Communities of larger fungi of ombrotrophic bogs in West Siberia

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SUMMARY

Bogs are common ecosystems in the Taiga of West Siberia. Little is known about mycological diversity in these important ecosystems. This article summarises the results of a two-year study of the macrofungi in two bogs near the town of Khanty-Mansiysk. Sporocarps were collected in 20 plots (about 300 m^2) established in Mukhrino Bog as well as during random walks in Mukhrino Bog and Chistoe Bog in the late summer–autumn of 2012 and 2013. The plots were established in two common bog habitats representing the *Ledo-Sphagnetum fusci* (LS) and *Scheuchzerio palustris-Sphagnetum cuspidati* (SS) plant community associations. A total of 59 distinct fungal taxa were collected from the two bogs, with the LS association having a higher species richness and diversity than the SS association (50 taxa *vs*. 16 taxa and 30–40 taxa per 1000 m^2 *vs*. 6–10 taxa per 1000 m^2, respectively). Each of the two plant community associations has its own characteristic fungal taxa, with the LS association having 13 characteristic taxa and the SS association having five. Nearly two thirds of the fungal taxa are saprotrophic, mainly of *Sphagnum* spp., while others are mycorrhizal, mainly with *Pinus* spp. Most taxa were collected fewer than ten times during the study period and, hence, are considered rare and may need to be recognised for conservation programmes in this region.

KEY WORDS: ecology of fungi; fungal diversity; macrofungi; oligotrophic bog; peatland

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INTRODUCTION

Peatlands, especially bogs, are common ecosystems in West Siberia, where they stretch almost continuously across the central and northern Taiga region (Walter 1997). The coverage of peatlands in West Siberia has been estimated at 68.5 × 10^6 ha (about 24.5 % of the total area). In the Middle Taiga zone, peatland reaches its maximum coverage, about 34.5 % (Peregon *et al.* 2009). The classification of peatlands in this region is based on their trophic status and dominant plant communities (Liss *et al.* 2001); all oligotrophic peatlands include 14 types of biogeocoenoses. Subsequently, Lapshina (2010) developed a floristic classification of peatlands for the south-eastern part of West Siberia, identifying two community classes for ombrotrophic vegetation, namely: *Scheuchzerio-Caricetalia nigrae* and *Oxycocco-Sphagnetea*. While floristic work on West Siberian peatlands has progressed considerably, comparatively little is known about the mycological communities of peatlands in this region.

The fungal communities of peatlands have been studied for more than 50 years. At the beginning of the twentieth century, peat was thought to be sterile. Since then, Waksman & Purvis (1932) have shown that fungal communities as well as fungal viability and the ability of fungi to decompose the constituents of peat vary between different peat layers, and Christensen & Whittingham (1965) have shown that fungal communities differ between mineral and organic soils. From a functional perspective, the role of fungi in the decomposition of organic matter was thought to be less important than that of bacteria (Waksman & Purvis 1932, Zaguralskaya 1967), but this view has shifted over the past decade. Fungi are now thought to be significant amongst the decomposer communities in peat, particularly in the oxic peat horizon, the acrotelm (Thormann & Rice 2007). Fungi also occur in the anoxic peat horizon, the catotelm, but they grow only slowly in this horizon due to lack of oxygen or low oxygen concentrations (Golovchenko & Polyanskaya 1999, Kurakov *et al*. 2008, Grum-Grzhimaylo 2013). Consequently, most of the fungal biomass occurs in the acrotelm. It has been assessed using a variety of methods including luminescent microscopy (Golovchenko *et al*. 1993, Golovchenko *et al*. 2002), counting of colony-forming units (Zaguralskaya 1967, Thormann *et al*. 2001) and by phospholipid fatty acid concentration (Sundh *et al*. 1997, Jaatinen *et al*. 2007, Andersen *et al*. 2010). About 600 fungal taxa have been reported from peatlands, with a similar taxonomic richness of ascomycetes and basidiomycetes (Thormann & Rice 2007). The commonest studies of fungi in peatlands have been incidental surveys for macromycetes, which have contributed most of our knowledge about peatland basidiomycetes (e.g. Salo 1979, Lange & Lange 1982, Redhead 1989, Salo 1993, Wurtzburger *et al*. 2004, Stasinska 2011); whereas our knowledge of peatland ascomycetes arises mostly from culture-based research (e.g. Thormann *et al*. 2001, 2003; Golovchenko *et al*. 2002, Kachalkin *et al*. 2005, Grum-Grzhimaylo 2013). There are records of about 800 fungal taxa in the Khanty-Mansiysk region (Filippova 2010), of which about half are lignicolous taxa and about 300 taxa are members of the Agaricales, known from forest ecosystems. Peatland-specific taxa are relatively unrecorded, however. Fungal surveys are important components of regional biodiversity inventories, as fungi contribute significantly to the biodiversity of an ecosystem. Ultimately, having a better understanding of the biodiversity of fungi at local or regional scales facilitates the development of conservation programmes that aim to maintain biodiversity at those scales.

Macromycetes have been investigated in numerous peatlands, and about 300 taxa have been reported globally (Thormann & Rice 2007). No more than 150 taxa have been reported from a single peatland class, and treeless bogs generally have a less diverse fungal flora than treed fens. For example, Favre (1948) reported about 400 taxa from different peatlands in the Jura mountains and Stasinska (2011) recorded a total of 191 fungal species in the raised and transitional bogs of Pomerania (Poland), including 12 taxa from a *Rhynchosporetum albae* community class, 15 from a *Caricetum rostratae* community class, 102 from a *Vaccinio uliginosi-Pinetum* community class, and 121 from a *Vaccinio uliginosi-Betuletum pubescentis* community class. In a study of two mountain bogs in the Czech Republic, Holec (1997) described two fungal communities with 21 and 19 species. About 100 taxa were reported from peatlands in Central Finland (Salo 1979), and 70–100 taxa were reported from different peatland classes in Romania (Tanase 2000, Chinan & Tanase 2009, Chinan 2011). Functionally, the macromycete community in peatlands consists primarily of ectomycorrhizas and saprotrophs of various organic constituents such as *Sphagnum*, peat and vascular plant litters (Favre 1948, Thormann & Rice 2007, Stasinska 2011).

Because many of the fungi found in peatlands are saprotrophic (e.g. Thormann 2006, Thormann & Rice 2007), it is important to understand their potential impacts on the carbon dynamics of peatlands, which form significant landscape components in the West Siberian plain. To that end, detailed mycological surveys were initiated in several peatlands near Khanty-Mansiysk in the early 2000s, focusing on phylloplane yeasts of *Sphagnum* spp. and vascular plant species (Kachalkin 2010), micromycete communities of different peat layers (Grum-Grzhimaylo unpubl. data), discomycetes of vascular plant and woody litters (Filippova 2012), and lignicolous macromycetes of common woody substrates in treed bogs (Filippova & Zmitrovich 2013). Most recently, autecological notes on several rare species have been published (Filippova & Bulyonkova 2013).

The objectives of this study were to describe the macrofungal communities in two bogs in West Siberia in an effort to gain a better understanding of mycocoenoses and the roles of fungi in these important ecosystems, particularly in relation to the potential impacts of fungi on the global carbon cycle.

METHODS

The study area

The study region is in the vicinity of the town of Khanty-Mansiysk in the central Taiga of West Siberia. The climate is subarctic with short, cool summers and long, cold winters. Snow cover persists for about 180 days in this region. The mean annual temperature is –1.3 °C, the mean temperature of the coldest month (January) being -19.8 °C and the temperature of the warmest month (July) being 18 °C. The total annual precipitation is 553 mm, with 70–80 % of the total annual precipitation falling in the summer months (Bulatov *et al*. 2007).

Study sites

Two bogs were selected for this study (Figure 1). Mukhrino Bog (60.892 °N, 68.674 °E) is on an ancient terrace of the Ob and Irtysh Rivers in the northern part of the Kondinskiy peatland district, of which about 57 % is peatland covered (Ivanov & Novikov 1976, Liss *et al*. 2001). This bog covers an area of about 10 km^2 and is dominated by ombrotrophic plant communities, with transitional plant communities only at the edges of the bog and along watercourses. Chistoe Bog (61.059 °N, 69.466 °E) is on an ancient terrace of the Ob River in the northern part of the Salymo-Yuganskiy peatland district which is about 34 % peatland covered (Ivanov & Novikov 1976, Liss *et al*. 2001). The area of this bog is about 3 km^2 and it is dominated by a complex of ombrotrophic and transitional plant communities.

