis flammula L.	0.58588	0.68966	0.636	0.005	**
Rhamnus alaternus L.	0.64880	0.51724	0.579	0.005	**
Daphne gnidium L.	0.93187	0.34483	0.567	0.005	**
Cistus monspeliensis L.	0.90227	0.31034	0.529	0.005	**
Erica multiflora L.	0.94441	0.29310	0.526	0.005	**
Quercus suber L.	0.80238	0.34483	0.526	0.005	**
Cistus salviifolius L.	0.63714	0.43103	0.524	0.005	**
Cistus creticus L.	0.54807	0.50000	0.523	0.005	**
Cytisus laniger DC.	0.93898	0.25862	0.493	0.005	**
Juniperus turbinata Guss.	1.00000	0.24138	0.491	0.005	**
Phillyrea angustifolia L.	0.91118	0.25862	0.485	0.005	**
Euphorbia dendroides L.	1.00000	0.22414	0.473	0.005	**
Rosmarinus officinalis L.	0.74067	0.29310	0.466	0.005	**
Juniperus macrocarpa Sibth. & Sm.	0.86659	0.22414	0.441	0.005	**
Ceratonia siliqua L.	0.95757	0.18966	0.426	0.005	**
Daphne sericea Vahl	0.69544	0.25862	0.424	0.005	**

Table 6 (continued)

Atriplex halimus L.	0.91118	0.17241	0.396	0.005	**
Thymelaea hirsuta (L.) Endl.	1.00000	0.15517	0.394	0.005	**
Genista monspessulana (L.) L.A.S.Johnson	0.90227	0.15517	0.374	0.005	**
Anthyllis barba-jovis L.	1.00000	0.13793	0.371	0.005	**
Halimium halimifolium (L.) Willk.	0.93490	0.12069	0.336	0.005	**
Chamaerops humilis L.	1.00000	0.10345	0.322	0.005	**
Vitex agnus-castus L.	0.82721	0.12069	0.316	0.005	**
Frangula alnus Mill.	0.82218	0.12069	0.315	0.005	**
Artemisia arborescens (Vaill.) L.	0.92487	0.10345	0.309	0.005	**
Coronilla valentina L.	0.92487	0.10345	0.309	0.005	**
Erica scoparia L.	0.78216	0.12069	0.307	0.005	**
Tamarix gallica L.	0.91118	0.08621	0.280	0.005	**
Anagyris foetida L.	1.00000	0.06897	0.263	0.005	**
S2	**A**	**B**	**IndVal**	***p*-value**	
Adenocarpus complicatus (L.) J.Gay	0.8159	0.1176	0.31	0.005	**
S3	**A**	**B**	**IndVal**	***p*-value**	
Fagus sylvatica L.	0.68950	0.82301	0.753	0.005	**
Sorbus aria (L.) Crantz	0.79842	0.67257	0.733	0.005	**
Laburnum anagyroides Medik.	0.70601	0.61062	0.657	0.005	**
Juniperus communis L.	0.63746	0.67257	0.655	0.005	**
Acer pseudoplatanus L.	0.68729	0.59292	0.638	0.005	**
Daphne oleoides Schreb.	0.88810	0.40708	0.601	0.005	**
Juniperus deltoides R.P.Adams	0.64164	0.54867	0.593	0.005	**
Amelanchier ovalis Medik.	0.95356	0.34513	0.574	0.005	**
Viburnum lantana L.	0.97430	0.31858	0.557	0.005	**
Rubus idaeus L.	0.87253	0.34513	0.549	0.005	**
Taxus baccata L.	0.81037	0.36283	0.542	0.005	**
Rosa pendulina L.	0.94853	0.30973	0.542	0.005	**
Sorbus aucuparia L.	0.89558	0.29204	0.511	0.005	**
Euonymus latifolius (L.) Mill.	0.77904	0.32743	0.505	0.005	**
Prunus mahaleb L.	0.76246	0.30088	0.479	0.005	**
Lonicera alpigena L.	0.93193	0.23009	0.463	0.005	**
Acer platanoides L.	0.82971	0.24779	0.453	0.005	**
Rhamnus saxatilis Jacq.	0.71923	0.28319	0.451	0.005	**
Lonicera xylosteum L.	0.82451	0.23894	0.444	0.005	**
Oreoherzogia alpina (L.) W.Vent	0.88979	0.20354	0.426	0.005	**
Euonymus verrucosus Scop.	0.85669	0.20354	0.418	0.005	**
Oreoherzogia fallax (Boiss.) W.Vent	1.00000	0.16814	0.410	0.005	**
Rosa subcanina (Christ) Vuk.	0.73741	0.21239	0.396	0.005	**
Ribes uva-crispa L.	1.00000	0.15044	0.388	0.005	**
Salix apennina A.K.Skvortsov	0.64449	0.23009	0.385	0.010	**
Rosa dumalis Bechst.	0.83339	0.16814	0.374	0.005	**
Rosa montana Chaix	0.89951	0.15044	0.368	0.005	**
Genista januensis Viv.	0.74917	0.17699	0.364	0.005	**

