Fungal ethnoecology: observed habitat preferences and the perception of changes in fungal abundance by mushroom collectors in Poland

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Abstract

Background: Scientists frequently raise the topic of data deficiency related to the abundance and distribution of macrofungi in the context of climate change. Our study is the first detailed documentation on locals' perception of fungal ecology which covers a large mycophilous region of Europe (Mazovia, Poland).

Methods: A total of 695 semi-structured interviews were carried out among local informants in 38 localities proportionally distributed throughout the study area (one locality approximately every 30 km). Interview questions concerned fungi species collected, their perceived habitats, and whether any changes had been noted in their abundance. As many as 556 respondents provided information concerning fungal ecology. In these descriptions, 35 taxa were mentioned by at least 5 respondents.

Results: The data collected during interviews allowed us to create collective folk descriptions of habitat preferences and a list of 98 different macro-, meso-, and microhabitats of macrofungi described by the respondents. This list of recurring habitats assigned to particular macrofungal taxa coincides with, and sometimes exceeds, data available in scientific publications. Some habitat preferences observed by the informants have not yet been researched or tested by science. Out of 695 respondents, 366 (53%) noticed a steady decrease in local macrofungi abundance, and only one person claimed to have observed a steady increase. Imleria badia was the only species with increased abundance, as noted by fifteen independent respondents. The main listed reason for abundance decrease was drought (f = 186).

Conclusions: Collected information on the ecology of fungi shows that local knowledge does not generally diverge from scientific knowledge. The acquired information related to macrofungal abundance and ecology may also be used as a tool for the formulation of new scientific questions and theories. The analysis of local fungi observations might contribute to broadening knowledge about local changes in fungi and enable new estimations related to large-scale analysis of macrofungal abundance.

Keywords: Ethnomycology, Ethnoecology, Folk habitats, Perception of change, Macromycetes, Fungi, Abundance, Habitat preference, Hypotheses, Mazovia

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Introduction

Since the mid-1950s, scientists have explored patterns of shared environmental knowledge that emerged from indigenous practices based on local human-nature relationships [1, 2]. This new research area came to form the broad cross-discipline of ethnoscience—a field of science based on collaboration between social and natural sciences [3]. Researchers who study local ecological issues have noticed that local traditional communities have developed an extensive body of traditional ecological knowledge (TEK) about plants, animals, fungi, ecosystems, landscapes, and the processes and changes they undergo [4]. This knowledge emerged from long-term observations, experiments, and direct personal interactions with surrounding living nature [5]. A rise in scientific interest in this body of knowledge led to the development of ethnoecology—a new sub-field of ethnoscience. Ethnoecology is the scientific study of how different groups of people living in different locations understand the ecosystems around them and what relationships they form with their surrounding environments [6]. Ethnomycology broadly considers human engagement with the kingdom of fungi, bringing together the interests of the humanities, fine arts, and social and natural sciences [7]. Our present research was conducted following a traditional view on fungal ecology.

Traditional ecological knowledge is not only ‘used’ by the local communities that develop and possess this knowledge, but it also provides its users with a deep understanding of the status and changes to the local environment. This knowledge can often complement scientific understanding [8], help environmental monitoring [9], and support the planning and execution of adaptive conservation management [10]. Additionally, local and traditional ecological knowledge can help to develop new scientific questions and testable hypotheses [11, 12].

Traditional ecological knowledge can be related to habitat and ecosystem types, including habitat classification and landscape partitioning [13, 14]. Although this domain still requires research, recent studies analysing folk habitat types have proven the complexity and multi-dimensional characteristics of folk habitat descriptions and landscape partitions. The studies conducted by Babai and Molnár [15] among Csángó people living in Gyimes (Carpathians, Romania) have also underlined the importance of the scale dimension, which plays a major role in folk habitat classifications. The significance of topographical and topological aspects of scale in folk habitat classifications has also been confirmed by Gantuya et al. [16] among Mongolian herders. In general, folk habitat types can be grouped into macro-, meso-, and micro-scale habitats. Macrohabitats usually occupy large areas and comprise many habitat types, forming a mosaic. Mesohabitats are usually smaller in extension, homogenous, and often dominated by a single type of vegetation. Microhabitats are embedded in mesohabitats and provide special niches for particular species [14].

Because environmental changes are caused not only by natural but also by societal processes, by interacting and shaping their environment, local communities have developed their own perception of these changes [17]. Recently, local observations of environmental change are becoming recognized by science [18]. According to Nakashima et al. [19], people who interact with nature on a daily basis display knowledge that can be essential in introducing measurements to adapt and fight climate change. In her work, Gantuya et al. [16], besides noticing the important role of seasonal changes and pasture dynamics in determining the most suitable grazing area, emphasized the importance of long-term ecological stability for local herders. Ujházy et al. [20] compared farmers’ and conservationists’ perception of landscape changes. The results showed that the two groups shared similar views on perceived landscape changes, but they evaluated these changes differently. Farmers mostly focused on the impact on habitat usefulness, while conservationists had a primarily eco-centric approach. The common message of studies focusing on folk knowledge in relation to environmental change is the need for a deeper understanding of local perceptions [18, 21]. Studying local knowledge could broaden our understanding of the trends in ongoing ecological changes [22]. Having completed quantitative analysis of a large number of interviews, it is also possible to provide important information on the heterogeneity of social landscape perception [20].

The few studies that document local and traditional knowledge of fungal habitats and population changes (incl. abundance) usually focus on individual species [23, 24]. Lampman [25], however, undertakes a complete documentation of fungi-related knowledge shared by the Tzeltal Maya of the Chiapas highlands. In his work, Lampman focuses on knowledge concerning wild edible fungi ecology. However, the characteristics he describes often only provide a general overview of locally used macrofungi, without any detailed data on particular species. Lampman recorded information on the relationship of particular taxa to characteristics such as substrate preference, but without providing quantitative data (e.g. number of informants).

In our present study on fungal ethnoecology, we have the following objectives:

- To document the habitat types used by local Polish mushroom collectors to describe the habitat preferences of various fungal taxa;
To document the habitat preference of each mushroom species by appealing to the observations of a large number of mushroom collectors;
- To analyse local perception of macrofungal population trends (abundance) using local observations as a specific form of fungi monitoring;
- Finally, to generate a hypothesis for further research on fungi based on the above observations.

**Methods**

**Research area**

Mazovia is a historical region that lies in the Central-Eastern part of Poland. It is one of the ten major Polish historical regions within the country’s present-day borders. Mazovia was an independent principality throughout a major part of Polish mediaeval history [26]. In the case of the present study, its borders were determined by a map created for the ‘Historical Atlas of Poland in the 2nd Half of the 16th Century’ by Pałucki [27] (Fig. 1).

The region lies mainly within the current borders of the Mazovian Voivodeship and extends to part of the Łódź Voivodeship in the south-west and to Podlasie Voivodeship in the north-east. It covers about 33,900 km², spreading over the Mazovian Lowland in the valleys of the Vistula, Bug, and Narew rivers. It is currently inhabited by around 5.03 million people [28]. Mazovia is characterized by a cold temperate climate with high annual temperature amplitudes and a transitional character between oceanic and continental [29]. The average temperature (VI–VIII) is around 18°C in the summer and 1°C during winter (XII–II). Average annual rainfall ranges from 550 to 600 mm [30]. Forest vegetation covers 23.3% of the research area [31], the majority of which are coniferous forests (64%) mainly composed of *Pinus sylvestris* L.. The other species that are the most abundant in mixed and deciduous forests are *Quercus robur* L. and *Betula pendula* Roth.

Folk cultural characteristics shared by people living in this historical region are currently difficult to find. However, the region is still inhabited by a few ethnographic groups. Usually, they can be distinguished by their local traditions and cultures. These groups are the Podlasianie, Mazurzy, Łowiczanie, and Kurpie [32]. The capital city of Warsaw is situated in the centre of Mazovia. Despite the broad urban sprawl surrounding Warsaw, there are even forests used for recreational mushroom picking in the city’s agglomeration.

