CROWDSOURCING FUNGAL BIODIVERSITY: REVISION OF INATURALIST OBSERVATIONS IN NORTHWESTERN SIBERIA

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The paper presents the first analysis of crowdsourcing data of all observations of fungi (including lichens) and myxomycetes in Northwestern Siberia uploaded to iNaturalist.org to date (24.02.2022). The Introduction presents an analysis of fungal diversity crowdsourcing globally, in Russia, and in the region of interest. Materials and methods describe the protocol of uploading data to iNaturalist.org, the structure of the crowdsourcing community, initiative to revise the accumulated data, procedures of data analysis, and compilation of a dataset of revised crowdsourced data. The Results present the analysis of accumulated data by several parameters: temporal, geographical and taxonomical scope, observation and identification efforts, identifiability of various taxa, species novelty and Red Data Book categories and the protection status of registered observations. The Discussion provides data on usability of crowdsourcing data for biodiversity research and conservation of fungi, including pros and contras. The Electronic Supplements to the paper include an annotated checklist of observations of protected species with information on Red Data Book categories and the protection status, and an annotated checklist of regional records of new taxa. The paper is supplemented with a dataset of about 15 000 revised and annotated records available through Global Biodiversity Information Facility (GBIF). The tradition of crowdsourcing is rooted in mycological societies around the world, including Russia. In Northwestern Siberia, a regional mycological club was established in 2018, encouraging its members to contribute observations of fungi on iNaturalist.org. A total of about 15 000 observations of fungi and myxomycetes were uploaded so far, by about 200 observers, from three administrative regions (Yamalo-Nenetsky Autonomous Okrug, Khanty-Mansi Autonomous Okrug, and Tyumen Region). The geographical coverage of crowdsourcing observations remains low. However, the observation activity has increased in the last four years. The goal of this study consisted of a collaborative effort of professional mycologists invited to help with the identification of these observations and analysis of the accumulated data. As a result, all observations were reviewed by at least one expert. About half of all the observations have been identified reliably to the species level and received Research Grade status. Of those, 90 species (195 records) represented records of taxa new to their respective regions; 876 records of 53 species of protected species provide important data for conservation programmes. The other half of the observations consists of records still under-identified for various reasons: poor quality photographs, complex taxa (impossible to identify without microscopic or molecular study), or lack of experts in a particular taxonomic group. The Discussion section summarises the pros and cons of the use of crowdsourcing for the study and conservation of regional fungal diversity, and summarises the dispute on this subject among mycologists. Further research initiatives involving crowdsourcing data must focus on an increase in the quality of observations and strive to introduce the habit of collecting voucher specimens among the community of amateurs. The timely feedback from experts is also important to provide quality and the increase of personal involvement.

Key words: biodiversity data mobilisation, citizen science, fungal conservation, fungi, human observation, lichens, mycological society, new record, protected species, Red Data Book

Introduction

The citizen-science observations of biodiversity, or crowdsourcing, have become an important source of information for research and conservation along with the development of information technologies in the past two decades (Pocock et al., 2014, 2018; Theobald et al., 2015; Amano et al., 2016; Chandler et al., 2017; Seltzer, 2019). Global resources for uploading and storage of biodiversity observations provide a new massive pool of data, while machine-based technologies of image recognition and automated identification provide tools for its analysis. Citizen science-based platforms for biodiversity observation have become an important tool for learning, education and communication.

In mycology, the community of citizen scientists has been shaped by various mycological societies, from local mushroom enthusiast clubs to national and international networks (Webster, 1997; Halme & Kotiaho, 2012; Heilmann-Clausen et al., 2021; May, 2021; Frøslev et al., 2022). These communities have developed at different paces depending on the country and regional traditions. However, in today's world of information exchange, there is hardly a region in the world where the public is not interested in sharing, contributing and discussing of observations of fungi. The tradition of mycological societies in Europe is well-rooted in British, Danish, and Swedish mycological societies (Webster, 1997; Watling, 1998; Frøslev et al., 2022). The North-American Mycological Association currently includes hundreds of state or local level mushroom clubs or associations (https://namyco.org/). In Russia, there is a mycological branch of the Russian Botanical Society, the Saint-Petersburg Mycological Society, and several regional informal mycological communities or clubs. Among other activities, most of the mycological societies strive to accumulate observations of fungi made by its members during the collective or individual forays and integrate it into the global pool of knowledge, one way or another. In the past few decades, these observations have been integrated and published through more or less developed online data portals. We will mention several modern-day databases of national fungal observation programs: the FungiMap portal in Australia (https://fungimap.org.au), FunDis in North America (https://www.inaturalist.org/projects/fundis-biodiversity-database), Danish Mycological Society fungal records database (https://svampe.databasen.org/), and British Fungal Records Database (http://www.frdbi.info/). Besides, many countries have their national biodiversity observation portals, which are used by mycological associations when there are no online resources focused on fungi; for example, these are the Swedish Species Observation System (https://www.artportalen.se/), and the Finnish Biodiversity Information Facility (FinBIF https://laji.fi/).

The crowdsourcing of fungal biodiversity has become an important source of information for the publication of inventories and checklists (Haelewaters et al., 2019; Heilmann-Clausen et al., 2019; Sheehan et al., 2021), and analyses of phenology and climate-derived dynamics of fruiting (Gange et al., 2011; Heilmann-Clausen et al., 2016; Andrew et al., 2017). The fungal conservation has especially benefited from crowdsourcing, since many rare and protected species are difficult to find, yet quite often, they are reliably identifiable in the field (Barron, 2011; Molina et al., 2011; Mueller, 2017; Irga et al., 2020). An important development of the last few years is automated image recognition of species, especially since fungi are still less studied in this aspect compared to other groups. There has been rapid progress in this area, relying on the accumulated images and observations (Báthori et al., 2017; Tahir et al., 2018; Van Horn et al., 2018; Sulc et al., 2020).

