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The relationship between woody vegetation and environmental factors: a spatial discriminant analysis

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Abstract: A detailed analysis of the relationship between woody types and environmental variables (pedological and topographical) was carried out inside the city of Rome. Twenty-three sample sites 100 m^2 each were selected according to the principle that they were inside woody vegetation patches greater than 2.3 ha. Presence-absence data were analysed through hierarchical classification and principal coordinates analysis in order to detect woody vegetation types. The six groups identified were then analysed according to thirty-four variables: a spatial discriminant analysis was performed using soil physical and chemical variables measured in the A1 and A2 horizons, topographical variables (altitude, slope and aspect), and annual potential irradiation. This procedure was able to quantify the contribution of the spatial distribution of the samples with respect to that of the environmental variables, thus improving the discriminant model. The combination of three variables: aspect, organic matter A2 and exchangeable cations A2 is the most effective in discriminating the woody types allowing a hypothesis for the planning and management of these communities.

Nomenclature: Pignatti (1982).

Abbreviations: AFC - Aquifolo-Fagetum carpinetosum betuli, AWC - Available Water Capacity, CEC - Exchangeable Cations, EQF - Echinopo siculi-Quercetum frainetto, PCoA - Principal Coordinates Analysis, QQF - Quercetum frainetto-suberis, QQI - Orno-Quercetum ilicis.

Introduction

The city of Rome was previously investigated through studies concerning the phytosociological analysis of the natural vegetation (Attorre et al. 1997), landscape changes (Attorre et al. 1998) and GIS-mapping of vegetation (Attorre et al. 1999). The integration of the different analyses has highlighted an interesting phenomenon: during the last fifty years, the urban landscape was strongly modified by an often uncontrolled urbanization. However, the natural woody vegetation expanded thanks to spontaneous succession from secondary grasslands and shrublands. The increase is noteworthy since the wooded area was 400 ha in 1940 while now it is more than 800 ha (0.9% of the area analysed). In order to elaborate strategies for the planning and conservation of these areas, which are the main source of biodiversity of the city, a detailed study of the relationship between environmental factors and woody types was carried out. This approach was necessary since it has been demonstrated (Zerbe 1998) that vegetation dynamics in cultural landscapes, strongly influenced by human activity, cannot be well understood through extrapolations from small-scale information on natural potential vegetation. Instead "the exact documentation of the actual real vegetation on intermediate and large scale" is required (Zerbe 1998).

Discriminant analysis was used here because it has proved to be useful for detecting the relationship between soil characters and forest types (Gerdol et al. 1985), for analysing the spatial variation of herbaceous vegetation on soil rich in heavy metals (Babalonas et al. 1997) and for identifying homogeneous ecotopes (Vos and Stortelder 1992). However, a different approach, which takes into account the spatial distribution of the samples, was adopted here. In fact, the hypothesis of independence among observations assumed by traditional statistical techniques is a very convenient one. This conjecture is obviously violated in the present context, given that in all geographical and territorial studies "everything is related to everything else, but near things are more related than distant things", as stated in Tobler's first law of geography (Tobler 1970). For this reason, a discriminant model, which calculates the information linked to the spatial distribution of the sampled sites (contextual information) is necessary.

Study area

The sampled sites are situated within the many natural protected areas still present inside the city of Rome (Fig. 1). The landscape is characterised by low hills (the maximum altitude is Monte Mario, about 134 m a.s.l.) and small valleys cut by the streams of the drainage basin of the Tiber.

The sampled soils overlay sandy materials of Quaternary age which, together with the Pliocene marine clays, form the oldest sediments of the area. These sands emerge only on the right bank of the Tiber, as in the rest of the city they are covered by different materials: 1) pyroclastic tuffs ejected in the Upper Pleistocene by the volcanic complexes of the Sabatini and Albani hills; 2) the more recent alluvial deposits of the Tiber; 3) waste materials produced by thousands of years of human activity (Funicello 1995).

