Macrofungi of the altitudinal gradient, Northern Rocky Mountains
by John Henry Keck

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science . in Biological Sciences
Montana State University
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Abstract:
Macrofungal communities of four altitudinal zones of the Northern Rocky Mountain region are described and compared with respect to species richness, production (g/100m2/yr), functional structure (mycorrhizal vs. decomposer), seasonality of activity and relationship to temperature and rainfall. Two study sites of 100m2 were established in grasslands, Douglas-fir forest, subalpine fir (spruce-fir) forest and in the alpine. Each study site was visited fortnightly during the collecting season (May-September) in 1997 and 1998, monthly in 1999, with a limited number of trips to the alpine. All fungal sporocarps were collected, dried, weighed, and identified to species when possible. Soil moisture and soil temperature readings were taken at each visit during 1997 and 1998. Species richness varied with the elevational gradient from three species collected in grasslands, 60 species collected in Douglas-fir forests, 61 species collected in subalpine fir forests, and zero species collected in the alpine. Sixty-five species (out of 100 total species) fruited only during the wettest year of the study, 1997. Standing crop estimates ranged from 0.0002 to 0.005 g/100m2 in grassland, 0.01 to 2.16 g/100m2 in Douglas-fir forests, 0.04 to 1.63 g/100m2 in subalpine fir (spruce-fir forests) and no sporocarps were collected in the alpine. Standing crop was greatest in the grassland and forest sites in the wettest year, 1997. Species richness and production peaked earlier in the Douglas-fir forests (June), than in subalpine fir forests (August and September). With the majority of fungal species in the study fruiting only in the wettest year (1997), one might conclude that collecting sporocarps in a wet year provides a better indication of species richness than collecting in several typical (dry) years. The 100m2 plot size used in this study may bias for the sampling of saprophytic species, and may under-sample the more patchily distributed mycorrhizal species.

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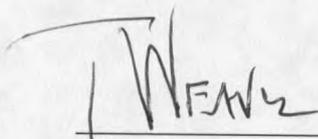Bozeman, Montana

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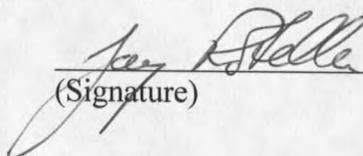
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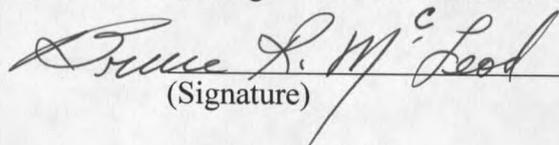
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ACKNOWLEDGEMENTS

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ABSTRACT

Macrofungal communities of four altitudinal zones of the Northern Rocky Mountain region are described and compared with respect to species richness, production ($g/100m^2/yr$), functional structure (mycorrhizal vs. decomposer), seasonality of activity and relationship to temperature and rainfall. Two study sites of $100m^2$ were established in grasslands, Douglas-fir forest, subalpine fir (spruce-fir) forest and in the alpine. Each study site was visited fortnightly during the collecting season (May-September) in 1997 and 1998, monthly in 1999, with a limited number of trips to the alpine. All fungal sporocarps were collected, dried, weighed, and identified to species when possible. Soil moisture and soil temperature readings were taken at each visit during 1997 and 1998. Species richness varied with the elevational gradient from three species collected in grasslands, 60 species collected in Douglas-fir forests, 61 species collected in subalpine fir forests, and zero species collected in the alpine. Sixty-five species (out of 100 total species) fruited only during the wettest year of the study, 1997. Standing crop estimates ranged from 0.0002 to 0.005 $g/100m^2$ in grassland, 0.01 to 2.16 $g/100m^2$ in Douglas-fir forests, 0.04 to 1.63 $g/100m^2$ in subalpine fir (spruce-fir forests) and no sporocarps were collected in the alpine. Standing crop was greatest in the grassland and forest sites in the wettest year, 1997. Species richness and production peaked earlier in the Douglas-fir forests (June), than in subalpine fir forests (August and September). With the majority of fungal species in the study fruiting only in the wettest year (1997), one might conclude that collecting sporocarps in a wet year provides a better indication of species richness than collecting in several typical (dry) years. The $100m^2$ plot size used in this study may bias for the sampling of saprophytic species, and may under-sample the more patchily distributed mycorrhizal species.

CHAPTER 1

GENERAL INTRODUCTION

Fungi are an important functional component of ecosystems which has been neglected in ecological studies of the Northern Rocky Mountain region. Fungi perform the functions of decomposition and nutrient cycling, maintaining the health of forest trees through mycorrhizal associations, and providing food for a variety of animals including humans. The scarcity of research papers on fungal ecology is due, in part, to the difficulty of quantifying fungal presence. In general, the fungal organism is composed of the mycelium, mycorrhizae (for some species) and the fruiting body, which is the reproductive structure and the only part of the fungus readily accessible for study. While the mycelium and mycorrhizae are the primary component of the fungus (Fogel and Hunt 1979), and quantifying them would provide a valuable characterization of fungal communities, there is presently no practical method for doing so. Instead the conventional approach is to collect, identify and weigh fruiting bodies as an index to their presence.

Due to the unpredictable production and short duration of fruiting bodies, ecologists usually establish permanent study plots and visit them repeatedly over time to collect fruiting bodies. Many studies of this nature have been conducted in forests due to the high abundance of sporocarps found there and the importance of fungi to the health of forest trees (Hering, 1966; Bills, et. al. 1986; Jansen, 1988; North, et. al. 1997).

The present study describes the change in fungal diversity and abundance as measured by sporocarp presence, frequency and biomass along an elevational gradient from grasslands through dry and moist forests and into the alpine of the northern Rocky Mountains. Examination of mushroom production along a transect of changing environmental conditions has been done with respect to rainfall (Eveling et. al. 1990; O'Dell et. al. 1999), and rainfall and temperature (Wilkins & Harris, 1946; Hering, 1966; Eveling et. al. 1990). Site selection and description is usually based on the type of dominant overstory vegetation (i.e. spruce-fir forest) and is therefore somewhat vague as to the specific environmental type studied. In contrast, this study uses the habitat typing system developed by Daubenmire (1968) to categorize the sites based on the dominant overstory and dominant understory vegetation present at climax, so that "all land areas potentially capable of producing similar plant communities at climax may be classified as the same habitat type" (Daubenmire, 1968). The diverse environments of the Northern Rocky Mountains have been classified (Daubenmire 1968) and those environments have been compared with respect to climate and soils (Weaver 1980, 2001). Climax communities occupying them have been compared with respect to composition, plant standing crop/production and animal associates. While the habitat typing system is well established in the study and management of forest and rangeland it has not been widely employed in the research and mangement of fungi (Pilz 1996).

Objectives

The objectives of this thesis are to describe and compare fungal communities of major ecosystems found in the Northern Rocky Mountain landscape: grassland environments, low-elevation Douglas fir environments, higher subalpine fir environments, and alpine environments. Chapters of this thesis will describe species composition and diversity (richness), standing crop and production, functional structure (mycorrhizae vs. decomposer), relationship to temperature and rainfall and how these factors trend up the elevational gradient. Use of Daubenmire's (1968) habitat typing system introduces this approach to ecologists and land mangers who wish to extend mycological data from unique sites to vast landscape segments they represent.

General Methods

Study Site Selection

To determine the common species and measure sporocarp productivity of macrofungi along an elevational gradient from grasslands to the alpine in the northern Rocky Mountain region, eight study sites were selected in four zones common to the area. The eight study sites included two grassland, two dry forest, two moist forest and two alpine sites (Table 1). The two grassland types represent relatively dry grassland (BS) and mid-range moisture grassland (AB). Moving up the elevational gradient, the forest sites chosen represent lower elevation Douglas fir (PS,b and PS,g) and higher elevation subalpine fir (AV,b and AV,g) conifer forests common to this region. The two alpine sites were chosen in a similar manner with *Dryas octopetala* (D) representing the

Table 1. Habitat type, location and abbreviation codes for eight study sites.

Habitat Type and Location	Site Abbreviation
Bouteloua gracilis/Stipa comata – Missouri Headwaters State Park	BS
Agropyron spicatum/Bouteloua gracilis – East side of Bozeman	AB
Pseudotsuga menziesii/Symphoricarpos albus – Gallatin Range (Kirk Hill)	PS,g
Pseudotsuga menziesii/Symphoricarpos albus – Bridger Range (Olson Cr.)	PS,b
Abies lasiocarpa/Vaccinium scoparium – Gallatin Range (History Rock Tr.)	AV,g
Abies lasiocarpa/Vaccinium scoparium – Bridger Range (Bracket Cr.)	AV,b
Dryas octopetala -- Bridger Range (Sacajawea Tr.)	D
Carex spp. -- Bridger Range (Sacajawea Tr.)	C

lower elevation and *Carex spp.* (C) representing the higher alpine. A map of the study area is given in figure 1.

Two other considerations in the choice of specific sites included accessability (close proximity to a road, trailhead and other study sites to minimize travel time) and location on public land.

Site Descriptions

Six study sites were established in September of 1996: two in grasslands, two in Douglas fir forests and two in subalpine fir forests. Two alpine sites were added in August of 1998. Each site conains four permanent plots measuring 1 meter by 25 meters for a total of 100 square meters per site. Plots within a site run parallel and are approximately 5 meters apart. A typical study site is diagrammed in figure 2. Each plot is divided into four sub-plots of equal size to produce a total of sixteen sub-plots per site. Use of elongate plots allowed for meticulous surveying without trampling in the plots. Site description information is given in table 2.

FIGURE 1. Map of study area.
Site locations: **BS** = *Bouteloua gracilis/Stipa comata* grassland; **AB** = *Agropyron spicatum/Bouteloua gracilis* grassland; **PS,g** = *Pseudotsuga menziesii/ Symphoricarpos albus* (Gallatin Mtns); **PS,b** = *Pseudotsuga menziesii/Symphoricarpos albus* (Bridger Mtns); **AV,g** = *Abies lasiocarpa/Vaccinium scoparium* (Gallatin Mtns); **AV,b** = *Abies lasiocarpa/Vaccinium scoparium* (Bridger Mtns); **C** = *Carex spp.* (alpine); **D** = *Dryas octopetala* (alpine). Weather stations (◆): **be** = Belgrade airport; **li** = Lick Cr.; **br** = Brackett Cr.

Figure 2. Study site design. Each site contains four 1m X 25m plots. Each plot is divided into four 1m X 6.25m subplots. Plots run parallel and are spaced approximately 5m apart. Subplots are numbered 1 – 16.

Sampling Methods

Study sites were visited every 2 weeks during the 1997 and 1998 field seasons and monthly during the 1999 field season. The two alpine sites were established and sampled in August of 1998 and were sampled only twice in 1999. Table 3 shows dates at which each site was visited.

At each sampling, all macrofungi found within a plot were collected, dried, weighed and stored. Field notes at the time of collection included: date, location (site, sub-plot)

Table 2. Environmental characteristics of eight sites representing four northern Rocky Mountain biomes.

Biome Site	Grassland BS,	AB	Dry Conifer PS,b	PS,	Moist Conifer AV,g,	AV,b	Tundra D	C
			Energy & water availability indices					
Altitude (ft)	4100	4875	5700	5700	6300	6600	8400	8900
Altitude (m)	1262	1500	1754	1754	1938	2030	2584	2738
Aspect (°)	/	122	270	300	80	/	9	230
	level	SSW	W	NW	E	level	E	SW
Slope (°)	0	20	25	22	23	0	17	22
			Soil temperature indices					
Warmest ST								
1997	18.8	-	15.5	14.4	11.1	14.4	-	-
1998	28.8	-	16.1	14.4	11.7	13.3	-	-
Fortnights > 10C								
1997	>7	-	5	4	4	4	-	-
1998	>9	-	5	5	4	4	-	-
			Soil water indices (-bars)					
Driest soil								
1997	8.3	-	3.7	2.1	0.4	0.4	-	-
1998	15	-	15	15	15	15	-	-
Fortnights <								
1997	3	-	1	1	0	0	-	-
1998	5	-	3	4	2	3	-	-
			Energy availability for saprobes, indices					
Soil Org. Cont. %	1.81	3.39	2.82	2.44	2.69	2.96	9.71	9.54
Litter, gm/m²								
Est dpth, cm	0	0	1.3	2.5	7.5	10.0	-	-
Dead wood,								
X, gm/m²	0	0	150	300	690	1230	0	0
SD, gm/m²	0	0	110	220	180	930	0	0
			Energy availability for ectomycorhizae, indices					
Live needle mass								
X, gm/m2	0	0	1390	2210	1290	1670	0	0
SD	0	0	620	730	520	670	0	0
			Host availability for ectomycorrhizal fungi					
Abies lasiocarpa,%			0	0	48	44		
Pinus contorta,%			0	0	26	33		
Picea spp, %			0	0	27	25		
Pinus albicaulis			0	0	+	-		
Pseudotsuga menziesii, %			100	100				
			Nutrient availability indices					
Organic C, %	1.81	3.39	2.82	2.44	2.69	2.96	9.71	9.54
total N, %	0.19	0.28	0.17	0.15	0.12	0.13	0.55	0.81
total S, %	0.003	0.014	0.007	0.005	0.008	0.009	0.022	0.064
CaCO3 %	12.5	0	0	0	0	0	30.5	5.0
pH	8.1	7.4	5.7	5.9	4.5	4.3	7.2	7.0

[1] Environmental series are Bouteloua gracilis/ Stipa comata, (BOGR), Agropyron spicatum/ Bouteloua gracilis (AGSP), Pseudotsuga menziesii/ Symphoricarpos albus (PSME), Abies lasiocarpa/ Vaccinium scoparium (ABLA), Dryas octopetala (DROC), and Carex spp (CARX).
[2] Locations are all in Gallatin County, MT. Trident and Bozeman are in the valley, Kirk Hill and History Rock are in the Gallatin Range, Olsen Creek, Bracket Creek, and Sacajawea are in the Bridger Mountains.
[3] Live needle mass (representing potential photosynthate) is a correlate for root area, ie for mycorrhizal niche.
[4] pH measured by MSU Soil testing lab on a 1 soil: 2 water slurry.
Total organic carbon is calculated as total carbon minus carbonate carbon.

