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Patterns of floristic variation on a montane beech forest in the central Apennines (central Italy)

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Abstract
Climate, history and human land use have a strong influence on the distribution and floristic composition of beech forest communities. In the last 50 years, the decrease in human activities has led to the resumption of reforestation dynamics, so a certain variability in floristic composition is expected. We aim to identify the causes of local floristic variability in different stands of beech forests, integrating floristic, structural and ecological analysis.
Cluster analysis and Indicator Species Analysis (ISA) were performed to highlight floristic differences; the clusters obtained were compared through environmental and topographic variables, Ellenberg indicator values, life forms, Social Behaviour Types (SBT) and structural parameters. The species heterogeneity derives from a climatic and edaphic gradient. Two main types of beech forests were recognized: a microthermal one, placed at higher altitudes and cooler aspects (*Cardamino kitaibelii - Fagetum sylvaticae*), and the termophilous one, lying at lower altitudes and warmer aspects (*Lathyro veneti - Fagetum sylvaticae*). SBT and structural parameters were useful for detecting the effects of dynamic processes of reforestation. The integration of the floristic, structural and ecological analysis led to an accurate coenological overview of the beech forest communities and to the detection of the natural reforestation processes currently ongoing.

Keywords: Ellenberg's Indicator Values, floristic composition, forest management, forest structure, Indicator Species Analysis, Social Behaviour Types.

Introduction

Fagus sylvatica is the most abundant broadleaved forest tree in central and southern Europe thanks to its physiological characteristics, and can form communities that dominate in a wide range of habitats, soil types and climatic conditions (Peters, 1997; Ellenberg, 1988). It represents the typical montane vegetation in the Apennine chain and, more generally, in the Mediterranean area (Di Pietro, 2009), as well as in Eastern Europe (Willner *et al*., 2009). Beech is found continuously throughout the Italian Peninsula from the southern Alps to Sicily with the exception of Sardinia and the smaller islands (Jalas & Suominen, 1972-1999). Within this range, *Fagus sylvatica* dominates in deciduous forests forming both pure and mixed communities from (400) 800 up to 2000 m a.s.l.; in the Apennines it is the uppermost forest type, showing a pronounced aptitude for expansion in different environmental conditions, including those moderately altered by human activities.

Apenninic beech forests have been intensely managed for centuries; however the depopulation and changes in the socio-economic conditions in Italy over the last 60 years have both led to a progressive drop in local demand for small size timber, firewood and charcoal, as in other Mediterranean countries (Romero-Calcerrada & Perry, 2004; Mottet *et al*., 2006; Geri *et al*., 2010; Bracchetti *et al*., 2012). As a consequence many areas have been almost completely abandoned (Ciancio *et al*., 2006; Sitzia *et al*., 2010) with no monitoring of their natural evolution. There are many phytosociological studies and reviews describing the sinecology of different beech forests throughout both the European and Mediterranean regions (Dierschke, 1990; Marinček *et al*., 1993; Bergmeier & Dimopoulos, 2001; Biondi *et al*., 2002; Willner, 2002); recently some studies have also started to take into account forest structure when describing forest's floristic and coenological patterns (e.g. Bartha *et al*., 2008; Burrascano *et al*., 2008, 2011; Canullo *et al*., 2011; Sabatini *et al*., 2013).

By integrating both floristic, structural and ecological analysis, this study aims to identify the causes of the floristic variability of the Duchessa beech forests. We set out to test if there are different communities in the forests surveyed; in particular, we want to answer to the following questions: (i) Are there different species assemblages in the local *Fagus sylvatica*-dominated communities, and can we distinguish different types of forests? (ii) Which environmental parameters determine the constitution of these communities?

As the Duchessa beech forests are included in the priority habitat 9210* ('Apennine beech forests with *Taxus* and *Ilex*', *sensu* 92/43/EEC Directive; EEC, 1992), understanding their floristic differentiation and increasing the knowledge of their coenological peculiarities, could help to preserve these communities and improve their management strategies for a better habitat conservation.

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Methods

Study area

The study was carried out in the Montagne della Duchessa massif, which is located within the northern portion of the Velino-Sirente chain, between the regions of Lazio and Abruzzo (central Italy) (Fig. 1). This mountainous site includes high altitude peaks such as Monte Morrone (2,141 m a.s.l.), Monte Costone (2,239 m) and Monte Murolungo (2,184 m). The surrounding area is mainly mountainous, characterized by a limestone substrate (Accordi *et al*., 1988) and can be referred to temperate region *sensu* Rivas-Martinez classification (Blasi, 2010). In particular, the bioclimate features, defined using rainfall and temperature data from Rosciolo (903 m a.s.l.) meteorological station (1971-2002) (Fig. 2), shows that the annual average rainfall is 838.7 mm, the wettest month is November (110.7 mm) and the driest July (32.8 mm). The annual average temperature is 11.4°C, the hottest month is August (28.7°C) and the coldest January (-1.2°C). The Rosciolo station belongs to the temperate bioclimate characterized by a lower supratemperate (mountain) thermotype and a subhumid ombrotype (Rivas-Martinez, 2004).

In the study area, beech forests occupy about 1,200 ha, ranging from 1,100 to 1,800 m a.s.l. These forests have been managed for centuries mainly as coppice with standards and as high forest. Historically, two main exploitation events have occurred: in 1915, when beech forests were intensively cut, mainly for coal and poles, and between '50s and '60s when cuts were broader and distributed over almost the entire area. After this latter event, these forests have no longer been exploited and the progressive reduction of the sheep-farming over the past 50 years has led to spontaneous reforestation processes, mainly at high altitudes (Avena & Blasi, 1980; Petriccione, 1993).

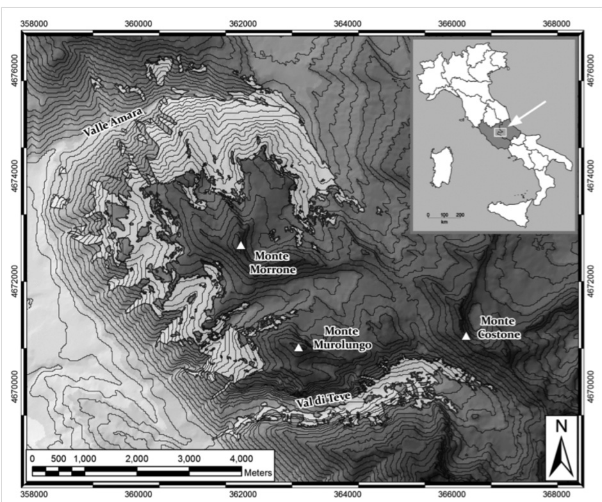

Fig. 1 – The study area, bounded and colored in light grey.

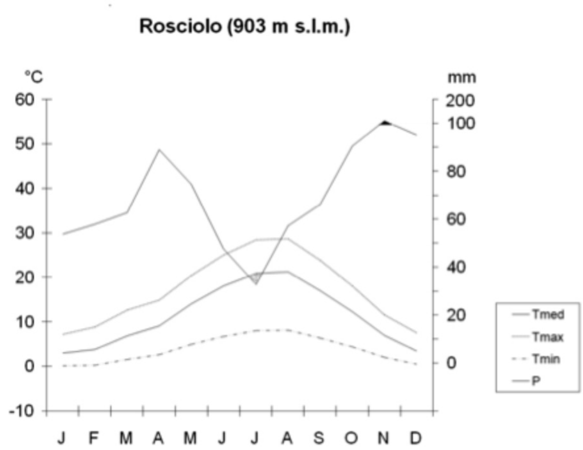

Fig. 2 - Thermopluviometric diagram (Rosciolo meteorological station [1971-2002; Data source: Ufficio Idrografico e Mareografico, Regione Lazio)].

The observed environmental conditions, bedrock composition and land-use history are regionally widespread in central Apennines; thus the Montagne della Duchessa massif could be considered a highly representative area for long-term environmental research (Theurillat *et al*., 2007; Cutini *et al*., 2012). Moreover, since the '90s, the Montagne della Duchessa site is a Regional Natural Reserve and, more recently, it has been recognized as a Special Protection Area (according to the European Directive 79/409/EEC). Part of it has also been recognized as a Site of Community Importance (European Directive 92/43/EEC).

