Survey of Mushroom Biodiversity in Hocking County, Ohio, USA

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ABSTRACT. True fungi and fungus-like species are a widely dispersed and highly diverse group of organisms. There is a lack of awareness about the ecological importance of macrofungi in forested landscapes. Further, there is little information about the biodiversity of mushrooms in Ohio, particularly in the southeastern part of the state. The main goal of this study was to complete the first inventory of mushrooms at Capital University's Primmer Outdoor Learning Center near Logan, Ohio. Field surveys (n = 5) were completed within the 74 acre property every 2 to 4 weeks during the summer from May to August 2019, largely conducted in the woodlot near the streams, in the forest edge, and along the forested ridge above the wetland. Of the 21 species inventoried in this study, 18 were classified in the phylum Basidiomycota and 3 belonged to the phylum Ascomycota. False turkey tail (*Stereum lobatum*), dryad's saddle (*Cerioporus squamosus*), and turkey tail (*Trametes versicolor*) were found throughout the entire study. Notable mushrooms included smooth chanterelle (*Cantharellus lateritius*), crown-tipped coral (*Artomyces pyxidatus*), and dryad's saddle (*C. squamosus*). Future work involves designing community programs and educational activities to promote citizen science, increasing public awareness of macrofungi, and conducting additional mushroom surveys on site particularly during the spring and fall seasons. Management recommendations for the university field site include closing several of the trails to the public to minimize foot traffic in the areas of highest mushroom biodiversity on site.

KEYWORDS. Fungi; inventory; woodland; citizen science; Hocking Hills.

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INTRODUCTION

The study of fungi is referred to as mycology (Ainsworth 1976). Mushrooms are an important group of fungi that regulate ecological processes in forest biomes. They are separated into 2 phyla, classified as the Ascomycota and Basidiomycota, which together are considered the subkingdom Dikarya (de Mattos-Shipley et al. 2016). Macrofungi have an easily observed spore-bearing structure. This above-ground fruiting body with a cap and stalk is more commonly known as a mushroom. The Ascomycota is the largest phylum of fungi containing more than 33,000 named species and includes yeasts, filamentous fungi that partner with algae to form lichens, mycorrhizal species, and species of macrofungi (Watkinson et al. 2016). There are at least 31,000 species in the Basidiomycota which contains the rest of the mushrooms, smuts, and rusts (Taylor et al. 2015). One measure of an ecosystem's overall health and quality is the biodiversity of the species found there. Although often overlooked, since most are small and inconspicuous (Bunyard 2003), mushrooms play a key role in ecosystem maintenance including the decomposition and the exchange of nutrients.

There are a variety of mushroom-forming species that are considered saprotrophs, which are organisms that live on dead organic matter (Dodd 1977). This leads to nutrients being supplied to the fungal body as well as recycling nutrients back into the soil. The nutrients are assimilated into the filaments known as hyphae, which make up the bulk of fungal biomass. Once the hyphae have died, the stored nutrients are then released into the soil, where they can be absorbed by surrounding plant species (Slot 2018). Due to this decomposition cycle, plants can absorb nutrients, creating a sustainable food chain in forest ecosystems.

Along with nutrient cycling through decomposition, mushrooms play an important role in forest ecosystems through symbiotic processes, more specifically the relationship between mycorrhizae and plants. The term "mycorrhiza" has Greek

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origins that translate to fungi and root, which helps define the relationship between plant and fungus. Mushrooms classified as mycorrhizal fall within the phyla Ascomycota and Basidiomycota (Bonfante and Anca 2009). Similar to nutrient exchange in fungal decomposition, these symbiotrophs cycle nutrients between live plant roots and the group of hyphae known as mycelium on the fungus.

The main function of symbiotic mycorrhizal relationships is to exchange nutrients with neighboring plant roots. Of these mycorrhizal fungi, fungi species that spawn mushrooms will mainly form an ectomycorrhizal bond. This form of mycorrhizae forms a "sheath" of mycelium around the root of the plant which improves water absorption and supplies nitrogen to the plant. Plants can also signal other plants by sending molecules through the fungal connection that can warn the other plants of possible insect invaders. In reciprocation, the plant will supply the mycorrhizal fungi with sugars in an act of symbiosis (Money 2016). This results in a more enriched plant that will have higher likelihood of survival, leading to healthier forests.

