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Macrofungal communities in Italian fir woods – short-term effects of silviculture and its implications for conservation

Elena SALERNI[*] *& Claudia PERINI*

Department Environmental Sciences « G. Sarfatti »,
University of Siena, Via P. A. Mattioli, 4 - 53100 Siena, Italy

Abstract – Field observations, lasting 3 years, were conducted to elucidate the role of tree cover and litter layer on changes in fungal community composition. The study areas were four reforestations of *Abies alba* in two age classes on Monte Amiata (Italy). Experiments designed for statistical analysis showed that different degrees of canopy thinning and litter removal had distinct effects on fungal communities. In particular, thinning mitigated the effects of other environmental factors, such as the age of the forest and the presence or absence of the litter layer, on the composition of the fungal communities. A comparison with other mycocoenoses in similar forest ecosystems in which no intervention had taken place showed substantial differences, thus the role of the various silvicultural manipulations should be taken into consideration when planning sustainable forest management.

***Abies alba* Miller / conservation stage / ecosystem manipulation / macromycetes / mycocoenoses**

INTRODUCTION

Timber and forest products have always been considered the most important use of forest resources, although non-wood forest products, such as floral greens, medicinal plants and wild mushrooms (Molina *et al.*, 1993; Pilz *et al.*, 1998; Sisak, 1998; Nanagulyan, 2000; Manzi *et al.*, 2001; Bonet *et al.*, 2004) have also gained importance in recent years.

In Italy more than 30% of the national territory is covered by forested areas (Blasi & Di Marzio, 2003; Biondi, 2005). According to the Forest Inventory, Tuscany is the Italian region with the greatest area of forest cover, totalling 1.156.000 hectares, i.e., 50% of the regional territory (Programma Forestale Regionale 2007-2011, art. 4 L.R. 39/00).

In Italy and especially Tuscany, woods are of great importance and satisfy a variety of needs. These range from characterization of the local landscape to the absorption and storage of carbon dioxide, which has become a global priority since the Kyoto Protocol (1997), and from hydrogeological and soil protection to the conservation of the rich biodiversity which is part of all forest ecosystems.

Issues related to the evaluation and conservation of biological patrimony have recently become of primary interest to mycologists, as they were to zoologists and botanists (Lawrynowicz & Perini, 1997; Arnolds, 1998). Numerous

* e-mail: salerni@unisi.it

central and northern European studies have sought to identify and describe fungal communities, their distribution and their evolution over the years (Arnolds, 1987; Fellner & Soukup, 1991; Arnolds & Jansen, 1992; Lizon, 1993; Bujon, 1997; etc.).

In Italy, the mycologists of the "G. Sarfatti" Department of Environmental Sciences at the University of Siena began mycocoenological surveys (the most effective way to obtain information about the ecology and the space-time distribution of fungal species) at the end of the 1970s. These surveys have involved a number of forest ecosystems in the Mediterranean area (De Dominicis & Barluzzi, 1983; Barluzzi *et al.*, 1986; 1992; Perini *et al.*, 1989; 1995; Laganà *et al.*, 2000; 2001; 2002a; 2002b; 2002c; Salerni *et al.*, 2001) and covered an ideal altitudinal transect, from coastal to mountain vegetation.

While they are of fundamental importance, these studies reflect static situations and do not deal with the response of fungal species to a type of forest management aimed at production. Meanwhile, other mycologists have begun to study the effects of clear-cutting (Kardell & Eriksson, 1987), thinning (Kranabetter & Kroeger, 2001), herbicide application (Ohenoja, 1988a), nitrogen fertilizers (Shubin, 1988; Wiklund *et al.*, 1995; Ohenoja, 1994), logging waste (Wästerlund & Ingelög, 1981) and various forest treatments (Fernández de Ana *et al.*, 1989a; 1989b; Egli & Ayer, 1997; Pilz *et al.*, 2003).

In this context, our study seeks to evaluate the effects on macrofungal communities of thinning and removal of the litter layer in forests composed of *Abies alba* Miller at differing ages (about 30 and 60 years), also from the point of view of conserving the fungal heritage in them.

The study was conducted in southern Tuscany on an isolated outcrop called Monte Amiata, which is an area exceptionally rich in fungi (Perini *et al.,* 1995; 2004; 2005; Salerni & Perini, 2003; Pecoraro *et al.,* 2007; 2009). Monte Amiata is 1738 m high and consists of volcanic rocks deposited on allochthonous substrates of Cretaceous and early Cenozoic Ligurian facies (Giannini *et al.*, 1972). The study areas are in a petrographic province of quartz-porphyrites of ignimbrites (Carta Geologica d'Italia, 1965). Climatically, the mountain is a true oceanic island in an area with a Mediterranean climate, acting as a "condenser" of moist winds from the Tyrrhenian Sea (Selvi, 1996). The mean annual temperature is < 10°C and the mean annual rainfall is > 1400 mm (Barazzuoli *et al.*, 1993). From December until March there can be snow, occasional on the ground for a few hours or days. According to the climate classification proposed by Thornthwaite (1948), the study areas have a perhumid (type A) climate with a global humidity index Im > 100, water surplus 800-900 mm, water deficit <100 mm and potential evapotranspiration < 650 mm.

MATERIALS AND METHODS

Study area

In the spring of 1999, four study areas were chosen in artificial fir woods of different ages on Monte Amiata (in the municipality of Abbadia S. Salvatore, province of Siena) (Fig. 1). The first three (areas 1, 2 and 3, forest age about 30 years) are situated near "Podere La Cipriana" in forests belonging to the "Comunità Montana Amiata Senese". The fourth (area 4, forest age about

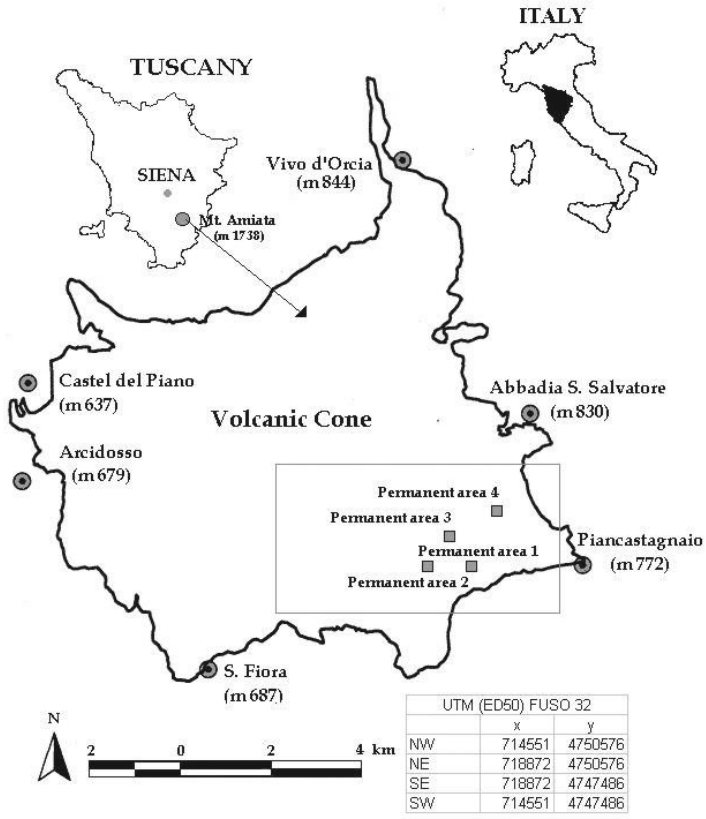

Fig. 1. Map of the study areas.

60 years) is located at "Biagiotti", on the farming and forest property of Mr. A. Morellini. The study areas, at altitudes between 1000 and 1100 m, are dominated by *A. alba*, with a minority of *Picea abies* (L.) Karsten, clusters of *Pinus nigra* s.l. and broadleaf species such as *Acer monspessulanum* L., *Castanea sativa* Miller, *Fagus sylvatica* L. and *Prunus avium* L.; shrubs are rare and the herbaceous layer is very sparse.

Establishment of the plots

A total of 54 plots (each of 250 m^2) were chosen randomly: one third of them were subject to moderate thinning (MT), one third to heavy thinning (HT) and the other third (control - NT) were not thinned at all (Fig. 2). Analysis of the tree structure and distribution in the artificial fir woods selected showed marked dissimilarities between them (Salerni & Perini, 2004a). Since this could have prejudiced the study, as much uniformity as possible was sought among plots undergoing the same type of treatment. On the basis of the principal dendrometric results it was decided to carry out medium and heavy thinning, taking the tree basal area (G m^2/ha) as the standard. Medium to heavy thinning

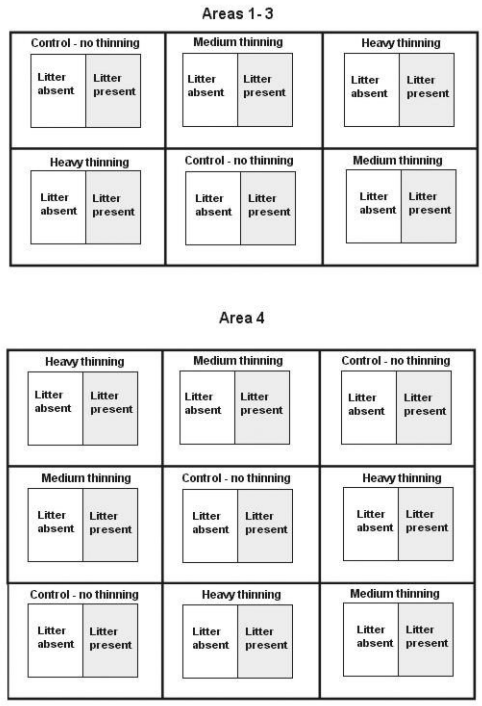

Fig. 2. Experimental design.

is intended as a mean removal of 20% to 40% of plants in relation to the standard area. In each station, buffer areas were left in order to reduce edge effects (Termorshuizen, 1990). In accordance with various other authors (Tyler, 1991; Termorshuizen, 1990; Baar & ter Braak, 1996) who have evaluated the effects of litter on the fruiting process, the litter layer was removed manually in half of the stations (i.e. 27) (Fig. 2). For further details of the method employed, see Salerni & Perini (2004a).

Environmental variables

Environmental variables were recorded for all 54 stations (Table 1). Site variables included forest structure (mean number of trees, forest age, tree basal area), some soil parameters (such as pH, Al^{3+}, Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, N, organic carbon) and climatic characteristics, which were calculated for each site based on data from the nearest meteorological station.

