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Exploring the relationship between the fungi assemblages and the vascular plant communities in unmanaged- and managed vegetation types, in the Belső-Cserehát

PhD Thesis

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I. SCIENTIFIC ANTECEDENTS AND AIMS

All organisms inclusive of fungi too are threatened by negative effects in consequences of the human activities. It is known that habitat degradation adversely influences the number of fruiting bodies of macrofungi and diminishes the diversity of the fungal community (Arnolds 1988, 1991; Ohenoja 1988; Zak 1992; Miller and Lodge 1997). Macrofungi are an often neglected component of biodiversity due to the lack of information on their abundance and distribution, and their unexplored taxonomic diversity. Researchers have attempted to solve these problems through the use of better-known surrogate taxa, such as vascular plants. However, there is no clear evidence that higher plant diversity indicates higher fungal diversity (Virolainen et al. 2000; Chiarucci et al. 2005; Schmit et al. 2005; McMullan-Fisher et al. 2010). In consequence of habitat degradation beside species protection, the habitat protection of macrofungi is getting necessary more and more. In Europe the marking of the habitat-based protected areas of macrofungi (Senn-Irlet et al. 2007) was started however, in Hungary such protected areas are absolutely lacking. The recognition of the bioindicator role of macrofungi open the door to monitoring of natural and degradation processes of different habitats (Kost and Haas 1989; Bujakiewicz 1992, Tarvainen et al. 2003; Pál-Fám and Rudolf 2003; Siller et al. 2004).

The aim of the present study was to present the relationship between vegetation and macrofungi assemblages using mycological and botanical data which were collected from semi-natural and degraded vegetation types in the Belső-Cserehát. Furthermore, we studied the consequences of habitat degradation on fungal communities. This aim was realized by the undermentioned sub-targets:

1. The taxonomic characterization of the macrofungi of Belső-Cserehát and the establishment of the indicator macrofungi.
2. Myco- and phyto-coenological surveys of the representative vegetation types.
3. The coenological and habitat characterization of the investigated plant associations and establishment of naturalness of those.
4. The coenological characterization and comparative evaluation of macrofungi assemblages of typical vegetation types.
5. Exploring the relationship between macrofungi diversity, abundance, as well as vascular plant diversity and naturalness.
6. The conservation status of the macrofungi of the Belső-Cserehát and investigated stands.

II. THE STUDY AREA AND APPLIED METHODS

The study area is the Belső-Cserehát (360 km²) which belongs to the Cserehát small regional group in the Borsod-hills. The Belső-Cserehát had large forests but nowadays it is dominated by agricultural cultivation. Due to agricultural cultivation and excessive forestry management, hunting and grazing majority of the forests have been changed, fragmented significantly. Presumably, this contributed to the fact that this area was not unfolded neither mycologically nor phyto-coenologically.

The survey of the Belső-Cserehát was made in 1995-2005.Vegetation types typical in the study area and the sample sites which represent the fungi assemblages present in the area were selected after a thorough fieldwork. Besides taking into account of the above mentioned aspects, those sample sites were selected which showed different degradation states based on the preliminary exploration of the vegetation. Myco- and phyto-coenological sites are situated near the villages Abaújlak-Szanticska, Nyésta as well as Irota, Szendrőlád and Büdöskútpuszta. In a few sites only one survey was made for supplement of funga of the investigated area.

The size of myco- and phyto-coenological samples was determined on the basis of myco-coenological point of view with plots of 25x25 $m^{2.}$ Macrofungi species were sampled on the basis of fruit bodies on five to eight occasions in each year between July and November in 1995–2005. The phyto-coenological samples were collected according to the Zürich-Montpellier method in the spring and summer aspects however, the cover of the vascular plants were estimated visually (Bullock 2006) in the herb, shrub, and canopy layers separately in 1995-1996 and 2004-2005.

The funga of the Belső-Cserehát was compiled by myco-coenological data as well as presence data which were collected during the surveys in a wider environment (0,5–3 ha). These data were completed by other field data which were collected near the villages Büdöskútpuszta, Felsővadász, Gagybátor and Szebenye and where a few phyto-coenological samples were collected too. Altogether, 21 myco- and 66 phyto-coenological samples were evaluated.