Table 6 (continued)

Daphne mezereum L.	0.89390	0.14159	0.356	0.005	**
Juniperus sabina L.	0.88505	0.13274	0.343	0.005	**
Daphne alpina L.	0.93648	0.12389	0.341	0.005	**
Pinus mugo Turra	0.93648	0.12389	0.341	0.010	**
Betula pendula Roth	0.80815	0.14159	0.338	0.010	**
Oreoherzogia pumila (Turra) W.Vent	0.91328	0.08850	0.284	0.005	**
Acer cappadocicum Gled.	1.00000	0.07965	0.282	0.005	**
Ribes alpinum L.	1.00000	0.07965	0.282	0.005	**
Abies alba Mill.	0.90456	0.07965	0.268	0.015	*
Rosa subcollina (Christ) Vuk.	0.90456	0.07965	0.268	0.015	*
Salix breviserrata Flod.	1.00000	0.07080	0.266	0.005	**
Rosa villosa L.	0.82575	0.07965	0.256	0.020	*
S1-S2	**A**	**B**	**IndVal**	***p*-value**	
Rubia peregrina L.	0.8875	0.7119	0.795	0.005	**
Rosa sempervirens L.	0.9457	0.6271	0.770	0.005	**
Smilax aspera L.	0.9612	0.5989	0.759	0.005	**
Asparagus acutifolius L.	0.8055	0.7006	0.751	0.005	**
Rubus ulmifolius Schott	0.7358	0.7627	0.749	0.005	**
Ulmus minor Mill.	0.7682	0.6893	0.728	0.005	**
Hedera helix L.	0.7106	0.7006	0.706	0.035	*
Quercus ilex L.	0.7575	0.6554	0.705	0.005	**
Phillyrea latifolia L.	0.9235	0.4802	0.666	0.005	**
Sorbus domestica L.	0.7777	0.5028	0.625	0.005	**
Laurus nobilis L.	0.8975	0.3785	0.583	0.005	**
Viburnum tinus L.	0.8617	0.3898	0.580	0.005	**
Arbutus unedo L.	0.9426	0.3220	0.551	0.005	**
Cercis siliquastrum L.	0.8915	0.3390	0.550	0.005	**
Emerus major Mill.	0.7605	0.3842	0.541	0.020	*
Olea europaea L.	0.8696	0.3277	0.534	0.005	**
Humulus lupulus L.	0.8653	0.3051	0.514	0.005	**
Quercus robur L.	0.7982	0.3051	0.493	0.005	**
Cytisus villosus Pourr.	0.7889	0.3051	0.491	0.010	**
Pyrus spinosa Forssk.	0.9811	0.2429	0.488	0.005	**
Alnus glutinosa (L.) Gaertn.	0.7959	0.2994	0.488	0.010	**
Erica arborea L.	0.8694	0.2712	0.486	0.005	**
Vitis vinifera L.	0.8651	0.2542	0.469	0.005	**
Osyris alba L.	0.7778	0.2768	0.464	0.025	*
Euphorbia characias L.	0.7995	0.2429	0.441	0.020	*
Quercus frainetto Ten.	0.9586	0.1921	0.429	0.005	**
Tamarix africana Poir.	1.0000	0.1299	0.360	0.010	**
S1-S3	**A**	**B**	**IndVal**	***p*-value**	
Tilia cordata Mill.	0.78814	0.16374	0.359	0.045	*
Rosa spinosissima L.	0.94664	0.08187	0.278	0.020	*
S2-S3	**A**	**B**	**IndVal**	***p*-value**	