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Table 3. Site collection schedule for eight study sites. An "x" depicts dates at which a given site was visited.

Year		BS	AF	BAV	GAV	BPS	GPS	C	D
1997	6/19	x	x	x	x	x	x		
	7/4	x	x	x	x	x	x		
	7/22	x	x	x	x	x	x		
	8/10	x	x	x	x	x	x		
	8/24	x	x	x	x	x	x		
	9/9	x	x	x	x	x	x		
	9/22	x	x	x	x	x	x		
1998	5/17	x	x	x	x	x	x		
	6/4	x	x	x	x	x	x		
	6/18	x	x	x	x	x	x		
	7/1	x	x	x	x	x	x		
	7/15	x	x	x	x	x	x		
	8/5	x	x	x	x	x	x		
	8/19	x	x	x	x	x	x	x	x
	9/10	x	x	x	x	x	x		
	9/30	x	x	x	x	x	x		
1999	5/31	x	x	x	x	x	x		
	6/23	x	x	x	x	x	x		
	7/22	x	x	x	x	x	x	x	x
	8/29	x	x	x	x	x	x	x	x
	9/29	x	x	x	x	x	x		

and ephemeral characteristics needed to aid in identification of the fungi (such as smell, texture, taste (when necessary), color, viscidity and size). All specimens were put in a plastic box with dividers, which was stored in a cooler until the end of the collection day. Samples were stored under refrigeration for up to one week while specimens were being identified. Unfamiliar species were identified in the laboratory with the help of notes, fresh samples, books (Singer 1962; Arora 1986; Lincoff 1987; Phillips 1991; Dahncke 1993; Phillips 1994), and the help of Dr. C. Cripps and Dr. D. Mathre. Authorities are according to Moser (1978). After identification the sporocarps were dried

at 60 degrees centigrade for 48 hours and weighed to the nearest hundredth of a gram.

All specimens are deposited at the fungal herbarium at Montana State University.

Soil temperature was measured at each visit in 1997 – 1998. Temperature was

measured at the center of each 1m x 25m plot using a thermometer with a metal probe

extending 10cm below the soil surface. The four soil temperature values for each site

were averaged and reported in table 4.

Table 4. Soil temperature (C) recorded at each site for each visit in 1997 and 1998.

| Date | Site | | | | | |
	BS	AB	PS,b	PS,g	AV,g	AV,b
19 June 1997	15.5	20	10.6	10	10	*
4 July	14.4	19.4	9.3	10	8.25	7.7
22 July	16.6	20	15.5	12.2	12.2	11.1
10 Aug	15	16.6	11.1	11.1	10	10
24 Aug	18.8	18.8	14.4	14.4	11.1	14.4
9 Sept	16.6	17.7	12.2	12.2	10.6	11.1
22 Sept	15.5	18.8	8.8	10	6.6	7.7
17 May 1998	13.3	15.5	5.5	5.5	4.4	3.3
4 June	17.8	15.5	5.5	5.5	3.3	4.9
18 June	16.6	13.9	5.5	6.6	3.3	5.5
1 July	24.4	23.3	10	11.1	7.7	8.8
15 July	25.6	27.2	14.4	13.3	11.1	10.6
5 Aug	28.8	27.7	16.1	14.4	11.7	11.1
19 Aug	27.2	25.5	14.4	12.8	10	12.2
10 Sept	26.6	24.4	13.3	14.4	11.1	13.3
30 Sept	21.1	18.8	10	7.7	4.4	8.26

* data not gathered.

Soil water regimes were compared across sites, years, and seasons by use of plaster

block sensors buried at 10 cm and read with an ohmmeter (Soil test), and calibrated in

soils adjusted to particular water potentials with the pressure membrane apparatus

(Weaver 1987). A sensor was buried at the center of each 1m x 25m plot. Data are averaged across the site and reported in table 5.

Table 5. Soil moisture (-bars) recorded at each site for each visit in 1997 and 1998. (bars x 0.1 = mPa)

Date	Site					
	BS	AB	PS,b	PS,g	AV,g	AV,b
19 June 1997	0.25	0.25	0.26	0.24	0.25	*
4 July	0.23	0.23	0.25	0.36	0.24	0.25
22 July	0.45	0.59	0.26	0.31	0.24	0.19
10 Aug	1.02	0.7	0.3	0.45	0.25	0.29
24 Aug	8.35	6.3	0.25	0.34	0.35	0.18
9 Sept	16.5	7	3.7	2.1	0.39	0.39
22 Sept	2.92	0.5	0.41	0.44	0.32	0.31
17 May 1998	22.7	0.69	0.35	0.41	0.35	0.33
4 June	19.5	19.5	0.48	0.51	0.38	0.34
18 June	0.3	0.83	0.39	0.35	0.36	0.24
1 July	0.32	0.4	0.35	0.25	0.35	0.25
15 July	6.2	5.7	0.37	0.43	0.19	0.36
5 Aug	25	25	0.44	25	0.64	0.49
19 Aug	25	25	25	25	2.8	5.8
10 Sept	25	25	25	25	25	25
30 Sept	19.5	16.6	15	7	1	4.8

* data not gathered.

Monthly precipitation data from three weather stations representing grasslands, Douglas-fir forests and subalpine fir forests is presented in table 6. Annual precipitation for each year of the study, as well as average annual rainfall at each weather station is reported in table 7. Each weather station recorded high amounts of precipitation during 1997 with a moderate amount of moisture in both 1998 and 1999.

Table 6. May – September precipitation (cm) recorded at weather stations representing dry grasslands (Belgrade*), dry conifer forests (Lick Creek**) and moist conifer forests (Bracket Creek**).

Year	Weather station	Month				
		May	June	July	August	Sept.
1997	Belgrade	6.9	7.1	10.4	3.8	3.8
	Lick Cr.	16.2	12.2	6.4	6.9	6.9
	Bracket Cr.	13	15.5	8.9	5.8	10.9
1998	Belgrade	4.3	9.9	1.5	2.0	2.0
	Lick Cr.	4.9	16.8	4.5	5.1	3.5
	Bracket Cr.	8.6	18.8	3.8	4.0	3.0
1999	Belgrade	5.8	5.1	0.3	4.8	1.0
	Lick Cr.	10.4	7.6	2.0	1.6	3.0
	Bracket Cr.	12.2	9.9	0.5	9.1	3.0

* Belgrade weather station: National Weather Service Data.
** Lick Cr. and Bracket Cr. weather stations: Soil Conservation Service SNOTEL data.

Table 7. Yearly precipitation (cm), (1997-1999) and average annual precipitation* for 3 weather stations.

Weather station	Year			Average annual precipitation
	1997	1998	1999	
Belgrade	46.2	28.7	30.2	37.6
Lick Cr.	104.1	74.7	69.8	88.4
Bracket Cr.	149.4	99.3	102.8	134.6

*Average annual precipitation 1969-1999.

CHAPTER 2

COMPARISON OF FUNGAL COMMUNITIES ON THE ALTITUDINAL

GRADIENT IN THE NORTHERN ROCKY MOUNTAINS

Introduction

The complexity of Nothern Rocky Mountain (NRM) landscapes with respect to

elevation, aspect, slope and substrate generates many environmental types (Daubenmire

1968; Pfister 1997). Each environmental type supports a different climax plant

community (Daubenmire 1943; Holdridge 1967; Whittaker 1972) and several seral

communities (Daubenmire 1943). Each of the many plant communities in a region is

expected to support a decomposer community including microbes, fungi and

invertebrates, as well a community of mycorrhizal fungi associated with plant roots.

There are no published, plot-based studies describing the fungal communities

associated with the many environment/vegetation types present in the region or

comparing the fungal communities on gradients connecting these environment/vegetation

nodes of the NRM. Reconnaisance studies in the NRM region describe macrofungal

diversity in the alpine (Cripps and Horak 1999) and in aspen stands (Cripps and Miller

1993). Most of the quantitative (plot-based) studies done in the western United States

have focused on hypogeous fungi and were carried out in the Washington and Oregon

(Cooke 1955; Fogel and Hunt 1979; Hunt and Trappe 1987; Luoma et al. 1991; North et al. 1997).

This paper lists and compares the species of epigeous (above-ground) macrofungi in major altitudinal zones of the Northern Rocky Mountains.

Thus the objectives of this chapter are 1) to describe the mushroom communities of representative arid and dry grasslands, dry forests, moist forests, and tundra of the Northern Rocky Mountains, and by comparing these 2) demonstrate the altitudinal distribution of each species found on the gradient, and 3) demonstrate changes in community richness on the gradient.

Methods

Climax communities from four altitudinal zones were sampled in the Rocky Mountains of south-central Montana. Two examples of each were chosen to provide some measure of variation among sites in each zone. One grassland was arid (*Stipa comata-Bouteloua gracilis*), the other (*Agropyron spicatum-Bouteloua gracilis*) represented a dry site. The dry forests (*Pseudotsuga menziesii-Symphoricarpos albus*) were replications, one from the Gallatin Range and one from the Bridger Range. The subalpine fir forests (*Abies lasiocarpa-Vaccinium scoparium*) were also replicates, from the Gallatin and Bridger Ranges. The sites were chosen to be representative of widespread environmental types and sufficiently accessible to make the study feasible. Four plots were installed at each of the eight study sites. These were 1x 25 meters long, parallel, and approximately 5 m apart. Elongate plots were used to permit close

examination without trampling. Each plot was subdivided into four equal segments (1x 6.25m) so a frequency calculation will provide an indication of ubiquity of a species at the site (Daubenmire 1943; Bills et al. 1986). Species frequency is the number of subplots (1 x 6.25m) in which the species fruited one or more times during a three-year period. Percent frequency was calculated by dividing the total number of subplots in which the species occurred by 16 (total number of subplots in each site) and multiplying by 100.

The plots were sampled periodically both because most species have an inherent seasonality (Richardson 1970; Bills et al. 1986) and because pulse events, especially rainfall, stimulate fruiting in many fungi (Bills et al. 1986; Villeneuve 1989; Nantel and Neumann 1992). Communities were sampled fortnightly in 1997 and 1998 and monthly in 1999 (Table 3). Alpine sites were visited only three times.

Sampling consisted of identifying all species in each 1x 6.25m subplot and counting the sporocarps of each species therein. All macrofungi were collected, identified, dried, weighed and stored. Field notes at the time of collection included: date, location (site and subplot) and ephemeral characteristics to aid in identification such as smell, texture, taste (when necessary), color, viscidity and size. All specimens were put in a plastic box with dividers, which was then placed in a cooler until the end of the collection day. Samples were then stored under refrigeration for up to one week to identify the unknown specimens. Unfamiliar species were identified in the laboratory with the help of notes, fresh samples, books (Singer 1962; Arora 1986; Lincoff 1987; Phillips 1991; Dahncke 1993; Phillips 1994), and the help of Dr. C. Cripps and Dr. D. Mathre. Authorities are

according to Moser (1978). Sporocarps were dried at approximately 60 degrees centigrade for 48 hours and weighed to the nearest hundredth of a gram.

Change in species composition on an environmental gradient is traditionally demonstrated with a relevee table (Bills et al. 1986; Villeneuve 1989; Nantel and Neumann 1992; O'Dell et al. 1999), a matrix of species names vs. environmental quality. Each row of a relevee table shows the change in the importance of a species on the gradient. The rows describing species with similar distributions are grouped to facilitate comparison of species with contrasting distributions and for consideration of reasons for their co-occurrance (perhaps similarity of environmental or host requirements). Communities may differ in richness (i.e. number of species, Whittaker 1972), as well as component species or species groups. Given a relevee table, we tested for such variation by counting and comparing the numbers of species in stands representing different environmental gradient segments.

<u>Results</u>

Table 8 lists the one hundred species found on the study plots and locates them on the gradient from grassland through forests to the alpine. As in similar studies (Bills et al. 1986; Villeneuve 1989; O'Dell et al. 1999), our primary measure of presence is frequency, which is the percentage of subplots occupied by the species as demonstrated by observation over the course of the study.

Table 8. Percent frequency of macrofungal species collected at five sites. Percent frequency is the percentage of the number of subplots out of 16 at each site in which a species occurred. AV = subalpine fir; PS = Douglas fir; b = Bridger Mtn Range; g = Gallatin Mtn Range; BS = *Bouteloua* grassland.