These soils have, therefore, developed on pre-volcanic sediments. In fact, the sampled areas are situated beyond the boundary of the pyroclastic outcrops, while on the slopes of the other areas the shallow cover of pyroclasts has been eroded and washed away by the surface runoff.

Rome's climate is transitional between the Mediterranean climate of the coast and the temperate one of the Apennines: the mean annual temperature varies between 14.8 and 15.8 °C, and there are three months of summer drought. However, the mean annual rainfall, ranging from 810 to 940 mm, is able to mitigate the aridity which is typical of the Mediterranean climate of the coastal areas.

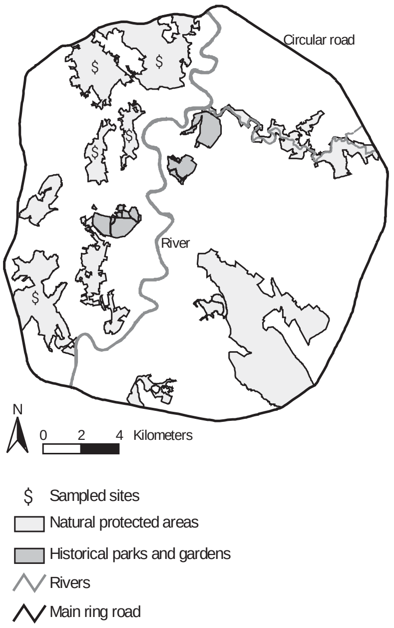

Figure 1. Study area and sampled sites.

Sampling and data analysis

Twenty-three sample sites were selected such that they were inside woody vegetation patches greater than 2.3 ha. In fact, this surface is the minimun one suitable to host mesic species in urban areas (Hobbs 1988, Levenson 1981). For each site of 100 m^2 size, the vegetation was recorded according to the Braun-Blanquet method and the data simplified to presence-absence (23 sites x 106 species) were subjected to hierarchical classification, using the average link algorithm from Ochiai distances, and principal coordinates analysis (PCoA). Subsequently, the original matrix was re-arranged using the Block Clustering technique with a chi-square based strategy to highlight the species groups which characterise the identified site groups (Appendix EA4-1). For all the above analyses we used the SYNTAX package (Podani 1994).

Furthermore, in each site, soil profiles were localised according to the procedure of Vos and Stortelder (1992): each profile was made at the intersection of the diagonals, while additional observations were made by augering at four points midway along the diagonals between the centre and the edges of the site.

The profiles were made according to the methodology of the Soil Survey Manual (Soil Survey Staff 1993) and for the physical and chemical analyses the methods of the Soil Survey Staff (1972) have been followed. The available water capacity (AWC) was calculated for each profile using the Salter and Williams formula (1967). Based on the AWC values and the mean monthly temperature and rainfall data of the Monte Mario weather station, the soil-water balance was calculated following Thornthwaite and Mather (1957). It has been found that, for all the profiles, the soil moisture regime is always xeric due to a summer deficit that lasts from two to four months. The temperature regime has proved to be thermal, as the average temperature is between 15 and 22 °C, and the difference between the mean summer and the mean winter soil temperature, at a depth of 50 cm, is greater than 5 °C. The Soil Taxonomy system has been used for soil classification purposes up to "subgroup" level (Soil Survey Staff 1975).

