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Assessing the habitat conservation status by soil parameters and plant ecoindicators

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The aim of this study was to assess the conservation status of a Natural Reserve located in central Italy through an integrated analysis including soil, lithotype and edaphic parameters, landforms, and plant species. The relationships between soil and vegetation was investigated using soil variables and plant ecoindicators, expressed by: (i) the Ellenberg's bioindication model; and (ii) the Hemeroby Index. Vegetation and soil data have been collected in thirty vegetation relevés and soil profiles. Cluster analysis, performed on a matrix 12 variables / 30 relevés allowed the detection of two main clusters, each divided into sub-clusters, characterized by peculiar floristic composition and soil characteristics. Clusters were markedly discriminated by soil Available Water Capacity (AWC). Canonical Correspondence Analysis (CCA) performed on variables and species matrices allowed to separate two main habitats: (i) a core habitat represented by patches of temperate forest correlated to soil cycles of water and nutrients; (ii) an ecotonal habitat composed by mixed evergreen and thermophilous deciduous oak forest, mainly related to the light, temperature and human disturbance regimes.

Keywords: Mediterranean Forest Vegetation, Soil, AWC, Ellenberg's Indicators, Hemeroby Index, CCA

Introduction

The assessment of habitat conservation status, especially in protected areas, is nowadays one of the main tasks of local, national and international offices attending to nature conservation and management. In this context, recent studies in applied ecology focused on methods based on ecoindicators for habitat survey and monitoring. The usefulness of ecoindicators is well known (Cairns et al. 1993), in particular for the early detection of trends in ecological factors such as climate, soils and disturbances (Fanelli & Testi 2008, Hill et al. 2002).

The main challenge in applied ecology is the identification of the key factors involved in the response of species and communities to disturbances and in their ecological structure (Fanelli et al. 2006a, Borhidi 1995). Focusing on the relationship between soil and vegetation, static factors such as soil pH and texture, soil carbon and nitrogen stock, exchangeable bases, etc. can be easily measured by soil profiles and laboratory analyses. Instead, dynamic factors like mineralization rate, water availability and annual average temperature, etc. are harder to be obtained without long-term research efforts (Schimel & Bennet 2004). Nonetheless, the above factors may be easily assessed by the use of plant ecoindicators, such as Ellenberg's indicators (Ellenberg 1974, Testi et al. 2006, Diekmann 1995) and Hemeroby Index for the anthropic disturbance evaluation (Kowarik 1990). Using the above indexes, the detection of changes in species and communities along spatio-temporal gradients and at different scale levels have been successfully carried out (Angermeier & Karr 1994, Lalanne et al. 2010, Hillebrand 2005).

Ellenberg's indicator values (EIVs) express through a numerical value the average realized niches along seven fundamental gradients (light, temperature, continentality, soil moisture, soil pH, nutrients, salinity). EIVs summarize in scales with nine degrees (up to twelve for soil moisture indicator) the large amount of ecological information on plants and plant communities associated with environmental measurements of edaphic and climatic parameters. Limitation and strengths of the Ellenberg's approach have been long debated (*e.g.*, Ewald 2003), though a number of studies showed a good agreement between indicators and environmental variables (*e.g.*, Fanelli et al. 2007, Schaffers & Sykora 2000, Schmidtlein & Ewald 2003, Southall et al. 2003, Kaiser & Käding 2005). EIVs represent a first model of bioindication applied for the first time to the flora of Germany (Ellenberg 1974), and then extended to Netherlands (van der Maarel et al. 1985), Norway (Vevle & Aase 1980), Sweden (Diekmann 1995), Estonia (Pärtel et al. 1996, 1999), Poland (Roo-Zieliska & Solon 1988), Great Britain (Hawkes et al. 1997), northeastern France (Thimonier et al. 1994) and Italy (Celesti Grapow et al. 1993, Pignatti 2005, Fanelli et al. 2006b). EIVs have been shown to successfully describe the ecological patterns of plant communities and to be related to important functional traits (Schaffers & Sykora 2000, Pignatti et al. 2001, Testi et al. 2004). They are mainly used for environmental monitoring (Ellenberg et al. 1992), and in ecological studies for the interpretation of ordinations in terms of known gradients (Grime et al. 1988). EIVs have been largely applied in botanical studies (Van der Maarel 1975, Diekmann 1995) and more recently in ecological investigations (Testi et al. 2012, Godefroid et al. 2007, Jones et al. 2007).

Closely related to EIVs is the hemeroby index (H) which is related to the degree of past and present human impacts on ecosystems according to a ten-point scale (Van der Maarel 1975, Kowarik 1990, Fanelli & De Lillis 2004). Direct estimation of disturbance and human impact is usually difficult. However, hemeroby index has been successfully applied in studies based on changes in the composition of communities and species in order to assess the response of vegetation to disturbance (Fanelli & Testi 2008).

