A Survey of Macromycete Diversity in Bandelier National Monument, 1991–1993

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Abstract.—This paper reports the progress of an ongoing project to develop an initial inventory of the fungi of the Bandelier area, and describes their relationships with vascular plants and fire ecology. The goal of this ongoing survey has been to collect and identify (at least to genus) as many macroscopic fungi species as possible, and thereby inventory the diversity of such fungi in Bandelier National Monument and adjoining Los Alamos County. The survey covered the three summer seasons of 1991–1993. We collected 836 specimens from a variety of habitats. These were identified as well as possible, recorded in a computer database, dried, and stored, in an herbarium. We found members of 228 species in 118 genera. We were able to identify 95% of the specimens to genus, and 81% to species. In Bandelier alone, we collected 145 specimens in 1991–92 and 270 specimens in 1993, representing at least 74 genera and 93 species. All three basic types of fungi were found: Parasitic, Saprophytic (feeding on dead wood and litter), and Mycorrhizal (in a beneficial symbiosis with a plant). Mycorrhizal fungi compose roughly three fourths of the collection. A variety of sites were studied, with special attention to sites at Bandelier that have burned in recent years, or are planned to be burned soon. The fruitings varied widely (and wildly), making correlation with site location, burns, and other parameters difficult or impossible. The only distinct correlation was with precipitation (and thus elevation). Future needs and possible studies are discussed.

INTRODUCTION

Since the great La Mesa Fire of 1977 in Bandelier much attention has been given to the ensuing course of plant and animal life in that area. Until 1991 however, no studies were conducted on the role of fungi, the third great eukaryotic kingdom of living organisms. This neglect of fungi is common. "Out of sight, out of mind", the fungal vegetative form is most often microscopic and in thin filaments (hyphae), hidden in the soil or in its animal or plant host. Indeed, the study of fungal taxonomy and interrelations with other life forms is perhaps 100 years behind botany and zoology.

Despite our relative ignorance of their affairs, fungi are extraordinarily widespread, diverse, abundant, and ecologically important. Roughly 70,000 species of fungi have been identified out of the one to two million fungal species conservatively estimated to exist (Raven 1994). There are three types of macroscopic fungi (macromycetes): 1) *saprophytic*—consumers of dead, burned, or decaying organic material (these are especially important in breaking down the cellulose and lignin of dead trees); 2) *parasitic*—fungi that feed on living plants, animals or other fungi; and 3) *mycorrhizal*—fungi in mutually beneficial symbiotic relationships with vascular plants, through intimate unions of the fungal hyphae and the feeding rootlets of the vascular plants.

A knowledge of mycorrhizal fungi and their ecological relationships to vascular plants in Bandelier is of special importance in understanding vegeta-

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tion changes since the La Mesa Fire, as mycorrhizal fungi associated with trees and shrubs were the most common type found in this study. The feeding rootlets of most large woody trees are dominated by fungal symbionts (Kendrick 1992), where each rootlet is attached to hundreds or thousands of fungal hyphae. This symbiotic association greatly increases the collection of water and nutrients for uptake by the vascular plant, while in return the fungus receives sugars and other carbohydrates from the tree. The welfare of both the fungi and trees depends upon this obligate relationship, an interdependence which has evolved through the ages. It has been estimated that there are roughly 2500 kg of fungal hyphae per hectare in the soil of a typical forest. The welfare of many species of plants and possibly every vascular plant of Bandelier is intricately bound to an associated fungus, in a beneficial relationship which has co-evolved concurrently with the evolution of the plant species (Kendrick 1992).

No studies of fungi were included in the 1981 Symposium on the La Mesa Fire (Foxx 1984). Given the ecological importance of fungi in forested ecosystems it is essential to begin developing local knowledge about fungi and their ecological roles. This paper reports the progress of an ongoing project to develop an initial inventory of the fungi of the Bandelier area, and describes their relationships with vascular plants and fire ecology.

METHODS

Scope and Range of the Survey

The goal of this ongoing survey has been to collect and identify (at least to genus) as many macroscopic fungi species as possible, and thereby inventory the diversity of such fungi in Bandelier National Monument (BNM) and adjoining portions of Los Alamos County, with special attention paid to Los Alamos National Laboratory (LANL) lands. This survey began in 1991 when Craig Allen of the National Park Service at BNM, in collaboration with Teralene Foxx of the LANL Biological Resource Evaluations Team (LANL Group ESH–20), sponsored this study as part of botanical and zoological surveys of park and Laboratory areas. Most of the inventoried portions of Bandelier are within Los Alamos County, and all of these lands are situated on the Pajarito Plateau on the east flank of the Jemez Mountains in north-central New Mexico.

The request of the sponsors was for a diversity survey—to collect and identify as many different fungi species as possible. Most of the survey (85%) was done in 1992 and 1993. Broad diversity surveys of fungi are not common in the United States (Nishida et al. 1992; Ammirati et al. 1994), and, as is the case with this report, certain taxa are excluded in the survey.

The objects we collected and cataloged were macroscopic "fleshy" fungi (Figure 1)—fungal fruits of the sexual phase (Teleomorphs) visible to the naked eye in the field (but including hypogeous [underground] species). Almost all the specimens collected and cataloged were in the kingdom Eumycota (Fungi). We found several species of "slime molds" now thought to be in the animal kingdom, as well as a common Juniper rust, and included them in the list for interest. Most mycorrhizal and many saprophytic fungi put up visible fruits making them easier to find and identify. A study of the many species of microscopic fungi (smuts, rusts, mildews, yeasts, blights, and soil fungi. etc.) was not attempted due to the difficulties associated with their identification and our lack of resources, although these fungi are extremely important in the ecology and management of vascular plants (e.g., forest trees and agricultural crops).

In Bandelier we placed special emphasis on collecting in areas burned or scheduled to be burned, particularly in the area of the La Mesa fire of 1977. Burned sites sampled within Bandelier (Figure 2) included: near Juniper and Ponderosa campgrounds; around the park headquarters in Frijoles Canyon; portions of the La Mesa Fire on Burnt Mesa and in the Apache Springs area; and the prescribed burn areas around Corral Hill and near the Dome Road junction with State Highway 4. In Los Alamos National Laboratory we focused on areas where ESH–20 has been conducting botanical and zoological surveys.