Spatial discriminant analysis was performed using soil physical and chemical variables measured in the A1 and A2 horizons and topographical variables: altitude, slope and aspect (Appendix EA4-2). The angular values of aspect were re-classified according to Lo Bue et al. (1994) as shown in Figure 2. Furthermore, using the lati-

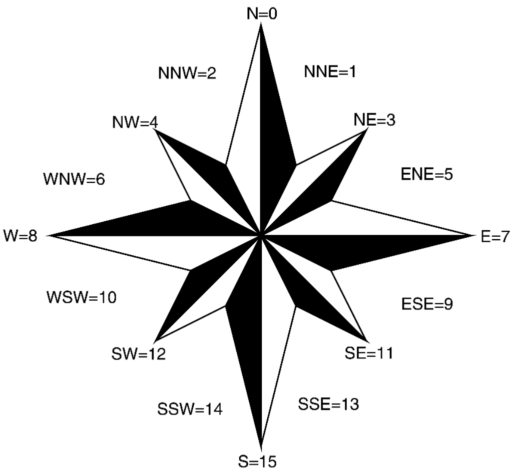

Figure 2. Aspect values from Lo Bue et al. (1994) modified.

tude, slope and aspect values, annual potential irradiation was calculated for each sample site (Frank and Lee 1966).

Discriminant analysis was made using the SPSS Software, version 10 performed in three steps. Initially a linear discriminant analysis was carried out to obtain the canonical functions. Then the variables more correlated with those functions were used for a logistic discriminant analysis. Finally, using a matrix of relative distances, a spatial parameter was introduced (Alfò and Postiglione 1999).

Results and discussion

Vegetation data

Hierarchical classification identified six groups (Figure 3) which are confirmed by the ordination diagrams along the first three PCoA axes (Figs 4a-c). Problems with the syntaxonomy of the six groups were discussed in detail elsewhere (Attorre et al. 1997). Only the main features of the types were described (Appendix EA4-1).

Carpinus betulus wood (Aquifolo-Fagetum carpinetosum betuli Feoli and Lagonegro 1982 – AFC). This association represents the most mesophilous woody vegetation community of the city and is characterised by *Carpinus betulus*, *Ilex aquifolium* and many other mesophilous species belonging to the Fagetalia sylvaticae with a Central European distribution: *Polystichum setiferum*, *Ranunculus lanuginosus*, *Cardamine bulbifera*, *C. impatiens* and *C. trachelium*.

Ostrya capinifolia wood (Echinopo siculi-Quercetum frainetto Blasi and Paura 1993 mesophilous facies to *Ostrya carpinifolia* – EQFa). This plant community can be considered as transitional towards the mesophilous woods of Aquifolio-Fagetum carpinetosum betuli plant community. A part of *Quercus cerris* and *Ostrya carpinifolia*, depending on microclimatic conditions *Fraxinus ornus, Acer campestre, Quercus robur, Q. ilex* can also be found. In the undergrowth *Ruscus aculeatus, Rubia peregrina, Asparagus acutifolius, Euonymus europaeus, Crataegus monogyna, and Ligustrum vulgare* are abundant.

Quercus cerris and *Quercus frainetto* wood (Echinopo siculi-Quercetum frainetto Blasi and Paura 1993 – EQFb). On the basis of the climatic characteristics of the city, this plant community represents the natural potential vegetation (Blasi 1994). Apart from *Quercus cerris* and *Q. frainetto*, other characteristic species are present, such as *Mespilus germanica*, *Sorbus domestica*, *Echinops siculus* and *Euphorbia amygdaloides.*

Quercus ilex and *Fraxinus ornus* wood (Orno-Quercetum ilicis Horvatic (1956) 1958 – OQI). This is represented by a mixed wood of evergreen sclerophyllous species, mainly *Quercus ilex*, and deciduous species, such as *Ostrya carpinifolia* and *Fraxinus ornus*. This plant community is considered extra-zonal with respect to the climatic characteristics of the area because it is linked to particular edaphic conditions (Blasi et al. 1995). Characteristic species are *Rubia peregrina, Smilax aspera, Lonicera implexa, Carex olbiensis, C. distachya, Phillyrea latifolia* and *Myrtus communis*.