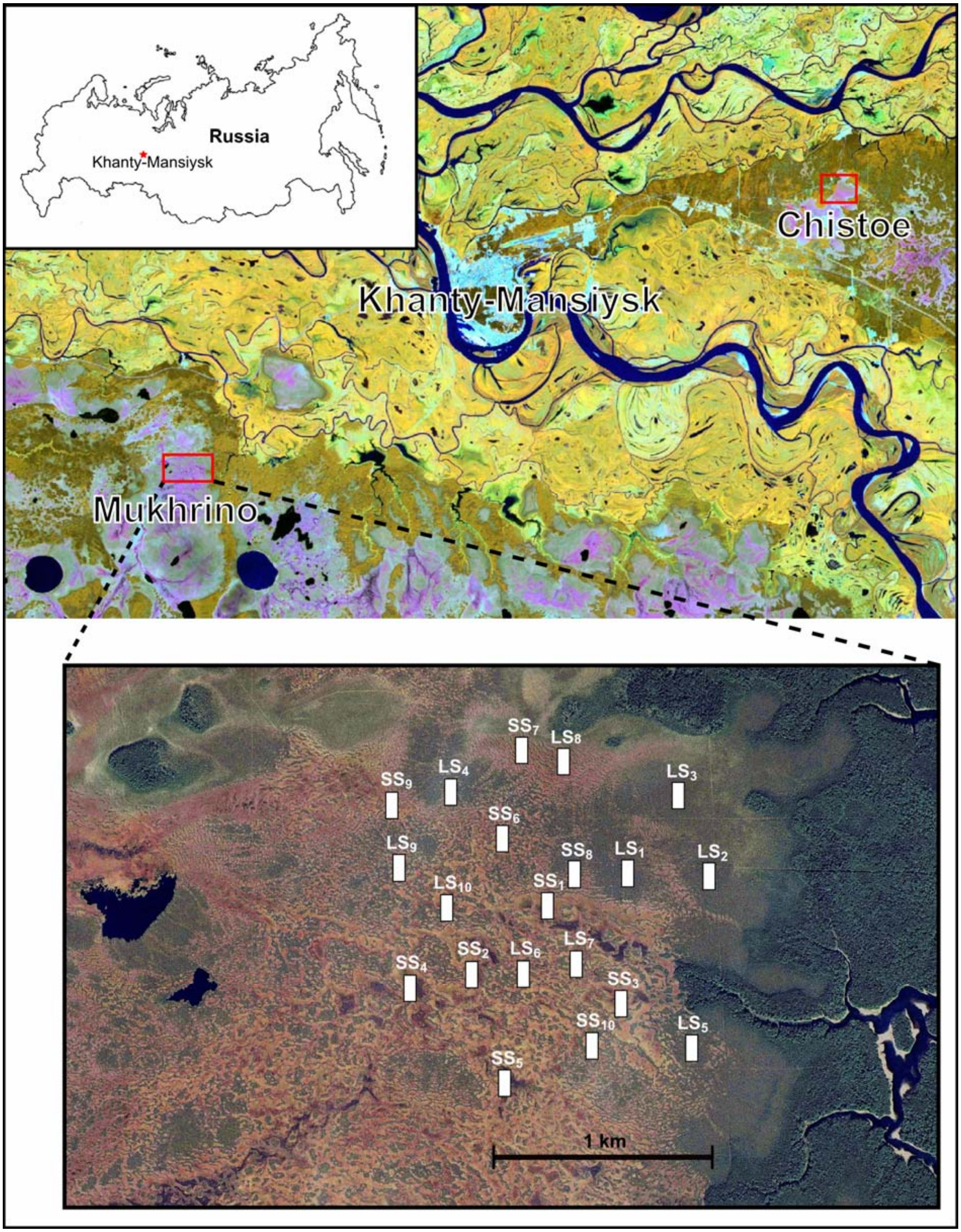

Figure 1. Locations of the two bogs near Khanty-Mansiysk in the Siberian Plain of Russia (upper panel, Landsat satellite image) and the positions of plots in Mukhrino Bog (lower panel, QuickBird satellite image). Plant communities are: SS = *Scheuchzerio palustris-Sphagnetum cuspidati*; LS = *Ledo-Sphagnetum fusci*.

The same two plant communities occurred in both bogs. These were a treed pine-dwarf shrubs-*Sphagnum* community and a graminoid-*Sphagnum* lawn community. The treed pine-dwarf shrubs-*Sphagnum* community was relatively dry, with water table usually 30–50 cm below the moss surface. *Pinus sylvestris* and *Pinus sibirica* dominated the tree stratum, while *Ledum palustre*, *Chamaedaphne calyculata*, *Andromeda polifolia*, *Vaccinium uliginosum*, *Vaccinium vitis-idaea*, *Oxycoccus microcarpus* and *Betula nana* dominated the well-developed dwarf shrub stratum. The herbaceous plant stratum was poorly developed and consisted mostly of *Rubus chamaemorus*, *Eriophorum vaginatum* and *Drosera rotundifolia*. The dominant bryophytes were *Sphagnum fuscum* on hummock-tops, and *Sphagnum magellanicum* and *Sphagnum angustifolium* on mid-hummock and lower hummock positions. According to Lapshina (2010), this was a *Ledo-Sphagnetum fusci* (LS) association from the class *Oxycocco-Sphagnetea*. The graminoid-*Sphagnum* lawn community has developed in water-saturated locations, with water level usually 0–20 cm below the moss surface. The poorly developed dwarf shrub stratum consisted mainly of *Andromeda polifolia* and *Oxycoccus palustris*; the herbaceous plant stratum was dominated by *Carex limosa*, *Scheuchzeria palustris*, *Eriophorum russeolum* and *Rhynchospora alba*; and the bryophyte stratum by *Sphagnum jensenii*, *Sphagnum balticum*, *Sphagnum majus*, *Sphagnum lindbergii* and *Sphagnum papillosum*. Several floristic associations from the class *Scheuchzerio-Caricetea nigrae* were present in this community, the *Scheuchzerio palustris-Sphagnetum cuspidati* (SS) association being predominant.

Sampling design

In the first year of the study (2012), a random walk technique was used in August and September to collect sporocarps of macromycetes from the Mukhrino and Chistoe Bogs. In 2013 this technique was augmented by setting up permanent study plots in the Mukhrino Bog. The study plots were established in each of two distinct oligotrophic plant communities (ten plots in each type). The plots were 100–300 m apart within a circle of radius 1.0 km (Figure 1). The sampling scheme of Mueller *et al*. (2004) was followed in this study. Briefly, small circular sub-plots (5 m^2) were set up along two or three transects at the borders of each of the 20 permanent study plots, resulting in 40–60 sub-plots per permanent study plot. The borders of the circles were defined using a pole and a rope, and the abundance of each fungal taxon encountered was determined by counting its sporocarps within each sub-plot. All plots were sampled from August to September, as sampling at this time yielded the most sporocarps. Half of the plots were visited twice, i.e. at the beginning of the sampling season and again at the end, and the data from these plots were used to examine the temporal variation of fruiting.

The minimum number of sub-plots required to obtain meaningful ecological data was estimated on the basis of species-area curves, which accumulate new species over the sampled area and depend on species identity. These curves were developed from two permanent study plots in each of the two plant community associations, SS$_2$ and LS$_3$ (the pilot plots; Figure 2). Based on data from the pilot plots, the species-area curve in the SS plant community reached its plateau after the inclusion of data from 33 sub-plots (165 m^2). In contrast, the species-area curve in the LS plant community reached its plateau after the inclusion of data from 150 sub-plots (750 m^2). Due to sampling ease in the lawn community (SS) and sampling constraints (dense tree cover) in the treed community (LS), 40–60 sub-plots were set up in both plant communities. Hence, the fungal communities in the treed community may be under-estimated. Species-area curves were developed using the free software EstimateS (Statistical Estimation of Species Richness and Shared Species from Samples) (Colwell 2013).

Entire sporocarps of all fungi encountered in each sub-plot were carefully extracted from their substrates with a knife, transported in plastic bags, placed in a drying oven at 40 °C within 24 hours and left there until dry. All specimens were identified to genus, and species when possible, using morphological characteristics. Microscopic characteristics were observed under a Zeiss Axiostar microscope and stereo-lens with a mounted AxioCam ERc5s digital camera. Samples were mounted in water (vital specimens) or 3 % KOH (dehydrated specimens), and dyed with Congo red when necessary. All specimens were described and photographed according to the standards outlined by Wu *et al*. (2004) and accessioned at the Fungarium of Yugra State University (Khanty-Mansiysk).

Data analyses

For twice-visited sub-plots, the maximum abundance of sporocarps per visit was used to determine the abundance of each species per plot (Arnolds 1992). The nine-partite logarithmic scale of Arnolds (1981) was applied to develop abundance classes, based on sporocarps per 1000 m^2: Class I: 1–3, Class II: 3–10, Class III: 10–

30, Class IV: 30–100, Class V: 100–300, Class VI: 300–1000, Class VII: 1000–3000, Class VIII: 3000–10,000, and Class IX: >10,000 sporocarps per 1000 m^2. The species richness of the fungal community per standardised area (i.e. 1000 m^2) was estimated using rarefaction curves (see later). The same model was applied to estimate species list completeness for each community type by extrapolation of their respective species-area curves. Rarefaction and extrapolation were based on the Bernoulli product model, implemented in EstimateS (Colwell *et al*. 2012). Rarefaction analysis allows the calculation of species richness for a given number of individual samples and is a statistically appropriate analytical approach here because the sample size (number of sub-plots) differed between plots (Hurlbert 1971, Simberloff 1972, Krebs 1989). The resultant curves, which are generated by randomly re-sampling the pool of N samples multiple times and then plotting the average number of species found in each sample, show the number of species found in an ecosystem as a function of the number of samples. Thus, rarefaction analyses generate the expected number of species in a small collection of n individuals (or n samples) drawn at random from the large pool of N samples (Hurlbert 1971, Simberloff 1972, Krebs 1989).

To supplement the rarefaction analyses, Shannon diversity indices, H, were calculated from the abundance data for all sub-plots in each community type (e.g. 280 sub-plots for treed and 290 sub-plots for lawn communities), since rarefaction analyses do not take into consideration species evenness. EstimateS software was used to calculate H and its standard deviation (Colwell 2013).