The research was conducted in 38 villages or small market towns, which were dispersed in a 30-km grid throughout the whole Mazovian region (Fig. 1). These were Burakowskie, Całownie, Chyżyny, Cieciorzy, Dąbrowa, Faustynowo, Flesze, Gostków, Kluki, Klusek, Kocierzew, Konopki (Grajewo County), Konopki (Łomża County), Korytów, Koziuty, Kęgi, Lekszyn, Łątczyn, Łękawica, Mamino, Mchowo, Mistrzewice, Nowy Gołym, Piaski, Przedświt, Psucin, Pszczonów, Radzymin, Regnów, Sojcyn, Stare Babice, Szczaki, Szydłowo, Świerze, Węgrzynowice, Wyrzychy, Zdunek, and Żurawka (currently the district of Sulejówek).

This network of settlements forms part of the larger grid of the Ethnographic Atlas of Poland, which was also used to collect data on mushroom picking between 1964 and 1969. At that time, chosen localities were described as ‘large moderately backward’ settlements.

**Field research**

The field research took place between 2014 and 2018, from April to November—the months of abundance of traditionally collected wild edible fungi in Poland. Data collection was spread evenly across the research period, while the volume of collected data depended mostly on weather conditions and population density. Data were collected through individual semi-structured interviews conducted among local informants, which constitutes the classic method in ethnobiology [33]. Aside from data concerning local knowledge on collected species, folk taxonomy and cultural significance presented in previous work [34], we have also documented knowledge about collected species ecology and their changes in abundance observed during the years of active fungi collection (usually since childhood to the day of interview). Information about macrofungi gathered or recognized as edible was collected by using the freelisting method. All freelists were made orally and written down. Questions relating to knowledge about species habitat and changes to abundance were asked in relation to each listed species. The information was acquired through informants’ answers to general questions: ‘Where would you look for this mushroom species?’, ‘Did you notice any changes in the abundance of this species?’, and ‘What do you think is the main cause of mushroom abundance changes?’ All of 695 respondents were asked questions concerning fungal habitat and abundance changes. Not everyone was able to answer them. In case of habitat descriptions, lack of answer was classified as ‘unknown’; therefore, it was not used in habitat description and analysis (Table 1). In case of abundance changes, lack of answer was classified as ‘unnoticed’ and is present in data analysis (Fig. 4).

At least one landscape walk or joined collection trip was conducted in each village. The majority of voucher specimens for further identification were collected fresh during field interviews, and some were acquired in dried form from respondents. A total of 695 individual interviews have been conducted where respondents provided information on folk taxonomy of collected fungi species [34]. Among them, 556 respondents provided information on fungal ecology related to 92 taxa. Women
accounted for 52% (362) and men for 48% (333). The age of informants ranged from 17 to 95. The mean age was 63 (SD = 13.7) and the median 64. Informants were selected during village walks or using the ‘snowball’ sampling technique [35]. The selection of informants was haphazard—based on their willingness to participate in the interview—and therefore socio-demographic characteristics were varied. However, like in most ethnobiological studies, we aimed at talking to middle-aged and older people.

Data analysis

The majority of fungal fruiting bodies were identified with the support of mushroom pictures or identification guides [36]. Some of the interviews were conducted simultaneously with mushroom collection. This method enabled us to recognize taxa on the spot and to collect voucher specimens, which were additionally identified by DNA barcoding [34].

All folk habitat terms mentioned by the respondents in the interviews were extracted and grouped. Synonymous folk habitat names were grouped according to dimensions such as dominant symbiotic species, succession, land use, vegetation structure, forest vegetation physiognomy, geomorphology, soils, hydrology, human, and animal disturbances [15, 16].

After analysing 556 interviews and 3999 reports concerning particular fungal taxa, we also selected 35 taxa
Table 1: Habitat types used to describe the habitat preference of various mushroom species listed by the respondents (n = 556).

| Habitat                              | Frequency | Habitat                              | Frequency |
|--------------------------------------|-----------|--------------------------------------|-----------|
| Pine *Pinus sylvestris* L. (occurrence correlated with pine presence) | 1178      | Blackberries (*Rubus* L. spp.)       | 8         |
| Birch (*Betula* L. spp.)             | 746       | Boar rooting (grounds disturbed by boar activity) | 8         |
| Mixed forests (coniferous and deciduous) | 622      | Orchards                             | 8         |
| Sandy soils                          | 383       | Water’s edge                         | 8         |
| Small/young trees                    | 381       | Firebreaks                            | 7         |
| Oak (*Quercus* L. spp.)              | 345       | Hazel (*Corylus avellana* L.)        | 7         |
| Coniferous forests                   | 334       | On trees                              | 7         |
| Meadows                              | 221       | Hills/scarps                         | 6         |
| Moss (presence in the groundcover)   | 217       | Potato fields                         | 6         |
| Terrain elevations/hillocks          | 206       | Snow (under the snow-cover)          | 6         |
| forest edge                          | 170       | Bogs                                  | 5         |
| Deciduous forests                    | 146       | Near feeding rack                     | 5         |
| Various habitats (occurring in many unrelated habitats) | 138      | Stubble                               | 5         |
| Grasses                              | 135       | Thin forests                          | 5         |
| Old/tall forests                     | 129       | White moss (*Leucobryum glaucum* (Hedw.) Ångstr.) | 5         |
| Roadsides                            | 104       | Balks (i.e. strips between fields)    | 4         |
| Tree stumps                          | 103       | Lichens                               | 4         |
| Common aspen                         | 83        | Parks                                 | 4         |
| Humid soils                          | 78        | Short grass                           | 4         |
| Fields                               | 76        | Beech (*Fagus sylvatica* L.)          | 3         |
| Trenches/depressions                 | 62        | Bird cherry (*Prunus padus* L.)       | 3         |
| Litter with conifer needles          | 59        | Black poplar (*Populus nigra* L.)    | 3         |
| Thickets                             | 52        | Fallen pine bark/mulching bark        | 3         |
| Cows/horses (presence – mainly pastures) | 49      | *Frangula alnus* Mill.               | 3         |
| Spruce (*Picea abies* (L.) H.Karst.) | 48        | *Robinia pseudoacacia* L.            | 3         |
| Forest clearings                     | 43        | Bog blueberry (*Vaccinium uliginosum* L.) | 2         |
| Alder (*Alnus* Mill. spp.)           | 41        | Secondary forest                      | 2         |
| Heather (*Calluna vulgaris* (L.) Hull) | 39       | Near tree trunks                      | 2         |
| Under fallen branches                | 39        | Poplars (*Populus L. spp.*)           | 2         |
| Clear/light forest                   | 35        | Rich undergrowth                      | 2         |
| Clearcutting areas                   | 33        | Without undergrowth                   | 2         |
| Dry soils                            | 33        | Ash tree (*Fraxinus excelsior* L.)    | 1         |
| Blueberries (*Vaccinium myrtillus* L.) | 29      | Burned areas                          | 1         |
| Open areas                           | 29        | Compost                               | 1         |
| Yards                                | 28        | Dense forest                          | 2         |
| High sun exposure                    | 25        | Elder trees (*Sambucus nigra* L.)     | 1         |
| Fallows/wastelands                   | 23        | Elm (*Ulmus L. spp.*)                 | 1         |
| Among litter                         | 21        | Ferns                                 | 1         |
| Hornbeam (*Carpinus betulus* L.)     | 19        | Fertile soil                          | 1         |
| Juniper (*Juniperus communis* L.)    | 16        | Fir (*Abies alba* Mill.)              | 1         |
| Larch (*Larix decidua* Mill.)        | 15        | Foxholes                              | 1         |
| Dead wood                            | 14        | Garbage dumps                         | 1         |
| Self-sown forest                     | 14        | Green moss                            | 1         |
| Forest plantations                   | 12        | Hardwood trees                        | 1         |
with 5 or more individual ecological descriptions (Fig. 2). In order to remove singular folk reports and focus on the most frequently mentioned habitats, we only selected habitats that were listed by more than 5% of respondents in relation to particular taxa and were listed more than once. Habitats mentioned by a fewer number of respondents were grouped as ‘other’. In order to present the acquired data, we used Sankey diagram created with the use of Tableau software version 2020.4.