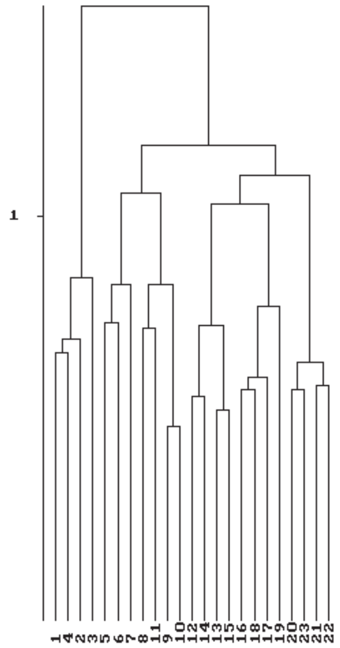

Figure 3. Dendrogram of woody types. 1-4 = AFC; 5-7 = EQFa; 8-11= EQFb; 12-15= OQI; 16-19= EQFc; 20-23 = QFS.

Quercus ilex and *Fraxinus ornus* wood (Orno-Quercetum ilicis Horvatic (1956) 1958 – OQI). This is represented by a mixed wood of evergreen sclerophyllous species, mainly *Quercus ilex*, and deciduous species, such as *Ostrya carpinifolia* and *Fraxinus ornus*. This plant community is considered extra-zonal with respect to the climatic characteristics of the area because it is linked to particular edaphic conditions (Blasi et al. 1995). Characteristic species are *Rubia peregrina, Smilax aspera, Lonicera implexa, Carex olbiensis, C. distachya, Phillyrea latifolia* and *Myrtus communis*.

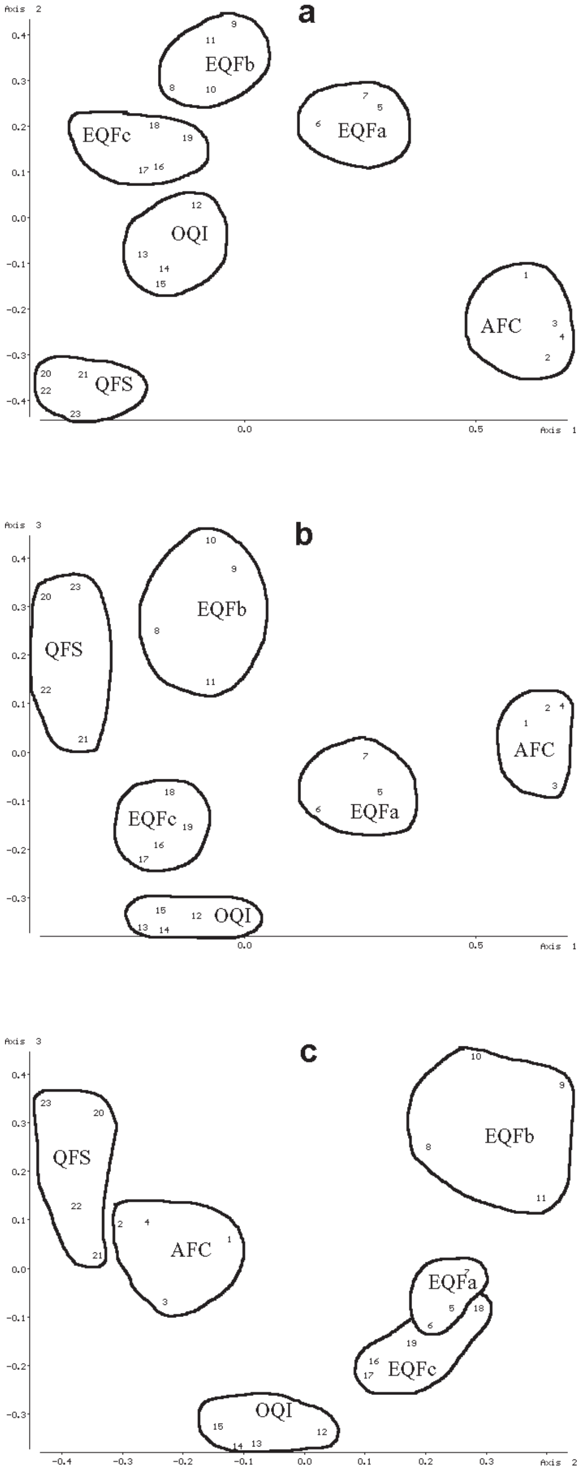

Figure 4. PCoA ordination of the sites along the first three axes (a: 1-2, b: 1-3, c: 2-3).