Fungal fruiting depends heavily on soil warmth, moisture, and atmospheric humidity. These parameters in the Bandelier/Los Alamos area are in turn dependent on altitude. We searched areas at different altitudes and vegetation zones ranging from 1700 to 2900 m (5500 to 9500 ft) altitude (see Figure 2).

Collection Protocol

We established 45 collection locations in Bandelier and Los Alamos County (Figure 2)—Table 1 gives an abridged list of the Bandelier sites. Vegetation sampling transects of the types commonly used for vascular plants do not work well

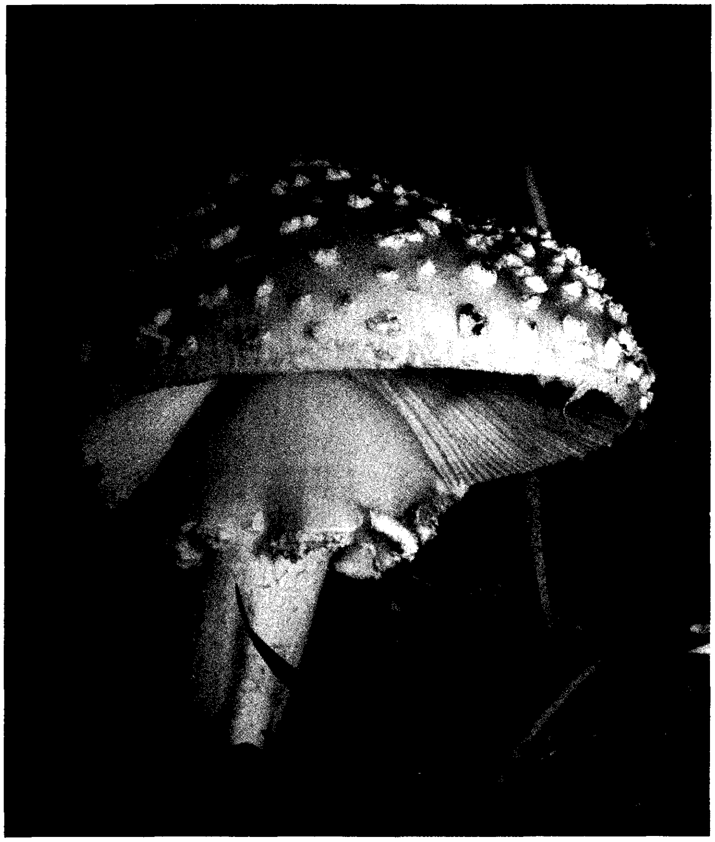

Figure 1.—A mycorrhizal fungi, Amanita muscaria.

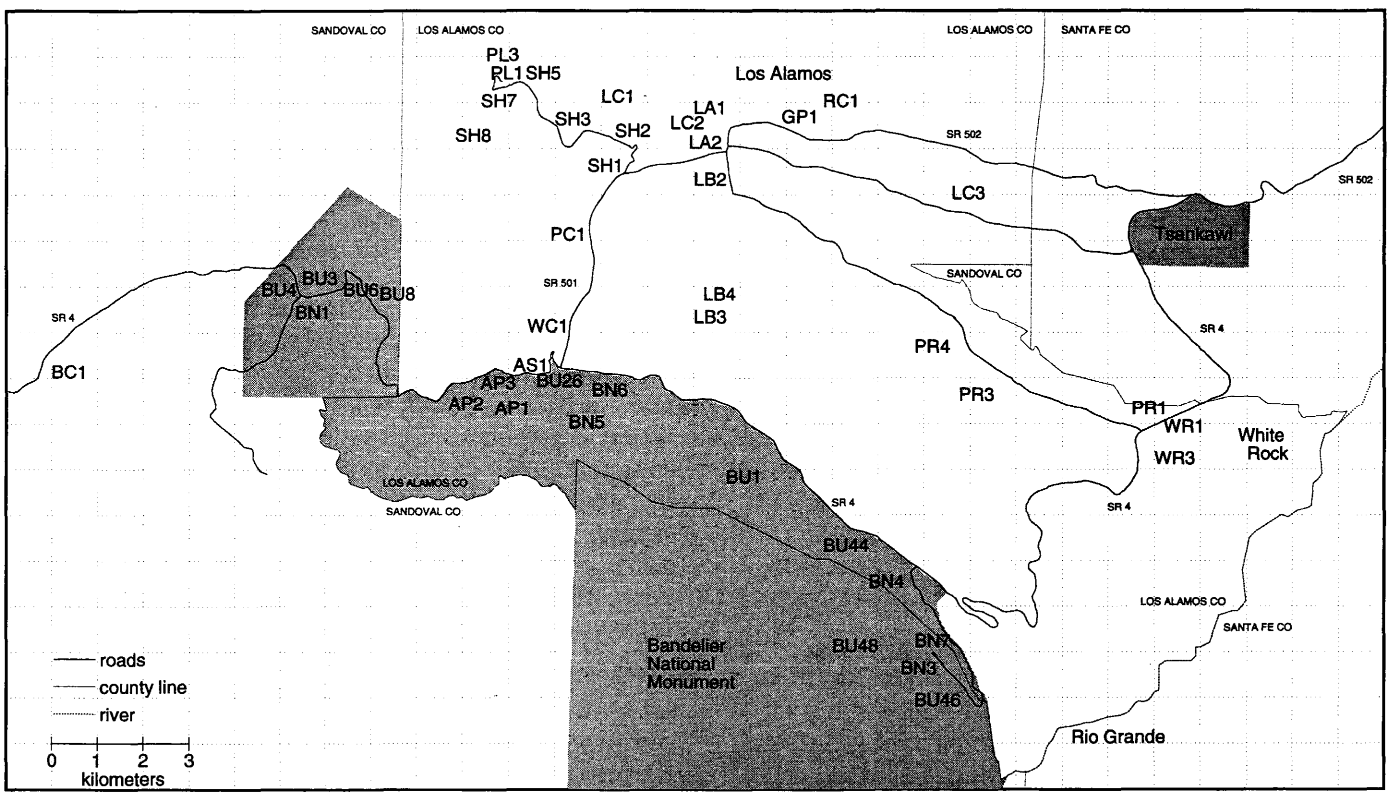

Figure 2.—Location map for collection sites, Bandelier/Los Alamos Fungi Survey. The elevation is lowest along the Rio Grande (lower right) and rises into the mountains at the upper left of the map.