The pH was measured in a 1:2.5 water-soil suspension using an ORION 420A Benchtop pH meter. Al^{3+}, Ca^{2+}, K^{+}, Mg^{2+} and Na^{+} were measured by flame atomic absorption spectrophotometry (FAAS) using the standard method of the Ministero delle Risorse Agricole, Alimentari e Forestali (M.R.A.A.F., Italian Agriculture, Food and Forestry Ministry, 1994). The results (in µg/g ppm) represent the proportion that went into the solution after mineralization with 3 ml of 65% HNO_3 under pressure for 9 hrs at 120°C. Carbon and nitrogen were measured using a Carlo Erba CNS NA 1500 instrument.

Table 1. List of recorded sites, soil parameters and climatic variables
(*: hottest month of each year in the period; **: coldest month of each year in the period)

Variable	*Scale*	*Range*	*Median*
Altitude	m	1000-1100	1000
Distance from sea	Km	70-80	75
Annual Mean Temperature	°C	-2,3-26,8	13
Mean Temp. hottest month *	°C	18-26,7	23,2
Mean Max Temp. hottest month*	°C	24,9-35,1	30,5
Mean Temp. coldest month**	°C	-1,7-9,6	2,5
Mean Min. Temp. coldest month**	°C	-7,3-7,1	1,0
Mean Annual Precipitation (mm)	mm	599,7-914,3	792,3
N° days with mean temp. ≥ 10°C	Class (ordinal)	0-692	346
N° rainy days	Class (ordinal)	0-409	205
Index seasonal concentration of the rains (winter)	Ratio	0,9-1,1	1,0
Index seasonal concentration of the rains (spring)	Ratio	0,5-1,4	0,9
Index seasonal concentration of the rains (summer)	Ratio	0,4-1,1	0,6
Index seasonal concentration of the rains (autumn)	Ratio	1,2-1,6	1,6
Mg^{2+}	ppm	1767-3598	2581
Al^{3+}	ppm	19285-59552	39001
Ca	ppm	562-2918	1301
Ca^{2+}	ppm	366-742	499
K^{+}	ppm	1386-2584	1986
N	%	0,6-1	1
C	%	6,7-13,2	10
pH	Ratio	4,54-5,26	4,9
Age	Years	30-60	30
Number of plants	Class (ordinal)	29-71	55
Number of *Abies alba* plants (n.p. Ab)	Class (ordinal)	15-64	33
Tree basal area (G)	Ratio	0,93-2,93	2
Diameter *Abies alba*	m	10,1-17,2	12,1

Sampling methods

The results were gathered over three years (2000-2002) of mycocoenological investigation. The frequency of qualitative (i.e. floristic) and quantitative (counting all carpophores or, in some cases, estimating the total number) observations of epigeous fungi varied from once a month in periods of low fungal production (January-August) to twice a month in autumn, when conditions are generally favourable for fruiting.

The sporocarps were identified in the field or collected for microscopic identification by means of various keys and monographs (Kühner & Romagnesi, 1953; Kühner, 1980; Moser, 1983; Candusso & Lanzoni, 1990; Breitenbach & Kränzlin, 1991; 1995; Stangl, 1991; Noordeloos, 1992; Antonìn & Noordeloos, 1993; Courtecuisse & Duhem, 1994; Bon, 1997; Sarnari, 1998-2005; Basso, 1999; Robich, 2003; Sarasini, 2005; etc.). For Basidiomycota all morphological groups were considered, with the exception of resupinate corticioid fungi, while for Ascomycota non-stromatic pyrenomycetes and inoperculate discomycetes with sporocarps smaller than 10 mm were excluded from this study. The taxa were attributed to trophic groups (M = mycorrhizal species; Sh = humicolous saprotrophs; Sl = litter-inhabiting saprotrophs; Sw = lignicolous saprotrophs) following Arnolds *et al.* (1995) and based on personal observations. Exsiccata are conserved at the *Herbarium Universitatis Senensis* (SIENA).

The nomenclature followes the Italian check-list (Onofri *et al.*, 2005). For taxa not in this list the authors followed the on-line Index of Fungi, a CABI bioscience database (http://www.indexfungorum.org/Names/NAMES.ASP). Species authorities were abbreviated according to Brummitt & Powell (1992). Latin names accompanied by nomenclatural authors of all listed taxa are reported in 3 tables (Table 2, 3, 4),

Data analysis

Data and species occurrence are ordered according to the frequency of findings. Table 2 presents the species found in control plots, Table 3 the species found in the plots that were moderately thinned and Table 4 shows the species found in more heavily thinned plots. Species names are accompanied by the trophic group (GT), the abbreviation used for the Detrended Correspondence Analysis (DCA) and the quantitative value determined using Arnolds' method (1981) modified for Mediterranean environments by Perini & Barluzzi (1987). The species that were found only once in a single plot and those of doubtful attribution are not listed, neither are they considered in the various calculations. All three tables comprise litter present and litter absent plots.

In order to analyse the patterns in fungal composition a data matrix was created, comprising mapped taxa (species data) and environmental variables from the individual study areas. Correlations between the physical and chemical characteristics of the study sites and fungi were analysed using the CANOCO 4.0 programme (ter Braak & Šmilauer, 1998). The variations in the species data were explained along the ordination axes by the environmental variables. The data set was analysed using Detrended Correspondence Analysis (DCA). The environmental data was used to interpret patterns from all variations with indirect gradient analysis in the detrended unimodal response model. The species data was not transformed.

The significance ($P < 0.05$) of differences between the control, tree thinning and litter removal samples was checked by ANOVA. Normality was checked using the Shapiro-Wilks test. In addition, for the ANOVA test, the homogeneity of variance was checked using Levene's test.

Correlations between the environmental variables and numbers of species were analysed using Pearson's linear coefficient. All calculations were performed with STATISTICA 7.0 (StatSoft. Inc.).

Table 2. Summary of mycocoenological sampling performed in non-thinned permanent plots (GT – trophic group; M – mycorrhizal species; Sh – humicolous saprotrophs; Sl – litter inhabiting saprotrophs; Sw – lignicolous saprotrophs; P – parasites; Abbrev. - Abbreviations of the fungal species used for the Detrended Correspondence Analysis (DCA).

GT	*Species*	*Abbrev.*	*litter absent*									*litter present*								
			2	*10*	*17*	*23*	*30*	*34*	*40*	*44*	*50*	*1*	*9P*	*18*	*24P*	*29*	*33*	*39*	*43*	*49*
M	Inocybe geophylla (Fr.) P. Kumm. var. lilacina (Peck) Gillet	IN LIL	2	4	4	4	4	4	4	2	3	3	3	4	3	3	3	4	5	2
M	Lactarius salmonicolor R. Heim and Leclair	LAC SAL	3	3	3	3	3	2	2	2	1	1	3	3	2	2	3	2	2	1
Sl	Mycena pura (Pers.) P. Kumm.	MY PUR	3	3	1	2	3	2	2	1		4	3	3	4	4	4	1	1	1
M	Inocybe fuscidula Velen.	IN FUS	2	4	2	2	5	4	2	1		3	4	5	3	3	4	2	4	
M	Inocybe geophylla (Fr.) P. Kumm.	IN GEO	5	2	5	3	4	1	5	3		1	2	4	2	3	3	4	4	
M	Amanita junquillea Quél.	AM JUN	2	2	1	3	3		3	1		3	3	2	3	3	3	3	3	1
Sl	Collybia butyracea (Bull.) P. Kumm.	COL BUT	2	4	4	3	1	3	1	2		1	2	1	4	5	5	1	1	
M	Inocybe whitei (Berk. and Broome) Sacc.	IN WHI	2	4	4	4	3	4	3	3		2	3	3	3	4	4		3	
Sl	Clitocybe nebularis (Batsch) P. Kumm.	CLI NEB	1	1	3	4	1	1			3	2	4	2	4	4		2	2	2
Sw	Galerina marginata (Batsch) Kühner	GAL MAR	2	3	1				3	2		2	4	3	3	2	3	2	2	2
M	Boletus edulis Bull.	BO EDU	1	1	2	1	3	2			1	2	2	1	2	1	2			
Sl	Mycena amicta (Fr.) Quél.	MY AMI	2	3	2		1		3	1		5	5	3		1	5	1	1	
M	Laccaria laccata s. l.	LA LAC		1	2		2		2	2	3		1			1	2	2	2	2
M	Inocybe sindonia (Fr.) P. Karst.	IN SIN	4	1	1		4	4				3	2	4	3	2	3		1	
Sh(M?)	Clitopilus prunulus (Scop.) P. Kumm.	CLIT PR	1	1	3	3	3	4	1			2		3	2	1	3			
Sl	Clitocybe fragrans (With.) P. Kumm.	CLI FRA	3	3		1	2	1				3	5	1	4	4	4		1	
Sl	Clitocybe phaeophthalma (Pers.) Kuyper	CLI PHA		2	3		3	1		1		6	3	4	3	5	5		2	
Sw	Tricholomopsis rutilans (Schaeff.) Singer	TRP RUT	1		4	2			3	3	2	3	2	3	1			1		1
M	Xerocomus badius (Fr.) J.-E. Gilbert	XER BAD					2	2	1	1	1				3	3	2	2	1	2
M	Amanita rubescens Pers.	AM RUB	1		3	3	3	2				2		3	2	2	2			
M	Russula fragilis (Pers.) Fr.	RUS FRA			1	1	2	2	1					2	2	1	1	2		
Sh	Lycoperdon perlatum Pers.: Pers.	LYC PER	2	3	1							4	2	4	4	2	5		4	
Sh (M?)	Clavulina coralloides (L.) J. Schröt.	CLA COR	4		4		2			4		4	4		4		5	2	2	
Sw	Pluteus cervinus (Schaeff.) P. Kumm.	PLU CER	1						1	2		1	2	1		1		1	1	1
Sh	Macrolepiota procera (Scop.) Singer	MAC PRO		1	1	1	2					1		3	2	3	2			

