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Forest Ecology and Management 141 (2001) 201–210

Forest Ecology and Management

www.elsevier.com/locate/foreco

Structure and floristic diversity in permanent monitoring plots in forest ecosystems of Tuscany☆

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Received 7 June 1999; received in revised form 5 October 1999; accepted 20 December 1999

Abstract

The sampling method is described which is used for the sampling of plant species richness and cover in a monitoring project on forest ecosystems in Tuscany (named MONITO). Species richness is sampled through a nested plot design, with plot size ranging from 1 to 2500 m^2, whereas species abundance is estimated in 100 m^2 plots. This sampling design is simple to install and to manage through time. Species diversity can be monitored not just at one single spatial scale but at many scales, and species–area relations can also be calculated. The analyses of the data that were collected produced the first available data on species richness in relation to plot size for Tuscan forest ecosystems, indeed for any Italian forests. The Arrhenius Power function and the General Root models showed the best fit. Turkey oak (*Quercus cerris*) woods located on slightly acidic soil were found to be the forest ecosystems with the highest species richness, confirming and quantifying well-established floristic-phytosociological knowledge. Habitat heterogeneity, measured by plot floristic resemblance, showed how the Turkey oak woods were the most heterogeneous at the smaller spatial scales, but not at larger ones.

Keywords: Forest ecosystem monitoring; Habitat-heterogeneity; Permanent plots; Species–area relations; Species diversity

1. Introduction

Programs aimed at monitoring the effects of global change on forest ecosystems are being implemented in many countries of the ECE region (Anonymous, 1994) as well as other continents (Palmer et al., 1991). Monitoring activities within these programs were initially limited to tree, soil and climatic parameters. Despite the lack of accepted standards, the assessment of ground vegetation is now being used in many monitoring programs (e.g., Dobremez et al., 1997). Quantitative aspects of species diversity are sometimes used, even though there is no agreement on methods for their investigation, at either landscape or community levels (Shmida, 1984; Stohlgren, 1994).

In Tuscany (Italy), a project (named MONITO) on forest ecosystem monitoring was promoted by the Regional Administration of Tuscany under EEC regulations 2157/92 and 3528/86. Permanent monitoring plots (PMPs) were established in 1995 in six sites, within forests dominated by *Fagus sylvatica* L. (sites: Vallombrosa and Foresta del Teso), *Quercus cerris* L. (Ulignano and Amiata) and *Quercus ilex* L. (at Cala

☆ Research MONITO (MONitoraggio Intensivo foreste TOscane), funded by the Regional Administration of Tuscany and the European Community on the Regulations EEC 2157/92 and 3528/86. Paper no. 12.

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0378-1127/01/$ – see front matter
PII: S0378-1127(00)00329-7

Violina and Colognole). Forests dominated by these species constitutes the majority of the forest vegetation in Tuscany from the Apennine mountains to the Mediterranean coastline, respectively (Bartolozzi et al., 1996). Within this project, the monitoring activities included periodic assessment of species diversity for vascular plants (Chiarucci et al., 1996), macro fungi (Laganà et al., 1996), bryophytes and lichens (Bonini and Loppi, 1996).

The aims of the present paper are to: (i) present the sampling strategy adopted in project MONITO to assess vascular plant diversity; (ii) analyse structure and species diversity of the six PMPs with special regard to species–area relations, one of the basic features of plant communities which has been found to change in relation to disturbance (Lawrey, 1991) and forest decline (Kwiatkowska, 1994); (iii) analyse the differences in vascular species richness of the main forest ecosystems of Tuscany. In fact, although differences in species richness of different forest types are relatively known by floristic-phytosociological data only few quantitative measures are available.