Table 1.—Numbers of taxa of macroscopic fungi found in Bandelier National Monument during the 1993 summer season (No. 1993), compared to the total found in 1991 and 1992 combined (No. 1991/92). The taxa are listed by the area searched. Eight new areas of burn sites were surveyed in 1993. All the new (burn) sites begin with "BU". The "BNM area" codes refer to planned burn units listed in Bandelier's draft Fire Management Plan. Habitat code: MC=Mixed Conifer forest, PP=Ponderosa Pine forest, PJ=Piñon/Juniper woodland, RI=Riparian. NS=Not Surveyed in 91/92.

Site	BNM area	Elevation ft.	Habitat	No. 1991/92	No. 1993	Date last fire yr. or mo./yr.
AP1	UF–23	8444	MC/PP	38	0	not recent
AP2	UF–23	8500	PP	8	0	6/77 in spots
AP3	UF–23	8500	MC	8	3	6/77 in spots
BN1	UF–10	8949	MC	31	1	not recent
BN3	HQ–47	6066	MC/PP/Ri.	11	34	86 & 88 spots
BN6	UH–27	7600	PP	21	30	85 & 77
BU1	UF–35	7200	PP	18	15	6/77
BU3	UF–3	8900	MC	NS	31	10/92 minor
BU4	UF–4	8900	MC	NS	38	87 minor
BU6	UF–6	8900	MC	NS	19	not recent
BU8	UF–8	9100	MC	NS	21	not recent
BU26	UF–26	8150	MC/Ri.	NS	21	93 Spring
BU44	HQ–44	6300	MC/PP/Ri.	NS	22	85 East part
BU46	HQ–46	6000	PP/PJ/Ri.	NS	14	85 in spots
BU48	BW–48	6630	PP/PJ	NS	21	92

Area	Place description
AP1:	Apache Springs itself in a little canyon. BNM area UF–23.
AP2:	Apache Springs, Ponderosa Grove to the NE. BNM area UF–23.
AP3:	Woods near Hwy 4 North of Apache Springs. BNM area UF–23.
BN1:	Bandelier, South of intersection of Dome road and Hwy 4: the North tip of BNM area UF–10.
BN3:	Within 400 m of Bandelier Headquarters, BNM area HQ–47.
BN6:	Bandelier, Ponderosa Campground, "Back Gate" BNM area UF–27.
BU1:	Bandelier, "Burnt Mesa" ESH–8 plots BM1, BM2, BM3 La Mesa Fire UF–35.
BU3:	Northeast of intersection of Dome Road and Hwy 4, evidence of mild burn. Not surveyed in 91/92. BNM area UF–3.
BU4:	West of intersection of Dome Road (FR 289) and Hwy 4, BNM area UF–4. Not surveyed in 91/92.
BU6:	South of Frijoles Cr. headwater. BNM area UF–6. Not surveyed in 91/92.
BU8:	East of BU6. Not surveyed in 91/92. BNM area UF–8.
BU26:	Gully southeast of Hwy 4 and Armstead Spring road). Not surveyed in 91/92. BNM area UF–26.
BU44:	Along Frijoles Cr. 2 mile upstream of Ceremonial Cave). Not surveyed in 91/92. BNM area HQ–44
BU46:	Area at and SE of Rainbow House ruin, BNM area HQ–46. Not surveyed in 91/92.
BU48:	Burn area mesa top, South of HQ, between Lummis and Alamo Canyon, BNM Area BW–48. Not surveyed in 91/92.

for fungi, due to the low density and sporadic appearance of fruiting specimens. We informally scanned each collection locality and its environs several times during the season, but our efforts were particularly concentrated on two sets of areas of special interest: 1) recent or planned burn sites in Bandelier; and 2) sites where ESH–20 was conducting botanical studies on Los Alamos National Laboratory lands. Universal Transverse Mercator (UTM) coordinates were determined for each collection site.

Our original goal was to conduct a fruiting density study as is done with vascular plants, using a dedicated plot of ground, with live and dead trees. However, it soon became clear that a "Fickle Fungi Fruiting Factor" exists which results in erratic fruiting of fungi year by year. Given the limits of available personnel and resources, a meaningful density study proved impossible. In addition, contrary to most plants, the vegetative body of fungi is almost always hidden in the soil or inside living or dead wood. Furthermore, most of the fruits perish rapidly, generally within a few days. The result is that our survey is essentially a "presence log" which simply says: "Yes, this species does exist in this habitat in this location at this time" and includes a subjective statement that it is abundant, common, uncommon, or rare.

We kept field notes, took photographs when possible, and, after identification, dried and preserved many specimens for storage in our fungal herbarium. Several genus specialists have asked for herbarium specimens. Mycologists have visited with us at Bandelier, and others have been available to us at major statewide or national forays to help with identifications. The primary effort was to identify specimens to genus, because many of the ecological factors (e.g. mycorrhizae) are common to the genus, or even family.

We entered our findings into a relational database (FoxBASE+/Mac) on a personal computer. Each entry record has 34 fields of information and a "memo" field that accepts additional comments. The detailed database will be available as part of a final report (Jarmie and Rogers, in preparation). Each specimen is given an accession number which uniquely identifies its database entry, herbarium position, field notes, etc.

RESULTS

A total of 836 specimens were collected, representing 228 species in 118 genera. Of the total, 96% of the specimens are in the Classes Hymenomycetes and Gastromycetes of the subdivision Basidiomycotina, with the remaining 4% in Orders of the Ascomycotina, an expected proportion. We were able to identify 95% of the specimens to genus, 81% to species. Of the total, we called 51 species "uncommon" and 2 "rare"; use of these adjectives is heavily biased by the observers rapidly developing state of knowledge and level of field experience. More uncommon or rare species may come out of future identifications among the unknown 19% of specimens. We found 34 species new to New Mexico, based upon the state master list of fungi taxa, kept for the New Mexico Mycological Society by R. Bronson. In Bandelier alone we collected 145 specimens in 1991–92 and 270 specimens in 1993. Of these 415 specimens, we identified 94 genera and 137 species. In 1993 alone we identified 74 genera and 93 species.

