Ekológia (Bratislava) Vol. 31, No. 3, p. 264–273, 2012
doi:10.4149/ekol_2012_03_264

BIOMASS OF EPIGEIC SPOROCARPS OF MACROMYCETES IN A SUBMOUNTAINOUS BEECH STAND EXPOSED TO CUTTING TREATMENT WITH VARIED DENSITY

IVAN MIHÁL

Institute of Forest Ecology of the Slovak Academy of Sciences, Štúrova 2, 960 53 Zvolen, Slovak Republic; e-mail: mihal@savzv.sk

Abstract

Mihál I.: Biomass of epigeic sporocarps of macromycetes in a submontainous beech stand exposed to cutting treatment with varied density. Ekológia (Bratislava), Vol. 31, No. 3, p. 264–273, 2012.

In this contribution we assessed the biomass production in sporocarps of macromycetes in a submountainous beech stand with plots of varied stocking density during 2007 and 2008. The individual partial research plots (PRPs) had stocking degrees from 0.0 for clear cut to 0.9 for the intact control. The total number of macromycetes species identified in the stands was 162. 90 of which were suitable for production evaluation. The dynamics of biomass production in fruiting bodies during the entire study period exhibited a trend which increased from the clear cut (0.86 and 2.23 $kg.ha^{-1}$) to the densest PRP (44.5 and 248.5 $kg.ha^{-1}$ fresh mass of fruiting bodies). The biomass production in sporocarps was mostly due to ectomycorrhizal macromycetes, which produced a total of 327.7 $kg.ha^{-1}$, and especially to the *Craterellus cornucopioides*, *Lactarius piperatus* and *Russula genus* species. Among lignicolous macromycetes, the highest biomass was produced by *Armillaria ostoyae*, *Hypholoma sublateritium* and *Kuehneromyces mutabilis* species. The lowest biomass amount of 5.3 $kg.ha^{-1}$ was produced by terrestrial saprophytic macromycetes, where their fruiting was limited by unfavourable climatic and ecological conditions, especially on the partial research plots with the lowest stocking density.

Key words: beech, *Fagus sylvatica* L., macromycetes, biomass of epigeic sporocarps, cutting treatments, Slovakia

Introduction

In 2008, beech forest stands comprized 31.2% of the total timber land area in the Slovak Republic (Collective, 2008). Consequently, beech is the most eminent woody plant in Slovak forests and its importance in landscape ecology and forest management is indisputable. Until recently, biotic factors, such as insect attacks and infection by pathogenic fungi, have only been considered to have little impact on beech decline (Korpeľ et al., 1991). However, a steep increase in damage to beech trees caused by biotic factors has become evident during the past few years. This also applies to the fungal diseases, where mycoses are often chronic. Their distribution ranges from a local attack to an epiphytocia.

Macromycetes in beech forest stands represent an intricate ecotrophic-ecotopic system connected with both the beech and the associated environment. The most important indicators distinctive in a given mycocoenosis involve the production of fruiting bodies, or epigeic sporocarps, of the individual macromycetes species.

Problems involving the determination, abundance and production of sporocarps in macromycetes in beech stands were studied by Janík, Mihál (1995), Mihál (1995a, 1998), Mihál, Bučinová (2007) in Slovakia, and by Holec (1994), Jennings, Lysek (1996), Matsuda (1994), Murphy, Miller (1993) and Salerni, Perini (2004) abroad. Several authors have also examined the species diversity, dominance and succession of macromycetes in beech stands. The last issue studied in Slovakia was by authors including Mihál (1995b), Mihál, Bučinová (2005) and Pavlik (1997), and abroad by Adamczyk (1995) and Andersson (1995).

The aim of this work is to contribute to the knowledge of production dynamics of the sporocarp biomass of epigeic macromycetes growing in submountain beech forest stands. The beech forest stands in the partial research plots in this study have been differently managed, and treated with regeneration cuts of various intensity over a long period.