PCA analysis was conducted on the basis of the matrix of the most frequently mentioned habitats in relation to different fungal taxa, which were selected in analysis presented in Fig. 2. The main purpose of the principal component analysis is to compute the principal components (in this case elements describing fungal habitats) and use them to determine certain groups of species related to specific multidimensional habitat description. This allows for a reduction in the dimensionality of data while preserving its variation. The first principal components can define which direction maximizes the variation of projected points, therefore enabling the division of certain fungal species into groups with similar habitat preferences. Data processing included normalization using the min-max scaling method and singular value decomposition (SVD). PCA analysis was performed in R programming language using the FactoMineR package in Rstudio software [37] (Fig. 3).

In order to compare folk ecology descriptions with scientific knowledge, we used the ‘Checklist of Polish Larger Basidiomycetes’ [38] as a reference point for the Basidionymycota species and ‘Grzyby i ich oznaczanie’ [39] for Ascomycota. This was supplemented with data from other scientific publications.

We recorded the number of respondents who noticed a change in general macrofungal abundance during the period of mushroom collection. In some cases, we collected reports on observed abundance changes of particular fungi. The collected data was used to create Macrofungi abundance decrease maps that recorded the main causes of these changes (Fig. 4). These maps were created on the basis of data collected in particular localities. Interpolations were made with the geometric interval method. Answers were classified as ‘anthropo-pressure’ when respondents mentioned human agents affecting the habitat in general without directly specifying official forest management. All maps were created using ArcMap 10.4.1.

**Results**

**Habitats listed by locals to describe habitat preference of mushroom species**

We found 98 habitat types mushroom collectors used to describe habitats of collected fungi (Table 1). Most habitats (65) may be regarded as mesic habitats (e.g. different forest types, such as coniferous forest, deciduous forest, mixed forest, pine forest, forest edges, openings), 28 as microhabitats (e.g. terrain elevations or hillocks, roadsides, tree stumps or fallen pine bark), and 4 as macro habitats (e.g. areas with or without forest vegetation).

Folk habitats referred to different characteristics of these habitats. The main dimensions were dominant species (e.g. Pinus sylvestris L., Populus tremula L.), vegetation succession (clearcut, forest plantation, forest age, grass presence, deadwood presence, forest density, grass size), land-use type (forests, pastures, meadows, fields, fallows, wastelands, orchards, yards, stubbles, parks), vegetation structure (coniferous forest, deciduous forest, mixed forest, forest edge, forest cover and understory structure, hardwood forest), forest vegetation physiognomy (open forest, forest clearings, little exposure to sun, burned areas), geomorphology (terrain elevations, hills, hillocks, scars, trenches, depressions, slopes, water edge), soils (sandy, fertile), hydrology (humid, dry, bogs), human and animal disturbances (roadsides, presence of tree stumps, presence of human-made structures, firebreaks, balks, boar rooting, manure presence, foxholes), and history of land use (forests on previously cultivated grounds).

**Observed habitat preference of mushroom species**

Field data concerning local knowledge about collected fungi species habitat preferences acquired during the field research was compiled into collective habitat descriptions for 35 different fungal taxa, enabling the creation of quantitative graphs depicting the most important habitats determining particular fungi species occurrence (Fig. 2, Table 3).
The collected data allowed to group species according to seven macrohabitats (Table 2).

Figure 3 shows a clear correlation between open area habitats—such as fields, meadows, and roadsides—and particular species of fungi, such as the saprotrophic *Marasmius oreades* (Bolton) Fr., *Agaricus campestris* L. or *Macrolepiota procera* (Scop.) Singer. *Leccinum* Gray spp. is closely correlated with birch and early successional habitats containing grasses. The top right part of the graph groups species correlated with dry, sandy, and disturbed soils (for example species from *Tricholoma* (Fr.) Staude, *Hygrophorus hypothejus* (Fr.) Fr. or *Gyromitra esculenta* (Pers.) Fr.). Habitats such as pine and moss are positively correlated, and they group species characteristic for pine forests, for example species from the *Suillus* genus. Species positively correlated with mixed forest habitats, birch forests, and a large number of various habitats are *Boletus subtomentosus* L., *Paxillus involutus* (Batsch) Fr., or species from the *Russula*Pers. genus.

**Abundance changes of fungi perceived by local mushroom collectors**

Most respondents (53%) observed a decrease of macrofungi abundance during their lifetime (10–50 years). Among them, 12 respondents (2%) emphasized that the biggest drop in abundance of fruiting bodies occurred...
during the last two decades. The 13% of respondents who noticed fluctuations in abundance attributed them to natural changes related to annual differences in yearly rainfall and temperatures. Over a third (34%) of respondents did not notice any changes in fungal abundance. Only one person (0.14%) noticed a steady increase of macrofungi abundance.

Respondents mainly focused on general abundance of edible macrofungi species. The general view on mushroom abundance emerged from the assumption that the majority of fungal species react to the same biotic and abiotic stresses. According to the majority of reports, there has been a noticeable decrease in the abundance of all macrofungi in the whole Mazovia region (Fig. 4). This concerns especially the northern and western parts of the region, where over 70% of the respondents have noticed a decrease in macrofungal abundance. The main reason for abundance decrease listed by the informants is drought ($n = 186$, 27% of respondents). Reports of progressive drought negatively affecting fungal abundance were recorded in all 38 research localities. Other reasons were as follows: forest management ($n = 30$), climate change ($n = 21$), anthropopressure ($n = 19$), environmental pollution ($n = 16$), overgrowing habitats ($n = 11$), and wild boar activity ($n = 5$). Sixty respondents were not able to list the cause of declining macrofungal abundance.

The lowest percentage of decrease in fungal abundance (around 35%) was recorded in the eastern part of the Mazovia region. In this area, the most often listed determinant of mushroom abundance decrease was forest habitats becoming overgrown by understory vegetation. In the north-eastern part of Mazovia, where the decrease in abundance is highest, respondents have declared that ‘forest management’ is the main cause of this phenomenon. In localities situated close to the southwest of the capital city, anthropopressure has been determined as the main cause of edible fungi abundance decrease. Aside from overall information on macrofungal abundance, some of the respondents also noted a significant decrease in the abundance of particular fungi species. Altogether, 27 independent respondents reported a significant decrease of *Lactarius deliciosus* (L.) Gray abundance, 19—a decrease of *Boletus edulis* Bull. abundance, 18—in species from the *Tricholoma* (Fr.) Staude genus. Additionally, 8 respondents recorded a significant...
decrease of *Tricholoma equestre* (L.) P. Kumm. abundance, 18—a decrease of *Cantharellus cibarius* Fr. abundance, 12—a decrease of *Agaricus campestris* L. abundance, and 10—a decrease of *Suillus luteus* (L.) Roussel abundance. An increased abundance of one species, *Imleria badia* (Fr.) Vizzini, has also been noted, with its increase reported by 15 independent respondents (Table 3).

**Discussion**

**Habits listed to describe habitat preference**

While describing fungi habitats, mushroom collectors mentioned 98 habitat types, of which most were meso- and microhabitats. Local ethnoecological knowledge on fungi was formed at a finer spatial scale than knowledge concerning plant ethnoecology documented in previous research [10, 15, 16].

Respondents usually described tree species only to the genus level. The respondents gave detailed descriptions of forest communities relatively rarely. However, they mentioned some very specific fungal habitats like hilllocks, firebrakes, self-sown forests, specific litter layer composition, or relevant tree species, as these features enable them to specify the landscape in which they usually look for certain species of fungi, implementing high complexity of folk knowledge related to fungal ecology.
On the other hand, in folk ecology descriptions, we can find recurring habitat characteristics that are still not scientifically evaluated in depth in relation to fungi occurrence. These include exposure to sun (mentioned particularly often), the shape of the terrain, or litter thickness. Such indicators were very often perceived as crucial during the description of particular fungi species habitats. This information may provide new guidelines that could determine the direction of further studies on ecology of local fungi.