The ecosystemic approach based on ecological indicators described above is particularly useful in the assessment of the conservation status of forest habitats that are increasingly threatened by human activities and urban sprawl, like in the surrounding of large cities. The aim of this study is to evaluate the conservation status of a natural reserve in the surroundings of Rome (Italy) through an integrated approach, analysing simultaneously soils, lithotypes, landforms, edaphic parameters and plant species.

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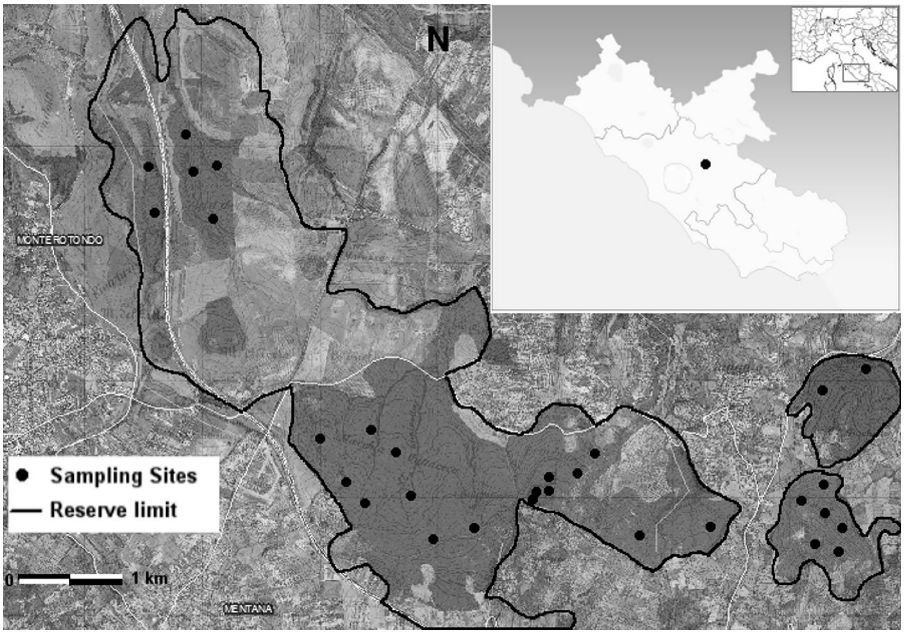

Fig. 1 - The study area (Regional Reserve "Macchia di Gattaceca e Macchia del Barco").

Materials and methods

Description of the study area

The "Macchia di Gattaceca e Macchia del Barco" natural reserve, established in 1997, is located in the Province of Rome, between the Tiber Valley and the Lucretili Mountains (UTM N 42° 05', E 12° 50' - Fig. 1). The protected area covers about 1000 hectares of forested hills, with altitude ranging between 78 and 241 m a.s.l. The area was subjected to a long-term historical disturbance, due to heavy cutting and burning, as well as to grazing, which has been recently restricted to some edge zones only.

From the geological point of view, the area is mainly made up of Mesozoic limestone formations of the Tiber Ridge (Soratte Mt - Cornicolani Mts), referring to the *Umbro-Sabina* succession. Since Pliocene, marine ingression/regression led to the deposition of yellow sand, calcareous conglomerates, clayey sand and yellowish clay, until the final emergence of the whole area in the Pleistocene (Martinis 1992). Pleistocenic pyroclastic products from the *Sabatino* and *Laziale* volcanic districts were then deposited (Anonymous 1993). Limestones in the area show intense fracturing and karst phenomena with numerous sink-holes, including *Pozzo del Merro*, the deepest explored sink-hole in the world (-392 m a.s.l. - Gary et al. 2003). Geological heterogeneity in the area is one of the causes of its geomorphological diversity, dolines, ditches, plains, slopes make the environmental mosaic.

The most widespread vegetation is a deciduous mixed oak forest, dominated by *Quercus cerris* and *Quercus frainetto*, co-dominants in some sites. *Quercus robur* is present in the diches, while *Quercus pubescens* and *Quercus ilex* shrublands are present on sunny calcareous slopes (Dowgiallo & Vannicelli 1993, Testi et al. 2000).

Climate is moderately Mediterranean with about 2 months drought in summer (July and August); average yearly temperature is 15.2 °C and annual rainfall 813 mm, with two peaks in October-November and April (Fig. 2). As for the pedoclimate (USDA 2010), temperature regime resulted to be Thermic. The soil moisture regime is Xeric for most of the studied soils. Only soils on plio-pleistocenic sediments with the highest available water capacity have Udic moisture regime.