Material and methods

This research into epigeic sporocarp biomass production was carried out in the four partial research plots (PRP) located in the sub-mountainous beech forest stands in the Ecological Experimental Stationary (EES) Kováčová in the Kremnické vrchy Mts in Central Slovakia. The EES consists of five partial research plots with different densities obtained by applying a series of regeneration shelter-wood cutting treatments with different intensities. The following mycological research was pursued on four of these PRPs, with the exception being the former clear cut plot ; PRP H with heavy treatment, PRP M with medium treatment, PRP L with light treatment and PRP C which was the untreated control plot. Our research on these four PRPs followed the second series of regeneration cuts in 2004, which had further reduced stocking density. The detailed description of the research plots is summarized in Table 1. The research was performed in the 2007 and 2008 vegetation periods at intervals of three to five weeks (in 2007 on 4 May, 7 June, 13 July, 14 August, 21 September, 17 October; and in 2008 on 6 May, 11 June, 8 July, 8 August, 23 September, 13 October).

The macromycetes species diversity and the abundance of their fruiting bodies were recorded during field surveys on the research plots. The evaluation of the biomass production was carried out with average samples (1–50 examples) of sporocarps of the relevant species, following weighing of the sampled material in the fresh state. The calculated average weight of one fruiting body was multiplied by the total abundance of exemplars of the given species identified during the entire study period, to give the result in $kg.ha^{-1}$. A more detailed description of this field methodology can be found in Mihál (1995a).

It is necessary to add, that in some cases only a single fruiting body of certain species was located during the entire study period. These species included *Inocybe rimosa, Pholiota adiposa, Scleroderma citrinum* and *Tricholoma sulphureum*. Here, this fruiting body gave the average weight for the given species. In addition, fruticose and resupinate fruiting bodies of lignicolous species were excluded from the evaluation of the production because it was not possible to precisely determine the number of their fruiting bodies. These species included *Bisporella citrina, Calocera viscosa, Hypoxylon multiforme* and *Trametes versicolor*. This influenced the abundance of species involved in the evaluation. For example, while 162 macromycetes species were determined on all research plots, only 90 species, or 60.5% of that total number, were involved in the production evaluation.

Problems encountered with the method correspond to the experience of other authors who studied the issue of biomass determination for epigeic sporocarps. For example, Gáper (1992) describes problems connected with the methods for exact determination of biomass of ectomycorrhizal macromycetes, from the viewpoint of determination of mycelium biomass and of persistence and frequency of occurrence of the fruiting bodies in the forest stand. Similarly, Holec (1994) studied the abundance and biomass production in the fruiting bodies and drew the conclusion that the absence of fruiting bodies in several years is not a reliable indicator of the absence of mycelium in the soil. The biological activity of the species is also influenced by the thickness of the litter layer and by the form of humus. On the other hand, biological activity need not necessarily be connected with the abundance of the macromycetes fruiting bodies.

Results

During the study period, a total of 162 macromycetes species were identified in the EES forest stand. The number of the identified species varied among the PRPs, dependent on the site condition factors on the individual plot. The most important factor was stocking degree which influenced the following: (1) the canopy density in the trees (2) the light supply to the stand, (3) light penetration reaching the ground, (4) stand microclimate (5) the dynamics of the herbaceous and shrub understorey and (6) from a longer perspective, the effectiveness of soil humification. All these characteristics, in accordance with the conditions listed in Table 1, created a specific micro-habitat for each PRP, and in this way influenced the species diversity in macromycetes and their abundance values. These factors had a direct impact on biomass production values.

As mentioned in Material and Methods, only 90 (60.5%) of the total number of the species identified in the beech stand at the EES, were suitable for evaluating production. The portions of these species on individual PRPs are listed in Table 2, which shows that these portions were higher in 2007 than in 2008, mainly due to the higher occurrence of agaricolous species with fruiting bodies suitable for production assessment. The portion of macromycetes species assessed in terms of production ranged from 38.0 to 58.0%. This percentage appears acceptable considering the long dry periods in these two years.

Table 3 illustrates the biomass production for fruiting bodies on individual PRPs in 2007. At first glance, there is a distinct general rise in biomass production from May to October, and local decreases in the warmer months of August and September, in accordance with the natural trend of mycocoenoses development during the growing season. There is also an obvious increase in values from PRP H, where the least densely stocked forest stand to the most stocked stands on PRPs L and C offer the macromycetes more favourable climatic-environmental conditions than those on the open PRP H, which is exposed to full light and desiccation. It is also necessary to accentuate that the highest values of biomass production on PRPs L and C were obtained during July and October, mainly due to abundant fruiting in the *Armillaria ostoyae* and *Lactarius piperatus* species.