The recent history of crowdsourcing the biodiversity of fungi in Russia includes several mycological forums, where amateur and professional mycologists have created a resource of observations. The community of the «Mushrooms of Kaluga Region» website and forum (http://mycoweb.narod.ru/) has been actively organising their observations of fungi. Many observations of new and noteworthy taxa were eventually published. The online community of Saint-Petersburg Mycological Society (https://vk.com/planeta_gribov) has also been collecting observations and discussing rare finds. The Encyclopedia of Fungi of Siberia (https://mycology.su/) project published several hundred descriptions of species based on observations of fungi in Siberia. However, these platforms do not have online databases and/or do not allow exporting data to the Global Biodiversity Information Facility (GBIF), and therefore they are unavailable for global analyses and research based on this platform. The crowdsourcing of fungal diversity on iNaturalist.org has become more popular in Russia in the last two years; however, until now there has not been any organised activity concerning expert analysis or publication of accumulated data. By April 2022, there is a total of about 178 000 observations of fungi and myxomycetes on iNaturalist.org from Russia. About 41% of these observations currently have the Research Grade status, with about 64 000 observations exported to GBIF.

The activity of amateur mycologists in Northwestern Siberia is a relatively new trend that has been on the rise for a couple of years. The Mycological Club of Yugra was established in 2018, which organises and hosts various activities and events, such as forays, educational shows, and workshops. Nowadays, the Siberian Mycological Society is a growing project uniting amateurs and professionals from various parts of Western Siberia (https://sibmyco.org/). As a part of this activity, in 2018, we initiated a project on iNaturalist.org titled «Fungi observations in the Yugra region». A series of educational events was organised, aimed to engage the public to participate in the project. It included «bioblitzes», social media activity, offering expert advices and personalised guidance in various messengers, and workshops in the field. This effort has been fruitful, establishing a steady interest in the subject, since the number of observations collected within the project already exceeds the number of specimens accumulated in regional scientific collections (Fungarium of the Yugra State University, and personal collections of researchers). This publication is the first attempt of the revision of image-based observations of fungi accumulated on iNaturalist.org as well as a formal publication of records of protected species and novelties in Northwestern Siberia within the administrative borders of three regions, namely Yamal-Nenetsky Autonomous Okrug, Khanty-Mansi Autonomous Okrug, and Tyumen Region.

Material and Methods

Instructions regarding user registration, image upload, and identification proposal are described in detail on the iNaturalist.org help page (https://www.inaturalist.org/pages/help); hence we omit these protocols in this publication. To monitor and analyse data on fungi and myxomycetes in the study area we have started a project in May 2018, called «Fungi observations in Yugra region», later renamed to «Fungi and Myxomycetes in Northwestern Siberia» with extended geographic boundaries (https://www.inaturalist.org/projects/mushroom-observations-in-northern-west-siberia). Data in the project were filtered by two high-rank taxa (kingdom Fungi and class Myxomycetes) and administrative borders of three regions (Yamal-Nenetsky Autonomous Okrug, Khanty-Mansi Autonomous Okrug, and Tyumen Region). An important part of the communication on iNaturalist.org is the project journal, existing since 2020, to summarise activities, report interesting records, and announce upcoming events. A series of «bioblitzes» was organised to draw the attention of the public to the project and iNaturalist.org in general; the most important regular event is «Mushroom iNat Marathon» (in Russian: «Грибной iNat Марафон»), taking place for one week every year in September since 2019 (https://sibmyco.org/events/bioblitz/). The project audit is being regularly published in Russian on the Siberian Mycological Society webpage in the social media (https://vk.com/sibmyco).

The geographic scope of the project has been defined by the history of the study area. Initially, we included only one region (Khanty-Mansi Autonomous Okrug), because, in this area, the majority of all activities of the Siberian Mycological Society have been held. Nonetheless, the Khanty-Mansi Autonomous Okrug is closely connected historically to the adjacent Yamalo-Nenetsky Autonomous Okrug and Tyumen Region; these three regions were united into a single administrative area in the past. In the latter two regions, the iNaturalist activity dealing with the diversity of fungi is still low compared to the Khanty-Mansi Autonomous Okrug, but we decided to include all three ones in the updated project and in this publication to cover the whole area of Northwestern Siberia as a single biogeographical region.

The critical component of the project on iNaturalist.org is its expert community, made up of professional mycologists who identify records and provide feedback on the quality of the incoming data and, as well as monitor the total number of uploaded observations. The expert community on iNaturalist.org includes anyone who is interested in a specific taxon and region and is willing to provide identifications. Nonetheless, the initial number of professional mycologists contributing to the taxon identification on iNaturalist.org in the region was low (up to five users). Therefore, we invited more experts, resulting in a group of 16 professional mycologists revising the accumulated observations for the purpose of creating this publication. We set three tasks: 1) to revise all observations in the project, including those with the Research Grade status for double-checking previous identifications; 2) to identify observations down to the lowest possible taxonomic level (species, genus, or family, etc.) from the features visible in the photographs; 3) to provide at least two expert identifications for each observation.

The table resulting from the work of experts on iNaturalist.org was downloaded on 24.02.2022 as a .csv file, and further analysed and visualised using the «tidyverse» collection of packages (Wickham et al., 2019) for R ver. 4.1.2 (R Core Team, 2021) in RStudio ver. 2021.09.1+372. To obtain information on identifications, data on project observations were downloaded through the iNaturalist API using the «rinat» package (Barve & Hart, 2022). New records for the study area were evaluated by comparison of the resulting species list with three literature-based datasets for Northwestern Siberia (Filippova et al., 2022a), Southwestern Siberia (Filippova et al., 2022b), and with the checklist of agaricoid and boletoid fungi of Russia (Bolshakov et al., 2021). The three datasets contained a total of 29 885 records and 4343 taxa for the three studied regions. To avoid a mix-up of taxonomical concepts in iNaturalist.org, GBIF, and literature datasets, names were synonymised using the GBIF Backbone taxonomy. For looking up scientific names, GBIF Species API (https://www.gbif.org/developer/species) was accessed using the «rgbif» package (Chamberlain & Boettiger, 2017; Chamberlain et al., 2022). The «metacoder» package was used to visualise the taxonomic coverage (Foster et al., 2017). The packages «tsibble» and «feasts» were used for temporal data analysis (Hyndman & Athanasopoulos, 2021). A distribution map was created in QGIS ver. 3.18 (QGIS Development Team, 2022).