Data collection

Forty square plots (400 m^2 each) were investigated during the May-July period of 2012. For each of them altitude (m), aspect (degrees) and slope (degrees) were measured. The sampling scheme included both vascular flora and forest structure surveys. Each plot was randomly selected throughout a stratified method, in GIS environment (ArgGIS 9.2, ESRI), on the basis of the main environmental parameters (altitude, aspect and slope) and the silvicultural management. The phytosociological relevés were made by following the methodology of the Sigmatist Zurich-Montpellier school (Braun-Blanquet, 1932), while floristic nomenclature follows Conti *et al*. (2005). As structural parameters we recorded the diameter at breast height (DBH, 1.3 m above ground level) of each tree with a diameter ≥ 2.5 cm and the number of trees in each plot.

The micromorphology was evaluated using the Terrain Ruggedness Index (TRI, Riley *et al*., 1999) calculated from the digital elevation model (20x20 m) using SAGA GIS software (Conrad, 2007). The TRI quantifies the topographic heterogeneity, and corresponds to the average elevation change (from a digital elevation grid) between any point on a cell and its surrounding area.

To characterize the community types, the standard Ellenberg's indicator values (L, T, M, R, N) optimized for the Italian Flora and the life forms were used (Pignatti, 2005), calculated as weighted averages per relevé. The recorded species were classified into Social Behaviour Types (SBT, Borhidi, 1995) on the basis of the species preference for a definite habitat, i.e. based on their similar phytocoenological role (Moola & Vasseur, 2004; Bartha *et al*., 2008). According to Bartha *et al*. (2008), five SBT categories were used: beech forest species (SBT1), forest generalist species (SBT2), non-forest species, i.e. species preferring open and sunny communities (SBT3), marginal species, i.e. exotic or members of ruderal or agricultural communities (SBT4) and gap species, linked to forest edges and gaps (SBT5). Each species was assigned to an SBT category according to its regional synecology, its main role in the local flora (Pignatti, 1982), and the field experience (a complete list of species distributed among the SBTs categories is shown in Tab. 1).

Data elaboration and analysis

The hierarchical arrangement of the surveyed communities was performed through a two way cluster analysis using a plot x species matrix in which cover values were transformed according to van der Maarel's cover-abundance scale (van der Maarel, 1979). A Relative Euclidean algorithm was used as a distance measure, and the Flexible Beta (β = -0.25) as linkage method. To test their ecological consistency, relevé groups derived from the dendrogram obtained through the cluster analysis were compared in terms of environmental parameters (altitude, aspect, slope and canopy closure), morphological features (rockiness, stoniness and TRI values), coenological indicators (Ellenberg Indicator Values, life forms and SBTs) and structural parameters (mean DBH, number of trees). Aspect values were transformed using the Heat Load Index formula (McCune *et al*., 2002), in order to obtain a continuous variable, ranging from 0 (NE) to +1 (SW). Normality distribution and variance homogeneity were tested through Kolmogorov-Smirnoff test; as data did not show a normal distribution, we performed a Kruskal-Wallis non-parametric test to understand which groups were significantly different ($P < 0.05$) from each other in relation to the selected groups of parameters. An Indicator Species Analysis (ISA; Dufrêne & Legendre, 1997) was carried out to identify the representative species (according to their occurrence and abundance) of each obtained cluster (McCune *et al*., 2002). For each species, the strength of its association with a specific cluster was tested using a Monte Carlo test (4999 permutations, α 0.05).

The same analysis was performed using a plot x Ellenberg Indicator Values matrix (L, T, M, R, N) and a plot x SBT classes matrix, in order to highlight the coenological descriptors that characterize each cluster.

To identify the main drivers that characterize the communities highlighted by the cluster analysis a constrained ordination method was performed and applied on a plot x species matrix, using the environmental, morphological and structural features that showed significance in the Kruskal-Wallis test as constrained variables. In order to choose the appropriate method, a Detrended Correspondance Analysis (DCA) was performed. Since the first axis length ranged between 3 and 4, an RDA was chosen as a constrained ordination method (Lepŝ & Ŝmilauer, 2003). Data were normalized using the Hellinger transformation method.

The Two Way Cluster Analysis and ISA were elaborated using PC-ORD software (McCune & Mefford, 1999), the Kruskal-Wallis test was performed using STATISTICA software (Anon, 2001), while the ordination methods and the Hellinger transformation were carried out using the R program (Package 'vegan', Oksanen *et al*., 2012).

Results

The dendrogram obtained from the classification analysis (Fig. 3) shows two main clusters: the first includes 29 plots and is divided into two sub-clusters (1a and 1b); the second includes 11 plots with a higher level of similarity.

The ISA made using the species x plot matrix (Tab. 2) showed that sub-cluster 1a has 16 indicator species, of which those having higher indicator values are *Cardamine kitaibelii, Galium odoratum, Rubus hirtus* and

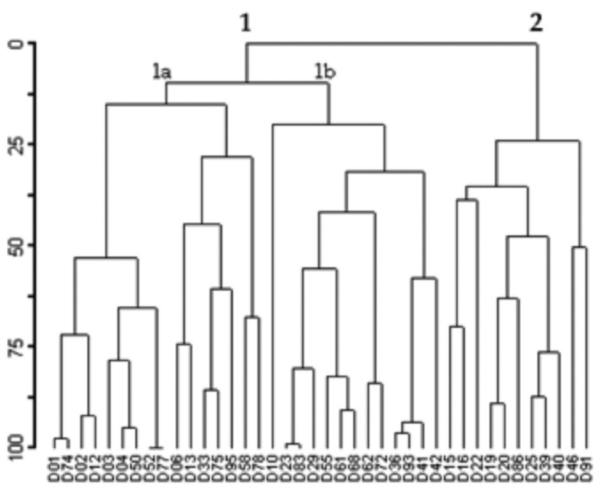

Fig. 3 - Cluster dendrogram.

Actaea spicata, while the sub-cluster 1b has no significant indicator species, even though it includes many exclusive species such as *Berberis vulgaris, Primula vulgaris, Silene nutans, Stellaria holostea, Ceterach officinarum, Cruciata laevipes, Cyanus triumfetti, Galium corrudifolium, Medicago lupulina, Poa trivialis, Stellaria montana, Trifolium pratense* and *Veronica officinalis*.

Cluster 2 showed the highest number (24) of significant indicator species, among which those with higher indicator values are *Acer opalus* subsp. *obtusatum, Brachypodium rupestre, Fraxinus ornus, Hepatica nobilis, Laburnum anagyroides, Lilium bulbiferum* and *Campanula trachelium*.

The Kruskal-Wallis test (Tab. 3) showed significant differences in terms of elevation, Ellenberg indicator values (L, T, C, R), life forms (P), and SBT (SBT1, SBT2 and SBT3) between sub-cluster 1a and 2. In addition there were some minor significant differences between sub-cluster 1a and 1b (G, DBH, number of trees) and between sub-cluster 1b and cluster 2 (L, C, R, P, SBT2, SBT3, SBT5).

The ISA made on the plot x Ellenberg indicator values matrix showed that sub-cluster 1 is associated to shade-tolerant species (L values = 2, 3, 4) typical of cold high mountain environment (T value = 2) on calcareous substrate (R value = 9), with high moisture levels (M value = 5) and humic soils (N value= 6). Cluster 2 is associated to species that cover a wider range of Ellenberg values: from partial shadow to full light (L values = 5, 6, 8), with temperature typical of lower mountain altitudes (T values = 5, 6, 7, 8) in both moderately acidophilous and calciphilous soils (R values= 3, 4, 7, 8), tendentially in more arid conditions (U values = 3, 6, 7) and with soils that range from scarce nutrient conditions to high levels (N values = 3, 4, 7, 8). Sub-cluster 1b did not show any association.

The ISA made on the plot x SBT matrix showed that the sub-cluster 1a is related to the beech forest specialist species (SBT1), while cluster 2 is related to forest generalist species (SBT2) and to open habitats (SBT3) and gaps (SBT5). No SBT were related to sub-cluster 1b.

