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Distribution and Diversity of Fungal Species in and Adjacent to the Los Alamos National Laboratory

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by

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Abstract

Previously archived information representing 43 sample locations was used to perform a preliminary evaluation of the distributions and diversity of fungal species at the Los Alamos National Laboratory and in adjacent environments. Presence-absence data for 71 species of fungi in five habitats, piñon-juniper, canyon-bottom ponderosa pine, ponderosa pine, canyon-bottom mixed conifer, and mixed conifer were analyzed. The results indicate that even though fungi occur in each of the habitats, fungal species are not distributed evenly among these habitats. The richness of fungal species is greater in the canyon-bottom mixed conifer and mixed conifer habitats than in the piñon-juniper, canyon-bottom ponderosa pine or ponderosa pine habitats. All but three of the fungal species were recorded in either the canyon-bottom mixed conifer or the mixed conifer habitats, and all but seven of the fungal species were found in the mixed conifer habitat. In addition, species fidelity increases from the piñon-juniper to the mixed conifer. Five of the species have a high fidelity to the mixed conifer, and 13 species have a high fidelity to the either the canyon-bottom mixed conifer or the mixed conifer habitats. In contrast, only eight fungal species were found in the piñon-juniper habitat, and none of these were found with high fidelity or in high abundance. Finally, only two species of fungi were collected in all five of the habitats.

Introduction

Diversity is a measure of the number of species and their relative abundance in communities (Lincoln et al. 1982). Although diversity is easy to comprehend and conceptualize, it is difficult to quantify and analyze in a meaningful way (Harper 1977, Magurran 1988, McIntosh 1985). Despite this elusiveness, diversity has remained one of the central themes of ecology. This is evident from the following definition offered by Krebs (1994); "Ecology is the scientific study of the interactions that determine the distribution and abundance of organisms." According to the definition, the elements of diversity are integral components of all subdisciplines that constitute the science of ecology.

Southwood (1987) contends that the most fundamental description of the nature of a biological community is provided by a measure of its diversity. Ecological communities do not all contain the same numbers of species, and one of the basic questions of ecology is why do some communities support more species than other communities (Whittaker 1975, Krebs 1994). Although these relationships may appear to be of academic interest only, diversity is also important to the applied sciences. For instance, in addition to being useful for describing the natural world, diversity is also important for evaluating the wellbeing of ecosystems (Magurran 1988). In particular, diversity is an important component to investigations and developments in biogeochemistry and nutrient cycling, keystone species and functional groups of species, vegetational succession and habitat modification, and policy decisions (Schulze and Mooney 1994).

Fungi are important components of ecosystems (Harper 1977, Pegg and Ayres 1987, Isaac 1992, Murphy 1996). They cooperate in mycorrhizae (Allan 1991), act as disease organisms that can alter community structure (Burdon 1982, 1987, Agrios 1988, Balice 1990), and recycle nutrients through decomposition (Barbour et al. 1987). Because of their importance to ecosystem functions and to the health of ecosystems, it is desirable to learn more about the distributions and diversity of fungi.

The results of a recent survey of macroscopic fungi at the Los Alamos National Laboratory (LANL) and in its surrounding environments provided an opportunity to evaluate the regional distributions and diversity of fungal species. Between 1991 and 1995, Jarmie and Rogers (1996, 1997) surveyed and collected macroscopic fungi (Kingdom, Eumycota) at 43 sample locations in Los Alamos County (LAC), the Bandelier National Monument (BNM), and LANL. These fungal samples were identified to the genus, species or subspecies level, and this information along with all associated environmental descriptors was entered into a database. The resulting database consists of 1,048 fungal collections, representing 140 genera and 227 species.

The current study employed the database to investigate fungal distributions and diversities. A subset of the data was defined, and a preliminary analysis was performed on presence-absence data for this collection of fungal species. The objectives of the analysis were to explore (1) the distributions of fungal species across selected habitat zones and (2) the diversity of fungi within and between these habitats.

Environmental Setting

LANL covers 112 sq km (43 sq mi) of land. It is located on the eastern slopes of the Jemez Mountains, approximately 120 km (80 mi) north of Albuquerque and 40 km (25 mi) northwest of Santa Fe (Figure 1). LANL is largely, but not completely, contained in Los Alamos County, the northeastern portion of LANL being in Santa Fe County. Los Alamos County land is administered by County governmental agencies, LANL, the Santa Fe National Forest of the U.S. Forest Service, and Bandelier National Monument. Bandelier National Monument extends to the south and the Santa Fe National Forest continues to the north and to the southeast. LANL and Los Alamos County are also bordered on the east by the Pueblo of San Ildefonso. Two populated

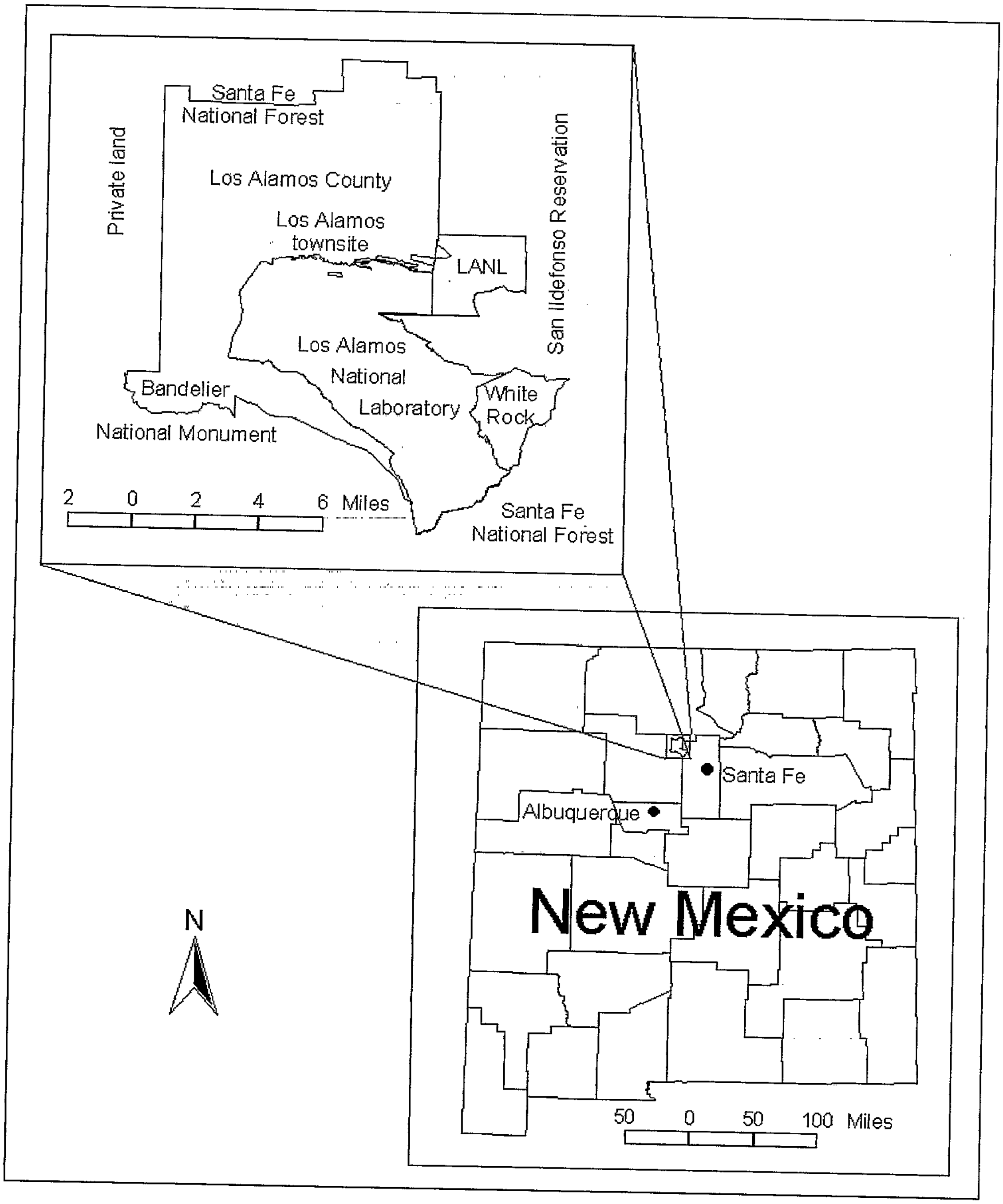

Figure 1. Location of Los Alamos County and Los Alamos National Laboratory.

areas, Los Alamos townsite and White Rock townsite are located adjacent to LANL on the north and southeast, respectively.