The recorded macromycetes' biomass production values were disproportionally higher in 2008 than in 2007 (Table 4). In this second study year, several species on PRPs L and C

T a b l e 1. Basic characteristics of the locality EES Kremnické vrchy Mts and the individual partial research plots (PRP).

Orographic unit	Kremnické vrchy Mts
Partial research plot	Ecological-Experimental Stationary Kováčová
Localisation	48°38‘10“ N, 19°04‘08“ E
Altitude (m a.s.l.)	470–490
Exposition	SW
Slope (°)	20
Geological substrate	andesite, tuffaceous agglomerates
Soil type	Cambisol (Andosol) saturated
Humus form	mull
Throughfall (mm) *	653
Temperature (° C) *	8.3
Forest type groups	*Fagetum pauper inferiora*
Vegetal association	*Dentario bulbiferae - Fagetum* Zlatník, 1936 *Carici pilosae - Fagetum* Oberd., 1958
Tree composition (%)	beech 95, fir 2, hornbeam 2, oak 1
Age of mature stand (years)	105–110
Stocking of stand (before 2004) ** Stocking of stand (since 2004) **	0.3–0.5–0.7–0.9 0.0–0.3–0.5–0.9
Crown canopy of total EES (%)	0.0–97.0
Area of total EES (ha^{-1})	1.2

* Throughfall and Temperature: average values from 2003–2005
** Stocking and Area of individual Partial Research Plots (PRP):
Before 2004:
PRP: H (heavy cutting intervention): stocking: 0.3 area: 0.35 ha^{-1}
PRP: M (light cutting intervention): stocking: 0.5 area: 0.35 ha^{-1}
PRP: L (mild cutting intervention): stocking: 0.7 area: 0.35 ha^{-1}
PRP: C (control plot - without cutting intervention): stocking: 0.9 area: 0.15 ha^{-1}
Since 2004:
PRP: H (clear cutting intervention): stocking: 0.0 area: 0.35 ha^{-1}
PRP: M (medium cutting intervention): stocking: 0.3 area: 0.35 ha^{-1}
PRP: L (light cutting intervention): stocking: 0.5 area: 0.35 ha^{-1}
PRP: C (control plot - without cutting intervention): stocking: 0.9 area: 0.15 ha^{-1}

T a b l e 2. Portion of macromycetes species (%) of the total number of the species identified on individual PRPs selected for assessment of fruiting bodies biomass production.

PRP	2007	2008
H	41.0	30.0
M	43.0	38.0
L	58.0	56.0
C	52.0	42.0

produced abundant fruiting bodies and thereby contributed significantly to the high biomass production not only on PRPs, but generally. High biomass production was observed

T a b l e 3. Biomass production values (kg.ha^{-1} fresh mass of fruiting bodies) on individual PRPs in 2007.

PRP	May	June	July	August	September	October	Total
H	0.37	0.31	0.07	0.01	0.17	1.32	2.23
M	0.4	2.75	2.51	0.02	0.16	1.69	7.53
L	0.6	2.01	5.01	0.12	3.86	32.9	44.5
C	0.0 *	4.37	12.4	0.0 *	2.6	1.9	21.27
Total	1.37	9.44	19.99	0.15	6.79	37.81	75.53

* no macromycetes occurred on the given PRP in the given month for production assessment

T a b l e 4. Biomass production values (kg.ha^{-1} fresh mass of fruiting bodies) on individual PRPs in 2008.

PRP	May	June	July	August	September	October	Total
H	0.0 *	0.02	0.50	0.02	0.31	0.01	0.86
M	0.01	0.25	1.6	12.51	16.95	0.08	31.4
L	0.0 *	1.14	4.41	19.48	13.59	16.0	54.62
C	0.0 *	0.1	19.01	128.0	101.0	0.4	248.51
Total	0.01	1.51	25.52	160.01	131.85	16.49	335.39

* no macromycetes occurred on the given PRP in the given month for production assessment

from July to October, primarily in the *Craterellus cornucopioides* (PRPs M and C), *Lactarius piperatus* (C), *Armillaria ostoyae*, *Kuehneromyces mutabilis* and *Hypholoma sublateritium* (L) species. While 2008 was characterized by very low production values in the cold month of May, a steep increase in production values was recorded in the summer months. The production trend in this year was confirmed to increase from the thinnest stand on PRP H to the most stocked stands on plots PRPs L and C, which we consider to be the most favourable for macromycetes occurrence.