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GT	*Species*	*Abbrev.*	*litter absent*									*litter present*							
			2	*10*	*17*	*23*	*30*	*34*	*40*	*44*	*50*	*1*	*9P*	*18*	*24P*	*29*	*33*	*39*	*43*	*49*
Sh	Cystoderma carcharias (Pers.) Fayod	CYS CAR	3	3					3				4	3	4		3		1	2
Sl	Marasmius androsaceus (L.) Fr.	MAR AND	4				3	1				5	5	4		5	5	2		
Sh	Mycena aetites (Fr.) Quél.	MY AET	1				1			4			4			3	3	1	2	
Sl	Collybia dryophila (Bull.) P. Kumm.	COL DRY		2		1	2	3					3		4	2	4			
Sl	Collybia confluens (Pers.) P. Kumm.	COR CON						5		4		1		5		3	4		3	5
Sl	Lepista flaccida (Sowerby) Pat.	LE FLA							5	2				1	2	5		5	3	3
M	Amanita muscaria (L.) Lam.	AM MUS	1		1	2	1						1	2	1					
Sl	Mycena epipterygia (Scop.) Gray	MY EPI		1						2		2	3		2		3		2	
Sl	Mycena flavoalba (Fr.) Quél.	MY FLA							3	3			3			1		3	5	1
Sl	Mycena rosea Gramberg	MY ROS						1	2			3		1		2	1		1	
Sl(Sw)	Mycena filopes (Bull.) P. Kumm.	MY FIL		1		2							1	4	3	4	5			
Sl(Sw)	Mycena leptocephala (Pers.) Gillet	MY LEP	1							2			3	1	2		4		1	
M	Inocybe mixtilis (Britzelm.) Sacc.	IN MIX			3			2				1		1		1	1			
Sh	Mycena abramsii (Murrill) Murrill	MY ABR										2	3	1		3	2		1	
Sw	Mycena vitilis (Fr.) Quél.	MY VIT	1			1							3	4	3	2				
Sw	Calocera viscosa (Pers.) Fr.	CA VIS									2			2	1		3		1	3
M	Tricholoma saponaceum (Fr.) P. Kumm.	TR SAP		3	4	4			3				1							
M	Cortinarius castaneus (Bull.) Fr.	COR CAS			5	4	2					1		1						
M	Tricholoma portentosum (Fr.) Quél.	TR POR			1	1		1						3			1			
M	Amanita citrina (Schaeff.) Pers.	AM CIT							1		1		1				1		1	
M	Suillus granulatus (L.) Roussel	SUI GR	1	1								1	2				1			
Sh	Agaricus essettei Bon	AG ESS	2				1					2				1			1	
Sh	Cystoderma amianthinum (Scop.) Fayod	CYS AMI										3	1		1	1			1	
Sl	Mycena sepia J. E. Lange	MY SEP		2								4	4			3	5			
Sw	Xylaria hypoxylon (L.) Grev.	XYL HYP					3				1	1							2	4

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Sw(P?)	Xerula radicata (Relhan) Dörfelt	XE RAD					2				1				1			1	1	
M	Russula cavipes Britzelm.	RUS CAV	2	1			1						2							
M	Boletus calopus Pers.	BO CAL							3	2								2	2	
M	Suillus gravillei (Klotzsch) Singer	SUI GRV			1	1							1		2					
M	Amanita spissa (Fr.) P. Kumm.	AM SPI									1							1	1	2
M	Russula mustelina Fr.	RUS MUS							2							1		1	1	
Sh	Conocybe siliginea (Fr.) Kühner	CON SIL		1			1			1							1			
Sl	Mycena galopus (Pers.) P. Kumm.	MY GAL											2	2			3		3	
M	Tricholoma ustale (Fr.) P. Kumm.	TR UST	3	2	1															
M	Inocybe flocculosa Sacc.	IN FLO	3				1												3	
M	Russula foetens (Pers.) Fr.	RUS FOE							2		1							2		
M	Laccaria amethystina Cooke	LA AME						1								4				1
M?	Caloscypha fulgens (Pers.) Boud.	CAL FUL							5										1	1
Sh	Agaricus niveolutescens Huijsman	AG NIV					1							1		2				
Sh	Clitocybe phyllophila (Pers.) P. Kumm.	CLI PHY								2						2			2	
Sl	Lepista nuda (Bull.) Cooke	LE NUD				1		2							3					
Sl	Mycena stylobates (Pers.) P. Kumm.	MY STY		1		1											1			
Sl	Collybia amanitae (Batsch) Kreisel	COL AMA											4				1		3	
Sl/Sw	Mycena pelianthina (Fr.) Quél.	MY PEL								1		1				3				
Sw	Leucoagaricus leucothites (Vittad.) Wasser s.l.	LEU LEU					1					1				1				
Sw	Psilocybe fascicularis (Huds.) Noordel.	PSI FAS							4									6	3	
M	Inocybe queletii Maire and Konrad	IN QUE	1					1												
M	Inocybe splendens R. Heim var. phaeoleuca (Kühner) Kuyper	IN SPL					3	4												
M	Tricholoma stans (Fr.) Sacc.	TR STA	1	1																
M	Chroogomphus rutilus (Schaeff.) O. K. Miller	CHR RUT	1										1							

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			2	*10*	*17*	*23*	*30*	*34*	*40*	*44*	*50*	*1*	*9P*	*18*	*24P*	*29*	*33*	*39*	*43*	*49*
M	Amanita pantherina (DC.) Krombh.	AM PAN																1		2
M	Inocybe cincinnata (Fr.) Quél. var. major (S. Petersen) Kuyper	IN CIN												2					1	
M(Sh)	Otidea onotica (Pers.) Fuckel	OTI ONO											1				1			
Sh	Agaricus silvicola (Vittad.) Sacc.	AG SIL					1									1				
Sh	Collybia peronata (Bolton) P. Kumm.	COL PER		2									2							
Sh	Cystoderma terrei (Berk. and Broome) Harmaja	CYS TER		1								1								
Sh	Macrolepiota excoriata (Schaeff.) Wasser	MAC EX					2								1					
Sh	Mycena capillaris (Schumach.) P. Kumm.	MY CAP								5									1	
Sh	Conocybe tenera (Schaeff.) Fayod	CON TEN											3	1						
Sh	Lycoperdon molle Pers. : Pers.	LYC MOL										1		2						
Sh	Macrolepiota mastoidea (Fr.) Singer	MAC MAS										1						1		
Sh(M)	Clavulina rugosa (Bull.) J. Schröt.	CLA RUG					5			2										
Sh(M)	Spatularia flavida Pers.	SPA FLA												1	3					
Sw	Hydropus marginellus (Pers.) Singer	HYD MAR				5								3						
Sw	Lycoperdon pyriforme Schaeff.: Pers.	LYC PYR	3									3								
Sw	Omphalina grossula (Pers.) Singer	OM GRO								1									3	
Sw	Psilocybe sublateritia (Fr.) Rode	PSI SUB							4									2		
Sw	Coprinus micaceus (Bull.) Fr.	COP MIC										4								3
Sw	Crucibulum crucibuliforme (Scop.) V.S. White	CRU CRU													2	4				
Sw	Marasmiellus vaillantii (Pers.) Singer	MAR VAI														4	4			
Sw (Sl)	Psilocybe aeruginosa (M.A. Curtis) Noordel.	PSI AER													1	1				
Sw(Sh)	Delicatula integrella (Pers.) Pat.	DEL INT															1		5	

Table 3. Synthesis of mycocoenological sampling done in moderately-thinned permanent plot (G.T – trophic group; M – mycorrhizal species; Sh – humicolous saprotrophes; Sl – litter inhabiting saprotrophes; Sw – lignicolous saprotrophes; P – parasites; Abbrev. - Abbreviations of the fungal species used for the Detrended Corrispondence Analysis (DCA).

GT	*Species*	*Abbrev.*	*litter absent*									*litter present*								
			4	*8*	*13*	*21*	*28*	*36*	*38*	*46*	*52*	*3*	*7*	*14*	*22*	*27*	*35*	*37*	*45*	*51*
M	Inocybe geophylla (Fr.) P. Kumm. var. lilacina (Peck) Gillet	IN LIL	4	3	2	2	4	4	2	3	3	3	5	2	4	3	3	4	2	3
M	Amanita junquillea Quél.	AM JUN	3	3	4	3	3	3	1	3	3	3	3	3	3	4	4		2	2
Sw	Galerina marginata (Batsch) Kühner	GAL MAR	2	4		2	1	1	4	1	2	3	4	4	3	1	4	3	2	1
M	Inocybe geophylla (Fr.) P. Kumm.	IN GEO	5	2	4	4	4	4	3	3	1	3	4		2	3	3	3	3	3
M	Inocybe whitei (Berk. and Broome) Sacc.	IN WHI	6	5	1	4	3	5	1	3	1	5	4	2		3	5	2	2	1
M	Lactarius salmonicolor R. Heim and Leclair	LAC SAL	2	3	2	3	3	3	1		1	2	4	1	3	2	3	3	2	1
M	Inocybe fuscidula Velen.	IN FUS	4	3	4		5	5	1	4	1	3	3	4	4	5	4			3
Sh (M?)	Clavulina coralloides (L.) J. Schröt.	CLA COR	5	3	5	5	4	3		1	3	2		4	4	4		3		4
Sw	Tricholomopsis rutilans (Schaeff.) Singer	TRP RU		4	3	2	3		1	3	2	2	3	3		3	3	1		2
Sl	Clitocybe nebularis (Batsch) P. Kumm.	CLI NEB	5	1	3	1	3	3				5			3	2	4	4	1	4
Sh(M?)	Clitopilus prunulus (Scop.) P. Kumm.	CLIT PR	2	3	3	4	3	3	1			2	1	4	3	4	2			
M	Laccaria laccata s. l.	LA LAC	4	5	2	4	4	3	2			4	4			5	2	3		1
Sl	Mycena pura (Pers.) P. Kumm.	MY PUR	2	3	1	3	4	4		2		3	3	2	2	4	5			
M	Amanita rubescens Pers.	AM RUB	3	1	2	3	3	4		1		3		1	3	2	3			
M	Boletus edulis Bull.	BO EDU	2	2	2	3	2	3				1	3	2	3	2	2			
M	Inocybe sindonia (Fr.) P. Karst.	IN SIN			4	4	2	1		1	3	1	2	4	2	3	2			
Sl	Collybia butyracea (Bull.) P. Kumm.	COL BUT				3	4	2		1		3		5	4	3	2	1		
Sl	Collybia confluens (Pers.) P. Kumm.	COL CON		4			2	2		3	1		5			6	3		2	4
Sh	Lycoperdon perlatum Pers.: Pers.	LYC PER	4				4	4		3		4			3	6	5	3	3	
Sh	Macrolepiota procera (Scop.) Singer	MAC PRO		2	1	1	2					1	3	3	2	2			1	
Sl	Mycena rosea Gramberg	MY ROS			1	1		2	1				1	2	2	1	2	1		
M	Xerocomus badius (Fr.) J.-E. Gilbert	XER BAD			4	3	1	ù	3	1		3				1		3	1	
Sl	Clitocybe fragrans (With.) P. Kumm.	CLI FRA	3	2	1						2	2	4		3	2	4			
Sh	Cystoderma carcharias (Pers.) Fayod	CYS CAR		3		2		2				2	3	3	3		2	1		
M	Russula fragilis (Pers.) Fr.	RUS FRA					1	1			1			1	1	2	3	1		1