All scripts for data import, preparation, synonymisation, analyses, preparation of tables and graphs and an annotated species lists were published in a repository (R project) on GitHub (https://github.com/sergbolshakov/iNat_FMWS_analysis). The resulting table, based on the original download of iNaturalist observations and complemented with fields indicating species novelties (dynamicProperties) and identification remarks (identifiedBy, identificationRemarks), was published as a dataset through GBIF (Filippova et al., 2022c).

Results

As the result of expert evaluation of about 15 000 observations (exactly 14 962), about half of them (8429, 56%) were reliably identified down to the species level and assigned up to the Research Grade (RG) status. The resulting data were analysed by various parameters. The analysis has covered all observations or only those with the RG status, depending on the scope.

Taxonomic coverage

The taxonomic coverage of the Research Grade observations, produced by the work of experts in the project, includes five phyla (Ascomycota, Basidiomycota, Entomophthoromycota, Mycetozoa, Zygomycota), 24 classes, 54 orders, 157 families, 433 genera, and 963 species (Fig. 1). As a result of comparison of the resulting checklist with previously published records for the region (represented by three literature-based datasets), 90 species (represented by 195 records) on iNaturalist.org were found to be new for the region. They were marked in the dataset published through GBIF with remarks (in dynamicProperties) and are also reported in this publication with short annotations (Electronic Supplement 2).

Geographic coverage

The selected coverage of the observations spans across three administrative regions of the country. The majority (91.8%) of the observations in the project come from the Khanty-Mansi Autonomous Okrug, 3.6% from Tyumen Region, and 3.3% from Yamalo-Nenetsky Autonomous Okrug (Table 1). Such geographic disparity in coverage is explained by the active ongoing promotion of iNaturalist among the public in the Khanty-Mansi Autonomous Okrug, while in the two other regions, there has been virtually no promotional activity and the public remained unaware of the initiative. Several professional mycologists working in the Khanty-Mansi Autonomous Okrug also contributed to a large number of observations in the study area.

The spatial distribution of observations is shown in Fig. 2. Grid analysis showed a highly uneven distribution of observations across a grid of 50 × 50-km cells, clearly demonstrating that most of the territory remains poorly studied, even with the considerable contributions from crowdsourcing. About 74% of the grid cells remain blank, i.e. without a single observation, while 24% of the cells have from one to 100 observations, and only 1.5% of grid cells have more than 100 observations each.

About half (7104) of all the observations in the project were made in Protected Areas of federal and regional status. The most well-studied are the Samarovskiy Chugas Natural Park (5825 observations), Kondinskie Ozera Natural Park (768 observations), and Natural Monument «Sistema ozer Un-Novyinklor i Ay-Novyinklor» (146 observations) (Table 2). The accumulation of observations in Protected Areas is valuable for education, recreation, and, most important, for various research and conservation efforts in the study area. All Protected Areas mentioned above have become activity hotspots on iNaturalist.org, and they use the portal for a variety of educational and scientific tasks.

Table 1. Regional coverage of observations of fungi and myxomycetes registered on iNaturalist.org in Northwestern Siberia

Region	Total number of observations	Number of RG observations	Number of species
Khanty-Mansi Autonomous Okrug	13 740	7935	713
Tyumen Region	732	304	105
Yamalo-Nenetsky Autonomous Okrug	490	170	65

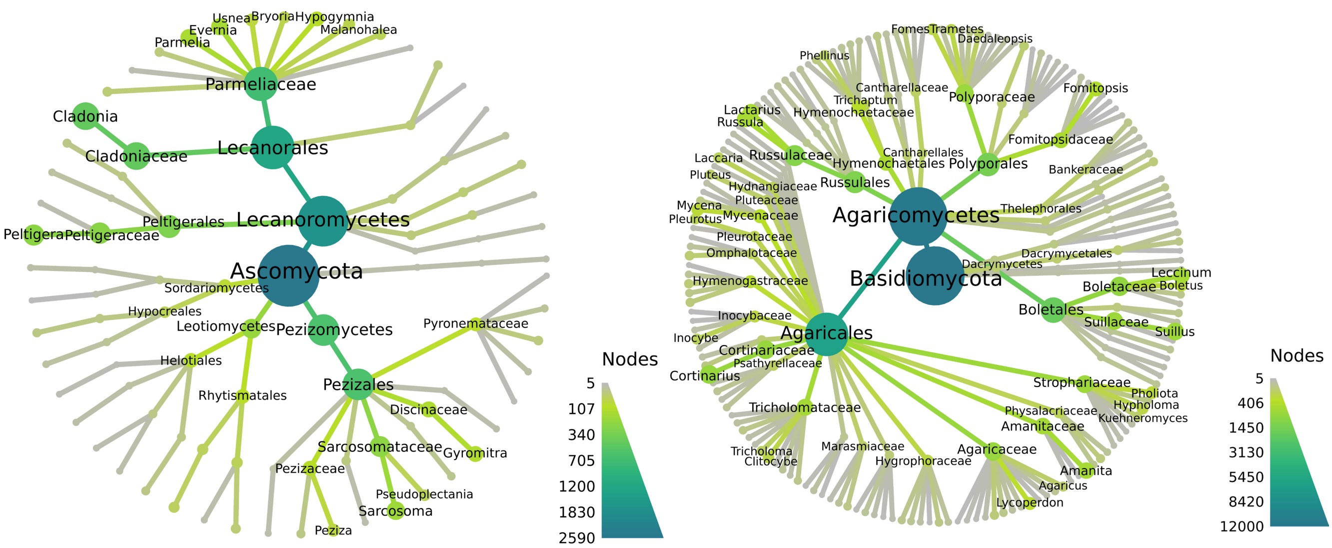

Fig. 1. The taxonomical structure of observations of fungi and myxomycetes on iNaturalist.org in Northwestern Siberia up to genera level (including Research Grade and Needs ID statuses). Node size and colour mark the number of observations. Only nodes with five and more observations are shown.

