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ECOLOGICAL CLASSIFICATION OF BEECH WOODLANDS IN THE CENTRAL APENNINE THROUGH FREQUENCY DISTRIBUTION OF ELLENBERG INDICATORS

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Abstract - Habitats are often described using a phytosociological approach, meaning that plant communities are classified through a floristic data set. As this approach is based exclusively on a floristic assemblage analysis, much of the ecological information about the species may be lost. For this reason, Ellenberg indicators (EIV) are used to incorporate the information provided by vegetation relevés; for each species, the EIVs express the ecological requirements for seven main environmental factors. Based on that assumption, this study focuses on the use of EIVs in detecting discriminants in a homogeneous habitat (via similarity-dissimilarity tests for each Ellenberg indicator). This helps to identify the key ecological factors structuring the vegetation. The study area is located in the Upper Sangro Valley in the central Apennines (Abruzzo region) where 94 phytosociological relevés and pedological profiles were carried out in beech and mixed woodlands. Based on a flora set, the Cluster Analysis divided the vegetation relevés into seven groups which are floristically distinguished. For each of the groups, the frequency distribution of the single EIV of all the recorded species in each relevé was compared through a non-parametric test which delivered the probability of two distributions being the same. Combining the results of the two different analyses we were able to rearrange the outcome of the cluster analysis into an ecological classification, which was then confirmed by field data on soil parameters.

Key words: beech forest, central Apennine, EIV, Ellenberg frequency distribution, ecological classification

INTRODUCTION

Ecologists have long been intrigued by the role of environmental factors in forest vegetation and species niches overlapping. As they often occur in deciduous forests (Whittaker, 1975), they may hide the discriminant and ordinator factors responsible for species assembling. Under phytosociological criteria, species patterns often follow a general long-term codified model. As resources are limited, it is therefore most useful to explore the key relationships between environmental factors and vegetation patterns (Tilman, 1985). One challenge of the phytosociological studies is to make a correlation between classification, traditionally based on the floristic composition of the communities, and the relationships to local environmental factors.

Factors concerning the cycle of nutrients and water in the soil, light and temperature either cannot be measured directly or require a great expenditure of time and money for chemical-physical analyses; ecoindicators can therefore be used to expedite this process.