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GT	*Species*	*Abbrev.*	*litter absent*									*litter present*								
			4	*8*	*13*	*21*	*28*	*36*	*38*	*46*	*52*	*3*	*7*	*14*	*22*	*27*	*35*	*37*	*45*	*51*
Sh	Conocybe siliginea (Fr.) Kühner	CON SIL		2			3	1			2	2	2	2						1
Sw	Pluteus cervinus (Schaeff.) P. Kumm.	PLU CER	2	1		1						2	1	1			1	1		
M?	Caloscypha fulgens (Pers.) Boud.	CAL FUL				1			3		1				3			2	3	3
Sl	Clitocybe phaeophthalma (Pers.) Kuyper	CLI PHAE			3			2			4		2			3	4	1		
M	Cortinarius castaneus (Bull.) Fr.	COR CAS	1		2	3	1	4								3	3			
M	Laccaria amethystina Cooke	LA AME					3		3		2	2	2			3				1
Sl	Marasmius androsaceus (L.) Fr.	MAR AND					3	4					5	3	2	3	4			
Sl	Mycena amicta (Fr.) Quél.	MY AMI	5					3				5	3		3	2			1	
Sl	Mycena sepia J. E. Lange	MY SEP	4					3				4		2	3	4	4			
M	Amanita muscaria (L.) Lam.	AM MUS			2	1							1	1		1	1			
M	Boletus calopus Pers.	BO CAL					3		2		1							2	3	2
Sw	Calocera viscosa (Pers.) Fr.	CA VIS							3		2			2	4			3		2
M	Inocybe praetervisa Quél.	IN PRA			1	1	2	1							3			1		
Sl	Lepista flaccida (Sowerby) Pat.	LE FLA	5						1								1	5	2	3
Sl	Mycena epipterygia (Scop.) Gray	MY EPI				2								2		2	4	1		1
Sw	Mycena vitilis (Fr.) Quél.	MY VIT					1					3	4		3	3	4			
Sh(M)	Clavulina cinerea (Bull.) J. Schröt.	CLA CIN				2	4	4		3						1				
Sh	Mycena abramsii (Murrill) Murrill	MY ABR		1									3			1	1			1
Sh	Mycena aetites (Fr.) Quél.	MY AET	2								1	1	2							1
Sl	Mycena flavoalba (Fr.) Quél.	MY FLA	2													5		2	2	3
Sl(Sw)	Mycena leptocephala (Pers.) Gillet	MY LEP					1	3			2					2				2
Sl	Mycena stylobates (Pers.) P. Kumm.	MY STY	1	1								1	1			3				
M	Russula foetens (Pers.) Fr.	RUS FOE							2	1	1							2	3	
Sh(M)	Clavulina rugosa (Bull.) J. Schröt.	CLA RUG			1	2					1		2							
Sl	Collybia dryophila (Bull.) P. Kumm.	COL DRY				1	3	1							2					

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GT	*Species*	*Abbrev.*	*litter absent*									*litter present*								
			4	*8*	*13*	*21*	*28*	*36*	*38*	*46*	*52*	*3*	*7*	*14*	*22*	*27*	*35*	*37*	*45*	*51*
M	Inocybe flocculosa Sacc.	IN FLO									1		2		1			1		
Sl(Sw)	Mycena filopes (Bull.) P. Kumm.	MY FIL	1			2						3					4			
Sl	Mycena galopus (Pers.) P. Kumm.	MY GAL										2			2	1	1			
Sw (Sl)	Psilocybe aeruginosa (M.A. Curtis) Noordel.	PSI AER					1						1	1		1				
M	Tricholoma portentosum (Fr.) Quél.	TR POR						4				1	1	1						
M	Tricholoma saponaceum (Fr.) P. Kumm.	TR SAP	3	3								2	3							
Sw	Xylaria hypoxylon (L.) Grev.	XYL HYP			1				3	2										3
M	Amanita citrina (Schaeff.) Pers.	AM CIT	1				1		1											
Sh	Clitocybe phyllophila (Pers.) P. Kumm.	CLI PHY		3			3									2				
Sl	Collybia amanitae (Batsch) Kreisel	COL AMA									1	2								1
Sw	Crucibulum crucibuliforme (Scop.) V.S. White	CRU CRU				2										1	4			
Sh	Cystoderma amianthinum (Scop.) Fayod	CYS AMI	1	2		1														
Sw(Sh)	Delicatula integrella (Pers.) Pat.	DEL INT							1						1	1				
Sw	Hydropus marginellus (Pers.) Singer	HYD MAR				3				1							4			
M	Inocybe mixtilis (Britzelm.) Sacc.	IN MIX	1	2								2								
M	Inocybe queletii Maire and Konrad	IN QUE								1	2								2	
Sh	Lepiota castanea Quél.	LEP CAS		4				1									1			
Sh	Lepiota clypeolaria (Bull.) P. Kumm.	LEP CLY					1						1				2			
Sw	Marasmiellus vaillantii (Pers.) Singer	MAR VAI						4								3	3			
Sl/Sw	Mycena pelianthina (Fr.) Quél.	MY PEL					3						4				2			
Sw	Pholiota lenta (Pers.) Singer	PHO LEN										4							1	1
Sw	Psilocybe fascicularis (Huds.) Noordel.	PSI FAS							2						2					4
Sh	Rhodocybe popinalis (Fr.) Singer	RHO POP		2								2	1							
M	Russula fragilis (Pers.) Fr. f. viridilutea Bon	RUS VIR			1	1								1						
M	Amanita spissa (Fr.) P. Kumm.	AM SPI					2													1

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GT	*Species*	*Abbrev.*	*litter absent*									*litter present*								
			4	*8*	*13*	*21*	*28*	*36*	*38*	*46*	*52*	*3*	*7*	*14*	*22*	*27*	*35*	*37*	*45*	*51*
Sw	Baeospora myosura (Fr.) Singer	BAE MYO														2	1			
M	Boletus erythropus Pers.	BO ERY			2		1													
M	Chroogomphus rutilus (Schaeff.) O. K. Miller	CHR RUT										1			1					
Sl	Collybia erythropus (Pers.) P. Kumm.	COL ERY					1					1								
Sh	Entoloma chlorophyllum Noordel.	EN CLO															1		1	
P	Heterobasidion annosum (Fr.) Bref.	HET ANN												1		1				
M	Inocybe cincinnata (Fr.) Quél. var. major (S. Petersen) Kuyper	IN CIN	1												1					
Sh	Lycoperdon molle Pers. : Pers.	LYC MOL	3					1												
Sh	Melanoleuca melaleuca (Pers.) Murrill	MEL MEL						1											2	
Sw	Panellus mitis (Pers.) Singer	PAN MIT											2							2
Sw	Psilocybe sublateritia (Fr.) Rode	PSI SUB							1	3										
M	Russula cavipes Britzelm.	RUS CAV							2				1							
M	Russula mustelina Fr.	RUS MUS								3									3	
M	Russula torulosa Bres.	RUS TOR							2									1		
M	Russula vesca Fr.	RUS VES					1						1							
M	Suillus granulatus (L.) Roussel	SUI GR										2	1							
Sw(P?)	Xerula radicata (Relhan) Dörfelt	XE RAD									1									1

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GT	*Species*	*Abbrev.*	*litter absent*									*litter present*								
			6	*12*	*15*	*19*	*26*	*32*	*42*	*48*	*54*	*5*	*11*	*16*	*20*	*25*	*31*	*41*	*47*	*53*
M	Inocybe whitei (Berk. and Broome) Sacc.	IN WHI	4	5	3	4	4	3	3	3	1	5	5	2	5	4	2	3	2	2
M	Amanita junquillea Quél.	AM JUN	2	3	3	2	2	1	3	1	2	3	5	2	3	3	2	1	1	
M	Inocybe geophylla (Fr.) P. Kumm.	IN GEO	3	2	2	3	4	3	5	4	2	3	3	3	4	4		4	3	3
M	Laccaria laccata s. l.	LA LAC	4	1	1	4	4		1	2	2	3	5	2	2	5	4	4	1	1
M	Lactarius salmonicolor R. Heim and Leclair	LAC SAL	1	1	2	2	3	1		2	1	3	2	2	4	4	2	3	3	2
M	Inocybe fuscidula Velen.	IN FUS	2	5	4	2	4	1	3		1	2	6	5	1	3	1	1		1
M	Inocybe geophylla (Fr.) P. Kumm. var. lilacina (Peck) Gillet	IN LIL	4	4	4	2	4		5	4	3	4	5		4	4	4	2	4	1
Sw	Tricholomopsis rutilans (Schaeff.) Singer	TRP RUT	2	4	3	3	2	2	3		1	2	3	3	2	2	3		3	3
Sw	Galerina marginata (Batsch) Kühner	GAL MAR	4	4	1	4				2	3	5	4	4	4	3	3	1	1	3
Sh(M?)	Clitopilus prunulus (Scop.) P. Kumm.	CLIT PR	1	2	2	4	4	4			1	2	4	4	3	4	4		1	
M	Xerocomus badius (Fr.) J.-E. Gilbert	XER BAD	2			4		2		1	1	4	2	1	2	3	4	2	1	1
Sl	Clitocybe nebularis (Batsch) P. Kumm.	CLI NEB	3	1		1				3	4	2	1	1	1	1	4	1		4
M	Amanita rubescens Pers.	AM RUB	1	2	4	3	1	1				1	4	1	2	3	2			
Sl	Collybia butyracea (Bull.) P. Kumm.	COL BUT		3	2		3			2	1	2	2	4	4	3	4			4
Sh	Conocybe siliginea (Fr.) Kühner	CON SIL	1	2			1	2	1		1		2	1	1			1	1	1
M	Boletus edulis Bull.	BO EDU		1	2	1	3	2				1	3	1	1	2	2			
Sl	Mycena pura (Pers.) P. Kumm.	MY PUR	3	5		2					1	4	3	3	3	4	4			1
Sw	Pluteus cervinus (Schaeff.) P. Kumm.	PLU CER		1		1				1	2		2	1	1	1		1	1	1
M	Amanita muscaria (L.) Lam.	AM MUS	1	3	1	2			1	1	1			1		2			1	
Sh (M?)	Clavulina coralloides (L.) J. Schröt.	CLA COR		4	3	1	3		1			3		4	5	4			2	
Sl	Clitocybe fragrans (With.) P. Kumm.	CLI FRA	3	4	2			2				4	4	4	3	1	3			
Sl	Collybia confluens (Pers.) P. Kumm.	COL CON		1							3	3	6	6	2	4	1	2		3
Sh	Macrolepiota procera (Scop.) Singer	MAC PRO	1	3			3	2					3		2	3	2	1	1	
Sl	Collybia dryophila (Bull.) P. Kumm.	COL DRY	2	1			2						2	2	2	3	3			3
M	Inocybe sindonia (Fr.) P. Karst.	IN SIN		4		1		1			1		4	3	1	2				1