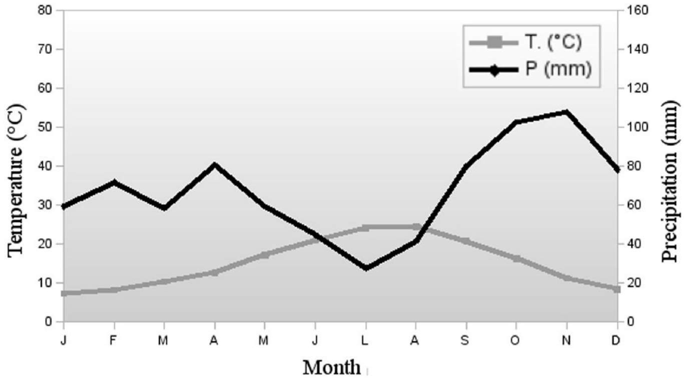

Fig. 2 - Climogram of the meteorological Guidonia-Montecelio station (89 m a.s.l.) nearby to the study area. Monthy means for the period 1971-2000.

Field data collecting and analysing

Thirty sampling sites, each of 100 m^2, were chosen using randomized-systematic method (Gillet 2000, Podani 2007). Samplings were distributed over the whole study area within the following geomorphological units:

- Unit A: ridges (6 samplings),
- Unit B: mountain slopes (6 samplings),
- Unit C: plain surfaces (6 samplings),
- Unit D: ditches, subdivided into D1-ditches bottom (4 samplings), D2-ditches gentle slopes (4 samplings) and D3-ditches steep slopes (4 samplings).

In each site phytosociological relevés and soil profiles were carried out simultaneously.

Vegetation

Phytosociological relevés were carried out using Braun-Blanquet method (Braun-Blanquet 1932, Westhoff & Van der Maarel 1978). All vascular plant species were determined in each site and their relative coverage recorded on a percentage basis. Nomenclature of species followed Pignatti (1982) revisited with MedCheckList (Greuter et al. 1984). Overall, a floristic matrix of 130 species x 30 relevés was obtained.

Ecoindicators

Ellenberg's Indicator Values (EIVs - Ellenberg 1974, Ellenberg et al. 1992) and Hemeroby Index (Kowarik 1990) were applied in this study. The full list of the indicators applied was as follows: (1) L: light; (2) T: temperature; (4) F: soil moisture; (5) R: soil reaction; (6) N: soil nitrogen; (7) hemeroby. Since salinity (S) is used only for saline soils and continentality (K) has a meaning only on a geographical scale, these two indicators were excluded from the analysis.

All the above indexes were weihted on species coverage.

Pedological analysis

In each sampling site soil profiles were obtained and described following the guidelines for Soil Survey by Costantini (2007). Seventy seven samples were collected and analysed with standard methods (MIPAF 2000) for: (i) texture; (ii) pH in a 1:2.5 soil/ water suspension; (iii) total carbonates; (iv) organic carbon and organic matter; (v): exchangeable acidity; (vi): exchangeable bases; (vii): cation exchange capacity; (viii) total nitrogen; (v) available phosphorus. Moreover, three additional parameters were calculated: available water capacity (AWC), base saturation and carbon/nitrogen ratio (C/N). Available water capacity (AWC, mm H_2O cm^{-1} soil depth) was estimated by the Salter & Williams (1969) equation based on textural composition and percentage of organic matter (eqn. 1):

$$AWC = 1.475 - 0.010 \cdot CS + 0.011 \cdot S + 0.138 \cdot OC$$

where *CS* is the percentage of the coarse sand, *S* is the percetage of silt and *CO* is the percentage of organic carbon in the sample.

Although all soil horizons were sampled and analysed separately, statistical analysis was applied on weighted averages, calculated by multiplying the value of each parameter by the horizon thickness, summing these values and dividing them by the total depth of the profile (Daniels et al. 2004, Feng et al. 2009, Benbi & Brar 2009).

Soils were classified to the subgroup level according to the Soil Taxonomy (USDA 2010).

Statistical treatment

For each one of the 30 sites studied, values were obtained for 12 variables: 6 ecoindicators and 6 soil parameters (Tab. S1 in Appendix 1). All variables were normalized and standardized (since having different scales and units) by subtracting the variable mean and dividing by their standard deviation (Podani 2007).

The following multivariate statistical analyses were applied on standardized variables: (i) cluster analysis (CA) on the variables/relevés matrix (12x30); (ii) Canonical Correspondence Analysis (CCA) on the whole data set (variables/relevés 12x30 and species/relevés 130x30 matrices).