Table 5 provides data for the five macromycetes species with the highest biomass production on individual PRPs in 2007. Similar to Tables 3 and 4, the production dynamics here show an increasing trend from PRP H to PRP C. It must be stated here that the species listed

T a b l e 5. The five macromycetes species with the highest biomass production on individual PRPs in 2007.

PRP	Species of macromycetes	(kg.ha^{-1})
H	*Pleurotus pulmonarius*, *Armillaria ostoyae*, *Panellus stipticus*, *Hypholoma sublateritium*, *Amanita vaginata*	1.67
M	*Lactarius piperatus*, *Armillaria ostoyae*, *Panellus stipticus*, *Megacollybia platyphylla*, *Pleurotus pulmonarius*	6.64
L	*Armillaria ostoyae*, *Lactarius piperatus*, *Gymnopilus sapineus*, *Craterellus cornucopioides*, *Lactarius salmonicolor*	37.0
C	*Lactarius piperatus*, *Lycoperdon pyriforme*, *Megacollybia platyphylla*, *Marasmiellus foetidus*, *Clitocybe nebularis*	18.22

T a b l e 6. The five macromycetes species with the highest biomass production on individual PRPs in 2008.

PRP	Species of macromycetes	($kg.ha^{-1}$)
H	*Lactarius piperatus*, *Craterellus cornucopioides*, *Russula aurea*, *Russula cyanoxantha*, *Russula foetens*	0.81
M	*Craterellus cornucopioides*, *Lactarius piperatus*, *Panellus stipticus*, *Russula foetens*, *Agaricus silvaticus*	31.1
L	*Craterellus cornucopioides*, *Kuehneromyces mutabilis*, *Armillaria ostoyae*, *Lactarius piperatus*, *Hypholoma sublateritium*	42.21
C	*Craterellus cornucopioides*, *Lactarius piperatus*, *Cantharellus cibarius*, *Russula cyanoxantha*, *Panellus stipticus*	246.71

in Table 5 covered 84.1% of the total biomass production of macromycetes recorded in the entire stand at the EES in 2007. This reveals their dominance in production assessment, and also their dominant status among the macromycetes in the EES stand.

A similar situation was observed in 2008, which had incomparably higher production values, especially on PRPs M and C (Table 6). The species listed in this table accounted for 95.7% of the total biomass production of macromycetes recorded in 2008 for the entire EES stand. Apart from the species recorded in 2007, the most productive species group in 2008 comprised *Russula* genus species and also *Agaricus silvaticus*, *Kuehneromyces mutabilis* and the *Hypoholoma sublateritium* species. These contributed significantly to the higher biomass production in 2008.

Biomass production values for the individual ecotrophic groups in the entire research period are shown in Table 7, which illustrates that the highest biomass production was in the ectomycorrhizal macromycetes species. This was mainly due to the abundant fruiting of the *Lactarius piperatus*, *Craterellus cornucopioides* and *Russula genus* species. The symbiotic macromycetes exhibited their highest abundance primarily on plots PRPs L and C, with the highest stocked stands offering the most favourable conditions for fruiting. Relatively high values of biomass production were also attained by lignicolous saproparasitic fungi *Armillaria ostoyae* and *Pholiota squarrosa*. These created fruiting bodies on stumps and

T a b l e 7. Biomass production values ($kg.ha^{-1}$ fresh mass of fruiting bodies) in individual ecotrophic groups on PRPs over the entire study period.

PRP	LP	LS	TS	EM	Total
H	0.45 *	1.07	0.03	1.54	3.09
M	0.84 *	1.9	0.27	36.0	39.01
L	36.1 **	30.0	4.0	30.0	100.1
C	0.0	8.11	1.0	260.23	269.34
Total	37.39	41.08	5.3	327.77	411.54

Notes: LP – lignicolous parasites, LS – lignicolous saprophytes, TS – terrestrial saprophytes, EM – ectomycorrhizal symbionts
* only *Armillaria ostoyae*, ** *Armillaria ostoyae* and *Pholiota squarrosa*

wood residues on PRPs H and M, and existed parasitically on live trees on PRP L. The main factors limiting terrestrial saprophytic species consisted of different climatic and environmental conditions on individual PRPs, and especially on the different degrees of stocking density.