The total explained variance for the dataset, constrained by environmental (altitude, aspect, slope), topographic (TRI) and structural variables (DBH, number of trees), was 16.5% (adj. R2). The RDA ordination showed a clear plots distribution within the space along the first axis (Fig. 4), highlighting a positive correlation between group 1a and higher altitudes (AL) and northern slopes (AS), while group 2 was found to be more related to higher steepness and rugged conditions of the ground. Group 1b showed a positive correlation to the number of trees (Nind) and negative correlation to DBH values (DBHm).

From a phytosociological point of view, on the basis of the occurrence of C*ardamine kitaibelii, Anemone nemorosa, Polystichum aculeatum* and *Epilobium montanum*, the microthermal beech forests (groups 1a and 1b) may be referred to the *Cardamino kitaibelii-Fagetum sylvaticae* association (see Tab. 4). This type of woodland is specifically present in the higher part of the montane belt in a wide part of the Central and Northern Apennine mountains on limestone substrate (Ubaldi *et al*., 1987; Biondi *et al*., 2002, 2013; Catorci *et al*., 2010). Our results confirm the microthermal characteristics of this forest type. The floristic composition of the termophilous communities (group 2) includes characteristic and differential species of *Lathyro veneti-Fagetum sylvaticae* association (Biondi *et al*., 2002), such as *Lathyrus venetus, Cyclamen hederifolium, Sorbus aria* and *Viola alba* subsp. *denhardtii* (see Tab. 5). This association generally refers to coenoses on limestone substrates of the central Apennines and is often a transitional coenosis between hilly woods dominated by *Ostrya carpinifolia* and the montane beech woods (Biondi *et al*., 2002, 2013; Catorci *et al*., 2010).

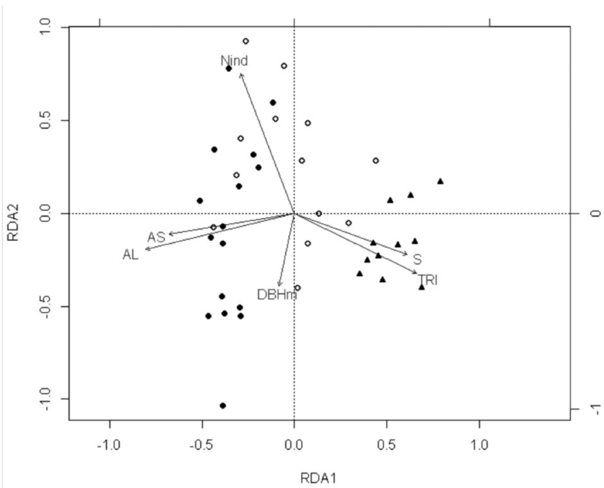

Fig. 4 - RDA plot. Filled and open circles represent the plots of clusters 1a and 1b, respectively, whereas triangles represent the plots of cluster 2. Vectors represent the association of the environmental and topographical parameters. Nind= number of trees; DBHm: mean diameter at breast height; AL= altitude; AS= aspect; S: slope; TRI= terrain ruggeddness index.

Discussion

Our results showed that altitude is the most significant environmental factor and, by creating a climatic gradient together with aspect, has a major effect in shaping the species composition of the forest communities. At the same time, the slope and micromorphology (terrain ruggedness) contribute to the creation of an edaphic pattern, mainly opposed to the climatic

Tab. 1 - Social Behaviour Types: 1 - Beech forest specialists 2 - Forest generalists 3 - Non forest species (preferring open sites) 4 - Ruderal species 5 - Gap species (linked to forest edges and gaps).

SBT 1	*Doronicum columnae*	*Viola alba*	*Veronica chamaedrys*
Acer opalus obtusatum	*Dryopteris filix-mas*	SBT 3	SBT 4
Acer pseudoplatanus	*Emerus majus*	*Acinos alpinus*	*Arisarum vulgare*
Actaea spicata	*Epipactis helleborine*	*Ajuga reptans*	*Cirsium eriophorum*
Adoxa moschatellina	*Euonymus latifolius*	*Arabis alpina*	*Prunus avium avium*
Anemone nemorosa	*Euphorbia amygdaloides*	*Arabis collina*	*Rumex obtusifolius*
Aremonia agrimonoides	*Festuca exaltata*	*Asphodelus macrocarpus*	*Scrophularia scopolii*
Cardamine bulbifera	*Festuca heterophylla*	*Berberis vulgaris*	*Senecio vulgaris*
Cardamine enneaphyllos	*Fragaria vesca*	*Brachypodium rupestre*	*Silene dioica*
Cardamine kitaibelii	*Fraxinus ornus*	*Bunium bulbocastanum*	*Silene vulgaris*
Carex pilosa	*Galanthus nivalis*	*Campanula glomerata*	*Stellaria media*
Cephalanthera damasonium	*Geranium robertianum*	*Campanula micrantha*	*Tanacetum parthenium*
Corydalis cava cava	*Geum urbanum*	*Carex humilis*	SBT 5
Epilobium montanum	*Hepatica nobilis*	*Carex macrolepis*	*Alliaria petiolata*
Fagus sylvatica	*Laburnum anagyroides*	*Ceterach officinarum*	*Arabis turrita*
Galium odoratum	*Lactuca muralis*	*Cotoneaster integerrimus*	*Chaerophyllum hirsutum*
Luzula sylvatica	*Lathyrus venetus*	*Crocus vernus*	*Clematis vitalba*
Mercurialis perennis	*Lathyrus vernus*	*Cyanus triumfetti*	*Crataegus monogyna*
Moehringia muscosa	*Melica uniflora*	*Cymbalaria muralis*	*Cruciata laevipes*
Polystichum aculeatum	*Melittis melissophyllum*	*Cytisophyllum sessilifolium*	*Digitalis lutea australis*
Polystichum setiferum	*Milium effusum*	*Dactylis glomerata*	*Helleborus foetidus*
Prenanthes purpurea	*Moehringia trinervia*	*Epipactis microphylla*	*Lamium garganicum*
Ribes uva-crispa	*Monotropa hypophegea*	*Euphorbia cyparissias*	*Lonicera alpigena*
Sanicula europaea	*Neottia nidus-avis*	*Fallopia convolvulus*	*Opopanax chironium*
Scilla bifolia	*Ostrya carpinifolia*	*Festuca circummediterranea*	*Peucedanum oreoselinum*
Sorbus aucuparia	*Peucedanum austriacum*	*Galium aparine*	*Potentilla micrantha*
Stellaria nemorum	*Poa nemoralis*	*Galium corrudifolium*	*Rubus hirtus*
Viola reichenbachiana	*Poa sylvicola*	*Hieracium piloselloides*	*Rubus idaeus*
SBT 2	*Polygonatum multiflorum*	*Hieracium species*	*Sorbus aria*
Adenostyles glabra	*Polygonatum odoratum*	*Juniperus communis*	*Vicia villosa*
Anemone apennina	*Primula vulgaris*	*Laserpitium latifolium*	
Aquilegia vulgaris	*Pulmonaria apennina*	*Lilium bulbiferum*	
Aristolochia lutea	*Quercus cerris*	*Lilium martagon*	
Asperula laevigata	*Ranunculus lanuginosus*	*Medicago lupulina*	
Brachypodium sylvaticum	*Rosa arvensis*	*Medicago species*	
Calamintha grandiflora	*Saxifraga rotundifolia*	*Poa compressa*	
Campanula persicifolia	*Scutellaria columnae*	*Poa trivialis*	
Campanula trachelium	*Senecio ovatus*	*Primula veris*	
Cephalanthera longifolia	*Senecio squalidus*	*Pteridium aquilinum*	
Clinopodium vulgare	*Silene nutans*	*Rhamnus alpina*	
Corylus avellana	*Solidago virgaurea*	*Sedum album*	
Cyclamen hederifolium	*Stellaria holostea*	*Sesleria nitida*	
Cyclamen repandum	*Tamus communis*	*Silene italica*	
Cystopteris fragilis	*Tilia platyphyllos*	*Tanacetum corymbosum*	
Daphne laureola	*Veronica officinalis*	*Trifolium pratense*	
Daphne mezereum	*Vicia peregrina*	*Veratrum nigrum*	

one, that indicates the degree of soil erosion. These two factors are able to modulate landscape patterns because they are strictly correlated to the resources availability (e.g. light, temperature), and can affect vegetation growth and distribution (Ellenberg, 1988; Franklin, 1998; Baeza *et al*., 2007). At the cooler end of the climatic gradient lies sub-cluster 1a, in which *Fagus sylvatica* is the dominant overstory species and the contribution of other phanerophytes is significantly lower (*Acer pseudoplatanus* and *Sorbus aucuparia* in the top layer and *Juniperus communis* in the shrub layer). Understory has a great abundance of species such as *Actaea spicata, Cardamine kitaibelii* and *Galium odoratum*. The coenological indicators demonstrate that this group can be considered as the microthermal forest, characterized by an understory that grows in shady, cool and moisty conditions. The soil is calcareous, humic, generally deep and less eroded: these are the environmental conditions in which beech forest species (SBT1) grow better (e.g. *Acer pseudoplatanus, Aremonia agrimonioides, Cardamine kitaibelii, Galium odoratum, Sorbus aucuparia, Stellaria nemorum, Viola reichenbachiana*, see also tab. 3). Moreover, species such as *Actaea spicata, Cardamine kitaibelii, Euphorbia amygdaloides, Lathyrus vernus* and *Viola reichenbachiana* are also beech forest diagnostic species (*sensu* 92/43/EEC Directive) (Biondi *et al*., 2009; Biondi *et al*., 2012) and are related to less fragmented