Table 6 (continued)

Acer campestre L.	0.78625	0.79310	0.790	0.005	**
Quercus pubescens Willd.	0.71831	0.85776	0.785	0.010	**
Quercus cerris L.	0.75039	0.77586	0.763	0.005	**
Ostrya carpinifolia Scop.	0.81117	0.70259	0.755	0.005	**
Corylus avellana L.	0.98523	0.57328	0.752	0.005	**
Clematis vitalba L.	0.76167	0.68966	0.725	0.005	**
Rosa canina L.	0.82252	0.63793	0.724	0.005	**
Prunus spinosa L.	0.74087	0.68966	0.715	0.010	**
Acer opalus Mill.	0.88008	0.56466	0.705	0.005	**
Cornus mas L.	0.86295	0.54310	0.685	0.005	**
Cornus sanguinea L.	0.73838	0.63362	0.684	0.040	*
Lonicera caprifolium L.	0.85691	0.51724	0.666	0.005	**
Euonymus europaeus L.	0.75221	0.57759	0.659	0.020	*
Carpinus betulus L.	0.85330	0.50000	0.653	0.005	**
Daphne laureola L.	0.92907	0.44828	0.645	0.005	**
Ligustrum vulgare L.	0.76584	0.53879	0.642	0.005	**
Crataegus laevigata (Poir.) DC.	0.95932	0.40517	0.623	0.005	**
Cytisophyllum sessilifolium (L.) O.Lang	0.89371	0.43103	0.621	0.005	**
Rosa arvensis Huds.	0.88708	0.40517	0.600	0.005	**
Castanea sativa Mill.	0.85435	0.40517	0.588	0.005	**
Rosa corymbifera Borkh.	0.92879	0.33621	0.559	0.005	**
Rubus caesius L.	0.87261	0.35776	0.559	0.005	**
Sambucus nigra L.	0.80286	0.38793	0.558	0.010	**
Salix purpurea L.	0.92562	0.32328	0.547	0.005	**
Prunus avium (L.) L.	0.86113	0.31897	0.524	0.005	**
Sorbus torminalis (L.) Crantz	0.78201	0.34052	0.516	0.040	*
Salix caprea L.	0.94166	0.27586	0.510	0.005	**
Ilex aquifolium L.	0.85236	0.29741	0.503	0.010	**
Populus tremula L.	0.86020	0.26293	0.476	0.005	**
Tilia platyphyllos Scop.	0.87980	0.25000	0.469	0.010	**
Ulmus glabra Huds.	0.93009	0.22845	0.461	0.005	**
Rosa balsamica Besser	1.00000	0.16810	0.410	0.005	**
Hypericum androsaemum L.	0.95122	0.16810	0.400	0.005	**
Quercus petraea (Matt.) Liebl.	0.90850	0.17241	0.396	0.005	**
Rhamnus cathartica L.	1.00000	0.15517	0.394	0.005	**
Salix eleagnos Scop.	0.90775	0.16810	0.391	0.030	*
Rosa pouzinii Tratt.	0.94130	0.13793	0.360	0.010	**
Buxus sempervirens L.	1.00000	0.07759	0.279	0.030	*