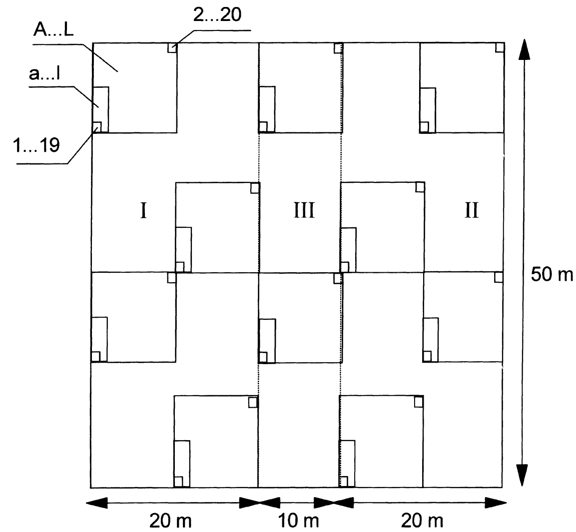


Fig. 1. Sampling design for the analysis of vascular plant diversity at different spatial scales adopted in project MONITO. Total area: 2500 m^2; area of the sub-plots I and II: 1000 m^2; sub-plot III: 500 m^2; sub-plots A-L: 10 m×10 m; sub-plots a-l: 2 m×5 m; subplots 1-20: 1 m×1 m.

2. Methodological problems and sampling method

Since species diversity is largely dependent on spatial scale (Kwiatkowska and Symonides, 1986; Van der Maarel, 1988; Lepš and Stursa, 1989; Podani et al., 1993; Palmer and White, 1994), its monitoring should be performed at different spatial scales. Various methods have been proposed for the sampling of species richness, the most important component of species diversity, in relation to plot size in plant communities. The classical method, proposed by R.H. Whittaker and described in detail by Shmida (1984), is based on plots of 1 m^2 (10 replicates), 10 m^2 (two replicates), 100 and 1000 m^2 (one replicate each). This multiple-scale method allows a better comparison of species richness in communities than single-scale measurements and, in spite of some criticisms (Rosenzweig, 1995), it is widely used (Whittaker, 1977; Naveh and Whittaker, 1979; Whittaker et al., 1979; Rice and Westoby, 1983; Shmida, 1984; Stohlgren et al., 1995). Recently, Stohlgren et al. (1995) suggested a modified version of this nested plot technique, trying to reduce the spatial autocorrelation of plots, by locating the three small-scale plots (1, 10 and 100 m^2) independently of each other, and thus reducing the non-independence to the 1000 m^2 plot.

In the MONITO project, an attempt was made to use a sampling scheme that would fulfil both theoretical requirements as well as practical criteria. The minimum plot size required by EU monitoring protocols is 0.25 ha (Reg. EEC 1071/94), whereas the size normally used to assess plant species diversity is 0.1 ha. The strategy adopted in the MONITO project to sample species richness was based on nested plots, with the classical scales of 1 m^2 (20 plots), 10 and 100 m^2 (10 plots each) and 1000 m^2 (two plots), plus the additional scales of 500 m^2 (one plot) and 2500 m^2 (one plot) to match the plot size required by monitoring protocols (Fig. 1). Since the plots are nested, the data follow the 'collector's curve' (Pielou, 1977) and, therefore, are not independent, thus reducing the possibility of statistical testing among the differences of parameters in the species–area curves. Because of their permanent nature, the use of independent plots would have been extremely difficult to apply. Smaller data-sets made by independent samples, can, however, be extracted for special analyses.

The sampling strategy chosen for the measurement of species abundance was based on the visual estimation of species cover, which ensures the lowest disturbance to the community; species nomenclature is in accordance to Pignatti (1982). Cover was visually estimated, as accurately as possible, for each species in the tree, shrub and herb layers, in the 100 m^2 plots. The use of a cover scale such as those of Braun-Blanquet (1927), Domin (Krajina, 1933) or others, as used in some monitoring projects (e.g., Dobremez et al., 1997), was avoided because ordinal scales reduce the power of statistical testing. On the other hand, the conversion of the ordinal data to percentage values a posteriori, as adopted by many authors, would surely cause larger errors than direct field estimation of cover percentage.