RESULTS

Species richness and diversity

In 2012 and 2013, 59 fungal taxa (see Appendix) were identified in the Mukhrino and Chistoe Bogs, using a combination of sub-plots (48 taxa) and a random walk method (11 taxa). Similar numbers of taxa were collected in both years (49 in 2012 and 53 in 2013); however, each year had unique taxa.

An estimated 9.4 fungal taxa should have been found in the SS after reaching the plateau of the species-area curve at about 400 sub-plots. In 2012 and 2013, a total of nine fungal taxa were actually found in the SS (Figure 3). Conversely, the fungal community in the LS was probably not adequately sampled, resulting in an under-estimate of species richness, as the species abundance curve reached its plateau at > 900 sub-plots (Figure 3). An estimated 46.7 fungal taxa should have been found in the LS, while only 43 were actually found.

Based on the rarefaction analyses, the unit area species richness was greater in the LS (mean 35 species 1000 m^{-2}, range 30–41 species 1000 m^{-2}) than in the SS (mean 8 species 1000 m^{-2}, range 6–10 species 1000 m^{-2}) (Figure 3). The Shannon diversity index was substantially greater in the LS than in the SS ($H_{\mathrm{LS}} = 2.27$ *vs*. $H_{\mathrm{SS}} = 0.85$, respectively).

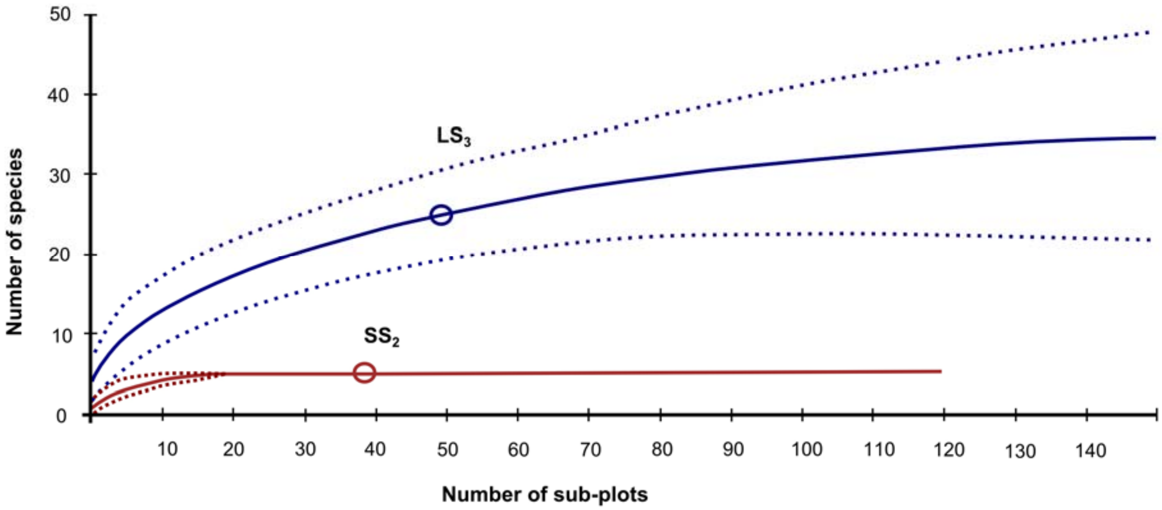

Figure 2. Sample-based rarefaction and extrapolation (by a factor of 3) for two pilot plots with 95 % unconditional confidence intervals for fungi in the *Scheuchzerio palustris-Sphagnetum cuspidati* (SS) and *Ledo-Sphagnetum fusci* (LS) plant community associations in bogs in the Khanty-Mansiysk region, West Siberia, Russia. The circles represent reference samples.

Temporal variation

In both plant community associations, the numbers of sporocarps collected in August and September 2013 differed substantially, with nearly five times as many sporocarps collected in the SS and nearly nine times as many collected in the LS in September than in August (Figure 4). Conversely, species richness in the SS and the LS was similar in August and September (Figure 5).

Mycocoenological characteristics

Scheuchzerio palustris-Sphagnetum cuspidati (SS)
This plant community association had low fungal species richness, with a total of 16 species (nine from the study plots (Table 1) and seven from the random walk method). Most of these species were saprotrophic on *Sphagnum* spp. or mixed graminoid-*Sphagnum* litter, and one taxon

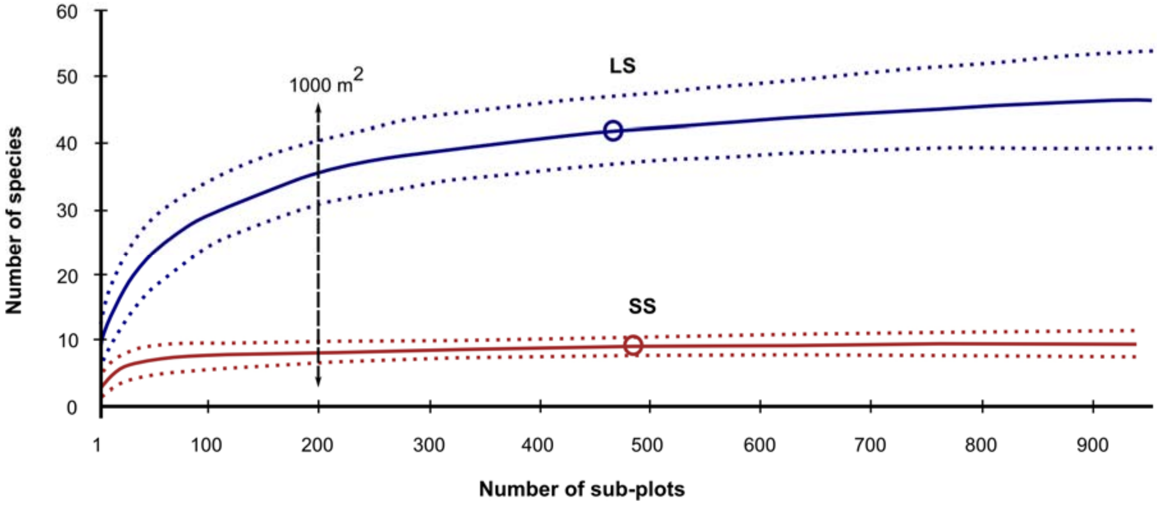

Figure 3. Sample-based rarefaction and extrapolation (by a factor of 2) for generated samples (collected from all sub-plots for each type) for fungi in the *Scheuchzerio palustris-Sphagnetum cuspidati* (SS) and *Ledo-Sphagnetum fusci* (LS) plant community associations in bogs in the Khanty-Mansiysk region, West Siberia, Russia. The circles represent reference samples.

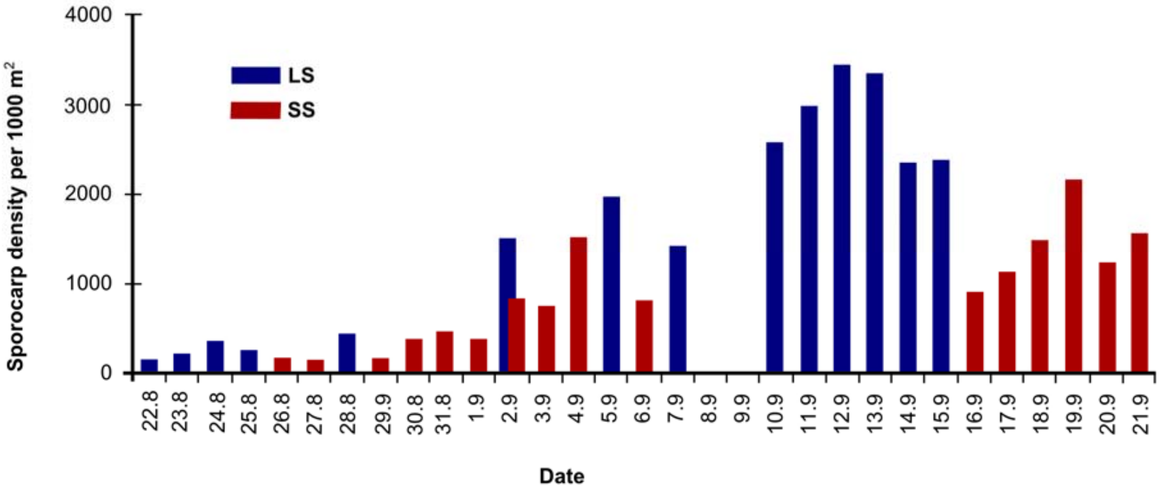

Figure 4. Temporal change in spatial density; sporocarps 1000 m^{-2} in 2013 for fungi in the *Scheuchzerio palustris-Sphagnetum cuspidati* (SS) and *Ledo-Sphagnetum fusci* (LS) plant community associations in bogs in the Khanty-Mansiysk region, West Siberia, Russia.