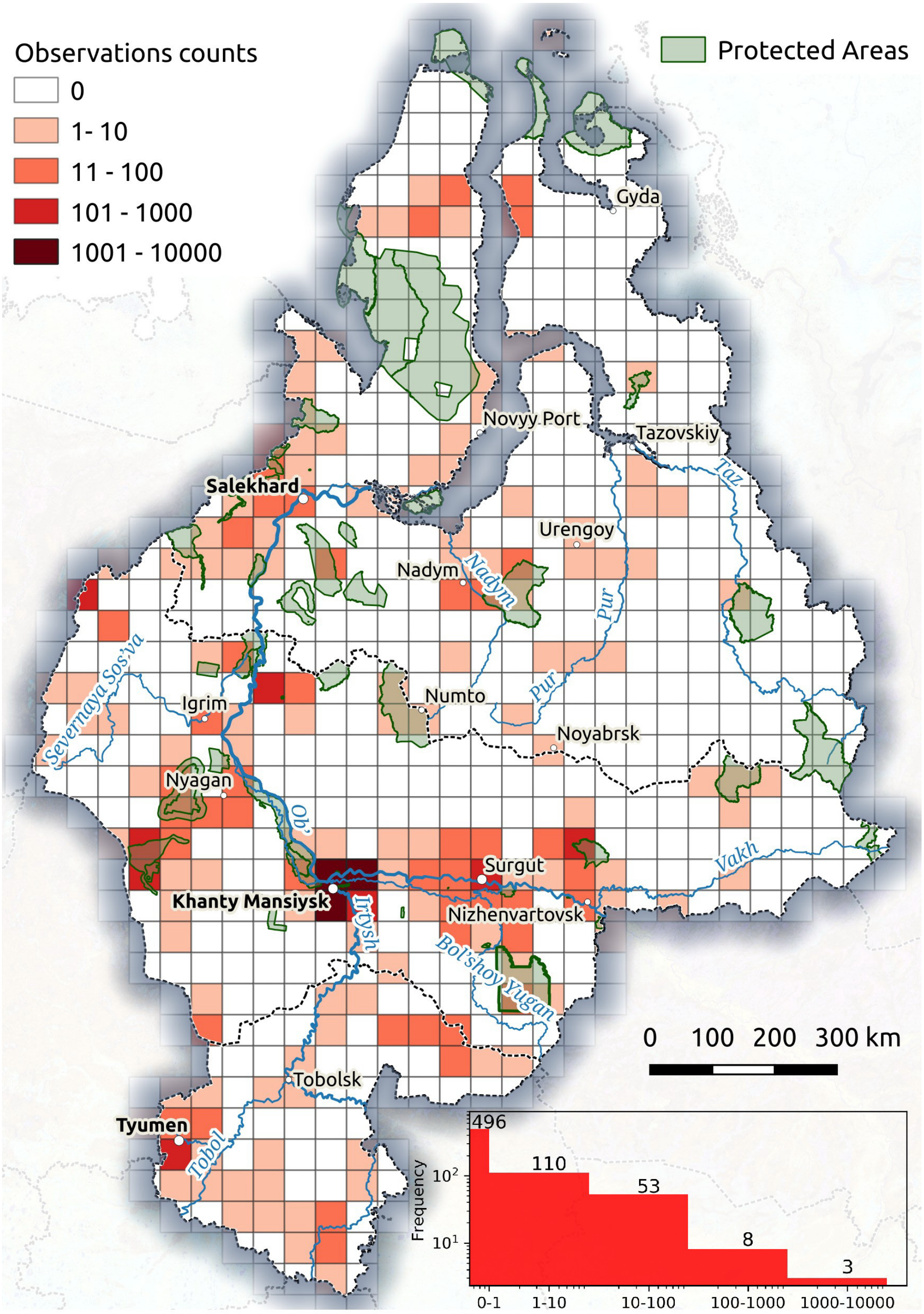

Fig. 2. The spatial distribution and frequency histogram of observations of fungi and myxomycetes on iNaturalist.org across a 50-km grid in Northwestern Siberia (including Research Grade and Needs ID statuses).

Temporal coverage

The temporal coverage of observations spans across ten years. But the majority (86%) of observations was made in the two last years (2020–2021) (Fig. 3). Although the project was initiated in May 2018, the first two years yielded only about 11% of the present amount of observations. The total number of observations made last year (2021) declined compared to the previous year (2020), possibly explained either by a decrease in the activity of the leading participants or by a weather-driven decline in the fruiting of fleshy fungi in that particular year. A short temporal coverage prohibits the use of these data for the analysis of long-term fruiting dynamics of fleshy fungi (Agaricomycetes), but the last two years can be used to compare the seasonal onset of fruiting. The onset of the key fruiting periods did not change through the years, but the total abundance of fruiting declined two-fold in 2021 compared to 2020 (Fig. 3). The reason for the decline could be explained by local weather conditions, but also by a drop of activity of the observers. Analysis of phenology of fruiting of Agaricomycetes shows that the total abundance of fruiting rises from April to September; the maximum fruiting in the region is registered in August and September, and drops in October (Fig. 4).

Table 2. The number of observations of fungi and myxomycetes collected on iNaturalist.org in various Protected Areas in Northwestern Siberia

Protected Area status	Protected Area category	Protected Area name	Number of observations	Research Grade observations	Species
In total in Protected Areas			7104	4246	811
Regional	Natural Park	Samarovskiy Chugas	5825	3609	479
Regional	Natural Park	Kondinskie Ozera	781	432	169
Regional	Natural Monument	Sistema ozer Un-Novyinklor i Ay-Novyinklor	146	52	27
Federal	Sanctuary	Verkhne-Konsinskiy	112	51	38
Federal	State Nature Reserve	Malaya Sosva	111	50	46
Federal	State Nature Reserve	Yugansky	37	25	20
Regional	Natural Park	Polyarno-Uralskiy	26	8	6
Regional	Natural Park	Numto	17	5	5
Regional	Sanctuary	Sobty-Yuganskiy	11	8	6
Regional	Sanctuary	Nadymskiy	10	1	1
Regional	Sanctuary	Pyakol'skiy	10	5	5
Regional	Natural Park	Sibirskie Uvaly	6	6	2
Regional	Sanctuary	Synsko-Voykarskiy	5	5	3
Regional	Natural Monument	Padunskiy	3	3	2
Regional	Sanctuary	Vogulka	2	2	1
Regional	Natural Monument	Ostrov Ovechiy	1	–	–
Regional	Sanctuary	Messo-Yakhinskiy	1	1	1