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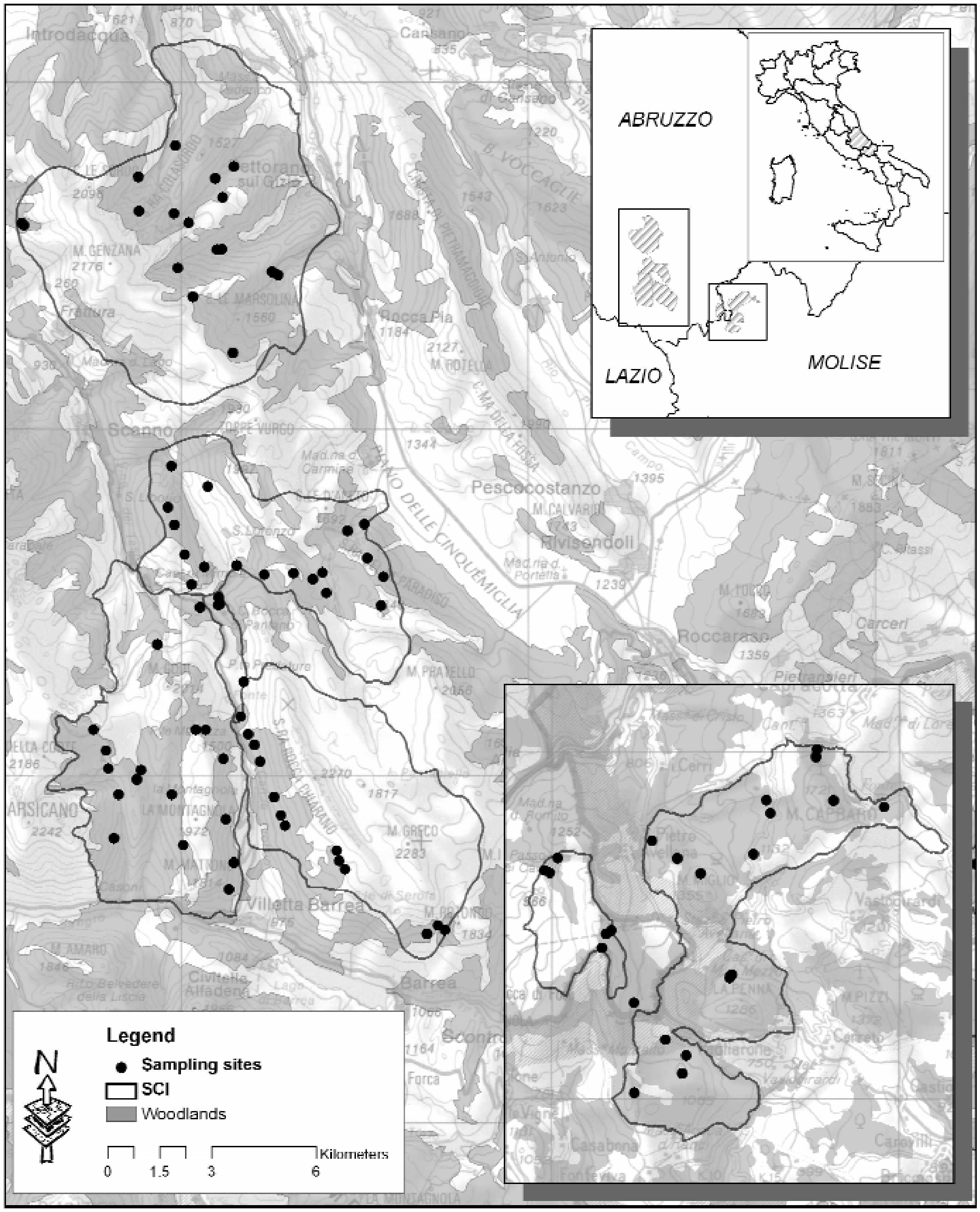

Figure 1. Location of the Study Area. Sampling plots are represented by black dots. Sites of Community Importance are within the square.

In botanical studies, Ellenberg indicators (Ellenberg, 1974-1979) represent a well-known and consolidated bioindication model (Van der Maarel, 1975; Fanelli *et al.*, 2006a, b; Testi *et al.*, 2006). They avoid the difficulties above, but present a limit due to the potential circularity of the data.

Since the beginning of phytosociology, Braun-Blanquet (1926) and Ellenberg (1963) foresaw the development of a multi-methodological analysis overcoming the approach exclusively based on a floristic assemblage analysis, which may lead to redundancy in syntaxonomical framework (Testi *et al.*,

2005) emphasizing small floristic variation that may only be due to local conditions.

In this study we follow consecutive steps, starting from traditional classification of the vegetation based on the phytosociological approach, which through multivariate analysis aggregated various relevés, then continuing by applying factors measured in the field, like ecoindicators and edaphic parameters.

The ecoindicators utilised here refer to well-known and consolidated bioindication models, such as Ellenberg indicators (Ellenberg, 1974-1979) largely applied in botanical studies (Van der Maarel, 1975; Diekmann, 1995) and more recently in ecological ones (Fanelli *et al.*, 2006a, b; Testi *et al.*, 2006). Moreover 85 plant associations including 6 beechwood communities were charaterized ecollogically using EIV-s (Borhidi *et al.*, 2000).

Ellenberg indicator values (EIV) are a set of numbers expressing the average realised niches of species along seven fundamental factors (light -L, temperature -T, continentality -K, soil moisture -F, pH -R, nutrients -N, salinity -S). They represent a first model of bioindication proposed and applied to the flora of Germany (Ellenberg, 1974-1979). To extend the model to Italian flora, a database was compiled by Pignatti *et al.* (2005) and Fanelli *et al.* (2006b).