In 2004, samples were taken with a Holger drill from the upper 20 cm of the sample quadrats at the same time of the fungi survey.

The investigated vegetation types: *Quercetum petraeae-cerris* Soó 1963; *Carici pilosae-Carpinetum* Neuhäusl & Neuhäuslová-Novotná 1964 em. Borhidi 1996; *Melittio-Fagetum* Soó 1964 emend. 1971; *Pinetum sylvestris cultum; Piceetum cultum; Robinietum cultum*; oak-wood pasture (P45-ÁNÉR categories).

The majority of the macrofungi species, -especially hardly identificable taxa- were documented with fungaria and photo. In addition, light-microscope photos were taken by Herpell-method of the spore of about 200 fungi species. The work of Simon (2000) was used for the identification of vascular plants.

The taxonomic identification of the macrofungi species list was on the basis of the works of Alexopulos et al. (1996) and Krieglsteiner (1991, 1993), the mark of species name on the basis of the current Index Fungorum (CABI 2013). The work of Arnolds et al. (1995) was used for the identification of the oecological groups. The mark of conservation status of the macrofungi (IUCN categories) was made by the work of Rimóczi et al. (1999).

The evaluation of the myco-coenological samples was made using the dominance, the total density of the fruiting bodies, the average density of the fruiting bodies per year, and the total temporal frequency. For comparison of macrofungi assemblages of sample plots, the classification data were calculated by group average (UPGMA) method and Sorensen coefficiens. The calculation of ordination data was made by principal coordinate analysis (PCoA) and Bray-Curtis coefficiens using the SYNTAX 2000 package (Podani 2001).

Rank-abundance curves based on the data of the different sampling plots were compared as suggested by Whittaker (1979). The numbers of fruitbodies of terricolous- and lignicolous macrofungi were analyzed separately because of the different properties of these groups. All analyses were done by the NuCoSa package (Tóthmérész 1993). Scale-dependent characterization of diversity, based on the data of sampling plots, was carried out by Rényi's generalized entropy-type diversity profile calculation.

Species composition of plant and fungal communities was compared using the Mantel test based on Sorensen (binary data) and Bray-Curtis (abundance data) dissimilarities (Legendre and Legendre 1998). Relationships of diversity, abundance and naturalness of the vegetation types and fungi assemblages were studied by generalized linear models (Crawley 2007) All analyses were carried out in R version 2.9.2 (R Development Core Team 2009) using the vegan package (Oksanen et al. 2009) for rarefaction and calculating diversity and evenness values, and the car package (Fox 2009) for F tests.

The sample sites were characterized by the „critically endangered" (IUCN 1), the „endangered" (IUCN 2), the „vulnerable" (IUCN 3) and the „lower risk" (IUCN 4) species categories on the basis of the Red List (Rimóczi et al. 1999). The semi-natural and degraded vegetation types were compared on the basis of species number of macrofungi and Red list fungi as well as degradation store calculated based on vascular plants.

Establishing the indicator macrofungi of the sample sites and the characterization of the investigated stands with indicator macrofungi were made based on own field observations and references.

The characterization of coenological and habitat of the vegetation types was made by own coenological samples. For coenological identification the works of Borhidi and Sánta (1999) as well as Borhidi (2003), for characterization of forest types on the basis of Mayer (1968) were made. The vegetation types were evaluated by oecological indices and the social behaviour types (Borhidi 1995), based on flora and abundance. The rate of the disturbance tolerant species found in coenological samples was calculated on the basis of Morschhauser (1995).

The comparison of the vegetation of the sample sites was made by multivariable analysis of presence-absence data using the SYNTAX 2000 package (Podani 2001) similarly to myco-coenological samples. The classification data were calculated by group average (UPGMA) method and Jaccard coefficiens. The calculation of ordination data was made by principal coordinate analysis (PCoA) and Bray-Curtis coefficiens. The analysis of the soil samples was made on the basis of Hungarian standard in the matter of some principal parameters.