Table 7 Indicator Species Analysis results: indicator genera and indicator values (component A, component B, and IndVal) for each native woody flora phytogeographic unit or combination of units at genus level (G1, G2, G3)

G1	A	B	IndVal	*p*-value	
Myrtus	0.68239	0.72414	0.703	0.005	**
Ceratonia	0.94948	0.34483	0.572	0.005	**
Rosmarinus	0.73294	0.41379	0.551	0.005	**
Anthyllis	1.00000	0.27586	0.525	0.005	**
Atriplex	0.89750	0.27586	0.498	0.005	**
Tamarix	0.67964	0.34483	0.484	0.005	**
Coronilla	0.92935	0.24138	0.474	0.005	**
Thymelaea	0.92935	0.24138	0.474	0.005	**
Artemisia	0.96918	0.20690	0.448	0.005	**
Chamaerops	0.94948	0.17241	0.405	0.005	**
Halimium	0.87368	0.17241	0.388	0.005	**
Frangula	0.80909	0.17241	0.373	0.005	**
Vitex	0.78986	0.17241	0.369	0.005	**
Lavandula	0.84935	0.10345	0.296	0.005	**
Suaeda	0.84935	0.10345	0.296	0.010	**
Medicago	1.00000	0.06897	0.263	0.025	*
Teucrium	1.00000	0.06897	0.263	0.010	**
G3	**A**	**B**	**IndVal**	***p*-value**	
Fagus	0.7637	0.7566	0.760	0.005	**
Laburnum	0.8058	0.5329	0.655	0.005	**
Amelanchier	0.9663	0.2632	0.504	0.005	**
Taxus	0.8268	0.2961	0.495	0.005	**
Oreoherzogia	0.9281	0.2368	0.469	0.005	**
Ribes	0.9428	0.1513	0.378	0.015	*
Betula	0.8658	0.1184	0.320	0.040	*
G1-G2	**A**	**B**	**IndVal**	***p*-value**	
Rubia	0.8011	0.6884	0.743	0.005	**
Smilax	0.8846	0.6159	0.738	0.005	**
Asparagus	0.7665	0.7029	0.734	0.005	**
Pistacia	0.8306	0.6304	0.724	0.005	**
Cistus	0.8544	0.5652	0.695	0.005	**
Phillyrea	0.8636	0.5217	0.671	0.005	**
Arbutus	0.9062	0.3623	0.573	0.005	**
Laurus	0.8218	0.3913	0.567	0.005	**
Olea	0.8485	0.3623	0.554	0.005	**
Euphorbia	0.8588	0.3406	0.541	0.005	**
Humulus	0.8264	0.3406	0.531	0.005	**
Alnus	0.7891	0.3261	0.507	0.010	**
Erica	0.8199	0.3116	0.505	0.020	*
Osyris	0.7951	0.3043	0.492	0.010	**
Cercis	0.7543	0.3188	0.490	0.020	*
Vitis	0.8456	0.2754	0.483	0.005	**

Table 7 (continued)

G1	A	B	IndVal	*p*-value	
Paliurus	0.8089	0.2319	0.433	0.020	*
G1-G3	**A**	**B**	**IndVal**	***p*-value**	
Juniperus	0.80488	0.63536	0.715	0.005	**
Daphne	0.78475	0.64088	0.709	0.005	**
Ilex	0.77662	0.33149	0.507	0.015	*
Genista	0.84597	0.19337	0.404	0.045	*
Pinus	0.95658	0.09945	0.308	0.025	*
G2-G3	**A**	**B**	**IndVal**	***p*-value**	
Acer	0.8615	0.8697	0.866	0.005	**
Rosa	0.8183	0.8544	0.836	0.005	**
Crataegus	0.8175	0.7739	0.795	0.005	**
Fraxinus	0.7929	0.7969	0.795	0.005	**
Prunus	0.8579	0.7356	0.794	0.005	**
Cornus	0.8580	0.7318	0.792	0.005	**
Rubus	0.7570	0.8008	0.779	0.005	**
Ostrya	0.8841	0.6782	0.774	0.005	**
Euonymus	0.9047	0.6552	0.770	0.005	**
Carpinus	0.8416	0.6590	0.745	0.005	**
Ulmus	0.8155	0.6705	0.739	0.005	**
Sorbus	0.7773	0.6820	0.728	0.010	**
Hedera	0.7521	0.6667	0.708	0.050	*
Corylus	0.9657	0.5096	0.702	0.005	**
Salix	0.7694	0.6284	0.695	0.025	*
Ligustrum	0.8888	0.5364	0.690	0.005	**
Cytisophyllum	0.9565	0.4023	0.620	0.005	**
Pyrus	0.8399	0.3563	0.547	0.020	*
Tilia	0.8892	0.2950	0.512	0.010	**
Celtis	0.8626	0.2069	0.422	0.050	*