Table 1 provides a summary of the 1991–1993 fungi collections in Bandelier. Comparison of the sum of specimens collected in 1991–1992 with the 1993 collections demonstrates the erratic nature of fungal fruitings through time. The identification percentages for Bandelier are similar to those given above. Table 2 lists the taxa collected in 1993 at *one* site (the Bandelier headquarters area) to give an indication of the variety of species present at a locality.

Table 3 presents the species list of all specimens found in Bandelier and Los Alamos County, extracted from our Fungus Registry Database (Jarmie and Rogers, in preparation). The full database includes numerous additional fields, such as location, date collected, habitat, elevation, abundance, reliability of identification, identification reference, and whether a herbarium voucher sample exists.

Table 2.—The entire list of taxa collected at the Bandelier Headquarters area (BN3), a typical site, in 1993. The number # before the date is the collection/herbarium accession number.

#	Date	Genus species	Area found
436	8/9/93	Agaricales sp.	BN3
442	8/9	Agaricus campestris	BN3
923	9/17	Agaricus sp.	BN3
858	9/10	Agaricus sp.	BN3
433	8/9	Amanita pantherina	BN3
910	9/17	Amanita vaginata	BN3
911	9/17	Armillaria mellea	BN3
914	9/17	Armillaria mellea grp.	BN3
919	9/17	Armillaria tabescens	BN3
862	9/10	Chroogomphus vinicolor	BN3
864	9/10	Clavariadelphus lovejoyae	BN3
912	9/17	Clavariadelphus truncatus	BN3
915	9/17	Cortinarius sp.	BN3
435	8/9	Cortinarius sp.	BN3
865	9/10	Cortinarius sp.	BN3
443	8/9	Crepidotus applanatus	BN3
861	9/10	Hebeloma sinapizans	BN3
913	9/17	Helvella crispa	BN3
449	8/9	Inocybe albodisca	BN3
859	9/10	Lactarius deliciosus	BN3
837	9/7	Lycoperdon echinatum	BN3
451	8/9	Lycoperdon pyriforme	BN3
434	8/9	Phaeolus schweinitzii	BN3
818	9/7	Phallus impudicus	BN3
821	9/7	Pholiota destruens	BN3
860	9/10	Phyllotopsis nidulans	BN3
440	8/9	Pluteus cervinus	BN3
437	8/9	Polyporus arcularius	BN3
441	8/9	Pycnoporus cinnabarinus	BN3
856	9/10	Russula brevipes	BN3
857	9/10	Stereum complicatum	BN3
863	9/10	Stereum striatum	BN3
439	8/9	Suillus granulatus	BN3
438	8/9	Suillus granulatus grp.	BN3

Collections in burn areas sparked an ongoing interest in the taxonomic Class Discomycetes (of subdivision Ascomycotina) whose small members appeared to have a greater density in burned areas; more evident, probably, because of the lack of the usual large mycorrhizal fungi. Typical genera found were Gyromitra, Cudonia, Coriolellus, Scutellinia, Spathularia, Helvella, and Peziza. Again, the erratic fruiting makes correlation difficult. We plan statistical correlation studies in the future with the complete database.

We often felt an aesthetic pleasure, a joy, from walking in the woods and discovering fungi new to us. The AP1 site at Apache Springs in Bandelier was a fungi showcase in 1992. In this moist narrow cleft, surrounded by expanses of drier ponderosa

Table 3.—Species list of fungi collected at Bandelier National Monument and Los Alamos County, 1991-1993. A "T" in the column "bndlr" indicates that a specimen was found within Bandelier, while a "F" denotes a sample collected elsewhere in Los Alamos County. "Year" describes the year of collection, and "ncode" is our accession and herbarium number.