LANL, Los Alamos County, and their neighboring administrative entities occupy lands that span an elevational gradient that ranges from approximately 1,631 m (5,350 ft), adjacent to the Rio Grande, to 3,199 m (10,496 ft) at its western extremities (Figure 2). White Rock Canyon, a rugged gorge that contains the Rio Grande occupies the lowest elevations. The Sierra de los Valles, a segment of the Jemez Mountains, is found to the west of LANL and in the western portions of Los Alamos County. Most of the LANL facilities and urban areas are located in the middle elevations, between 1,981 m and 2,286 m (6,500 ft and 7,500 ft).

The elevational gradient in the LANL region encompasses five major vegetational cover types that reflect changes in climatic conditions from low elevations to high elevations (Figure 3). These major cover types are defined by their dominant tree species and structural characteristics as follows: juniper savannas, piñon-juniper woodlands, ponderosa pine forests, mixed conifer forests and spruce-fir forests (Balice et al. 1997). The relationships between the vegetational zones and elevational and topographic conditions are shown in Figure 4. The additional cover types displayed in Figure 3 will not be discussed in detail in this report since they are related to topographic, geologic or edaphic conditions, past disturbances, or human developments. The juniper savannas were not included in the macroscopic fungi survey by Jarmie and Rogers (1996, 1997) and will also not be considered further in this report. The remaining four major vegetational cover types are briefly described in the following paragraphs.

<u>Piñon-juniper woodlands</u> Although piñon-juniper woodlands can extend to as low as 1,676 m (5,500 ft) on protected topographic positions, they are the dominant, upland community type between 1,768 m and 2,134 m (5,800 ft and 7,000 ft) in elevation (Foxx and Tierney 1980, Balice et al. 1997). They also can be found as high as 2,195 m (7,200 ft) on southerly facing exposures.

Piñon-juniper woodlands range from open-canopied to closed-canopied communities (Foxx and Tierney 1984; Balice et al. 1997). The dominant tree species are one-seed juniper (*Juniperus monosperma*) or piñon (*Pinus edulis*). The relative dominance between these two species depends on the elevation. Within the range of these woodlands, one-seed juniper is more abundant at lower elevations, while piñon is more abundant at higher elevations. Other tree species are absent or rare.

Piñon-juniper woodlands are patchy communities where the understories are dominated by an assortment of grasses and shrubs. Typical graminoid dominants include mountain muhly (*Muhlenbergia montana*) and blue grama (*Bouteloua gracilis*). In the shrub layer, oaks (*Quercus gambelii* and *Q. undulata*) and mountain mahogany (*Cercocarpus montanus*) are common species.

<u>Ponderosa pine forest</u> Ponderosa pine forests extend to as low as 1,829 m (6,000 ft) in some of the protected canyons in the LANL region (Foxx and Tierney 1980, Balice et al.

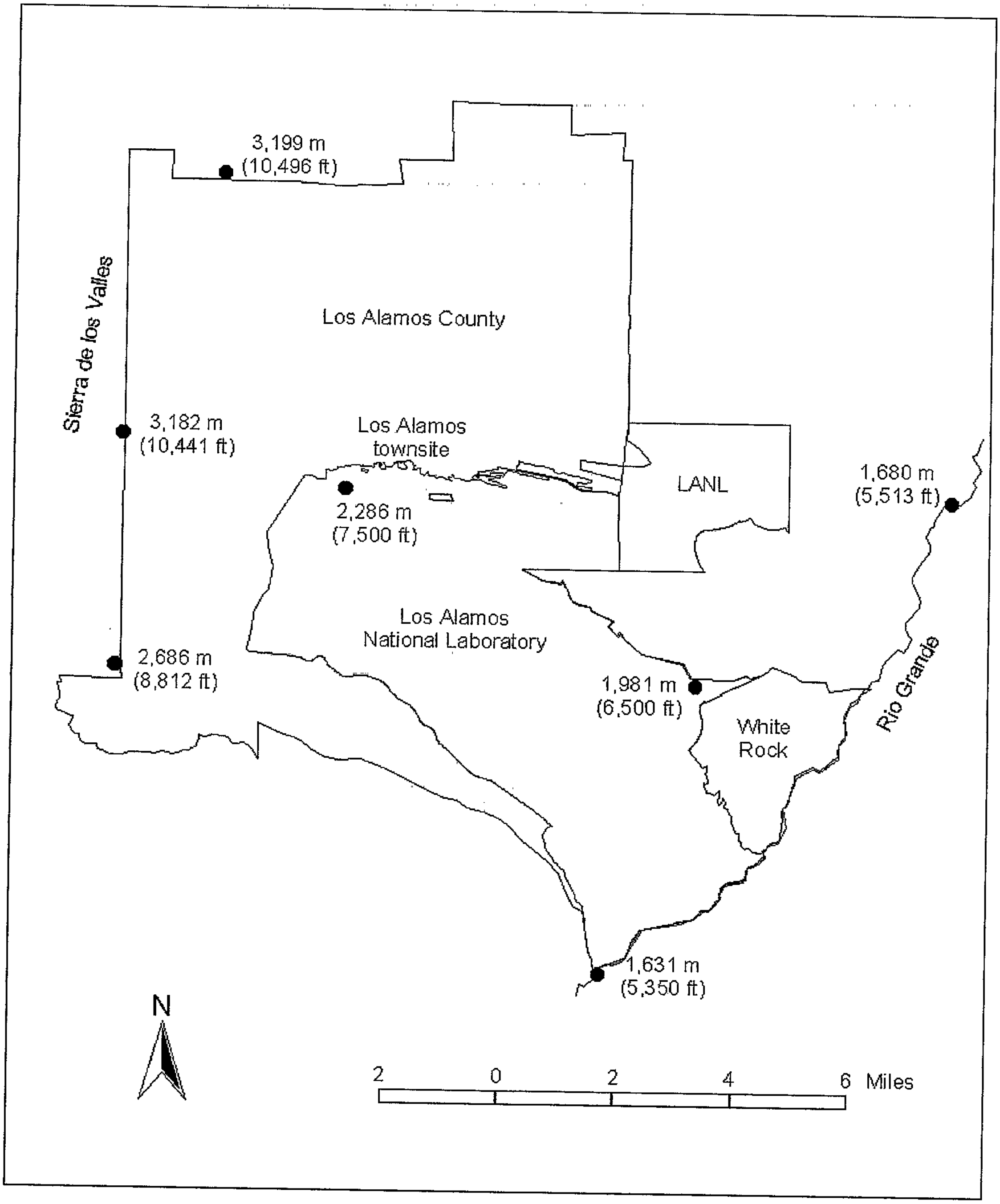

Figure 2. Los Alamos County and Los Alamos National Laboratory.