III. NEW SCIENTIFIC RESULTS

The dissertation presents new data in the matter of funga and plant associations of the Belső-Cserehát.

1. Thesis group: The funga

The macrofungi species list of the Belső Cserehát based on the sample sites, grouping of the fungi species on the basis of substratum, as well as an establishment of the indicator macrofungi were made.

In the Belső-Cserehát during the mycological field survey totally 442 macrofungi taxa (436 species and 6 varietas) were recorded with 2261 occurrence data. In this area mycological survey has not been made yet hence all data of the fungi species list are information values. In the Belső-Cserehát, the number of documented taxa is 19 % of the known macrofungi taxa (2337 taxa) in Hungary. This number is relatively significant because higher species number compared to Belső Cserehát were detected from Börzsöny (613), Mecsek (523), Őrség (553) and the thoroughly researched Aggteleki karsztvidék (526) (Locsmándi 1993; Vasas and Locsmándi 1995; Pál-Fám 2001; Benedek 2011). However, these areas on the one part are bigger than the Belső-Cserehát, on the other hand the majority of these are covered with semi-natural forests and have more precipitation. Accordingly, these areas produce favourable conditions for macrofungi species.

In the funga of the Belső-Cserehát based on substratum dependence, the number of the mycorrhizal species is the highest (204), but the number of soil (105)- and wood saprotrophic species (97) are significant, too. The number of the necrotrophic parasites is relatively low. The number of saprotrophic on other plant remains (9), the biotrophic parasites (1) and the species connected to moss (1) are very low.

In the study area, 56 indicator species were detected. Two of them lack forestry activities; one old forest stands; two the initial phase-, 5 the optimal phase- and 6 the final phase of wood decomposition; 1 higher lime content; one disturbation; 10 soil nitrogen increase; one trampling; one pasturing; 4 low in nutrient grassland; one xerofil habitat indicate. 13 species connected to humus, 21 to leaf litter, and 1 is a parasite on moss (some species are multi-indicators).

2. Thesis group: The vegetation types

<u>2.1. Detected vegetation types from the Belső-Cserehát</u>

Previously, in the Belső-Cserehát phytocoenological surveys were not made hence vegetation units had to be documented. During the phytocoenological surveys totally 418 vascular plant taxa were recorded which are floristical data, too. Following plant associations could be identificated on the basis of coenological samples: *Quercetum petraeae-cerris* Soó 1963; *Carici pilosae-Carpinetum*

Neuhäusl & Neuhäuslová-Novotná 1964 em. Borhidi 1996; *Melittio-Fagetum* Soó 1964 emend. 1971; *Pinetum sylvestris cultum; Piceetum cultum*.

The zonally developed plant association of the Belső-Cserehát is the Turkey oak forest. Some of the investigated stands developed on brown forest soil can be characterized with the *Quercus robur*, *Acer campestre* without dominant species in the canopy layer and *Acer tataricum, Ligustrum vulgare, Crataegus monogyna, C. oxyacantha* in the shrub layer. In its drier stands the *Quercus pubescens* s.l. is frequent however, in the mesofil stands the *Carpinus betulus, Fraxinus excelsior* are typical. Its herb layer is featureless. It consists of many forest and disturbance tolerant species as well as some light-demanding or xero-tolerant species (*Festuca rupicola, F. valesiaca, Brachypodium pinnatum, Carex flacca, C. humilis, C. michelii)*, in more mesofil habitat with early spring geophyton aspect (*Corydalis cava, C. solida, Ficaria verna)*. In these stands the significant occurrence of *Quercus robur*, *Acer campestre* and *Acer tataricum* may refer to the fact that *Aceri tatarici*-and *Aceri campestri-Quercetum roboris* forests occurred in the large area formerly. The actual Turkey oak forests turned into featureless in consequence of the management and changes during the last centuries.

The hornbeam-oak forest stands developed on brown forest soil with clay illuvation and slope sediment soil on loess are extrazonal, managed and changed significantly by forestry. These stands show frequently transition towards the Turkey oak forests.