Species and authority	Site				
	AV,b	AV,g	PS,g	PS,b	BS
Nolanea sp. #1	38	75	0	0	0
Cortinarius sp. #1	63	31	0	0	0
Laccaria laccata (Scop.ex Fr.) Bk. & Br. var. pallidifolia (Pk.) Pk.	38	25	0	0	0
Gerronema chrysophylla (Fr.) Sing.	0	38	0	0	0
Xeromphalina campanella (Batsch. ex Fr.) R. Mre.	19	13	0	0	0
Gymnopilus sapineus (Fr.) Mre.	6	38	0	0	0
Tricholoma sulphureum (Bull. ex Fr.) Kummer	6	38	0	0	0
Clavariadelphus ligula (Fr.) Donk.	19	0	0	0	0
Cystoderma fallax A.H. Sm. & Sing.	6	31	0	0	0
Otidea onotica (Pers. ex Fr.) Fuckel	13	13	0	0	0
Mycena lilacifolia (Pk.) A.H. Smith	0	25	0	0	0
Peziza repanda (Fr.)	13	6	0	0	0
Kuehneromyces vernalis (Pk.) Sing. & A.H. Smith	0	19	0	0	0
Tricholoma inamoenum (Fr. ex Fr.) Kummer	13	6	0	0	0
Lycogala epidendrum L.	0	13	0	0	0
Suillus sibiricus	0	13	0	0	0
Clavulina cristata (Fr.) Schroet.	13	0	0	0	0
Russula sp.	6	6	0	0	0
Hygrophorous purpurascens (Fr.) Fr.	6	6	0	0	0
Lyophyllum sp.	6	0	0	0	0
Stropharia semiglobata (Fr.) Quel	6	0	0	0	0
Hypholoma fasiculare (Huds. ex Fr.) Kummer	6	0	0	0	0
Russula brevipes (Pk.)	6	0	0	0	0
Clitocybe sp.	0	6	0	0	0
Mycena rorida (Fr.) Quel	0	6	0	0	0
Tubaria furfuracea (Pers. ex Fr.) Gill	0	6	0	0	0
Cortinarius sp. #2	0	6	0	0	0
Agaricus diminutivus (Pk.)	0	6	0	0	0
Agaricus silvicola (Vitt.) Pk.	6	0	0	0	0
Geastrum sp.	6	0	0	0	0
Hygrophorus pudorinus (Fr.) Fr.	6	0	0	0	0
Mycena acicula (Schaeff. ex Fr.) Kummer	0	6	0	0	0
Naucoria cf. vinicolor	0	0	0	0	0
Stropharia hornemanii (Fr. ex Fr.) Lundell & Nanni	6	0	0	0	0
Galerina heterocystis (Atk.) A.H. Sm. & Sing.	56	88	25	25	0
Xeromphalina cauticinalis (Fr.) Kuhner & Maire	38	69	6	0	0
Russula cf emetica (Schaef. ex Fr.) S.F. Gray	63	38	0	31	0
Lycoperdon perlatum Pers.	19	63	69	13	0
Clitocybe cf deceptiva Kauff.	31	50	63	31	0
Caloscypha fulgens (Pers. ex Fr.) Boud	6	75	31	6	0
Galerina autumnalis (Pk.) A.H. Sm. & Sing.	13	38	6	0	0
Mycena alcalina (Fr.) Kummer	19	50	75	44	0
Inocybe lanuginosa (Bull ex Fr.) Kummer	31	6	6	0	0

Table 8 (continued)

Species and authority	Site				
	AV,b	AV,g	PS,g	PS,b	BS
Mycena epipterygia (Fr.) S.F. Gray	6	19	0	6	0
Russula laurocerasii Melzer	25	0	6	19	0
Mycena elegantula Pk.	13	6	44	0	0
Tricholoma olida (Thiers) Overbo	6	13	6	0	0
Mycena pura (Pers. ex Fr.) Kummer	6	13	88	56	0
Russula olivacea (Schaef. ex Seer) Fr.	0	13	0	6	0
Inocybe sororia Kauff	13	0	13	13	0
Agrocybe cf praecox (Pers. ex Fr.) Fayod	13	0	6	0	0
Cortinarius cf cotoneus Fr.	0	13	0	0	0
Auricularia auricula (Hooker) Underwood	6	6	0	0	0
Mycena citinomarginata Gill.	0	6	0	6	0
Tricholoma portentosum (Fr.) Quel	0	6	0	6	0
Hygrophorus sp.	0	6	0	13	0
Amanita vaginata (Fr.) Vitt.	0	6	0	6	0
Morchella elata (Fr.)	0	6	0	6	0
Pluteus cervinus (Schaeff. ex Fr.) Kummer	6	0	13	0	0
Lepiota clypeolaria (Bull ex Fr.) Kummer	0	6	13	0	0
Suillus lakeii A.H. Smith & Thiers	6	0	0	31	0
Inocybe flocculosa (Berk.) Sacc.	0	0	6	0	0
Gomphidius subroseus Kauff.	0	0	6	0	0
Neolecta irregularis (Pk.) Korf.	0	0	6	0	0
Tricholoma flavovirens (Pers. ex Fr.) Lund et. Nan	0	0	6	0	0
Hypholoma dispersum (Fr.) Quel	0	0	6	0	0
Leptonia near cyanea (Pk.) Mazzer	0	0	0	6	0
Collybia tuberosa (Bull ex Fr.) Kummer	0	0	0	6	0
Conocybe tenera (Schaef. ex Fr.) Kuhner	0	0	6	0	0
Mycena haematopus (Pers. ex Fr.) Kummer	0	0	6	0	0
Crucibulum laevae (Huds.) Kambly	0	0	0	6	0
Hygrophorous chrysodon (Fr.) Fr.	0	0	0	6	0
Psathyrella velutina (Pers. ex Fr.) Sing.	0	0	6	0	0
Psathyrella hydrophila (Bull ex Mevat.) R. Mre.	0	0	6	0	0
Tricholoma pardinum Quel	0	0	6	6	0
Psathyrella gracilis (Fr.) Quel	0	0	6	6	0
Helvelia lacunosa Afz. ex Fr.	0	0	13	0	0
Clitocybe gibba (Pers. ex Fr.) Kummer	0	0	0	13	0
Lactarius deliciosus Fr.	0	0	0	13	0
Lentinellus omphalodes (Fr.) Karst	0	0	13	0	0
Collybia maculata (Alb. & Schw. ex Fr.) Kummer	0	0	13	6	0
Inocybe geophylla var. lilacina (Pk.) Gill	0	0	25	0	0
Clitocybe albirhiza Bigelow & A.H. Smith	0	0	6	25	0
Inocybe geophylla (Fr.:Fr.) Kummer	0	0	38	0	0
Inocybe fuscidula Velen.	0	0	38	0	0
Collybia butyracea (Bull ex Fr.) Kummer	0	0	38	0	0
Strobilurius trullisatus (Murr.) Lennox	0	0	50	0	0
Inocybe possible nitidiuscula (Britz.) Sacc.	0	0	50	0	0
Inocybe cf nitidiuscula (Britz.) Sacc.	0	0	56	0	0
Helvella compressa	0	0	19	44	0
Collybia alkavirens Sing.	0	0	69	25	0

Table 8 (continued)

Species and authority	Site				
	AV,b	AV,g	PS,g	PS,b	BS
Tricholoma cf myomyces (Pers. ex Fr.) J. Lange	0	0	69	38	0
Collybia sp. #1	0	0	69	38	0
Nolanea sp. #2	0	0	50	63	0
Entoloma rusticoides (Gill.) Noordel.	0	0	0	0	38
Panaeolus foenisecii (Pers. ex Fr.) R. Mre.	0	0	0	0	25
Bovista plumbea Pers.	0	0	0	0	6

Mushroom Communities

Grasslands. Our grassland plots contained few mushroom-producing species. Three

species appeared in the *Stipa-Bouteloua* plots, *Entoloma rusticoides*, *Panaeolus foenisecii*

and *Bovista plumbea*. None of these were in higher environments. No mushroom species

were found in the *Agropyron-Bouteloua* plots. Grasslands do support unsampled fungi.

Puff-balls in fairy rings have been repeatedly found in *Stipa-Bouteloua* grasslands near

the Stipa-Bouteloua site (Weaver, personal communication). *Geastrum spp.* and

unproductive fairy rings have been observed outside the plots at the *Agropyron-Bouteloua*

site (Weaver and Keck, personal communication).

Conifer Forests. Sixty species of fungi were found in Douglas-fir forests (Table 9).

Of these, 33 species were found only in Douglas-fir forests. Of the 33 unique to Douglas-

fir forests, nine appeared in both mountain ranges. *Mycena pura*, *Collybia sp. #1*,

Nolanea sp. #2 and *Clitocybe deceptiva* were present in all eight Douglas-fir plots.

Tricholoma cf. myomyces and *Collybia alkavirens* fruited exclusively in the Douglas-fir

forests, were present in 7 of 8 plots, and fruited every year of the study (Table 8). *Tricholoma cf. myomyces* was the most frequent *mycorrhizal* species exclusive to Douglas-fir forests. Of seven species of the genus *Inocybe* collected, five were exclusive to Douglas-fir sites. All five species of *Collybia* collected were found only in Douglas-fir forests (Table 8).

Table 9. Macrofungal species richness for four environmental zones.

	Grassland	Douglas-fir	Subalpine fir	Alpine
Number of 1 x 25m plots	8	8	8	8
Total number of species collected	3	60	61	0
Number of species found only in given environmental type	3	33	34	0
Number of species per plot:				
maximum	2	30	26	0
minimum	0	9	12	0
mean	1	19.6	19.1	0
SD, n = 8	1.19	6.2	4.9	0

Twenty-seven species were found in both Douglas-fir and subalpine fir forests. Fourteen of these appeared in both subalpine fir sites, eight appeared in both Douglas-fir sites and six appeared on all four conifer sites (Table 8). The most frequent species present in both forest types was *Clitocybe deceptiva*, which was present in 15 of 16 forest plots. *Mycena alcalina* was the next most frequent, being present in 13 of 16 forest plots.

Thirty-four species were found only in subalpine fir plots (Table 9). Of these, twelve appeared in both mountain ranges. No species was present in all eight subalpine fir plots. The most frequent species, fruiting in 7 of 8 plots and exclusive to subalpine fir forests was *Cortinarius sp. #1*. *Laccaria laccata* was the next most frequent species exclusive to

subalpine fir forests, being present in 6 of 8 plots. *Cortinarius sp. #1* was the most frequent mycorrhizal species exclusive to subalpine fir forests.

Alpine. No mushrooms were found in either arid (*Carex* dominated) or dry (*Dryas* dominated) alpine plots during the 3 visits to the alpine sites. A diverse array of mushrooms are being found in various alpine environments of the Beartooth Mountains less than 200 km to the southeast of the study area (Cripps and Horak 1999).

Species Richness

Temporal Richness. Of fungal species present (species richness), many may be invisible in a particular year or season, because conditions are not conducive to fruiting.

At our sites richness varied greatly between years. The number of species found was highest in wet 1997, and fewer in 1998 and 1999, the years receiving less rainfall (Figures 3 and 4). Of 100 total species collected during the 3 year sampling period, sixty-five fruited only in wet 1997 as compared to six species fruiting exclusively in dry 1998 but no other years, and 2 species fruiting exclusively in dry 1999 (Table 10).

Table 10. Total number of fungal species collected for 3 years (1997 – 1999).

	Year		
	1997	1998	1999
Total number of species collected	92	31	18
Number of species fruiting only in given year	65	6	2

Figure 3. Total number of fungal species collected at five sites over 3 years (1997 – 1999). BS = grassland, PS = Douglas-fir; AV = subalpine fir; b = Bridger Mtn Range; g = Gallatin Mtn Range. No sporocarps were collected at BS site in 1999.

Figure 4. Summer (May – September) precipitation (cm) recorded at three weather stations in the study area. The Belgrade weather station represents the grassland sites, the Lick Creek weather station [Gallatin Mtns near AV,g site] represents the Douglas-fir sites, the Bracket Creek weather station [Bridger Mtns near AV,b site] represents the subalpine fir sites.

We expect 1999 to have fewer species as sites were visited only monthly during that year rather than fortnightly as in the previous years.

Within years of below average precipitation during the collecting season (1998-1999), richness was highest in spring and fall. In contrast, in 1997, when it rained all summer, there was no mid-summer slump in the number of fungal species found.

At both Douglas-fir sites, more species fruited in the spring (May and June) each year than at the two subalpine fir sites (Figures 5 and 6). In August and September of each year more species fruited in the subalpine fir sites compared to the Douglas-fir sites (Figures 5 and 6).

Total Richness. Total richness includes all species occurring on the site, even those which are not apparent. It is measured by re-sampling a site over a variety of conditions (e.g. years and seasons).

Species richness (# of species) at one site and in one environmental zone is found by counting down rows of a relevee table. Table 8 summarizes our observations throughout the growing seasons of three years. Thus, its contents approximate the entire macro-fungal flora, i.e. far more than could be expected at any single visit.

The total number of species found were: 3 in dry grassland plots, 60 in Douglas-fir forests, 61 in subalpine fir forests, and none in the alpine plots (Figure 3). Total forest study areas for each forest type were the same size, 200 m^2, half at one site (Bridger Range) and half at the second (Gallatin Range). Samples were taken during 1997-1999 and at the same dates for all sites (except for alpine sites, which were visited only 3

Figure 5. Total number of fungal species collected during each collection date at five sites. BS = grassland; PS = Douglas-fir ; AV = subalpine fir ; b = Bridger Mtns; g = Gallatin Mtns. BAV site 9-22-97: data missing.

Figure 6. Summer (May – September) precipitation (cm) recorded at three weather stations in the study area. Be = grassland (Belgrade weather station near BS site); Li = Douglas-fir (Lick Creek weather station in Gallatin Mtns near AV,g site); Br = subalpine fir (Bracket Creek weather station in Bridger Mtns near AV,b site)

times). All the grassland species recorded were from the *Bouteloua-Stipa* site and none from the *Agropyron-Bouteloua* site. Richness in the alpine was biased downward because the site was sampled only 3 times, once in 1998 and twice in 1999. As both were relatively dry years they were expected to support little fruiting.

Discussion

Northern Rocky Mountain Fungal Floras

The composition and richness of Northern Rocky Mountain fungal floras is reported in the results section above. A list of all published studies of epigeous (aboveground) macrofungal communities in North America using permanent plots are listed with the present study in table 11.

Species richness in our forests was similar to that observed in a single species forest in a Northern Rocky Mountain climate (Visser 1995). Litter and wood inhabiting species were fewer in the Jack Pine forest, perhaps because there was less substrate. But we found less than half as many mycorrhizal species as were found in *Pinus banksiana* (Visser 1995). Or in a single species *Pinus taeda* forest from Mississippi (Cibula and Ovrebo 1988).