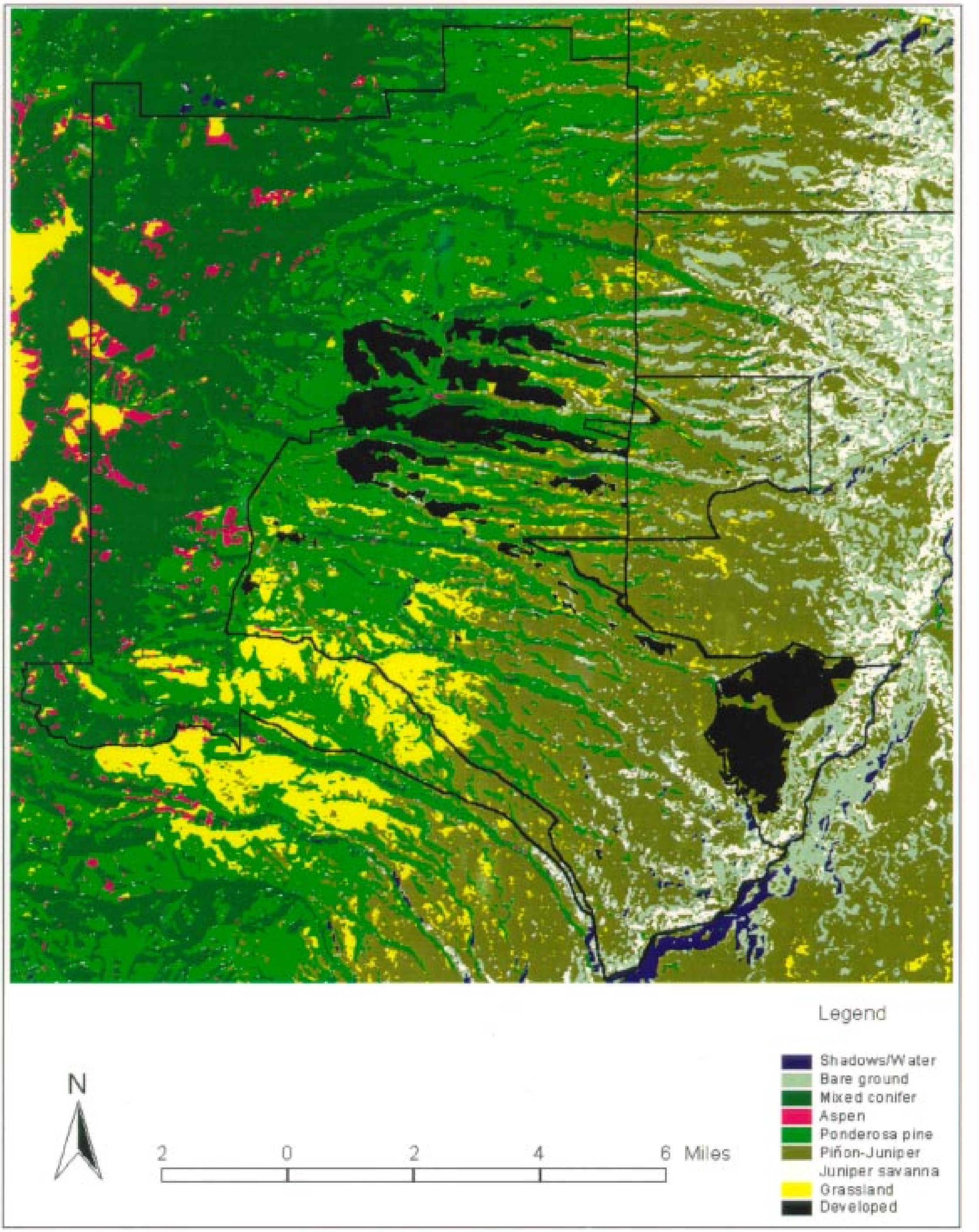

Figure 3. Major land cover types in the Los Alamos area.

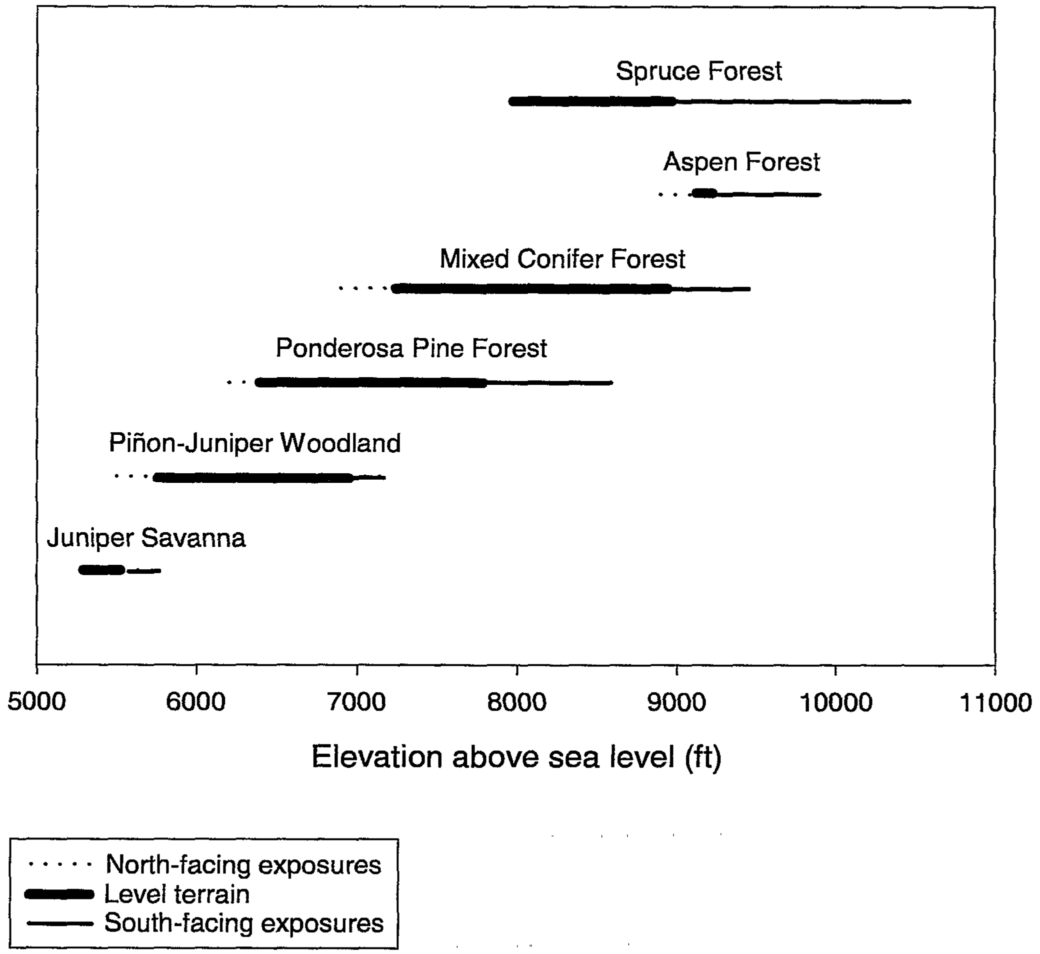

Figure 4. Elevational ranges of selected forested cover types.

1997). At these lower extremities ponderosa pine forests intergrade with piñon-juniper woodland. On the mesas and the lower slopes of the Sierra de los Valles, ponderosa pine forests extend to 2,377 m (7,800 ft) in elevation. They may also be found at higher elevations on steep, south-facing slopes.

This cover type is an open or closed forest. Ponderosa pine (*Pinus ponderosa*) is the dominant tree species. One-seed juniper and piñon may also be present, particularly at lower elevations, but other tree species are typically absent or rare. At higher elevations, Douglas fir (*Pseudotsuga menziesii*) and Rocky Mountain juniper (*Juniperus scopulorum*) can be found in ponderosa pine forests. Douglas fir may be especially common in areas that were protected from wildfires for prolonged periods.

The understories in the ponderosa pine zone are typically shrubby, with significant amounts of graminoid species also being present. Gambel oak (*Quercus gambelii*) and Colorado barberry (*Berberis fendleri*) are common associates in the shrub stratum. The most abundant graminoid species include sedges (*Carex* spp.), blue grama, mountain muhly, little bluestem (*Scizachyrium scoparium*), and pine dropseed (*Blepharoneuron tricholepis*).

<u>Mixed conifer forests</u> Mixed conifer forests begin as intergrades with ponderosa pine communities and as stringers on north aspects of the canyons above 2,103 m (6,900 ft) in elevation (Foxx and Tierney 1980, Balice et al. 1997). These communities continue to 2,743 m (9,000 ft) on eastern exposures and on flat topographic positions. On southern exposures, mixed conifer forests extend to 2,896 m (9,500 ft).

Douglas fir and white fir (*Abies concolor*) are the typical overstory dominants in mixed conifer forests. Ponderosa pine and aspen (*Populus tremuloides*) are also typically present. Frequently ponderosa pine is represented by a few, large individuals that are remnants from previous, open-canopied forest stands and by numerous pole-sized trees that have recently become established. Limber pine (*Pinus flexilis*) can also be found in mixed conifer forests, especially on rocky, ridgeline positions.

The understories in the mixed conifer forests are extremely variable. Shrubs, including ninebark (*Physocarpus monogynous*), kinnikinnik (*Arctostaphylos uva-ursi*), Gambel oak, wild rose (*Rosa woodsii*), cliffbush (*Jamesia americana*), Oregon grape (*Berberis repens*), myrtle boxleaf (*Pachystima myrsinites*), mountain maple (*Acer glabrum*), and dwarf juniper (*Juniperus communis*), are found along with numerous species of herbs and graminoids. Among the grasses and grass-like species, sedges, nodding brome (*Bromus inermis*), and muttongrass (*Poa fendleriana*) are the most commonly found.

<u>Spruce-fir forests</u> Spruce-fir forests can be found on north aspects as low as 2,438 m (8,000 ft) and on more exposed slopes as low as 2,743 m (9,000 ft) in the Sierra de los Valles (Foxx and Tierney 1984; Balice et al. 1997). These communities extend to the highest elevations of the Sierras (3,199 m [10,496 ft]).