EIV have been shown to successfully describe the ecological patterns of plant communities and to be related to important functional traits (Schaffers and Sýkora, 2000; Pignatti *et al.*, 2001, Testi *et al.*, 2004). EIV is mainly used for environmental monitoring (Ellenberg *et al.*, 1992; Körner, 1994) and a secondary purpose of interpreting ordinations, with the advantage that they provide an objective benchmark to interpret ordinations in terms of know gradients (Grime *et al.*, 1988). Ellenberg indicators are displayed through a scale of values expressing the degree of the factor. EIV are consequently divided in ranked categories (ordered from 1 to 9 or extended to 12) and not along a "continuous" and "same magnitude" scale (i.e. the difference between 1 and 5 is not five fold the difference between 1 and 2).

Most of the published literature on the use of EIV showed that the use of mean values is an efficient way to distinguish ecologically the different plant communities. However the use of the mean has sometimes been questioned due to the rank nature of the factor scale that cannot follow an "arithmetic" procedure; for this reason it would be more correct to represent a plant community by the frequency distribution of the EIV values. This is also more "robust" than simply using the median, especially to distinguish between communities at a detailed scale.

It is often difficult to assess if small differences among samples are significant, a case encountered in particular when dealing with local variability of vegetation. Significance is necessary to detect which, among the many ecological factors, are the key factors structuring the vegetation.

In this research we therefore use frequency distribution of EIV, which we considered a more detailed method to assess ecological differences within a homogeneous habitat and to recognize the key factors in an ecosystem, to better evaluate the phytosociological classification.

Since the EIV-s as rank-characters may not be used as ordinals in the mathematical-statistical operations without modifying them, Feoli and Orlóci (1979) recommended to submit the rank-numbers under a special treatment of the analysis of concentration. This is a rather time-end-work consuming procedure, used by Précsényi (1995) and Botta-Dukát Ruppert (1999). It is the task of further study, that the procedure used by the present study, how closely fits to the values obtained by analysis of concentration.

AIM

The aim of this study was to attempt an ecological classification of the investigated woodlands in the central Apennines through species assemblage and

	clu1	clu2	clu3	clu4	clu5	clu6	clu7
clu1		FTkNr	ltKr	L			
clu2			Tk				
clu3	*n*					t	n
clu4	*FtkNr*	*FkN*	*kn*		FTKNR	FtKR	
clu5	*FTKNr*	*FtkNr*	*kTN*			FTr	
clu6	*FtNR*	*FNR*	*NR*		*n*		
clu7	*tn*	*t*	*Tr*	*FTKnR*	*FTKNR*	*LFTKNR*	

Table 1 Ecotable of similarity-dissimilarity. Probability (P) that two frequency distribution are the same tested for each Ellenberg indicator. Light L, Temperature T, Continentality K, Soil Moisture F, Soil Reaction R, Soil Nutrients N. Similarity: Normal font uppercase P>0,8, normal font lower case 0,5<P<0,8. Dissimilarity: italic font uppercase P<0,0001, italic font lowercase P<0,001.

ecological requirement for several environmental factors.

MATERIALS AND METHODS

Study area

The study was carried out within the Life project 04/NAT/IT/000190 by the Department of Plant Biology of the University of Rome (La Sapienza) and the National Forest Service. The investigated beech woodlands are located in the Upper Sangro Valley in central Apennines (Abruzzo region). They include seven Sites of Community Importance (SCI) and extend for 200 km^2, with altitudes ranging between 1114 and 1994 m a.s.l. (Figure 1). This area has a long history of silvicultural management. As in most Apennine zones, overgrazing and fires degraded the habitat leading to soil thinning and a decrease in species diversity in the herbaceous layer. Over the last thirty years, however, silvicultural practices changed more towards an ecosystemic approach taking into account shrubs, herbs, faunistic and microbiological components and their relationships in forestry management.