Observer activity

The observer activity is an important characteristic of the crowdsourcing potential. The total number of observers with at least one observation of fungi or myxomycetes in the region exceeded 200 users. The effort is distributed rather unevenly, with the top 13 users (defined by > 100 observations per user) submitting about 84.3% of the observations (Fig. 5). The volume of species lists of individual observers is also highly heterogeneous: the histogram below shows that most of the users have registered from one to 100 species, while only eight users provided records of a higher number of species (Fig. 6); two of them are professional mycologists.

Expert activity

By the time the writing was started, the expert activity in the project remained quite low, with only a few regional experts contributing to identification and providing feedback. Inviting other mycologists from elsewhere in the country to join the effort, has considerably improved the situation. Currently, there are about 380 experts (anyone who has made at least one identification) in the project. The top 26 experts (with more than 100 identifications) are responsible for about 90% of all identifications in the project. Of them, 16 professional mycologists have made about 80% of all identifications (Fig. 7).

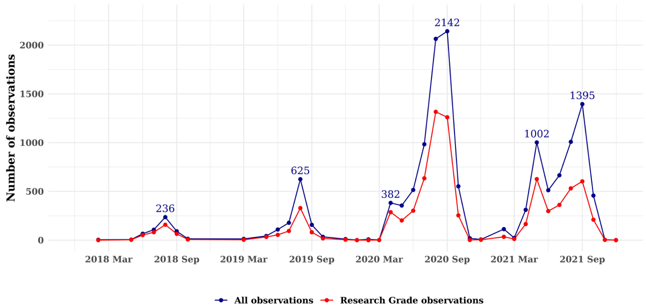

Fig. 3. Temporal coverage of observations of fungi and myxomycetes on iNaturalist.org in Northwestern Siberia.

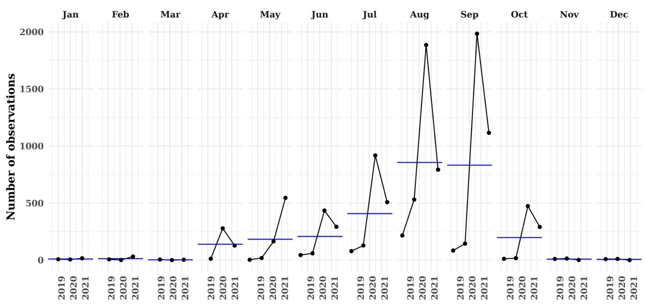

Fig. 4. Fruiting phenology of Agaricomycetes demonstrated by the number of observations on iNaturalist.org in Northwestern Siberia (including Research Grade and Needs ID statuses).

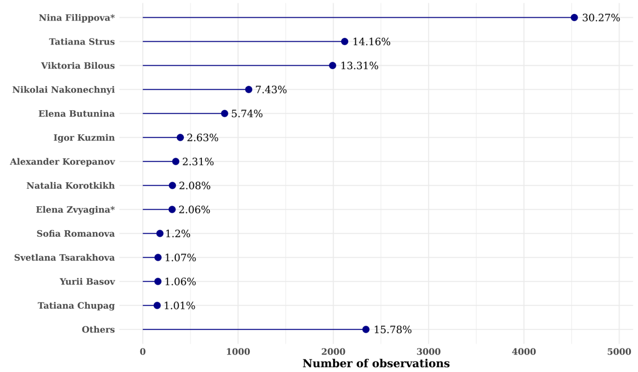

Fig. 5. The percentage of observations made by individual users (observers) of fungi and myxomycetes on iNaturalist.org in Northwestern Siberia (including Research Grade and Needs ID statuses) (professional mycologists marked with asterisk).

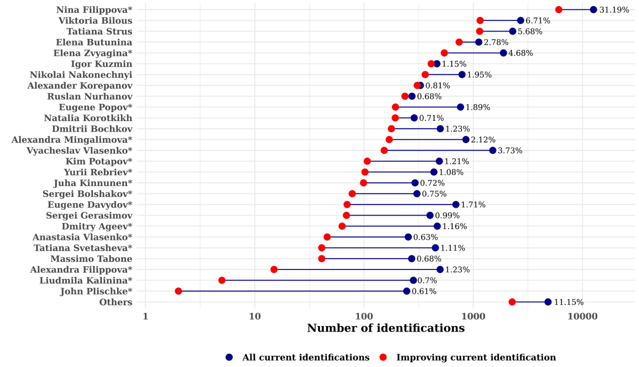

Fig. 7. Expert activity showing percentage of all and improving current identifications of fungi and myxomycetes made by users on iNaturalist.org in Northwestern Siberia (professional mycologists marked with asterisk).

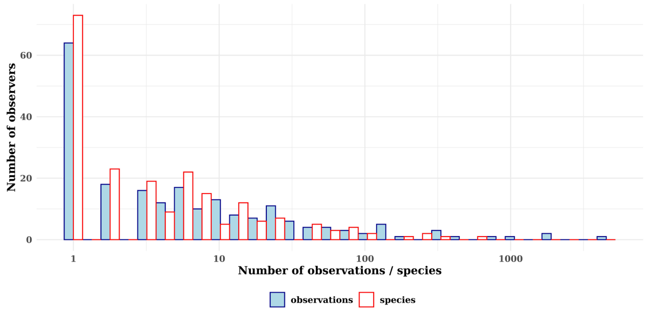

Fig. 6. The histogram showing the unequal ability of users to detect species of fungi and myxomycetes and collect number of observations on iNaturalist.org in Northwestern Siberia.

