Typology and synecology of aspen woodlands in the central-southern Apennines (Italy): new findings and synthesis

Giovanni Russo (1), Franco Pedrotti (2), Dan Gafta (3)

In order to review and complete our knowledge of the typology and synecology of the aspen communities from the central-southern Apennines, ten original relevés were performed on the Gargano plateau and a set of 35 relevés assigned to four community types (HP: *Holco mollis-Populetum tremulae*; MP: *Melico uniflorae-Populetum tremulae*; FP: *Fraxino orni-Populetum tremulae*; GP: *Geranio versicoloris-Populetum tremulae*) were assembled from literature. These relevés along with several environmental variables either measured or estimated were involved in cluster and ordination analyses. The relevés from Gargano formed a distinctive cluster and were assigned to a new community type (SP: *Stellario holostaeae-Populetum tremulae* ass. nova), which can be considered an Adriatic synvicariant of HP that is distributed in similar habitats (doline bottoms) but on the Tyrrhenian escarpment. At low levels of floristic similarity, the grouping of relevés in two clusters induces a sharp separation between the aspen communities distributed in the central Apennines (MP and FP) and those from the southern Apennines (SP, HP and GP), which is mainly due to compositional differences in the regional species pool. The ordination scores of relevés were best related to terrain slope, soil nitrogen, elevation, air temperature, light availability and, to a lesser extent, to soil moisture and reaction. Unlike MP and GP that appear the most mesophylic, the FP stands display a slightly more xerophylic and acidophylic character induced by the steeper slopes on which they occur. The HP habitat is the driest and lightest very likely because of the open overlying canopy, in contrast to MP stands featuring a high shrub cover. The highest occurrence of nitrophilous species was observed in SP and MP. The management of these pioneer woods should be aimed at conservation, as they play an important role in the recovery of forest herb diversity along the ecological succession towards hardwood forests.

Keywords: Differential Species, Distribution Area, Environmental Variable Fitting, Gargano, Multivariate Analyses, Phytosociologic Classification, Secondary Succession, *Stellario holostaeae-Populetum tremulae*

Introduction

Cultural landscapes not only represent a valuable legacy of human activity over millennia, but also a useful object of study for inferring patterns in vegetation dynamics (Foster et al. 2003). In particular, the long tradition of land cultivation and sheep farming in the Apennines has deeply shaped the vegetated landscape in these mountainous areas, a pattern which extends across the Euro-Siberian and Mediterranean regions. Around the middle of the 20th century, the profound changes brought about by industrial development has led to extensive abandonment of arable fields, pasturelands and mown grasslands (Ruggieri 1976). As a consequence, the natural secondary succession, which has been developing over the following decades, has induced visible changes in the landscape through the development of patches of scrub and pioneer woodlands (Falinski & Pedrotti 1990, Mandrini et al. 2018, Vitali et al. 2018). They both play an important role in vegetation recovery, especially in facilitating the establishment of late successional tree species throughout the nemoral and boreal forest zones (Flinn & Vellend 2005). On the positive side, this trend is beneficial for, among other processes, carbon sequestration (La Mantia et al. 2013, Novara et al. 2017), reduction of soil erosion (Erktan et al. 2016) and forest connectivity at landscape level (Hernández et al. 2015). On the other hand, woodland encroachment that follows the abandonment of traditional land use has also proved a matter of some concern with respect to the decline in biodiversity (Falcucci et al. 2007, Amici et al. 2013, Ascoli et al. 2019).

Aspen (*Populus tremula*) stands have a fine-grained, patchy distribution in the central-southern Apennines, also reaching the island of Sicily. The understory of these stands is usually dominated by ubiquitous
herbs from open habitats that are remnants of the past seral stages and persist due to the loose foliage of aspen crowns. In spite of such apparent floristic homogeneity, the composition of these forests varies more or less across ecoregions and along environmental gradients, given the wide variation in site (local) and geographical conditions in the central-southern Apennines. As a matter of fact, several forest community types (syntaxa) have been described in this geographical area: Melico uniflorae-Populetum tremulae (Pedrotti 1995), Fraxino orni-Populetum tremulae (Taffetani 2000), Holco mollis-Populetum tremulae (Rosati et al. 2010) and Geranio versicoloris-Populetum tremulae (Fascetti et al. 2013). In addition, a survey carried out recently on the Gargano peninsula (Russo & Strizzi 2013) has revealed particular aspen stands that need to be analysed in the context of similar communities for a proper syntaxonomical assignment. To date no synthesis exists on the floristic composition and ecology of these aspen community types.