Genus	Species	Family	Order	Bndler	Year	Ncode
Agaricus	bitorquis	Agaricaceae	Agaricales	F	1991	159
Agaricus	campestris	Agaricaceae	Agaricales	T	1993	442
Agaricus	haemorrhoidarius	Agaricaceae	Agaricales	F	1991	160
Agaricus	pinyonensis	Agaricaceae	Agaricales	F	1993	689
Agaricus	silvicola	Agaricaceae	Agaricales	F	1991	111
Agaricus	xanthodermus	Agaricaceae	Agaricales	F	1991	139
Agrocybe	praecox	Bolbitiaceae	Agaricales	T	1991	166
Amanita	bisporigera	Amanitaceae	Agaricales	T	1991	165
Amanita	caesarea	Amanitaceae	Agaricales	T	1993	455
Amanita	constricta	Amanitaceae	Agaricales	T	1993	824
Amanita	fulva	Amanitaceae	Agaricales	T	1993	417
Amanita	magniverrucata cf.	Amanitaceae	Agaricales	F	1993	930
Amanita	muscaria v. muscar.	Amanitaceae	Agaricales	T	1991	119
Amanita	pantherina	Amanitaceae	Agaricales	T	1993	433
Amanita	vaginata cf	Amanitaceae	Agaricales	T	1993	632
Arcyria	denudata	Trichiaceae	Trichiales	F	1993	933
Armillaria	albolanaripes	Tricholomataceae	Agaricales	F	1993	642
Armillaria	mellea cf.	Tricholomataceae	Agaricales	T	1993	561
Armillaria	straminia cf	Tricholomataceae	Agaricales	F	1993	478
Armillaria	tabescens cf.	Tricholomataceae	Agaricales	T	1993	919
Astraeus	hygrometricus	Astraeaceae	Sclerodermatales	T	1992	344
Auricularia	auricula	Auriculariaceae	Auriculariales	T	1991	134
Auriscalpium	vulgare	Hydnaceae	Aphyllophorales	T	1992	202
Battarrea	phalloides	Tulostomataceae	Tulostomatales	F	1991	140
Bisporella	citrina	Leotiaceae	Helotiales	T	1992	388
Bjerkandera	adusta	Polyporaceae	Aphyllophorales	T	1993	763
Boletus	barrowsii	Boletaceae	Agaricales	T	1993	807
Boletus	calopus	Boletaceae	Agaricales	F	1993	518
Boletus	chrysenteron cf.	Boletaceae	Agaricales	T	1993	740
Boletus	edulis	Boletaceae	Agaricales	T	1991	118
Boletus	haematinus	Boletaceae	Agaricales	F	1993	651
Boletus	rubripes	Boletaceae	Agaricales	T	1993	771
Caloporus	dichrous	Polyporaceae	Aphyllophorales	T	1992	386
Calvatia	gigantea	Lycoperdaceae	Lycoperdales	F	1991	106
Cantharellus	cibarus	Cantharellaceae	Aphyllophorales	T	1991	164
Catathelasma	ventricosa	Tricholomataceae	Agaricales	F	1993	900
Ceratiomyxa	fruticulosa	Ceratiomyxaceae	Ceratiomyxales	T	1992	206
Cheimonophyllum	candidissimus	Tricholomataceae	Agaricales	F	1993	409
Chlorociboria	aeruginascens	Dermatiaceae	Helotiales	T	1992	236
Chlorophyllum	molybdites	Lepiotaceae	Agaricales	F	1991	137
Chroogomphus	tomentosus	Gomphidiaceae	Agaricales	F	1993	582
Chroogomphus	vinicolor	Gomphidiaceae	Agaricales	T	1993	862
Clavariadelphus	lovejoyae	Clavariaceae	Aphyllophorales	T	1993	864
Clavariadelphus	pistillaris	Clavariaceae	Aphyllophorales	F	1993	580
Clavariadelphus	truncatus	Clavariaceae	Aphyllophorales	F	1991	110
Clavicorona	pyxidata	Clavariaceae	Aphyllophorales	T	1992	232
Clavulina	cristata	Clavariaceae	Aphyllophorales	T	1992	226
Clavulina	rugosa	Clavariaceae	Aphyllophorales	F	1991	152
Clavulinopsis	corniculata	Clavariaceae	Aphyllophorales	T	1992	214
Clitocybe	dealbata	Tricholomataceae	Agaricales	T	1992	306
Clitocybe	dilatata	Tricholomataceae	Agaricales	T	1993	532
Clitocybe	gibba	Tricholomataceae	Agaricales	T	1992	308
Clitocybe	gigantea cf.	Tricholomataceae	Agaricales	T	1993	744
Collybia	dryophila	Tricholomataceae	Agaricales	T	1992	230
Coltricia	perennis	Polyporaceae	Aphyllophorales	T	1992	868
Coniophora	puteana	Coniophoraceae	Aphyllophorales	T	1992	373
Conocybe	lactea cf.	Bolbitiaceae	Agaricales	F	1993	428
Coprinus	atramentarius	Coprinaceae	Agaricales	T	1993	722

continued

Table 3 (continued).—Species list of fungi collected at Bandelier National Monument and Los Alamos County, 1991-1993. A "T" in the column "bndlr" indicates that a specimen was found within Bandelier, while a "F" denotes a sample collected elsewhere in Los Alamos County. "Year" describes the year of collection, and "ncode" is our accession and herbarium number.

Genus	Species	Family	Order	Bndler	Year	Ncode
Coprinus	comatus	Coprinaceae	Agaricales	F	1991	163
Coprinus	lagopus cf.	Coprinaceae	Agaricales	T	1993	697
Coprinus	micaceus	Coprinaceae	Agaricales	T	1992	207
Coriolellus	carbonarius	Polyporaceae	Aphyllophorales	T	1992	213
Coriolopsis	gallica	Polyporaceae	Aphyllophorales	T	1993	822
Cortinarius	alboviolaceus cf.	Cortinariaceae	Agaricales	F	1993	654
Cortinarius	anomalus	Cortinariaceae	Agaricales	T	1993	737
Cortinarius	calochrous	Cortinariaceae	Agaricales	T	1993	540
Cortinarius	glaucopus	Cortinariaceae	Agaricales	F	1991	112
Crepidotus	applanatuscf.	Crepidotaceae	Agaricales	T	1993	443
Crepidotus	herbarum	Crepidotaceae	Agaricales	F	1992	256
Crepidotus	mollis	Crepidotaceae	Agaricales	T	1992	225
Crucibulum	laeve	Nidulariaceae	Aphyllophorales	T	1993	531
Cudonia	circinans	Leotiaceae	Helotiales	T	1992	393
Cyathus	striatus	Nidulariaceae	Aphyllophorales	T	1992	170
Cyptotrama	chrysopeplum	Tricholomataceae	Agaricales	T	1992	371
Cystoderma	amianthinum	Tricholomataceae	Agaricales	T	1992	350
Cystoderma	granulosum	Tricholomataceae	Agaricales	T	1993	828
Dacrymyces	palmatus	Polyporaceae	Aphyllophorales	F	1993	931
Flammulina	velutipes	Tricholomataceae	Agaricales	T	1992	211
Fomitopsis	canjanderi	Polyporaceae	Aphyllophorales	F	1992	341
Fomitopsis	pinicola	Polyporaceae	Aphyllophorales	T	1992	394
Fuligo	septica	Physaraceae	Physarales	T	1993	808
Galerina	autumnalis	Cortinariaceae	Agaricales	T	1992	303
Gamoderma	applanatum	Polyporaceae	Aphyllophorales	T	1992	194
Gautieria	mexicana	Gautieriaceae	Gautieriales	F	1993	934
Geastrum	coronatum	Geastraceae	Lycoperdales	F	1993	686
Geastrum	saccatum	Geastraceae	Lycoperdales	F	1991	156
Geastrum	triplex	Geastraceae	Lycoperdales	T	1992	227
Globifomes	graveolens cf.	Polyporaceae	Aphyllophorales	F	1993	411
Gloeophyllum	sepiarium	Polyporaceae	Aphyllophorales	T	1992	212
Gomphidius	glutinosus	Gomphidiaceae	Agaricales	T	1993	309
Gomphidius	oregonensis	Gomphidiaceae	Agaricales	T	1992	203
Gomphus	bonari	Cantharellaceae	Aphyllophorales	T	1992	316
Gomphus	floccosus	Cantharellaceae	Aphyllophorales	T	1992	229
Guepiniopsis	alpinus	Dacrymycetaceae	Dacrymycetales	F	1992	172
Gymnopolis	sapineus	Cortinariaceae	Agaricales	T	1993	817
Gymnosporangium	speciosus	Puccinianceae	Uredinales	T	1992	181
Gyromitra	infula	Helvellaceae	Pezizales	T	1992	221
Hebeloma	crustiliniforme	Cortinariaceae	Agaricales	T	1993	778
Hebeloma	sinapizans cf.	Cortinariaceae	Agaricales	T	1993	784
Helvella	acetabulum	Helvellaceae	Pezizales	F	1991	146
Helvella	crispa	Helvellaceae	Pezizales	F	1991	161
Helvella	elastica	Helvellaceae	Pezizales	F	1992	247
Helvella	lacunosa	Helvellaceae	Pezizales	F	1991	149
Hemitrichia	clavata cf	Trichiaceae	Trichiales	F	1993	603
Hericium	abeitis	Hydnaceae	Aphyllophorales	T	1993	769
Hohenbuehelia	petaloides cf.	Tricholomataceae	Agaricales	F	1993	670
Humaria	hemispherica	Pyronemataceae	Pezizales	T	1992	231
Hygrophoropsis	aurantiaca	Paxillaceae	Agaricales	F	1992	283
Hygrophorus	acutoconica	Hygrophoraceae	Agaricales	T	1993	831
Hygrophorus	chrysodon	Hygrophoraceae	Agaricales	T	1993	698
Hygrophorus	conicus	Hygrophoraceae	Agaricales	T	1992	175
Hygrophorus	marginatus	Hygrophoraceae	Agaricales	T	1993	713
Hygrophorus	pudorinus	Hygrophoraceae	Agaricales	T	1992	235
Hygrophorus	speciosus	Hygrophoraceae	Agaricales	T	1992	354
Hypomyces	chrysospermum	Hypocreaceae	Sphaeriales	T	1993	853
Hypomyces	hyalinus	Hypocreaceae	Sphaeriales	T	1993	704