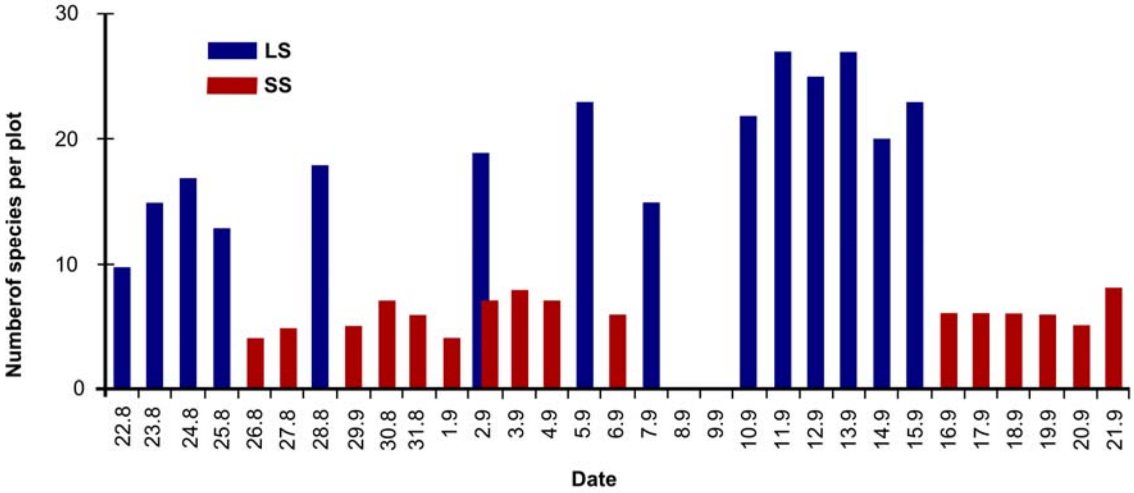

Figure 5. Temporal change in species richness per plot in 2013 for fungi in the *Scheuchzerio palustris-Sphagnetum cuspidati* (SS) and *Ledo-Sphagnetum fusci* (LS) plant community associations in bogs in the Khanty-Mansiysk region, West Siberia, Russia.

(*Tephrocybe palustris*) was parasitic on *Sphagnum* spp. There was substantial variation in the number of sporocarps collected in each of the plots at different times during the year, with a standardised range of 360–2400 sporocarps 1000 m^{-2} (mean 1250 sporocarps 1000 m^{-2}).

Four species, *Ascocoryne turficola*, *Arrhenia onisca*, *Galerina sphagnicola*, and *Hypholoma udum* (Table 1), were registered with high abundance at all plots in the SS and were not seen at all in the LS (Table 2). One species, *Psilocybe turficola*, occurred occasionally in the SS. Three species (*Galerina cerina, Galerina tibiicystis* and *Tephrocybe palustris*) were common in both SS and LS (Tables 1 and 2). Seven taxa were collected outside the study plots using the random walk method. Of these, three species (*Hypholoma elongatum*, *Hypholoma eximium* and *Psathyrella* sp.) occurred among *Sphagnum* spp. in the SS; two (*Gymnopilus fulgens* and *Hygrocybe cinerella*) were collected at hummock bases in transitional zones between two habitats, and two (*Arrhenia sphagnicola* and *Omphaliaster borealis*) were characteristic for LS and only rarely seen in the SS.

Table 1. Average species abundance (sporocarps 1000 m^{-2}) and abundance classes for fungi in the *Scheuchzerio palustris-Sphagnetum cuspidati* (SS) plant community association on bogs in Khanty-Mansiysk region, West Siberia, Russia.

Species	Abundance	Class*
Galerina sphagnicola	928.0	VI
Galerina cerina	107.0	IV
Hypholoma udum	59.7	IV
Ascocoryne turficola	48.3	IV
Arrhenia onisca	41.8	IV
Galerina tibiicystis	36.7	IV
Tephrocybe palustris	23.0	III
Psilocybe turficola	3.5	I
Geoglossum glabrum	0.3	I

* Class I: 1–3; Class II: 3–10; Class III: 10–30; Class IV: 30–100; Class V: 100–300; Class VI: 300–1000.

Most of the species collected in the sub-plots occurred frequently, i.e. they had high abundance classes (IV and higher), with only two species occurring rarely (i.e. Class I; *Psilocybe turficola* and *Geoglossum glabrum*, <10 sporocarps 1000 m^{-2}) (Table 1).

Ledo-Sphagnetum fusci

This plant community association had high fungal species richness, with a total of 50 species (43 from the study plots (Table 2) and seven from the random walk method). Most of these taxa were mycorrhizal with trees (*Pinus sylvestris* and *P. sibirica*) and dwarf birch (*Betula nana*) (21 taxa) or saprotrophic on *Sphagnum* spp. or litter (20 taxa). One taxon (*Tephrocybe palustris*) was parasitic on *Sphagnum* spp. There was substantial variation in the number of sporocarps collected in each of the sub-plots at different times during the year, with a standardised range of 250–2300 sporocarps 1000 m^{-2} (mean 2130 sporocarps 1000 m^{-2}).

Table 2. Average species abundance (sporocarps 1000 m^{-2}) and abundance classes for fungi in the *Ledo-Sphagnetum fusci* plant community association on bogs in Khanty-Mansiysk region, West Siberia, Russia.

Species	Abundance	Class*
Cortinarius obtusus	529.2	VI
Galerina sphagnorum	439.4	VI
Cortinarius huronensis	370.1	VI
Galerina cerina	161.0	V
Cortinarius semisanguineus	112.6	V
Cortinarius flos-paludis	96.1	IV
Hebeloma incarnatulum	66.6	IV
Mycena concolor	59.8	IV
Cortinarius albovariegatus	42.0	IV
Lactarius rufus	36.0	IV
Gymnopus androsaceus	32.5	IV
Cortinarius stillatitius	23.0	III
Gymnopus dryophilus	22.2	III
Cortinarius flexipes	21.2	III
Cortinarius sp. 3	17.0	III
Galerina tibiicystis	12.7	III
Collybia cirrhata	9.6	II
Galerina allospora	9.6	II
Suillus variegatus	7.9	II
Cortinarius vibratilis	6.2	II
Mycena epipterygia	5.4	II
Lactarius helvus	4.5	II
Omphaliaster borealis	4.5	II
Arrhenia sphagnicola	4.1	II
Sphagnomphalia brevibasidiata	4.0	II
Cortinarius sp. 2	3.4	II
Gymnopilus penetrans	3.3	II
Suillus sibiricus	3.2	II
Tephrocybe palustris	3.1	II
Cortinarius sp. 1	2.1	I
Thelephora terrestris	2.0	I
Amanita porphyria	2.0	I
Cortinarius scaurus var. *sphagnophilus*	2.0	I
Lichenomphalia umbellifera	1.5	I
Mycena megaspora	1.4	I
Mycena galopus	1.1	I
Hypholoma udum	0.9	I
Entoloma fuscomarginatum	0.7	I
Cortinarius caperatus	0.5	I
Galerina paludosa	0.5	I
Hygrocybe cinerella	0.5	I
Cortinarius pholideus	0.4	I
Leccinum holopus	0.3	I

* Classes 1–VI are defined as in Table 1.

Of the 50 fungal taxa, only three also occurred in the SS, the rest being restricted to LS. However, because several of the treed bog taxa have also been reported from forests, a determination of LS taxa that are specific to treed bogs must be regarded as dubious. Tentatively, these taxa include *Arrhenia sphagnicola*, *Cortinarius albovariegatus*, *Cortinarius flexipes*, *Cortinarius flos-paludis*, *Cortinarius huronensis*, *Cortinarius obtusus*, *Cortinarius stillatitius*, *Galerina allospora*, *Galerina sphagnorum*, *Gymnopus dryophilus*, *Hebeloma incarnatulum*, *Mycena concolor*, *Omphaliaster borealis* and *Sphagnomphalia brevibasidiata* (Table 3). The ecology and distribution of some of these taxa, e.g. *Cortinarius* spp., is unclear, and they may have a wider ecological niche than the target community of this study.

Seven taxa were collected outside the study plots using the random walk method. These were *Clavaria sphagnicola*, *Hypholoma capnoides*, *Laccaria proxima*, *Lactarius* sp. 1, *Pseudoplectania sphagnophila*, *Russula paludosa*, and *Xeromphalina cornui*. Nearly half the fungal species of this plant community occurred frequently (abundance classes III–VI; Table 2). The three most common species were *Cortinarius obtusus*, *Galerina sphagnorum*, and *Cortinarius huronensis* (530–370 sporocarps 1000 m^{-2}). Fourteen taxa were only rarely collected (Class I); these were *Amanita porphyria*, *Cortinarius caperatus*, *Cortinarius pholideus*, *Cortinarius scaurus* var. *sphagnophilus*, *Cortinarius* sp. 1, *Entoloma fuscomarginatum*, *Galerina paludosa*, *Hygrocybe cinerella*, *Hypholoma udum*, *Leccinum holopus*, *Lichenomphalia umbellifera*, *Mycena galopus*, *Mycena megaspora* and *Telephora terrestris* (Table 2).

Rare obligate peatland species

By examining the presence/absence data of all fungal taxa in this study at the plot sub-level, it was possible to classify the fungal taxa (following Magurran 2004) as 'common' (with more than ten collections in a biodiversity survey) or 'rare' (with ten or fewer collections). Based on this approach, 24 fungal taxa were classified as rare in this study, of which 13 taxa were, as far as we know, obligate peatland taxa. These were *Ascocoryne turficola*, *Cortinarius scaurus* var. *sphagnophilus*, *Entoloma fuscomarginatum*, *Galerina allospora*, *G. paludosa*, *Geoglossum glabrum*, *Hygrocybe cinerella*, *Lactarius helvus*, *Lichenomphalia umbellifera*, *Mycena megaspora*, *Omphaliaster borealis*, *Psilocybe turficola*, and *Sphagnomphalia brevibasidiata* (Table 4).