In the present study we aimed at: (i) characterising syntaxonomically and synecologically the aspen stands from Gargano; (ii) reviewing all aspen forest types from the central-southern Apennines; (iii) detecting the sitegeographical factors that might be responsible for the variation in plant species composition of these woods.

Materials and methods

Study area

The Gargano peninsula is situated in the southern part of the Adriatic (eastern) side of the Italian peninsula and lies over a geological complex exclusively composed of limestones and dolomites. The area surveyed is located in the core part of the peninsula, that is on the High Plain of San Marco in Lamis and Cagnano Varano roughly between 600 and 1000 m a.s.l. The land topography is typical for karst areas, with many scattered dolines and lack of surface waters. At the lowest elevations (565–570 m) the mean monthly temperature ranges from 5.4 °C (in January) to 24.1 °C (in July), whereas the mean monthly rainfall varies between 37 mm (in August) and 125 mm (in December) summing up to a mean of 900 mm per year. According to Pesaresi et al. (2017), the study area is included within a climatic unit characterised by a temperate oceanic bioclimate, lower supratemperature thermotype and upper subhumid ombrotrope. Biogeographically the area investigated is part of the Mediterranean region, East-Mediterranean subregion, Adriatic province and Apulian sector (Rivas-Martinez et al. 2004).

The high plain is covered by secondary grasslands, abandoned fields and Turkey oak-dominated forests (Physospermo verticillati-Quercetum cerridis Aita et al., 1977 em. Ubaldi et al., 1987), the latter representing the natural potential vegetation. Dry grasslands and small Turkey oak woodlots occur on the doline slopes, whereas their bottoms are covered by aspen woods or abandoned crops invaded by Persicaria aquilina.

Data collection in the field and from literature

The floristic survey of aspen stands from Gargano was carried out following the phytosociological approach (Westhoff & Van Der Maarel 1978). A single relevé (plant community sample) was performed on the bottom of each doline that was covered by a well-developed aspen canopy. In total, a number of ten relevés (SP01-SP10) were performed by visually estimating the relative cover of each vascular plant species. An additional set of 35 relevés, performed in aspen stands throughout the central-southern Apennines, were digitised from published literature as follows: ten relevés (MP01-MP10) of Melico uniflorae-Populetum tremulae (Pedrotti 1995, Pirone et al. 2010); eleven relevés (FP01-FP11) of Fraxino orni-Populetum tremulae (Taffetani 2000, Pirone et al. 2010); four relevés (HP01-HP04) of Holco mollis-Populetum tremulae (Rosati et al. 2010); ten relevés (GP01-GP10) of Geranio versicoloris-Populetum tremulae (Fascetti et al. 2013). The geographical distribution of the first two and the last two aspen syntaxa reflects to some extent a regional vicariance (Fig. 1). All aspen community types considered in this study are jointly presented in a synoptic table (see Tab. S2 in Supplementary material).

Elevation and terrain slope were measured at each sampled site. Other environmental variables were estimated indirectly by means of ordinal ranks of species ecological optima, namely ecological indicator values for light, air temperature, edaphic moisture, soil reaction and nitrogen (Pignatti 2005).

The botanical and syntaxonomical nomenclature followed the latest online version of Euro+Med PlantBase (Euro+Med 2006) and respectively, the "Prodromus of the vegetation of Italy" (Biondi & Blasi 2005).