Tab. 2 - Indicator species list for the three clusters obtained by ISA; α values are shown only when significant (P<0.05).

Classification group	1a			1b			2		
Number of relevés	16			13			11		
.	Frequency class	Indicator value	α *	Frequency class	Indicator value	α *	Frequency class	Indicator value	α *
Acer pseudoplatanus L.	II	31	0.015	.	.	.	.	.	.
Actaea spicata L.	III	50	0.000	.	.	.	.	.	.
Adenostyles glabra Miller (DC)	III	46	0.003	I	.	.	.	.	.
Anemone apennina L.	III	34	0.025	.	.	.	II	.	.
Aremonia agrimonoides (L.) Neck.	IV	48	0.001	II	.	.	.	.	.
Cardamine bulbifera (L.) Crantz	IV	49	0.002	I	.	.	II	.	.
Cardamine kitaibelii Bech.	IV	69	0.000	.	.	.	.	.	.
Dryopteris filix-mas (L.) Schott	III	44	0.001	.	.	.	.	.	.
Galium odoratum (L.) Scop.	V	74	0.000	II	.	.	.	.	.
Lactuca muralis (L.) Gaertn.	IV	41	0.009	II	.	.	I	.	.
Lathyrus vernus (L.) Bernh.	III	36	0.029	II	.	.	I	.	.
Pulmonaria apennina Cristof. & Puppi	III	38	0.008	I	.	.	.	.	.
Rubus hirtus Waldst. & Kit.	III	50	0.000	.	.	.	.	.	.
Sorbus aucuparia L.	II	25	0.035	.	.	.	.	.	.
Stellaria nemorum L.	II	25	0.033	.	.	.	.	.	.
Viola reichenbachiana Jord. ex Boreau	IV	45	0.004	II	.	.	I	.	.
Berberis vulgaris L.	.	.	.	I	.	.	.	.	.
Cardamine enneaphyllos (L.) Crantz	II	.	.	II	.	.	II	.	.
Ceterach officinarum Willd.	.	.	.	I	.	.	.	.	.
Clinopodium vulgare L.	I	.	.	I	.	.	.	.	.
Cruciata laevipes Opiz	.	.	.	I	.	.	.	.	.
Cyanus triumfetti (All.) Dostál ex Á. & D.Löve	.	.	.	I	.	.	.	.	.
Cymbalaria muralis Gaertn., Mey. & Scherb.	I	.	.	I	.	.	.	.	.
Daphne mezereum L.	I	.	.	II	.	.	.	.	.
Epipactis microphylla (Ehrh.) Sw.	I	.	.	II	.	.	I	.	.
Festuca exaltata C. Presl	I	.	.	I	.	.	.	.	.
Festuca heterophylla Lam.	I	.	.	II	.	.	I	.	.
Galium corrudifolium Vill.	.	.	.	I	.	.	.	.	.
Geranium robertianum L.	I	.	.	II	.	.	.	.	.
Juniperus communis L.	.	.	.	I	.	.	I	.	.
Lamium garganicum L.	I	.	.	I	.	.	.	.	.
Medicago lupulina L.	.	.	.	I	.	.	.	.	.
Moehringia muscosa L.	I	.	.	II	.	.	I	.	.
Poa nemoralis L.	I	.	.	II	.	.	I	.	.
Poa sylvicola Guss.	I	.	.	I	.	.	.	.	.
Poa trivialis L.	.	.	.	I	.	.	.	.	.
Polystichum aculeatum (L.) Roth	I	.	.	II	.	.	.	.	.
Primula vulgaris Huds.	.	.	.	I	.	.	.	.	.
Silene nutans L.	.	.	.	I	.	.	.	.	.
Stellaria holostea L.	.	.	.	I	.	.	.	.	.
Stellaria media (L.) Vill.	I	.	.	I	.	.	.	.	.
Stellaria montana Pierrat	.	.	.	I	.	.	.	.	.
Trifolium pratense L.	.	.	.	I	.	.	.	.	.
Veronica officinalis L.	.	.	.	I	.	.	.	.	.
Acer opalus Mill. subsp. obtusatum (Waldst. & Kit. ex Willd.) Gams.	I	.	.	II	.	.	V	82	0.000
Arabis turrita L.	.	.	.	.	.	.	II	36	0.002
Brachypodium rupestre (Host) Roem. & Schult.	.	.	.	I	.	.	IV	51	0.001
Campanula trachelium L.	I	.	.	.	.	.	IV	58	0.000
Cephalanthera damasonium (Mill.) Druce	I	.	.	.	.	.	III	41	0.005
Corylus avellana L.	.	.	.	.	.	.	II	27	0.018
Cyclamen hederifolium (Aiton.)	.	.	.	.	.	.	II	27	0.017
Daphne laureola L.	I	.	.	I	.	.	III	37	0.017
Fraxinus ornus L.	.	.	.	.	.	.	IV	73	0.000
Hepatica nobilis Schreb.	.	.	.	I	.	.	IV	52	0.001
Laburnum anagyroides Medik.	I	.	.	.	.	.	IV	68	0.000
Laserpitium latifolium L.	I	.	.	.	.	.	II	31	0.023
Lilium bulbiferum L.	I	.	.	.	.	.	IV	58	0.001
Melittis melissophyllum L.	.	.	.	.	.	.	II	36	0.002
Neottia nidus-avis (L.) Rich.	II	.	.	.	.	.	III	37	0.010
polygonatum odoratum Mill.	I	.	.	I	.	.	IV	45	0.003
Primula veris L.	.	.	.	.	.	.	II	27	0.015
Quercus cerris L.	.	.	.	.	.	.	II	27	0.018
Rosa arvensis Huds.	I	.	.	I	.	.	III	32	0.029
Scutellaria columnae All.	.	.	.	.	.	.	III	46	0.001
Sesleria nitida Ten.	I	.	.	I	.	.	II	26	0.043
Solidago virgaurea L.	I	.	.	.	.	.	II	27	0.026
Sorbus aria (L.) Crantz	I	.	.	.	.	.	III	44	0.002
Viola alba Besser	II	.	.	.	.	.	III	34	0.034

forests (Carranza *et al*., 2012). *Actaea spicata, Dryopteris filix-mas, Lathyrus vernus, Stellaria nemorum* and *Viola reichenbachiana* are also species linked to 'ancient forest' conditions on the basis of their dispersal capacity and ecology (Hermy *et al*., 1999).