Protected species

Protected species are an issue of paramount importance in fungal diversity crowdsourcing, since they are rarely encountered, but are reliably identifiable in the field based on macroscopical characters alone, considering the general prerequisite to include well identifiable species in conservation programmes. Our aim was to create a resource of new records of protected fungi, which can be used to update the existing information on species occurrence for future conservation programmes and Red Data Book editions. All three regions have fungi in their regional Red Data Books (Gashev & Zamyatin, 2010; Vasin & Vasina, 2013; Petrova, 2020). The federal-level Red Data Book also has a section on fungi (Bardunov & Novikov, 2008). In the Khanty-Mansi Autonomous Okrug, the number of protected species registered in crowdsourcing efforts is quite high. Furthermore, there are nine species (represented by 222 occurrences) from the IUCN Red List (IUCN, 2021) recorded in the regional project for Northwestern Siberia. The number of recorded occurrences varies from one to 168 for each of the protected species, with eight species having more than ten recorded occurrences (Table 3). The protected species checklist with Red Data Book categories and protection status is presented in Electronic Supplement 1.

Table 3. The number of protected species in the regional and national Red Data Books and IUCN Red List (IUCN, 2021), and number of species and occurrences added by crowdsourcing on iNaturalist.org for Northwestern Siberia (Research Grade status of observations)

Region and the year of Red Data Book last edition	Number of species of fungi included in a Red Data Book or Red List	Number of species / observations of fungi registered on iNaturalist
IUCN Red List, 2021	550	9 / 222
Russia, 2008	66 in general list (+ 27 in monitoring list)	9 / 260
Khanty-Mansi Autonomous Okrug, 2013	67 in general list (+ 15 in monitoring list)	34 / 393
Yamal-Nenetsky Autonomous Okrug, 2010	13 in general list (+ 6 in monitoring list)	0 / 0
Tuymen Region, 2020	23 in general list (+ 5 in monitoring list)	1 / 1
Total number of species/observations in any of Red Data Books observed on iNaturalist.org for the whole study area		53 / 876

Identifiability

An important problem of identifying iNaturalist observations, based on macromorphological characters visible in the uploaded photographs, stems from the fact that not all taxa are equally identifiable. Based on the presumption that our team of professional experts did the best in their knowledge to identify all observations to the lowest possible level, we analysed this degree of identifiability by classes and genera. Seven classes could not be identified down to the species level at all. For 12 classes, only 25% to 85% of records could be identified, and two classes were completely identified down to the species level. However, these conclusions are made based only on species represented in the project and could change significantly if additional species are added to these classes here. A more interesting finding arises from genus-level analysis. For the demonstration, we have reduced the total number of genera (420) to genera with over 100 observations (yielding 31 genera) (Fig. 8). Only two genera have been 100% identifiable (*Fome*s and *Sarcosoma*). For 20 genera, at least 50% of observations could be identified. For others, the identification rate was less than 50%. The less identifiable genera on this list include *Russula*, *Inocybe*, *Cladonia*, *Gyromitra*, all of which are predictably difficult taxonomically. This may also indicate either the absence of experts, poor knowledge of these genera in the study area, or both mentioned reasons.

The total number of observations reaching species level identification and RG status has been increased to more than a half (56.2%) after an intensive revision of observations by 16 professional mycologists. About 1000 observations (985) have only one expert opinion (agreement or disagreement), and others have from two to eleven expert opinions (Fig. 9).

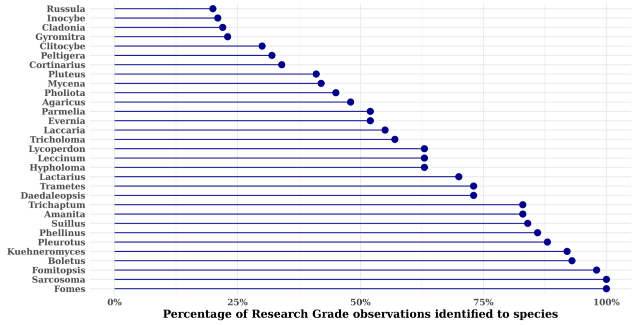

Fig. 8. The percentage of identifiability to the species level (defined by Research Grade status) for the most common genera (each with over 100 observations) of fungi and myxomycetes on iNaturalist in Northwestern Siberia.

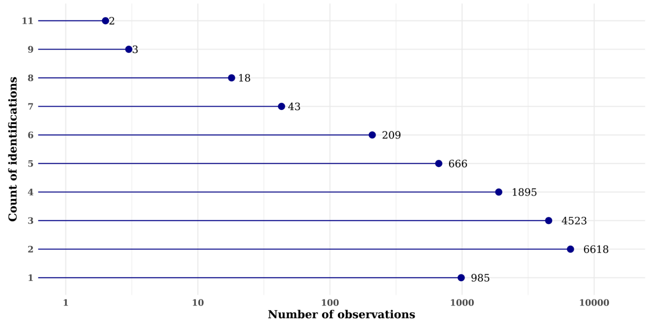

Fig. 9. The number of observations ordered by the number of expert opinions (agreements/disagreements) for fungi and myxomycetes observations on iNaturalist.org in Northwestern Siberia.

Discussion

Occasional observations on iNaturalist.org in Northwestern Siberia span a decade (mainly due to uploading of archival photos), but the observers' activity boomed in the last four years. About half of all the observations (8427) in the project collected during this period have been reliably identified to species level (a total of 963 species), thereby contributing scientifically important information on the fungal diversity of the region. The first attempt to verify and revise such a large amount of information has allowed us to outline pros and cons of using the crowdsourced data for the study and conservation of fungal diversity, both in the study area and globally.

Pros

1. The crowdsourcing provides additional data on rare or under-detected species. The initiative has yielded a significant number of records of regional novelties of fungi and myxomycetes (see Electronic Supplement 2). Some species from the list are quite rare in general and had not been previously registered by researchers in the study area. Some other species are conventionally common and reported regularly on iNaturalist.org, but, for some reasons, they were omitted in previous publications (either because a particular group in the study area had not been studied, or because trivial species were not considered in publications on finds of rare and noteworthy species). Crowdsourcing easily reveals common species of fungi, which is especially beneficial for poorly studied areas.