Species richness is expected to rise in forests with more species and more substrate. The median mixed conifer and hardwood forest has a similar number of litter decomposers as our forests have (Table 11). And ten times as many wood decomposers (Table 11). The median mixed forest or hardwood forest has twice as many mycorrhizal species as our forests (Table 11). One might deduce that our forests provide a similar

Table 11. Comparison of surveys of macrofungal diversity in North America

Study	Forest type	State or province	Number of plots	Plot size (sq. m.)	Duration (yrs)	Leaf litter and soil species	Wood inhabiting species	Mycorrhizal species
Present study	Douglas-fir	Montana	2	100	3	33	4	22
Present study	Subalpine fir	Montana	2	100	3	34	4	20
Visser (1995)	Jack Pine	Alberta	4	2000	2	11	10	50
O'Dell (1999)	Douglas-fir and Pacific Silver fir	Washington	100	4	2			160
Cibula and Ovrebo (1988)	Loblolly pine	Mississippi	2	1340	5			65
Villeneuve et al. (1989)	Mixed hardwood and conifers	Quebec	3	2000	2	16	22	57
Bills et al. (1986)	Spruce and hardwood	Virginia	6	256	3			35
Palmer et al. (1994)	Mixed hardwood and conifers	Virginia	3	1905	1			114
Brunner et al. (1992)	Hardwood	Alaska	4	1000	1	49	64	18
Villeneuve et al. (1989)	Mixed hardwood	Quebec	1	2000	2	31	31	27
Nantel and Neuman (1992)	Birch-Maple	Quebec	11	400	2			240
Schmidt (1999)	Mixed hardwood	Indiana	2	1000	3	59	79	36

number of litter niches, half as many mycorrhizal niches, and a tenth as many wood niches. Because severe climate of grasslands and alpine seem to reduce species diversity, it is also possible that the relatively mild climates of mixed conifer and hardwood forests ·support more mushroom diversity.

Determinants of Distribution.

Changes in fungal (mushroom) communities on the altitudinal gradient might be due to changes in physical conditions (especially temperature and moisture), structure of the plant communities (e.g. physical openings), or plant associates (e.g. hosts, mutualists, plants with antagonistic chemicals, or microbial/invertebrate associates).

Gradual changes in the character of the fungal community across two environmental types suggest adaptation to changes in the physical environment. A change progressing from grassland to Douglas-fir to subalpine fir could be due to confounded declines in temperature and increases in water availability.

On a long gradient, the tendency of mushrooms to appear consistently across widely ·separated replications of one environment (i.e. in both mountain ranges), but not in altitudinally adjacent environments suggests biological determination of the altitudinal differences. *Cortinarius sp. #1* and *Laccaria laccata*, both mycorrhizal and both found frequently and exclusively at subalpine fir sites in the two mountain ranges are likely to be associated with either *Abies* or *Picea* versus Dougals-fir. *Tricholoma cf. myomyces*, a mycorrhizal species found frequently and exclusively at both Douglas-fir sites is likely symbiotic with *Pseudotsuga* and not *Abies* or *Picea*.

Species restricted to the grassland zone could be determined by environment (because they don't range upward) or by plant associates, but since they are at the end of the gradient the cause is undetermined; the literature gives us no support in estimating that cause. However, two of the three species found in grasslands are typical grassland inhabitants (*Panaeolus foenisecii* and *Bovista plumbea*).

The increase in fungal species richness from grassy to forest sites might be due to increases in the number of niches or richer provisioning of these niches.

1) Forests probably have more niches due to the larger size of forest plants. Trees provide more volume and surface area to support a mushroom-bearing associate than a single grass. Forests provide greater lateral heterogeneity by having more distinct zones (e.g. littered area under trees, dripline, and herb/shrub areas between trees). The forest environment contains substrates missing in grasslands (wood, bark and litter in addition to plants). It seems unlikely that seasonal differences (i.e. spring, summer, fall niches) are greater in forests than grasslands. Most importantly, forests support ectomycorrhizal fungi (9 to 37% of the total number of fungal species collected at each forest site in this study) whereas grasslands do not. 2) If forests are more productive than grasslands, forest niches may be better provisioned and better able to support mushroom bearing fungi. 3) Increases in species diversity due to one or more of these factors may be exponential due to creation of niches by interaction of fungal species with each other or with plant species.

Fruiting Phenology

Fruiting phenology is probably influenced by various factors including soil temperature and soil moisture. Soil climates become progressively cooler as we move from lower to higher elevations and soils become more dry from grassland to alpine and Douglas-fir to subalpine fir (Weaver 1980, 2001). However, due to lack of shading, alpine soils may warmer and drier in summer than subalpine forest soils. Because soils warm later upslope we expect early season fruiting to progress from grassland to Douglas-fir to subalpine as seen in figure 5. From mid-summer until the autumn rains begin we expect the moister soils of the higher forest elevations to produce more fruiting, as seen in figures 5 and 6.

In the NRM region, we expect spring rains (April-June), summer drought (July-August) and a secondary September peak (Weaver 1980), but precipitation can continue throughout the summer (Figure 6).

Macrofungal fruiting response to rainfall pulses is often recorded (Bills 1986; Mehus 1986; Nantel and Neumann 1992). Responses might be too broad (high rainfall over a season) or narrow (single rainfall) pulses. Response to a broad pulse is clearly shown by differences in production between wet (1997) and moderate (1998 and 1999) years. Some species fruit in wet seasons only, while others only fruit in dry years (Table 10). Our sampling periods were too long to detect response to single rainfall events, though such responses have been suggested by others (Richardson 1970; Eveling et al. 1990; Watling 1994).

Sampling adequacy

Years

Most studies involving sampling in several years have found some species fruit in dry years only, more species fruit in wet years, and some species fruit in all years. (Bills et al. 1986; Villeneuve 1989; O'Dell et al. 1999). Our data demonstrates this phenomenon well (Table 10).

The work of Arnolds (1981) suggests that by sampling in only three years we may have captured 75-92% of the total species that will appear at our sites through time. After 2 years of collecting sporocarps in a moist Douglas-fir forest on the Olympic peninsula, O'Dell (1999) reported that 35% of the species collected fruited in both years. Our data suggests that, for the NRM region, sampling in a wet year may detect more species than sampling in multiple years of average precipitation (Figures 3 and 4, Table 10), but that sampling in wet years only may over-look some species.

Plot size.

In a homogeneous environment, one expects to find only one species at a point (spatial limitation) with numbers of species in larger plots increasing (as spatial limitation disappears) to a limit (when all adapted species are included). [The limit will not be reached if inclusion of new area brings in new environment, e.g. new altitudes, new substrates, or disturbance (Whittaker 1972)]. Given the homogeneous environment we sought (homogeneous locale or two environment equivalent locales = replicates) one can

estimate adequacy of sampling for species presence by graphing species number against

the area sampled to form a species area curve (Figure 7). Species number will have risen

rapidly with increasing plot size and begun to level when a large enough area has been

sampled. Species-area curves for all four forest sites still show increasing numbers of

species at the largest area (200 m^2), so that larger sample areas would be required to

include all the species present in each forest type. For all of the four forest sites,

however, the slope of the species area curve declines between areas smaller than 25 m^2

and those of 100 m^2 to 200 m^2. Thus an approach toward an adequate plot size is

indicated. The species area curve actually understates sample adequacy, because, while

sampling for the first three plot sizes was conducted in a truly homogeneous area, the

jump from 100 m^2 to 200 m^2 plots included a jump from one mountain range to two and

probably to a new level of environmental heterogeneity. The species area curve for

Bouteloua grasslands suggests an adequate sample.

Figure 7. Species – area curves for five study sites.

[···*···] = BS grassland; [- - ● - -] = PS,b (Douglas-fir Bridger Mtns); [- - ○ - -] = PS,g
(Douglas-fir Gallatin Mtns); [—◇—] = AV,g (subalpine fir Gallatin Mtns); [—◆—] =
AV,b (subalpine fir Bridger Mtns). The total number of species in the sample areas were
plotted against increasing areas of contiguous subplots. When 100 square meters, the
size of one site, was reached the areas of similar forest types were combined.

CHAPTER 3

STANDING CROP AND PRODUCTION OF MUSHROOMS
ON THE ALTITUDINAL GRADIENT, NORTHERN
ROCKY MOUNTAINS

Introduction

The most observable part of a fungal community on the altitudinal gradient is the mushroom component. While it may comprise a small fraction of fungal biomass (and activity), it identifies many component species and provides an index to two important functions: production of spores and production of sporocarp biomass.

Fungal sporocarps provide food for many mycophagists. Deer, elk and bear eat them, perhaps opportunistically (Fogel and Trappe 1978). Some small mammals such as pocket gophers, most voles and almost all squirrels and chipmunks rely on mushrooms or truffles for a substantial portion of their diet (Fogel and Trappe 1978; Maser et al. 1978; Carey 1991). Many of these animal species are a crucial food source for higher predators such as raptors, martens and fishers (Grenfell and Fasenfest 1979). The commercial harvest of forest fungi for human food has become a multi-million dollar industry (Schlosser and Blatner 1995). Fungal sporocarps remain an untapped reservoir of potential medicines for viral diseases such as AIDS and some cancers (Jong and Donovick 1989).

Knowledge of fruiting strategies and annual sporocarp production (g/m²/yr) estimates for mushrooms is important for the proper management of forest fungi.

While indices of mushroom production are available for other regions (Richardson 1970; Vogt et al. 1981; O'Dell et al. 1999) there are none for the Northern Rocky Mountains (NRM). Thus, the objectives of this paper are: 1) to estimate sizes of standing crops at representative points on the altitudinal gradient, 2) to compare year to year variation, and 3) to compare season-to-season variation.

Methods

Mushroom production on the altitudinal gradient was examined by sampling representative points, i.e. dry grassland, dry forest, moist forest, and the alpine. Two examples of each were selected for their accessibility and representation of conditions in the zone (Daubenmire 1943; Pfister 1997). These were: *Stipa comata-Bouteloua gracilis* and *Agropyron spicatum-Bouteloua gracilis* grasslands; *Pseudotsuga menziesii-Symphoricarpos albus* forests in the Bridger (dry) and Gallatin (moister) ranges; *Abies lasiocarpa-Vaccinium scoparium* forests in the Gallatin (dry) and moister Bridger (with moss and *Picea*) range; and tundra on a dry ridge (*Carex spp.*) and on a more sheltered cirque site (*Dryas octopetalia*).

A 100m² plot was staked at each site. It consisted of four 1 x 25 m plots, which were parallel and approximately 5 m apart. Data were recorded separately in sixteen sub-plots, each 25% of a 1 x 25 m plot. Elongate plots were studied to facilitate search for fruiting

bodies, to prevent trampling of the study area, and to minimize effects of possibly patchy fungal distributions.

The plots were sampled fortnightly in 1997-1998 and monthly in 1999, except alpine sites which were visited only 3 times (Table 3). On each sample date all mushrooms in each 6.25m^2 segment were plucked, bagged by species, dried at 60 degrees centigrade for 48 hours and weighed to the nearest hundredth of a gram. The weights were entered into a table listing weights by species, date and subplot. Most values discussed here were calculated by summing across subplots.

To see which species of fungi, if any, fruit every year and produce sufficient sporocarp biomass to serve as a dependable food or drug source, the maximum biomass collected on any single visit was calculated for each year of the study.

Results

Standing crop

The largest standing crop (gm/100m^2) observed in a vegetation type on a single collection day provides an index to the maximum standing crop available to a passing predator. For grassland, dry forest, moist forest, and alpine vegetation these were 0.54 gm/100m^2, 69gm/100m^2, 98gm/100m^2, and 0gm/100m^2 in moist 1997 and 0.02 gm/100m^2, 12 gm/100m^2, 17 gm/100m^2, and 0gm/100m^2 in dry 1998 (Table 12, Figure 8). Values from dry 1999 were similar to those of dry1998.

To index sporocarp production of individual species across wet, average and dry years, the maximum biomass collected for each species on any single collection date was

Table 12. Maximum biomass (hundredths of grams/100m^2) of sporocarps collected for each species on any single site visit for 3 years (1997 – 1998 – 1999).

Species	BS	PS,b	PS,g	AV,g	AV,b
			Site		
Nolanea sp. #1	0	0	0	258-57-40	42-44-10
Cortinarius sp. #1	0	0	0	95-0-10	252-0-0
Laccaria laccata	0	0	0	151-126-164	2190-92-527
Gerronema chrysophylla	0	0	0	154-0-0	0
Xeromphalina campanella	0	0	0	0-5-22	153-15-0
Gymnopilus sapineus	0	0	0	86-0-0	40-0-0
Tricholoma sulphureum	0	0	0	426-0-0	63-0-0
Clavariadelphus ligula	0	0	0	0	91-0-0
Cystoderma fallax	0	0	0	110-0-41	10-0-0
Otidea onotica	0	0	0	54-0-0	127-0-0
Mycena lilacifolia	0	0	0	3-5-0	1-0-0
Peziza repanda	0	0	0	0-20-0	0-42-0
Kuehneromyces vernalis	0	0	0	72-0-0	0
Tricholoma inamoenum	0	0	0	180-0-0	370-0-0
Lycogala epidendrum	0	0	0	15-0-0	0
Suillus sibiricus	0	0	0	230-313-0	0
Clavulina cristata	0	0	0	0	178-0-0
Hygrophorous purpurascens	0	0	0	300-0-0	500-0-0
Lyophyllum sp.	0	0	0	0	220-0-0
Stropharia semiglobata	0	0	0	0	16-0-0
Hypholoma fasiculare	0	0	0	0	81-0-0
Mycena rorida	0	0	0	1-0-0	0
Tubaria furfuracea	0	0	0	14-0-0	0
Cortinarius sp. #2	0	0	0	160-0-189	0
Agaricus diminutivus	0	0	0	3-0-0	0
Agaricus silvicola	0	0	0	0	100-0-0
Geastrum sp.	0	0	0	0	0-8-0
Hygrophorus pudorinus	0	0	0	0	290-0-0
Mycena acicula	0	0	0	2-0-0	0
Naucoria vinicolor	0	0	0	0	5-0-0
Stropharia hornemanii	0	0	0	0	300-0-0
Galerina heterocystis	0	15-0-0	5-0-0	61-13-52	28-5-0
Xeromphalina cauticinalis	0	0	30-0-0	49-3-22	18-5-0
Russula emetica complex	0	991-0-0	0	197-35-0	667-16-0
Lycoperdon perlatum	0	55-0-0	675-0-0	699-85-16	300-0-0
Clitocybe cf deceptiva	0	120-0-0	277-0-362	46-10-0	40-46-0
Caloscypha fulgens	0	0-0-19	0-0-294	0-0-357	0-0-15
Galerina autumnalis	0	0	0-2-0	0-141-0	0-34-0
Mycena alcalina	0	16-6-0	78-34-0	41-13-9	4-4-6
Inocybe lanuginosa	0	0	0	5-0-0	91-0-0
Mycena epipterygia	0	1-0-0	0	9-18-0	6-0-0
Russula laurocerasi	0	4220-0-0	58-0-0	0	940-0-0
Mycena elegantula	0	0	15-50-0	12-0-0	0-5-0
Tricholoma olida	0	0	350-0-0	870-0-0	58-0-0
Mycena pura	0	166-3-107	71-6-414	30-0-0	19-0-0