continued

Table 3.—(continued) Species list of fungi collected at Bandelier National Monument and Los Alamos County, 1991-1993. A "T" in the column "bndlr" indicates that a specimen was found within Bandelier, while a "F" denotes a sample collected elsewhere in Los Alamos County. "Year" describes the year of collection, and "ncode" is our accession and herbarium number.

Genus	Species	Family	Order	Bndler	Year	Ncode
Hypomyces	lactifluorum	Hypocreaceae	Sphaeriales	T	1991	101
Inocybe	albodisca cf.	Cortinariaceae	Agaricales	T	1993	449
Inocybe	fastigiata	Cortinariaceae	Agaricales	F	1993	429
Inocybe	lanuginosa	Cortinariaceae	Agaricales	T	1992	305
Inocybe	maculata cf.	Cortinariaceae	Agaricales	F	1993	448
Inocybe	sororia	Cortinariaceae	Agaricales	T	1993	774
Laccaria	amethystina cf.	Tricholomataceae	Agaricales	T	1993	773
Laccaria	laccata	Tricholomataceae	Agaricales	T	1992	310
Lactarius	deliciosus	Russulaceae	Agaricales	T	1992	346
Lactarius	olivaceoumbrinus	Russulaceae	Agaricales	F	1993	669
Lactarius	rubrilacteus	Russulaceae	Agaricales	T	1993	352
Lactarius	torminosus	Russulaceae	Agaricales	T	1993	634
Lactarius	uvidus	Russulaceae	Agaricales	T	1992	302
Leccinum	aurantiacum	Boletaceae	Agaricales	T	1992	311
Leccinum	insigne	Boletaceae	Agaricales	F	1991	122
Lentinellus	omphalodes cf.	Tricholomataceae	Agaricales	T	1993	781
Lentinellus	ursinus cf.	Tricholomataceae	Agaricales	F	1993	630
Lentinus	ponderosus	Tricholomataceae	Agaricales	F	1992	188
Lenzites	betulina	Polyporaceae	Aphyllophorales	T	1992	369
Lepiota	clypeolaria	Lepiotaceae	Agaricales	F	1993	523
Lepiota	cristata	Lepiotaceae	Agaricales	F	1993	524
Lepiota	rhacodes	Lepiotaceae	Agaricales	F	1993	615
Leucopaxillus	amarus	Tricholomataceae	Agaricales	T	1992	299
Leucophleps	spinispora	Leucogastraceae	Leucogastrales	F	1993	937
Lycogala	epidendrum	Reticulariaceae	Liceales	T	1992	208
Lycogala	flavofuscum	Reticulariaceae	Liceales	T	1992	191
Lycoperdon	americanum	Lycoperdaceae	Lycoperdales	T	1992	297
Lycoperdon	echinatum	Lycoperdaceae	Lycoperdales	T	1993	837
Lycoperdon	perlatum	Lycoperdaceae	Lycoperdales	T	1992	224
Lycoperdon	pyriforme	Lycoperdaceae	Lycoperdales	T	1992	304
Marasmius	reades	Tricholomataceae	Agaricales	F	1991	132
Melanoleuca	sp.	Tricholomataceae	Agaricales	T	1992	367
Morchella	augusticeps	Morchellaceae	Pezizales	F	1992	176
Morchella	elata	Morchellaceae	Pezizales	F	1992	177
Morchella	esculenta	Orchellaceae	Pezizales	F	1992	171
Mycena	haemotopus	Tricholomataceae	Agaricales	F	1993	602
Nidula	candida	Nidulariaceae	Nidulariales	T	1991	133
Panaeolus	foenisecii	Coprinaceae	Agaricales	F	1992	183
Panaeolus	retiruges	Coprinaceae	Agaricales	T	1992	218
Peniophora	gigantea	Corticiaceae	Aphyllophorales	T	1992	351
Peniophora	rufa cf.	Corticiaceae	Aphyllophorales	F	1993	470
Peziza	repanda	Pezizaceae	Pezizales	T	1993	777
Peziza	succosa	Pezizaceae	Pezizales	T	1992	317
Phaeolus	schweinitzii	Polyporaceae	Aphyllophorales	T	1993	434
Phallus	impudicus	Phallaceae	Phallales	T	1993	818
Pholiota	aurivella cf.	Strophariaceae	Agaricales	T	1993	764
Pholiota	destruens	Strophariaceae	Agaricales	T	1992	383
Pholiota	limonella cf.	Strophariaceae	Agaricales	T	1993	559
Pholiota	squarrosa	Strophariaceae	Agaricales	F	1991	155
Phylloporus	rhodoxanthus	Paxillaceae	Agaricales	F	1991	144
Phyllotopsis	nidulans	Tricholomataceae	Agaricales	T	1992	307
Pleurotus	ostreatus	Tricholomataceae	Agaricales	T	1991	136
Pleurotus	sapidus	Tricholomataceae	Agaricales	T	1992	234
Pluteus	cervinus	Pluteaceae	Agaricales	T	1992	204
Pluteus	cervinus v.alba	Pluteaceae	Agaricales	F	1992	291
Polyporus	arcularius	Polyporaceae	Aphyllophorales	T	1992	372
Polyporus	badius cf.	Polyporaceae	Aphyllophorales	F	1993	407
Polyporus	elegans	Polyporaceae	Aphyllophorales	F	1992	360