Data analysis

Given the scale of observations, the emphasis on species turnover over species dominance, the inevitable bias in species cover estimates and the nature of multivariate methods subsequently applied on data, the binary community matrix based only on the presence-absence of species was employed in all analyses (Fortin 1997, Podani 2006, Wilson 2012). The community dissimilarity matrix was built on the basis
of the complement of the Sørensen index, which has many desirable properties (Jongman et al. 1995, Boyce & Ellison 2001). Following many previous findings (Lötter et al. 2013), the flexible beta algorithm was employed in the hierarchical clustering of relevés. The output corresponding to beta = -0.46 was finally retained as suggested by the largest value of the agglomerative coefficient (0.84). The optimal number of clusters was assessed based on the maximum value of the Calinski & Harabasz (1974) index, as all the other internal validation criteria displayed monotonic relationships with the number of clusters. No further refinement of classification could be achieved by reallocating the relevés among groups through optimisation algorithms that maximise either the cluster average silhouette or the within-cluster / among-cluster similarity ratio (Roberts 2015). Finally, the cluster stability was estimated by the level of bootstrap mean similarity (BMS), with values larger than 70% being considered acceptable for the distinction of plant community types. The holotype of the newly described community-type was selected on the basis of the largest positive silhouette width in the target cluster. The plant species best associated with the distinguished community types were identified by means of the group-equalised, point biserial correlation coefficient (r.g), which accounts for differences in sample size (number of relevés) and enables the selection of potential diagnostic species.

The ordination of relevés in the reduced space of species was performed through local non-metric multidimensional scaling (NMDS), as it is a non-parametric, flexible technique making only few assumptions about the nature of the data. A number of three axes was extracted as suggested by the “elbow rule” applied to the distribution of the stress index with increasing dimensions (Mair et al. 2016). The correlation between the NMDS axes and the species occurrence was estimated through the point biserial correlation coefficient. The importance of the environmental variables in terms of proportion of floristic variance explained (R-square) was assessed separately through non-parametric linear fitting with respect to all NMDS axes by using a modified function (“envfit.lv”), which addresses the bias in the relationship between mean species attributes (i.e., mean ecological indicator values) and relevé scores along ordination axes (Zeleny & Schaffers 2012). The environmental variables displaying only marginal, linear effects on NMDS scores were involved in generalised additive models, in order to fit smooth surfaces through thin-plate splines in the ordination space.

The statistical significance of the above statistics was estimated by 104 random permutations. All numerical analyses were carried out in R ver. 3.6.1 (R Core Team 2019) using the packages “vegan” (Oksanen et al. 2019), “cluster” (Maechler et al. 2019), “hpc” (Hennig 2019), “optpart” (Roberts 2016) and “indicspecies” (De Caceres & Janssen 2019).

Results

Classification of all aspen stands

At first glance, the dendrogram of relevés revealed that these might have been reasonably grouped in two to six clusters (Fig. 2a). The classification in two clusters (distinguished at the nodes marked by black dots in Fig. 2a) would have matched exactly the regional distribution of relevés, that is in the southern and, respectively, the central Apennines (Fig. 1). Nevertheless, the maximum value of the Calinski-Harabasz index pointed to five clusters as the optimal classification of relevés (Fig. 2b). Considering also the fair to high stability of clusters, with the exception of HP clusters that included only four relevés, the solution with five groups was finally retained.

All the ten relevés performed in Gargano were gathered in one cluster (SP), whereas the other four clusters of relevés (HP, MP, GP and FP) were perfectly circumscribed to the aspen wood types described in the literature (Fig. 2a).

Fig. 2. (a) Dendrogram of the relevés performed in aspen woods from the central-southern Apennines. The ten relevés from the cluster SP were assigned to a new syntaxon named Stellario holostaea-Populetum tremulae ass. nov. hoc loco, within the Aceri obtusati-Populenion tremulae Taffetani 2000 suballiance, Corylo avellanae-Populion tremulae (Br.-Bl. ex O. Bolòs, 1973) Rivas-Martínez & Costa, 1998 alliance, Betulo pendulae-Populetalia tremulae Rivas-Martínez & Costa, 2002 order and Querco-Fagetea Br.-Bl. & Vlieger, 1937 class (Tab. S1 in Supplementary material). The relevé SP08, displaying both the largest positive silhouette and the highest mean similarity to the SP cluster, was selected as the holotype of the new syntaxon (Tab. S1). The most important understory species in terms of relative cover are Pteridium aquilinum and Rubus caesius.

Within the context represented by the other aspen wood types from the central-southern Apennines, several species displaying significant correlation with the Stellario-Populetum group of relevés were detected (Tab. 1). Of these discriminant species only three are shade-tolerant understorey species (Stellario holostea, Carex depauperata and Allium pendulum).

The refined list of differential species associated with each of the five aspen wood types is highlighted in the synaptic table.
The classification of relevés drawn from the central-southern Apennines confirmed the compositional separation of the four woodland types. The Geranio-Populetum and Fraxino-Populetum were poorly represented by differential species compared with the other forest types.