Table 12 (continued)

Species	BS	PS,b	PS,g	AV,g	AV,b
			Site		
Russula olivacea	0	4790-0-0	0	2270-748-0	0
Inocybe sororia	0	20-0-0	80-0-0	0	110-0-0
Agrocybe cf praecox	0	0	0-0-350	37-0-0	0-53-56
Cortinarius cf cotoneus	0	0	26-0-0	37-0-0	68-0-0
Auricularia auricula	0	0	0	122-0-0	0-21-0
Mycena citinomarginata	0	5-0-0	0	2-0-0	0
Tricholoma portentosum	0	120-0-0	0	520-0-0	0
Hygrophorus sp.	0	27-45-0	0	35-0-0	0
Amanita vaginata	0	40-0-0	0	90-0-0	0
Morchella elata	0	150-0-0	0	0-163-0	0
Pluteus cervinus	0	0	34-0-0	0	29-0-0
Lepiota clypeolaria	0	0	27-0-0	55-0-0	0
Suillus lakeii	0	1910-0-0	0	0	710-0-0
Inocybe flocculosa	0	0	8-0-0	0	0
Gomphidius subroseus	0	0	0-88-0	0	0
Neolecta irregularis	0	0	18-0-0	0	0
Tricholoma flavovirens	0	0	62-0-0	0	0
Hypholoma dispersum	0	0	10-0-0	0	0
Leptonia near cyanea	0	10-0-0	0	0	0
Collybia tuberosa	0	290-0-0	0	0	0
Conocybe tenera	0	0	3-0-0	0	0
Mycena haematopus	0	0	0-0-90	0	0
Crucibulum laevae	0	0	0	0	0
Hygrophorous chrysodon	0	40-0-0	0	0	0
Psathyrella velutina	0	0	240-278-280	0	0
Psathyrella hydrophila	0	0	0-60-0	0	0
Tricholoma pardinum	0	9-0-0	52-0-0	0	0
Psathyrella gracilis	0	18-0-0	6-0-0	0	0
Helvella lacunosa	0	0	69-0-0	0	0
Clitocybe Gibba	0	395-0-0	0	0	0
Lactarius Deliciosus	0	470-0-0	0	0	0
Lentinellus omphalodes	0	0	21-0-0	0	0
Collybia maculata	0	56-0-0	98-0-0	0	0
Inocybe geophylla var. lilacini	0	0	46-0-0	0	0
Clitocybe albirhiza	0	320-0-0	270-0-0	0	0
Inocybe geophylla	0	0	39-67-0	0	0
Inocybe fuscidula	0	?	0	0	0
Collybia butyracea	0	0	34-98-499	0	0
Strobilurius trullisatus	0	0	27-0-0	0	0
Inocybe possible nitidiuscula	0	0	907-0-0	0	0
Inocybe cf nitidiuscula	0	0		0	0
Helvella compressa	0	252-0-0	196-0-0	0	0
Collybia alkavirens	0	93-0-86	63-109-391	0	0
Tricholoma cf myomyces	0	405-0-0	225-114-333	0	0
Collybia sp. #1	0	61-0-0	93-0-0	0	0
Nolanea sp. #2	0	93-2-0	124-0-0	0	0
Entoloma rusticoides	35-0-0	0	0	0	0
Panaeolus foenisecii	19-0-0	0	0	0	0
Bovista plumbea	0-2-0	0	0	0	0

Figure 8. Total biomass (g/100m²) of fungal species collected at five sites over 3 years (1997 – 1999). BS = grassland; PS = Douglas-fir; AV = subalpine fir; b = Bridger Mtn Range; g = Gallatin Mtn Range.

Figure 9. Summer (May – September) precipitation (cm) recorded at three weather stations in the study area. The Belgrade weather station represents the grassland sites, the Lick Creek weather station [Gallatin Mtns near AV,g site] represents the Douglas-fir sites, the Bracket Creek weather station [Bridger Mtns near AV,b site] represents the subalpine fir sites.

calculated and is shown in table 12. Only 11 species out of 100 were consistently present within one or more sites during each year of the study. These were: *Laccaria laccata, Tricholoma cf. myomyces, Psathyrella velutina, Collybia alkavirens, Collybia butyracea, Clitocybe cf. deceptiva, Lycoperdon perlatum, Mycena pura, Galerina heterocystis, Mycena alcalina* and *Xeromphalina cauticinalis*. Two of these species; *Laccaria laccata* at the Gallatin subalpine fir (AV,g) site and *Tricholoma cf. myomyces* at the Gallatin Douglas-fir (PS,g) site, produced an average of over $0.01 gm/m^2/yr$ (dry wt.), and fruited every year of the study. Over the 3 years of the study, *L. laccata* and *Tricholoma cf. myomyces* were each found exclusively in the one forest type mentioned above. Other notable producers include: *Psathyrella velutina*, averaging $0.026 gm/m^2/yr$ at the PS,g site and fruiting all 3 years; *Russula olivacea*, producing $0.48 g/m^2$ in 1997 at the Bridger Douglas-fir (PS,b) site (fruited only one year there) and an average of $0.3 g/m^2$ for 1997 and 1998 at the Gallatin subalpine fir site (AV,g).

The sum of weights collected at a site over the year provides an index of productivity $(gm/m^2/yr)$. The sums were high in the conifer zone and low in treeless areas below and above it. The total mass collected in the *Stipa-Bouteloua* site ranged from 0.0002 (1998) to 0.0054 (1997) gm/m^2 (Table 13). Masses at the Douglas-fir sites ranged from 0.01 (1998) to 2.16 (1987) gm/m^2 (Table 13). Masses at the subalpine fir sites ranged from 0.04 (1998) to 1.63 (1997) gm/m^2 (Table 13). No mushrooms were observed at the alpine sites during the 3 visits.

Table 13. Total sporocarp biomass collected, (= minimal estimate* of production) at
eight sites over 3 years (1997-1999).

Site	Year 1997	Year 1998	Year 1999
Number of collection dates	7	9	5
BS (*Bouteloua-Stipa* grassland)	0.005	0.0002	0
AB (*Agropyron-Bouteloua* grassland)	0	0	0
PS,b (Douglas-fir, Bridger Mtns)	2.16	0.01	0.02
PS,g (Douglas-fir, Gallatin Mtns)	0.91	0.31	0.31
AV,g (subalpine fir, Gallatin Mtns)	1.25	0.25	0.13
AV,b (subalpine fir, Bridger Mtns)	1.63	0.04	0.11
D (alpine, *Dryas*)	0	0	0
C (alpine, *Carex*)	0	0	0

* Minimal estimate: The annual sum of sporocarp biomass is reduced by disappearances
  of mushrooms between collection dates. Estimates for 1999 are especially low because
  the number of collection dates is low.

We expected all sums to be lower in dry 1999 than in dry 1998 because the number of
sample dates was smaller, i.e. some mushrooms were lost due to decomposition and
predation. While they may be a more accurate estimate of production, the 1997-1998
data are also biased downward due to loss of mushroom mass between sampling periods.

Family and Genus Contribution

The relative contribution of fungal families to production is compared (Table 14), by
comparing the total weight harvested from that family, 1997-1999. Lycoperdaceae
(puffballs) and Entolomataceae were important in all four forest zones. Coprinaceae were
important in grasslands and dry forests. Helvellaceae was most notable in dry forests.
Russulaceae and Tricholomataceae were the two most important families, in terms of

Table 14. Total biomass collected (by family) at five sites. Masses are summed (in hundredths of grams/100m²). BS = Bouteloua grassland; PS = Douglas fir; AV = subalpine fir; b = Bridger Mtn Range; g = Gallatin Mtn Range.

Family	Site				
	BS	BPS	GPS	GAV	BAV
Family	BS	PS,b	PS,g	AV,g	AV,b
Coprinaceae	19	18	864	0	0
Entolomataceae	35	205	282	597	369
Lycoperdaceae	2	55	1657	1767	392
Russulaceae	0	15406	58	3544	3455
Tricholomataceae	0	3388	6426	4634	7842
Cortinariaceae	0	993	3185	1268	1270
Helvellaceae	0	343	316	0	0
Gomphidiaceae	0	0	137	0	0
Helotiaceae	0	0	18	0	0
Nidulariaceae	0	3	0	0	0
Boletaceae	0	2071	0	673	710
Pezizaceae	0	19	294	446	196
Bolbitiaceae	0	0	38	0	109
Pluteaceae	0	0	52	0	29
Morchellaceae	0	150	0	163	0
Amanitaceae	0	40	0	90	0
Lepiotaceae	0	0	45	55	0
Hygrophoraceae	0	128	0	335	790
Strophariaceae	0	0	10	72	409
Agaricaceae	0	0	0	3	100
Tremellaceae	0	0	0	148	21
Clavariaceae	0	0	0	0	284

production, across all forest types. Boletaceae, Cortinariaceae, and Pezizaceae were the next most productive families throughout the conifer zone.

Under the best conditions, particular genera can produce especially large (instantaneous) standing crops (e.g. over 5 gm/100m², Table 12). No highly productive families appear in grassland or alpine. In dry *Pseudotsuga* forests they include *Russula*

and *Suillus*. In moister *Abies* forests they include (listed alphabetically) *Hygrophorus*, *Laccaria*, *Mycena*, *Russula*, and *Suillus*.

Seasonality

Total mushroom standing crop varies from season to season and apparently in parallel with rainfall (Figures 10 and 11). In dry 1999 production peaked in a moist month, June. In dry 1998, production peaked in June and again with September rains (Figures 10 and 11). In moist 1997, mushroom standing crops were large in mid-summer (July-August), as well as in June and September (Figures 10 and 11).

Discussion

Table 15 lists production estimates from plot-based studies in conifer forests of epigeous (above-ground) macrofungi where production estimates are based on sporocarp dry weight.

Table 15. Comparison of production estimates of epigeous macrofungi from studies in coniferous forests.

Study	Forest type	Location	Production estimates (gm/m^2/yr)
Richardson (1970)	Scots pine	Sweden	$0.01 - 1.6$
Richardson (1970)	Spruce	Sweden	$<0.01 - 0.03$
Vogt et al. (1981)	Pacific silver fir	Washington	$0.1 - 0.12$
Vogt et al. (1981)	Pacific silver fir	Washington	$2.7 - 3.4$
O'Dell et al. (1999)	Pacific silver fir,Douglas-fir	Washington	$0 - 0.38$
Keck et al. (present study)	Douglas-fir	Montana	$0.01 - 2.16$
Keck et al. (present study)	Subalpine fir	Montana	$0.04 - 1.63$

Figure 10. Total biomass of fungal species collected during each collection date at five sites. BS = grassland; PS = Douglas-fir; AV = subalpine fir; b = Bridger Mtns; g = Gallatin Mtns. BAV site 9-22-97: data missing.
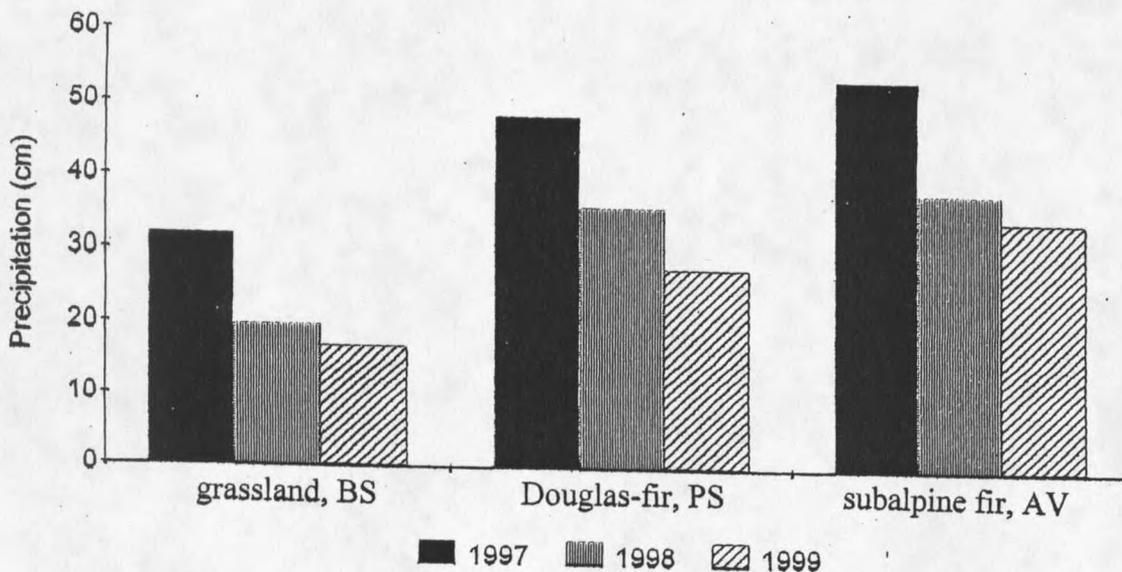

Figure 11. Summer (May – September) precipitation (cm) recorded at three weather stations in the study area. Be = grassland (Belgrade weather station near BS site); Li = Douglas-fir (Lick Creek weather station in Gallatin Mtns near AV,g site); Br = subalpine fir (Bracket Creek weather station in Bridger Mtns near AV,b site)

The yearly production estimates from our Rocky Mountain forests are similar to estimates from other coniferous forests (Table 15). O'Dell (1999) reported 0 to 0.38 $gm/m^2/yr$ in Pacific silver fir/Douglas-fir forests, similar to dry year (1998-1999) production estimates obtained in this study (0.01 to 0.31 $gm/m^2/yr$). In wet 1997, however, production ranged from 0.91 to 2.16 gm/m^2 in our forests, substantially more than those reported from most other forests (Table 15). Higher production (2.7 to 3.4 $gm/m^2/yr$) was reported in Pacific silver fir stands in Washington (Vogt et al. 1981).