2. Additional spatial data coverage. A sufficient number of observers from various localities allows a better geographical coverage. This is especially relevant for macromycetes, as most of them have a very limited time of fruiting, which reduces the likelihood of their detection by a limited number of professional mycologists.

3. Large volume of data on fungal fruiting dynamics. Data collected using crowdsourcing can be useful in the study of phenology of species or climate-dependent fruiting dynamics.

4. Additional information on protected species. Noteworthy species (with the focus on rare and vulnerable taxa, such as *Sarcosoma globosum* (Schmidel) Casp.) are regularly observed on iNaturalist, which contributes to the global knowledge of their distribution and population dynamics.

Cons

1. Low identifiability based on macro-morphological characters visible in photographs. A large percentage of fungal, lichen and myxomycete taxa require microscopic, chemical or molecular examination for reliable identification. Moreover, the absence of up-to-date regional taxonomic revisions for the majority of specific taxa in the region further hinders identification. As a result, unlike with animals or vascular plants, the identification quality for fungi will remain low in photography-based crowdsourcing projects (May, 2021).

2. Low quality of observations (bad images, absence of notes on key characters, lack of notes on ecology, substrate, and others). The majority of crowdsourced observations have at least some flaws, limiting the possibilities of a reliable identification. Nevertheless, the situation can be improved by organising regular forays and workshops to reach out to the general public, scout for willing enthusiasts, and teach volunteers for the basics of identification of fungi.

3. Lack of regional experts for particular taxonomic groups. Such deficit of expert input is another reason for the accumulation of under-identified observations in some taxonomic groups. It should be noted that the expert evaluation is a time-consuming procedure, and the abundance of observations with low-quality photographs further complicates this process.

Perspectives and possibilities

A strategy to improve the potential of crowdsourcing for the study of fungal diversity was developed and discussed in several publications. For example, the Fungal Biodiversity Survey (Sheehan, 2017; Sheehan et al., 2021) proposed four levels of the volunteer participation, from simple visual (photographic) observations to contributing voucher collections, DNA extraction and molecular sequences producing, which encourages the community to improve the quality and scientific value of the collected data and observations. The concept of target species was introduced by the Fungimap project in Australia (May, 2021); it consists of the use of a selection of 200 easily identifiable species in fungal diversity crowdsourcing.

Personal experience of the authors during the revision of regional observations contributed to iNaturalist.org showed that both strategies are valuable for regional crowdsourcing programmes. In the Khanty-Mansi Autonomous Okrug, we encourage iNaturalist observers to deposit collected specimens in the Fungarium of the Yugra State University (however, only a dozen specimens have been deposited so far). The extraction of molecular sequences from collections remains a matter of the future in the study area, but can be realistically anticipated to be implemented in the following decades.

The image recognition is an important tool that can be used to improve the quality of crowdsourced observations and help experts to handle large volume of data provided by the community. Still, the potential of image recognition of fungi in the study area remains low compared to other groups of organisms. Identifying and understanding patterns in data has long been an integral part of science and engineering. For example, Carl Linnaeus found patterns in features of living organisms, and classified and categorised them into certain taxa (Bishop, 2006). This effort requires manual labour and is time consuming, but today, with the aid of computers to process and identify patterns in large datasets, several of these processes can be automated. In recent years, advancements have been made in fields such as machine learning and artificial intelligence (AI), bioinformatics, and image analysis. An emerging and rapidly growing part of the image analysis and AI is a computer vision. The research in this field aims to automate information collection from images in a way similar to human vision. For example, classification, identification, and detection of animals in images have been successfully automated with AI and machine learning. Utilising the Snapshot Serengeti dataset, which contains over 7 million images of 48 different animals in combination with a deep convolutional neural network (CNN), as described by Norouzzadeh et al. (2018), shows a top1 accuracy rate of 96.6% when classifying species. In comparison, AI models of fungi have until recently shown a significantly lower accuracy rate. In 2020, Picek et al. (2022) achieved a classification top1 accuracy rate of 48.8% with the FGVCx Fungi dataset and a CNN model. In 2022, the same group improved their method of fungi classification. Ultimately, the top1 accuracy achieved by a computer was 83.4%. This increase in accuracy was achieved by a combination of measures presented in Table 4. Changing to a dataset with a larger number of images per species yielded the largest increase in accuracy. Utilising a vision transformer (ViT) computer model and inclusion of metadata further improved accuracy (Picek et al., 2022).

Picek et al. (2022) also tested the accuracy of identifications by citizen scientists with the aid of the model. The average accuracy rate of participants who could choose between the top five choices of the model was 87.1%. Another study by Van Horn et al. (2018) using iNaturalist 2017 open dataset and a CNN model achieved a top1 classification accuracy rate of 74% for 121 species of fungi. A comparison of the dependency of model accuracy on datasets is presented in Table 5. One can assume the best accuracy is achieved using Snapshot Serengetti or Danish fungi 20. However, comparison of models utilising FGVCx Fungi’18 and iNaturalist 2017 clearly shows that there are other factors affecting the accuracy, such as dataset balance, minimum number of images per species, image size, crop size, computer model, and others.

Based on the discussion, to improve the accuracy of fungi classification in Northwestern Siberia, the following is proposed: 1) increase the number of images for each species; 2) focus on species with few images to reduce dataset imbalance; 3) deal closely with computer model creators, e.g. by discussing computer-assisted image recognition problems on the iNaturalist.org forum.

Conclusions

The paper presents the first revision of crowdsourcing data on iNaturalist.org for fungi (including lichens) and myxomycetes in Northwestern Siberia from the beginning of observation to the present, with a total of about 15 000 observations. After intensive work of 16 professional mycologists specialising on fungal diversity in Russia, about half of the observations were identified to the species level and received the Research Grade status on iNaturalist.org. The second half of all observations remain under-identified, either because of insufficient detail of morphological characters visible in the photographs, or due to taxonomical complexities (when certain identification requires microscopic or molecular characteristics), or also because of a lack of expertise in a particular taxonomic group.