continued

Table 3.—(continued) Species list of fungi collected at Bandelier National Monument and Los Alamos County, 1991-1993. A "T" in the column "bndlr" indicates that a specimen was found within Bandelier, while a "F" denotes a sample collected elsewhere in Los Alamos County. "Year" describes the year of collection, and "ncode" is our accession and herbarium number.

Genus	Species	Family	Order	Bndler	Year	Ncode
Polyporus	varius	Polyporaceae	Aphyllophorales	F	1993	639
Poria	corticola cf.	Polyporaceae	Aphyllophorales	F	1993	444
Poria	spissa	Polyporaceae	Aphyllophorales	T	1993	878
Psathyrella	velutina	Coprinaceae	Agaricales	T	1993	546
Pycnoporellus	alboluteus	Polyporaceae	Aphyllophorales	F	1992	174
Pycnoporus	cinnabarinus	Polyporaceae	Aphyllophorales	T	1992	335
Ramaria	vinosimaculaus	Clavariaceae	Aphyllophorales	F	1993	652
Rhizopogon	subsalmonius	Rhizopogonaceae	Hymenogastrales	T	1993	936
Russula	aeruginea	Russulaceae	Agaricales	F	1993	653
Russula	brevipes	Russulaceae	Agaricales	T	1991	117
Russula	emetica cf.	Russulaceae	Agaricales	T	1993	534
Russula	maculata cf.	Russulaceae	Agaricales	T	1993	701
Russula	rosacea cf.	Russulaceae	Agaricales	T	1993	554
Sarcoscypha	coccinea	Sarcoscyphaceae	Pezizales	F	1992	401
Scutellinia	erinaceus cf	Pyronemataceae	Pezizales	F	1993	685
Scutellinia	scutellata	Pyronemataceae	Pezizales	T	1992	205
Sparassis	crispa	Clavariaceae	Aphyllophorales	F	1993	568
Sparassis	radicata	Clavariaceae	Aphyllophorales	F	1993	462
Spathularia	flavida	Geoglossaceae	Helotiales	T	1992	301
Spongipellus	pachyodon	Polyporaceae	Aphyllophorales	F	1993	426
Steccherinum	ochraceum	Hydnaceae	Aphyllophorales	T	1991	135
Stereum	complicatum	Stereaceae	Aphyllophorales	T	1993	857
Stereum	hirsutum grp.	Stereaceae	Aphyllophorales	F	1992	382
Stereum	striatum	Stereaceae	Aphyllophorales	T	1993	863
Stropharia	coronilla	Strophariaceae	Agaricales	T	1992	216
Suillus	granulatus	Boletaceae	Agaricales	T	1992	362
Suillus	lakei	Boletaceae	Agaricales	T	1993	553
Suillus	sibiricus	Boletaceae	Agaricales	F	1993	514
Thelephora	terrestris cf.	Thelophoraceae	Aphyllophorales	T	1993	794
Trichaptum	abietinum	Polyporaceae	Aphyllophorales	T	1992	399
Tricholoma	sp.	Tricholomataceae	Agaricales	T	1992	389
Tricholomopsis	platyphylla	Tricholomataceae	Agaricales	F	1992	267
Truncocolumella	citrina	Rhizopogonaceae	Hymenogastrales	F	1991	143
Tubifera	sp.	Reticulariaceae	Liceales	F	1993	466
Tulostoma	brumale cf.	Tulostomataceae	Tulostomatales	F	1993	687
Tulostoma	simulans	Tulostomataceae	Tulostomatales	T	1993	829
Tyromyces	guttulatus	Polyporaceae	Aphyllophorales	F	1992	190
Volvariella	bombycina	Pluteaceae	Agaricales	T	1993	841
Xeromphalina	campanella	Tricholomataceae	Agaricales	T	1992	219
Xerula	americana	Tricholomataceae	Agaricales	T	1992	258

pine/mixed conifer forest, is a small riparian habitat which provided for a profuse fairyland of mushrooms. There were troops of tiny orange *Xeromphalina campanella* on fallen logs, guarded by flanks of the purpled-pored cups of *Humaria hemisphaerica*, and orange corals (*Clavicorona pyxidata*) amidst red "eye-lash" cups (*Scutellinia scutellata*). We collected 38 species in all from that single site in August/September 1992.

CONCLUSIONS

The main conclusion of our survey is that a broad diversity of macroscopic fungi exist locally. The contents of our complete database (Jarmie and Rogers—in preparation) provides additional details on this diversity. We collected 836 fruiting bodies belonging to 228 species, 118 genera, 39 families, 12 orders, 5 classes, 2 subdivisions, and 1 division of the kingdom Eumycota (Fungi). The "Fickle Fungi Fruiting Factor" certainly operates in the Jemez Mountains. For example, while only 11 taxa were collected at site BN3 in 1991 and 1992 combined, 34 were found there in 1993 (Table 1, 2); in contrast, at Apache Springs (AP1) this pattern was reversed, with many more species collected in 1991/92 than in 1993 (Table 1). A fruiting of a given species may happen erratically, with a 10 to 15 year barren interval possible between fruitings (Burdsall 1992). These fluctuations are not well understood. At the least, they are a complex function of rains and rain history, humidity, soil and air contamination, nutrients, length of day, temperature, competition (for nitrogen and other nutrients) with other organisms, and the health of symbiont partner (if there is one). With such variable factors involved we found it difficult to correlate local fruiting patterns with environmental conditions—the only distinct correlation was with precipitation and moist soil conditions.