At the warmer end of the climatic gradient (lower altitude), and in steeper slopes we found group 2; this is the termophilous community, where the overstory is richer and characterized by the presence of different woody species (higher phanerophytes contribution including *Acer opalus* subsp. *obtusatum, Fraxinus ornus, Laburnum anagyroides, Quercus cerris* and *Ostrya carpinifolia*). Understory is generally rich and composed by species that show an heterogeneous habitat preference but are also mainly related to lighter, warmer and drier conditions, and to thinner and eroded soils. The species more correlated to these conditions are the forest generalists and the open habitats species (e.g. *Campanula trachelium, Cyclamen hederifolium, Hepatica nobilis, Brachypodium rupestre, Sesleria nitida*). The high frequency of these species groups can be also interpreted as an effect of the spatial heterogeneity due to the existence of morphological discontinuities and rocky outcrops and to a higher degree of human activities at lower altitudes, such as farming and forestry. In particular, intense exploitation in the past (Nocentini, 2009; Carranza *et al*., 2012) favored this floristic pattern, characterized by the presence of species linked to open and disturbed habitats. Group 1b shows intermediate conditions between microthermal and termophilous communities. Unlike the microthermal community (group 1a), this group shows a lower species richness, geophytes and beech forest species. Moreover, it seems not to be associated to any particular coenological indicator. This is consistent with the fact that this group includes plots at lower altitudes but lying in the bottom of valleys where some climatic traits resemble plots at higher elevations. The diversification of this group is mainly related to structural features (see RDA analysis). In forests that have no been managed for decades, a higher number of trees with lower DBH can be seen as an indirect evidence of a dynamic process of spontaneous reforestation, but other structural analyses will be necessary for an adequate and more complete interpretation. Over the past 50 years, the progressive abandonment of both forestry and grazing among the upper-montane belt has led to a natural reforestation of secondary grasslands. Therefore the maximum degree of dynamic transformations is mainly found at relatively higher elevations where soil erosion degree is lower. In the reported case study, the observed natural reforestation process is conducted by *Fagus sylvatica*. This species shows a pronounced aptitude for expansion in many environmental conditions, both at high altitudes by natural reforestation and occupancy of 'open spaces' (grassland and shrub/grassland mosaics) and at low altitudes, this also being thanks to infiltration into mixed woodland, similar to what was observed in other districts of the Apennines (Peroni *et al*., 2000; Sitzia *et al*., 2010; Bracchetti *et al*., 2012). As geophytes are generally related to mature forest stands (Decocq *et al*., 2004; Hermy *et al*., 1999), their scarcity in this particular group (1b) contributes to its being considered as a developmental stage derived from the forest advancement.

Tab. 3 - Explanatory variables of the three clusters (means, ± S.D. and S.E.). Ellenberg indicator values, life forms and chorotypes are used under weighted mean form. Different superscript letters indicate significant differences in the Kruskal-Wallis test ($p<0.05$). Only the significant parameters are shown.

Cluster	1a		1b		2	
Number of relevés	16		13		11	
	Mean ± S.D.	S.E.	Mean ± S.D.	S.E.	Mean ± S.D.	S.E.
Altitude	1590.19 ± 147.84^{a}	± 36.96	1561.92 ± 190.42^{ab}	± 52.81	1375.91 ± 108.59^{b}	± 32.74
Ellenberg L	4.01 ± 0.48^{a}	± 0.12	4.26 ± 0.65^{a}	± 0.18	4.79 ± 0.3^{b}	± 0.09
Ellenberg T	4.41 ± 0.46^{a}	± 0.11	4.77 ± 0.55^{ab}	± 0.15	5.28 ± 0.5^{b}	± 0.15
Ellenberg C	4.3 ± 0.17^{a}	± 0.04	4.33 ± 0.27^{a}	± 0.08	4.62 ± 0.17^{b}	± 0.05
Ellenberg R	4.14 ± 0.45^{a}	± 0.11	3.53 ± 1.19^{a}	± 0.33	5.1 ± 0.23^{b}	± 0.07
Phanerophytes	89.88 ± 2.19^{a}	± 0.55	89.77 ± 4.26^{a}	± 1.18	109.45 ± 14.36^{b}	± 4.33
Geophytes	5.97 ± 2.81^{a}	± 0.70	1.81 ± 1.71^{b}	± 0.48	7.41 ± 5.45^{a}	± 1.64
Richness	20.75 ± 8.84^{a}	± 2.21	11.15 ± 5.54^{b}	± 1.54	24.45 ± 9.98^{a}	± 3.01
DBH	13.32 ± 6.27^{a}	± 1.57	9.14 ± 2.34^{b}	± 0.65	11.46 ± 2.38^{a}	± 0.72
Number of trees	42.31 ± 21.72^{a}	± 5.43	52.08 ± 29.44^{b}	± 8.17	61.69 ± 30^{a}	± 9.05
SBT1	0.44 ± 0.12^{a}	± 0.03	0.38 ± 0.15^{b}	± 0.04	0.14 ± 0.07^{b}	± 0.02
SBT2	0.43 ± 0.11^{a}	± 0.03	0.43 ± 0.15^{a}	± 0.04	0.56 ± 0.11^{b}	± 0.03
SBT3	0.02 ± 0.04^{a}	± 0.01	0.09 ± 0.17^{a}	± 0.05	0.1 ± 0.06^{b}	± 0.02
SBT5	0.09 ± 0.1^{ab}	± 0.02	0.08 ± 0.1^{a}	± 0.03	0.18 ± 0.09^{b}	± 0.03