3. Data analysis

Structural diversity and habitat heterogeneity were investigated by means of: (i) species richness in the three vegetation layers, and (ii) the habitat-heterogeneity h index (Qian et al., 1997); this was defined as the mean of all the possible $n(n-1)/2$ pairwise dissimilarity indices between the n sub-plots (for the scales of 1, 10, 100 and 1000 m^2), calculated according to the formula:

$$h = \frac{2}{n(n-1)} \sum_{j=1}^{n-1} \sum_{k=j+1}^{n} \left(1 - \frac{2c_{jk}}{a_j + b_k}\right)$$

Where c_{jk} is the number of species common to both plots j and k ($j<k$) in the ith pairwise comparison ($i=1, 2, 3, \ldots, n(n-1)/2$), a_j and b_k were the total number of species in two plots j and k, respectively.

Species richness in relation to the spatial scale was analysed by fitting species–area curves for the Linear model ($S=C+zA$), the Log S model ($\log_e S=C+zA$, Connor and McCoy, 1979), the Arrhenius (1921) Power function ($S=CA^z$), the Gleason (1922) Exponential model ($S=C+z \log_e A$) and the General Root model ($S^x=C+z \log_e A$) proposed by Gitay et al. (1991) as an intermediate model. In the formulas, S is the number of species; A, the sampling area, C, z and x site optimised parameters. Other models involving a larger number of parameters (e.g., that proposed by Buys et al., 1994) were not tested. Some models predict S, some log S, and others another transformation of S, but it is essential to minimise the same derivative of S in each ease (Gitay et al., 1991). The model fitting was made according to Gitay et al. (1991), who used the method of O'Neil (1971) and Chambers and Ertel (1974), minimising the sum of squares of deviations (deviance) between observed and estimated values for log S.

4. Results and discussion

4.1. Vegetation features

The beech woods had the lowest species richness in the tree and shrub layers (Table 1), because of both ecological factors (shading by *Fagus* canopies, winter cold stress, low soil pH) and, to a greater extent, forest management, which favoured the formation of a single-aged tree canopy (Bernetti, 1987). The herb layer of the beech woods had intermediate to low species richness.

Table 1
Mean number of species (±S.E.) in the ten 100 m^2 plots and total number found in the 2500 m^2 plots in the tree, shrub and herb layers, in the six PMPs

Site	Dominant species	Tree layer		Shrub layer		Herb layer	
		x±S.E.	Total	x±S.E.	Total	x±S.E.	Total
Cala Violina	*Q. ilex*	3.3±0.2	7	6.7±0.6	13	8.2±0.8	21
Colognole	*Q. ilex*	6.0±0.3	16	10.8±0.6	22	7.7±0.5	19
Ulignano	*Q. cerris*	3.0±0.3	6	20.7±0.6	34	28.3±1.5	68
Amiata	*Q. cerris*	2.6±0.2	6	15.2±1.6	26	38.0±1.8	74
Vallombrosa	*F. sylvatica*	1.0±0.0	1	0.3±0.2	2	7.8±0.4	22
Foresta del Teso	*F. sylvatica*	1.0±0.0	1	1.0±0.0	1	12.4±1.2	31

Table 2
Habitat-heterogeneity diversity (index *h*) of the six PMPs calculated for the plot sizes of 1, 10, 100 and 1000 m^2

Site	Dominant species	Plot size/no. of plots (*n*)[a]			
		1/190	10/45	100/45	1000/1
Cala Violina	*Q. ilex*	0.714 ab	0.473 a	0.473 ab	0.280
Colognole	*Q. ilex*	0.555 d	0.557 ab	0.491 a	0.308
Ulignano	*Q. cerris*	0.762 bc	0.586 bc	0.378 c	0.337
Amiata	*Q. cerris*	0.796 c	0.673 c	0.408 c	0.262
Vallombrosa	*F. sylvatica*	0.688 a	0.489 a	0.421 bc	0.444
Foresta del Teso	*F. sylvatica*	0.730 ab	0.591 bc	0.562 d	0.407

[a] For each plot size (except the largest one) different letters within indicate statistically significant differences between PMPs, according to the Tukey test at $P<0.05$.