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GT	*Species*	*Abbrev.*	*litter absent*									*litter present*							
			6	*12*	*15*	*19*	*26*	*32*	*42*	*48*	*54*	*5*	*11*	*16*	*20*	*25*	*31*	*41*	*47*	*53*
M	Laccaria amethystina Cooke	LA AME					1		1	1		2	3			4	2	3	1	
Sh	Lycoperdon perlatum Pers.: Pers.	LYC PER	1	3								2	3	4	2	3	1		3	
Sw	Calocera viscosa (Pers.) Fr.	CA VIS				4			2	2				1			3	2	1	3
M	Cortinarius castaneus (Bull.) Fr.	COR CAS	1	2	3		2						3	3	3	3				
Sl	Marasmius androsaceus (L.) Fr.	MAR AND		4	1	3	5					4	3		5	5				
Sl	Mycena epipterygia (Scop.) Gray	MY EPI		1						3	1			1	4	3	3			2
Sh	Cystoderma carcharias (Pers.) Fayod	CYS CAR	2								2	3	2		4	2				2
Sl	Mycena amicta (Fr.) Quél.	MY AMI	4	2					1			4	1			2	1			
M	Russula fragilis (Pers.) Fr.	RUS FRA								2				2	1	1	2	1	2	
Sl	Lepista flaccida (Sowerby) Pat.	LE FLA						2		2	3				4		2			3
Sl(Sw)	Mycena filopes (Bull.) P. Kumm.	MY FIL		1									3	2	2	3	4			
Sl(Sw)	Mycena leptocephala (Pers.) Gillet	MY LEP				4	1					2	2		1	1				
Sw	Xylaria hypoxylon (L.: Fr.) Grev.	XYL HYP		2					1		3		3	4				2		
M	Boletus calopus Pers.	BO CAL							1		1			1				2	2	
Sh(M)	Clavulina cinerea (Bull.) J. Schröt.	CLA CIN		1	3	1	3									1				
M	Inocybe mixtilis (Britzelm.) Sacc.	IN MIX					3				3		1		3					2
Sh	Lycoperdon umbrinum Pers. : Pers.	LYC UMB		2								1	3			3	2			
Sh	Mycena abramsii (Murrill) Murrill	MY ABR					1	1				2					2			1
Sl	Mycena galopus (Pers.) P. Kumm.	MY GAL					1					2		2	3		1			
Sl/Sw	Mycena pelianthina (Fr.) Quél.	MY PEL		1			2				2						3			1
Sl	Mycena rosea Gramberg	MY ROS	1					3				1			1		3			
M	Russula cavipes Britzelm.	RUS CAV	2							1						1		1	1	
M	Tricholoma saponaceum (Fr.) P. Kumm.	TR SAP	2	1								3	3		1					
M	Tricholoma ustale (Fr.) P. Kumm.	TR UST	2			1		1					1		3					
Sw(P?)	Xerula radicata (Relhan) Dörfelt	XE RAD	1					1		1			1					1		

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GT	*Species*	*Abbrev.*	*litter absent*										*litter present*							
			6	*12*	*15*	*19*	*26*	*32*	*42*	*48*	*54*	*5*	*11*	*16*	*20*	*25*	*31*	*41*	*47*	*53*
M	Amanita spissa (Fr.) P. Kumm.	AM SPI							1		1							2	1	
Sh(M)	Clavulina rugosa (Bull.) J. Schröt.	CLA RUG		1		1						3			2					
Sl	Clitocybe phaeophthalma (Pers.) Kuyper	CLI PHAE	3												4		2			4
Sh	Conocybe tenera (Schaeff.) Fayod	CON TEN						1	2						1	1				
Sh	Cystoderma amianthinum (Scop.) Fayod	CYS AMI			2									4	3		4			
M	Inocybe praetervisa Quél.	IN PRA		1			2								1	1				
Sl	Mycena flavoalba (Fr.) Quél.	MY FLA									1		2		3					3
Sl	Mycena sepia J. E. Lange	MY SEP		2									1	3		4				
M	Russula foetens (Pers.) Fr.	RUS FOE							1	2									3	1
M	Russula mustelina Fr.	RUS MUS								1	1		1							2
M	Suillus granulatus (L.) Roussel	SUI GR	2					2					1				3			
Sh	Clitocybe phyllophila (Pers.) P. Kumm.	CLI PHY						1							2		3			
M	Inocybe flocculosa Sacc.	IN FLO	1										2					1		
Sh	Macrolepiota konradii (P. D. Orton) M. M. Moser	MAC KON		1			2									3				
Sh	Mycena aetites (Fr.) Quél.	MY AET	3	1									2							
Sw (Sl)	Psilocybe aeruginosa (M.A. Curtis) Noordel.	PSI AER						1				3				2				
Sw	Psilocybe fascicularis (Huds.) Noordel.	PSI FAS																2	3	2
Sw	Psilocybe sublateritia (Fr.) Rode	PSI SUB								2								2	4	
M	Russula vesca Fr.	RUS VES									1		1			1				
Sw	Tapinella atrotomentosa (Batsch) Fr.	TAP ATR			1		1				1									
M	Amanita citrina (Schaeff.) Pers.	AM CIT			1		1													
M?	Caloscypha fulgens (Pers.) Boud.	CAL FUL							1		3									
Sh	Clitocybe foetens Melot	CLI FOE				1									2					
Sh	Clitocybe odora (Bull.) P. Kumm.	CLI ODO									1				1					
Sh	Collybia peronata (Bolton) P. Kumm.	COL PER						1								1				

Table 4. Summary of mycocoenological sampling performed in heavily-thinned permanent plots (GT – trophic group; M – mycorrhizal species; Sh – humicolous saprotrophs; Sl – litter inhabiting saprotrophs; Sw – lignicolous saprotrophs; P – parasites; Abbrev. - Abbreviations of the fungal species used for the Detrended Correspondence Analysis (DCA). *(continued)*

GT	*Species*	*Abbrev.*	*litter absent*										*litter present*							
			6	*12*	*15*	*19*	*26*	*32*	*42*	*48*	*54*	*5*	*11*	*16*	*20*	*25*	*31*	*41*	*47*	*53*
M	Cortinarius decipiens (Pers.) Fr.	COR DEC													2		2			
Sw	Crucibulum crucibuliforme (Scop.) V.S. White	CRU CRU												4	1					
Sw	Cyathus striatus (Huds. : Pers.) Willd.	CYAT ST												3		2				
Sh	Cystoderma terrei (Berk. and Broome) Harmaja	CYS TER							1								4			
Sh	Entoloma corvinum (Kühner) Noordel.	EN COR									1									2
Sh	Gamundia striatula (Kühner) Raithelh.	GAM STR	1										3							
M	Inocybe cincinnata (Fr.) Quél. var. major (S. Petersen) Kuyper	IN CIN		3													1			
M	Inocybe posterula (Britzelm.) Sacc.	IN POS			2											1				
M	Lactarius pyrogalus (Bull.) Fr.	LAC PYR												2					1	
Sh	Lepiota clypeolaria (Bull.) P. Kumm.	LEP CLY			1									1						
Sh	Lycoperdon molle Pers. : Pers.	LYC MOL													1		1			
Sl	Marasmius bulliardii Quél.	MAR BUL		1											1					
Sl	Mycena metata (Fr.) P. Kumm.	MY MET					2									5				
Sw	Mycena vitilis (Fr.) Quél.	MY VIT																1	1	
Sh	Rhodocybe fallax (Quél.) Singer	RHO FAL											3			4				
Sh	Rhodocybe popinalis (Fr.) Singer	RHO POP												2		3				
M	Russula chloroides (Krombh.) Bres.	RUS CHL			1				1											
M	Russula torulosa Bres.	RUS TOR	1																1	
M	Suillus gravillei (Klotzsch) Singer	SUI GRV				1									1					
M	Tricholoma imbricatum (Fr.) P. Kumm.	TR IMB				1									2					
M	Tricholoma portentosum (Fr.) Quél.	TR POR												1	1					
M	Tricholoma stans (Fr.) Sacc.	TR STA												2	2					
M	Xerocomus subtomentosus (L.) Quél.	XER SUB							1									1		

RESULTS

General species richness patterns

Summaries of the mycocoenological sampling performed over the three years of observation are reported according to the type of silviculture carried out: Table 2 includes the non-thinned plots, Table 3 the moderately thinned plots and Table 4 the heavily thinned plots.

In the 54 plots studied, 130 species of epigeous macrofungi were identified, belonging to 51 genera: 47 of the phylum *Basidiomycota* and only 4 of the phylum *Ascomycota*. *Mycena* was represented by the highest number of species (16 sp.) and the ectomycorrhizal genus *Inocybe* by 12 different taxa. However, most of the genera were represented by a single, specific item (Tables 2, 3 and 4).

Of the 130 macromycetes found, *Baeospora myosura, Caloscypha fulgens* and *Omphalina grossula* are considered at risk in Italy and are therefore included in the national red list proposals (Venturella *et al.*, 2003). One hundred and twenty species are included in the red lists (or red list proposals) compiled for various European countries: Malta (Schembri & Sultana, 1989), Holland (Arnolds *et al.*, 1995), Norway (Bendiksen *et al.*, 1997), former Yugoslavia (Ivancevic, 1998), Estonia (Järva *et al.*, 1998), Greece (Diamandis, 2000), Sweden (Gardenförs, 2000), Macedonia (Karadelev, 2000), etc.