Quercus suber and *Quercus pubescens* wood (Echinopo siculi-Quercetum frainetto Blasi and Paura 1993 thermophilous facies to *Quercus pubescens* – EQFc).

Quercus suber and *Erica arborea* wood (Quercetum frainetto-suberis Blasi et al. 1997 – QFS). These two kinds of woods belong to a typology that is very widespread on the south-facing slopes of the main alluvial valleys of the Tiber drainage basin. These slopes, hardly suitable for cultivation, were occupied by plantations of *Quercus suber* used for collecting cork. The decline of commercial interest in this type of activity, especially in the more urbanised areas, led to the progressive development of these formations towards woody vegetation types more in equilibrium with the local environmental conditions. The first group is characterised by many shrubs and herbaceous species belonging to the Quercetalia pubescenti-petraeae order: *Crataegus monogyna, Ulmus minor, Cornus mas, Brachypodium sylvaticum* and *Bouglossoides pourpureocaerulea*. The second group can be found mainly within the Pineto Park, already studied by many authors (Pignatti and Lucchese 1990, Testi and Lucattini 1994, Dowgiallo et al. 1997). Together with *Quercus suber* many acidophilous species are present such as *Erica arborea, Pulicaria odora, Cytisus villosus* and other belonging to the Quercetea ilicis class: *Phillyrea latifolia, Ruscus aculeatus* and *Rosa sempervirens*.

Soil data

Thirty-four variables were used for the analysis (Appendix EA4-2). Linear discriminant analysis produced five canonical functions as their number cannot exceed that of the variables and/or of the groups. Only the first two were then used as they together explain 87.6% of the total variance (Table 1).

Aspect, correlated with the first function, and CEC (exchangeable cations) A2 as well as organic matter A2, correlated with the second function (Table 2), were used to perform the logistic discrimination. Other variables, such as annual potential irradiation, C/N A2, K A2, Na A2 and base saturation A2, were not included since they were strongly correlated with those already chosen. The strong correlation between aspect and annual potential irradiation is of particular interest here. This result is, in fact, tied to the characteristics of the area analysed. Here the rem-

Table 1. Eigenvalues associated to the discriminant functions and related statistics.

Function	Eigenvalue	% of variance	Comulative %	Canonical correlation
1	125.3	73.8	73.8	0.996
2	23.4	13.8	87.6	0.979
3	16.0	9.4	97.0	0.970
4	4.1	2.4	99.4	0.896
5	1.0	0.6	100.0	0.707

Table 2. Structure matrix. Within group correlations between discriminant variables and canonical standardised discriminant functions.

Function	1	2
Altitude	.081	-.020
Aspect	.127	-.090
Slope	.008	.026
Ann. Pot. Irrad. kcal/cm^2	.137	-.024
Sand A1 (%)	.008	-.148
Silt A1 (%)	-.015	.101
Clay A1 (%)	.008	.138
pH A1	-.036	.058
Org. Matter A1 (%)	-.006	.000
N A1 (%)	-.033	-.026
C/N A1	.030	.044
H A1 meq/100g	.017	.004
Ca A1 meq/100g	-.004	.079
Mg A1 meq/100g	-.041	.007
K A1 meq/100g	-.012	.017
Na A1 meq/100g	-.202	-.203
CEC A1 meq/100g	-.007	.068
Bases A1 (%)	-.123	-.056
AWC A1 mm/cm	.007	.013
Sand A2 (%)	.004	-.147
Silt A2 (%)	-.040	.129
Clay A2 (%)	.071	.136
pH A2	-.067	.002
Org. Matter A2 (%)	-.059	.328
N A2 (%)	.025	.248
C/N A2	-.54	.315
H A2 meq/100g	-.101	.066
Ca A2 meq/100g	.051	.120
Mg A2 meq/100g	.114	.301
K A2 meq/100g	-.260	.269
Na A2 meq/100g	.158	.276
CEC A2 meq/100g	.048	.302
Bases A2 (%)	.129	.207
AWC A2 mm/cm	-.057	.298