Table 8 Indicator Species Analysis results: indicator families and indicator values (component A, component B, and IndVal) for each native woody flora phytogeographic unit or combination of units at family level (F1, F2, F3)

F1	**A**	**B**	**IndVal**	***p*-value**	
Myrtaceae	0.73120	0.59375	0.659	0.005	**
Cistaceae	0.56362	0.73438	0.643	0.005	**
Lamiaceae	0.74501	0.42188	0.561	0.005	**
Chenopodiaceae	0.84615	0.17188	0.381	0.005	**
Arecaceae	1.00000	0.09375	0.306	0.005	**
Asteraceae	0.79314	0.10938	0.295	0.005	**
F2	**A**	**B**	**IndVal**	***p*-value**	
Staphyleaceae	0.85903	0.09375	0.284	0.015	*
F3	**A**	**B**	**IndVal**	***p*-value**	

Table 8 (continued)

Taxaceae	0.8053	0.3231	0.510	0.005	**
Grossulariaceae	0.8904	0.1692	0.388	0.005	**
F1-F2	**A**	**B**	**IndVal**	***p*-value**	
Rubiaceae	0.8043	0.6562	0.727	0.005	**
Asparagaceae	0.7661	0.6812	0.722	0.005	**
Smilacaceae	0.8683	0.5562	0.695	0.005	**
Anacardiaceae	0.7590	0.5188	0.627	0.005	**
Cannabaceae	0.8230	0.4438	0.604	0.005	**
Lauraceae	0.8744	0.3938	0.587	0.005	**
Ericaceae	0.8062	0.4188	0.581	0.005	**
Euphorbiaceae	0.7736	0.2750	0.461	0.050	*
Tamaricaceae	0.9799	0.1750	0.414	0.005	**
F1-F3	**A**	**B**	**IndVal**	***p*-value**	
Thymelaeaceae	0.8277	0.6701	0.745	0.005	**
Cupressaceae	0.8353	0.6495	0.737	0.005	**
Rhamnaceae	0.7615	0.5567	0.651	0.010	**
Malvaceae	0.7610	0.3247	0.497	0.040	*
Pinaceae	0.9583	0.1392	0.365	0.005	**
F2-F3	**A**	**B**	**IndVal**	***p*-value**	
Sapindaceae	0.7754	0.8938	0.832	0.005	**
Betulaceae	0.7556	0.8982	0.824	0.005	**
Fagaceae	0.6880	0.9823	0.822	0.015	*
Cornaceae	0.8031	0.7699	0.786	0.005	**
Salicaceae	0.7632	0.7655	0.764	0.005	**
Celastraceae	0.7610	0.6593	0.708	0.005	**
Ulmaceae	0.7407	0.6770	0.708	0.015	*
Solanaceae	0.8245	0.2876	0.487	0.025	*
Aquifoliaceae	0.8007	0.2920	0.484	0.040	*
Moraceae	0.8026	0.2788	0.473	0.030	*
Hypericaceae	0.9217	0.1770	0.404	0.005	**
Loranthaceae	0.9122	0.1726	0.397	0.020	*