Table 3. Characteristic fungal taxa for the *Scheuchzerio palustris-Sphagnetum cuspidati* (SS) and *Ledo-Sphagnetum fusci* (LS) plant community associations; taxa that are shared between the SS and the LS; and taxa collected in the two bogs that are also common to forest ecosystems in the Khanty-Mansiysk region, West Siberia, Russia (number of sporocarps 1000 m^{-2}).

Plot no.	Species	SS 1	SS 2	SS 3	SS 4	SS 5	SS 6	SS 7	SS 8	SS 9	SS 10	LS 1	LS 2	LS 3	LS 4	LS 5	LS 6	LS 7	LS 8	LS 9	LS 10
Characteristic of SS																					
1	*Galerina sphagnicola*	790	720	855	50	865	1225	2105	620	1360	690										
2	*Hypholoma udum*		267	145	3	145	5	15	7	3	7					4.0				5.0	
3	*Ascocoryne turficola*	90	120	35	26	165			13	17	17										
4	*Arrhenia onisca*	27	95	30	90	40	63	16		23	33										
5	*Psilocybe turficola*							25	10												
Characteristic of LS																					
6	*Arrhenia sphagnicola*											4	10	4			7	17			
7	*Cortinarius obtusus*											656	668	1096	235	1,264	3	20	400	515	435
8	*Galerina sphagnorum*							17				484	912	952	175	576		90	565	390	250
9	*Cortinarius huronensis*											464	580	588	240	644	83	107	375	340	280
10	*Cortinarius flos-paludis*											132	104	80	75	140	37	3	85	225	80
11	*Hebeloma incarnatulum*											88	120	120	35	190	3	10	30	15	55
12	*Mycena concolor*											28	16	124	10	205			185	30	
13	*Cortinarius albovariegatus*											28	68	72	15	64		3	40	85	45
14	*Cortinarius stillatitius*											28	8	3	45	16	3	7	10	30	80
15	*Gymnopus dryophilus*											20	4	3		5	10	70	65	20	25
16	*Cortinarius flexipes*											36	16		85	10			35	15	15
17	*Omphaliaster borealis*											20				20				5	
18	*Sphagnomphalia brevibasidiata*											4	12	4	5	5				5	5

(continued overleaf)

(continuation of Table 3)

Plot no.	Species	SS 1	SS 2	SS 3	SS 4	SS 5	SS 6	SS 7	SS 8	SS 9	SS 10	LS 1	LS 2	LS 3	LS 4	LS 5	LS 6	LS 7	LS 8	LS 9	LS 10
Occurring in both associations																					
19	*Galerina cerina*	15	353	70	147	375		3	7	87	13	348	224	60	255	175	40	23	85	345	55
20	*Tephrocybe palustris*	7					7	170	37	10				8		10		13			
21	*Galerina tibiicystis*	23.3	3.6	56.7	43.3	3.3	26.7	103.3	40.0	16.7	50.0	6.7		66.7			16.7	36.7			
Species with forest ecology and low prevalence in LS																					
22	*Cortinarius semisanguineus*											160	124	252	115	280	27	3	40	80	45
23	*Lactarius rufus*													20	85				45	210	
24	*Gymnopus androsaceus*												43	8			7	7	255	5	
25	*Cortinarius* sp. 3											12	4	4	50	10			20	30	40
26	*Galerina allospora*											4	4	8	60	15			5		
27	*Collybia cirrhata*											20	24	40		12					
28	*Suillus variegatus*											8				4		7	55	5	
29	*Cortinarius vibratilis*											28	24		5	5					
30	*Mycena epipterygia*												4			50					
31	*Lactarius helvus*																		45		
32	*Cortinarius* sp. 2												20	4							10
33	*Gymnopilus penetrans*												10	10		10		3			
34	*Suillus sibiricus*											10	4		5	10	3				
35	*Cortinarius* sp. 1												16							5	
36	*Thelephora terrestris*													4		8		3	5		
37	*Amanita porphyria*																			10	10
38	*Cortinarius scaurus*												3			10	7				

Species with total mean density < 1 sporocarp 1000 m^{-2}

Lichenomphalia umbellifera, *Mycena megaspora*, *Mycena galopus*, *Entoloma fuscomarginatum*, *Cortinarius caperatus*, *Galerina paludosa*, *Hygrocybe cinerella*, *Cortinarius pholideus*, *Geoglossum glabrum* and *Leccinum holopus.*

Table 4. Number of collections of fungal species and collection frequency based on all fungal specimens collected from two bogs in the Khanty-Mansiysk region, West Siberia, Russia. Rare species with preferential occurrence in bogs are shown in **bold** type.

Taxa	Number of Collections	Collection Frequency (%)
Common Taxa		
Cortinarius obtusus	304	31.3
Cortinarius huronensis	270	27.8
Galerina sphagnicola	227	23.4
Galerina cerina	178	18.4
Galerina sphagnorum	187	19.3
Cortinarius semisanguineus	138	14.2
Cortinarius flos-paludis	117	12.1
Hebeloma incarnatulum	83	8.6
Galerina tibiicystis	70	7.2
Ascocoryne turficola	48	4.9
Cortinarius albovariegatus	57	5.9
Arrhenia onisca	43	4.4
Hypholoma udum	43	4.4
Mycena concolor	36	3.7
Tephrocybe palustris	30	3.1
Cortinarius stillatitius	28	2.9
Gymnopus dryophilus	30	3.1
Cortinarius flexipes	28	2.9
Cortinarius sp. 3	24	2.5
Gymnopus androsaceus	21	2.2
Arrhenia sphagnicola	11	1.1
Cortinarius vibratilis	11	1.1
Lactarius rufus	11	1.1
Rare Taxa		
Gymnopilus penetrans	8	0.8
Galerina allospora	7	0.7
Suillus variegatus	9	0.9
Sphagnomphalia brevibasidiata	7	0.7
Suillus sibiricus	7	0.7
Collybia cirrhata	5	0.5
Cortinarius scaurus **var.** ***sphagnophilus***	5	0.5
Cortinarius sp. 2	5	0.5
Lactarius helvus	5	0.5
Thelephora terrestris	5	0.5
Cortinarius sp. 1	4	0.4
Lichenomphalia umbellifera	2	0.2
Mycena megaspora	3	0.3
Omphaliaster borealis	3	0.3
Psilocybe turficola	2	0.2

DISCUSSION

This is the first study that has examined macrofungal communities in peatlands in West Siberia, augmenting previous studies on phylloplane yeasts of *Sphagnum* spp. and vascular plant species (Kachalkin 2010), micromycete communities of different peat layers (Grum-Grzhimaylo unpubl. data), discomycetes of vascular plant and woody litters (Filippova 2012), and lignicolous macromycetes of common woody substrates in treed bogs (Filippova & Zmitrovich 2013) in that region.

A total of 59 macrofungal taxa were identified in two the plant community associations (LS and SS) on two bogs near Khanty-Mansiysk over a two-year period. Overall, the SS plant community association was characterised by a relatively low fungal species richness, with only 16 fungal taxa recorded. Most of these taxa were saprotrophic on *Sphagnum* spp. or mixed graminoid-*Sphagnum* litter, and most of them occurred frequently in 2012 and 2013. Only two species (*Psilocybe turficola* and *Geoglossum glabrum*) occurred rarely (Table 1). In contrast, the fungal association of the LS plant community was characterised by a substantially higher fungal species richness, with 50 fungal taxa recorded. Most of these were mycorrhizal with *Pinus sylvestris*, *P. sibirica* and *Betula nana*, or saprotrophic on *Sphagnum* spp. or litter, and nearly half of the fungal taxa occurred frequently in 2012 and 2013. The three most common species were *Cortinarius obtusus*, *Galerina sphagnorum* and *Cortinarius huronensis* while 14 taxa, or about 30 % of all species in this plant community association, were only rarely collected (Table 2). From a community analysis perspective, each of the two plant community associations had its own characteristic fungal taxa, with the LS association having 13 characteristic taxa and the SS association having five characteristic fungal taxa (Table 3).

At present, only a few studies have examined macrofungal communities in raised bogs globally (Table 5). Based on these studies, the macrofungal communities in bogs in Pomerania (Stasinska 2011)

Table 5. Previous studies of macrofungus communities in peatlands, and taxon similarities with the present study.