In the Belső-Cserehát the oak-wood pastures have significant natural values. These areas remaining after the abandonment of the grazing become more and more conspicuous as protected areas nowadays, Europe wide. The investigated stand is characterized by alternation of old trees in small groups or standing alone and patches of grass and a herb layer rich in species. These cannot be classified according to coenotaxa, hence they can be identified by P45 ÁNÉR categories. The Irota oak wood-pasture has been formed from turkey and hornbeam oak forests by deforestation and grazing. The investigated stand had developed on slightly acid brown forest soil with pseudogley.

In the Belső-Cserehát the beech forest is rare. It is found only in extrazonal-edafic conditions. The investigated beech forest stand is situated on a steep (30-40 degree) in north slope. Its soil type is shallow brown rendzina with calcareous screes which pH is slightly basic. It is an old grown forest in which the growing stock belongs to several age groups. Physiognomy of the stand can be characterized by 150-years-old trees. The stand has not been managed by the forestry because of its soil protecting role, therefore there are a lot of stumps and deadwood decomposed to different degrees. This is the characteristic of the unmanaged semi-natural stands.

The alien Scots pine plantation was formed secondarily, planted by forestry mainly in the place of Turkey oak forests. Its soil type is brown forest soil with clay illuvation on loess whose pH is acid. The growing stock of the canopy layer belongs to several age groups with a few old trees.

The Norway spruce plantations are rare in the Belső-Cserehát. The Norway spruce stand has been planted in the place of a hornbeam-oak forest. The soil type is brown forest soil with clay illuvation on loess which pH is slightly acid.

Its growing stock belongs to one age group, which is about 30-40 years old. At present the stand has not been managed by the forestry, therefore there are a lot of stumps and deadwood.

The locust-tree plantations are frequent in the Belső-Cserehát. The canopy layer of the investigated stand consists fully of Robinia pseudoacacia, the shrub layer is absent. There are weeds as well as disturbance-tolerant species in the poor herb layer.

2.2. The habitat indication and the naturalness of the vegetation types

Among ecological indices on the basis of the soil moisture index, the majority of the plant associations are semihumid habitats however, the turkey-oak forests, the Scots pine plantation and the oak-wood pasture are drier. On the basis of the soil reaction, index soils of the habitats are neutral and slightly basic which refer to higher pH than the results of the soil examination would predict. The difference may derive either from the relativeness of the phytoindication or from the generalization of the analysis results conducted at the same time. The spectra of the nitrogen index is the widest among all indices which refers to the most various habitats in nutrient respect. Especially the Scots pine plantation indicates extreme habitat in consequence of former grazing. On the basis of the beech- and hornbeam-oak, forests are richer in nutrients than other plant communities. Conversely, the turkey-oak forests and oak-wood pasture especially are poorer in nutrients.

On the basis of the social behaviour types, the plant associations can be ranked according to naturalness: the beech forest is natural, the turkey-oak-, Norway spruce and hornbeam-oak forests are slightly degraded, while the flora of the oak-wood pasture and Scots pine plantation are medium disturbed on average.

3. Thesis group: Characteristics of the fungi assemblages

Grouping the macrofungi assemblages of the investigated vegetation types, description of the vegetation types are new results in this area connection. The comparison of the macrofungi assemblages on the basis of the species number, diversity, oecological groups has new results in the Belső-Cserehát connection.

3.1. The grouping of the fungi assemblages

The classification made on the basis of species set of terricolous macrofungi shows the beech sample plots separated from other plots. In the unmanaged old stand, the terricolous macrofungi assemblage consists of some rare species than in other vegetation types. On the other hand there are some species which can be found only in this vegetation type. Other groups are evolved on the basis of the habitat.

The ordination made on the basis of species set of terricolous macrofungi shows the sample sites form groups on the basis of common, widespread species with high- and medium abundance. Probably, the terricolous macrofungi assemblages (soil saprotrophic and ectomycorrhizal species) depend especially on habitat conditions (climate, host tree species, age of trees, physical and chemical properties of the dead fallen leaves and soil) (Bujakiewicz 1989; Pál-Fám et al. 2002; Fodor 2003).