Engelmann spruce (*Picea engelmannii*) and Douglas fir are typically the dominant tree species, although white fir may also be abundant. Aspen (*Populus tremuloides*) is also a major overstory species in some areas. On north-facing slopes aspen is present as a successional species. However, on south-facing slopes with bouldery soils, aspen appears to be a persistent species and may dominate these sites indefinitely.

The understories in the spruce-fir forests are typically shrubby and herbaceous. Shrubs are represented by mountain maple, cliffbush, ninebark, myrtle boxleaf, and whortleberry (*Vaccinium myrtillus*). Among the herbaceous species, Arizona peavine (*Lathyrus arizonicus*), sidebells (*Pyrola secunda*), false Solomon's seal (*Smilacina racemosa*), forest fleabane (*Erigeron eximius*), rattlesnake plantain (*Goodyera oblongifolia*) and Fendler meadowrue (*Thalictrum fendleri*) are commonly found. Bracken fern (*Pteridium aquilinum*) replaces many of these species in the aspen forests. Nodding brome is the only graminoid species that is widely distributed in the spruce-fir zone. Grasses, such as nodding brome and slender wheatgrass (*Agropyron trachycaulum*) become abundant only where aspen dominates the overstory.

Methods

The data analyzed in this project were provided by Jarmie and Rogers (1996, 1997). They had surveyed macroscopic fungi (Kingdom, Eumycota) from 1991 to 1995 at specified sample locations within LANL and in the surrounding areas. The fungal samples were identified to the genus, species or subspecies level and recorded in a database. As a result of this effort, 1,048 fungal collections, including 140 genera and 227 species, were obtained.

The network of sample sites that was surveyed by Jarmie and Rogers (1996, 1997) consisted of 43 sample locations at LANL, Bandelier National Monument, and the Santa Fe National Forest. Although urban areas were included in the sample, the primary focus of the survey was on forested and wooded areas on LANL property and in the immediate surroundings. This largely consists of forested or wooded mesas, canyons, and mountain slopes between the elevations of 1,829 m (6,000 ft) and 3,048 m (10,000 ft).

The first step in the analysis was to define major habitat groupings that are consistent with previously defined vegetational cover types. This was accomplished by adopting five habitat classes previously defined by Jarmie and Rogers (1996). These habitat classes include piñon-juniper (P-J), canyon-bottom ponderosa pine (CBPP), ponderosa pine (PP), canyon-bottom mixed conifer (CBMC), and mixed conifer (MC). Each of the 43 original sampling locations was grouped into one of these habitats. These habitat groups correspond to selected Level I classes discussed in Balice et al. (1997) with the following exceptions. In the current report, both the ponderosa pine type and the mixed conifer type are subdivided into canyon and noncanyon environments. Also, since the mixed conifer forests and spruce-fir forests were not distinguished in the original database, all high elevation sampling locations were included in the mixed-conifer zone for this analysis.

The second step in the analysis was to define the subset of the original database of 1,048 fungal collections that was suitable for analysis of fungal diversity. This required a reformatting of the database for a Windows operating system on the personal computer. Then, the data were reorganized by species, sample location, and by date of collection. Next, each fungal species with high identification reliability were retained for further analysis. To accomplish this, the following identification reliability codes were adopted from Jarmie and Rogers (1996):

1 "Well known, no doubt, species sure, no close brothers."
2 "Well identified, but slight possibility of being a near species in a close group."
3 "Genus sure, species likely but difficult to separate from closely related species."
4 "Genus only."
5 "Family only."
6 "Order only."
7 "Unknown."

Only collections with identification reliability codes of 1, 2, or 3 were included in this analysis. Grades 1 and 2 indicate a high level of confidence in the species identification, while grade 3 indicates a lower level of confidence in the species identification.

The resulting subset of fungi, 835 species, was sorted by habitat, by sample location, and by the date of the sample. Then, the mean number of fungal species collected per visit was calculated for each of the 43 sample locations. Means, standard deviations, and standard errors of the means were also calculated for each of the habitat groups. Next, a Kruskal-Wallis test (Conover 1980) was conducted to determine if the mean numbers of fungal species collected per visit per site were significantly different between the habitats.

The third step in the analysis was to identify the fungal species that were present in the study with sufficient frequency to merit distributional analyses, and to perform the analysis on a species-by-species basis. From the previously selected subset of 835 fungal species, all fungal species with two or more collections were retained for further analysis. The presence-absence data for each species with four or more occurrences were summed by sample location and grouped according to the five habitats. Constancy, the number of sample locations within a particular habitat where the species occurred, and percent constancy, the constancy value relative to the total number of sample locations in the habitat group, were calculated for each species. Finally, the species were grouped according to their respective fidelities to the five habitats. These fidelity groupings were tabulated and displayed graphically.

Results

The subdivisions of the sample locations into habitat zones are provided as separate tables in Appendix A. The approximate location of each sample site is shown in Figure 5. Six, ten, seven, six, and fourteen sample locations were grouped into the P-J, CBPP, PP, CBMC, and MC habitats, respectively. In addition to summarizing the habitat zones,

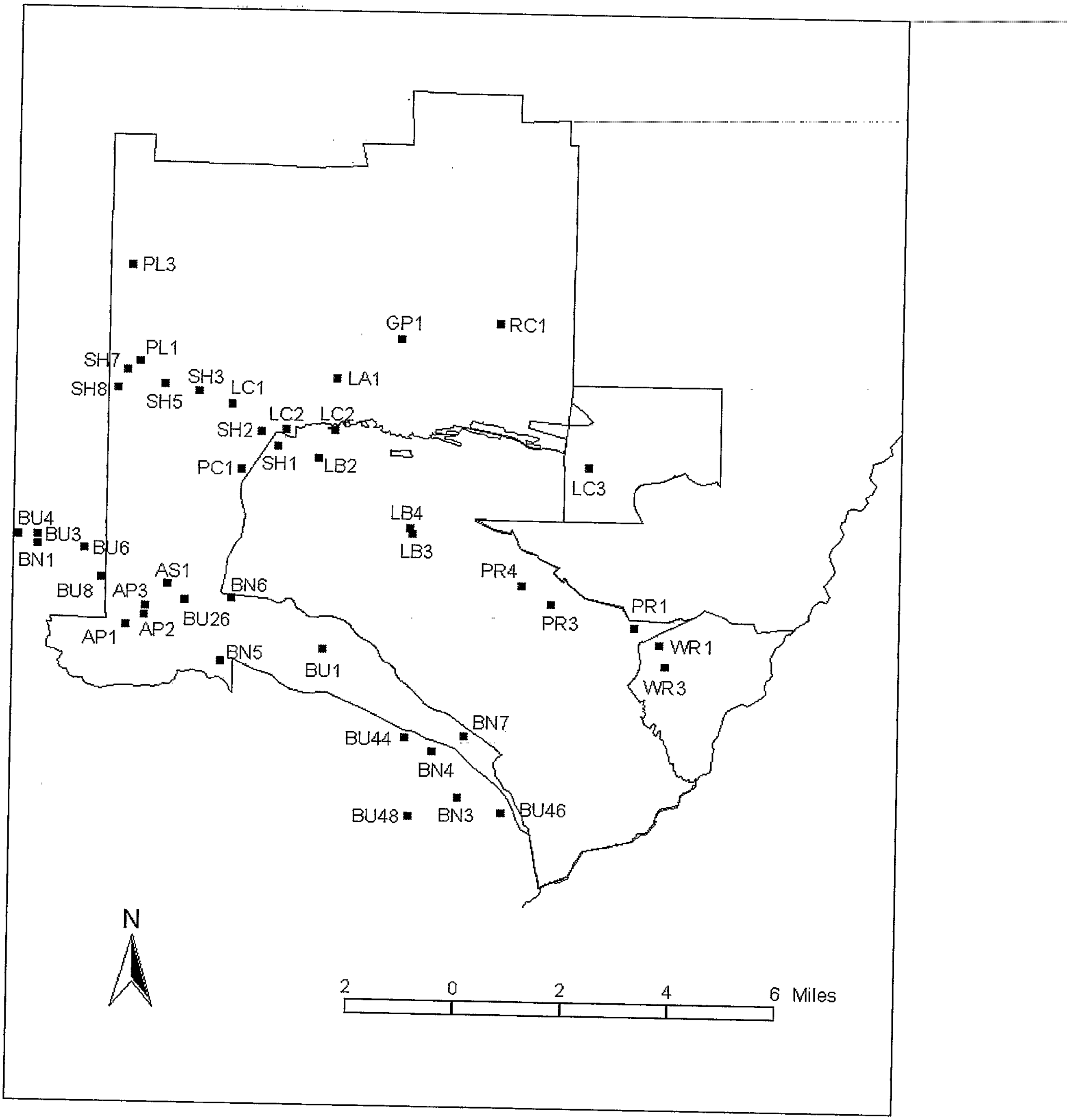

Figure 5. Fungi sample locations.