References	Community types	Total number of species reported	No. species shared with the present study
Steklova (1979)	Peat bogs with *Pinus mugho* (*Vaccinio uliginosi-Pinetum mughi* plant community association), Czech Republic.	18	8
Salo (1993)	Drained and virgin bogs with *Pinus sylvestris* and *Picea abies*, North Karelia, Finland.	137	25
Holec (1997)	Two mountain *Sphagnum* bogs with *Pinus* spp., ericoid dwarf shrubs and *Eriophorum* spp., Sumava Mountains, Czech Republic.	35	14
Holec (2000)	Peat bogs, Bohemian Forest, Czech Republic.	49	14
Roberts *et al*. (2004)	Bogs with *Pinus contorta*, *Thuja plicata*, *Tsuga heterophylla*, *Ledum groenlandicum* and *Sphagnum* spp., Vancouver Island, British Columbia, Canada.	69	6
Chinan (2011)	Treed bog with *Pinus sylvestris, Picea abies, Betula pendula* and *Betula alba*, eastern Carpathian Mountains, Romania.	69	16
Stasinska (2011)	Raised and transitional bogs representing eight treeless and two treed associations, Pomerania, Poland.	191	27
Vasutova *et al*. (2013)	Raised bog, Hrubý Jeseník Mountains, Czech Republic.	13	9

and Finland (Salo 1993) are the most similar to those found in West Siberia (overlap of 27 and 25 taxa, respectively). Conversely, the macrofungal communities in bogs in the Czech Republic (Steklova 1979, Vasutova *et al*. 2013) and Canada (Roberts *et al*. 2004) are least similar to this study (overlap of only eight, nine and six taxa, respectively; Table 5). This study included 13 species that had not previously been reported from peatlands (Table 4), of which three species are mycorrhizal with *Pinus* spp. (*Cortinarius stillatitius*, *Hebeloma incarnatulum*, and *Suillus sibiricus*) and the remainder are saprotrophs of *Sphagnum* spp. (*Entoloma fuscomarginatum*, *Galerina allospora*, *G. cerina*, *Geoglossum glabrum*, *Gymnopilus fulgens*, *Hygrocybe cinerella*, *Hypholoma eximium*, *Psathyrella sphagnophila*, *Psilocybe turficola*, and *Xeromphalina cornui*). Both *H. incarnatulum* and *P. turficola* occurred frequently in treed bogs and lawns, respectively, and are possibly restricted to bogs in this region. The other eleven species were encountered infrequently in 2012 and 2013 and may be rare species.

This study showed that plot sizes for macrofungal community analyses need to be tailored for specific plant community associations. The species-area curves showed that plots covering an area of about 200 m^2 are sufficiently large for the SS communities; however, the total plot area needed to be substantially larger in the LS communities (about 800 m^2; Figure 2), as these communities have a substantially greater species diversity than SS communities. Since the same number of sub-plots was established in the SS and LS communities, macrofungal species diversity in the LS community was probably underestimated in this study. The same conclusion was reached by Arnolds (1992), who determined that plot areas for treeless communities should be 500 m^2 but twice as large in wooded communities (1000 m^2).

This is the first study of macrofungal communities in bogs in West Siberia. Owing to the irregularity of fruiting of some fungal taxa, both seasonally and inter-annually (e.g. Mueller *et al*. 2004), continued monitoring of the study plots at Mukhrino and Chistoe Bogs will undoubtedly reveal additional fungal taxa in the future. The preliminary data of this study already showed that some taxa collected in 2012 were not collected in 2013, and vice versa. Ultimately, gaining a better understanding of the fungal communities and their dynamics in peatlands will provide valuable information towards understanding the role of these fungal communities in regional and global carbon dynamics.

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Appendix

Species list with annotations

There follows an annotated species list of the 59 fungal taxa that were collected at the two bogs. Each annotation lists the accession numbers and the year(s) of collection, the relative abundance of the taxon, collection methods (from study plots or random walk collections outside study plots), a general habitat description (including substrate), inferred general ecological role of the taxon, and previous records of the taxon in northern Europe or North America. Taxa that could not be reliably identified to species are marked with asterisks.

ASCOMYCETES

Ascocoryne turficola (Boud.) Korf
2012 - #4066; 2013 - #4403. Several collections made in five locations in the northern and central Taiga (Filippova *et al*. 2013), collected regularly (IV) in plots on lawns (Filippova & Bulyonkova 2013), saprotroph on *Sphagnum* and graminoid litter. Characteristic of SS, but occurring more frequently in the *Hepatico-Rhynchosporetum albae* and rarely in the *Eriophoro vaginati-Sphagnetum baltici*. This species has occasionally been reported from different types of peatlands (fens and bogs) in Europe and North America (Bunyard *et al*. 2008, Van Vooren 2012); also reported from the Leningrad and Moscow regions in Russia. Protected in most countries where it is known to occur, and included in the Red List of Khanty-Mansiysk region (Vasin & Vasina 2013).

Geoglossum glabrum Pers.: Fr.
2013 - #4405. Only a single collection of one ascocarp was made in SS, where it grew on liverworts covering a peaty surface in the central part of an extensive lawn. Saprotroph of *Sphagnum* or peaty substrates. Another location was registered in a mesotrophic bog outside the study plots in the northern part of the region. Reported from *Sphagnum* bogs in northern Europe (Hansen & Knudsen 2000). Included in the Red List of Khanty-Mansiysk region (Vasin & Vasina 2013).

Pseudoplectania sphagnophila (Pers.) Kreisel
2012 - #0136; 2013 - #4228 and #4279. Collected by the random walk method in June–July, on *S. fuscum* hummocks in treed bogs; saprotroph of *Sphagnum*. Reported from *S. fuscum* in northern Europe (Hansen & Knudsen 2000).

BASIDIOMYCETES

Amanita porphyria Alb. & Schwein.
2012 - #4058 and #4111; 2013 - #4416. Rare species (I) in the study plots, but several collections using random walk method, in treed community and at the edge of the bog, forming mycorrhiza with *Pinus*. A species with a wide ecological niche in forests and bogs. Reported in northern Europe from *Pinus* and *Picea* forests (Hansen *et al*. 1992).

Arrhenia sphagnicola (Berk.) Redhead, Lutzoni, Moncalvo & Vilgalys
2012 - #3940 and #3954; 2013 - #4077. Common species (its abundance (II) under-estimated in this study because it fruits earlier), characteristic for treed communities, often among *S. fuscum* and (rarely) on hydrophilic *Sphagnum* spp. Saprotroph on *Sphagnum*. Reported on *Sphagnum* in northern Europe (Hansen *et al*. 1992).

****Arrhenia onisca*** (Fr.: Fr) Quel.
There is taxonomic uncertainty among several *Sphagnum*-inhabiting *Arrhenia* spp. (*A. gerardiana*, *A. sphagnicola* and *A. onisca*) in the literature. In this study, there were two distinct morpho-species: (1) cap light brown, inhabiting hummocks (presently identified as *A. sphagnicola*), growing among *S. fuscum*; and (2) cap dark brown, fruitbody stouter, growing in wetter lawns (presently identified as *A. onisca*). Further taxonomic work is required to elucidate the taxonomy and ecology of this genus in peatlands.
#4398 – 2013. Common (IV) in lawns, on hydrophilic *Sphagna*, characteristic of SS. Saprotroph on *Sphagnum.* In northern Europe, reported on *Sphagnum* in bogs in late summer (Hansen *et al*. 1992).

Clavaria sphagnicola Boud.
2012 - #3745, #3796, #3822, and #4006. Common species in treed communities at Chistoe Bog (random walk method), on hummocks among *S. fuscum*, *S. magellanicum* and *S. angustifolium*, saprotroph on *Sphagnum*. The species was not collected in the study plots, otherwise it could be characteristic of treed communities. Reported from *Sphagnum* bogs in northern Europe (Hansen & Knudsen 1997).

Collybia cirrhata (Pers.) Cumm.
2012 - #3794 and #3863; 2013 - #4415. Common species (II) in treed communities on old sporocarps of some agarics. Species not specific to bogs, occurring wherever its substrate occurs. Very common in the temperate-subarctic zone of northern Europe (Knudsen & Vesterholt 2008).

****Cortinarius*** cf. ***albovariegatus*** (Velen.) Melot
2012 - #3820, #3848, #3938, #3984, #3986, #4040, and #4092; 2013 - #4396. Common species (IV) in treed communities, forming mycorrhiza with *Pinus*. Characteristic of treed bogs. In northern Europe, reported from mesic coniferous forests with *Picea* (Niskanen *et al*. 2008).

Cortinarius caperatus (Pers.: Fr.) Fr.
Collected once in treed community outside plot borders, forming mycorrhiza with *Pinus*. Common forest species, occasionally occurring in bogs. Locally very common in the hemiboreal-arctic zone of northern Europe (Knudsen & Vesterholt 2008), in coniferous and deciduous forests.

****Cortinarius flexipes*** (Pers.) Fr.
2012 - #3765, #3802, #3818, and #3842; 2013 - #4376. Common species (III) in treed communities, forming mycorrhiza with *Pinus*. Characteristic of treed bogs. In northern Europe, associated with deciduous trees e.g. *Fagus*, *Betula*, and *Quercus*, and with conifers, preferably in moist and acidic habitats (Niskanen *et al*. 2008).

****Cortinarius*** cf. ***flos-paludis*** Melot
2012 - #3836, #3961, #3985, #3989, and #3950; 2013 - #4378. Common species (IV) in treed communities, forming mycorrhiza with *Pinus*. Characteristic of treed bogs. Reported in northern Europe with *Picea* and *Pinus*, often among *Sphagnum* (Niskanen *et al*. 2008).

****Cortinarius huronensis*** Ammirati & A.H. Sm.
2012 - #3751, #3769, #3798, #3799, #3800, #3801, #3803, #3813, #3850, #3873, #3942, #3849, #3965, and #4115; 2013 - #4383. Common species (V) in treed communities, forming mycorrhiza with *Pinus*. Characteristic of treed bogs. In northern Europe, reported among *Sphagnum* in fens, bogs or swamp forests, most frequent under *Pinus*, less frequently associated with *Picea* or *Betula* (Niskanen *et al*. 2008).