**Fig. 3** - NMDS ordination of all the relevés in the reduced, bidimensional space determined by the axes 1 and 2 (a), and by the axes 1 and 3 (b). Convex hulls corresponding to each aspen woodland type are drawn by dotted lines. The environmental predictors explaining significant fractions of floristic variation are represented through vectors. Abbreviations as in Fig. 1.

**Tab. 3** - Summary statistics of the generalised additive models employed for fitting smooth surfaces referring to indicator values of soil reaction and moisture within the space determined by the first two NMDS axes.

| Response variable | Smooth term F (NMDS1, NMDS2) | Intercept F value | Intercept P-value | Adj-R² | Deviance explained (%) |
|-------------------|-------------------------------|------------------|------------------|--------|------------------------|
| Soil moisture     | 4.685                         | 168.5            | <0.0001          | 0.489  | 51.6                   |
| Soil reaction     | 5.466                         | 174.0            | <0.0001          | 0.528  | 57.9                   |

**Tab. 1** - Group-equalised point biserial correlation coefficients (r_g) between species and the group of Stellario-Populetum tremulae relevés in the context of all aspen woodland types from the central-southern Apennines. Only the highest ranked ten species in terms of strength of positive correlation are listed.

| Differential species       | r_g   | P-value (>r_g) |
|----------------------------|-------|----------------|
| Vicia cassubica            | 0.873 | <0.0001        |
| Stellaria holostea         | 0.807 | 0.0003         |
| Poa trivialis             | 0.750 | <0.0001        |
| Crucia glabra              | 0.694 | <0.0001        |
| Rubus caesius              | 0.591 | 0.0003         |
| Carex depauperata          | 0.590 | 0.0043         |
| Allium pendulinum          | 0.590 | 0.0051         |
| Peucedanum oreoselinum     | 0.590 | 0.0052         |
| Aristolochia pallida       | 0.590 | 0.0054         |
| Poa pratensis              | 0.590 | 0.0063         |

**Tab. 2** - Independent testing of the effects of different environmental variables on NMDS relevé scores by permutational linear fitting.

| Response variable | NMDS axis 1 | NMDS axis 2 | NMDS axis 3 | R² | P-value (>R²) |
|-------------------|-------------|-------------|-------------|----|---------------|
| Elevation         | -0.373      | 0.422       | -0.827      | 0.488 | <0.0001       |
| Terrain slope     | 0.758       | 0.532       | -0.376      | 0.454 | <0.0001       |
| Light             | -0.088      | -0.978      | 0.189       | 0.684 | 0.0025        |
| Air temperature   | 0.633       | -0.749      | 0.194       | 0.727 | 0.0007        |
| Soil moisture     | -0.292      | 0.955       | -0.051      | 0.485 | 0.0673        |
| Soil reaction     | 0.538       | 0.839       | 0.084       | 0.442 | 0.1009        |
| Soil nitrogen     | -0.871      | 0.491       | -0.024      | 0.543 | 0.0342        |

**Discussion**

Overall, the indirect ordination of relevés in the tridimensional NMDS space revealed a fair between-group separation that matched the five clusters previously distinguished (Fig. 3). The first NMDS axis was best correlated (negatively and positively) with Geum urbanum (r = -0.79) and Juniperus communis (r = +0.57), which pointed to a nitrogen-based fertility gradient (i.e., from Fraxino-Populetum to Stellario-Populetum). The second NMDS axis was best positively correlated with Melica uniflora (r = +0.84) and negatively correlated with Agrimonia eupatoria (r = -0.60) and Dactylis glomerata (r = -0.59), suggesting an altitudinal gradient (i.e., from Melico-Populetum to Holco-Populetum). Finally, the NMDS axis 3 was best negatively correlated with Geranium versicolor (r = -0.57) but positively correlated with Acer campestre (r = +0.55), which alluded to an altitudinal gradient (i.e., from Stellario-Populetum/Fraxino-Populetum to Geranio-Populetum).