Respondents determined habitats using diverse dimensions (see section “Habitats listed by locals to describe habitat preference of mushroom species”). Studies conducted with other local communities show that these dimensions are shaped by different environments that make them characteristic for certain local groups [15]. When comparing dimensions used to determine fungal habitats with dimensions used by different communities, we can notice some similarities. The most important dimensions recorded in the present study, such as dominant species, land-use type, or vegetation structure, are characteristic for local communities living in the Carpathians and are less important to people living in Western Canada or Mongolia [16]. This suggests similarities in habitat perception between Central European communities that are worthy of further investigation.

Table 2 Fungi habitat preferences according to the interviewees (Mazovia, Poland)

| Grasslands       | Forest clearcutting | Semi-open and light forest | Various habitats | Deciduous forest | Coniferous forest | Mixed forests |
|------------------|---------------------|----------------------------|------------------|------------------|-------------------|--------------|
| Agaricus campestris | Armillaria mellea   | Boletus edulis             | Amanita vaginata | Armillaria mellea | Armillaria mellea | Amanita vaginata |
| Macrolepiota procera | Gyromitra esculenta | Boletus subtomentosus     | Boletus edulis   | Boletus edulis   | Boletus edulis   |
| Marasmius oreades | Morchella spp.      | Lactarius deliciosus      | Boletus reticulatus | Cantharellus cibarius | Cantharellus cibarius | Boletus reticulatus |
| Pleurotus ostreatus | Leccinum scabrum    | Leccinum scabrum          | Cantharellus cibarius | Cortinarius caperatus | Boletus subtomentosus |
| Macrolepiota procera | Macrolepiota procera | Leccinum aurantiacum     | Gyromitra esculenta | Cantharellus cibarius |
| Paxillus involutus | Paxillus involutus  | Leccinum pseudosubcubrum  | Gyroporus cyanescens | Continarius caperatus |
| Russula spp.     | Russula spp.       | Leccinum scabrum          | Hygrophorus hypothéjus | Craterellus comucopodioides |
| Suillus bovinus  | Suillus bovinus    | Leccinum scabrum          | Imelria badia     | Gyromitra esculenta |
|                  |                     | Paxillus involutus        | Lactarius deliciosus | Gyroporus cyanescens |
|                  |                     | Russula spp.              | Morchella spp.    | Imelria badia |
|                  |                     | Paxillus involutus        | Lactarius deliciosus |
|                  |                     | Russula spp.              | Leccinum aurantiacum |
|                  |                     | Sarcodon squamosus        | Leccinum scabrum |
|                  |                     | Suillus bovinus           | Macrolepiota procera |
|                  |                     | Suillus grevillei         | Morchella spp.    |
|                  |                     | Suillus luteus            | Paxillus involutus |
|                  |                     | Suillus variagatus        | Pleurotus ostreatus |
|                  |                     | Tricholoma equestre       | Russula spp.      |
|                  |                     | Tricholoma portentosum    | Sarcodon squamosus |
|                  |                     |                           | Suillus bovinus    |
|                  |                     |                           | Suillus variagatus |
|                  |                     |                           | Tricholoma equestre |
|                  |                     |                           | Tricholoma portentosum |
Table 3 Habitats preferences and abundance changes of selected fungal taxa.