****Cortinarius*** cf. ***obtusus*** (Fr.) Fr.
2012 - #3963, #3966, #3967, #3968, #3969, #3974, #3976, #3979, #3980, #3987, and #4093; 2013 - #4384. Common species (VI) in treed communities, forming mycorrhiza with *Pinus*. Characteristic of treed bogs. In northern Europe, reported from mesic to damp coniferous forests with *Picea*, sometimes with *Pinus*, *Betula* and *Salix* dwarf shrubs, in needle litter or among mosses (Niskanen *et al*. 2008).

Cortinarius pholideus **(Fr.: Fr.) Fr.**
2013 - #4424. Only a single collection from a treed community, forming mycorrhiza with *Pinus* (also with *Betula*). Forest species, rarely found in bogs. Common in hemiboreal-subarctic zone, less common in western parts of northern Europe (Niskanen *et al*. 2008), where it is reported under birch, often on acid soils.

Cortinarius scaurus var. ***sphagnophilus*** Fr. (Fr.)
2012 - #3778, #3804, #3821, #3930, #3970, and #3983; 2013 - #4397. Rare species (I) in the study plots, but occurring regularly in treed communities in 2012, forming mycorrhiza with *Pinus*. The variation could be characteristic for treed bogs. In northern Europe, reported from coniferous forests on moist, silicious soil and in bogs (Niskanen *et al*. 2008).

Cortinarius semisanguineus (Fr.) Gillet
2012 - #3841, #3936, #3964, and #4089; 2013 - #4389. Common species (V) in treed communities, forming mycorrhiza with *Pinus*. Species with a wide ecological niche, occurring in forests and bogs. In northern Europe reported from humus, needle litter, or among mosses in poor coniferous forests, often on sandy soil in open *Pinus* forests, rarely in other forest types, occasionally with *Picea*, rarely with *Betula* or *Fagus* (Niskanen *et al*. 2008).

Cortinarius cf. ***vibratilis (Fr.: Fr.) Fr.***
2012 - #3923 and #3944; 2013 - #4409. Regular species (II) in treed bogs, forming mycorrhiza with *Pinus*. Species with a wide ecological niche, occurring in forests and bogs. In northern Europe reported from forests with *Picea* and *Pinus* (Niskanen *et al*. 2008).

Cortinarius sp. 1
2012 - #3971; 2013 - #4423. Rare species (I) in treed bogs.

Cortinarius sp. 2
2013 - #4388. Rare species (II) in treed bogs.

Cortinarius sp. 3
2013 - #4407. Regular species (III) in treed bogs.

Cortinarius stillatitius Fr.
2012 - #3744, #3750, and #3819; 2013 - #4417. Regular species (III) in treed bogs, forming mycorrhiza with *Pinus*. Species with a wide ecological niche, occurring in forests and bogs. Reported in northern Europe from *Vaccinium myrtillus-Picea* forests, more rarely among *Pinus*, also in montane *Betula* forests or in *Fagus* forests (Niskanen *et al*. 2008).

Entoloma fuscomarginatum (Fr.) P. Kumm.
2012 - #3749, #3761, #3797, #3823, #3851, #3859, #3871, #4004, #4063, and #4077; 2013 - #4400. Only a single collection was made in 2013 (LS), but this species was regularly found in treed bogs in 2012 (random walk method), saprotroph on *Sphagnum*. Common in Atlantic peat bogs of the U.K., rare in central European mountain bogs (Noordeloos 1992). The species is on the Red Lists of some European countries (Dahlberg 2011), and it is on the Red List of Khanty-Mansiysk region (Vasin & Vasina 2013).

Galerina allospora A.H. Sm. & Singer
2012 - #3763, #3793, #3922, #3933, #3941, #4041, #4117, #4118, and #4119; 2013 - #4385. Rare species (II) in treed bogs, occurring on *S. angustifolium* or *S. balticum*, saprotroph on *Sphagnum* and wood (pine bark). In northern Europe, reported from mosses (*Sphagnum*, *Dicranum*, *etc*.) and from rotting stumps and litter of *Picea* (Hansen *et al*. 1992); in North America, reported from debris and dead *Sphagnum* under *Picea* or on lightly burned areas in bogs (Smith & Singer 1964).

Galerina cerina A.H.Smith & Singer
2013 - #4379. Common species (V), occurring in all communities on hummocks and in hollows, mostly on peat among liverworts, saprotroph. In northern Europe reported from bogs, acidic forests and ericaceous communities, among different mosses and *Sphagnum* (Gulden 2008).

Galerina paludosa (Fr.) Kühner
2012 - #3790. Only a single collection from the study plots (in a treed community), but several collections from the random walk method (from treed communities and mesotrophic bogs), saprotroph on *Sphagnum*. Reported from oligotrophic mires, bogs, and swampy forests in northern Europe (Hansen *et al*. 1992). Smith & Singer (1964) reported it being “the most common species in the *Sphagnum* bogs throughout the United States and Canada, also well known in Europe, and is very likely circumpolar in distribution”.

Galerina sphagnicola (G.F. Atk.) A.H. Sm. & Singer
2012 - #3752, #3753, #3764, #3770, #3771, #3772, #3773, #3774, #3775, #3789, #3791, #3792, #3810, #3811, #3812, #3843, #3844, #3845, #3898, #3897, #3899, #3900, #3901, #3910, #3925, #3926, #3934, #3972, #4065, #4078, #4081, and #4084, 2013 - #4399. The most abundant species, as estimated from sporocarp density (VI), saprotroph on *Sphagnum*. Characteristic for SS. Reported from bogs in northern Europe (Hansen *et al*. 1992); in North America, reported to occur scattered to gregarious on *Sphagnum* in bogs (Smith & Singer 1964).

Galerina sphagnorum (Pers.) Kühner
2013 - #4394. Common species in treed communities (VI), rarely in lawns (on low hummocks), saprotroph on *Sphagnum*, characteristic for LS. Smith & Singer (1964) reported it growing on various species of *Sphagnum* and that it was widely distributed. Reported from bogs and acidic forests in northern Europe (Gulden 2008).

Galerina tibiicystis (G.F. Atk.) Kühner
2012 - #3902; 2013 - #4380. Common species (IV) collected in all communities, saprotroph on *Sphagnum*. More abundant in lawns, but also occurring in treed communities. In northern Europe reported from mires, bogs, mossy banks of streams, and lakes (Hansen *et al*. 1992).

Gymnopilus fulgens (J. Favre & Maire) Singer
2012 - #4064, 2013 - #4419. Only two collections were made outside study plots at the same location in a dwarf shrubs-*Sphagnum* bog in subsequent years, among *S. magellanicum* and *S. papillosum* (a third collection was made in a eutrophic fen on sedge peat), saprotroph on *Sphagnum* and sedge peat. Ecological niche may include oligotrophic and eutrophic peatlands. Reported from *Sphagnum* and moist peat in northern Europe (Hansen *et al*. 1992).

****Gymnopilus penetrans*** (Fr.) Murrill
2012 - #3943, #3945, and #3946; 2013 - #4386. Rare species (II) in treed communities on *S. fuscum* hummocks or in the vicinity of pine stumps, saprotroph on *Sphagnum*. A species with a wide ecological niche, occurring in forests and bogs if considered within the presently accepted taxon. In northern Europe reported from wood of conifers, more rarely on deciduous trees (Hansen *et al*. 1992).

Gymnopus androsaceus (L.) J.L. Mata & R.H. Petersen
2012 - #3807 and #3947; 2013 - #4427. Regular species (IV) in treed communities on different litter, including *Pinus sylvestris* needles and branches, leaves and branches of dwarf shrubs, leaves of *Eriophorum vaginatum* and leaves of *Rubus chamaemorus*. Black rhizomorphs grow abundantly on the surface of *Sphagnum*, saprotroph. Species with a wide ecological niche, occurring in forests and bogs. In northern Europe, reported from branches and needles of coniferous and deciduous trees and shrubs in oligotrophic sites (Hansen *et al*. 1992).

****Gymnopus dryophilus*** (Bull.) Murrill
2012 - #3762, #3743, #3838, #3953, #4009, and #4087; 2013 - #4392. Regular species (III) in treed communities, among *S. fuscum* and other *Sphagna* or on litter of *R. chamaemorus*, saprotroph. Characteristic of treed bogs. In northern Europe reported from wood and different litter in deciduous forests and alpine heaths (Hansen *et al*. 1992), also on humus or well decayed wood in coniferous forests (Halling 1983).

Hebeloma incarnatulum A.H. Sm.
2012 - #3746, #3759, #3847, and #3939; 2013 - #4390. Common (IV) species in treed communities, forming mycorrhiza with *Pinus*. Characteristic of treed bogs. Vesterholt (2005) reported this species as one of the most common agarics in Fennoscandia, occurring among mosses, sometimes among *Sphagnum*, and in association with *Picea* or *Pinus* in spruce forests.

Hygrocybe cinerella (Kühner) Arnolds
2012 - #3928; 2013 - #4430. Rare (I) species with only two collections in the same bog each year, at low level on a hummock in a lawn (among *S. papillosum* and *S. jensenii*) and on a *S. fuscum* hummock in a treed community, saprotroph on *Sphagnum*. Rare globally, reported only from Scandinavia, Iceland and Greenland, in marshes or on peat or *Sphagnum* (Boertmann 1995).