Lastly, mushrooms can act as food sources for various animals within forest biomes. Deer mice (*Peromyscus maniculatus*) and white-footed mice (*P. leucopus*) have been found to consume fungi in winter months as a supplementary food source when plant species and arthropods are not as readily available (Jameson 1952; Jones 1969). The consumption of fungal species can allow mouse species to prepare for colder months, but can also be advantageous for the fungi. Through the digestion of mushrooms, rodents and other small mammals can spread the spores of the aforementioned mushrooms leading to increased genetic diversity and range of habitat (Stephens and Rowe 2020). Unfortunately, due to a lack of awareness by both biologists and the public of the importance of macroscopic fungi (Bunyard 2003), there has been little recent research to inventory the biodiversity of mushrooms in Ohio.

Published studies of mushroom diversity in Ohio, especially in southeastern Ohio, are lacking. From the years 2000 to 2001, a survey was conducted at The West Woods, a 900-acre park in Geauga County, northeastern Ohio (Bunyard 2003). Prior to this survey, past inventories focused on 32 fungi collected primarily from Geauga County in 1964 by Cibula (1974). Other published studies on fungi in Ohio have focused primarily on ascomycetes in southwestern Ohio (Fink 1915; Fink and Richards 1915; Corrington 1921; Fink 1921). Across these studies, over 153 species were correctly identified and categorized by class followed by family then species. More recently, a thesis compiled a checklist of Ohio fungi based on digitized vouchers (Grootmyers 2021). Prior to that, the last statewide fungal inventory was completed before 1900 (Kellerman and Werner 1894).

In addition to increasing awareness, another goal of assessing fungal diversity is to protect natural areas with high species richness from encroaching development (Bunyard 2003). In the Midwestern United States there are likely over 2,000 species of mushroom (Rhodes et al. 2013). The majority of these species are of unknown edibility, but some are known to be poisonous (Rhodes et al. 2013). Mushrooms are often overlooked since they are ephemeral even with optimal growing conditions (Bunyard 2003).

The Primmer Outdoor Learning Center—near the city of Logan, Hocking County, in the Hocking Hills region of southeastern Ohio—is on land donated to Capital University in 2005 (Capital University 2024). The main goal of the current study was to assess the overall biodiversity of mushrooms at the Primmer Outdoor Learning Center. This is the first extensive mushroom inventory completed on the property. Mushrooms play important roles in nutrient cycling, symbiotic relationships, and food sources for other organisms, and are one of the most diverse taxonomic groups in forest biomes (Bunyard 2003). However, there is a lack of awareness about the importance of macrofungi and their role in maintaining a balanced ecosystem. Assessments of mushroom biodiversity can inform researchers of the current conditions of plant and animal populations within forested ecosystems of Ohio, and provide management recommendations to protect high quality natural areas in the southeastern portion of the state.

METHODS AND MATERIALS

Study Site

Surveys were completed at Capital University's Primmer Outdoor Learning Center located at Lat 39°32′42″N, Long 82°26′33″W, approximately 17.7 km (11 miles) by road northeast of the Hocking Hills State Park Visitor Center. This property is used

for education, outreach, and research. Past student research projects have focused on amphibians (Musial 2013; Shipley and Anderson 2018), fish (Rains and Anderson 2019), and antibiotic resistant bacteria in soils (Brock and Larson 2020). In addition, white-footed mice (*P. leucopus*) have been live-trapped to study population dynamics over a decade in 2 different ecosystems (Dotts 2013; Bope 2014; Hanlin 2016; Farleigh and Anderson 2018; Austin and Anderson 2019; Young and Anderson 2024).

The property covers 30 ha (74 acres) containing 7 different ecosystems, including a secondary growth deciduous forest, groundwater streams, restored prairies, and a 6 ha (15-acre) wetland. Surveys and collections were primarily conducted in the woodlot and streams near the Salamander Trail (location No. 1) (Fig. 1), the forest edge along a portion of the Mouse Trail (location No. 2), and the forested ridge above the wetland along the Frog Trail (location No. 3), which were all near the center of the property. The woodlot is located approximately 425 m (¼ of a mile) from the entrance of the property, within a depression containing 3 to 5 groundwater seeps that feed into small streams that converge prior to entering the wetland (see locations No. 1 and No. 2 in Fig. 1). Due to the ability to retain moisture, this part of the forest is where most of the mushrooms were observed.