The comparison of revised observations with the previously reported species list of fungi and myxomycetes, revealed 90 species (represented by 195 observations) of regional novelties which are described in detail on the annotated checklist (see Electronic Supplement 2). The resulting dataset of revised observations, complemented with three fields on species novelty and identification remarks, was published through GBIF (Filippova et al., 2022c).

Table 4. Performance in terms of top1 accuracy for various computer-vision models when classifying fungi by Picek et al. (2022)

Computer model	Dataset	Top1 Accuracy rate	Comment
CNN model	FGVCx Fungi’18	48.8%	Initial model
CNN model	Danish fungi 20	75.48%	New dataset
ViT model	Danish fungi 20	80.45%	Change model
ViT model with metadata	Danish fungi 20	83.4%	Inclusion of metadata

Table 5. Comparison of various datasets for image recognition in regards to the number of images and the number of species

Datasets	iNaturalist 2017	Danish Fungi 20	FGVCx Fungi’18	Snapshot Serengetti
Number of images	≈ 10 000	≈ 300 000	≈ 100 000	≈ 7 000 000
Species	121	1604	1394	48
Images per species	≈ 83	≈ 187	≈ 71	≈ 150 000

The analysis of the geographical coverage of crowdsourcing observations showed that the density of species records in the study area is still low and quite uneven. The temporal coverage of crowdsourcing observations is quite short, with only two years of intensive crowdsourcing and preceding eight years of occasional contributions. Nevertheless, the crowdsourcing data from this period were used to visualise the fruiting dynamics of fleshy fungi in the last two years.

The number of observers in the study area exceeds two hundred, including 13 users who have contributed over 100 observations. The number of experts has exceeded 380, including 16 professional mycologists invited to take part in this project to monitor and revise the accumulated data.

The crowdsourcing project has added valuable information on records of protected species, including nine species on the IUCN Red List of Threatened Species, nine species in the Federal Red Data Book, and 34 species in regional Red Data Books. About 50% of all observations come from Protected Areas, highlighting the great value of crowdsourcing for biodiversity conservation programmes.

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Supporting Information

The threatened taxa of fungi and myxomycetes of Northwestern Siberia found on iNaturalist (Electronic Supplement 1. An annotated list of protected species on regional, national or global (IUCN) Red Lists registered on iNaturalist.org in Northwestern Siberia (observations in Research Grade status)), and new records of taxa for the three administrative regions (Electronic Supplement 2. An annotated list of new regional occurrences registered for the first time on iNaturalist.org in any of the three administrative regions in Northwestern Siberia) may be found in the **Supporting Information**.

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ВОЛОНТЕРЫ ИЗУЧЕНИЯ РАЗНООБРАЗИЯ ГРИБОВ: РЕВИЗИЯ НАБЛЮДЕНИЙ НА ПЛАТФОРМЕ INATURALIST НА СЕВЕРЕ ЗАПАДНОЙ СИБИРИ

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В работе представлен первый анализ краудсорсинговых данных наблюдений грибов (включая лишайники) и миксомицетов на севере Западной Сибири, загруженных с начала наблюдений по настоящее время (24.02.2022 г.) на платформу iNaturalist.org. Во введении представлена история любительских наблюдений грибов на базе микологических обществ в мире, в России и на территории исследования. В разделе «Материал и методы» описан протокол загрузки данных на iNaturalist.org и развитие волонтерского движения на этой платформе на территории исследования, задачи и принципы организации ревизии накопленных данных, процедура обработки и анализа данных, составление списка новых региональных находок, охраняемых видов и составления результирующего набора данных для публикации в Global Biodiversity Information Facility (GBIF). В разделе «Результаты» представлен анализ накопленных данных по различным параметрам: временной, географический и таксономический охват, активность участников по наблюдению и определению, идентифицируемость различных таксонов, новизна находок и охранный статус видов. В разделе «Дискуссии» обсуждаются возможности использования любительских наблюдений для исследования биоразнообразия и охраны грибов, включая положительные и отрицательные моменты. В Электронном приложении к статье представлен аннотированный список охраняемых видов, включенных в региональные, национальные или международные (IUCN Red List) списки и список новых региональных находок. К статье прилагается набор исходных данных (датасет в GBIF): скачанный на момент завершения ревизии архив наблюдений из iNaturalist.org и дополненный полями о новизне находок и охранном статусе видов, а также протокол и код обработки данных, опубликованный на GitHub. Традиция любительских наблюдений грибов уходит своими корнями в историю микологических обществ по всему миру и в России. На севере Западной Сибири с 2018 г. был создан региональный микологический клуб, который поощрял своих участников делать наблюдения грибов на сайте iNaturalist.org. Всего с начала наблюдений по настоящее время загружено около 15 000 наблюдений грибов и миксомицетов, сделанных почти 200 наблюдателями в границах трех административных округов (Ямало-Ненецкий автономный округ, Ханты-Мансийский автономный округ и Тюменская область). Географический охват наблюдений на платформе iNaturalist остается достаточно низким, как показывает анализ плотности наблюдений на 50-километровой сетке. Однако интенсивность наблюдений возросла за последние четыре года, и ожидается продолжение этого роста. В результате ревизии накопленных данных, выполненной профессиональным сообществом, около половины наблюдений (56.2%) были надежно идентифицированы до видового уровня и получили статус Research Grade. Из них около 90 видов (195 записей) представляют собой новые региональные находки и приведены в Электронном приложении с краткими аннотациями; 53 вида (876 записей) с разным охранным статусом являются важным источником информации для природоохранных мероприятий. Вторая половина наблюдений, не идентифицированных до вида, представлена либо фотографиями плохого качества, либо сложными таксонами (невозможно идентифицировать без микро- или молекулярных исследований); сказывается также слабая изученность некоторых групп на территории исследования. При использовании данных краудсорсинга для изучения биоразнообразия грибов особое внимание в будущем следует уделять повышению качества наблюдений и сбору ваучерных образцов для подтверждения определений по фотографиям. Своевременная обратная связь от экспертов также важна для обеспечения качества и повышения личной вовлеченности волонтеров.

Ключевые слова: грибы, Красная книга, лишайники, любительская наука, микологическое общество, новая находка, мобилизация данных о биоразнообразии, охрана грибов, охраняемый вид