Hypholoma capnoides (Fr.) P. Kumm.
2012 - #3975 and #4113. Only two collections were made from the random walk method, in a treed community, from logs of *P. sylvestris* buried in peat, saprotroph on wood. In northern Europe reported from wood (stumps and roots) of *Picea* and *Pinus* (Hansen *et al*. 1992).

Hypholoma elongatum (Pers.) Ricken
2012 - #3828, #3908, #3960, #3997, #3999, #4000, #4003, #4074, and #4112. Though frequently collected from the random walk method in 2012 (Chistoe and Mukhrino Bogs, in lawns), it was not found in 2013, saprotroph on *Sphagnum*. In northern Europe reported among *Sphagnum*, on peaty soil, rarely among *Polytrichum* (Hansen *et al*. 1992).

Hypholoma eximium (C. Laest.) Rald
2012 - #3909; 2013 - #4421. Only two collections were made from the random walk method, both in lawns on bare peat (the first at an exposed peaty surface after dry weather, the second at a disturbed surface on a bog path), saprotroph on peaty substrate. In northern Europe reported on bare soil in snow beds (Hansen *et al*. 1992).

Hypholoma udum (Pers.) Quél.
2012 - #3748, #3755, #3824, #3858, #3903, #3959, #4075, and #4108; 2013 - #4432. Common species (IV) in lawns, but occasionally collected in depressions in treed communities, saprotroph on *Sphagnum*. Characteristic for SS, less common in LS. Reported among *Sphagnum* or on peaty soil in northern Europe (Hansen *et al*. 1992).

Laccaria proxima (Boud.) Pat.
2012 - #3757, #3870, #3904, #4085, and #4109; 2013 - #4431. All collections made by the random walk method, in treed communities, mostly in disturbed locations (on bog paths), forming mycorrhiza (possibly facultative) with *Pinus*. In northern Europe reported from moist, oligotrophic sites, often with *Sphagnum* (Hansen *et al*. 1992).

Lactarius helvus (Fr.) Fr.
2012 - #4059 and #4097; 2013 - #4428. Rare species (II) in treed communities, often in disturbed locations (e.g. on bog paths), forming mycorrhiza with *Pinus*. In northern Europe reported from moist to wet ground under conifers and *Betula*, often on disturbed soils (Hansen *et al*. 1992) and on sandy and peaty soil, typically among *Sphagnum* (Heilmann-Clausen *et al*. 1998).

Lactarius rufus (Scop.) Fr.
2012 - #3768, #3816, #3837, #3872, and #4096; 2013 - #4425. Regular species (IV) in treed communities, forming mycorrhiza with *Pinus*. Species with a wide ecological niche in bogs and forests. In northern Europe reported from coniferous forests, particularly among *Pinus*, but also in *Betula* forests and in arctic/alpine areas with *Betula nana* (Hansen *et al*. 1992).

Lactarius sp. 1
2012 - #4095; 2013 - #4429. Known from several collections made by the random walk method from a treed bog, forming mycorrhiza with *Pinus.*

Leccinum holopus (Rostk.) Watling
2012 - #3747 and #3756; 2013 - #4391. Rare species (I) in treed bogs, mycorrhizal with *Betula nana*, also collected at bog edge with *B. pubescens*. Species with a wide ecological niche in bogs and forests. Associated with *Betula* in *Sphagnum* bogs or among grasses and mosses on humid, peaty soil (den Bakker 2005).

Lichenomphalia umbellifera (L.) Redhead, Lutzoni, Moncalvo & Vilgalys
2012 - #3982, #4073, and #4088; 2013 - #4414. Rare species (I) in treed communities, on *S. fuscum* hummocks, often in disturbed locations (on bog paths), on peaty surfaces, lichen-forming. In northern Europe reported on moss, *Sphagnum*, peat or rotten wood (Hansen *et al*. 1992).

Mycena concolor (J.E. Lange) Kühner
2012 - #3839, #3932, #3996, and #4083; 2013 - #4395. Common species (IV) in treed communities, on peaty substrates in hollows and near tree trunks or among *S. fuscum* and *S. angustifolium*, saprotroph on *Sphagnum* and peat. Characteristic in treed bogs. Reported in northern Europe from peat bogs, among *Sphagnum* (Hansen *et al*. 1992).

Mycena epipterygia (Scop.: Fr.) S.F. Gray
2013 - #4413. Rare species (II) in treed communities in conifer litter. Species with a wide ecological niche in bogs and forests. Different varieties of this species inhabit the wood and litter of conifers and are found on humus, among mosses and grasses (Hansen *et al*. 1992, Geesteranus 1992).

Mycena galopus (Pers.) P. Kumm.
2012 - #3777 and #4002; 2013 - #4394. Rare species (I) in treed communities on peaty substrates in depressions, saprotroph. Species with a wide ecological niche in bogs and forests. Reported in northern Europe from various habitats including dead leaves, among *Sphagnum*, or in burnt places (Hansen *et al*. 1992).

Mycena megaspora Kauffman
2012 - #3830, #4012, and #4086; 2013 - #4422. Rare species (I) in treed communities on *S. fuscum* hummocks, collected by random walk method from mesotrophic bogs and boggy forests, saprotrophic on *Sphagnum* and litter. In northern Europe reported from burnt places, on peaty ground, or among *Sphagnum* (Hansen *et al*. 1992).

Omphaliaster borealis (M. Lange & Skifte) Lamoure
2012 - #3814, #3931, #3956, #4005, #4008, #4062, #4076, #4121, #4122, and #4123; 2013 - #4420. Rare species (II) in study plots, but regularly collected in 2012 at both bogs (often in treed communities, also in lawns), saprotroph on *Sphagnum*. Characteristic of treed bogs (though with low frequency). In northern Europe reported from moist, acidic, boreal heaths (Hansen *et al*. 1992), in raised bogs, also in alpine heaths and snowbeds (Vasutova *et al*. 2013).

****Psathyrella*** cf. **sphagnicola** (Maire) J. Favre
Resemblance to *P. sphagnicola*, but additional collections are required to confirm identity.
2013 - #4433. Single collection of a fruitbody from a graminoid-*Sphagnum* lawn outside the study plots, saprotroph on *Sphagnum*. In north Europe reported on *Sphagnum* or other wet mosses like *Polytrichum*, in forests of conifers or *Betula* (Knudsen & Vesterholt 2008).

Psilocybe turficola (Lasch) Gillet
2012 - #3927, #3896, and #4406; 2013 - #4114. Rare species (II) in study plots, collected more frequently in 2012 than in 2013, occurred in lawn communities on both bogs, saprotroph on *Sphagnum*. Characteristic with low constancy for SS. Reported from peatlands and other wet places in northern Europe (Hansen *et al*. 1992).

****Russula paludosa*** Britzelm.
2012 - #3758, #3817, #3846, #3868, #4043, #4094, and #4107. All collections made from the random walk method, common in treed communities, forming mycorrhiza with *Pinus*. Reported from coniferous forests in northern Europe (Hansen *et al*. 1992).

Sphagnomphalia brevibasidiata (Singer) Redhead, Moncalvo, Vilgalys & Lutzoni
2012 - #3952; 2013 - #4411. Rare species (II) in treed communities on *S. fuscum* hummocks, saprotroph on *Sphagnum*. Characteristic of treed communities, generally occurring in low abundances. Reported among *Sphagnum* in bogs (Hansen *et al*. 1992).

Suillus sibiricus Sing.
2012 - #3981; 2013 - #4382. Rare species (II) in treed communities, forming mycorrhiza with *Pinus*. Species with wide ecological niche in bogged forests and bogs. In Europe reported from the Alps, growing with *Pinus cembra* (Munoz 2005).

Suillus variegatus (Sw.) Kuntze
2012 - #3978, #4039, and #4061; 2013 - #4402. Rare species (II) in treed bogs, forming mycorrhiza with *Pinus*. Species with a wide ecological niche in forests and bogs. Reported from dry *Pinus* forests in northern Europe (Hansen *et al*. 1992).

Tephrocybe palustris (Peck) Donk
2012 - #3840 and #4079; 2013 - #4401. Common species (III) in lawns and in treed bogs (on low hummocks and in depressions), parasitic on *Sphagnum*. Growing in *Sphagnum* bogs (Hansen *et al*. 1992).

Thelephora terrestris Ehrh.
2012 - #3760, #3869, and #4098. Rare species (I) in treed bogs, on *S. fuscum* hummocks and in depressions, on *E. vaginatum* tussocks, among *R. chamaemorus* stems, saprotroph on *Sphagnum* and litter, also mycorrhizal with *Pinus*. Species with a wide ecological niche in forests and bogs. In northern Europe reported from humus, roots, or among mosses in coniferous forests; saprotroph, mycorrhizal, or semi-parasitic (Hansen & Knudsen 1997).

Xeromphalina cornui (Quél.) J. Favre
2012 - #3795 and #4042. Collected twice *via* the random walk method (in Chistoe Bog) on hummocks of *S. fuscum* in a treed bog, saprotroph on *Sphagnum* (stems attached to brown parts of shoots 2–3 cm below the capitulum). Species with a wide ecological niche in forests and bogs. In northern Europe, reported from conifer debris among *Sphagnum* (Hansen *et al*. 1992).