The dominant overstory trees include American beech (*Fagus grandifolia*), American basswood (*Tilia americana*), northern red oak (*Quercus rubra*), white oak (*Q. alba*), buckeye (*Aesculus* sp.), black cherry (*Prunus serotina*) and sugar maple (*Acer saccharum*) (Dotts 2013). Many of the snags and fallen logs were ash trees (*Fraxinus* sp.) that died due to emerald ash borer (*Agrilus planipennis*) infestation. Skunk cabbage (*Symplocarpus foetidus*), multiflora rose (*Rosa multiflora*), spicebush (*Lindera benzoin*), violets (*Viola* sp.), May-apple (*Podophyllum peltatum*), and leaf litter, as well as mosses and ferns, are common throughout the woodlot and surrounding forest.

Data Collection

Field surveys were completed every 2 to 4 weeks during May to August 2019 for a total of 5 sessions. The entire property was investigated during the first session in mid-May. Consequently, the woodlot, forest edge, and forest ridge above the wetland were extensively searched over the next 4 sessions (Fig. 1). Each session took 2 to 3 hours to complete while walking transects spaced approximately 10 m apart throughout the study area (marked by numbers 1 to 3 in Fig. 1). Special attention was given to inspecting fallen logs and snags. Mushrooms were identified in the field and photographs were taken to confirm identification using field guides (Rhodes et al. 2013; Kuo and Methven 2014; Marrone and Sturgeon 2016; Lincoff 2018; Sturgeon 2018) and by conferring with an expert mycologist. Specimens were typically left in their ecosystem. A complete list of the species organized by phylum, class, and family was compiled similar to that reported in another Ohio mushroom survey (Bunyard 2003).

RESULTS

Twenty-one species of macrofungi were identified and cataloged in this study (Table). Within these 21 species, 18 were from the phylum Basidiomycota and 3 from the phylum Ascomycota. Most macrofungi observed are saprotrophic (17 of 21 = 81%), while *Hortiboletus campestris, Cantharellus lateritius*, and *Strobilomyces strobilaceus* are considered mycorrhizal, and *Tremella mesenterica* is parasitic towards the mycelium of the crust fungi *Peniophora* (Kuo and Methven 2014). The seasonal timing of the mushrooms varied throughout the study. Only a few (3 of 21 = 14%) of the mushrooms were found throughout the entire study, including false turkey tail (*Stereum lobatum*), dryad's saddle (*Cerioporus squamosus*), and turkey tail (*Trametes versicolor*). Smooth chanterelle (*C. lateritius*) was observed in June and July only, and old man of the woods (*S. strobilaceus*) was found in July only.

Most of the mushrooms were observed in location No. 1, with the remaining fungi found in locations No. 2 and No. 3, which were all closed canopy forest habitat (Fig. 1). None of the mushrooms were considered dangerous or highly toxic. Only one of the species found is classified as choice edibility, meaning that it is not toxic and highly sought after: the smooth chanterelle (*C. lateritius*) (Fig. 2a). Aside from edibility, some of the mushrooms had notable body structures making them easily identifiable. These specimens included crown-tipped coral (*Artomyces pyxidatus*) (Fig. 2b) and dryad's saddle (*C. squamosus*) (Fig. 2c).