All statistical analyses were performed by the software R (R Development Core Team 2012) using the package "vegan" for community ecology (Oksanen et al. 2012), "cluster" for cluster analysis (Maechler 2012) and "ecodist" for distance calculation (Goslee & Urban 2007).

To recognize the main gradients in the dataset, normalized variable scores were calculated from their weights on CCA axes. To test the significance of species/environmental factors correlation, two-ways ANOVA with permutation was performed on the CCA model, variables and axes (Legendre & Legendre 1998). Using the R package "anova.cca" the number of permutations is controlled by targeted "critical" *P* value and accepted Type II or rejection error (β); permutations were performed until the *P* value obtained differs from the targeted α at risk level given by β.

Analysis of variance (one-way ANOVA) was performed on clusters obtained by CA to test for possible differences in soil parameters and ecoindicator means.

Results

Cluster Analysis

Results of the cluster analysis carried out on the variables/relevés matrix revealed the existence of two main groups of relevés (Fig. 3), each one divided into sub-clusters, distinguished by floristic (Table S2 in Appendix 1), ecological (Ellenberg's indicators) and edaphic characteristics. Overall, 5 clusters were identified (I°a, I°b; II°a, II°b, II°c - see Tab. 1). Vegetation, soil types, bedrocks and geomorphological units of the sampled areas are summarized in Tab. 2. Following is a brief description of the two main clusters and the five subclusters identified.

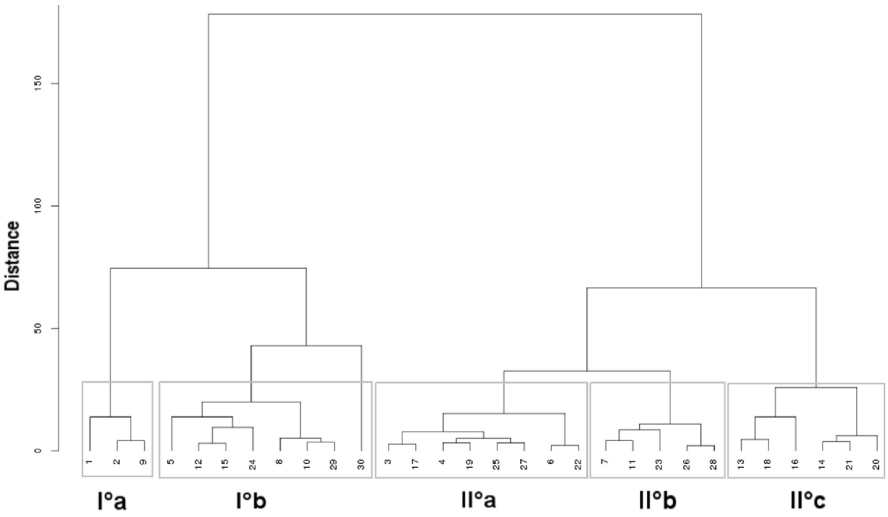

Fig. 3 - Dendrogram of the relevés from the cluster analysis carried out on the matrix of 12 variables (6 ecoindicators and 6 soil parameters) x 30 sites. Two main clusters are outlined, each one further distinguished into sub-clusters.

I° cluster: Thermophilous submediterranean /mediterranean woodlands and shrublands with *Quercus cerris* along with *Quercus ilex* and *Quercus pubescens* (locally dominant) on calcareous rocks, lithic soils. Geomorphological units are ridges (A) and mountain tops (B).

- *I°a sub-cluster:* sclerophyllous shrublands dominated by *Quercus ilex*, with *Viburnum tinus* on the ridges.
- *I°b sub-cluster:* open woodlands and shrublands of *Quercus pubescens* and *Quercus ilex* along with Mediterranean species (such as *Pistacia terebinthus*, *Phyllirea latifolia* and *Cercis siliquastrum*) on moderately to strongly steep slopes.

II° cluster: Mesophilous and hygrophilous woodlands dominated by *Quercus cerris* and *Quercus frainetto* with the occurrence of *Quercus robur* on deep and very deep soils on plio-pleistocenic marine sediments (slopes of ditches and gorges), tuffs (gentle slopes) and calcareous rocks (depressions and gentle slopes). This vegetation type is the most common in the study area. Geomorphological units are plain surfaces (C) and ditches (D).

- *II°a sub-cluster*: mesophilous woodlands with *Quercus robur* on tuffs.
- *II°b sub-cluster*: hygrophilous woodlands with *Quercus robur*, *Acer obtusatum*, *Ulmus minor*, *Sambucus nigra* and *Corylus avellana* on marine sediments and calcareous bedrocks and soils with the highest AWC values (Tab. 1).
- *II°c sub-cluster*: more open woodlands

Tab. 1 - Mean values (± standard deviations) of soil parameters and ecoindicators in the 5 groups identified by cluster analysis.