The classification and ordination also made on the basis of species set of lignicolous macrofungi shows the deciduous sample sites in separate group from the coniferous sample sites. The species composition of lignicolous macrofungi assemlages is mainly influenced by the composition of trees of plant associations (Bujakiewicz 1989; Fodor 2003).

3.2. Detected fungi assemblages in the Belső-Cserehát

In the Belső Cserehát, the detected macrofungi assemblages are newly established units considering that such surveys have not been made yet in large area (for example Északi Középhegység). The coenosystematical state of these fungi assemblages can be established only by myco-coenological surveys of vegetation types of larger area.

In the vegetation units based on substratum-dependence two fungi assemblages can be separated: terricolous- and lignicolous macrofungi assemblages.

On the basis of the coenological indices the terricolous- and lignicolous macrofungi assemblages of the semi-natural beech forest have the most characteristic structure among the researched stands. Its terricolous macrofungi community consists of some species which are indifferent to plant associations, dominant species finding deciduous forest, local character species as well as rare species can be found only in this vegetation types. The terricolous macrofungi assemblage of the Norway spruce plantation has a sufficiently characteristic structure because beside the frequent and indifferent to plant associations species, some character- and rare species attaching to *Picea abies* were found in this stand. However, its lignicolous assemblage has a simple structure. The terricolous- and lignicolous macrofungi assemblages of the oak-wood pasture show a simple structure which has not been formed yet. The terricolous macrofungi assemblages of the hornbeam-oak- and Turkey oak forests have no characteristic structure with widespread, frequent species without character species. In these stands, the structure of lignicolous assemblages has not been formed yet due to the low species number. The terricolous macrofungi assemblage of the Scots pine forest shows a simple structure. Among its frequent species, the pine connected ones play a significant role. The lignicolous assemblage has not been formed yet due to the low species number.

3.3. Coenological characteristics of the fungi assemblages

Species number

Species numbers of the sample sites have differences which may occur due to different habitat conditions and naturalness. The favourable microclimatical conditions of the habitat and the substratum variedly decomposed in different degrees and species set may result in high species number (137 species) in semi-natural, old forest stand, for example in the case of the beech sample plots. However, it may result a similar species diversity when such alien tree species are relocated which are able to grow mycorrhizal with several types of fungi, and the indigenious samples can remain, as shown by the spruce example (137 species). If the replacement is done with trees out of the region which lack mycorrhizal partners, and even the site is changed in an unfavourable way for fungi, the number of species is very low, as shown by the Robinia example (28 species).

In the managed, slightly degraded and disturbed as an average stands the fruit-body numbers of the sample plots show similarity with each other however, these values are significantly lower than the unmanaged, reserve-like deciduous forests. The fruit-body numbers of the beech forest and the oak-wood pasture show similarity to each other, while the fruit-body number of the Norway spruce plots is extremely high because of the high abundance of *Trichaptum fuscoviolaceum*.

Diversity

The structure and diversity of terricolous macrofungi assemblages decreased in following order: beech forest, Norway spruce plantation, oak-wood pasture. The structure and diversity of terricolous macrofungi assemblages of the moderately disturbed turkey-oak forests and hornbeam-oak forests are similar. The Scots pine forest has the most simple structure and the lowest diversity among the researched vegetation types. On the basis of the results it can be established that the diversity and structure of the terricolous macrofungi assemblages are mainly affected by climatic and habitat conditions and the degradation of the plant associations to a lesser degree (Rudolf et al. 2012).

The lignicolous macrofungi assemblage of the beech forest is more complicate and diverse than the Norway spruce plantation which has more homogeneity. The nyésta and abaújlak forest types are young or mature. The quantity of the available substrate is not sufficient for the development of a wood-inhabiting fungi assemblage. The diversity of the lignicolous macrofungi strongly depends on the presence, quantity and quality of deadwood (Kost and Haas 1989, Siller 2004) accordingly, the form and degree of forest management, as well as the age of the growing stocks (Arnolds 1988) affect species set and diversity of the fungi community.