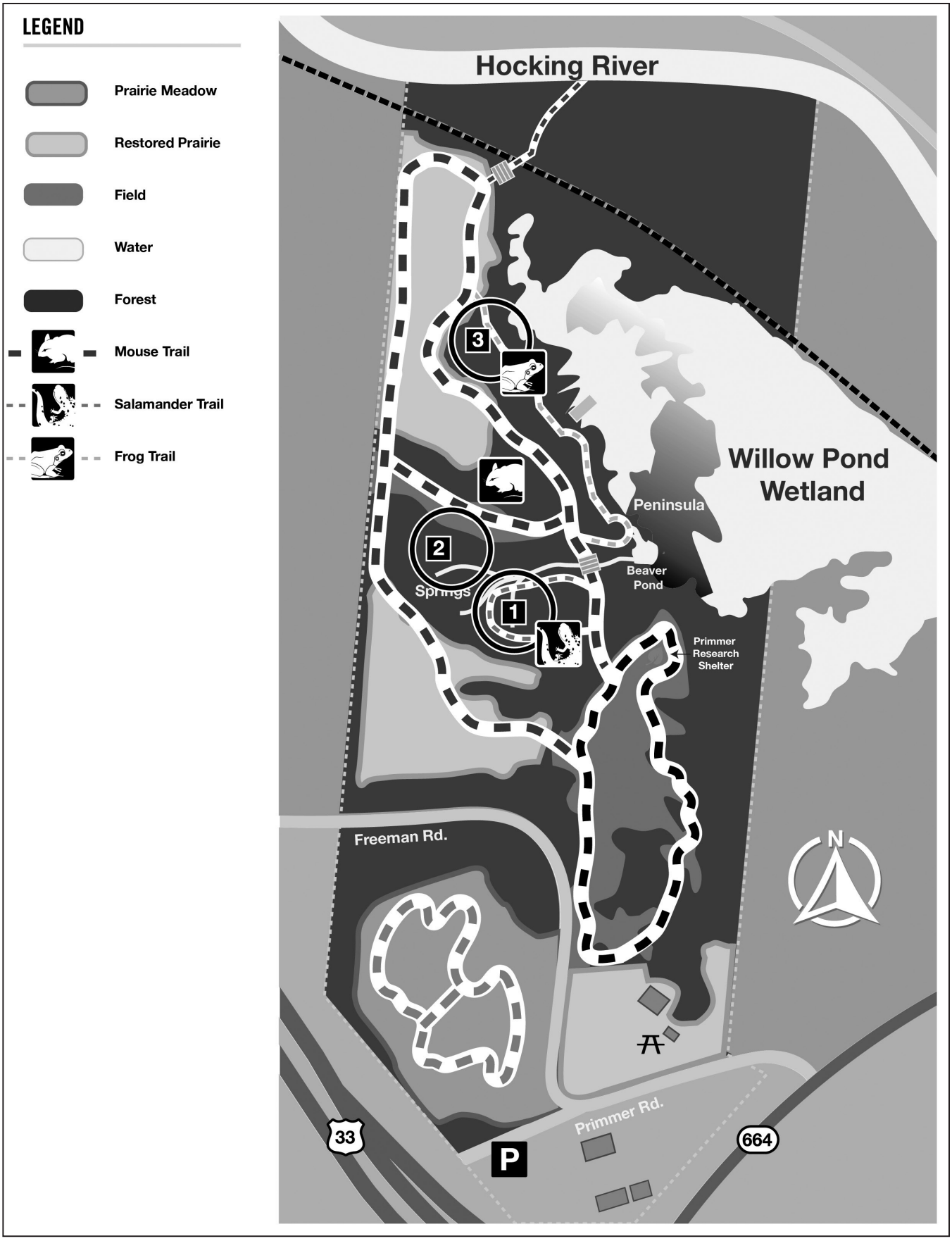

FIGURE 1. Map of Capital University's Primmer Outdoor Learning Center near Logan, OH. Forest locations where intensive surveys were conducted in 2019 are marked by numbers 1 to 3.

Table
Taxonomy of macrofungi identified at the Primmer Outdoor Learning Center near Logan (Hocking County), Ohio

Phylum	Class	Family	Species
Ascomycota	Pezizomycetes	Pyronemataceae	*Scutellinia scutellata*
〃	〃	Sarcosomataceae	*Galiella rufa*
〃	Sordariomycetes	Xylariaceae	*Xylaria polymorpha*
Basidiomycota	Agaricomycetes	Auriscalpiaceae	*Artomyces pyxidatus*
〃	〃	Boletaceae	*Hortiboletus campestris*
〃	〃	〃	*Strobilomyces strobilaceus*
〃	〃	Cantharellaceae	*Cantharellus lateritius*
〃	Dacrymycetes	Dacrymycetaceae	*Calocera cornea*
〃	Agaricomycetes	Hymenochaetaceae	*Phellinus rimosus*
〃	〃	Marasmiaceae	*Marasmius capillaris*
〃	〃	〃	*Marasmius rotula*
〃	〃	〃	*Megacollybia rodmanii*
〃	〃	Mycenaceae	*Mycena leaiana*
〃	〃	Polyporaceae	*Lentinus arcularius*
〃	〃	〃	*Cerioporus squamosus*
〃	〃	〃	*Cerioporus varius*
〃	〃	〃	*Trametes versicolor*
〃	〃	Schizophyllaceae	*Schizophyllum commune*
〃	〃	Stereaceae	*Stereum lobatum*
〃	Tremellomycetes	Exidiaceae	*Protohydnum album*
〃	〃	Tremellaceae	*Tremella mesenterica*