| Species               | Habitat               | Habitat (n) | Abundance changes | Increase (n) | Increase cause | Decrease (n) | Decrease cause                  |
|-----------------------|-----------------------|-------------|-------------------|--------------|----------------|--------------|---------------------------------|
| Macromycetes general  | Table 1               | Table 1     | 1                 | Imprecise    | 186            | Drought      |                                 |
|                       |                       |             |                   |              | 60             | Imprecise    |                                 |
|                       |                       |             |                   |              | 30             | Forest management |                                 |
|                       |                       |             |                   |              | 21             | Climate changes |                                 |
|                       |                       |             |                   |              | 19             | Antropopression (general) |                                 |
|                       |                       |             |                   |              | 16             | Pollution     |                                 |
|                       |                       |             |                   |              | 11             | Habitat overgrowing |                                 |
|                       |                       |             |                   |              | 10             | Mycelium/litter damage |                                 |
|                       |                       |             |                   |              | 3              | Boars        |                                 |
|                       |                       |             |                   |              | 3              | Grazing abandonment |                                 |
|                       |                       |             |                   |              | 3              | Low night temperatures |                                 |
|                       |                       |             |                   |              | 2              | Incorrect collection |                                 |
|                       |                       |             |                   |              | 2              | Urbanization |                                 |
|                       |                       |             |                   |              | 2              | Increased pest activities |                                 |
|                       |                       |             |                   |              | 1              | Logging       |                                 |
|                       |                       |             |                   |              | 1              | Unraked litter |                                 |
|                       |                       |             |                   |              | 1              | High night temperatures |                                 |
| Agaricus campestris s.l. | Meadow              | 104         | 0                 | None         | 12             | Grazing abandonment |                                 |
|                       | Field                 | 31          |                   |              |                |              |                                 |
|                       | Cows/horses           | 31          |                   |              |                |              |                                 |
|                       | Other                 | 29          |                   |              |                |              |                                 |
| Amanita vaginata      | Various habitats      | 6           | 0                 | None         | 1              | Forest management |                                 |
|                       | Mixed forest          | 5           |                   |              |                |              |                                 |
|                       | Coniferous forest     | 3           |                   |              |                |              |                                 |
|                       | Other                 | 5           |                   |              |                |              |                                 |
| Armillaria mellea s.l. | Tree stumps          | 100         | 0                 | None         | 2              | Imprecise     |                                 |
|                       | Old/tall forest       | 20          |                   |              |                |              |                                 |
|                       | Clearcut area         | 18          |                   |              |                |              |                                 |
|                       | Pine                  | 17          |                   |              |                |              |                                 |
|                       | Young/small forest    | 16          |                   |              |                |              |                                 |
|                       | Deciduous forest      | 12          |                   |              |                |              |                                 |
|                       | Dead wood             | 12          |                   |              |                |              |                                 |
|                       | Humid ground          | 10          |                   |              |                |              |                                 |
|                       | Oak                   | 9           |                   |              |                |              |                                 |
|                       | Alder                 | 7           |                   |              |                |              |                                 |
|                       | Other                 | 61          |                   |              |                |              |                                 |
| Boletus edulis s.l.   | Oak                   | 194         | 0                 | None         | 9              | Imprecise     |                                 |
|                       | Pine                  | 158         |                   |              | 6              | Drought       |                                 |
|                       | Mixed forest          | 102         |                   |              | 2              | Pollution     |                                 |
|                       | Birch                 | 90          |                   |              | 1              | Antropopression (general) |                                 |
|                       | Coniferous forest     | 32          |                   |              | 1              | Forest management |                                 |
|                       | Forest edge           | 30          |                   |              |                |              |                                 |
|                       | Deciduous forest      | 26          |                   |              |                |              |                                 |
| Species                     | Habitat        | Habitat (n) | Abundance changes | Increase (n) | Increase cause | Decrease (n) | Decrease cause |
|-----------------------------|----------------|-------------|-------------------|--------------|----------------|--------------|----------------|
| Boletus reticulatus        | Old/tall forest| 26          |                   |              |                |              |                |
|                             | Other          | 189         |                   |              |                |              |                |
|                             | Oak            | 13          | None              | 0            | None           | 0            | None           |
|                             | Sandy ground   | 5           |                   |              |                |              |                |
|                             | Birch          | 3           |                   |              |                |              |                |
|                             | Mixed forest   | 2           |                   |              |                |              |                |
|                             | Other          | 4           |                   |              |                |              |                |
| Boletus subtomentosus s.l. | Mixed forest   | 27          | None              | 0            | None           | 1            | Imprecise      |
|                             | Pine           | 15          |                   |              |                |              |                |
|                             | Various habitats| 14          |                   |              |                |              |                |
|                             | Birch          | 9           |                   |              |                |              |                |
|                             | Moss           | 5           |                   |              |                |              |                |
|                             | Forest edge    | 4           |                   |              |                |              |                |
|                             | Grasses        | 4           |                   |              |                |              |                |
|                             | Other          | 42          |                   |              |                |              |                |
| Cantharellus cibarius s.l. | Mixed forest   | 106         | None              | 0            | None           | 13           | Imprecise      |
|                             | Pine           | 99          |                   |              |                | 5            | Drought        |
|                             | Birch          | 64          |                   |              |                |              |                |
|                             | Oak            | 43          |                   |              |                |              |                |
|                             | Moss           | 37          |                   |              |                |              |                |
|                             | Sandy ground   | 35          |                   |              |                |              |                |
|                             | Coniferous     | 32          |                   |              |                |              |                |
|                             | forest         | 32          |                   |              |                |              |                |
|                             | Various habitats| 20          |                   |              |                |              |                |
|                             | Other          | 127         |                   |              |                |              |                |
| Cortinarius caperatus      | Pine           | 32          | None              | 0            | None           | 2            | Drought        |
|                             | Moss           | 20          |                   |              |                | 1            | Forest management |
|                             | Mixed forest   | 16          |                   |              |                | 1            | Imprecise      |
|                             | Coniferous     | 16          |                   |              |                |              |                |
|                             | needles        | 16          |                   |              |                |              |                |
|                             | Old/tall forest| 12          |                   |              |                |              |                |
|                             | Birch          | 8           |                   |              |                |              |                |
|                             | Sunny areas    | 8           |                   |              |                |              |                |
|                             | Clear/transparent forest| 8 |                   |              |                |              |                |
|                             | Other          | 52          |                   |              |                |              |                |
| Craterellus cornucopoides  | Pine           | 4           | None              | 0            | None           | 2            | Imprecise      |
|                             | Oak            | 4           |                   |              |                |              |                |
|                             | Mixed forest   | 2           |                   |              |                |              |                |
| Gyromitra esculenta        | Pine           | 10          | None              | 0            | None           | 0            | None           |
|                             | Forest plantation| 8          |                   |              |                |              |                |
|                             | Young/small forest| 5          |                   |              |                |              |                |
|                             | Clearcut area  | 4           |                   |              |                |              |                |
|                             | Sandy ground   | 3           |                   |              |                |              |                |
|                             | Mixed forest   | 2           |                   |              |                |              |                |
| Species                      | Habitat                  | Habitat (n) | Abundance changes | Increase (n) | Increase cause | Decrease (n) | Decrease cause |
|------------------------------|--------------------------|-------------|-------------------|--------------|----------------|--------------|----------------|
| **Gyroporus cyanescens**     | Firebreaks               | 2           |                   |              |                |              |                |
|                              | Other                    | 6           |                   |              |                |              |                |
|                              | Sandy ground             | 21          | 0                 | None         | 2              | Imprecise    |                |
|                              | Pine                     | 7           |                   |              |                |              |                |
|                              | Roadside                 | 6           |                   |              |                |              |                |
|                              | Oak                      | 4           |                   |              |                |              |                |
|                              | Yard                     | 4           |                   |              |                |              |                |
|                              | Forest edge              | 3           |                   |              |                |              |                |
|                              | Young/small forest       | 3           |                   |              |                |              |                |
|                              | Juniperus spp.           | 2           |                   |              |                |              |                |
|                              | Moss                     | 2           |                   |              |                |              |                |
|                              | Other                    | 2           |                   |              |                |              |                |
| **Hygrophorus hypothejus**   | Pine                     | 9           | 0                 | None         | 0              | None         |                |
|                              | Coniferous forest        | 3           |                   |              |                |              |                |
|                              | Young/small forest       | 3           |                   |              |                |              |                |
|                              | Moss                     | 2           |                   |              |                |              |                |
|                              | 'Man's forest'           | 2           |                   |              |                |              |                |
|                              | Other                    | 2           |                   |              |                |              |                |
| **Imleria badia**            | Pine                     | 200         | 15                | Imprecise    | 2              | Imprecise    |                |
|                              | Mixed forest             | 82          |                   |              |                |              |                |
|                              | Moss                     | 61          |                   |              |                |              |                |
|                              | Coniferous forest        | 51          |                   |              |                |              |                |
|                              | Various habitats         | 20          |                   |              |                |              |                |
|                              | Other                    | 163         |                   |              |                |              |                |
| **Lactarius deliciosus s.l.**| Grasses                  | 29          | 0                 | None         | 16             | Drought      |                |
|                              | Pine                     | 24          |                   |              | 8              | Imprecise    |                |
|                              | Forest edge              | 15          |                   |              | 2              | Forest management | Pollut | |
|                              | Meadow                   | 15          |                   |              | 1              | Pollution    |                |
|                              | Mixed forest             | 14          |                   |              |                |              |                |
|                              | Trenches/depressions     | 14          |                   |              |                |              |                |
|                              | Coniferous forest        | 12          |                   |              |                |              |                |
|                              | Spruce                   | 10          |                   |              |                |              |                |
|                              | Oak                      | 7           |                   |              |                |              |                |
|                              | Moss                     | 7           |                   |              |                |              |                |
|                              | Humid ground             | 7           |                   |              |                |              |                |
|                              | Other                    | 50          |                   |              |                |              |                |
| **Leccinum aurantiacum s.l.**| Birch                    | 175         | 0                 | None         | 3              | Drought      |                |
|                              | Aspen                    | 69          |                   |              | 1              | Pollution    |                |
|                              | Mixed forest             | 33          |                   |              |                |              |                |
|                              | Deciduous forest         | 26          |                   |              |                |              |                |
|                              | Alder                    | 15          |                   |              |                |              |                |
|                              | Other                    | 121         |                   |              |                |              |                |
| **Leccinum pseudoscabrum**   | Hornbeam                 | 7           | 0                 | None         | 3              | Imprecise    |                |
| Species         | Habitat         | Habitat (n) | Abundance changes | Increase (n) | Increase cause | Decrease (n) | Decrease cause |
|-----------------|-----------------|-------------|-------------------|--------------|---------------|--------------|----------------|
|                 | Old/tall forest | 4           |                   |              |               |              |                |
|                 | Humid ground    | 2           |                   |              |               |              |                |
|                 | Bog             | 2           |                   |              |               |              |                |
|                 | Birch           | 2           |                   |              |               |              |                |
|                 | Other           | 3           |                   |              |               |              |                |
| Leccinum scabrum| Birch           | 195         | 0                 | None         | 1             | None         | Imprecise      |
|                 | Mixed forest    | 38          |                   |              | 1             | Drought      |                |
|                 | Grass           | 16          |                   |              |               |              |                |
|                 | Pine            | 14          |                   |              |               |              |                |
|                 | Various habitats| 14          |                   |              |               |              |                |
|                 | Other           | 97          |                   |              |               |              |                |
| Leccinum spp.   | Birch           | 137         | 0                 | None         | 2             | Drought      |                |
|                 | Mixed forest    | 29          |                   |              |               |              |                |
|                 | Oak             | 14          |                   |              |               |              |                |
|                 | Pine            | 11          |                   |              |               |              |                |
|                 | Other           | 99          |                   |              |               |              |                |
| Macrolepiota procera | Meadow   | 78          | 0                 | None         | 1             | None         | Imprecise      |
|                 | Forest edge     | 50          |                   |              |               |              |                |
|                 | Field           | 36          |                   |              |               |              |                |
|                 | Mixed forest    | 33          |                   |              |               |              |                |
|                 | Various habitats| 19          |                   |              |               |              |                |
|                 | Open area       | 16          |                   |              |               |              |                |
|                 | Grasses         | 13          |                   |              |               |              |                |
|                 | Roadside        | 12          |                   |              |               |              |                |
|                 | Pine            | 11          |                   |              |               |              |                |
|                 | Fallow          | 10          |                   |              |               |              |                |
|                 | Other           | 91          |                   |              |               |              |                |
| Marasmius oreades | Roadside     | 16          | 0                 | None         | 2             | None         | Grazing abandonment |
|                 | Cows/horses     | 13          |                   |              |               |              |                |
|                 | Yard            | 7           |                   |              |               |              |                |
|                 | Meadow          | 4           |                   |              |               |              |                |
|                 | Trenches/depressions | 2       |                   |              |               |              |                |
|                 | Other           | 8           |                   |              |               |              |                |
| Morchella esculenta s.l. | Pine       | 5           | 0                 | None         | 2             | None         | Habitat overgrowing |
|                 | Clear-cut area  | 3           |                   |              |               |              |                |
|                 | Fallen bark     | 3           |                   |              |               |              |                |
|                 | Oak             | 2           |                   |              |               |              |                |
|                 | Mixed forest    | 2           |                   |              |               |              |                |
|                 | Moss            | 2           |                   |              |               |              |                |
|                 | Other           | 4           |                   |              |               |              |                |
| Paxillus involutus s.l. | Mixed forest | 20          | 0                 | None         | 4             | Drought      |                |
|                 | Various habitat | 12          |                   |              | 1             | None         | Imprecise      |
|                 | Pine            | 7           |                   |              |               |              |                |
Table 3  Habitat preferences and abundance changes of selected fungal taxa. (Continued)