Discussion

In our production assessment, lignoparasitic and lignosaprophytic macromycetes were rarer than the other agaricolous saprophytic or symbiotic macromycetes. A major underlying cause is that the majority of lignicolous species create resupinate or fruticous fruiting bodies whose abundance is very difficult to quantify with current methods, where it is often not possible to separate and weigh a single fruiting body precisely as a sample for the additional production assessments (see Material and methods). These species are exemplified by *Schizophyllum commune*, *Trametes velutina* and *T. versicolor*, which Willig, Schlechte (1995) reported as the species with the most abundant fruiting bodies and highest frequency on dead beech wood. These species which are analogous to other lignicolous macromycetes in the EES stand form a part of the eudominant macromycetes group (Mihál, Bučinová, 2005). The dynamics of biomass production for fruiting bodies of the Agaricolous lingoparasitic species *Armillaria ostoyae* has been continually assessed in the forest stand at the EES since 1991. The biomass production in this species in 1991–1994 ranged from 65.4 to 143.8 $kg.ha^{-1}$ of the fresh mass (Mihál, 1995a). The absence of *A. ostoyae* fruiting in 2003 and 2004 is interesting when compared with our results in 2007 and 2008 which exhibited high biomass production in their fruiting bodies. This was especially the case on PRP L, where this contributed to the higher biomass production values. In general, we can state that lignicolous macromycetes at the EES never showed higher biomass production values in their fruiting bodies than ectomycorrhizal macromycetes. For example, the total biomass production of lignicolous saprophytic species *Marasmius alliaceus* was 8.35 $kg.ha^{-1}$ fresh mass of fruiting bodies in 1991–1994, compared to the 73.19 $kg.ha^{-1}$ for *Hygrophorus eburneus* species, in the same period (Mihál, 1998). On the other hand, it is necessary to add that in the environmental conditions existing at the EES, the biomass production in lignicolous species was lower in numeric values, but more or less continuous over the whole season, while the ectomycorrhizal species produced a much higher biomass, but this was frequently in particular, or often single, productions during the season.

For terrestrial saprophytes, the soil humification process and humus layer thickness are additional limiting factors to the site's micro-climate (Baldrian, Šnajdr, 2006; Tuomela et al., 2005). In their studies on the macromycetes from the Strophariaceae, Bolbitiaceae and Triholomataceae families living on decomposed foliage, these authors suggest that enzymes such as lactase and manganese-peroxidase enable them to enter into the carbon cycle and to, decompose substances contained in humus to individual nutrients with their help. In this way they can exert a primarily influence on nitrogen return to soil. Holec

(1994) suggests that thickness of forest litter and the form of humus control the abundance of both saprophytic and ectomycorrhizal fungi, and also their ratio. Tyler (1991) examined the impact of removal of fallen leaves on the fruiting bodies production in macromycetes. This author discovered that fruiting body production was higher in (1) saprophytic species such as *Mycena cinerella, M. galopoda* and *Rhodocollybia butyracea* f. *asema* on plots covered with litter, and also in (2) the *Lactarius* and *Russula genera* species on plots where the litter layer had been removed. In their studies in a sub-mountainous beech stand, Mihál and Bučinová (2007) observed the highest biomass in the terrestric saprophytic species *Marasmius rotula*, at 11.21 kg.ha^{-1} and in *Rhodocollybia butyracea* f. *asema*, which had 5.39 kg.ha^{-1} fresh fruiting body mass. At the same time, it must be accentuated that the high species diversity and fruiting of terrestrial saprophytes in beech forest ecosystems guarantees the formation of humus substances in soils with a favourable ratio between humic acids and fulvic acids, and also faster decomposition of dead-wood debris and leaf litter. Thus, these fungi participate in enrichment of the humus layer of forest soils with essential nutrients and chemical substances.