The Turkey oak woods showed the highest species richness in the understorey (shrub and herb) layers, which were extremely species-rich. This can be ascribed to ecological factors (intermediate altitude and climate) and traditional forest management based on frequent coppicing (Bernetti, 1987), ensuring an open canopy cover and, consequently, a high solar radiation. The tree layer was composed of few species (mostly *Quercus cerris*, *Q. pubescens*, *Sorbus domestica*, *Sorbus torminalis*), but other tree species were found as shrubs because of frequent coppicing.

The evergreen holm oak woods had a species-rich tree layer, a shrub layer with intermediate species richness, and a herb layer relatively poor in species. Species richness of the shrub and tree layers of the two holm oak woods differed between sites. Colognole had higher species richness in these layers, probably because of its wetter climate (978 nm of annual rainfall and 15.1°C of average temperature, versus 637 nm and 14.7°C at Cala Violina, Cozzi, 1996), more typical for a mixed deciduous wood than for an evergreen holm oak wood (Pignatti, 1984), and disturbance due to complex geology and past human activity (Chiarucci et al., 1996; Cozzi, 1996). Colognole showed a particularly rich tree layer, in which three climbing species (*Hedera helix*, *Rubus ulmifolius*, *Vitis vinifera* ssp. *sylvestris*) were found. The dominance of the evergreen *Q. ilex* is likely to be a consequence of silvicultural selection by humans over a period of some thousands years (Romane and Terradas, 1992).

4.2. Habitat heterogeneity

Habitat-heterogeneity data showed a complex picture (Table 2). At the smaller spatial scale (1 m^2), the Turkey oak woods (Ulignano and Amiata) showed the highest values of the *h* index and the Colognole holm oak wood the lowest one. At the scale of 10 m^2, the Turkey oak woods had the highest habitat-heterogeneity diversity, but that of the Foresta del Teso beech wood was also relatively high. At the scale of 100 m^2, the Turkey oak woods showed the lowest habitat-heterogeneity diversity, whereas those of the beech woods and the holm oak woods were significantly higher. At the largest spatial scale, although the picture is not very significant since a single pairwise comparison was possible, the beech woods showed the highest habitat-heterogeneity diversity.

Although it is based only on floristic data, habitat-heterogeneity diversity is one of the major components of mosaic diversity, which reflects habitat complexity (Scheiner, 1992; Qian et al., 1997). Habitat-heterogeneity diversity was negatively related to spatial scale in all the PMPs, indicating that larger samples include a higher proportion of the species living in a given environment (Podani et al., 1993), or that the species-pool of each habitat (vegetation) type is being reached (Eriksson, 1993; Pärtel et al., 1996). In addition, the changes in the relative ordering of PMPs at the different spatial scales investigated suggest that the habitat-heterogeneity diversity index is strongly dependent on the spatial scale considered (Kwiatkowska and Symonides, 1985) and that comparison of different sites should be performed at the same spatial scale.

4.3. Species richness

The Turkey oak (*Q. cerris*) woods were the richest in species at all the spatial scales (Table 3). The beech

Table 3
Species richness (x±S.E.) in relation to plot sizes in the six PMPs

Site	Forest type	Plot size/no. of plots (n)[a]					
		1/20	10/10	100/10	500/1	1000/2	2500/1
Cala Violina	*Q. ilex*	2.7±0.3 ab	5.8±0.4 a	11.6±0.9 a	20.0	21.5±2.5 a	27.0
Colognole	*Q. ilex*	4.2+0.3 a	8.4±0.6 a	18.2±0.8 b	19.0	33.0±2.0 b	39.0
Ulignano	*Q. cerris*	10.6±0.8 c	24.1±1.6 b	43.3±1.6 c	60.0	69.0±1.0 c	86.0
Amiata	*Q. cerris*	10.6±0.6 c	25.3±1.7 b	49.4+2.0 d	67.0	73.0±2.0 d	88.0
Vallombrosa	*F. sylvatica*	1.9±0.3 b	4.8±0.5 a	7.8±0.4 a	17.0	14.0±1.0 a	22.0
Foresta del Teso	*F. sylvatica*	3.0±0.3 ab	5.8±0.6 a	12.2±1.1 a	23.0	21.5±0.5 a	31.0