Appendix A also includes the codes of the sample locations, the approximate elevations in feet, a brief description for the location of each sample site, the number of sample visits, and the total number of fungal samples collected at each site.

The tables in Appendix A also list summary statistics describing the numbers of fungi sampled at each site. The mean numbers of fungal species collected per visit per site and the standard errors of the means are displayed graphically in Figure 6. The calculated Kruskal-Wallis statistic ($T = 16.78$) was significant at the 0.05 level when compared with the appropriate t value ($t = 1.69$, $df = 40$). Paired comparisons were significant for all of the habitat pairs except for the following combinations: P-J vs PP, CBPP vs PP and CBMC vs MC.

Figure 6 indicates a tendency for species diversity to increase from lower elevation habitats to higher elevation habitats. The CBMC and the MC habitats have the greatest species richness. The P-J habitat has the lowest species richness, although this value was not significantly different than the richness of PP. The species richness of CBPP and PP is intermediate between these two extremes.

Appendix B lists the fungal species with at least two collections that are considered to be somewhat reliable at the species level. A total of 130 species, representing 748 collections, is included in Appendix B. These species are arranged according to their prevalence in the database (number of samples) and according to their percent identification reliability (percent reliable). The percent identification reliability for each species is the number of collections with reliability codes of 1 or 2 relative to the number of collections with reliability codes 1, 2, or 3. Appendix B also includes columns containing six-letter abbreviations for each fungal species and the associated taxonomic families.

Suillus granulatus and *Crepidotus mollis* are the most common species in the database with 22 and 20 collections, respectively (Appendix B). Overall, a total of 22 species is represented in the database by at least ten collections. A total of 71 fungal species, representing 609 collections, occurred in the database at least four times. These species were retained for further analysis. Most of these species were also identified with a high level of confidence.

The fungal constancies and percent constancies within each habitat are listed in Appendix C. Within this appendix, the fungal species are grouped according to their observed fidelities to specific habitat zones or to combinations of habitat zones. Those species that have a high fidelity to the mixed conifer zone are listed first. Species with increasing tendencies to occupy low-elevation environments follow in their respective groups. The species fall into a total of 11 fidelity groups. In addition to being tabulated in Appendix C, the percent constancy results are also displayed graphically (see Appendix D—Figures 1 through 10).

All but three of the fungal species were found in either the CBMC or the MC habitats (Appendix C). Moreover, all but seven of the fungal species were collected in MC

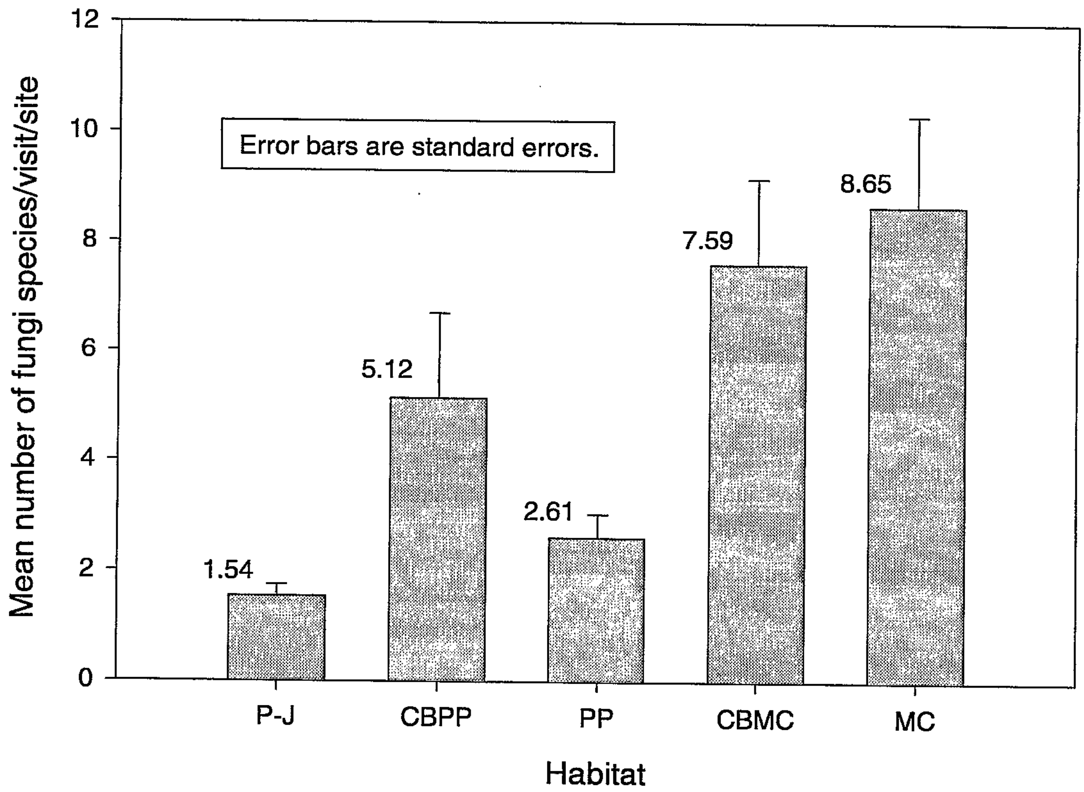

Figure 6. Mean number of fungal species by habitat.

habitats. Five fungal species had high fidelity in the MC habitat and, 13 species had high fidelity in the CBMC and the MC habitats (Appendix D, Figures 1 and 2).

In contrast, only eight fungal species were collected in the P-J habitat (Appendix C). Of these, only *Russula brevipes* and *Amanita constricta* were collected more than once. None of the species had a high fidelity in the P-J zone, and only two species, *Marasmius oreades* and *Agaricus campestris* were collected with high fidelity in the CBPP and the PP habitats.

Most of the fungal species were collected in more that one habitat zone (Appendix C). Eleven species were collected primarily in higher elevation sites. Six species tended to occur in canyon-bottom positions, while eight fungal species tended to occur on mesa positions. Two fungal species, *Lycoperdon perlatum* and *Russula brevipes*, were collected in all five of the habitats.

Discussion

Although fungal species were encountered in each of the habitats, they were not evenly distributed throughout the range of habitats. There was a clear tendency for the fungi to occur at higher elevations and in more moist habitats. This tendency appeared to be accentuated in 1997, which was wetter than normal. However, the reconnaissance surveys at the 43 sampling locations had been completed before 1997. Therefore, this conclusion is based on qualitative observations.

The results of this analysis are considered to be preliminary because the measures of distributions and diversity are based on presence-absence data that were gathered during reconnaissance surveys. Future surveys of fungi would benefit from the development of a species abundance measure, a systematic sampling design that spans the growing season, and incorporation of extraneous factors, such as weather patterns, soils characteristics and disturbance history, into the analysis. These are not trivial issues and previous attempts by other investigators to incorporate these factors were frustrated by the reconnaissance sampling design, by the growth form of this Kingdom of organisms, and by the unpredictable and ephemeral fruiting habit of these species (Stolp 1988, Norvell 1996). Furthermore, fungi may be distributed in a patchy manner within seemingly homogeneous environments as a result of the uneven distribution of their hosts (Giller 1984).

Fungi have demonstrated their ability to diversify and specialize to take advantage of new environments (Murphy 1996). These species are essential to the normal functioning of ecosystems and the impacts of human activities may be harmful to fungi. There is a need to inventory fungi throughout the range of their environments. Only then can we determine the trends in the distributions and diversity of fungal species, begin to understand their importance to ecosystem health, and evaluate their interactions with humans.

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Appendix A

Sampling Locations and Habitat Groups

Table 1. Fungi sampling sites in the piñon-juniper habitat (P-J).

Location Code[1]	Elevation (feet)	Location description	Number of sample visits	Total number of fungi samples
WR3	6480	White Rock, 122 Piedra Loop, La Senda Subdivision	6	18
WR1	6500	White Rock, 116 Sierra Vista, La Vista Subdivision	6	7
PR1	6540	LANL, Pajarito Canyon at Cañada del Buey	2	6
PR3	6700	LANL, Pajarito Canyon at Building 36-135, 1.8 mi northwest of Hwy 4	1	1
BN7	6689	Bandelier Nat. Mon., Juniper Campground	2	5
LB3	7300	LANL, TA-67, mesa area	2	5
		Totals	19	42

Mean number of fungi collections/visit/site	1.54
Standard deviation	0.51
Standard error of the mean	0.21

[1]Location codes are used for identifying the sample sites.