Functional groups

In the case of in detail investigated vegetation types the rate of the mycorrhizal species is the highest. The proportion of the mycorrhizal species is increased by the number of tree species formed by some mycorrhizal relationships. The rate of lignicolous macrofungi shows similarity to the value of the managed deciduous forests, excluding Scots pine forest and oak-wood pasture. In the beech forest, this rate —since unmanaged stand— is low. In the turkey-oak- and hornbeam-oak forests proportion of the necrotrophic parasites show similarity to the managed deciduous forests. This rate was the highest in the beech forest, whereas in the planted coniferous forests (Scots pine- and Norway spruce forests) as well as the oak-wood pasture was the lowest. This is due to the more natural and older forests forming a more suitable habitat for necrotrophic parasites depending significantly on the habitat degradation than the alien plantations. In the majority of the habitat, the rate of the soil saprotrophic is higher than managed deciduous forests, especially in the case of the coniferous forests. However, in the beech forest the rate of the soil saprotrophic falls in with managed deciduous forests.

Nevertheless, on the basis of the abundance (except for oak-wood pasture) the rate of the wood- and soil saprotrophics is higher than of the mycorrhizal species. The rate of the soil saprotrophic may be increased by the accumulation of dead organic substratum. However, if the litter decomposes slowly due to unfavourable microclimatic conditions, therefore, the abundance of the terricolous species may be reduced. The rate of soil saprotrophics may be increased by degree of the habitat degradation (Rudolf and Pál-Fám 2005). On the basis of the fruit-body number, in the majority of the investigated stands the proportion of the necrotrophic parasites decreased, moreover, this functional group disappeared in the hornbeam-oak forest.

The functional spectra based on fruit-body numbers is more susceptible indication of the different human activities.

4. Thesis group: The relationship between vegetation and macrofungi assemblages

According to the Mantel tests, there is a congruence between the composition of plant and fungal communities. The composition of terricolous fungal communities was more strongly related to plant communities than lignicolous fungal communities, because due to forest management dead-wood is almost absent from the studied plots.

Exploring of diversity of vegetation and macrofungi assemblages shows that species richness of macrofungi assemblages proved to be independent from the diversity and degradation of vascular plant communities. Therefore, diversity of vascular plants (including richness and evenness) cannot be used as the proxy of macrofungi diversity: neither diversity values, nor their components: species richness and evenness. The lack of positive correlation between the diversity of vascular plants and macrofungi assemblages may be attributed to: 1. Small-sized habitats were sampling within a relatively small and fragmented area. 2. Due to the pauperization of European flora during the Ice Age, even the most diverse European forests are more species poorer than temperate forests in other continents. This narrower range of tree diversity values makes hard to find a significant macrofungi-plant relationship. 3. Different fungal groups may respond different environmental factors and may correlated to different proxies.

Macrofungi abundance is negatively related to plant richness and independent from plant evenness. In the case of the Norway spruce plantation and the Oak-wood pasture degree of negative correlation is remarkable. Plots in the Norway spruce plantation show low plant diversity and evenness, while the abundance of macrofungi had high values which are mainly caused by the high number of fruitbodies of the lignicolous species. The Oak wood-pasture is the richest in vascular plants, but the fungal abundance is low there. There are several possible explanations for low fungal abundance: warmer and drier microclimatic conditions, the abandonment of the grazing, the species richness of arboreal vegetation.

The abundance of terricolous macrofungi depend on degree of degradation of vegetation but it does not influence the abundance and diversity of lignicolous macrofungi. At low disturbance level (indicated by the degradation of vegetation) the number of sporocarps of terricolous macrofungi is low. The increase of the degradation of the vegetation is followed by the increasing abundance of terricolous macrofungi up to a moderate disturbance level. However, a further increase of disturbance causes a decrease in the number of sporocarps. Obviously, the fructification of macrofungi speeds up in case of increase of disturbance, as an answer to this pressure. However, beyond a certain disturbance level, the fructification is blocked then ceased. This pattern appears only in terricolous macrofungi, because the occurrence of lignicolous macrofungi strongly depends on the presence, quantity and quality of deadwood. Therefore, the intermediate disturbance hypothesis may be detected in the case of the terricolous macrofungi, on the basis of the abundance. This result is the first on international level in connection with the macrofungi.