| Species | Habitat | Habitat (n) | Abundance changes | Increase (n) | Increase cause | Decrease (n) | Decrease cause |
|---------|---------|-------------|-------------------|-------------|----------------|-------------|----------------|
|         | Deciduous forest | 4            |                   |             |                |             |                |
|         | Other     | 15           |                   |             |                |             |                |
| Pleurotus ostreatus | Mixed forest | 2            | 0                 | None        | 0              | None        | None           |
|         | Dead wood | 2            |                   |             |                |             |                |
|         | Clear-cut area | 2            |                   |             |                |             |                |
|         | Other     | 4            |                   |             |                |             |                |
| Russula aeruginea s.l. | Mixed forest | 13           | 0                 | None        | 2              | Imprecise   |                |
|         | Various habitats | 9            |                   |             | 1              | Drought     |                |
|         | Birch     | 7            |                   |             |                |             |                |
|         | Coniferous forest | 4           |                   |             |                |             |                |
|         | Pine      | 3            |                   |             |                |             |                |
|         | Forest edge | 2            |                   |             |                |             |                |
|         | Grass     | 2            |                   |             |                |             |                |
|         | Other     | 7            |                   |             |                |             |                |
| Russula integra s.l. | Birch | 3            | 0                 | None        | 0              | None        | None           |
|         | Coniferous forest | 2           |                   |             |                |             |                |
|         | Various habitats | 2            |                   |             |                |             |                |
|         | Mixed forest | 2            |                   |             |                |             |                |
|         | Other     | 2            |                   |             |                |             |                |
| Russula virescens | Birch | 4            | 0                 | None        | 2              | Imprecise   |                |
|         | Various habitats | 2            |                   |             |                |             |                |
|         | Other     | 4            |                   |             |                |             |                |
| Russula spp. | Mixed forest | 22           | 0                 | None        | 2              | Drought     |                |
|         | Various habitats | 11           |                   |             | 1              | Antropopression (general) |                |
|         | Pine      | 4            |                   |             | 1              | Imprecise   |                |
|         | Birch     | 4            |                   |             |                |             |                |
|         | Coniferous forest | 3           |                   |             |                |             |                |
|         | Deciduous forest | 3           |                   |             |                |             |                |
|         | Oak       | 3            |                   |             |                |             |                |
|         | Grasses   | 3            |                   |             |                |             |                |
|         | Other     | 10           |                   |             |                |             |                |
| Sarcodon squamosus | Pine | 14           | 0                 | None        | 2              | Drought     |                |
|         | Coniferous forest | 8           |                   |             | 2              | Forest management |                |
|         | Old/tall forest | 8           |                   |             | 1              | Imprecise   |                |
|         | Elevations/hillocks | 5        |                   |             |                |             |                |
|         | Mixed forest | 3            |                   |             |                |             |                |
|         | Other     | 3            |                   |             |                |             |                |
| Suillus bovinus | Pine | 15           | 0                 | None        | 1              | Drought     |                |
|         | Various habitats | 7            |                   |             | 1              | Imprecise   |                |
|         | Mixed forest | 4            |                   |             |                |             |                |
|         | Young/small forest | 4          |                   |             |                |             |                |
|         | Forest edge | 3            |                   |             |                |             |                |
|         | Elevations/hillocks | 3 |                   |             |                |             |                |
| Species            | Habitat         | Habitat (n) | Increase (n) | Increase cause | Decrease (n) | Decrease cause |
|--------------------|-----------------|-------------|--------------|----------------|--------------|----------------|
| Suillus grevillei | Larch           | 12          | 0            | None           | 0            | None           |
|                    | Other           | 1           |              |                |              |                |
| Suillus luteus s.l.| Pine            | 239         | 0            | None           | 5            | Imprecise      |
|                    | Young/small forest | 204       | 3            | Drought        |              |                |
|                    | Coniferous forest | 78         | 2            | Antropopression (general) |     |                |
|                    | Grasses         | 20          |              |                |              |                |
|                    | Thickets        | 19          |              |                |              |                |
|                    | Other           | 112         |              |                |              |                |
| Suillus variegatus | Pine            | 19          | 0            | None           | 1            | Imprecise      |
|                    | Humid ground    | 7           |              |                |              |                |
|                    | Young/small forest | 7          |              |                |              |                |
|                    | Mixed forest    | 5           |              |                |              |                |
|                    | Coniferous forest | 4          |              |                |              |                |
|                    | Moss            | 4           |              |                |              |                |
|                    | Deciduous forest | 2           |              |                |              |                |
|                    | Juniper         | 2           |              |                |              |                |
|                    | Elevations/hillocks | 2         |              |                |              |                |
|                    | Grasses         | 2           |              |                |              |                |
|                    | Blueberries     | 2           |              |                |              |                |
|                    | Clear/transparent forest | 2     |              |                |              |                |
|                    | Trenches/depressions | 2       |              |                |              |                |
|                    | Other           | 10          |              |                |              |                |
| Tricholoma equestre | Sandy ground | 82          | 0            | None           | 5            | Imprecise      |
|                    | Pine            | 78          | 2            | Antropopression (general) |     |                |
|                    | Elevations/hillocks | 47       | 1            | Habitat overgrowing |     |                |
|                    | Coniferous forest | 21         |              |                |              |                |
|                    | Young/small forest | 20         |              |                |              |                |
|                    | Moss            | 19          |              |                |              |                |
|                    | Mixed forest    | 12          |              |                |              |                |
|                    | Other           | 61          |              |                |              |                |
| Tricholoma portentosum | Sandy ground | 77          | 0            | None           | 1            | Antropopression (general) |
|                    | Pine            | 62          | 1            | Drought        |              |                |
|                    | Elevations/hillocks | 43       | 2            | Imprecise      |              |                |
|                    | Coniferous forest | 23         |              |                |              |                |
|                    | Moss            | 18          |              |                |              |                |
|                    | Young/small forest | 18         |              |                |              |                |
Respondents described coniferous forests as richer in fungi species than deciduous forests. However, this is not reflected in scientific studies [39]. This result might be related to the composition of local forests. These forests are dominated by pine, which often creates monocultures and is included in mixed woodlands [31]. Therefore, coniferous forests are visited most often, which makes respondents more familiar with the composition of coniferous forest fungi.

### Observed habitat preference of mushroom species

Data provided by scientific publications seldom displays information which habitat characteristics have the biggest importance for the development of a particular species. The large number of interviewees allows us to define the significance of particular habitat indicators based on the percentage of the most often mentioned characteristics.