In the same manner as saprophytic species, the symbiotic macromycetes are able to produce large volumes of fruiting body biomass in favourable climatic-ecological conditions provided by beech forest stands. Unlike saprophytic species which are able to fruit regularly several times throughout the season in optimum conditions, the fruiting in mycorrhizal species displays larger or smaller seasonal fluctuations. The biomass of mycelium of ectomycorrhizal species plays an important role in carbon cycling in ecosystems, because it provides one third of the total soil biomass (Högberg M.N., Högberg P., 2002). The mycelia of ectomycorrhizal species deliver large amounts of carbon substances from plant roots to the forest soil. Similar data was provided by Jennings, Lysek (1996), who reported that up to 30–35% of the total amount of assimilates in beech stands is metabolized with the aid of mycorrhizal species. Gryndler et al. (2004) reported that production of fruiting bodies in ectomycorrhizal macromycetes is mainly governed by the quality of the stand, herb cover and soil condition. The arbuscular mycorrhizal species dominate in deciduous forests with rich herb under-storey and mull humus form, while ectomycorrhizal species are dominant in forests with poorer herb layer and moderate humus form. One example is the *Fagetum pauper* species group of forest types. Coniferous forests are generally more productive, because they produce higher biomass volumes of fruiting bodies of ectomycorrhizal species than deciduous broad-leaved forests. The maximum production in coniferous forests occurs soon after formation of the closed crown canopy, and it decreases later. However, Lesná, Kulhavý (2003) report that the nutrient cycling in beech stands occurs faster, and the amount of humic acids is also more favourable compared to that in spruce stands. Salerni, Perini (2004) studied the production of fruiting bodies in the *Boletus edulis* ectomycorrhizal species, and they concluded that the fruiting body production therein was highest on opened plots with a thin canopy, and that removal of leaf litter had a greater negative influence on fruiting in this species. The *B. (Xerocomus) badius* species was observed to occur more frequently in older forest stands where the canopy was more closed.

Conclusion

The production dynamics of sporocarps in macromycetes was evaluated in 2007 and 2008 in a sub-mountainous beech stand with different stocking densities. The stocking degree of the individual partial research plots (PRPs) ranged from 0.0 in the clearing plot to 0.9 in the control plot without intervention. The total number of macromycetes species determined in the stand was 162, of which 90, or 60.5% of the total species diversity, were suitable for production assessment. Over the entire study period, the biomass production dynamics of fruiting bodies followed an increasing trend from 0.86 and 2.23 $kg.ha^{-1}$ in the clear cut plot to the densest PRPs which recorded 44.5 and 248.5 $kg.ha^{-1}$ fresh-fruiting bodies mass. The sporocarp biomass total of 327.7 $kg.ha^{-1}$ was mainly due to production in ectomycorrhizal macromycetes. This especially included the *Craterellus cornucopioides*, *Lactarius piperatus* species, and species from the *Russula* genus. The largest biomass volume in the lignicolous macromycetes were from *Armillaria ostoyae*, *Hypholoma sublateritium* and *Kuehneromyces mutabilis* species' production. The lowest fruiting-body biomass of 5.3 $kg.ha^{-1}$ was produced by terrestrial saprophytic macromycetes, where fruiting was limited by unfavourable climatic-ecological conditions, and this primarily occurred on plots with the lowest stocking density. The dynamics of biomass production in sporocarps on individual PRPs varied according to the climatic-ecological conditions on the particular plots, and it was determined by the degree of stand stocking density.

Translated by D. Kúdelová
English corrected by R. Marshall

Acknowledgements

This work was supported by the Vega Grant Agency of the Ministry of Education of the Slovak Republic (Grant No. 2/0160/09).

References

Adamczyk, J., 1995: Ecological groups of macrofungi in beech forest on Częstochowa Uplands, Southern Poland. Feddes Repertorium, 106: 303–315. http://dx.doi.org/10.1002/fedr.19951060324

Andersson, H., 1995: Untersuchungen zur Pilzflora von *Fagus sylvatica* – Stubben. Zeitschrift fűr Mykologie, 61: 233–244.

Baldrian, P., Šnajdr, J., 2006: Production of ligninolytic enzymes by litter-decomposing fungi and their ability to decolorize synthetic dyes. Enzyme Microb. Technol., 39: 1023–1029. http://dx.doi.org/10.1016/j.enzmictec.2006.02.011

Collective, 2008: Report of the Forest Management of the Slovak Republic 2008 – Green Report (in Slovak). MP SR Bratislava, NLC LVÚ Zvolen, 168 pp.