Parameters	I°a	I°b	II°a	II°b	II°c
pH	7.8 ± 0.5	7.2 ± 0.5	6.4 ± 0.7	7.6 ± 0.8	6.8 ± 1
$CaCO_3$ (%)	0.3 ± 0.5	1.4 ± 4	0.1 ± 0.1	3.4 ± 4.4	0.1 ± 0.2
Org (%)	2.8 ± 0.4	4.3 ± 1.3	2.5 ± 0.8	3.3 ± 0.1	1.4 ± 0.5
N (%)	0.2 ± 0	0.5 ± 0.2	0.3 ± 0.1	0.3 ± 0	0.2 ± 0.1
C/N	11.5 ± 2.1	8.9 ± 1.4	8.9 ± 1.5	10.3 ± 0.8	8.6 ± 1.7
AWC (mm)	137 ± 6.9	98 ± 14	219 ± 5.1	240 ± 6.3	195 ± 9.7
H	2.7 ± 0.4	2.6 ± 0.6	2.5 ± 0.4	2.3 ± 0.1	2.3 ± 0.2
L	3.7 ± 0.5	4.3 ± 1	3.4 ± 0.3	3.5 ± 0.4	3.3 ± 0.1
T	7 ± 0.6	7 ± 0.6	6.4 ± 0.3	6.6 ± 0.3	6.4 ± 0.3
F	5.3 ± 0.6	5.3 ± 0.7	5.9 ± 0.2	5.8 ± 0.4	5.9 ± 0.2
R	7.2 ± 0.3	7.4 ± 0.1	7.3 ± 0.2	7.4 ± 0	7.4 ± 0.1
N	5 ± 1.2	5.4 ± 0.8	6.1 ± 0.4	5.9 ± 0.4	6.2 ± 0.3

Tab. 2 - Integrated table of geomorphological units, bedrocks, soil types and vegetation following sub-clusters.

Subcluster	Bedrocks	Land Forms	Dominat soil types	Dominat tree species
I°a	Calcareous rocks	A-ridge	TYPIC HAPLOXEREPTS: fine, thermic, superactive. Shallow soils, with low water availability (< 140 mm). Clay. Neutral to weakly alkaline slightly calcareous. Very high E.C.C.(40-50 cmol/kg) and very high Base Saturation (80-90%)	*Quercus ilex* *Quercus pubescens* *Quercus cerris*
I°b	Calcareous rocks	B-mountain slope	LITHIC HAPLOXEROLLS: fine, thermic, superactive. Shallow soils, stony, with rather low water availability (< 110 mm). Clay loam- clay. Weakly alkaline. Slightly calcareous or acalcareous. Very high E.C.C. (50-70 cmol/kg) and very high Base Saturation (>90%).	*Quercus ilex* *Quercus pubescens* *Quercus cerris*
II°a	Tuffs	D2-ditches gentle slopes C-plain surfaces	TYPIC HAPLOXEREPTS, MOLLIC/TYPIC HAPLOXERALFS: fine, thermic, active. Shallow to moderately deep soils, with moderate to high water availability (210 to 220 mm). Weakly acid. Silty clay to clay. High E.C.C. and high Base Saturation (60-75%).	*Quercus cerris* *Quercus frainetto*
II°b	Plio-pleistocenic marine sediments and calcareous rocks	D2-ditches gentle slopes D1-ditches bottom	ENTIC HAPLUDOLLS: fine silty, thermic, superactive. Very deep soils, with very high water availability (230-250 mm) and udic moisture regime. Silt loam. Moderately alkaline, weakly to moderately calcareous (2-14% CaCO3) . Very high E.C.C.(60-70 cmol/kg) and very high Base Saturation (100%).	*Quercus cerris* *Quercus frainetto* *Quercus robur*
II°c	Calcareous rocks	D1-ditches bottom C-plain surfaces	ULTIC HAPLOXERALFS and TYPIC EUTRUDEPT: fine, thermic, active. Deep soils with very high water availability (>200 mm). Silty clay - clay. Moderately to weakly acid. High E.C.C.(40 to >50 cmol/kg) , high Base Saturation (60-70%).	*Quercus cerris* *Quercus frainetto* *Quercus robur*

characterized by large cover of *Prunus spinosa* and exclusive occurrence of ruderal and edge species, such as *Onopordum illyricum*, *Bellis perennis*, *Dactylis glomerata*, *Holcus lanatus* on calcareous rocks.