By analysing the most frequently mentioned fungal habitats, we were able to create collective ethnobotanical descriptions with characteristics comparable to scientific knowledge. Comparison of local folk habitat descriptions with the available scientific knowledge allowed us to select those observations which are present in scientific literature or need further investigation (Table 4).

The following folk observations correspond to already published scientific reports:

1. The importance of grazing areas and animal manure for the abundance of saprotrophic fungi such as *Agaricus campestris* L., *Marasmius oreades* (Bolton) Fr. and *Macrolepiota procera* (Scop.) Singer [40–43].

2. *Leccinum scabrum*’s (Bull.) Gray preference for sylvopastoral habitats [39];

3. *Armillaria* (Fr.) Staude spp.’s preference towards living young pine trees—fungus’ ability to produce fruiting bodies decreases with the age of the infected pine tree [45, 46];

4. *Hygrophorus hypothejus*’ (Fr.) Fr., *Suillus bovinus*’ (L.) Roussel, and *Suillus luteus*’ (L.) Roussel preference towards young pine forest stands [48–52];

5. *Boletus edulis*’ Bull., *Cortinarius caperatus*’ (Pers.) Fr., *Sarcodon squamosus*’ (Schaeff.) Quéhl. preference towards old forest stands [55–58];

6. *Armillaria mellea*’s (Vahl) P. Kumm. s.l. need for relatively higher moisture than other wood-decaying basidiomycetes [60];

7. Higher abundance of *Lactarius deliciosus* (L.) Gray s.l. fruiting bodies in trenches and small depressions—the appropriate slope and elevation are significant predictors of *Lactarius deliciosus* (L.) Gray s.l. [66, 67];

8. *Lactarius deliciosus*’ (L.) Gray complex requirement for high moisture in conjunction with access to strong sunlight [47, 66, 68–70];

9. *Suillus bovinus*’ (L.) Roussel preference for relatively higher moisture than other macrofungi [50, 71, 72];

10. Moss presence as one of the parameters potentially determining the habitat of *Cantharellus cibarius* Fr., *Cortinarius caperatus* (Pers.) Fr. and *Suillus bovinus* (L.) Roussel [61, 63, 73, 74];

11. *Suillus bovinus* (L.) Roussel and *Suillus luteus* (L.) Roussel fruiting bodies’ occurrence on thin litter layer [48, 51, 75];

12. *Suillus variegatus* (Sw.) Richon & Roze fruiting bodies’ occurrence on thick litter layer [76];

| Species          | Habitat            | Habitat (n) | Abundance changes | Increase (n) | Increase cause | Decrease (n) | Decrease cause |
|------------------|--------------------|-------------|-------------------|--------------|---------------|--------------|----------------|
| *Tricholoma spp.* | Pine               | 124         | Increase          | 0            | None          | 10           | Imprecise      |
|                  | Sandy ground       | 118         | Increase          | 8            | Drought       |              |                |
|                  | Elevations/hillocks| 54          | None              |              |               |              |                |
|                  | Coniferous forest  | 33          | None              |              |               |              |                |
|                  | Mixed forest       | 28          | None              |              |               |              |                |
|                  | Young/small forest | 28          | None              |              |               |              |                |
|                  | Moss               | 24          | None              |              |               |              |                |
|                  | Other              | 79          | None              |              |               |              |                |

Table 3: Habitat preferences and abundance changes of selected fungal taxa. (Continued)
Table 4 Evaluation of reports of Polish mushroom collectors by present scientific mycological knowledge

| Reports correspond with scientific literature | Mentioned as possible in literature but not yet tested | Not mentioned in literature and not yet tested |
|-----------------------------------------------|-----------------------------------------------------|-----------------------------------------------|
| The importance of grazing areas and animal manure for the abundance of saprotrophic fungi such as Agaricus campestris, Marasmius oreades, and Macrolepiota procera [40–43] | The xerophillic character of Amanita vaginata. Unconfirmed for A. vaginata but confirmed for some species from the Vaginatae section [44] | Higher abundance of Hygrophorus hypothejus's fruting bodies in pine forests growing on former arable land than in ancient forest locations |
| Leccinum scabrum's preference for sylvopastoral habitats [39] | High amplitudes of litter temperature as a stimulator of the production of fruiting bodies [47] | Suillus bovinus, Tricholoma equestre and Tricholoma portentosum abundance is higher on uneven ground surface |
| Armillaria spp.’s preference towards living on young pine trees – the fungus’ ability to produce fruting bodies decreases with the age of the infected pine tree [45, 46] | Low canopy density and exposure of litter to sun stimulating the fruiting of Cortinarius caperatus [47] | Litter density as one of the main factors determining particular Suillus species fructification |
| Hygrophorus hypothejus, Suillus bovinus, and Suillus luteus’ preference towards young pine forest stands [48–52] | Higher presence of Pleurotus ostreatus in cutting and managed areas [53, 54] | Boar rooting as a stimulator of the production of Suillus bovinus fruting bodies |
| Boletus edulis, Cortinarius caperatus, Sarcodon squamosus’ preference towards old forest stands [55–58] | The positive effect of forest age on the abundance of production of fungal fruiting bodies [59] | The declining abundance of saprotrophic fungi in analysed areas as related to grazing abandonment and the use of synthetic fertilizers |
| Armillaria mellea’s need for relatively higher moisture than other wood-decaying basidiomyctes [60] | Influence of moss on the fungal fructification process (e.g. its protective effect, increasing soil nitrogen and phosphorus content and being the source of saprobiotic nutrition) [61–65] | |
| Higher abundance of Lactarius deliciosus fruting bodies in trenches and small depressions – the appropriate slope and elevation are significant predictors of Lactarius deliciosus [66, 67] | | |
| Lactarius deliciosus’ complex requirement for high moisture in conjunction with access to strong sunlight [47, 66, 68–70] | | |
| Suillus bovinus’ preference for relatively higher moisture than other macrofungi [50, 71, 72] | | |
| Moss presence as one of the parameters potentially determining the habitat of Cantharellus cibarius, Cortinarius caperatus and Suillus bovinus [61, 63, 73, 74] | | |
| Suillus bovinus and Suillus luteus fruting bodies’ occurrence on thin litter layer [48, 51, 75] | | |
| Suillus variegatus fruting bodies' occurrence on thick litter layer [76] | | |
| Broken or ploughed forest cover inducing the production of Gyromitra esculenta and Morchella spp. ascocarps [77–80] | | |
| Higher abundance of Boletus edulis, Boletus subtomentosus and Russulaeae fruting bodies in lighter forest areas such as forest edges [81–83] | | |

13. Broken or ploughed forest cover inducing the production of Gyromitra esculenta (Pers.) Fr. and Morchella Dill. ex Pers. spp. ascocarps [77–80];
14. Higher abundance of Boletus edulis Bull., Boletus subtomentosus L. and Russulaeae L.fruiting bodies in lighter forest areas such as forest edges [81–83].

Some phenomena observed by the informants have not yet been researched or tested by science, e.g.:

1. Higher abundance of Hygrophorus hypothejus’s (Fr.) Fr. fruting bodies in pine forests growing on former arable land than those in ancient forest locations;
2. Suillus bovinus (L.) Roussel, Tricholoma equestre (L.) P. Kumm. and Tricholoma portentosum (Fr.) Qué. abundance is higher on uneven ground surface;
3. Litter density as one of the main factors determining particular Suillus species fructification;
4. Boar rooting as a stimulator of the production of Suillus bovinus (L.) Roussel fruiting bodies;
5. The declining abundance of saprotrophic fungi in analysed areas as related to grazing abandonment and the use of synthetic fertilizers.