Production estimates on individual sites varied widely between years. The largest range of production occurred at the Bridger Douglas-fir (PS,b) site (0.01 – 2.16 $gm/m^2/yr$) which is a greater than 99% change from 1997 to 1998. Others have reported large (97%, Mehus 1986) variation between consecutive years. This wide variability in sporocarp production makes it difficult for obligate mycophagists to evolve.

Data in table 12 suggests that mycophagist specialists must also be selected against in Rocky Mountain forests because so few mushroom species (11 out of 98) were consistently present at a site in each year, 1997 – 1999. None of the eleven species of fungi that fruited every year of the study at one or more sites was listed by North et al. (1997) as a preferred species by mycophagist animals. Species of *Clavulina* (coral fungi) and *Cantharellus* were the epigeous sporocarps most preferred by mycophagists (North et al. 1997). One coral fungus, *Clavulina cristata*, was present during one visit at the Bridger subalpine fir site in 1997 producing a total of 2.84g/100m^2 (dry wt.). While no chanterelles were present on permanent plots, *Cantharellus cibarius* has been harvested within 100m of the Gallatin subalpine fir site (AV,g) by the author. The only

commercially popular species found in the study plots was *Morchella elata*, (the Black

Morel), found once in 1997 at the Bridger Douglas-fir site (PS,g), producing 1.5g/100m^2

(dry wt.), and once in 1998 at the Gallatin subalpine fir (AV,g) site, producing

1.63g/100m^2 (dry wt). Excluding years after a forest fire, the rare and infrequent fruiting

of the Black Morel make it an unlikely candidate for commercial harvest in the Northern

Rocky Mountains.

Sporocarp production was much greater in the forests than in grassland and alpine

habitat types where few or no sporocarps were collected. This is to be expected as trees

provide niches for ectomycorrhizal fungi and forests offer more substrate for saprophytic

fungi. Studies from grasslands (Arnolds 1981; Lange 1984), and alpine (Cripps and

Horak 1999), demonstrate that macrofungi are present and produce sporocarps in those

environments. The low production recorded in the alpine and grassland sites

demonstrates the very low productivity of fungal communities in these habitats.

Peak fruiting progressed from *Bouteloua* to Douglas-fir to subalpine fir. Douglas fir

sites were most productive during the first half of the growing season. Subalpine fir sites

produced more sporocarp biomass during the latter half of the season. This trend was

observed in all years of the study (Figures 10 and 11). The most likely explanation for

this trend is earlier warming in the grassland and Douglas-fir sites (Weaver 2001). Others

have observed that, given moist soils, production is favored by high soil temperatures

(Hering 1966; Peredo et al. 1983).

CHAPTER 4

FUNGAL GUILDS IN NORTHERN ROCKY

MOUNTAIN COMMUNITIES

Introduction

Fungi can be divided into three main guilds (functional groups) each with several

sub-guilds. Saprophytic fungi decompose dead material including litter, wood and soil

organic material. Mycorrhizal fungi obtain nutrients from plant roots and are divided into

those occupying root surfaces (ectomycorrhizae) and those reaching inward

(endomycorrhizal). Parasitic fungi are internal to plant parts from the root to the leaf.

Sporocarps are typically produced by all guilds from mycelial masses occupying these

organic resources and demonstrate the presence of the fungal species. Comparison of

fungal guilds across forest types shows greater numbers of mycorrhizal species fruiting in

coniferous forests than in hardwood forests (Vogt et al. 1981;Villeneuve et al. 1989;

Gulden 1992). Quantitative studies in coniferous forests generally report greater numbers

of mycorrhizal than saprophytic species (Table 11). The percent of mushroom biomass

due to epigeous mycorrhizal sporocarps varies from 14 to 93 percent in coniferous forests

(Richardson 1970; Vogt et al.1981; Ohenoja 1978). Between 64 and 90 percent of

fruitbody production (biomass) in northwest Pacific silver fir/Douglas-fir forests was

from mycorrhizal species (Vogt et al. 1981).

No studies have compared the contributions of mycorrhizal and saprophytic fungi in the Northern Rocky Mountains (NRM). Thus the object of this chapter is to compare the sporocarp production of fungal guilds (e.g. saprophytes, mycorrhizal) among major ecosystems, including grasslands, conifer forests and the alpine. Comparison can be made with respect to diversity, sporocarp production (biomass) and the temporal distribution of sporocarp production.

Methods

Climax communities from four altitudinal zones were sampled in the Rocky Mountains of central Montana. Two examples of each were chosen to provide some measure of variation among sites in each zone. One grassland was dry (*Stipa comata-Bouteloua gracilis*), the other (*Agropyron spicatum-Bouteloua gracilis*) represented a moister grassland. The dry forests (*Pseudotsuga menziesii-Symphoricarpos albus*) were replications, one from the Gallatin Range and one from the Bridger Range. The subalpine fir forests (*Abies lasiocarpa-Vaccinium scoparium*) were also replicates, from the Gallatin and Bridger Ranges. The sites were chosen to be representative of widespread environmental types (Daubenmire 1968; Pfister 1997) and sufficiently accessible to make the study feasible. Four plots were installed at each of the eight study sites. These were 1x 25 meters long, parallel, and approximately 5 m apart. Elongate plots were used to permit close examination without trampling. Each plot was subdivided into four equal segments (1x 6.25m)

Sampling consisted of identifying all species in each 1x 6.25m plot and counting the individuals of each species therein. All macrofungi were collected, identified, dried, weighed and stored. Field notes at the time of collection included: date, location (site and subplot). All specimens were put in a plastic box with dividers and then placed in a cooler until the end of the collection day. Samples were identified with the help of field guides then stored under refrigeration for up to one week while the unknown specimens were identified. Unfamiliar species were identified in the laboratory with the help of notes, fresh samples, books (Singer 1962; Arora 1986; Lincoff 1987; Phillips 1991; Dahncke 1993; Phillips 1994), and the help of Dr. C. Cripps and Dr. D. Mathre. Authorities are according to Moser (1978). Sporocarps were dried at approximately 60 degrees centigrade for 48 hours.

Results

Diversity

Saprophytic species were more numerous than mycorrhizal species in all environments and all years (Table 16).

The percent of mycorrhizal species collected at each site ranged from 9% to 37% during the 3 years of the study (Table 17). This percentage decreased with each consecutive year at each site.

Diversity varied with rainfall. The wettest year of the study, 1997, had the greatest diversity of both mycorrhizal and saprophytic species.

Diversity varied with vegetation/environmental type. The greatest diversity of mycorrhizal species occurred in the Gallatin subalpine fir (AV,g) site with a total of 16 species collected. The greatest diversity of saprophytic fungi was seen in the Gallatin Douglas-fir site (PS,g), with a total of 30 species collected.

Table 16. Number of mycorrhizal (myco) and saprophytic (sap) species of fungi collected at five sites for 3 years (1997 – 1999).

	Year					
	1997		1998		1999	
Site	myco.	sap	myco	sap.	myco.	sap.
AV,b (subalpine fir, Bridger Mtns)	14	26	2	14	1	10
AV,g (subalpine fir, Gallatin Mtns)	16	28	5	15	2	9
PS,g (Douglas fir, Gallatin Mtns)	14	30	4	14	2	11
PS,b (Douglas fir, Bridger Mtns)	12	20	4	9	0	6
BS (*Bouteloua* grassland)	0	2	0	1	0	0

The Bridger Douglas-fir site had the lowest diversity of both fungal guilds in a given year, with zero mycorrhizal and six saprophytic species collected in 1999.

Table 17. Percent of total number of fungal species collected that are mycorrhizal at five sites for 3 years (1997 – 1999).

	Year		
Site	1997	1998	1999
AV,b (subalpine fir, Bridger Mtns)	35%	13%	9%
AV,g (subalpine fir, Gallatin Mtns)	36	25	18
PS,g (Douglas-fir, Gallatin Mtns)	32	22	15
PS,b (Douglas-fir, Bridger Mtns)	37	31	14
average	35	22	14

Biomass

Production of both mycorrhizal and saprophytic species at all study sites was greatest

in the wettest year (1997, Table 18).

Table 18. Total biomass (g) of mycorrhizal (myco) and saprophytic (sap) sporocarps
collected at five sites for 3 years (1997 – 1999).

	Year					
	1997		1998		1999	
Site	myco.	sap	myco.	sap.	myco.	sap.
AV,b (subalpine fir, Bridger Mtns)	136.9	25	1.1	3.1	10.3	0.9
AV,g (subalpine fir, Gallatin Mtns)	86.7	33.3	13.2	11.5	5.5	7.5
PS,g (Douglas-fir, Gallatin Mtns)	43.6	44.6	26.9	8.2	5.1	21.3
PS,b (Douglas-fir, Bridger Mtns)	182.9	33.2	1.1	0.1	0	2.1
BS (*Bouteloua* grassland)	0	0.54	0	0.02	0	0

The percentage of sporocarp biomass produced in a year by mycorrhizal species at

each site ranged from 0 to 92% (Table 19).

Table 19. Percent of total sporocarp biomass produced by mycorrhizal fungi at four
forest sites for 3 years (1997 – 1999).

	Year		
Site	1997	1998	1999
AV,b (subalpine fir, Bridger Mtns)	84%	26%	91%
AV,g (subalpine fir, Gallatin Mtns)	72	53	42
PS,g (Dougals-fir, Gallatin Mtns)	49	76	19
PS,b (Douglas-fir, Bridger Mtns)	85	92	0
average	73	62	38

The Bridger Douglas-fir (PS,b) site produced the most biomass for one guild

(mycorrhizal), during one year (1997), at 1.83 g/ m2 . This was largely due to a large

fruiting of mycorrhizal *Russula olivacea* in June. The mycorrhizal guild was again least productive at the same PS,b site during 1999, with zero sporocarps produced.

The saprophytic guild varied less with the peak of production at the Gallatin Douglas-fir (PS,g) site in 1997 with 44.6 grams, and the lowest production occurring at the PS,b site with 0.1 grams in 1998 (Table 18).

Minimal sampling area

The average number of saprophytic species present in each 1m x 6.25m subplot was greater than the average number of mycorrhizal species present on all sites (Table 20). The greatest number of saprophytic species fruiting in one 1m x 6.25m subplot was 14, at the subalpine fir Gallatin (AV,g) site, in contrast to the maximum of seven mycorrhizal species present in one subplot, also at the subalpine fir Gallatin (AV,g) site (Table 20).

Discussion

The data reveals no apparent differences between subalpine fir and Douglas-fir forests with respect to the number of species of mycorrhizal fungi vs. the number of saprophytic species present (Table 16). The Douglas-fir forest contained 22 species of ectomycorrhizal fungi, similar to the 20 found in the subalpine fir sites.

The wide range of percentages of mycorrhizal sporocarp biomass (0 to 92%) collected in a given year is similar to the wide range of percentages reported by Richarson (1970)

Table 20. Maximum and average number of saprophytic and mycorrhizal species
collected per 1m x 6.25m subplot at five sites*.

	Site				
	BS	PS,b	PS,g	AV,g	AV,b
Maximum number of saprophytic species collected	2	10	11	14	9
Maximum number of mycorrhizal species collected	0	7	6	7	6
Average number of saprophytic species collected	0.7	4.3	8.2	8.6	4.3
Average number of mycorrhizal species collected	0	1.9	3.3	2.3	3.1

* BS = Bouteloua grassland; PS = Douglas-fir forest; AV = Subalpine fir forest;
  b = Bridger Mtn Range; g = Gallatin Mtn Range.

(14 to 93%) in a Scots pine forest. No discernable patterns emerge from these biomass percentages when looking across forest types or years.

The number of mycorrhizal species fruiting may reflect the number of available niches in the rhizosphere, but the literature provides few estimates of mycorrhizal species density in small (< 10 m^2) areas. At the Bridger Douglas-fir (PS,b) site, seven species of ectomycorrhizal fungi were present in the richest 1m x 6.25m subplot (Table 20). The richest 1m x 6.25m subplot at the Gallatin subalpine fir site contained six species of ectomycorrhizal fungi. This is similar to Bills et al. (1986) who reported up to seven species of ectomycorrhizal fungi fruiting in a single 2m x 2m quadrat. Deacon et al.

(1983) reported at least five types of ectomycorrhizae occuring within a 7m radius of a young birch. Seven species of ectomycorrhizal fungi have been isolated from a single 4 year old *Pinus elliottii* tree (Zak and Marx 1964). Some studies suggest *Pseudotsuga menziesii* hosts a broader range of ectomycorrhizal symbionts than other trees (Fogel and Trappe 1978; O'Dell et al. 1999). For example, O'Dell et al. (1999) reported finding 154 ectomycorrhizal species in a Douglas-fir dominated forest area of 10,400 m^2, twice the number of ectomycorrhizal species (84) found in *Betula* and *Picea* dominated forest areas of similar size by Villeneuve et al. (1989).

Four possible explanations are suggested for the greater number of saprophytic than mycorrhizal species present in our 1m x 6.25m subplots.