DISCUSSION

A total of 21 mushroom species were positively identified in this study. One of the significant discoveries during the current study was smooth chanterelle (*C. lateritius*)—a mushroom highly sought after in the culinary world for its gourmet-tasting profile. *Cantharellus lateritius* has a yellow-orange color and a fragrant, fruity odor. It often occurs near oak trees as this mushroom forms a symbiotrophic mycorrhizal relationship with oaks (Sturgeon 2018). Another notable mushroom species found was *Cerioporus squamosus*. A common mushroom in Ohio, dryad's saddle is easily identifiable by its feather markings on the cap. Due to the cap design, this mushroom has also been given the common name pheasant's back mushroom. This mushroom is not considered to be of choice edibility, but it is still able to be eaten (Marrone and Sturgeon 2016). In the early growth stages it is much more tender and can be consumed, but it is not the most flavorful mushroom. Along with its distinguishable markings, *C. squamosus* also plays a vital role in the ecosystem as a decomposer. It is occasionally a parasite on living trees but is primarily saprotrophic, meaning that on dead wood it is an efficient decomposer that drains nutrients, leaving behind fertile new soil material (Sturgeon 2018). Lastly, another notable fungus found during the study was *A. pyxidatus*. Commonly known as crown-tipped coral, *A. pyxidatus* has a unique fruiting body with upward growing stems that are uniquely shaped like coral as the name suggests. It is saprotrophic and can be identified by little crowns on the tip of the stems (Sturgeon 2018).

A few species of mushrooms were unexpectedly absent in this study. The giant puffball (*Calvatia gigantea*) is a common field mushroom in Ohio (Lincoff 2018). It is often found in late summer

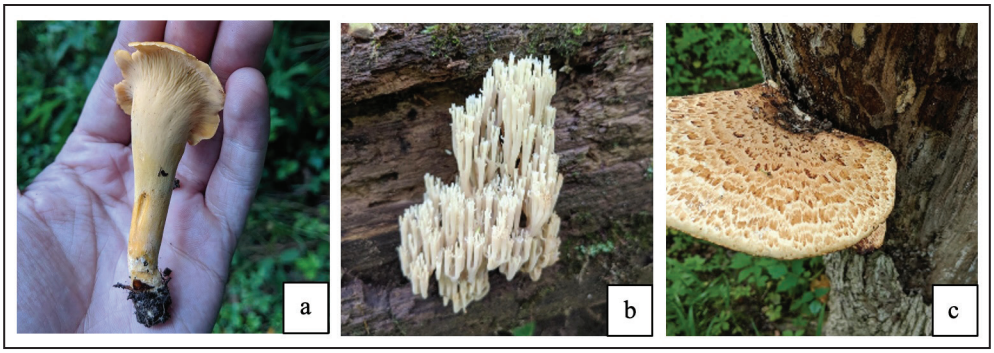

FIGURE 2. Notable mushrooms found in Hocking Hills during the 2019 survey included (a) smooth chanterelle (*Cantharellus lateritius*), (b) crown-tipped coral (*Artomyces pyxidatus*), and (c) dryad's saddle (*Cerioporus squamosus*)

through mid-autumn (Rhodes et al. 2013). This species was also missing from a mushroom inventory completed in Ohio from April to November 2000 and 2001 (Bunyard 2003). Future work should include surveying from early spring to late fall. If the study could have begun earlier in the spring, then it would have increased the possibility of finding morel mushrooms (*Morchella* sp.). Arguably the most sought-after mushroom, morels are prized for their exquisite taste and texture, which has made them popular in fine-dining establishments (Rhodes et al. 2013). The season for morels is short and usually lasts only for the spring, making them a rare mushroom to find (Marrone and Sturgeon 2016). For future surveys, it would be advantageous to start at the end of March and conclude the study at the end of October to obtain a more comprehensive list of fungal species.