Tab. 4 - *Cardamino kitaibelii-Fagetum sylvaticae* Ubaldi, Zanotti, Puppi, Speranza et Corbetta 1987 ex Ubaldi 1995.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Relevé number from dendrogram Fig. 3	D01	D74	D02	D12	D03	D04	D50	D52	D77	D06	D13	D33	D75	D95	D58	D78	D10	D23	D83	D29	D55	D61	D68	D62	D72	D36	D93	D41	D42
Altitude (m)	1417	1485	1694	1522	1449	1590	1422	1378	1503	1799	1639	1773	1553	1649	1713	1857	1811	1696	1672	1333	1762	1683	1681	1631	1677	1319	1312	1320	1408
Aspect	N	NE	EEN	N	NNE	NE	NNE	N	NNW	NE	W	NNW	NNW	NWW	NNW	E	E	EES	EES	NE	N	NNE	NW	S	SSE	NW	SSE	NNE	NWW
Slope (degrees)	30	38	22	30	18	12	20	25	38	18	30	38	35	33	20	35	30	22	40	35	28	35	18	25	18	32	36	35	40
Area (m^2)	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
Cover total (%)	100	100	100	99	100	100	100	100	100	98	100	100	100	99	99	96	98	100	99	100	100	99	99	100	100	97	100	100	95
Cardamino kitaibelii-Fagetum sylvaticae Ubaldi, Zanotti, Puppi, Speranza et Corbetta 1987 ex Ubaldi 1995 *Aremonio-Fagion sylvaticae* (Horvat 1938) Torok, Podani et Borhidi 1989*																													
Lathyrus vernus (L.) Bernh. s.l.	+	+	+	+	.	+	.	+	+	.	.	.	+	+	.	.	.	.	+	.	.	.	.	+	+	.	.	.	.
Cardamine kitaibelii Bech.	+	+	+	+	+	1	1	+	+	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pulmonaria apennina Cristof. & Puppi	.	.	.	+	+	+	+	.	+	.	.	+	+	+	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.
Actaea spicata L.	+	.	.	+	+	+	+	+	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Aremonia agrimonoides (L.) DC. subsp. agrimonoides*	.	.	+	+	.	+	+	.	.	+	+	+	+	+	1	+	.	.	.	.	+	.	+	+	+	.	.	.	.
Cardamine enneaphyllos (L.) Crantz	.	.	.	.	.	.	.	.	.	+	+	+	+	.	1	+	.	.	.	.	.	+	+	.	.	+	.	+	1
Lathyrus venetus (Mill.) Wohlf.	.	+	.	.	+	.	.	.	.	.	1	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Adenostyles glabra (Mill.) DC. subsp. glabra*	.	.	.	+	.	+	+	.	.	.	+	1	1	+	1	+	.	.	.	.	.	+	+	.	.	.	.	.	.
Anemone nemorosa L.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Epilobium montanum L.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Polystichum aculeatum (L.) Roth	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	+	+	+	.	.	.	.	.	.
Adoxa moschatellina L. s.l.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Saxifraga rotundifolia L. subsp. rotundifolia*	.	.	.	+	.	.	.	.	.	.	.	+	.	+	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.
Ranunculus lanuginosus L.*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Fagetalia sylvaticae Pawlowski in Pawlowski, Sokolowski & Wallisch 1928																													
Fagus sylvatica L. subsp. sylvatica	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Galium odoratum (L.) Scop.	+	1	+	+	+	+	+	.	1	+	1	+	1	+	1	1	.	.	.	.	.	+	+	+	.	+	.	.	.
Lactuca muralis (L.) Gaertn.	+	+	.	+	+	.	.	.	.	+	+	+	+	.	+	+	+	.	.	.	.	.	.	.	+	.	.	.	+
Cardamine bulbifera (L.) Crantz	.	.	.	.	+	+	+	+	+	+	+	+	+	+	1	+	.	+	.	.	.	+	.	.	.	.	.	.	.
Euphorbia amygdaloides L. subsp. amygdaloides	.	.	.	.	+	+	+	.	.	+	+	+	+	+	1	+	.	.	.	.	+	.	+	.	+	.	.	.	.
Neottia nidus-avis (L.) Rich.	+	+	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rosa arvensis Huds.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Carex pilosa Scop.	.	.	+	+	.	.	.	+	+	.	.	.	+	.	+	.	.	+	.	.	.	.	.	1	1	.	.	.	.
Dryopteris filix-mas (L.) Schott	.	.	.	+	.	+	+	+	+	.	.	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Euonymus latifolius (L.) Mill.	.	.	.	+	+	+	.	.	.	.	.	+	.	.	+	.	.	.	.	+	.	.	.	+	.	.	.	.	.
Cephalanthera damasonium (Mill.) Druce	.	.	.	.	.	.	+	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Acer pseudoplatanus L.	.	.	.	.	.	.	.	1	1	.	+	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Melica uniflora Retz.	.	.	.	+	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Solidago virgaurea L. subsp. virgaurea	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Moehringia trinervia (L.) Clairv.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Campanula trachelium L. subsp. trachelium	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Polystichum setiferum (Forssk.) T. Moore ex Woyn.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Doronicum columnae Ten.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	+
Geranium robertianum L.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	+	+	.	.	.	+	.	+	.
Lilium martagon L.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Milium effusum L.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Festuca heterophylla Lam.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	1	+	.	.	.	.
Prunus avium L. subsp. avium	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sanicula europaea L.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hepatica nobilis Schreb.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.
Mercurialis perennis L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1
Stellaria holostea L. subsp. holostea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Anemone apennina L. subsp. apennina	.	.	.	.	+	.	+	+	.	+	+	+	.	1	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Sorbus aria (L.) Crantz subsp. aria	.	.	+	+	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Viola alba Besser subsp. dehnhardtii (Ten.) W. Becker	.	.	.	.	.	.	.	+	+	.	+	.	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Corydalis cava (L.) Schweigg. & Körte subsp. cava	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Scilla bifolia L.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Daphne laureola L.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.
Acer opalus Mill. subsp. obtusatum (Waldst. & Kit. ex Willd.) Gams	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	+	+	1	2	.
Querco-Fagetea Br.-Bl. & Vlieger in Vlieger 1937																													
Viola reichenbachiana Jord. ex Boreau	+	+	+	+	+	+	1	+	.	+	+	.	.	.	1	.	.	.	.	.	+	+	+	+	.	.	.	.	.
Rubus hirtus Waldst. & Kit.	+	.	+	.	+	+	+	1	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ajuga reptans L.	.	.	.	.	+	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Poa nemoralis L. s.l.	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.	+	+	.	.	+	.	.	.	.	+	.	.	.	.
Epipactis helleborine (L.) Crantz s.l.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	+	.	+	.	.	+	.	.	.	+	.	.	.
Ostrya carpinifolia Scop.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Laburnum anagyroides Medik. s.l.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cephalanthera longifolia (L.) Fritsch	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Lilium bulbiferum L. subsp. croceum (Chaix) Jan	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stellaria media (L.) Vill. subsp. media	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Geum urbanum L.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Potentilla micrantha Ramond ex DC.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	+	.	+	+	.	.	.	.
Brachypodium rupestre (Host) Roem. & Schult.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.
Fragaria vesca L. subsp. vesca	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Luzula sylvatica (Huds.) Gaudin subsp. sylvatica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.
Primula vulgaris Huds. subsp. vulgaris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Alliaria petiolata (M. Bieb.) Cavara & Grande	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	+
Calamintha grandiflora (L.) Moench	.	.	+	+	.	.	.	.	.	.	.	+	1	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Clinopodium vulgare L. s.l.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.
Cystopteris fragilis (L.) Bernh.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Daphne mezereum L.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.	.	.	+	.	+	.	.	.	.
Epipactis microphylla (Ehrh.) Sw.	+	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	+	+	.	.	+	+	.	.	.	.
Festuca circummediterranea Patzke	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.
Festuca exaltata C. Presl	.	.	.	+	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.
Lamium garganicum L. subsp. laevigatum Arcang.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	+
Moehringia muscosa L.	.	.	.	+	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+
Polygonatum odoratum (Mill.) Druce	+	.	.	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Sorbus aucuparia L. subsp. aucuparia	.	.	.	1	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Stellaria nemorum L. subsp. montana (Pierrat) Berher	.	.	.	.	+	.	.	.	.	.	.	+	.	.	+	+	.	.	.	.	.	.	+	.	.	.	.	.	.
Sporadic species	0	0	0	0	1	0	0	0	0	2	1	5	1	1	15	12	13	0	1	2	0	0	0	3	2	0	0	3	1

Tab. 5 - *Lathyro veneti-Fagetum sylvaticae* Biondi, Casavecchia, Pinzi, Allegrezza et Baldoni 2002 ex Biondi, Casavecchia, Pinzi, Allegrezza e Baldoni 2013 in Biondi, Allegrezza, Casavecchia, Galdenzi, Gigante, Pesaresi 2013.