Analysis of variance

Significant differences among the five sub-clusters identified were detected for the variable AWC after one-way ANOVA (df=4; SS=92959.3; F=252.2, P<0.0001). To test the significance of differences among sub-clusters' means, Fisher LSD test was carried out (P<0.05). Results showed that sub-cluster I°a and I°b had means significantly lower than the mean of the other three sub-clusters (II°a, II°b, II°c). Sub-cluster I°b showed that means for ecoindicator L (DF=4, SS=4.44; F=3.39, P<0.024), organic carbon (DF=4, SS=31.49; F=11.14, P<0.0001) and nitrogen (DF=4, SS=0.42; F=5.29, P<0.003) were significantly higher than the means of sub-clusters II°a, II°b, II°c. Furthermore, sub-cluster I°a showed a N-indicator mean significantly lower (DF= 4, SS=4.98; F=3.38, P<0.024) than the mean of sub-clusters II°a, II°b and II°c.

CCA

Results of the CCA analysis on the matrix of 30 relevés, 130 species and 12 variables confirmed the differences between the two main clusters previously identified (Tab. 3, Fig. 4a and Fig. 4b) . The first CCA axis accounted for 66% of the total variance and was highly correlated (P<0.01) with the ecoindicators for N (r = 0.73) and T (r = -0.64); it was also correlated (P<0.05) with F (r = 0.52) and H (r = -0.41) indicators, as well as with the ratio C/N (r = - 0.42).

The second CCA axis accounted for 42% of the total variance and showed a highly significant (P<0.01) correlation with L (r = 0.91) and F (r = -0.76) ecoindicators; it was also correlated (p<0.01) with organic carbon (r = 0.63) and with measured nitrogen (r =0.76). The third axis accounted for 29% of the variance in the dataset and showed a significant correlation (p<0.05) with the R indicator (r = -0.80).

A small group of species exclusive of cluster I° was projected onto two branches of CCA plane (Fig. 4): on the bottom left of the scattergram, species with large abundance or exclusive presence in the sub-cluster I°a (like *Quercus ilex*, *Viburnum tinus*, *Aegilops geniculata, Lotus ornithopodioides* and *Polypodium cambricum*) are displayed; on the right top of the same plot, species largely

Tab. 3 - CCA Outputs. (1) Partitioning of mean squared contingency coefficient; (2) Eigenvalues and their contribution to the mean squared contingency coefficient (first three axes); (3) Biplot scores for constrained variables. (*): p<0.05; (**) p<0.01; (***): p<0.001.

Output 1	**Inertia**	**Proportion**	**Rank**
Total	3.768	1	-
Constrained	2.505	0.665	13
Unconstrained	1.263	0.335	17
Output 2	**CCA1**	**CCA2**	**CCA3**
Eigenvalue	0.655	0.415	0.295
Proportion Explained	0.174	0.11	0.078
Cumulative Proportion	0.174	0.284	0.362
Output 3	**CCA1**	**CCA2**	**CCA3**
pH	-0.089	0.106	-0.362
$CaCO_3$%	0.003	0.132	-0.335
Org C%	-0.199	0.626**	-0.131
N %	-0.088	0.762*	-0.05
C/N	-0.415*	-0.234	-0.052
AWC (mm)	0.289	-0.457**	0.074
H	-0.409*	0.348	-0.27
L	-0.184	0.912**	-0.156
T	-0.641**	0.635	0.03
F	0.522*	-0.756**	0.04
R	0.181	0.181	-0.802*
N	0.733**	-0.519	0.041