Thus in general, more fungi and more taxa were seen at the higher, moister elevations, especially in mixed conifer habitats. However, we also observed heavy, intermittent fruiting in typically barren piñon-juniper habitats at lower elevation sites, but usually not until extended rainfall created moist soil conditions for a week or two. Some species, especially in the genera *Agaricus* and *Amanita*, seem to favor piñon-juniper habitats. (Klopatek et al. 1987, 1988). Attempts to make meaningful correlations were again frustrating. For example, 29 specimens were collected from piñon-juniper habitats, but 15 of the specimens could not be reliably identified to species. One identified specimen, *Agaricus pinyonensis*, is known only to occur with piñon-juniper in New Mexico. We also identified *Amanita constricta* that we saw only in the piñon-juniper habitat, yet this species is found mostly under oak or other hardwoods in California (Jenkins 1986).

Apparent symbiotic relationships between trees and fungi were consistently observed. Intensely burned areas where the trees did not survive the 1977 La Mesa Fire lacked the fruits of mycorrhizal fungi. For example, site BN6 (Figure 2), a ponderosa pine grove near "Backgate" (Table 1), produced expected mycorrhizal genera (*Amanita, Russula, Lactarius*), whereas the nearby site BU1, burned clear of ponderosa pine trees in the La Mesa Fire, displayed none of these genera, or others known to be mycorrhizal.

Fungi species unique to burned habitats, for example *Coriolellus carbonarius*, were found in recently burned areas. There also seemed to be a higher than normal fruiting density of fungi in the class Discomycetes at recently burned sites.

Information gained from an ongoing literature search and from contact with fungi experts seemed at times as important as the survey itself. For example:

1. An obligate mycorrhizal relationship with plants is very common; over 90% of higher plants have fungal symbionts. Major boreal tree families, such as Pinaceae, are thought to be 100% mycorrhizal (Kendrick 1992). This relationship is an important parameter in forest fires (Dhillion et al. 1987, Pilz and Perry 1983). Mycorrhizal relationships apparently help maintain vascular plant diversity (Grime et al. 1987).

2. A variety of studies provide glimpses of the ecological complexity of fungal activity in soils after fires. For example, an increase in soil temperature results in a *decrease* in the density of higher fungi, but with an associated *increase* in bacteria and actinomycetes (Wright and Tarrant 1957). It is apparent that complete studies which include all forms of fungi, bacteria, and other life forms, are necessary to fully understand the ecological interactions of fire and fungi (Moffat 1993, Rose and Hutchins 1988, Wicklow-Howard 1989, Harvey et al. 1976). Local diversity inventories such as the present effort will support more sophisticated fungi-fire research.

3. Tree seedlings used in reforestation must be inoculated with a mycorrhizal partner for survival past one year (Trappe 1977), and there is a succession through time of different symbiotic fungal partners as the trees mature (Visser and Danielson 1990, States 1993).

4. There are subtle factors involved in the ecology of fungi in post-fire environments. For example, in reforestation efforts, attention should paid to fungal health after inoculation of seedlings; parameters like soil moisture and temperature, and thus time of year and the amount of shade in the area, affect fungal and tree health, with implications for the use of clear-cutting and other forest management techniques (States 1993). Soil nitrogen depletion after fire is an important factor for fungi growth and mycorrhizae (Freeman 1984, see also A.P. Kinzig, and R.H. Socolow 1994).

5. Interesting ecological cycles involving fungi exist, including many that are poorly known. For example, there is a strong relation between ponderosa pine trees, truffles (mycorrhizal Gastromycetes or Discomycetes that are hypogeous—occur underground), and Abert squirrels (Sciurus aberti). These truffles exude aromas to attract the squirrels, who dig up and eat these fungi, thereby spreading the spores through their feces, especially to ponderosa pine seedlings which need to be inoculated with these mycorrhizal fungi (Trappe 1977; States et al. 1988). This coevolutionary relationship likely developed over a long time. Near Bandelier headquarters in 1993 an Abert

squirrel noisily scolded us for digging up its truffle dinner from the ponderosa pine needle duff in which it had previously been foraging.

6. In Europe, mycologists have made major fungi diversity surveys for many years, far ahead of American studies, and have charted the changes of fruiting boundaries of various species through time. Detrimental changes in the environment, such as acidic rain, have been correlated with major retreats in the geographic distributions of both fungal species and associated forest plants (Arnolds 1992). Which symbiont partner dies first?

7. In Washington State it has been suggested that there is more commercial value in a possible mushroom harvest than from timber harvests (Molina 1993), a remarkable statement given that this is one of the most productive forestry areas in the world.

Future Possibilities and Considerations

Clearly, more intensive and extensive literature searches would be very productive, as much information on ecological interactions between fungi and fire may already be available in the literature, especially from Forest Service or National Park Service sources.

More focused fungi surveys are needed to use the present resources more efficiently. For example, a few permanently marked plots, 100 to 200 m in diameter, could be set up in key areas and surveyed with higher frequency, in contrast to the current effort to conduct a total diversity study of this whole landscape. Such fungal plot studies could be also be more closely coordinated with other biological surveys.

The fungi database we have developed could be used to decipher additional correlations between local fungal distributions and environmental conditions, such as the associations between intense La Mesa Fire burn sites and certain fungi noted above. For example, it would be useful to compare detailed climatic data (e.g., rainfall patterns) with our fungal fruiting data.

Soil and wood cores could be taken to identify the hyphal vegetative states of fungi using DNA sequence analysis. These new techniques can also help identify single or few celled fungi and bacteria, which are surely very important components of local soil ecosystems. However, such methods are beyond the scope of our current work. To achieve significant additional advances in our knowledge of local fungi diversity and ecology will require increases in funding and personnel devoted to such work.

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