Vegetation sampling and Ellenberg indicators

In the study area 94 plots were randomly sampled. In each of these plots vegetation composition was surveyed with phytosociological relevés and field

Cluster 1 similarity with: • 2 and 3 for TK; • 2 for NF; • 3 and 4 for L. dissimilarity with: 3, 4 ,5, 6 for N 4, 5, 6 for TFR	**Cluster** 2: similarity with: • 3 for TK dissimilarity with: • 4, 5, 6 for FN.	**Cluster** 3: similarity with: • 1, 2, 6 for T dissimilarity with: • 4, 5, 6 for N 6, 7 for R.	**Cluster** 4: similarity with: • 5, 6 for TK; dissimilarity with: • 1, 2, 3, 7 for KN.
Cluster 5: similarity with: • 6 for TF; dissimilarity with: • 1, 2, 3 for TKN.	**Cluster** 6: similarity with: • 4, 5 for F dissimilarity with: • 1, 2, 3 for RN.	**Cluster** 7: dissimilarity with: • 1,2,3,4,5,6 for T; • 4, 5, 6 for FKNR.	

data, including: aspect, slope; elevation; rockiness.

A matrix of 175 species x 94 relevés was obtained and subjected to procedures of statistical multivariate analysis, using the complete linkage, using software Syntax 2000 (Podani, 2000). Output of this initial 'data exploration' generated a dendrogram which clustered relevés into seven groups (see results).

The different groups were also analysed taking into account outcomes acquired from a previous related study (Testi *et al.*, 2009) which investigated relationships between soil and vegetation.

For each of the seven groups detected by the Cluster Analysis, the frequency distribution of the single EIV of all the recorded species in each relevé, (for a total of 175 species x 2240 records) was compared through non parametric test. Values were considered unweighted (without consideration of cover values).

To assess if the set of frequencies differs among clusters, a non-parametric two independent sample test was carried out, delivering the probability (P value) that two distribution are the same. Consequently the complete analysis is displayed as an "ecoindicator table of similarity-dissimilarity" (Table 1), where for each factor, there is the probability of the frequency distribution among clusters being the same.

RESULTS

Vegetation sampling

Cluster Analysis (dendrogram) divided the vegetation relevés into seven groups which are distinguished floristically as follows:

1 - pioneer open beech woodland at low altitude with *Laburnum anagyroides, Pinus nigra* subsp. *nigra, Digitalis micrantha*, on rendzina-type soils overlying a stony C horizon, often on steep sunny slopes;

2 - beech woodland with *Acer obtusatum, Lonicera caprifolium, Saxifraga rotundifolia*, *Adiantum capillus-veneris,* on rendzina-type soils overlying a stony C horizon, occasionally on steep sunny slopes;

3 - beech woodland with *Ilex aquifolium, Taxus baccata, Daphne laureola*, *Cyclamen hederifolium, Mycelis muralis, Galium odoratum, Polystichum aculeatum* on soils rich in carbon and with high water availability;

4 - beech woodland at high altitude with *Epilobium montanum, Geranium robertianum, Scilla bifolia, Campanula trachelium*;

5 - beech woodland with *Prenanthes purpurea, Gagea lutea, Ribes nigrum, Aquilegia vulgaris, Polystichum aculeatum* on soil distinguished by high Carbon/Nitrogen (C/N) ratio;

6 - mature beech woodland stands with *Anemone ranunculoides, Cardamine bulbifera, Cephalanthera damasonium*;

7 - mixed woodland at low altitude with *Quercus cerris, Ligustrum vulgare, Acer campestre, Crataegus monogyna, Malus sylvestris, Corylus avellana, Cyclamen repandum, Potentilla micrantha, Viola reichenbachiana.*

Ellenberg Frequency Distribution

From the results shown in the ecotable (Table 1), summarised in the following scheme, several similarities and dissimilarities among clusters are evident.