	1	2	3	4	5	6	7	8	9	10	11
Relevé number from dendrogram Fig. 3	D15	D16	D22	D19	D20	D86	D25	D39	D40	D46	D91
Altitude (m)	1329	1422	1375	1523	1285	1521	1347	1450	1448	1196	1239
Aspect	SSW	SW	SWW	NNE	SWW	NNE	EES	SW	S	SSE	NNE
Slope (degrees)	30	28	28	30	28	45	40	45	41	35	43
Area (m2)	400	400	400	400	400	400	400	400	400	400	400
Cover total (%)	100	100	97	99	98	98	100	95	99	100	99
Lathyro veneti-Fagetum sylvaticae Biondi, Casavecchia, Pinzi, Allegrezza et Baldoni 2002 ex Biondi, Casavecchia, Pinzi, Allegrezza e Baldoni 2013 in Biondi, Allegrezza, Casavecchia, Galdenzi, Gigante, Pesaresi 2013											
Geranio versicoloris-Fagion sylvaticae Gentile 1969*											
Acer opalus Mill. subsp. obtusatum (Waldst. & Kit. ex Willd.) Gams*	1	1	2	2	2	1	2	1	2	2	2
Daphne laureola L.*	+	+	.	+	.	+	.	.	.	+	1
Sorbus aria (L.) Crantz subsp. aria	.	.	+	.	.	+	+	1	1	1	.
Anemone apennina L. subsp. apennina	.	.	1	1	1	.	.	.	.	.	.
Viola alba Besser subsp. dehnhardtii (Ten.) W. Becker	+	.	+	.	+	+	+	.	.	+	.
Lathyrus venetus (Mill.) Wohlf.	.	.	+	+	+	+	.	.	+	.	.
Cyclamen hederifolium Aiton subsp. hederifolium	.	.	+	.	+	.	.	.	.	.	+
Galanthus nivalis L.	.	.	+	.	.	.	.	.	.	.	.
Scilla bifolia L.	.	.	.	+	.	.	.	.	.	.	.
Polygonatum multiflorum (L.) All.	.	.	.	.	.	.	+	.	.	.	.
Fagetalia sylvaticae Pawlowski in Pawlowski, Sokolowski & Wallisch 1928											
Fagus sylvatica L. subsp. sylvatica	5	5	5	5	5	5	5	5	5	3	5
Rosa arvensis Huds.	+	+	+	.	+	+	.	.	.	.	.
Cephalanthera damasonium (Mill.) Druce	+	+	+	.	+	.	.	+	+	.	.
Neottia nidus-avis (L.) Rich.	+	.	+	+	+	.	.	+	+	.	.
Campanula trachelium L. subsp. trachelium	+	+	+	.	+	.	+	+	+	.	.
Hepatica nobilis Schreb.	.	.	.	.	+	+	+	+	+	+	1
Lathyrus vernus (L.) Bernh. s.l.	.	+	.	.	.	.	.	.	.	.	.
Euphorbia amygdaloides L. subsp. amygdaloides	.	.	+	+	+	+	+	.	+	.	.
Cardamine bulbifera (L.) Crantz	.	.	+	.	+	.	.	.	.	.	+
Solidago virgaurea L. subsp. virgaurea	.	.	+	.	.	.	+	+	+	.	.
Milium effusum L.	.	.	+	.	.	.	.	.	.	.	.
Festuca heterophylla Lam.	.	.	+	.	.	.	.	.	.	.	+
Prunus avium L. subsp. avium	.	.	+	.	.	.	.	.	.	.	.
Adoxa moschatellina L. s.l.	.	.	+	.	.	.	.	.	.	.	.
Moehringia trinervia (L.) Clairv.	.	.	.	.	+	.	.	.	.	.	.
Cardamine enneaphyllos (L.) Crantz	.	.	.	.	.	1	.	.	1	.	1
Mercurialis perennis L.	.	.	.	.	.	.	.	.	+	+	1
Lactuca muralis (L.) Gaertn.	.	.	.	.	.	.	.	.	+	.	.
Euonymus latifolius (L.) Mill.	.	.	.	.	.	.	.	.	+	.	.
Melica uniflora Retz.	.	.	.	.	.	.	.	.	.	.	+
Saxifraga rotundifolia L. subsp. rotundifolia	.	.	.	.	.	.	.	.	.	.	+
Trasgressive species from the order *Quercetalia pubescenti- petraeae* Klika 1933 corr. Moravec in Beguin & Theurillat 1984											
Fraxinus ornus L. subsp. ornus	1	.	1	.	1	.	2	1	1	3	2
Laburnum anagyroides Medik. s.l.	.	1	+	+	+	.	+	1	+	+	.
Ostrya carpinifolia Scop.	.	.	.	.	.	.	.	.	1	2	1
Lilium bulbiferum L. subsp. croceum (Chaix) Jan	+	.	+	+	+	+	.	+	.	.	+
Melittis melissophyllum L. subsp. melissophyllum	.	.	1	.	+	.	.	+	+	.	.
Cephalanthera longifolia (L.) Fritsch	+	.	.	.	.	.	+	+	.	.	.
Epipactis helleborine (L.) Crantz s.l.	.	.	.	+	+	+	.	.	+	.	+
Helleborus foetidus L. subsp. foetidus	.	.	.	.	.	.	+	.	.	.	.
Quercus cerris L.	1	.	2	.	.	.	.	.	.	1	.
Campanula persicifolia L. subsp. persicifolia	.	.	+	.	.	.	.	.	.	.	.
Emerus majus Mill. s.l.	.	.	.	.	.	.	.	+	.	.	.
Silene italica (L.) Pers. s.l.	.	+	.	.	.	.	.	+	.	.	.
Querco-Fagetea Br.-Bl. & Vlieger in Vlieger 1937											
Corylus avellana L.	+	.	+	.	.	.	.	.	.	2	.
Brachypodium rupestre (Host) Roem. & Schult.	+	.	+	+	.	+	+	+	.	+	.
Poa nemoralis L. s.l.	+	+	.	.	.	.	.	.	.	.	.
Potentilla micrantha Ramond ex DC.	+	+	+	.	.	+	.	.	.	.	.
Tamus communis L.	.	.	.	.	.	.	+	.	.	+	.
Luzula sylvatica (Huds.) Gaudin subsp. sylvatica	.	.	.	.	.	+	+	+	+	.	.
Viola reichenbachiana Jord. ex Boreau	.	.	+	.	.	.	.	.	.	.	.
Brachypodium sylvaticum (Huds.) P. Beauv. subsp. sylvaticum	.	.	+	.	.	.	.	.	.	.	.
Fragaria vesca L. subsp. vesca	.	.	+	.	.	.	.	.	.	.	.
Tilia platyphyllos Scop. subsp. platyphyllos	.	.	.	.	.	.	.	.	.	.	2
Sporadic species	5	9	19	2	8	5	3	16	5	2	6

Conclusions

The climatic and spatial patterns expressed along the altitudinal gradient, together with the effect of the progressive land use abandonment in the Duchessa area, has led to a marked diversification in species composition of the local beech forest. The selected environmental parameters defined a climatic and edaphic 'gradient' that were found to be the main driving factors underlying the variations in species composition within these communities. The spatial patterns of these two main environmental gradients seem to be mainly driven by morphology.

Two main beech forests were recognized: i) microthermal communities, that show a high degree of structural heterogeneity caused by dynamic processes (spontaneous reforestation); ii) termophilous communities, that show a relatively lower degree of structural heterogeneity but a higher degree of floristic heterogeneity caused by the occurrence of species coming from the adjacent termophilous mixed forests and from open, disturbed areas. Within the microthermal communities, two subtypes were recognized: i-I) communities with a relatively higher occurrence of typical beech forest shade-tolerant species (like *Cardamine kitaibelii, Galium odoratum, Actaea spicata* and *Stellaria holostea*); i-II) communities showing a juvenile canopy and a relatively higher occurrence of some generalist non-forest species (like *Brachypodium rupestre* and *Campanula trachelium*).

In conclusion, our results confirm that, as the silvicultural exploitation (clearcutting in particular) may have negative effects on soil erosion, particular attention should be paid to forest stands that lie on steeper slopes; in these cases a decrease in the intensity of thinning could reduce the negative effects of the canopy opening on soil, as also confirmed by other studies (Ciancio *et al*., 2006). Finally, this study highlights this kind of research's importance, taking into account forest management so as to better understand the floristic patterns and its dynamics in different silvicultural conditions. This could, in turn, improve understanding the relation between forest management and conservation goals.

Syntaxonomical scheme

QUERCO-FAGETEA Br.-Bl. & Vlieger in Vlieger 1937
FAGETALIA SYLVATICAE Pawlowski in Pawlowski, Sokolowski & Wallisch 1928
Aremonio-Fagion sylvaticae (Horvat 1938) Torok, Podani & Borhidi 1989
Cardamino kitaibelii-Fagenion sylvaticae Biondi et al. ex Biondi, Casavecchia, Pinzi, Allegrezza, Baldoni 2013
Cardamino kitaibelii-Fagetum sylvaticae Ubaldi et al. ex Ubaldi 1995
Geranio versicoloris-Fagion sylvaticae Gentile 1969
Doronico orientalis-Fagenion sylvaticae (Ubaldi, Zanotti, Puppi, Speranza & Corbetta ex Ubaldi 1995) Di Pietro, Izco & Blasi 2004
Lathyro veneti-Fagetum sylvaticae Biondi et al. ex Biondi, Casavecchia, Pinzi, Allegrezza, Baldoni 2013

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Appendix 1: dates and localities

Tab. 4: Rel.1: 2012.06.21, loc. Mandria di Stefanella; Rel.2: 2012.07.03, loc. Iaccio fonte dell'Avena; Rel.3: 2012.07.02, loc. Fonte dell'Avena; Rel.4, Rel.7: 2012.06.27, loc. Mandria di Stefanella; Rel.5: 2012.06.26, loc. Valle dell'Asino; Rel.6: 2012.07.03, loc. Fonte dell'Avena; Rel.8: 2012.06.21, loc. Bosco di Cartore; Rel.9: 2012.06.26, loc. Mandria di Stefanella; Rel.10: 2012.07.12, loc. Mercaturo; Rel.11: 2012.07.14, loc. Iaccio Fonte dell'Avena; Rel.12: 2012.07.13, loc. Monte Ginepro; Rel. 13: 2012.07.04, loc. Iaccio Fonte dell'Avena; Rel.14: 2012.06.07, loc. Vallone del Cieco; Rel. 15: 2012.07.13, loc. Iaccio Fonte dell'Avena; Rel.16: 2012.07.11, loc. Iaccio Fonte dell'Avena; Rel.17: 2012.07.13, loc. Mercaturo; Rel.18: 2012.07.26, loc. Bosco di Cartore; Rel.19: 2012.06.27, loc. Vallone del Cieco; Rel.20: 2012.07.22, loc. Mandria di Stefanella; Rel.21, Rel.23: 2012.07.20, loc. Praticchio del Tordo; Rel.22: 2012.05.15, loc. Pietra Grossa; Rel.24: 2012.07.26, loc. Pietra Grossa; Rel.25: 2012.07.21, loc. Pratone della Cesa; Rel.26: 2012.05.26, loc. Mandria di Stefanella; Rel.27: 2012.08.01, loc. Valle Amara; Rel.28: 2012.05.30, loc. Bosco di Cartore; Rel.29: 2012.05.24, loc. Vallone della Cesa.