First, there might be more niches for saprophytes and/or fewer niches for mycorrhizal fungi in Rocky Mountain communities. The number of mycorrhizal niches may be largely a product of different hosts (single or multiple species) or age of host. As compared to other forests (Villeneuve et al. 1989; Gulden 1992; Visser 1995; O'Dell et al. 1999) Rocky Mountain forests may be host tree species poor. This seems unlikely, as studies mentioned above have collected high numbers of mycorrhizal species in coniferous (especially Douglas-fir) forests. In contrast, there may be a greater number of saprophytic niches in the NRM determined by material used (litter, wood), stage of decomposition, and different microhabitats varying for example, in water availability, oxygen availability (distance from the surface), or chemical inhibition (under trees, drip-line, between trees). This seems more likely, as studies with much larger plots (2000 m^2),

(Villeneuve et al. 1989; Visser 1995) report smaller total numbers of saprophytic species than the present study.

Second, Rocky Mountain forests may be low in mycorrhizal species because of less precipitation. The relative decrease in mycorrhizal species fruiting in consecutive years at every forest site coincides with decreased precipitation at each mountain range, which suggests mycorrhizal species may be present but less likely to fruit in dry years compared to saprophytic fungi.

Third, the $100m^2$ plot size at each site may adequately sample saprophytic fungi richness, but may be too small to adequately sample mycorrhizal species present. With the larger plot sizes (>1000 m^2) used in many studies, the smaller saprophytic sporocarps are less likely to be noticed during collection. Saprophytic sporocarps in the present study were usually smaller than mycorrhizal sporocarps. Many of the saprophytic genera collected were *Mycena* and smaller members of *Collybia* and *Clitocybe*. Almost all of the large sporocarps collected were mycorrhizal, with *Russula* and *Suillus* comprising a large portion of the total mycorrhizal biomass.

The fourth possibility is that mycorrhizal fungi have a more patchy distribution and therefore larger plot sizes are required to adequately sample them.

These discrepancies between the present study and studies of mycorrhizal and saprophytic species in other regions underscore the importance of the need for more research of macrofungi in the Rocky Mountain region.

CHAPTER 5

CONCLUSIONS

Species composition varied on the altitudinal gradient. No sporocarps were collected in the alpine, possibly due to the low number of visits. All species collected were exclusive to either grassland or forest. Two genera, *Panaelous* and *Entoloma*, were present in both grassland and forest. Approximately half of the species found in Douglas-fir forests and half of the species found in subalpine fir forests were exclusive to a particular forest type, although few conclusions can be made with regard to those species found only once or twice in one forest type.

Species diversity varied greatly between grasslands and forests. Species diversity (numbers of species present) did not vary between forest types. Both forest types had lower mycorrhizal than saprophytic species diversity.

Species diversity was highest in the wettest year of the study (1997) and lower during the drier years (1998 and 1999). Sixty five percent of the species collected during this study fruited only in the wettest year (1997), although seven species fruited only in one of the two drier years (1998 and 1999).

Fungal sporocarp production was less in grasslands than in forests. Sporocarp production differed little between the two grassland types and little between the two forest types.

There are a few possible explanations for the greater number of saprophytic species than mycorrhizal species collected at each site in each year: There may be more niches for saprophytic species in our area; Less precipitation in the Northern Rocky Mountains may cause a decrease in the fruiting of mycorrhizal species; The smaller plot sizes utilized in this study may be adequate for the sampling of saprophytic sporocarps, whereas larger plot sizes are needed to sample for the more patchily distributed mycorrhizal species.

There are no other published, quantitative studies of fungal communities in our region, the Northern Rocky Mountains. This study provides the first measures of diversity and production for major ecosystem types in the Northern Rocky Mountains.

The discrepancies between this study and those performed in wetter climates emphasize the need for more plot-based research of fungal communities in the Northern Rocky Mountain region.

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APPENDIX A

FREQUENCY TABLE

Frequency table. Species are listed vertically. Each column represents one of sixteen sub-plots comprising each site. In the matrix is the number of sporocarps found within the corresponding sub-plot. The three numbers separated by hyphens represent each collecting year: 1997-1998-1999. A zero means no sporocarps of that species were collected in that subplot. Total number of fruiting bodies collected at each site for each species is listed on the right hand side (total #f.b.). Percent frequency (percentage of sub-plots which produced one or more fruiting bodies of that species at any time during the study) is listed in the far right hand column.

Site: BS = *Bouteloua gracilis/Stipa comata* grassland

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Entoloma rusticoides	0	0	1-0-0	0	0	0	0	1-0-0	0	3-0-0	1-0-0	0	0	0	2-0-0	1-0-0	9	38
Panaeolus foenisecii	2-0-0	0	0	3-0-0	0	2-0-0	0	0	0	0	0	1-0-0	0	0	0	0	8	25
Bovista plumbea	0	0	0-1-0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6

Site: PS,b = Pseudotsuga menziesii/Symphoricarpos albus Bridger Mtns

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Galerina heterocystis	0	0	0	0	0	0	0	0	0	4-0-0	0	0	2-0-0	0	9-0-0	1-0-0	16	25
Xeromphalina cauticinalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloscypha fulgens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0-0-2	2	6
Galerina autumnalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Russula emetica complex	0	0	0	0	0	0	1-0-0	1-0-0	0	0	0	1-0-0	0	0	1-0-0	1-0-0	5	31
Tricholoma olida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena epipterygia	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	1	6
Auricularia auricula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe lanuginosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agrocybe cf praecox	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe sororia	0	0	1-0-0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	2	13
Inocybe pudica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lycoperdon perlatum	0	0	1-0-0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	2	13
Mycena citinomarginata	0	3-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6
Mycena elegantula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tricholoma portentosum	0	0	0	0	0	0	0	0	0	3-0-0	0	0	0	0	0	0	3	6
Hygrophorus sp.	0	0	0	0-3-0	0	0	0	0	0	0	0	0	0	0	0	4-0-0	7	13
Morchella elata	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	1	6
Amanita vaginata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	1	6
Cortinarius cf cotoneus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pluteus cervinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Russula laurocerasi	0	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	5-0-0	1-0-0	7	19
Lepiota clypeolaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clitocybe cf deceptiva	0	5-0-0	0	0	0	1-0-0	0	3-0-0	2-0-0	0	0	0	0	0	0	1-0-0	12	31
Russula olivacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2-0-0	2	6

Site: PS,b = Pseudotsuga menziesii/Symphoricarpos albus Bridger Mtns (continued)

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Mycena alcalina	0	3-0-0	0	0	0	0	0	0	3-0-0	2-0-0	2-0-0	3-0-0	0-4-0	0	5-0-0	0	22	44
Suillus lakeii	1-0-0	2-0-0	3-0-0	0	0	0	0	0	0	3-0-0	0	0	0	0	0	1-0-0	10	31
Mycena pura	0-0-5	0	0	3-0-0	0	1-0-0	5-0-0	0-0-2	4-0-5	0	0	0	0-1-0	0	7-0-0	4-0-0	37	56
Clitoctbe Gibba	1-0-0	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13
Lactarius Deliciosus	0	0	0	0	0	0	0	2-0-0	0	0	0	0	0	0	1-0-0	0	3	13
Tricholoma cf myomyces	15-0-0	0	0	0	0	0	2-0-0	0	0	0	0	0	1-0-0	5-0-0	7-0-0	1-0-0	31	38
Leptonia near cyanea	0	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	1	6
Hypholoma dispersum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tricholoma flavovirens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tricholoma pardinum	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	0	1	6
Collybia dryophila	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neolecta irregularis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphidius subroseus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conocybe tenera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena cf galericulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe flocculosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helvella lacunosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena haematopus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collybia butyracea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crucibulum laevae	0	0	0	3-0-0	0	0	0	0	0	0	0	0	0	0	0	0	3	6
Collybia maculata	0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	1	6
Hygrophorous chrysodon	0	0	0	0	0	0	0	0	0	4-0-0	0	0	0	0	0	0	4	6
Psathyrella gracilis	0	0	0	0	0	0	0	0	4-0-0	0	0	0	0	0	0	0	4	6
Lentinellus omphalodes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clitocybe albirhiza	0	1-0-0	0	0	0	0	0	0	1-0-0	1-0-0	0	0	0	1-0-0	0	0	4	25
Psathyrella velutina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psathyrella hydrophila	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Site: PS,b = Pseudotsuga menziesii/Symphoricarpos albus Bridger Mtns (continued)

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Collybia tuberosa	1*-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1*	6
Inocybe geophylla var. lilacina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe geophylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helvella compressa	0	0	0	0	3-0-0	2-0-0	0	0	0	2-0-0	6-0-0	0	2-0-0	2-0-0	1-0-0	0	18	44
Strobilurius trullisatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collybia sp. #1	0	2-0-0	0	0	0	0	0	6-0-0	1-0-0	0	0	1-0-0	0	1-0-0	5-0-0	0	16	38
Nolanea sp. #2	0	0	0	4-0-0	1-0-0	1-0-0	0-1-0	3-0-0	4-0-0	0	1-0-0	0	0	1-0-0	1-0-0	4-0-0	21	63
Inocybe possible nitidiuscula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe fuscidula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collybia alkavirens	0	0	0	1-0-0	0	0	5-0-0	0	9-10-0	0-2-0	0	0	0	0	0	0	27	25
Inocybe cf nitidiuscula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Site: PS,g = Pseudotsuga menziesii/Symphoricarpos albus Gallatin Mtns

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Galerina heterocystis	0	0	0	2-0-0	0	1-0-0	0	3-0-0	1-0-0	0	0	0	0	0	0	0	7	25
Xeromphalina cauticinalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11-0-0	11	6
Caloscypha fulgens	0	0	0	0	0	0	0-0-4	0-0-9	0	0-0-2	0	0	0-0-2	0	0	0-0-14	31	31
Galerina autumnalis	0	0	0	0	0	0	0	0	0-1-0	0	0	0	0	0	0	0	1	6
Russula emetica complex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tricholoma olida	0	0	0	0	0	0	0	0	0	3-0-0	0	0	0	0	0	0	3	6
Mycena epipterygia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Auricularia auricula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe lanuginosa	0	0	0	0	0	0	0	0	0	0	0	3-0-0	0	0	0	0	3	6
Agrocybe cf praecox	0	0	0	0	0	0	0	0	0	0	2-0-0	0	0	0	0	0	2	6
Inocybe sororia	0	0	1-0-0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	2	13
Inocybe pudica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lycoperdon perlatum	1-0-0	0	1-0-0	0	3-0-0	8-0-0	0	0	4-0-0	2-0-0	1-0-0	5-0-0	1-0-0	3-0-0	4-0-0	0	33	69
Mycena citinomarginata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena elegantula	0	0	0	0-1-0	0	0	0-1-0	0	0	0	0	1-1-0	0-3-0	0-1-0	0-1-0	1-1-0	11	44
Tricholoma portentosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hygrophorus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Morchella elata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amanita vaginata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cortinarius cf cotoneus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pluteus cervinus	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	1-0-0	0	2	13
Russula laurocerasi	0	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	1	6
Lepiota clypeolaria	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	2-0-0	0	0	3	13
Clitocybe cf deceptiva	0	0	0	1-0-0	1-0-0	2-0-0	5-0-0	0	2-0-0	1-0-0	0	3-0-1	3-15-0	5-0-0	0	2-0-0	41	63
Russula olivacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Site: PS,g = Pseudotsuga menziesii/Symphoricarpos albus Gallatin Mtns (continued)

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Mycena alcalina	16-0-0	0	0	2-0-0	0	0-1-0	8-3-0	1-3-0	0-2-0	2-3-0	0	1-0-0	0-5-0	0-3-0	27-0-0	4-4-0	85	75
Suillus lakeii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena pura	1-0-12	7-0-0	2-0-4	11-0-13	0-0-2	2-0-9	9-0-2	5-1-1	1-0-0	0	0	4-0-0	1-0-3	6-0-0	0-0-12	2-0-0	111	88
Clitoctbe Gibba	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lactarius Deliciosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tricholoma cf myomyces	0-6-0	1-9-0	0-0-6	0-1-0	5-51-6	0-1-0	0-2-0	0-14-1	0	0	0	0	0	1-7-0	1-1-2	1-0-0	116	69
Leptonia near cyanea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypholoma dispersum	0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	1	6
Tricholoma flavovirens	0	0	0	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	1	6
Tricholoma pardinum	0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	1	6
Collybia dryophila	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neolecta irregularis	0	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	1	6
Gomphidius subroseus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0-1-0	1	6
Conocybe tenera	0	0	0	0	0	0	0	0	0	0	2-0-0	0	0	0	0	0	2	6
Mycena cf galericulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe flocculosa	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	1	6
Helvella lacunosa	0	0	0	0	0	0	1-0-0	1-0-0	0	0	0	0	0	0	0	0	2	13
Mycena haematopus	0	0	0	0-0-3	0	0	0	0	0	0	0	0	0	0	0	0	3	6
Collybia butyracea	0-6-19	0	0	0	0	3-0-0	0-0-9	0-0-9	1-0-0	0	0	0	0	0	0	0-0-10	57	38
Crucibulum laevae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collybia maculata	2-0-0	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	13
Hygrophorous chrysodon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psathyrella gracilis	0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	1	6
Lentinellus omphalodes	0	0	0	0	0	0	0	0	3-0-0	4-0-0	0	0	0	0	0	0	7	13
Clitocybe albirhiza	0	0	0	0	0	0	0	0	0	0	0	9-0-0	0	0	0	0	9	6
Psathyrella velutina	1-3-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	6
Psathyrella hydrophila	0	0	0	0	0	0	0	0	0-11-0	0	0	0	0	0	0	0	11	6

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Site: PS,g = Pseudotsuga menziesii/Symphoricarpos albus Gallatin Mtns (continued)