Effects of thinning and litter removal

97 species were identified in the 18 plots in which no silviculture was carried out (NT): 92 in the plots with litter layer and 81 in plots from which it had been removed (Table 2). Of the 36 ectomycorrhizal species observed, 33 were found in the plots from which the litter had been removed and 32 in those from which it had not. Concerning the saprotrophic (lignicolous, humicolous and litter-inhabiting) species, there were considerably fewer taxa in the plots without litter (Table 2).

The most frequently found species were those with a broad ecological range, even if they are often more or less exclusively linked to coniferous woods (*Amanita rubescens*, *Collybia butyracea*, *Galerina marginata*, *Laccaria laccata*, *Mycena pura*, *Russula fragilis*, *Tricholomopsis rutilans*). On the other hand, *Lactarius salmonicolor* (Basso, 1999; Bon, 1988; Courtecuisse & Duhem, 1994; Kost & Haas, 1989) is an ectomycorrhizal species exclusive to *A. alba*.

The other species that were found more frequently and are worthy of attention include *Inocybe geophylla* and its *lilacina* variety. Although the areas studied all had acidic soils, according to the literature (Boudier, 1901; Ohenoja & Väre, 1993; Rücker *et al.*, 1990) these species prefer alkaline and calcium-rich soils. The presence of *Pluteus cervinus* in all the plots of the fourth area (39P, 40A, 43P, 44A, 49P, 50A) could be attributed to the greater presence of *Fagus sylvatica* in this area compared to the others. Although it has a wide ecological distribution, this fungal species seems to be particularly associated with the presence of beech trees (Thoen, 1970; 1971; Darimont, 1973; Bujakiewicz, 1973; Wojewoda, 1974; Bieri *et al.*, 1992; Arnolds *et al.*, 1994).

Interestingly, although *Cystoderma amianthinum* and *Mycena abramsii a*re considered humicolous saprotrophs (Arnolds *et al.*, 1995), they also seem to be associated with litter, since none were found in the plots in which there was no

litter cover. On the other hand *Clavulina rugosa, Inocybe queletii, I. splendens* var. *phaeoleuca, Tricholoma stans* and *T. ustale* were found exclusively in the plots in which the litter was preserved.

Compared to the control plots (NT), slightly fewer macrofungi were found in the moderately thinned plots (MT): 92 species, compared to the 97 found in the NT plots (Table 3). Of the fungi in the MT plots, 35 were ectomycorrhizal species, 18 humicolous, 21 litter-inhabiting and 17 lignicolous saprotrophs. In this case, the numbers found in the plots with or without the litter layer was substantially the same for both the symbiontic and the saprotrophic species.

The most diffuse taxa were those without particular ecological needs (Table 3) or those with a marked preference for coniferous woods (*Inocybe whitei, Lactarius salmonicolor*, *Tricholomopsis rutilans*, etc.).

Comparing the samples collected in the MT plots with those of the NT plots (Table 3 and 2) it can be seen that 21 species disappeared after thinning. Of particular note are *Agaricus essettei*, *A. niveolutescens* and *A. silvicola* which, according to Malençon & Llimona (1980) and Cappelli (1984), are species that grow in open habitats. At the same time, however, 16 new species appeared. Among these, the presence of *Entoloma chlorophyllum* and *Melanoleuca melaleuca* seem to confirm the preference of these species for open and sunny places (Moser, 1983; Noordeloos, 1992; Gyosheva & Vassilev, 1994). The appearance of *Pholiota lenta*, which can also grow in burnt areas (Breitenbach & Kränzlin, 1995), could be related to the presence of some such zones in the study area, as a consequence of the burning of prunings following tree felling.

98 fungal species were counted in the heavily thinned plots (HT) (Table 4). Of these, 40 were ectomycorrhizal species, 25 were humicolous, 20 litter-inhabiting and 13 lignicolous saprotrophs. Also in this case there was some similarity in the distribution of species between the plots with or without litter (Table 4), with the exception of the lignicolous species, which were mostly observed in plots with a litter layer.

Compared to the plots in which no silviculture was carried out (Table 2), 23 fungal species disappeared from the plots that had been heavily thinned (Table 4). Nine of these (*Agaricus essettei*, *A. niveolutescens*, *A. silvicola*, *Inocybe splendens* var. *phaeoleuca*, *Lepista nuda*, *Leucoagaricus leucothites*, *Macrolepiota excoriata*, *M. mastoidea* and *Marasmiellus vaillantii*) were species commonly found in grasslands, clearings or other open habitats in central and northern Europe (Malençon & Llimona, 1980; Cappelli, 1984; Brunner & Horak, 1990; Candusso & Lanzoni, 1990; Stangl, 1991; Antonin & Noordeloos, 1993; Basso, 1999). On the contrary, of the 24 species found exclusively in the thinned plots, only 5 (*Clitocybe foetens*, *Entoloma corvinum*, *Gamundia striatula*, *Lactarius pyrogalus* and *Macrolepiota konradii*) were species that prefer open and sunny habitats (Candusso & Lanzoni, 1990; Breitenbach & Kränzlin, 1991; Noordeloos, 1992; Bon, 1997; Basso, 1999); the others are normally associated with wooded environments.

The specific composition found in the plots treated with different types of thinning (moderate, heavy or no thinning) was compared using DCA (Detrended Correspondence Analysis) and correlated with the environmental data (Figs 3, 4 and 5).

The ordination diagram of the species found in the non-thinned plots explains 25.4% of the total variation, and reveals the presence of three distinct groups (Fig. 3). The first is close to the origin of the axes, where all the plots of the first three study areas with preserved litter layers can be found and where there are some species which, according to Keizer (1993), are closely associated with litter, such as *Collybia dryophila* (COL DRY) and *Mycena filopes* (MY FIL).

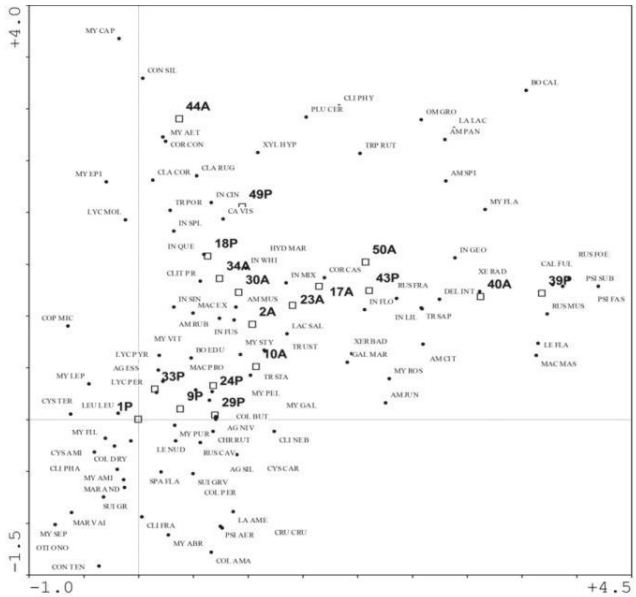

Fig. 3. Detrended correspondence analysis (DCA) ordination diagram with non-thinned permanent plots (□) and fungal species (•). The abbreviations of fungal names are given in Table 2. A – permanent plots without litter; P – permanent plots with litter.

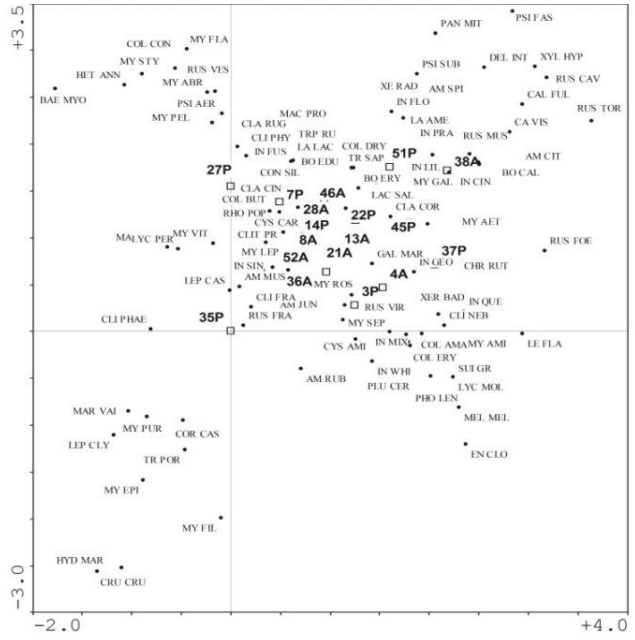

Fig. 4. Detrended correspondence analysis (DCA) ordination diagram with moderately-thinned permanent plots (□) and fungal species (•). The abbreviations of fungal names are given in Table 3. A – permanent plots without litter; P – permanent plots with litter.

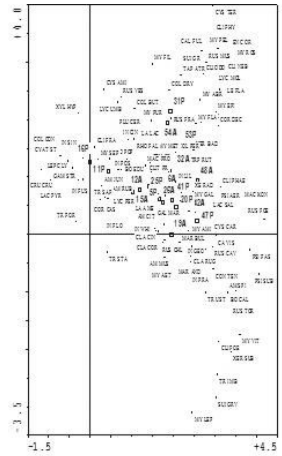

Fig. 5. Detrended correspondence analysis (DCA) ordination diagram with heavily-thinned permanent plots (□) and fungal species (•). The abbreviations of fungal names are given in Table 4. A – permanent plots without litter; P – permanent plots with litter.

The second group is composed of plots from the same first three sampling areas (Fig. 3) but without litter; in fact, these areas are home to species like *Amanita muscaria* (AM MUS) and *A. rubescens* (AM RUB), which fruit where litter is lacking (Baar & Kuyper, 1993). The final group is composed of plots in older forest populations (Fig. 3). The position of the symbols and the statistically significant ($p < 0.05$) positive correlation ($r = 0.9080$) with the first axis leads us to hypothesize the greater maturity of the woods. This is also confirmed by the position of species such as *Amanita pantherina* (AM PAN), *A. spissa* (AM SPI), *Russula foetens* (RU FOE) and *R. mustelina* (RU MUS), which are found preferentially in mature forests (Mason *et al.*, 1982; Bonet *et al.*, 2004). The first axis is also positively correlated ($r = 0.796$) with the diameter of the silver firs (*A. alba*) found in non-thinned plots, and negatively correlated ($r = – 0.7764$) with the total number of trees.