nant patches of woody vegetation are found on the steepest slopes which are not suitable for agriculture and building.

From the comparison of the two discriminant models, it becomes evident that the introduction of the spatial parameter has noticeably improved discriminatory power (Table 3). This was underlined by the increase of both the χ^2 and pseduo-R^2 values. Furthermore, in the spatial discriminant model, the classification of the samples is perfect. This means that the groups were completely separated with respect to the variables chosen.

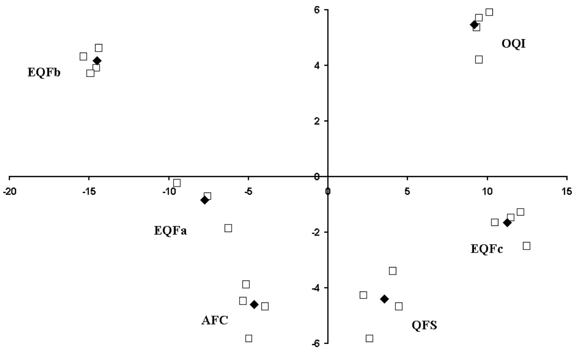

Figure 5. Ordination of the sites according to the first two canonical discriminant functions. ◆ = centroids of the groups.

The likelihood ratio test (Table 4) showed that aspect had the greatest discriminatory power with $\chi^2 = 26.884$, while the spatial distribution of samples (YLAG) was the second one ($\chi^2 = 22.515$). Of smaller, though meaningful, importance were the variables CEC A2 and organic matter A2.

The ecological explanation of these results can be achieved by comparing them with the diagram of the distribution of the canonical scores for each sample and the values of the functions at the barycentre of the groups (Figure 5). In fact, a gradient along the first axis, correlated with aspect, can be identified. This gradient clearly separates the groups characterised by deciduous woods (AQF, EQFa, EQFb) from the mixed sclerophyllous and deciduous ones (QFS, EQFc, OQI). The second axis shows two parallel gradients correlated with the two pedological variables (CEC A2 and organic matter A2). In particular, organic matter gradually decreases along the direction AFC- EQFa-EQFb in the sector of deciduous woods and that of QFS-EQFc-OQI in the sector of mixed sclerophyllous and deciduous woody types. The main reason for this trend seems to be linked to the direct and indirect removal of organic matter from the *Carpinus betulus* (AFC) and *Quercus suber* woods (QFS). In these woods, in fact, grazing by sheep is still permitted, and in the *Quercus suber* woods (QFS) cork is harvested occasionally. The progressive reduction of human disturbance, which is almost absent in the *Quercus cerris* and *Q. frainetto* (EQFb) and in the *Q. ilex* (OQI) woods permits the accumulation of organic matter in the epipedon.

Table 3. a. Logistic discriminant analysis results. **b.** Logistic spatial discriminant analysis results.

a

Model	-2 Log likelihood	χ^2	df	Sig.	Pseudo-R^2	Global classification of samples
Intercept only	67.84				Cox and Snell = .958	
Final	7.392	60.448	15	.000	Nagelkerke = .986	89.5 %
					McFadden = .891	

b

Model	-2 Log likelihood	χ^2	df	Sig.	Pseudo-R^2	Global classification of samples
Intercept only	67.840				Cox and Snell = .972	
Final	.000	67.840	20	.000	Nagelkerke = 1.000	100 %
					McFadden = 1.000	

Table 4. The likelihood ratio test for spatial discriminant analysis.