[a] Statistical differences, according to the Tukey test at P<0.05, among 1, 10, 100 and 1000 m^2 plots of the different PMPs are indicated by different letters.

and holm oak woods were more similar, although the Colognole plot showed species richness values intermediate between the holm oak wood of Cala Violina and the two Turkey oak woods.

The higher species richness of the Turkey oak woods can be explained by the more favourable climatic condition of their sites compared to sites with holm oak and beech woods. Although six plots are too few for a statistical analysis, climatic variables are often the most important in determining species richness patterns, especially at the larger spatial scales (Wright et al., 1993). In the present data set, summer drought is the most important limiting factor for species richness in evergreen forest vegetation along the coasts. The Colognole plot, located in a wetter habitat than Cala Violina, had significantly higher species richness. On the other hand, winter-cold stress limits species richness in mountain areas. Forests of sites with lower climatic limitations, such as hilly areas, showed the highest species richness at all the spatial scales.

Although there is a large amount of phytosociological data on the forest ecosystems of Italy, it is not possible to make a direct comparison between species richness of the vegetation types, because phytosociologists do not use standard plot sizes, but field relevés, and therefore, different sites are sampled at different spatial scales. Comparable data, with respect to the Turkey oak wood PMPs, exist at the 0.1 ha scale from some deciduous woods on hilly sites in Tuscany and dominated by *Q. pubescens*, *Q. cerris* or *Castanea sativa* (Table 4). The Turkey oak woods studied in this project showed the highest species richness (69.0±1.0 at Ulignano and 73.0±2.0 at Amiata). These are

Table 4
Species richness at the 1000 m^2 spatial scale in different forest ecosystems of Tuscany

Dominant tree species	Site	Altitude (m)	Species richness (mean±S.E.)	No. of plots (n)	Source
Q. ilex	Cala Violina	5	21.5±2.5	2	*
Q. ilex	Colognole	250	33.0±2.0	2	*
Q. pubescens	Travale	450	45	1	(1)
Q. cerris	Val di Merse (acid soil)	260–390	29.3±3.3	4	(2)
Mixed *Q. cerris* and *Q. pubescens*	Montagnola Senese (basic soil)	240–490	50.0±0.8	4	(3)
Q. cerris	Ulignano	440	69.0±1.0	2	*
Q. cerris	Amiata	650	73.0±2.0	2	*
F. sylvatica	Vallombrosa	1170	14.0±1.0	2	*
F. sylvatica	Foresta del Teso	1350	21.5±0.5	2	*
C. sativa	Merse Valley	465	38	1	(4)

[*] Data marked with an asterisk refer to the two 1000 m^2 plots in the six PMPs; data sources for the other plots are: (1) Alfieri, unpublished thesis; (2) Salerni, unpublished thesis; (3) Laganà, unpublished thesis and (4) Morrocchi, unpublished thesis.

Table 5
Deviance (SS of log *S*) between observed and predicted values of the species–area models fitted for the six PMPs[a]

Model	Site					
	Cala Violina	Colognole	Ulignano	Amiata	Vallombrosa	Foresta del Teso
Arrhenius	0.024	**0.166**	0.037	0.078	0.115	0.042
Gleason	0.221	0.351	0.069	0.053	0.288	0.334
Linear	1.185	0.949	1.052	1.206	1.226	1.108
Log S	1.993	1.478	1.523	1.664	2.009	1.943
General Root	**0.009**	**0.166**	**0.002**	**0.010**	**0.099**	0.039

[a] The best fit for each PMP is indicated in bold.

followed by four mixed deciduous oak woods dominated by *Q. pubescens* and located on basic soils (50.0±0.8 species), and by a *Q. pubescens* wood also located on a calcareous soil (45 species). Oak woods on acidic soils dominated by *Q. cerris* were found to have an appreciably lower species richness (29.3±6.6 species). The wood dominated by *C. sativa* had an intermediate species richness (38). All these values are within the range of values of species richness reported by Rice and Westoby (1983) for temperate forest ecosystems in North America.