The DCA of the species found in the MT and HT plots (Figs 4 and 5) explains respectively 22.5% and 26.4% of the total variance and reveals quite different situations from those found in the NT plots (Fig. 3). First of all, it would seem that reduced canopy decreases the effects caused by the removal of the litter layer, since there was no distinction between the plots with or without litter in either of the two cases (Figs 4 and 5). At the species level as well, the abovementioned *Collybia dryophila* (COL DRY) and *Mycena filopes* (MY FIL), which are associated with litter (Keizer, 1993), can be found together with species (*Laccaria laccata* – LAC LAC; *Amanita muscaria* – AM MUS, *A. rubescens* - AM RUB, etc.) that generally fruit where the litter has been removed (Baar & Kuyper, 1993; Baar & de Vries, 1995). The disparities caused by the differing ages of the two forest populations also seem to be decreased by silviculture: there was no clear distinction between the plots with younger populations (plots 1 to 36) and the older plots (from 37 to 54) concerning either the fungi communities found in the moderately thinned plots (Fig. 4) or those found in the heavily thinned plots (Fig. 5).

Highly significant ($p < 0.001$) effects were seen in the total number of species, and the numbers of ectomycorrhizal species, humicolous, lignicolous and litter-inhabiting saprotrophic species, in relation to both thinning and litter removal (Tab. 5).

Table 5. The effects of thinning and litter removal on a) total number of species, b) number of mycorrhizal species, c) number of humicolous saprotrophs, d) number of litter-inhabiting saprotrophs, e) number of lignicolous saprotrophs as revealed by two-way ANOVA.

Source	*DF*	*MS*	*F*	*p*
a) Total number of species				
Thinning	2	629.38	11.9839	< 0.001
Litter removal	1	35344.80	673.0011	< 0.001
Thinning x Litter removal	2	1655.76	31.5274	< 0.001
Error	1803	52.51820		
b) Number of mycorrhizal species				
Thinning	2	185.7584	28.33045	< 0.001
Litter removal	1	111.5247	17.00889	< 0.001
Thinning x Litter removal	2	270.6130	41.27183	< 0.001
Error	1803	6.556846		
c) Number of humicolous saprotrophs				
Thinning	2	116.716	16.4852	< 0.001
Litter removal	1	1320.279	186.4784	< 0.001
Thinning x Litter removal	2	415.714	58.7161	< 0.001
Error	1803	7.080065		
d) Number of litter saprotrophs				
Thinning	2	955.205	86.7394	< 0.001
Litter removal	1	8680.814	788.2795	< 0.001
Thinning x Litter removal	2	108.885	9.8876	< 0.001
Error	1803	11.01236		
e) Number of lignicolous saprotrophs				
Thinning	2	45.975	19.952	< 0.001
Litter removal	1	2309.204	1002.142	< 0.001
Thinning x Litter removal	2	99.579	43.215	< 0.001
Error	1803	2.304270		

Effects of some environmental parameters on the fungal communities

Figure 6 shows the monthly trend of mean temperature and total rain during the three years of the study (2000-2002) and reports the number of species counted in the plots with different silviculture treatments. The fruiting processes were concentrated in two periods of the year: late spring (May) and autumn (September-November), which are the most favourable seasons in central Italy. In these periods there was no significant difference between the number of species gathered in the control plots and those found in the thinned plots (Fig. 6). The months in which the greatest mycodiversity occurred were October in the first two years and September in 2002. In the last year of the study, a distinct increase in precipitation brought the fruiting processes on early, in July, but a sharp drop in the temperature put a stop to them by the end of the following month (Fig. 6). This confirms the research carried out by Hueck (1953) and Meyer, in Ellenberg *et al.* (1986), who claim that there is a close correlation between vegetative growth in spring and the subsequent fruiting phase. In fact, the precipitation fluctuated throughout 2002 and especially in the spring, which is normally the period of greatest vegetative growth.

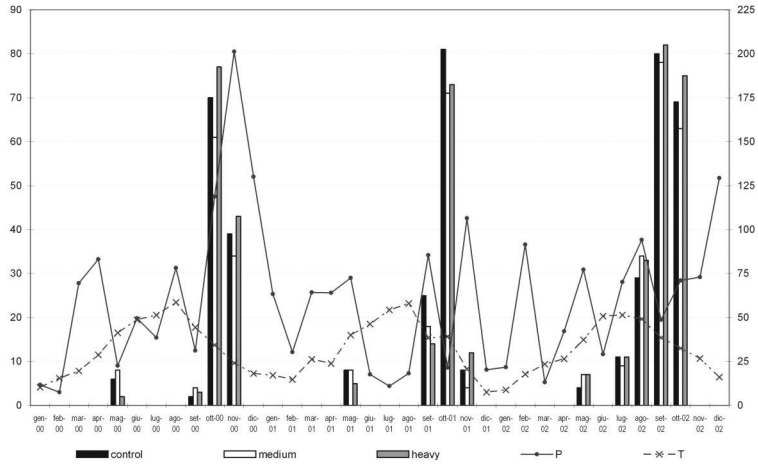

Fig. 6. Mean monthly temperature (T), total monthly rainfall (P) and number of species found in the 3 types of permanent plots during the study period (control – plots not thinned; medium – moderate thinned plots; heavy – heavily thinned plots).

Analysis of the correlations between the total number of species, their relative subdivision into trophic groups, the available soil data (pH, Al^{3+}, Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, N, organic carbon) and forest structure information (mean number of plants, basal area and age) highlighted that the structural parameters of the woods have a clear influence on the growth and composition of fungal communities (Tab. 6). In particular, the ectomycorrhizal species appear to be positively correlated ($p \leq 0.05$) with the total number of fir trees and negatively correlated ($p \leq 0.01$) with the diameter of *A. alba* and the age of the forest population (Tab. 6).

In the MT plots, from which a number of plants equivalent to 20% of the basal area was removed, almost all of the parameters considered were correlated with the fungi species found there (Tab. 6). Nonetheless, it should be pointed out that no relationship was found between the total number of ectomycorrhizal species and the age of the population in the thinned plots (Tab. 6).

Comparison with other fungal communities in *Abies alba* woods of Tuscany

The data acquired during this study were compared with those of a 3-year mycocoenological study carried out in 4 fir woods (2 natural and 2 planted; plots 66, 78 and 67, 59 here; 1, 2 and 3, 4 in Perini *et al.*, 1995) on Monte Amiata, and 3 fir woods (2 natural and 1 planted; Fonte di Guido, Fangacci and Stammerina plots here; 6, 7 and 5 in Perini *et al.*, 1995) in the Casentino Forests.

The seven fir woods studied in the past had a higher level of fungal biodiversity (235 species) and, although the natural areas contained more species than the planted ones (Perini *et al.*, 1995), the number of species found in the planted areas was still greater than in the plots described here (Fig. 7).

Fifteen species indicated by Perini *et al.* (1995) as locally differential in both natural and planted fir woods were found in the non-thinned (NT) plots of the present study. Sixteen species were found in the MT plots and 14 in plots

Table 6. Correlations (r-value) between number of species and their division among the trophic groups (M = mycorrhizal species; Sh = humicolous saprotrophs; Sl = litter-inhabiting saprotrophs; Sw = lignicolous saprotrophs) and environmental parameters (soil parameters; forest age; nt - number of trees; n Aa - number of plants of *Abies alba*; G Aa - tree basal area of *A. alba*; D Aa - diameter of *A. alba* trees).

	Control					*Medium thinning*					*Heavy thinning*				
	sp.	*M*	*Sh*	*Sl*	*Sw*	*sp.*	*M*	*Sh*	*Sl*	*Sw*	*sp.*	*M*	*Sh*	*Sl*	*Sw*
Mg^{2+}	– 0,51	– 0,47	– 0,57	– 0,51	0,23	– 0,15	– 0,12	– 0,39	– 0,08	0,20	– 0,69	– 0,47	– 0,58	– 0,69	0,03
	*	*	*	*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	**	*	*	**	N.S.
Al^{3+}	0,27	0,52	0,20	0,25	-0,32	0,68	0,61	0,67	0,52	– 0,01	– 0,35	– 0,32	– 0,05	– 0,23	– 0,69
	N.S.	*	N.S.	N.S.	N.S.	**	**	**	*	N.S.	N.S.	N.S.	N.S.	N.S.	**
Ca^{2+}	– 0,24	– 0,32	– 0,26	– 0,25	0,29	– 0,13	0,14	– 0,05	– 0,17	– 0,23	0,00	0,04	– 0,29	– 0,09	0,75
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	**
Na^{+}	0,00	0,00	– 0,16	– 0,03	0,31	0,53	0,36	0,40	0,53	0,00	– 0,14	– 0,12	0,11	– 0,15	– 0,40
	N.S.	N.S.	N.S.	N.S.	N.S.	*	N.S.	N.S.	*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
K^{+}	0,02	0,05	– 0,11	0,03	0,14	0,72	0,64	0,85	0,57	– 0,20	– 0,19	– 0,17	0,05	– 0,18	– 0,38
	N.S.	N.S.	N.S.	N.S.	N.S.	**	**	**	*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
N	– 0,16	– 0,42	– 0,18	– 0,16	0,48	– 0,56	– 0,39	– 0,75	– 0,46	0,18	0,03	– 0,02	– 0,16	0,04	0,39
	N.S.	N.S.	N.S.	N.S.	*	*	N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
C	– 0,07	– 0,34	– 0,10	– 0,09	0,47	– 0,41	– 0,32	– 0,57	– 0,29	0,12	– 0,07	0,03	– 0,37	– 0,12	0,62
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	**
pH	– 0,09	0,03	– 0,15	– 0,12	0,01	– 0,01	0,42	– 0,01	– 0,22	– 0,10	0,30	0,26	0,19	0,25	0,18
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Age	– 0,48	– 0,60	– 0,47	– 0,44	0,31	– 0,68	– 0,45	– 0,76	– 0,61	0,10	– 0,50	– 0,27	– 0,72	– 0,51	0,49
	*	**	*	N.S.	N.S.	**	N.S.	**	**	N.S.	*	N.S.	**	*	*
n.t	0,34	0,56	0,34	0,30	– 0,38	0,70	0,50	0,64	0,63	0,00	0,34	0,16	0,58	0,35	– 0,49
	N.S.	*	N.S.	N.S.	N.S.	**	*	**	**	N.S.	N.S.	N.S.	*	N.S.	N.S.
n Aa	0,35	0,54	0,35	0,25	– 0,24	0,65	0,41	0,46	0,69	0,02	0,32	0,30	0,44	0,21	– 0,16
	N.S.	*	N.S.	N.S.	N.S.	**	N.S.	N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
G Aa	0,25	0,36	0,27	0,07	0,04	0,15	0,02	– 0,11	0,29	0,13	0,00	0,07	– 0,04	– 0,09	0,19
	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
D Aa	– 0,41	– 0,61	– 0,37	– 0,41	0,40	– 0,67	– 0,49	– 0,69	– 0,57	0,04	– 0,36	– 0,28	– 0,56	– 0,30	0,42
	N.S.	**	N.S.	N.S.	N.S.	**	*	**	*	N.S.	N.S.	N.S.	*	N.S.	N.S.

subjected to more intense thinning (HT). The majority of the differential species were those found in the fir woods on Monte Amiata (Perini *et al.*, 1995), while *Coprinus micaceus, Cystoderma amianthinum, C. carcharias, Heterobasidion annosum, Mycena filopes, M. metata, Pholiota lenta* and *Psilocybe aeruginosa* were cited as differentials in the fir woods of the Casentino Forests, where *Fagus sylvatica* has a greater presence (Perini *et al.*, 1995).