Another future research project would be to collect specimens, particularly those difficult to identify, for DNA barcoding of the ITS (internal transcribed spacer) and other regions (Khaund and Joshi 2014). There has been some progress in DNA sequencing for identifying fungi (Seifert 2009), including a number of commercially-available kits on the market that include extraction, PCR, sequencing, and bioinformatics. However, this method does come with some limitations (Kauserud 2023). Finally, surveying additional study sites in the Hocking Hills region (including the Hocking Hills State Park), other areas in Ohio that have not been recently assessed, and neighboring states where comparable inventories of fungi are lacking would help determine whether there are any fungi truly endemic to Ohio. Then, those rare species could be potential candidates for listing as state or federally endangered species, and those habitats in which rare fungi occur could be conserved (Grootmyers 2021).

In 2023, the Hocking Hills area where Primmer is located was among the ranks of the year's best places to travel and was deemed "perhaps Ohio's prettiest" (Donaldson 2023). Ecotourism accounts for a growing percentage of Hocking County's larger economy (Donaldson 2023), and the area will continue to feel the effects from continuous population growth in the Columbus, Ohio, area (ODD 2021; ODD 2022). The Hocking Hills Tourism Association estimates up to 5 million visitors come to the area each year for recreational usage (Wartenburg 2022). In fact, the pandemic has increased the popularity of the area, creating traffic jams and bottlenecks on the most popular trails in Old Man's Cave at the Hocking Hills State Park (Wartenburg 2022). This increase in foot traffic can harm the fragile sandstone environment including fungi, plants, and other sensitive species found there.

Primmer, only 17.7 km (11 miles) from the Hocking Hills State Park Visitor Center, is also experiencing increased foot traffic due to being the second stop on the Hocking Hills Butterfly Trail funded by the Hocking Hills Tourism Association. Based on the findings of the current study, there is a plan to close the salamander, mouse, and frog trails (where mushrooms were predominantly found) to visitors (see Fig. 1). This action would minimize disturbance to the forest ecosystem and the fungal biodiversity found there. There are still plans to design programs and activities to increase awareness of mushroom biodiversity in southeastern Ohio through select events for students and the public.

To conduct more efficient and comprehensive surveys for mushrooms in Ohio, and throughout the midwest, scientists may rely more on the use of citizen science. Citizen science is defined as using public volunteers rather than members of a science discipline (Eitzel et al. 2017). The use of citizen science can greatly lower the cost of conducting a study, and a large geographic region can be studied in a short amount of time (Van Vliet and Moore 2016). To facilitate a robust citizen science foray, proper data collection methods and a way to validate data are needed to have a successful study with the participants (Silvertown 2009). One example of such a project is the Mushroom Observer (Silvertown 2009) which holds The Great North American Fungi Quest every September and October. A bioblitz, an event that has participants search to discover as many different organisms as possible in a given amount of time, could be another viable option to provide helpful data to mycologists. Hence, a solution to missing information in the field of mycology could be found in the citizen science community. Future events can be held at the university's Primmer Outdoor Research Center to add to the mushroom inventory for the property while engaging with students and the public to increase awareness of the ecological importance of higher fungi.

Conclusions

It is estimated that there are approximately 2 to 4 million fungal species globally, with only approximately 100,000 having been studied to date (Hawksworth and Lücking 2017; Calla-Quispe et al. 2020). True fungi and fungus-like species are the second most diverse group of organisms based on richness estimates on the planet (Lücking et al. 2020). Unfortunately, surveys of mushrooms in Ohio, particularly in southeastern Ohio near parks with a high ecotourism rate, are lacking. From surveys conducted from May to August 2019 at the university field site in Hocking County, the current study reported 21 species of mushrooms. Most were saprotrophic, which are important in the decomposition of organic matter and nutrient cycling (Dodd 1977). The next step in this work is to design programming activities to promote citizen science, increase awareness, and collect additional data particularly during the spring and fall seasons. Additionally, the central trails should be closed to the public. Since these trails were the location of the highest mushroom biodiversity on site, their closure would conserve the ecology of the forest. Altogether, this study is the most recent mushroom inventory reported in this part of Ohio.

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