Soil nitrogen and terrain slope were linearly but oppositely related to the NMDS axis 1, whereas light and temperature were both linearly and concordantly related to the NMDS axis 2 (Tab. 2, Fig. 3a). Among the environmental variables, only elevation was linearly and significantly related to the NMDS axis 3 (Tab. 2, Fig. 3b). Although non-linear, the responses of NMDS scores to soil reaction and moisture were statistically significant and mostly oriented along the axis 2 (Tab. 3, Fig. 4).
previously described aspen community types as well as the floristic distinction of the forest stands inventoried in Gargano. It is also worth mentioning that, at low levels of compositional resemblance, the grouping of relevés in two clusters induced a sharp separation between the aspen communities distributed in the central Apen-

nines (Melico-Populetum and Fraxino-Populetum) and those from the southern Apennines (Stellario-Populetum, Holco-Populetum and Geranio-Populetum). Such distinction at a large spatial scale was mainly due to compositional differences in the re-

gional species pool.

The newly described “plant association” (community type), Stellario holosteae–

Populetum tremulae, was assigned to the class Querco-Fagetea as these stands developed in Gargano were physiognomically tall, al-

most closed canopy woods and hosted several mesophilous forest herbs as well as sporadic Quercus cerris, Castanea sativa and Acer obtusatum saplings. As Stellario-Populetum tremulae belongs undoubtedly to the Apenninic suballiance Aceri obtusati-

Populion tremulae, we had to make ref-

erence (for the time being) to the upper ranked syntaxon, i.e., the alliance Corylo-

aPopulion, despite it bears a nomen ambi-

guum (Mucina et al. 2016). These authors proposed the Astrantio-Corylion avellanae

Passarge, 1978 as an alternative valid name but the latter syntaxon encompasses only scrub communities, being part of the order Prunetalia spinosae Tx., 1952 and the class Crataegeo-Prunetalia spinosae (syn. Rhamno-

Prunetea). We argue that the aspen com-

munities of Aceri obtusati-Populo-

nion tremulae do not fit into the latter upper ranked vegetation units and therefore, the syntax-

onomical framework herein should be maintained until the nomenclatural issues are sorted out.

Syndynamically, the stands of Stellario-

Populetum tremulae are likely to be re-

placed by Turkey oak stands (Physosperma verticillati-Quercetum cerridis), which are acknowledged as the mature stage of that dynamic series (Biondi et al. 2010). The bot-

toms of the shallower dolines were cov-

ered by Pteridium aquilinum-dominant

soils underlying the Holco-Populetum stands appeared the poorest in bases (and also the driest), as inferred from the plant indicator values. This is in part due to the sinkholes that have enhanced the water drainage and base leaching (Ma et al. 2018). On the other side, the Melico-Popule-

tum woods are the most mesophilous, very likely because of the finer soil texture de-

termined by the underlying marls (Verheye & De La Rosa 2009). The second most me-

sophilous aspen forest type is Geranio-Popule-

tum of which stands occur on average at higher elevations than the others.

Apart from the main environmental driv-

ers responsible for the differentiation of the five aspen forest types, there are other factors (anthropogenic and developmen-
tal) that have induced more subtle floristic differences between these communities. First, a higher amount of soil nitrogen, ei-

ther remnant from old crops or washed through rainfall run-off from the surround-

ing pastures, was probably responsible for the preferential occurrence of nitrophilous species such as Rubus caesius and Poa trivi-

alis in Stellario-Populetum stands, or Ae-

gopodium podagraria and Heracleum spho-

ndylum in Melico-Populetum stands. Sec-

ond, the larger tree canopy openness in the Holco-Populetum stands, as opposed to the relatively high cover of Corylus avellana in the Melico-Populetum stands, has deter-

mined the exclusive occurrence of shade-

intolerant, therophilous species such as Asphodeline liburnica and Aristolochia lutea in the former aspen woods.

Conclusions and implications for management

On the basis of current knowledge, five types of aspen wood can be distinguished in the central-southern Apennines. Differ-

ences in topography, edaphic conditions and light availability are the main factors responsible for the observed variation in the floristic composition of these woods. The present findings are based on a rela-

tively low number of relevés (especially those circumscribed to Holco-Populetum tremulae) and, therefore, some observed patterns may slightly change once new
data are added and analysed. Aspen stands have little economic value because of the low density of their timber. As a consequence, the forest management should be aimed at conservation, as these pioneer woods play an important role in the recovery of forest herb diversity along the ecological succession towards hardwood forests. To address the concerns regarding the decline in biodiversity due to aspen woodland encroachment, an adequate fraction of meadows and pastures should be continuously maintained in the landscape and managed appropriately.