Table 2. Fungi sampling sites in the canyon bottom ponderosa pine habitat (CBPP).

Location Code[1]	Elevation (feet)	Location description	Number of sample visits	Total number of fungi samples
BU46	6000	Bandelier Nat. Mon., Rainbow House	1	15
BN3	6066	Bandelier Nat. Mon., Frijoles Canyon, West of Headquarters	14	50
BN4	6200	Bandelier Nat. Mon., Frijoles Canyon, Ceremonial Cave area	1	1
BU44	6300	Bandelier Nat. Mon., Frijoles Canyon, 0.1 mi. west of Ceremonial Cave	6	30
RC1	6500	Los Alamos townsite, Rendija Canyon, 0.8 mi. east of Barranca Mesa	2	4
PR4	6700	LANL, Pajarito Canyon, at TA-18, 2.5 mi. northwest of Hwy 4	1	1
BU48	6580	Bandelier Nat. Mon., trail between Lummis and Alamo Canyons	2	23
GP1	7000	Los Alamos townsite, Guaje Pines area	3	14
BN5	7023	Bandelier Nat. Mon., Frijoles Canyon, Upper Crossing	2	6
LB4	7100	LANL, Pajarito Canyon at TA-67	1	8
		Totals	33	152

Mean number of fungi collections/visit/site	5.12
Standard deviation	4.92
Standard error of the mean	1.56

[1]Location codes are used for identifying the sample sites.

Table 3. Fungi sampling sites in the ponderosa pine habitat (PP).

Location Code[1]	Elevation (feet)	Location description	Number of sample visits	Total number of fungi samples
BU1	7200	Bandelier Nat. Mon., Burnt Mesa area	5	34
LB2	7400	LANL, mesa area on southwest margin of TA-3	11	28
LA1	7400	Los Alamos townsite, Urban Park area	8	16
SH1	7500	LANL, Ski Hill Road, at Santa Fe Nat. For., 0.2 mi. from Hwy 501	6	10
BN6	7600	Bandelier Nat. Mon., near Ponderosa Campground	28	74
SH2	8000	Santa Fe Nat. For., Ski Hill Road, 0.8 mi. from Hwy 501	4	9
AP2	8500	Bandelier Nat. Mon., northeast of Apache Springs	3	8
		Totals	65	179

Mean number of fungi collections/visit/site	2.61
Standard deviation	1.13
Standard error of the mean	0.43

[1]Location codes are used for identifying the sample sites.

Table 4. Fungi sampling sites in the canyon bottom mixed conifer habitat (CBMC).

Location Code[1]	Elevation (feet)	Location description	Number of sample visits	Total number of fungi samples
LC3	6620	LANL, Los Alamos Canyon, 1.5 mi. west of Hwy 4	1	10
LA2	7200	LANL, Los Alamos Canyon, east of the skating rink	11	31
LC2	7400	Santa Fe Nat. For., Los Alamos Canyon, 0.6 mi. west of West Rd.	2	31
LC1	7700	Santa Fe Nat. For., Los Alamos Canyon, 0.25 mi. west of reservoir	2	40
PC1	7900	Santa Fe Nat. For., Pajarito Canyon, 0.2 mi. west of Hwy 501	8	59
AP1	8444	Bandelier Nat. Mon., Apache Springs	7	40
		Totals	31	211

Mean number of fungi collections/visit/site	7.59
Standard deviation	3.82
Standard error of the mean	1.56

[1]Location codes are used for identifying the sample sites.

Table 5. Fungi sampling locations in the mixed conifer habitat (MC).

Location Code[1]	Elevation (feet)	Location description	Number of sample visits	Total number of fungi samples
BU26	8100	Bandelier Nat. Mon., south of Hwy 4, 1.2 mi. west of Hwy 501	1	20
AS1	8200	Santa Fe Nat. For., American Springs Rd., 0.3 mi. north of Hwy 4	1	13
AP3	8500	Bandelier Nat. Mon., northeast of Apache Springs	7	12
SH3	8600	Santa Fe Nat. For., Ski Hill Road, turnout 2.6 mi. from Hwy 501	5	9
BN1	8949	Bandelier Nat. Mon., 0.1 mi. southeast of Hwy 4-Rd 289	1	31
BU3	8960	Bandelier Nat. Mon., 0.2 mi. northeast of Hwy 4-Rd 289	8	80
BU4	8960	Bandelier Nat. Mon., 0.3 mi. northwest of Hwy 4-Rd 289	2	39
BU6	9000	Bandelier Nat. Mon., Frijoles Canyon, 1.4 mi. north of park boundary	2	18
BU8	9000	Bandelier Nat. Mon., Frijoles Canyon, 0.8 mi. north of park boundary	2	22
SH5	9200	Santa Fe Nat. For., Ski Hill Road, 0.5 mi. below the ski lodge	22	116
PL1	9200	Santa Fe Nat. For., Upper Quemazon Trail, 0.2 mi. north of Ski Hill Rd	5	32
SH7	9260	Pajarito Ski Area, 0.1 mi. southwest of Upper Quemazon Trailhead	4	11
PL3	9540	Santa Fe Nat. For., Pipeline Road at Guaje Canyon Trail	2	14
SH8	10,000	Pajarito Ski Area, 0.45 mi. southwest of Upper Quemazon Trailhead	5	41
		Totals	67	458

Mean number of fungi collections/visit/site	8.65
Standard deviation	6.18
Standard error of the mean	1.65

[1]Location codes are used for identifying the sample sites.

Appendix B

Fungi Identified to Species and Collected at Least Twice

Ordered list of fungi,
2 or more occurrences

Abbreviation	Genus	Species	Family	Number of samples	Percent reliable
SUIGRA	Suillus	granulatus	Boletaceae	22	82
CREMOL	Crepidotus	mollis	Crepidotaceae	20	95
ZERCAM	Xeromphalina	campanella	Tricholomataceae	18	100
RUSBRE	Russula	brevipes	Russulaceae	17	100
FLAVEL	Flammulina	velutipes	Tricholomataceae	16	100
BOLBAR	Boletus	barrowsii	Boletaceae	15	100
SUILAK	Suillus	lakei	Boletaceae	15	100
LACDEL	Lactarius	deliciosus	Russulaceae	15	73
GOMGLU	Gomphidius	glutinosus	Gomphidiaceae	14	100
POLARC	Polyporus	arcularius	Polyporaceae	14	100
PLUCER	Pluteus	cervinus	Pluteaceae	14	86
FOMPIN	Fomitopsis	pinicola	Polyporaceae	13	100
LYCEPI	Lycogala	epidendrum	Reticulariaceae	13	100
ARMMEL	Armillaria	mellea	Tricholomataceae	12	8
HYGCON	Hygrophorus	conicus	Hygrophoraceae	11	100
HYPLAC	Hypomyces	lactifluorum	Hypocreaceae	11	100
GOMFLO	Gomphus	floccosus	Cantharellaceae	11	91
LYCPER	Lycoperdon	perlatum	Lycoperdaceae	11	91
PLEOST	Pleurotus	ostreatus	Tricholomataceae	11	82
CYPCHR	Cyptotrama	chrysopeplum	Tricholomataceae	10	100
PHOSQU	Pholiota	squarrosa	Strophariaceae	10	30
AMAVAG	Amanita	vaginata	Amanitaceae	10	10
AMAMUS	Amanita	muscaria v. mus.	Amanitaceae	9	100
BJEADU	Bjerkandera	adusta	Polyporaceae	9	100
DACPAL	Dacrymyces	palmatus	Dacrymycetaceae	9	100
GANAPP	Ganoderma	applanatum	Polyporaceae	9	100
TRIABI	Trichaptum	abietinus	Polyporaceae	9	100
LEUAMA	Leucopaxillus	amarus	Tricholomataceae	9	78
AMAPAN	Amanita	pantherina	Amanitaceae	9	33
CLAPYX	Clavicorona	pyxidata	Clavariaceae	8	100
LACRUB	Lactarius	rubrilacteus	Russulaceae	8	100
PHODES	Pholiota	destruens	Strophariaceae	8	100
COPMIC	Coprinus	micaceus	Coprinaceae	8	88
BOLCHR	Boletus	chrysenteron	Boletaceae	8	0
RUSEME	Russula	emetica	Russulaceae	8	0
HYGPUD	Hygrophorus	pudorinus	Hygrophoraceae	7	100
HYGSPE	Hygrophorus	speciosus	Hygrophoraceae	7	100
PHASCH	Phaeolus	schweinitzii	Polyporaceae	7	100
PHYNID	Phyllotopsis	nidulans	Tricholomataceae	7	100
PYCCIN	Pycnoporus	cinnabarinus	Polyporaceae	7	100
GLOSEP	Gloepphyllum	sepiarium	Polyporaceae	7	86
HYGCHR	Hygrophorus	chrysodon	Hygrophoraceae	7	86
HEBSIN	Hebeloma	sinapizans	Cortinariaceae	7	0
RUSMAC	Russula	maculata	Russulaceae	7	0
AMACAE	Amanita	caesarea	Amanitaceae	6	100
AURAUR	Auricularia	auricula	Auriculariaceae	6	100
CLATRU	Clavariadelphus	truncatus	Clavariaceae	6	100
CORCAL	Cortinarius	calochrous	Cortinariaceae	6	100
HEBCRU	Hebeloma	crustiliniforme	Cortinariaceae	6	100