The extent of similarities and dissimilarities helped to focus the major ecological discriminants among the clusters, allowing us to rearrange them into three main groups:
Clusters 1, 2, 3
Clusters 4, 5, 6
Cluster 7

DISCUSSION

While multivariate statistical analysis based on species presence generated seven different clusters, the use of Ellenberg ecoindicators frequency distribution allowed us to rearrange the clusters in three different main ecological groups, which can be considered as three different communities phytosociologically classified as:

group a) pioneer silvofacies of the *Polysticho-Fagetum* -Feoli & Lagonegro 1982 -PF-corresponding to thermophile and disturbed beech woodlands;

group b) *Polysticho-Fagetum* corresponding to more mature and structured mesophile beech woodlands on relatively deep soil;

group c) *Aquifolio-Fagetum carpinetosum betuli* -Feoli & Lagonegro 1982- corresponding to mixed woodlands at lowest altitudes distinguished by many thermophile species in the herbaceous and shrub layers.

This new rearrangement is also supported by the related study (Testi *et al.*, 2009) which grouped the clusters according to soil characteristics such as $CaCO_3$, C/N ratio and mother rock. Calcium carbonate discriminates the pioneer silvofacies of PF in strongly eroded areas, where the dominant soils are rendzina-types underlaid by a stony C horizon; carbon/nitrogen ratio discriminates the more mature stands of the PF on fertile and deeper soils; marls substratum discriminates the mixed woodlands.

Beside rearranging the clusters, Ellenberg frequency distribution also detected small scale relationships even within homogeneous woodland, for example:

Similarity between two clusters in two different groups:

Clusters 1 (in group a) and 4 (in group b), while belonging to two different communities with different general ecological needs, are nevertheless similar for light -L requirements (Table 1). In particular Cluster 1 represents a pioneer silvofacies of PF at lower altitude with many heliophilous species colonising steeper sites on primitive/eroded soils; while Cluster 4 corresponds to a PF of higher altitude with more mature stands. In both these woodland types solar radiation is more available over the year: in the first case because the vegetation structure is open, in the second one because the higher altitude causes the persistence of the beech winter *habitus* for a longer time allowing the occurrence of early emergence herbaceous species.

Dissimilarity between two clusters in the same group:

Cluster 1 and 3 while pooled in the same group ("a") are different for nutrients -N requirements (Table 1). In cluster 1, vegetation grows on rendzina type soil (poor in nutrient), while in cluster 3 woodlands occur on soils with more carbon content and higher water availability.

In addition while in woodlands of cluster 3 some character species (including *Ilex aquifolium, Taxus baccata, Daphne laureola*) of the *Aquifolio-Fagetum* -Gentile 1969- occur we considered them as mesophile pioneer silvofacies of the *Polysticho-Fagetum*. From our surveys, in fact, the presence of the mentioned species is restricted to small niches where their survival is related to moisture availability due to local occurrence of watercourses and/or persistent fog.

This latter case represents a good example of the usefulness of EIV frequency distribution in detecting ecological discriminant factors also in presence of homogeneous plant communities. This analysis, in fact, overcame the vegetation classification exclusively based on floristic assemblage, suggesting the mentioned phytosociological arrangement. Similarities, for several factors, among clusters of group "a" are, indeed, higher than dissimilarities with all the other clusters. The habitat of cluster 3 is in fact fragmentary and can be considered ecotonal between the pioneer beech communities (group "a") and the mature-structured stands (group "b").

Furthermore the phytosociological/ecological rearrangement in three groups, compared to the seven initial clusters, better supports the field surveys performed during long-term data collection carried out for this study.

CONCLUSION

The results confirmed the effectiveness in describing various vegetation types in homogeneous habitats (such as the investigated woodlands) of an approach that combines data obtained from species assemblage and species ecological requirements.

The method applied in this study identified the key factors which play a major rule in an ecosystem, overcoming limitations due to interaction, which often makes it difficult to understand species and communities responses. In this case, temperature (T), soil nutrients (N) are the main factors responsible for structuring communities and determining species assemblage: soil factors are indicators of more mature beech woodlands, while climatic factors of pioneer beech woodlands. The use of EIV frequency distribution, which delivers the probability of two distributions being the same, may support phytosociological arrangement without the risk of redundancy in the syntaxonomical framework, weighting both species occurrence and ecological factors.

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