4.4. Species–area relationships

The deviances between observed and predicted values of the species–area models fitted for the six PMPs are shown in Table 5. The simpler models, namely the Linear and Log S models, fitted very poorly in all the six plots. The Gleason and especially the Arrhenius models gave a better fit. The General Root model showed the best fit in all the PMPs. The parameters fitted for the best fitting models are reported in Table 6. For the Arrhenius model, the parameter z corresponded to Preston's (1962) canonical value of 0.26, only in the two Turkey oakwood plots (Ulignano and Amiata), which were those with the higher species richness. In the other PMPs, the value of z was rather higher.

This agrees with the analyses of Leitner and Rosenweig (1997) who found that Preston's (1962) calculations and those of later workers were incorrect, that the classical model actually predicts a z value considerably higher than 0.26, and that values close to 0.26 can be expected only when the assumption of a range/abundance correlation is added. It also agrees with the conclusion of Durrett and Levin (1996) that on the basis of a reasonable null model a wide range of z values could be expected. For the General Root model, the x parameter was very variable: it ranged from 1.87 to 22.63. These values were higher than those presented by Gitay et al. (1991). In the fitting of the Gleason model the parameters showed lower variation. As in the data of Gitay et al. (1991) the General Root model gave a fitted curve intermediate between the Arrhenius Power function and the Gleason Exponential model (Fig. 2).

Table 6
Values of the parameters for the Arrhenius, Gleason and General Root models

Site	Arrhenius model		Gleason model		General Root model		
	C	z	C	z	x	C	z
Cala Violina	2.807	0.300	2.447	2.467	5.300	1.2	0.086
Colognole	4.345	0.274	3.883	3.173	22.628	1.066	0.014
Ulignano	11.9	0.260	10.13	8.047	2.502	2.579	0.419
Amiata	12.32	0.262	10.22	8.551	1.873	3.533	0.921
Vallombrosa	2.082	0.303	1.781	1.880	4.888	1.145	0.092
Foresta del Teso	2.968	0.303	2.677	2.632	13.286	2.025	0.001