Ordered list of fungi,
2 or more occurrences

Abbreviation	Genus	Species	Family	Number of samples	Percent reliable
AMACON	Amanita	constricta	Amanitaceae	6	50
BOLEDU	Boletus	edulis	Boletaceae	5	100
COPATR	Coprinus	atramentarius	Coprinaceae	5	100
FULSEP	Fuligo	septica	Physacaceae	5	100
HYGAUR	Hygrophoropsis	aurantiaca	Paxillaceae	5	100
LECAUR	Leccinum	aurantiacum	Boletaceae	5	100
LYCPYR	Lycoperdon	pyriforme	Lycoperdaceae	5	100
GOMBON	Gomphus	bonari	Cantharellaceae	5	80
POLVAR	Polyporus	varius	Polyporaceae	5	80
PEZREP	Peziza	repanda	Pezizaceae	5	60
GYRINF	Gyromitra	infula	Helvellaceae	5	40
LACLAC	Laccaria	laccata	Tricholomataceae	5	40
RUSROS	Russula	rosacea	Russulaceae	5	0
AGACAM	Agaricus	campestris	Agaricaceae	4	100
BISCIT	Bisporella	citrina	Leotiaceae	4	100
CLIGIB	Clitocybe	gibba	Tricholomataceae	4	100
COLPER	Coltricia	perennis	Polyporaceae	4	100
HELCRI	Helvella	crispa	Helvellaceae	4	100
MARORE	Marasmius	oreades	Tricholomataceae	4	100
COPCOM	Coprinus	comatus	Coprinaceae	4	75
AGASIL	Agaricus	silvicola	Agaricaceae	4	50
LACUVI	Lactarius	uvidus	Russulaceae	4	0
AMAFUL	Amanita	fulva	Amanitaceae	3	100
CANCIB	Cantharellus	cibarus	Cantharellaceae	3	100
CHECAN	Cheimonophyllum	candidissimus	Tricholomataceae	3	100
CHLMOL	Chlorophyllum	molybdites	Lepiotaceae	3	100
CRULAE	Crucibulum	laeve	Nidulariaceae	3	100
CYASTR	Cyathus	striatus	Nidulariaceae	3	100
IRPLAC	Irpex	lacteus	Polyporaceae	3	100
LECINS	Leccinum	insigne	Boletaceae	3	100
LENPON	Lentinus	ponderosus	Tricholomataceae	3	100
PHYRHO	Phylloporus	rhodoxanthus	Paxillaceae	3	100
PYCALB	Pycnoporellus	alboluteus	Polyporaceae	3	100
SPAFLA	Spathularia	flavida	Geoglossaceae	3	100
CHRVIN	Chroogomphus	vinicolor	Gomphidiaceae	3	67
GEASAC	Geastrum	saccatum	Geastraceae	3	67
HYPCHR	Hypomyces	chrysospermum	Hypocreaceae	3	67
LEPCRI	Lepiota	cristata	Lepiotaceae	3	67
STESPL	Stemonitis	splendens	Stemonitaceae	3	67
XERAME	Xerula	americana	Tricholomataceae	3	67
ASTHYG	Astraeus	hygrometricus	Astraeaceae	3	33
AMABIS	Amanita	bisporigera	Amanitaceae	3	0
PORCOR	Poria	corticola	Polyporaceae	3	0
CHLAER	Chlorociboria	aeruginascens	Dermatiaceae	2	100
CLIDIL	Clitocybe	dilatata	Tricholomataceae	2	100
CORGAL	Coriolopsis	gallica	Polyporaceae	2	100
DAECON	Daedaleopsis	confragosa	Polyporaceae	2	100
FOMCAN	Fomitopsis	canjanderi	Polyporaceae	2	100
INOSOR	Inocybe	sororia	Cortinariaceae	2	100

Ordered list of fungi,
2 or more occurrences

Abbreviation	Genus	Species	Family	Number of samples	Percent reliable
LACBAR	Lactarius	barrowsii	Russulaceae	2	100
LENBET	Lenzites	betulina	Polyporaceae	2	100
LYCFLA	Lycogala	flavofuscum	Reticulariaceae	2	100
LYCAME	Lycoperdon	americanum	Lycoperdaceae	2	100
PANFOE	Panaeolus	foenisecii	Coprinaceae	2	100
PENGIG	Peniophora	gigantea	Corticiaceae	2	100
PLULUT	Pluteus	lutescens	Pluteaceae	2	100
SUISIB	Suillus	sibiricus	Boletaceae	2	100
TRIPLA	Tricholomopsis	platyphylla	Tricholomataceae	2	100
ARMALB	Armillaria	albolanaripes	Tricholomataceae	2	50
CALGIG	Calvatia	gigantea	Lycoperdaceae	2	50
CLACOR	Clavulinopsis	corniculata	Clavariaceae	2	50
CONPUT	Coniophora	puteana	Coniophoraceae	2	50
CORCAR	Coriolellus	carbonarius	Polyporaceae	2	50
GOMORE	Gomphidius	oregonensis	Gomphidiaceae	2	50
GYMSAP	Gymnopolis	sapineus	Cortinariaceae	2	50
HUMHEM	Humaria	hemispherica	Pyronemataceae	2	50
INOFAS	Inocybe	fastigiata	Cortinariaceae	2	50
LACBIC	Laccaria	bicolor	Tricholomataceae	2	50
LACTOR	Lactarius	torminosus	Russulaceae	2	50
LYCECH	Lycoperdon	echinatum	Lycoperdaceae	2	50
NIDCAN	Nidula	candida	Nidulariaceae	2	50
PENRUF	Peniophora	rufa	Corticiaceae	2	50
POLELE	Polyporus	elegans	Polyporaceae	2	50
THETER	Thelephora	terrestris	Thelephoraceae	2	50
CLIGIG	Clitocybe	gigantea	Tricholomataceae	2	0
COLLEN	Collybia	lentinoides	Tricholomataceae	2	0
CYSAMI	Cystoderma	amianthinum	Tricholomataceae	2	0
HOHPET	Hohenbuehelia	petaloides	Tricholomataceae	2	0
HYGMAR	Hygrophorus	marginatus	Hygrophoraceae	2	0
LENOMP	Lentinellus	omphalodes	Tricholomataceae	2	0
STEHIR	Stereum	hirsutum	Stereaceae	2	0
			Total of all species =	748	
			Total (n > 3) =	609	