Some phenomena mentioned by informants are known to many mycologists but have no scientific confirmation or were only suggested by some authors:

1. The xerophilic character of Amanita vaginata (Bull.) Lam. Unconfirmed for A. vaginata, but confirmed for some species from the Vaginatae section [44];
2. High amplitudes of litter temperature as a stimulator of the production of fruiting bodies;
3. Low canopy density and exposure of litter to sun stimulating the fruiting of Cortinarius caperatus (Pers.) Fr.—unconfirmed, but recent studies show its lower abundance in relatively high moisture conditions [47], which might be connected with low sun exposure;
4. Higher presence of Pleurotus ostreatus (Jacq.) P. Kumm. in cutting and managed areas; unconfirmed but suggested by a few authors (dead and damaged wood presence, wood inoculation) (e.g. [53, 54]);
5. The positive effect of forest age on the abundance of production of fungal fruiting bodies; mainly unexplored with one publication contradicting it [59];
6. Influence of moss on fungal fruiting process (e.g. protective effect, increasing soil nitrogen and phosphorus content and source of saprobic nutrition); mostly unexplored but suggested by [61–65].

Perceived abundance change of mushrooms

Mushroom collectors had the general perception that the decrease of mushroom abundance is the general trend in the areas they visit to collect mushrooms. The steady decrease of macrofungal abundance in Europe was already noticed in the 1970s [84–86]. At the beginning of the 1990s, scientists started to talk about the Mass Extinction of European Fungi [87, 88]. However, this tendency was formulated only on the basis of single reports, without presentation of any statistical figures [89].

The extensive research on the decline in the abundance of macrofungi was initiated at the end of the 1980s by the Dutch scientist, Eef Arnolds. The declining abundance of saprotrophic species occurring in the grasslands has been recorded mostly in connection to the newly implemented agricultural practices and use of artificial fertilizers [89]. A similar correlation has also been noticed by people living in Mazovia. When reporting on the abundance decrease of the field mushroom (Agaricus campestris L.) (12 persons), respondents stated grazing abandonment, changes in agricultural practices, and application of artificial fertilizers as the main causes of their decline. Arnolds [89] noticed a significant abundance decrease of 55 out of 126 analysed fungal species. It was mainly related to species characteristic of coniferous forests, which is the dominating type of forest in Mazovia (64%). Air and soil pollution were taken to be the main cause of the decreasing abundance of macrofungi [89–91]. Arnolds based his research on long-term field observations preceding data analysis (1912–1954 and 1973–1982 as well as data collected during two decades of individual research preceding its publication). The results of the analysis showed a drop in the number of macrofungi species occurring in the Netherlands from 37 to 12 per 1000 m². Similarly, as in case of studies contacted in Mazovia, Arnolds [89] observed that species which suffered the most significant decrease belonged to the Lactarius, Cantharellus, Boletus, Tricholoma, and Suillus genus. According to his studies, the biggest abundance decrease is observed among ectomycorrhizal fungi species—a group to which the majority of species mentioned in present work belong to. However, Arnolds did not take the gradual changes occurring in soil water regimes into consideration. According to recent studies on soil water content changes, in the last few decades we have been dealing with a gradual decrease of soil water content in Poland [91–93]. Respondents, too, listed it as one of the main reasons for the decrease in fungal abundance in Mazovian forests (Fig. 4).

Current studies also confirm Arnolds’ reports on the visible decrease of macrofungi abundance. Research from Norway [94] confirms the significantly negative influence of nitrogen fertilization on the occurrence of fungal fruiting bodies. However, the same research also shows a high influence of drought on the decrease in the production of fruiting bodies. Studies conducted in northern Spain proved that partial rain exclusion (~30%) lowered the production of fungal fruiting bodies by 60% [95]. De Aragón et al. [96] noticed that the right balance between accumulated monthly mean precipitation and evapotranspiration was of the greatest importance for macrofungi occurrence.

It was established that the main indicators of basidio-mycetes’ fruiting bodies presence are soil moisture and its temperature back in the mid-20th century [97]. Certain levels of these indicators have to occur simultaneously for a period of time relevant to the particular species. While all different species depend on different ranges of temperature, all species rely on an increased level of soil moisture. Dahlberg [98] showed that similar weather conditions can determine the
production of 55–88% fruiting bodies of basidiomycetes species (after [94]).

The impact of climate change on fungi is scientifically indisputable. Gange [99] conducted 56-year-long research on the period of macrofungal fructification. Data collected on 315 different species shows a tendency for the average first date of fructification to come earlier in the year as time goes on, while the average last fruiting date now occurs significantly later. In his studies on climate change, Schär et al. [100] focused not on the gradual rise of temperatures, but on increasing temperature variability in Central Europe. According to his observations, one of the main results of this phenomenon is summer droughts such as the one which occurred in Poland in 2003 [101]. The progressive drought observed by the respondents, with its impact on changes in local mycobiota, might be related to scientifically observed changes in climate.

It has been recognized that the act of mushroom picking has no significant impact on macrofungal fruiting body abundance [102]. Mycorrhiza compression, on the other hand, can have a large impact on the occurrence of fruiting bodies. During present research, 10 independent respondents noticed a relationship between number frequencies of mushrooms and the introduction of heavy machinery to forest management. According to their reports, the abundance of fungal fruiting bodies decreased after band-saw operators were replaced with devices equipped with felling heads. The highly negative impact of the pressure of heavy machinery on forest litter layer has been confirmed by Arnolds [91] and Frey [103]. The correlation between heavy machinery use and mushroom abundance decrease is so significant that it is visible to a respondent’s naked eye. Therefore, it is important to conduct further studies on the scale of this problem and to search for a new solution to be implemented in forest management. The decrease in fungal abundance could be also related to disturbances in the environmental nitrogen cycle as a result of artificial management use, as confirmed by Vitousek [104].

The increased abundance of *Imbleria badia* (Fr.) Vizzini, as observed by 15 respondents, can be explained by the Bay Bolete’s high capacity to adapt to habitats with acidic soils [105]. This type of soil dominates in pine forests—the main forest type in Mazovia. The research conducted in European countries by Rosinger et al. [106]. shows that species such as *Xerocomus badius* (Fr.) E.-J. Gilbert (currently *Imbleria badia* (Fr.) Vizzini), *Scleroderma citrinum* Pers. and *Paxillus involutus* (Batsch) Fr. usually occur in areas that combine high annual temperature and low annual rainfall. This may also explain the higher *Imbleria badia* occurrence. Furthermore, Clemmensen [107], Morgado [108], and Fernández [109] classify the Bay Bolete to the group of long-distance exploration fungi. In other words, this species is able to create long rhizomorphs that enable efficient habitat penetration. Aside from improving its ability to explore, long rhizomorphs also improve water transportation and accumulation [110].

**Conclusions**

The interviewed Polish mushroom collectors had a deep understanding of fungal habitats. They used different scales of habitats to describe the habitat preferences of various fungi species. The high number of 98 fungal habitats listed by the respondents confirms the highly mycophillic character of people living in the studied area [34]. We found that some phenomena which have not yet been studied or tested by science were observed by multiple informants. Locals had the unanimous perception that fungal abundance is decreasing, and they identified drought as the key driver of the change.

We conclude that local ecological knowledge of lay mushroom collectors could offer new stimuli for scientific research and contribute to citizen-based monitoring of macrofungi.

Our large area study on fungal ethnoecology has a preliminary character and aims to encourage further research on this topic in other regions inhabited by mycophillic societies.

**Authors’ contributions**

ŁŁ and MK contributed to the concept of the study. MK contributed to the field work, data analysis, and first draft of the paper. ZM contributed to the analysis of folk habitat classification. All the authors contributed to the final draft. All authors read and approved the final manuscript.

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**Availability of data and materials**

Voucher specimens for species were deposited in the herbarium of Warsaw University (WAW).

**Declarations**

**Ethics approval and consent to participate**

The methods of obtaining data during fieldwork followed guidelines set by International Society of Ethnobiology Code of Ethics [109] and the American Anthropological Association Code of Ethics [110] and adhere to the local traditions for such research. Prior oral informed consent was obtained from all study participants. No ethical committee permits were required. No permits were required to collect voucher specimens.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare that they have no competing interests.

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