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Collybia tuberosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe geophylla var. lilacina	0	0	0	0	1-0-0	0	0	0	1-0-0	1-0-0	3-0-0	0	0	0	0	0	6	25
Inocybe geophylla	8-4-0	0	2-0-0	5-0-0	0	0	0	3-3-0	0	0	1-0-0	2-0-0	0	0	0	0	28	38
Helvella compressa	0	1-0-0	0	1-0-0	0	2-0-0	0	0	0	0	0	0	0	0	0	0	4	19
Strobilurius trullisatus	3-0-0	0	4-0-0	2-0-0	0	0	6-0-0	2-0-0	2-0-0	0	0	4-0-0	0	0	2-0-0	0	25	50
Collybia sp. #1	1-0-0	1-0-0	0	0	7-0-0	1-0-0	1-0-0	1-0-0	2-0-0	1-0-0	0	0	4-0-0	4-0-0	0	6-0-0	29	69
Nolanea sp. #2	2-0-0	2-0-0	1-0-0	0	1-0-0	0	2-0-0	0	0	2-0-0	0	3-0-0	1-0-0	0	0	0	14	50
Inocybe possible nitidiuscula	0	7-0-0	0	1-0-0	0	1-0-0	0	6-0-0	0	0	25-0-0	8-0-0	1-0-0	0	0	7-0-0	56	50
Inocybe fuscidula	0	0	0	3-0-0	0	12-0-0	0	3-0-0	6-0-0	13-0-0	7-0-0	0	0	0	0	0	44	38
Collybia alkavirens	2-0-3	0	0	0-0-14	0-0-1	0	0-0-3	1-0-0	2-0-2	0	0	0-6-2	0-10-8	2-2-1	0-8-14	0-0-2	83	69
Inocybe cf nitidiuscula	0	5-11-0	0	4-0-0	0	0-1-0	6-4-0	0-1-8	0	0	9-19-0	9-15-1(	0-2-0	0	0	0-6-4	134	56

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Site: AV,g = Abies lasiocarpa/Vaccinium scoparium Gallatin Mtns

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Laccaria laccata	0	1-0-0	0	2-0-0	0	0	0	0	4-4-5	0	0	6-0-0	0	0	0	0	22	25
Xeromphalina campanella	0	0	0	0	0	0-4-0	0	0	0	0	0	0	0	0	0-0-5	0	9	13
Nolanea sp. #1	0-1-0	7-0-0	3-0-1	3-0-1	0	2-5-1	2-1-0	1-0-0	0	5-0-0	0	0-1-0	0	8-0-0	0-1-0	4-0-0	47	75
Gerronema chrysophylla	0	0	0	6-0-0	0	1-0-0	5-0-0	4-0-0	0	0	0	0	1-0-0	0	21-0-0	0	38	38
Clavariadelphus ligula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galerina heterocystis	4-0-0	7-0-0	3-0-0	9-0-0	16-0-3	12-0-1	8-0-0	13-0-0	20-1-0	0	3-0-0	0	0-0-7	8-3-0	0	0	118	75
Lyophyllum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stropharia semiglobata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Otidea onotica	0	0	0	0	1-0-0	0	0	0	0	0	0	0	0	0	0	7-0-0	8	13
Cystoderma fallax	1-0-0	2-0-0	0	0	4-0-0	0	1-0-0	0	0	0	0	1-0-0	0	0	0	0	9	31
Gymnopilus sapineus	1-0-0	0	0	4-0-0	2-0-0	1-0-0	1-0-0	3-0-0	0	0	0	0	0	0	0	0	12	38
Tricholoma sulphureum	3-0-0	3-0-0	1-0-0	1-0-0	2-0-0	1-0-0	0	0	0	0	0	0	0	0	0	0	11	38
Kuehneromyces vernalis	0	9-0-0	0	1-0-0	0	0	0	0	0	0	0	0	0	0	2-0-0	0	12	19
Hypholoma fasiculare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena lilacifolia	0	0	0	0	0	5-0-0	0	1-0-0	1-0-0	0	0	0	0	0	1-0-0	0	8	25
Lycogala epidendrum	0	0	0	0	0	0	0	0	1-0-0	0	0	4-0-0	0	0	0	0	5	13
Russula brevipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clitocybe sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0-3-0	0	0	3	6
Mycena rorida	0	0	0	0	0	0	0	0	2-0-0	0	0	0	0	0	0	0	2	6
Russula sp.	0	0	0	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	1	6
Suillus sibiricus	0	0	0	0	0	0	0	0	0	0	0	0	1-1-0	1-0-0	0	0	3	13
Hygrphorus pudorinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubaria furfuracea	0	0	0	0	0	2-0-0	0	0	0	0	0	0	0	0	0	0	2	6
Clavulina cristata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agaricus diminutivus	0	0	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6
Agaricus silvicola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Site: AV,g = Abies lasiocarpa/Vaccinium scoparium Gallatin Mtns (continued)

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Cortinarius sp. #1	3-0-0	0	1-0-0	0	0	0	1-0-0	5-0-0	0	0	0	0	2-0-0	0	0	0	12	31
Cortinarius sp. #2	0	0	0	1-0-1	0	0	0	0	0	0	0	0	0	0	0	0	2	6
Geastrum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peziza repanda	0	0	0	0	0	0	0	0	0	0	0	0-1-0	0	0	0	0	1	6
Hygrophorous purpurascens	0	0	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6
Mycena acicula	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	0	0	1	6
Naucoria vinicolor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stropharia hornemanii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tricholoma inamoenum	0	2-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6
Galerina heterocystis	4-0-0	7-0-0	5-0-0	9-0-0	16-0-3	9-0-1	11-0-0	15-0-0	20-1-0	5-0-0	3-0-0	1-0-0	0-0-7	8-3-0	0	0	128	88
Xeromphalina cauticinalis	0-0-1	2-0-0	0	6-0-0	10-0-0	7-1-1	0	0-1-0	1-0-0	5-0-0	1-0-0	0	5-0-0	8-0-0	0	0	49	69
Caloscypha fulgens	0	0-0-2	0-0-1	0-0-39	0-0-2	0	0-0-7	0-0-9	0-0-2	0	0-0-1	0	0-0-2	0-0-1	0-0-1	0-0-16	83	75
Galerina autumnalis	0	0	0	0-2-0	0-5-0	0	0	0	0-8-0	0-2-0	0	0	0-5-0	0	0-4-0	0	26	38
Russula emetica complex	1-0-0	3-0-0	1-0-0	0	0	7-0-0	0-1-0	1-0-0	0	0	0	0	0	0	0	0	14	38
Tricholoma olida	2-0-0	0	0	10-0-0	0	0	0	0	0	0	0	0	0	0	0	0	12	13
Mycena epipterygia	0	0	0	0	0	0	0	0	3-2-0	0	0	0	0	0-1-0	0-5-0	0	11	19
Auricularia auricula	0	0	0	0	0	0-1-0	0	0	0	0	0	0	0	0	0	0	1	6
Inocybe lanuginosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2-0-0	2	6
Agrocybe cf praecox	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe sororia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inocybe pudica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lycoperdon perlatum	2-1-0	2-0-0	4-0-0	3-0-0	3-0-0	2-0-0	0	0	6-12-0	0	0-0-1	0	4-0-0	0	0	8-0-0	48	63
Mycena citinomarginata	0	0	0	0	0	0	0	0	4-0-0	0	0	0	0	0	0	0	4	6
Mycena elegantula	0	0	0	3-0-0	0	0	0	0	0	0	0	0	0	0	0	0	3	6

Site: AV,g = Abies lasiocarpa/Vaccinium scoparium Gallatin Mtns (continued)

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Tricholoma portentosum	0	0	4-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	6
Hygrophorus sp.	0	0	0	0	0	0	0	0	0	0	0	0	4-0-0	0	0	0	4	6
Morchella elata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0-1-0	0	1	6
Amanita vaginata	0	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	1	6
Cortinarius cf cotoneus	0	0	1-0-0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	2	13
Pluteus cervinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Russula laurocerasi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepiota clypeolaria	0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	1	6
Clitocybe cf deceptiva	0	4-0-0	1-0-0	0	1-0-0	0	1-0-0	3-0-0	1-0-0	0	0	0	6-0-0	0	1-0-0	0	18	50
Russula olivacea	0	0	0-3-0	5-1-0	0	0	0	0	0	0	0	0	0	0	0	0	9	13
Mycena alcalina	1-4-0	0	0	0-2-0	0	1-0-0	0	0-1-0	13-4-0	0	1-0-0	0	1-0-1	0-0-3	0	0	32	50
Suillus lakeii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena pura	0	1-0-0	0	0	0	0	0	2-0-0	0	0	0	0	0	0	0	0	3	13

Site: AV,b = Abies lasiocarpa/Vaccinium scoparium Bridger Mtns

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Laccaria laccata	0	0	0	9-0-0	0	0	0	40-0-0	9-0-9	0	0	16-0-0	21-9-15	1-0-0	0	0	129	38
Xeromphalina campanella	0	51-0-0	0-6-0	0	0	0-5-0	0	0	0	0	0	0	0	0	0	0	62	19
Nolanea sp. #1	15-0-0	1-1-0	0	0	0	0	0	0	2-0-0	0	3-0-0	0	3-1-1	0	0	0-2-0	29	38
Gerronema chrysophylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clavariadelphus ligula	0	0	0	0	4-0-0	17-0-0	0	0	0	1-0-0	0	0	0	0	0	0	22	19
Galerina heterocystis	11-0-0	1-1-0	3-0-0	5-4-0	0	0	0	0	1-0-0	0	6-0-0	0	5-0-0	0	3-0-0	1-0-0	41	56
Lyophyllum sp.	0	0	0	0	0	0	17-0-0	0	0	0	0	0	0	0	0	0	17	6
Stropharia semiglobata	0	0	0	15-0-0	0	0	0	0	0	0	0	0	0	0	0	0	15	6
Otidea onotica	0	0	0	0	4-0-0	0	0	0	0	0	0	0	0	0	0	3-0-0	7	13
Cystoderma fallax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	1	6
Gymnopilus sapineus	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	0	1	6
Tricholoma sulphureum	0	0	0	0	2-0-0	0	0	0	0	0	0	0	0	0	0	0	2	6
Kuehneromyces vernalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypholoma fasiculare	0	0	0	0	0	0	0	11-0-0	0	0	0	0	0	0	0	0	11	6
Mycena lilacifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lycogala epidendrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Russula brevipes	0	0	0	0	0	5-0-0	0	0	0	0	0	0	0	0	0	0	5	6
Clitocybe sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena rorida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Russula sp.	0	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6
Suillus sibiricus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hygrophorus pudorinus	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	1	6
Tubaria furfuracea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clavulina cristata	0	0	0	1-0-0	0	0	0	0	0	0	2-0-0	0	0	0	0	0	3	13
Agaricus diminutivus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agaricus silvicola	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6

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Site: AV,b = Abies lasiocarpa/Vaccinium scoparium Bridger Mtns (continued)

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Cortinarius sp. #1	1-0-0	0	0	0	4-0-0	0	1-0-0	4-0-0	4-0-0	1-0-0	0	0	2-0-0	2-0-0	2-0-0	2-0-0	23	63
Cortinarius sp. #2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geastrum sp.	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6
Peziza repanda	0-1-0	0	0-1-0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13
Hygrophorous purpurascens	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	0	0	1	6
Mycena acicula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naucoria vinicolor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stropharia hornemanii	0	0	0	0	0	0	0	0	0	0	0	0	1-0-0	0	0	0	1	6
Tricholoma inamoenum	1-0-0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	0	0	0	2	13
Galerina heterocystis	11-0-0	1-0-0	3-0-0	5-4-0	0	0	0	0	1-0-0	0	6-0-0	0	5-0-0	0	3-0-0	1-0-0	40	56
Xeromphalina cauticinalis	17-0-0	0	0	0	2-0-0	0	2-0-0	1-0-0	0	0	0	0	12-0-0	0	2-0-0	0	36	38
Caloscypha fulgens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0-0-1	0	1	6
Galerina autumnalis	0	0	0	0	0	0-3-0	0	0-6-0	0	0	0	0	0	0	0	0	9	13
Russula emetica complex	0	2-0-0	3-0-0	3-0-0	0	1-0-0	0	2-0-0	0-1-0	0	4-0-0	0	2-0-0	1-0-0	2-0-0	0	21	63
Tricholoma olida	0	1-0-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6
Mycena epipterygia	0	0	0	0	0	0	0	0	0	0	0	0	7-0-0	0	0	0	7	6
Auricularia auricula	0	0	0	0	0	0-3-0	0	0	0	0	0	0	0	0	0	0	3	6
Inocybe lanuginosa	0	0	0	0	6-0-0	1-0-0	1-0-0	0	0	0	0	0	6-0-0	0	1-0-0	0	15	31
Agrocybe cf praecox	0	0	0	0	0	0	0	0-1-1	0	1-0-0	0	0	0	0	0	0	3	13
Inocybe sororia	0	0	1-0-0	0	0	0	0	3-0-0	0	0	0	0	0	0	0	0	4	13
Inocybe pudica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lycoperdon perlatum	1-0-0	1-0-0	0	0	0	0	3-0-0	0	0	0	0	0	0	0	0	0	5	19
Mycena citinomarginata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena elegantula	0	0-2-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0-1-0	3	13

Site: AV,b = Abies lasiocarpa/Vaccinium scoparium Bridger Mtns (continued)

Subplot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	# f.b. total	%freq. 1/16
Species																		
Tricholoma portentosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hygrophorus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Morchella elata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amanita vaginata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cortinarius cf cotoneus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pluteus cervinus	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	0	0	0	1	6
Russula laurocerasi	0	0	0	0	1-0-0	2-0-0	3-0-0	0	0	0	1-0-0	0	0	0	0	0	7	25
Lepiota clypeolaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clitocybe cf deceptiva	2-0-0	1-8-0	0	0	2-0-0	0	0	1-0-0	0	0	0	1-0-0	0	0	0	0	15	31
Russula olivacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycena alcalina	0	0	0	0	4-3-0	0	0	0	0	0	0	0	0-0-3	0	1-0-0	0	11	19
Suillus lakeii	0	0	0	0	0	0	0	1-0-0	0	0	0	0	0	0	0	0	1	6
Mycena pura	0	0	0	0	0	0	0	0	0	0	0	0	2-0-0	0	0	0	2	6

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