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Conflict of interest
The authors declare that they have no conflict of interest.

References
Amici V, Santi E, Fillbeck G, Diekmann M, Geri F, Landi S, Scoppola A, Chiarucci A, Vetaas O (2015). Influence of secondary forest succession on plant diversity patterns in a Mediterranean landscape. Journal of Biogeography 40: 2335-2347. - doi: 10.1111/jbi.12182
Ascoli D, Lonati M, Marzano R, Bovio G, Cavalleri A, Lombardi G (2013). Prescribed burning and browsing to control tree encroachment in southern European heathlands. Forest Ecology and Management 289: 69-77. - doi: 10.1016/j.foreco.2012.09.041
Biondi E, Blasi C (2015). Promogus of the vegetation of Italy. Ministry of the Environment and of the Protection of the Territory and the Sea, Rome, Italy, web site. [in Italian] [online] URL: http://www.promogus-vegetazione-italia.org/
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyd RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
Boyce RL, Ellison PC (2001). Choosing the best measurement of total observed species: relationship between species and sample size. Evolutionary Ecology 15: 391-409. - doi: 10.1023/A:1008959412497
Biondi E, Casavecchia S, Beccarini L, Marchioli S, Medaglì P, Zuccarello V (2010). The vegetation series in the Region Apulia. In: “The Vegetation of Italy” (Blasi C ed). Palumbi Editore, Rome, Italy, pp. 391-409.
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Cartographic Service, University of Leon, Spain. Roberts DW (2015). Vegetation classification by two new iterative reallocation optimization algorithms. Plant Ecology 216: 741-758. - doi: 10.1007/s11258-014-0403-2

Roberts DW (2016). Package 'optpart': optimal partitioning of similarity relations. R package version 2.3-0, user manual, pp. 48. [online] URL: http://cran.r-project.org/web/packages/optpart/optpart.pdf

Rosati L, Filibeck G, De Lorenzis A, Lattanzi E, Surbera S, Fascetti S, Blasi C (2010). The forest vegetation of the Alburni Mts. (Cilento National Park, Campania, southern Italy): syntaxonomy and phytogeography. Fitosociologia 47: 17-55. [in Italian]

Ruggieri M (1976). The abandoned fields: a new component of the landscape. Bolletino della Società Geografica Italiana 5: 441-464. [in Italian]

Russo G, Strizzi C (2013). The vegetation of the Gargano National Park (Promontory of Gargano and Tremiti Islands). In: Proceedings of the “Stelvio Congress” (Pedrotti F ed.). Colloques Phytosociologiques 39, J. Cramer, Berlin, Germany, pp. 577-603. [in Italian]

Taffetani F (2000). Vegetation series of the geomorphological system of Mount Ascensione (central Italy). Fitosociologia 37: 93-151. [in Italian]

Verheye WH, De La Rosa D (2009). Mediterranean soils. In: “Encyclopedia of Land Use, Land Cover and Soil Sciences” - vol. VII, part 2 (Verheye WH ed.). UNESCO-EOLSS Publishers, Oxford, UK, pp. 96-120. [online] URL: http://books.google.com/books?id=lorTCwAAQBAJ

Vitali A, Urbinati C, Weisberg PJ, Urza AK, Garbarino M (2018). Effects of natural and anthropogenic drivers on land-cover change and treeline dynamics in the Apennines (Italy). Journal of Vegetation Science 29: 189-199. - doi: 10.1111/jvs.12598

Westhoff V, Van Der Maarel E (1978). The Braun-Blanquet approach. In: “Classification of Plant Communities” (Whittaker RH ed.). Junk, The Hague, Netherlands, pp. 287-399. - doi: 10.1007/978-94-009-9183-5_9

Wilson JB (2012). Species presence/absence sometimes represents a plant community as well as species abundances do, or better. Journal of Vegetation Science 23: 1013-1023. - doi: 10.1111/j.1654-1103.2012.01430.x

Tab. S1 - Phytosociological table of the relevés performed in aspen stands of Gargano (Stellario holosteae-Populetum tremulae ass. nova hoc loco).

Tab. S2 - Synoptic table of aspen wood types distinguished in the central-southern Apennines.

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