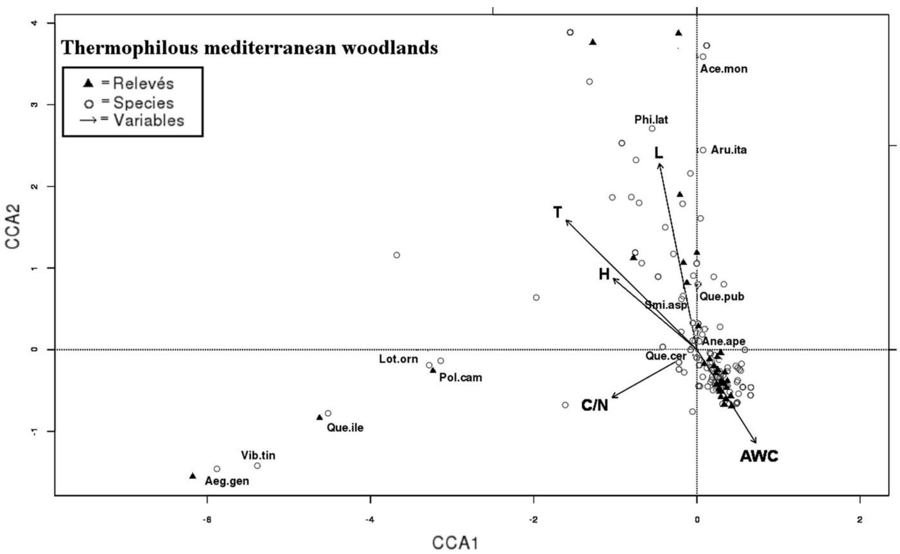

Fig. 4 - CCA triplot according to axes 1 and 2: species, relevés and variables of thermophilous Mediterranean woodlands (cluster I°) are projected into two branches on the bottom left (sub-cluster I°a) and on the top left (sub-cluster I°b). Most representing species are indicated with labels (see Tab. S2 in Appendix 1 for species abbreviations) and most correlated soil parameters are displayed.

abundant in the sub-cluster I°b may be found, such as *Acer monspessulanum, Cercis siliquastrum, Quercus pubescens, Smilax aspera, Arum italicum*.

In the central sector of CCA (Fig. 5), the cloud of species projected in the direction of AWC, F and N indicators belongs to the II° cluster and corresponds to meso-hygrophilous woodlands dominated by *Quercus cerris* with the exclusive occurrence of *Quercus frainetto* and *Quercus robur*. All the species belonging to cluster II° (like *Sambucus nigra, Corylus avellana, Acer obtusatum, Cornus, sanguinea, Symphytum officinale, Ranunculus lanuginosus* and *Stachis sylvatica*) exhibit a low requirement for T and high for N and F indicators (Tab. 1).

All the species of the two branches of cluster I° exhibit a high requirement for T (range 7-9) and low for N (range 2-6) and F indicators.

The two main forest types respectively represented by thermophilous (cluster I°) and meso-hygrophilous (cluster II°) communities were clearly separated along CCA axis 1, while the two sub-clusters of cluster I° were separated along CCA axis 2.

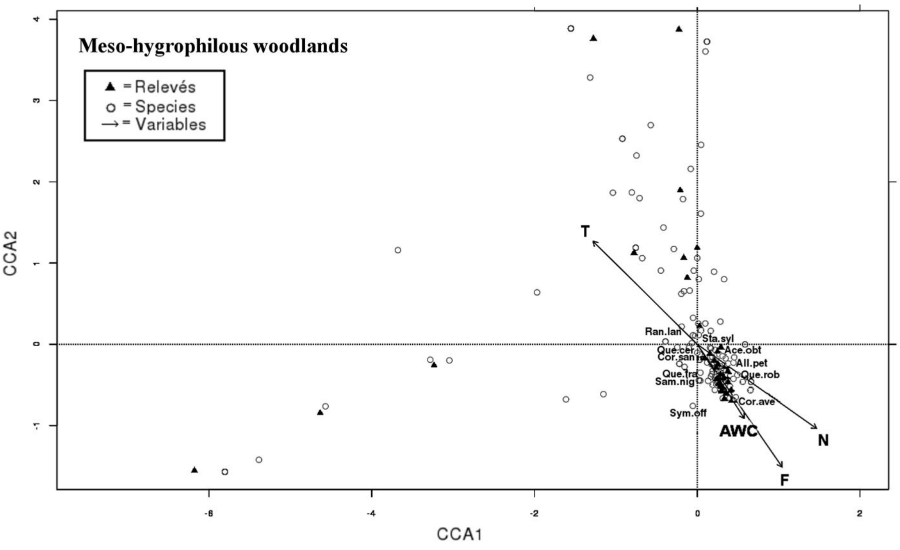

Fig. 5 - CCA triplot according to axes 1 and 2: species, relevés and variables of meso-hygrophilous woodlands (cluster II°) are projected in the centre of axes plane. Most representing species are indicated by labels (see Tab. S1 in Appendix 1 for species abbreviations) and most correlated variables are displayed.

Discussion

The results from the canonical correspondence analysis carried out may be easily interpreted based on the ecoindicator values used in this study. Species of the meso-hygrophilous woodlands (cluster II°) were distributed along the gradients of water and nutrients, as revealed by their F and N indicator values, as well as by the measured soil AWC parameter. In fact, water and nutrients represent the key factors responsible for survival of forest patches dominated by *Quercus frainetto* and *Quercus robur* on deep soils with the highest water availability (Göransson et al. 2006). In the investigated area the above communities occur on plain surfaces, as well as on the steep slopes of the ditches, on plio-pleistocenic marine sediments and on tuffs (Tab. 2).