Effect	-2 Log likelihood	χ^2	df	Sig
Intercept	.000	.000	5	1.000
Aspect	26.884	26.884	5	.000
CEC A2	9.881	9.881	5	.079
Org. Matter A2	9.128	9.128	5	.0104
YLAG	22.515	22.515	5	.000

Table 5. Contingency table between woody types and soil groups and subgroups.

	AFC	EQFa	EQFb	OQI	EQFc	QFS
Haploxeralf						
ultic	1		1			
typic	1		3	1	1	
Xerorthent						
acquic	2	1				
typic		2			1	1
Xeropsamment						
dystric						3
typic				3	2	

Moreover, this accumulation seems to influence positively the quantity of exchangeable cations (CEC A2).

A further insight was obtained by comparing woods and soil types. In fact in the study area two main soil types were found, which were correlated with lithological units.

*L*essivated soils – haploxeralfs. These are soils characterised by a clayey B horizon; they develop on red continental sands, rich in weatherable material.

Regosoils. These soils are subdivided into two groups: xerorthents and xeropsamments. The main difference between the two edaphic types is the matrix of the horizon which is typically sand for the xeropsamments and sandy-loam for the xerorthents. They both developed on yellow sands, which can be classified according to the period of deposition into two main types. Yellow bioclastic sand of marine origin (Calabrian period of Pleistocene) and yellow siliceous sands deposited in a lagoonal environment during the Sicilian period.

The contingency table beetween woody and soil types (Table 5) shows that the deciduous woods are characterised, not only by the northern exposure, but also by the presence of haploxeralfs and xerorthents. Even if these soils differ, they have a higher water capacity than the xeropsamments. In fact, these latter soils characterise the mixed sclerophyllous and deciduous woods, thus increasing the aridity of the south-facing slopes.

In relation to the second gradient, it is noted that the two extreme values of CEC A2 are dependent not only on organic matter but also on the pedological substratum. In fact, the soils of the *Q. ilex* woods (OQI) are mainly characterised by yellow bioclastic sands, which supply a noticeable amount of exchangeable cations expecially Ca and Mg (typic xeropsamments). On the contrary the soils found below the *Q. suber* and *Erica arborea* woods (QFS) are characterised by yellow siliceous sands sterile and poor in carbonates of bioclastic origin (dystric xeropsamments). This last edaphic character seems to allow the spontaneous renewal of *Q. suber*, that in the other environmental situations found in the study area is not competitive respect to the other tree species. For this reason it appears that the areas of Quercetum frainetto-suberis are the most suitable to conserve the traditional landscape of cork oak plantations, which is rapidly disappearing in the Italian peninsula because of industrialization.

Conclusions

Spatial discriminant analysis proved to be a useful approach to analyse the relationships between woody types and environmental variables especially inside an urban environment, where the remnant woody patches are characterised by high fragmentation and by thousands of years of human activity. In this way it was possible to quantify the contribution of the spatial distribution of the sites and that of each single environmental variable included in the discriminant model. It is probable that the addition of further variables such as those linked to the management of the sites can improve the model. Nevertheless, the results confirm the importance of obtaining an accurate documentation on the actual real vegetation in order to understand its dynamics as a basis for nature conservation and planning.

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Electronic appendices

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Appendix EA4-1. Matrix of sites rearranged using block clustering: the groups of species characterising the woody types are put in evidence. Sites 1-4 = AFC; 5-7 = EQFa; 8-11 = EQFb; 12-15 = OQI; 16-19 = EQFc; 20-23 = QFS.

Appendix EA4-2. Mean and standard deviation of the thirty-four variables for the six woody types.