Tab 5: Rel.1, Rel.2: 2012.08.01, loc. Valle dell'Asino; Rel.3, Rel.8: 2012.06.14, loc. Prime Prata; Rel.4: 2012.05. 29, loc. Piè di Monte; Rel.5: 2012.06.13 loc. Prime Prata; Rel.6: 2012.05.28, loc. Piè di Monte; Rel.7: 2012.07.25, loc. Pietra Incacchiata; Rel.9: 2012.06.20, loc. Piè di Monte; Rel.10: 2012.07.04, loc. Pietra Incacchiata; Rel.11: 2012.06.05, loc. Valle Amara.

Appendix 2: sporadic species

Tab. 4: Rel. 5: Ribes uva-crispa L. +; Rel. 10: Digitalis lutea L. subsp. australis (Ten.) Arcang. +, Scrophularia scopolii Hoppe ex Pers. +; Rel. 11: Prenanthes purpurea L. +; Rel. 12: Cirsium eriophorum gr. +, Monotropa hypophegea Wallr. +, Silene italica (L.) Pers. s.l. +, Cymbalaria muralis Gaertn., B. Mey. & Scherb s.l. +, Prenanthes purpurea L. +; Rel. 13: Senecio ovatus (P. Gaertn., B. Mey. & Scherb.) Willd. s.l. +; Rel. 14: Crocus vernus (L.) Hill s.l. +; Rel. 15: Acinos alpinus (L.) Moench s.l. +, Arisarum vulgare Targ. Tozz. +, Campanula micrantha Bertol. +, Laserpitium latifolium L. +, Sedum album L. +, Senecio vulgaris L. +, Veronica chamaedrys L. subsp. chamaedrys +, Poa sylvicola Guss. +, Carex macrolepis DC. +, Aquilegia vulgaris auct. Fl. Ital. +, Chaerophyllum hirsutum L. s.l. +, Poa compressa L. +, Rubus idaeus L. +, Silene dioica (L.) Clairv. +, Prenanthes purpurea L. +; Rel. 16: Arabis alpina L. s.l. +, Rosa pendulina L. +, Rumex obtusifolius L. subsp. obtusifolius +, Senecio squalidus L. s.l. +, Tanacetum parthenium (L.) Sch. Bip. +, Sesleria nitida Ten. +, Bunium bulbocastanum L. +, Aquilegia vulgaris auct. Fl. Ital. +, Chaerophyllum hirsutum L. s.l. +, Poa compressa L. +, Rubus idaeus L. +, Silene dioica (L.) Clairv. +; Rel. 17: Juniperus communis L. 1, Arabis collina Ten. s.l. +, Campanula glomerata L. +, Cyanus triumfetti (All.) Dostál ex Á. & D. Löve +, Euphorbia cyparissias L. +, Galium corrudifolium Vill. +, Medicago lupulina L. +, Poa trivialis L. +, Silene vulgaris (Moench) Garcke s.l. +, Trifolium pratense L. s.l. +, Vicia villosa Roth subsp. varia (Host) Corb. +, Dactylis glomerata L. s.l. +, Bunium bulbocastanum L. +; Rel. 19: Sesleria nitida Ten. +; Rel. 20: Berberis vulgaris L. subsp. vulgaris +, Carex macrolepis DC. +; Rel. 24: Silene nutans L. s.l. +, Veronica officinalis L. +, Poa sylvicola Guss. +; Rel. 25: Cruciata laevipes Opiz +, Dactylis glomerata L. s.l. +; Rel. 28: Ceterach officinarum Willd. s.l. +, Poa sylvicola Guss. +, Cymbalaria muralis Gaertn., B. Mey. & Scherb s.l. +; Rel. 29: Galium aparine L. +.

Tab. 5: Rel. 1: Epipactis microphylla (Ehrh.) Sw. +, Dactylis glomerata L. s.l. +, Polygonatum odoratum (Mill.) Druce +, Galium aparine L. +, Arabis collina Ten. s.l. +; Rel. 2: Galium aparine L. +, Arabis collina Ten. s.l. +, Carex humilis Leyss. +, Clematis vitalba L. +, Hieracium piloselloides Vill. +, Juniperus communis L. +, Lonicera alpigena L. subsp. alpigena +, Vicia villosa Roth subsp. varia (Host) Corb. +, Digitalis lutea L. subsp. australis (Ten.) Arcang. +; Rel. 3: Asphodelus macrocarpus Parl. subsp. macrocarpus 1, Veratrum nigrum L. 1, Dactylis glomerata L. s.l. +, Polygonatum odoratum (Mill.) Druce +, Asperula laevigata L. +, Campanula glomerata L. +, Cyclamen repandum Sm. subsp. repandum +, Peucedanum austriacum (Jacq.) W.D.J. Koch s.l. +, Pteridium aquilinum (L.) Kuhn subsp. aquilinum +, Silene vulgaris (Moench) Garcke s.l. +, Tanacetum corymbosum (L.) Sch. Bip. subsp. achilleae (L.) Greuter +, Aquilegia vulgaris auct. Fl. Ital. +, Scutellaria columnae All. subsp. columnae +, Aristolochia lutea Desf. +, Primula veris L. subsp. suaveolens (Bertol.) Gutermann & Ehrend. +, Arabis turrita L. +, Bunium bulbocastanum L. +, Alliaria petiolata (M. Bieb.) Cavara & Grande +, Digitalis lutea L. subsp. australis (Ten.) Arcang. +; Rel. 4: Bunium bulbocastanum L. +, Alliaria petiolata (M. Bieb.) Cavara & Grande +; Rel. 5: Veratrum nigrum L. +, Fallopia convolvulus (L.) Á. Löve +, Aristolochia lutea Desf. +, Primula veris L. subsp. suaveolens (Bertol.) Gutermann & Ehrend. +, Arabis turrita L. +, Bunium bulbocastanum L. +, Alliaria petiolata (M. Bieb.) Cavara & Grande +, Vicia villosa Roth subsp. varia (Host) Corb. +; Rel. 6: Crataegus monogyna Jacq. +, Laserpitium latifolium L. +, Sesleria nitida Ten. +, Aquilegia vulgaris auct. Fl. Ital. +, Scutellaria columnae All. subsp. columnae +; Rel. 7: Polygonatum odoratum (Mill.) Druce +, Sesleria nitida Ten. +, Scutellaria columnae All. subsp. columnae +; Rel. 8: Polygonatum odoratum (Mill.) Druce +, Arabis collina Ten. s.l. +, Carex macrolepis DC. +, Cytisophyllum sessilifolium (L.) O. Lang +, Euphorbia cyparissias L. +, Monotropa hypophegea Wallr. +, Opopanax chironium (L.) W.D.J. Koch +, Peucedanum oreoselinum (L.) Moench +, Vicia peregrina L. +, Moehringia muscosa L. +, Laserpitium latifolium L. +, Sesleria nitida Ten. +, Scutellaria columnae All. subsp. columnae +, Arabis turrita L. +, Vicia villosa Roth subsp. varia (Host) Corb. +, Digitalis lutea L. subsp. australis (Ten.) Arcang. +; Rel. 9: Polygonatum odoratum (Mill.) Druce +, Moehringia muscosa L. +, Laserpitium latifolium L. +, Primula veris L. subsp. suaveolens (Bertol.) Gutermann & Ehrend. +, Alliaria petiolata (M. Bieb.) Cavara & Grande +; Rel. 10: Polygonatum odoratum (Mill.) Druce +, Arabis turrita L. +; Rel. 11: Cotoneaster integerrimus Medik. 1, Polygonatum odoratum (Mill.) Druce +, Rhamnus alpina L. s.l. +, Laserpitium latifolium L. +, Sesleria nitida Ten. +, Scutellaria columnae All. subsp. columnae +.