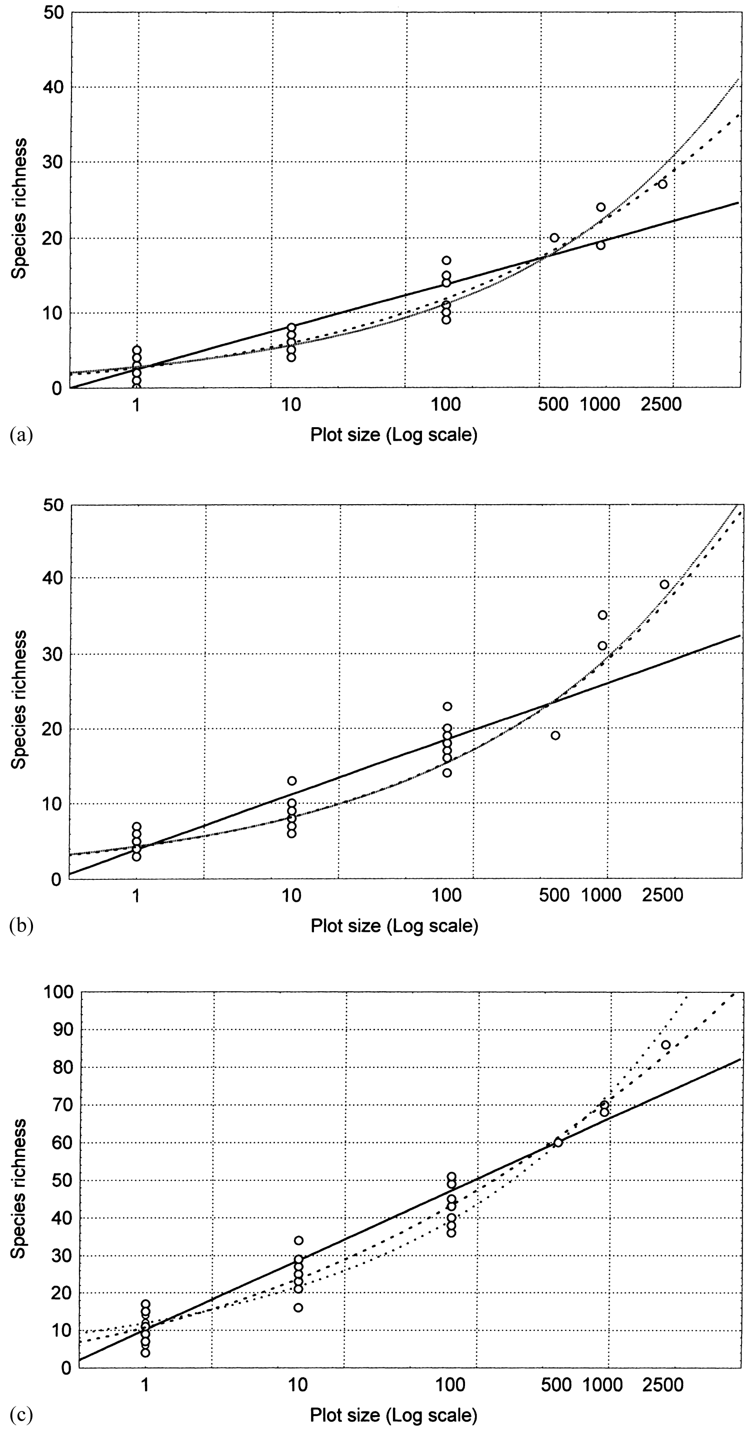
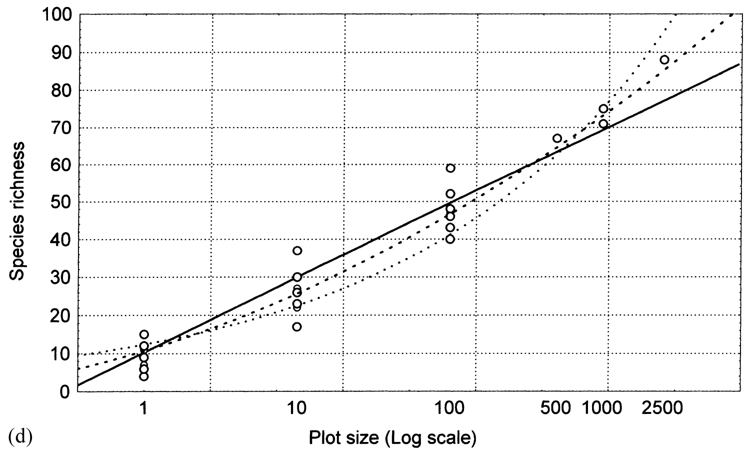
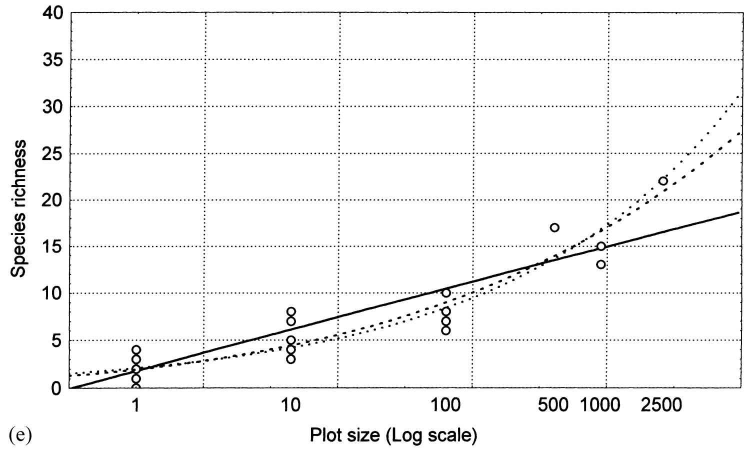