Gáper, J., 1992: Problems and possibilities of evaluation of ectomycorrhizal fungi biomass (in Slovak). In Metodológia v produkčnej ekológii. Arborétum Mlyňany – Ústav dendrobiológie SAV, Vieska nad Žitavou, p. 119–203.

Gryndler, M., Baláž, M., Hršelová, H., Jansa, J., Vosátka, M., 2004: Mycorrhizal symbiosis – mutual coexistence between fungi and plants root (in Czech). Academia, Praha, 366 pp.

Holec, J., 1994: Fungi from the Šumava Mts beech stands (in Czech). Živa, 2: 52–54.

Högberg, M.N., Högberg, P., 2002: Extramatrical ectomycorrhizal mycelium contributes one-third of microbial biomass and produces, together with associated roots, half the dissolved organic carbon in a forest soil. New Phytol., 154: 791–795. http://dx.doi.org/10.1046/j.1469-8137.2002.00417.x
Janík, R., Mihál, I., 1995: The production of shoot biomass of herbage and selected terrestrial fungi in a beech ecosystem (in Slovak). Lesn. Čas. – Forestry Journal, 41: 331–338.
Jennings, D.H., Lysek, G. 1996: Fungal biology: understanding the fungal lifestyle. BIOS Scientific Publishers Limited, Guilford, Great Britain, 156 pp.
Korpeľ, Š., Peňaz, J., Saniga, M., Tesař, V., 1991: Forest management (in Slovak). Príroda, Bratislava, 472 pp.
Lesná, J., Kulhavý, J., 2003: Evaluation of humus conditions under different forest stands: beech vs. spruce dominated forest stand. Ekológia (Bratislava), 22: 47–60.
Matsuda, Y., 1994: Seasonal occurrence and spatial distribution of fruitbodies of ectomycorrhizal fungi on the border of a man-made and naturally regenerated forest. Bulletin of the Nagoya University Forest, 13: 109–118.
Mihál, I., 1995a: Abundance and production of *Armillaria ostoyae* (R o m a g n.) H e r i n k in a fir-beech forest. Ekológia (Bratislava), 14: 229–236.
Mihál, I., 1995b: Abundance and distribution of fruitbodies of fungi under conditions of thinned beechwood (in Slovak). Lesnictví – Forestry, 41: 218–223.
Mihál, I., 1998: Abundance and production of selected basidiomycetous fungi in fir-beech forest stand of the Kremnické vrchy Mts (in Slovak). Folia Oecol., 24: 165–170.
Mihál, I., Bučinová, K., 2005: Species diversity, abundance and dominance of macromycetes in beech forest stands. J. For. Sci., 51: 187–194.
Mihál, I., Bučinová, K., 2007: Biomass of epigeic sporocarps in submountain beech stands exposed to different immission load. Ekológia (Bratislava), 26: 201–210.
Murphy, J.F., Miller, O.K., 1993: The population biology of two litter decomposing agarics on a southern Appalachian Mts. Mycologia, 85: 769–776. http://dx.doi.org/10.2307/3760608
Pavlík, M., 1997: Macromycetes species spectrum as a reflection of immission impact on beech forests (in Slovak). In Les – drevo – životné prostredie. Proceedings, TU Zvolen, p. 253–260.
Salerni, E., Perini, C., 2004: Experimental study for increasing productivity of *Boletus edulis* s.l. in Italy. For. Ecol. Man., 201: 161–170. http://dx.doi.org/10.1016/j.foreco.2004.06.027
Tuomela, M., Steffen, K.T., Kerko, E., Hartikainen, H., Hofrichter, M., Hatakka, A., 2005: Influence of Pb contamination in boreal forest soil on the growth and lignolytic activity of litter-decomposing fungi. FEMS Microbiol. Ecol., 53: 179–186. http://dx.doi.org/10.1016/j.femsec.2004.11.008
Tyler, G., 1991: Effects of litter treatments on the sporophore production of beech forest macrofungi. Mycol. Res., 95: 1137–1139. http://dx.doi.org/10.1016/S0953-7562(09)80561-3
Willig, J., Schlechte, B.G., 1995: Pilzsukzession an Holz nach Windwurf in einen Buchennaturwaldreservat. AFZ – Der Wald, 15: 817–818.