Based on the classification of the macrofungal communities found in this study and the communities found in Perini *et al.* (1995), some main clusters (Fig. 8), with a fairly high linking level (0.7-0.8), can be identified. The first cluster groups together all seven of the stations studied in the past (Perini *et al.*, 1995) and is separate from the other plots. The second cluster links the plots comprising

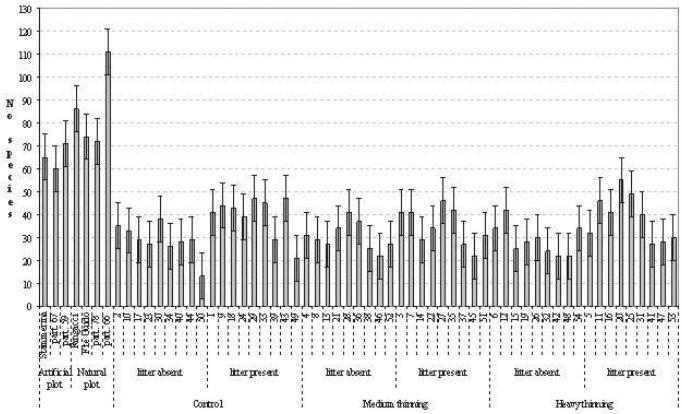

Fig. 7. Comparison between the number of fungal species found in the natural and artifical fir woods of Monte Amiata and the Casentino Forests and in the fir woods studied here.

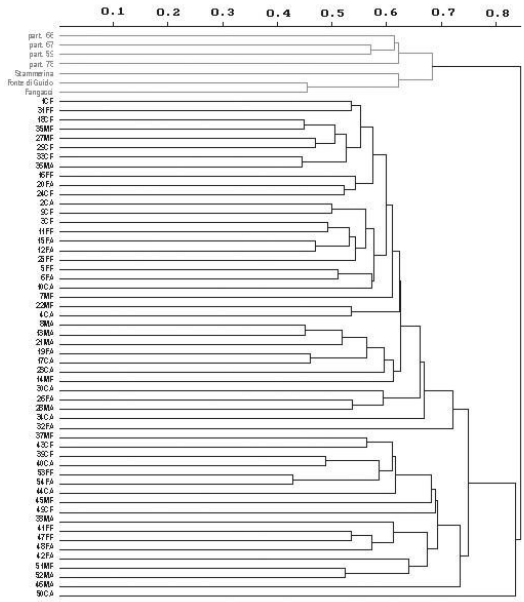

Fig. 8. Classification of the fungal communities in fir woods studied by Perini et al. (1995) (grey) compared to the communities found in this study (black) using the mean link algorithm.

younger forests, independently of whether silviculture was performed or not (Fig. 8), and is linked to a third cluster composed, instead, of the plots in the older forested areas. Lastly, plot 50 is linked to these two clusters; this plot was not thinned but the litter layer was removed.

DISCUSSION

General species richness patterns

During the three years of mycocoenological observations, 130 species of epigeous fungi were found in fifty-four 250 m^2 plots, in *A. alba* woods managed in different ways (thinning and removal of litter layer). The comparison of these results with those of other mycocoenological studies carried out over the last 25 years by the staff of the same Department in other forest ecosystems (evergreen oak woods on hills or on the coast, heathland stands, chestnut groves, fir woods and deciduous oak woods) in Tuscany (De Dominicis & Barluzzi, 1983; Barluzzi *et al.*, 1986; 1992; Perini *et al.*, 1989; 1995; Salerni *et al.*, 2001) brings to light a certain mycofloristic poverty. Over three years 235 species were found in 7 fir woods plots of approximately 625 m^2 (Perini *et al.*, 1995); in broad-leaved plots (evergreen oak woods on hills and on the coast, chestnut groves and deciduous oak woods) the number varied from a minimum of 181 species found in five 2000 m^2 plots in evergreen oak woods on hills (De Dominicis & Barluzzi, 1983) to a maximum of 309 taxa recorded in the five 2000 m^2 plots in evergreen oak woods on the coast (Perini *et al.*, 1989). A greater number of species (143) was also found in the five 2000 m^2 plots of *Calluna vulgaris* in a highly degraded environment whose evolution has been slowed by reforestation with pines (Salerni & Perini, 2004b).

The species found in the present study were not numerous and almost all are at risk of extinction in many European countries. This should be taken into consideration when planning the management of forest heritage. As Heilmann-Clausen & Christensen (2005) pointed out, after studying the lignicolous fungal species associated with beech woods from a conservation viewpoint, it is more useful to create forecasting models to protect habitats rather than a single species. It is also useful to highlight that the Mediterranean area has an extremely rich mycodiversity, even in totally artificial habitats such as the ones studied here.

Effects of thinning and litter removal

The study reported here focused above all on an evaluation of fungal community changes in forests of different ages of *A. alba* due to thinning and removal of the litter layer. At the level of single-species ecology, there were noticeable differences between the thinned and the non-thinned plots. In particular it was noticed that, of the species that were present in the control plots and (according to the literature) are associated with open and sunny habitats, some disappeared from the heavily thinned plots. This result seems to confirm the report of Perini *et al.* (1989) concerning some species habitually found in the grasslands of northern and central Europe. In typically Mediterranean climates such species "take refuge" in woods, where temperature and humidity conditions are less extreme. It is also interesting to note that this "migration" takes place even in montane or sub-montane habitats, like the one in this study.

Thinning also brought about changes at the level of macromycete communities. In fact, in the non-thinned plots the composition of the fungal communities seems to be influenced above all by the age of the forest; this dependence seems to decrease following silviculture, especially in ectomycorrhizal species. This result seems to confirm what Bonet *et al.* (2004) noted while studying the fruiting processes of *Lactarius deliciosus* in pinewoods of differing ages. These

Authors hypothesized that modifying the forest in order to create similar edaphic and microclimatic conditions to those found in the younger woods in which *L. deliciosus* achieves optimum growth and development would be sufficient to increase the production of carpophores in this species.

Our results seem to suggest that thinning would even mitigate the effect attained by the removal of the litter layer; according to many authors (Jahn, 1986; Tyler, 1991; Baar & Kuyper, 1993; Baar & de Vries, 1995; Baar & ter Braak, 1996) the latter would favour the fruiting process of numerous species, especially ectomycorrhizal ones.

Effects of some environmental parameters on the fungal communities

Regarding the influence of meteorological conditions (temperature and rainfall) on the fruiting processes of the species, more intense thinning and thus increased exposure to atmospheric elements did not have a significant effect on the production of fruit bodies. The fruiting period coincided with the autumn months in all cases. This seems to confirm and reinforce the concept expressed first by Perini *et al.* (1996) and subsequently by Salerni *et al.* (2002), that the processes leading to the production of fruit bodies are independent of the composition and, as shown here, the structure of forest ecosystems.

Various authors (Termoshuizen, 1990; Keizer & Arnolds, 1993; Baar & de Vries, 1995) claim that although the age of woods is one of the most important factors in determining fungal diversity, the latter is also strongly correlated to other parameters such as the composition of the lithologic substrate and land-use history. This is also confirmed by the data reported here, especially for the fungal species in the MT plots. The mycofloral wealth appeared to be negatively correlated with the quantity of nitrogen present in the soil; this is in line with many experimental studies conducted on coniferous woods (Menge *et al.*, 1977; Menge & Grand, 1978; Wästerlund, 1982; Ohenoja, 1988a; 1988b; Shubin, 1988; Kuyper & de Vries, 1990; Termorshiuzen, 1990), deciduous forests (Keizer, 1993) and open habitats (Arnolds, 1981), all of which have underlined the negative influence of nitrogen enrichment via fertilizers on the ectomycorrhizal community. Termorshiuzen (1990) observed that nitrogen fertilizers stimulated vegetative growth in the host plant but caused a decline in ectomycorrhizal flora by inhibiting production, rather than by initial inoculation. Björkman (1942) suggested that ammonium and nitrate increase carbohydrate availability, meaning less exchange among symbionts.

Comparison with other fungal communities found in *Abies alba* woods in Tuscany

Substantial differences were found in relation to the mycocoenoses found in other fir woods studied in the past. The initial hypothesis was that the fungal communities of the 4 previously studied stations on Monte Amiata were similar to those studied here, since they are geographically proximate to each other, yet this hypothesis was not supported by our findings. These results are without doubt also due to a series of environmental differences (lithologic substrate, exposure, altitude, etc.) that influence fungal growth more than vegetational growth. Altitude in particular seems to play a predominant role in the assemblage of a fungal coenosis; in fact, Laganà *et al.* (1999) report that an increase in altitude leads to a decrease in ectomycorrhizal species. However, the differences among the macrofungal communities found in the areas treated by thinning and removing

litter, compared to those in the areas studied by Perini *et al.* (1995), show that silviculture can also significantly influence fungal growth. This result should be taken into consideration when planning forest management aimed at supporting sustainable forest development and conserving the fungal patrimony, even in areas of intense production.

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