5. Thesis group: The conservation status of the macrofungi of the Belső-Cserehát and the investigated stands.

The number of the macrofungi species of the Belső-Cserehát is significant in conformity with other areas however, some macrofungi species may be absent from the area. This can be concluded on the basis of the examination of the functional groups of the vegetation types. The rate of the necrotrophic parasites is low. At the same time the species set is contaminated by alien macrofungi species which were located by plantation of the alien trees, but the species set has not been increased by unindigenous invasion species. Thus the funga of the Belső-Cserehát shows disturbance.

From the aspect of environment protection it is important to declare that 243 species (56% of the total species) are located in the study area which are “endangered” according to the Red List plan (Rimóczi et al. 1999), which also determines the funga based value of the area. 7 species (1,6% of the total species number) belong to the „critically endangered” (IUCN 1), 18 species (4,1% of the total species number) to the „endangered” (IUCN 2) and 191 species (44% of the total species number) to the „vulnerable” (IUCN 3) categories. The number of the „lower risk” (IUCN 4) species is 27 (6,2% of the total species number). Tha rate of the 'higher risk' macrofungi is greater in several sites (Mátra, Bükk, Szigetköz, Zemplén), and only in Mecsek and Börzsöny was this number even higher.

Species on the Red List occur in large numbers in the Norway spruce plantations besides the fungi assemblages of the natural vegetation types. In their evaluation, the specialists related to the spruce pine should not be taken into account. The planted but not homogeneous Norway spruce forests have a unique position concerning the fungal protection, as providing a microclimate in the habitat they can save valuable species. However, the settling spruce pine specialist species may cause species change. The gradual transition of these stands is highly reasonable from a fungal protective point of view. The planted pineforests, Robinias, and the intensely treated, ingenuine forests, which give the characteristics of the main forest types of the Belső-Cserehát, lack that macrofungi species, therefore the Red List species, as well. The Belső-Cserehát is highly valuable from a fungal-environmental protective aspect nationwide which consists of regions to be protected among the mostly depreciated areas.

IV. Practical applications of the results

The funga, the phyto- and fungi coenological data of the study area may be applied in GIS analyes and for monitoring examinations. The macrofungal assemblages and the index derived from their data provide a basis for comparison in the course of the examination of fungi assemblages of the other areas.

Problems may occur during analyzing and comparing the diversities calculated from the basic data concerning the number of individuals and cover. These should be solved by applying the parametric diversity families instead of the single diversity index. Greater differences occurring in the abundance could be solved by the evaluation of random subsamples. The application of generalized linear models is suggested in any kinds of complex ecological examinations, when different assemblages and their relationship is examined.

In Hungary, there are macrofungi that are already protected or will be protected according to the Red List plan. However, there cannot be found any specifically protected areas which are developed based on the location of macrofungi. These should be marked as soon as possible. According to the analyses it can be established that the vascular plants cannot be used as substitute taxon for the surveys based on macrofungi. In terms of the Belső-Cserehát, the beech forest of Szendrőlád and the oak-wood pasture of Inota are suggested to be marked as protected areas based on present examinations. Further examinations are proposed on some other valuable oak-wood pastures of the Cserehát, some of which are protected (oak-wood pastures in Gagybátor and Viszló).

The removal operations of forestry wood (live and dead) should be limited in the protected areas with macrofungi, and the diversity should be provided. The abundance of macrofungi is the largest in case of medium disturbance, therefore the presence of humans and the appropriate level of disturbance is necessary.

Publications

I. Publications related to the dissertation

Rudolf, K., Morschhauser, T., Pál-Fám, F., Botta-Dukát, Z. (2013): Exploring the relationship between macrofungi diversity, abundance, and vascular plant diversity in semi-natural and managed forests in North-East Hungary. Ecological Research (DOI 10.1007/s11284-013-1044-y) (**2011. IF: 1,565)**.

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