Shrublands and open woodlands of *Quercus pubescens* and *Quercus cerris* (subcluster I°b) were distributed along the maximum variation of the T, L and H indicators (Fig. 4). T and H indicators were significantly correlated with CCA axis 1, while L indicator with CCA axis 2 (Tab. 3). Soils in the above communities are lithic and shallow, with low AWC values (Tab. 2). The above evidence indicate that light, temperature and disturbance are the key factors shaping these communities, mostly occurring on calcareous bedrocks.

As clearly revealed by the CCA triplot in Fig. 4, a small group of species dominated by *Quercus ilex* and *Viburnum tinus* are related with the highest C/N ratio values in the dataset. The above result can partly be explained by the slower decomposition rate of the sclerophyllous leaves leading to a consistent accumulation of organic carbon in these communities (Giordano 2002, Xamena et al. 1991).

Through the correlation of CCA axes with species and variables (Fig. 4, Fig. 5, Tab. 3) it was possible to identify two different types of habitats, corresponding to the clusters I° and II°:

1. a core habitat (cluster II°) represented by patches of temperate forest with higher diversity in species as well as in landforms and lithotypes, supported by high water and nutrients availability (Perakis & Hedin 2001);
2. an ecotonal habitat (cluster I°) characterized by mixed evergreen and thermophilous deciduous oak forest depending on light, temperature and human disturbance, on soils with the lowest AWC values (Tab. 1).

The above habitats were distributed along three multi-composite gradients identified by CCA: (i) soil moisture and nutrients (F, N indicators, AWC); (ii) light and temperature (L, T indicators); and (iii) disturbance (H indicator). Soil AWC was the main factor summarizing the complexity of the vegetation gradients investigated, as well as the species and communities distribution in the two habitats. Indeed, large differences in soil AWC were detected among species assemblages characterized by high environmental heterogeneity of landforms, substrates and soils (Testi et al. 2004, Oswalt et al. 2006, Murata et al. 2009). AWC also showed marked differences among community structures (Tab. 1): from more mature and complex communities with closed canopy of the core habitat (cluster II°) to younger ones with tendency towards open woodlands of the ecotonal habitat (cluster I°).

Among the soil parameters measured in this study, AWC was the most efficient for the description of vegetation changes, being an aggregate set of more than one variable, such as organic matter, sand, silt and soil depth, and therefore summarizing soil characteristics at the community scale (Wilson et al. 2001). Among EIVs, light (L) and nutrients (N) were the main factors responsible for structuring communities and determining species assemblage: higher N values were associated to more mature and complex meso-hygrophilous communities, while higher L values were linked to younger thermophilous woodlands.

In the Mediterranean environments anthropic disturbance affects mainly the meso-hygrophilous vegetation in respect to the more resilient thermo-xerophilous communities (Lucchese & Pignatti 1990, Hill et al. 2002). For this reason, the persistence of the meso-hygrophilous vegetation of the core habitat within an area historically affected by human activities is particularly valuable. The conservation of these patches of humid vegetation was favored not only by the peculiar geomorphology of some sites (ditches) in the Reserve, but also by water and nutrients availability (Fig. 5). For the above reasons, conservation activities aimed at preservation of the core habitat should be adopted, including the realization of ecological corridors connecting the different patches of habitat (Diamond 1972, Newmark 1987, Testi et al. 1996), and the conservation of soil nutrients and water regime to prevent soil fertility losses and erosion (Godefroid et al. 2007).

Our study highlights the importance of protecting the more vulnerable core habitat, keeping a light and controlled sheep grazing only on the edges of the thermophilous woodlands which are historically adapted to disturbance (Naveh 1987). The protection must be on a local scale, where the key ecological factors emerged from the multiple set of indicators and parameters (Niemela et al. 1996, Keddy 2005, Chávez & Macdonald 2010).

Conclusion

Multi-dimensional data analysis may help in the identification of key factors underlying the ecosystem complexity (Lalanne et al. 2010). In this study, the combined use of soil parameters and plant ecoindicators allowed to detect differences and similarities among the investigated communities at a fine scale.

Our results showed the ability of light (L) and soil nutrients (N) indicators and of soil measured parameter AWC to detect differences in ecological requirements of species and communities (Testi et al. 2004, 2009). AWC resulted a good synthetic soil parameter able to detect this diversity of gradients, species and communities, confirming the results of previous researches in the Mediterranean environments (Testi et al. 2004, Piccolo et al. 1996).

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Supplementary Material

Appendix 1

Tab. S1 - Values of soil parameters and eco-indicators reported for each vegetation relevé and soil profile.

Tab. S2 - Species coverage in the sub-clusters expressed as percentage values.

Link: Sicuriello_963@suppl001.pdf