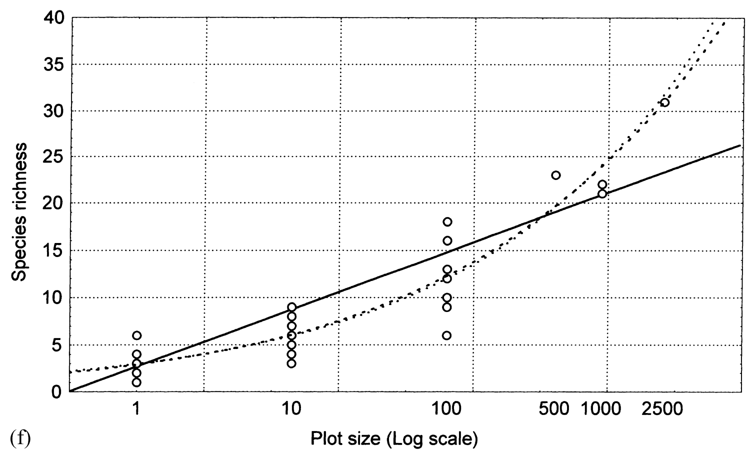
Fig. 2. Species area curves in the six PMPs: (a) Cala Violina; (b) Colognole; (c) Ulignano; (d) Amiata; (e) Vallombrosa; (f) Foresta del Teso. The curves are fitted for the Arrhenius Power Function (······), Gleason Exponential model (—) and Power Function (- - -).



(d)



(e)



(f)

Fig. 2. (*Continued*).

5. Conclusion

The assessment of within-community plant diversity has been the subject of a large number of papers, but its application to monitoring purposes is still very rare. The method adopted for the MONITO project is simple to install and manage, the sub-plots are not so numerous as to be too time-consuming, which is important in monitoring projects, and the method can provide interesting data on species richness at multiple spatial scales. Species richness can be compared not just at one single spatial scale, as in most forest monitoring projects, but at several scales. Additionally, other basic features of the plant communities can be used as tools for monitoring, such as the slope of species–area curves as a scale-independent estimate of diversity (Rapson et al., 1997), or community heterogeneity.

The present study also represents the first attempt to assess the relationships between species richness and spatial scale in Tuscan forest ecosystems, indeed in any Italian forest. Among the forest types compared in the present survey, Turkey oak (*Q. cerris*) woods from slightly acidic soils (pH was 6–6.5 in the surface horizons at Ulignano and 5.5–6.5 at Amiata, unpublished data) from the hilly areas of Tuscany were found to be the forest ecosystems with the highest species richness. This confirms and quantifies the floristic-phytosociological knowledge that oak woods of hilly sites located on soil with a pH close to neutrality or slightly acidic are richer in species than oak woods on markedly acid soils. Oak woods on basic soils have intermediate species richness.

Habitat heterogeneity, measured by plot floristic resemblance, showed that the Turkey oak woods were the most heterogeneous at the smaller spatial scales, but not at the larger ones, confirming the importance of spatial scale in the analysis of habitat heterogeneity and the pattern of diversity.

Acknowledgements

The author would like to thank Dr. Lamberto Brogi and Dr. Iginio Calistri (formerly at the Tuscan Regional Administration) for their active collaboration to the project installation, Dr. Ilaria Bonini for assistance during field sampling and data analysis, Dr. Davide Morrocchi, Dr. Michele Marchiani and Dr. Michele Riccucci for the help during plot installation and field sampling.

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