Appendix C

Fungi Distributions by Habitat

Fungi Abundances,
by Habitat

					Constancy						Percent constancy			
ABBREVIATION	GENUS	SPECIES		P-J	CBPP	PP	CBMC	MC		P-J	CBPP	PP	CBMC	MC
BJEADU	Bjerkandera	adusta						7						50.0
LACLAC	Laccaria	laccata						4						28.6
COPATR	Coprinus	atramentarius						3						21.4
LECAUR	Leccinum	aurantiacum						3						21.4
LYCPYR	Lycoperdon	pyriforme			1			2			10.0			14.3
CREMOL	Crepidotus	mollis					2	12					33.3	85.7
GOMGLU	Gomphidius	glutinosus					3	9					50.0	64.3
FLAVEL	Flammulina	velutipes			1		1	9			10.0		16.7	64.3
FOMPIN	Fomitopsis	pinicola					5	8					83.3	57.1
LEUAMA	Leucopaxillus	amarus			1		2	6			10.0		33.3	42.9
PHOSQU	Pholiota	squarrosa					1	5					16.7	35.7
CYPCHR	Cyptotrama	chrysopeplum					5	4					83.3	28.6
CLAPYX	Clavicorona	pyxidata					2	4					33.3	28.6
HEBCRU	Hebeloma	crustiliniforme					2	4					33.3	28.6
GLOSEP	Gloepphyllum	sepiarium					1	4					16.7	28.6
RUSROS	Russula	rosacea					2	3					33.3	21.4
BISCIT	Bisporella	citrina					1	3					16.7	21.4
GYRINF	Gyromitra	infula					1	2					16.7	14.3
SUILAK	Suillus	lakei				1	4	8				14.3	66.7	57.1
XERCAM	Xeromphalina	campanella				2	6	7				28.6	100.0	50.0
GOMFLO	Gomphus	floccosus				1	2	6				14.3	33.3	42.9
COPMIC	Coprinus	micaceus				1	1	6				14.3	16.7	42.9
GANAPP	Ganoderma	applanatum				1	1	5				14.3	16.7	35.7
DACPAL	Dacrymyces	palmatus				1	3	3				14.3	50.0	21.4
RUSEME	Russula	emetica				3	2	3				42.9	33.3	21.4
CORCAL	Cortinarius	calochrous				1	2	3				14.3	33.3	21.4
LACRUB	Lactarius	rubrilacteus				3	1	2				42.9	16.7	14.3
HYGPUD	Hygrophorus	pudorinus				2	1	2				28.6	16.7	14.3
AURAUR	Auricularia	auricula				1	3	1				14.3	50.0	7.1

Fungi Abundances,
by Habitat

					Constancy						Percent constancy			
ABBREVIATION	GENUS	SPECIES		P-J	CBPP	PP	CBMC	MC		P-J	CBPP	PP	CBMC	MC
PLUCER	Pluteus	cervinus			2	2	3	7			20.0	28.6	50.0	50.0
BOLBAR	Boletus	barrowsii			1	2	2	6			10.0	28.6	33.3	42.9
SUIGRA	Suillus	granulatus			6	4	4	3			60.0	57.1	66.7	21.4
AMAMUS	Amanita	*muscaria v. mus.*			1	2	2	2			10.0	28.6	33.3	14.3
HYPLAC	Hypomyces	lactifluorum			1	1	2	2			10.0	14.3	33.3	14.3
AMAVAG	Amanita	vaginata			1	3	1	2			10.0	42.9	16.7	14.3
AMAPAN	Amanita	pantherina			2	1	1	2			20.0	14.3	16.7	14.3
PHASCH	Phaeolus	schweinitzii			1	1	1	2			10.0	14.3	16.7	14.3
PLEOST	Pleurotus	ostreatus			1		3	4			10.0		50.0	28.6
TRIABI	Trichaptum	abietinus			1		3	2			10.0		50.0	14.3
BOLCHR	Boletus	chrysenteron			2		2	2			20.0		33.3	14.3
POLVAR	Polyporus	varius			1		1	2			10.0		16.7	14.3
AGASIL	Agaricus	silvicola			1		1	2			10.0		16.7	14.3
PYCCIN	Pycnoporus	cinnabarinus			2		3	1			20.0		50.0	7.1
GOMBON	Gomphus	bonari				1		3				14.3		21.4
CLIGIB	Clitocybe	gibba				1		3				14.3		21.4
COLPER	Coltricia	perennis				1		3				14.3		21.4
COPCOM	Coprinus	comatus				1		3				14.3		21.4
LACUVI	Lactarius	uvidus				1		3				14.3		21.4
HYGSPE	Hygrophorus	speciosus				3		2				42.9		14.3
BOLEDU	Boletus	edulis				2		2				28.6		14.3
PEZREP	Peziza	repanda				1		2				14.3		14.3
ARMMEL	Armillaria	mellea			2	1		7			20.0	14.3		50.0
LACDEL	Lactarius	deliciosus			4	3		4			40.0	42.9		28.6
PHYNID	Phyllotopsis	nidulans			1	1		4			10.0	14.3		28.6
HYGCON	Hygrophorus	conicus			3	3		3			30.0	42.9		21.4
HEBSIN	Hebeloma	sinapizans			2	1		3			20.0	14.3		21.4
CLATRU	Clavariadelphus	truncatus			2	1		3			20.0	14.3		21.4
HELCRI	Helvella	crispa			2	1		1			20.0	14.3		7.1

Fungi Abundances,
by Habitat

				Constancy						Percent constancy				
ABBREVIATION	GENUS	SPECIES		P-J	CBPP	PP	CBMC	MC		P-J	CBPP	PP	CBMC	MC
LYCPER	Lycoperdon	perlatum		1	1	1	3	4		16.7	10.0	14.3	50.0	28.6
RUSBRE	Russula	brevipes		2	2	3	1	3		33.3	20.0	42.9	16.7	21.4
LYCEPI	Lycogala	epidendrum		1	1	2		6		16.7	10.0	28.6		42.9
RUSMAC	Russula	maculata		1	1	2		3		16.7	10.0	28.6		21.4
FULSEP	Fuligo	septica		1	1	1		2		16.7	10.0	14.3		14.3
HYGCHR	Hygrophorus	chrysodon		1	2	3		1		16.7	20.0	42.9		7.1
HYGAUR	Hygrophoropsis	aurantiaca				1	3					14.3	50.0	
AMACAE	Amanita	caesarea				2	1					28.6	16.7	
PHODES	Pholiota	destruens			4		2				40.0		33.3	
POLARC	Polyporus	arcularius		1	5	4	1			16.7	50.0	57.1	16.7	
MARORE	Marasmius	oreades				2						28.6		
AGACAM	Agaricus	campestris			2	1					20.0	14.3		
AMACON	Amanita	constricta		3	1	1				50.0	10.0	14.3		

Appendix D

Histograms of Fungi Distributions, by Fidelity Grouping

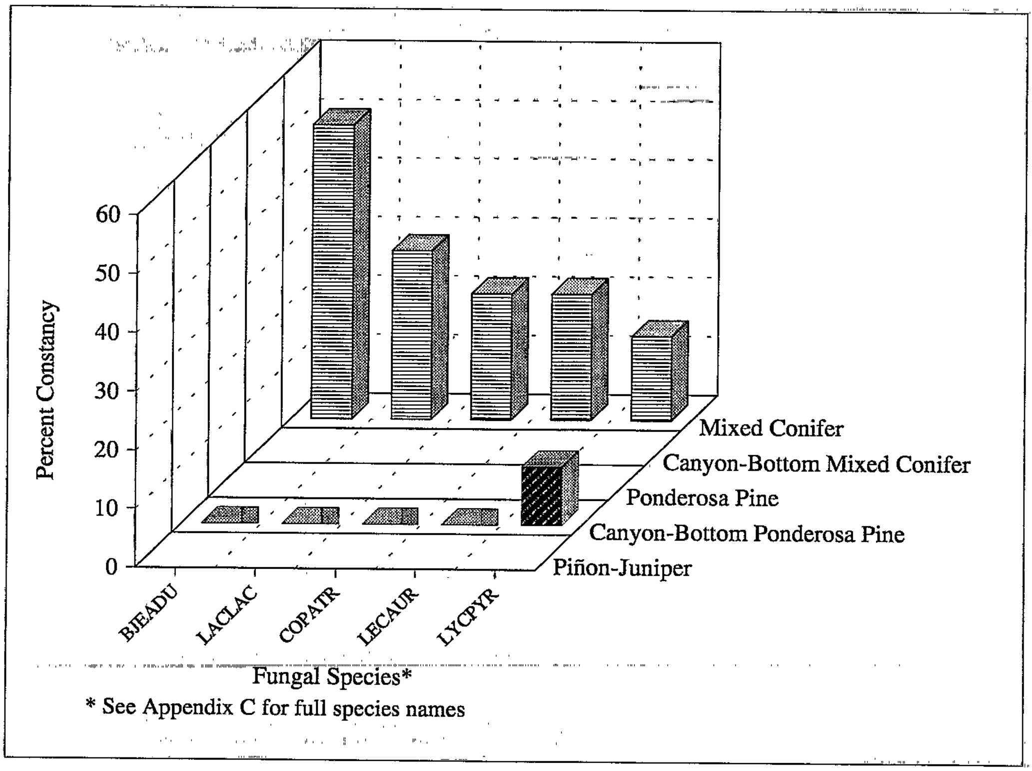

Figure 1. Fungal species found in the mixed conifer habitat.

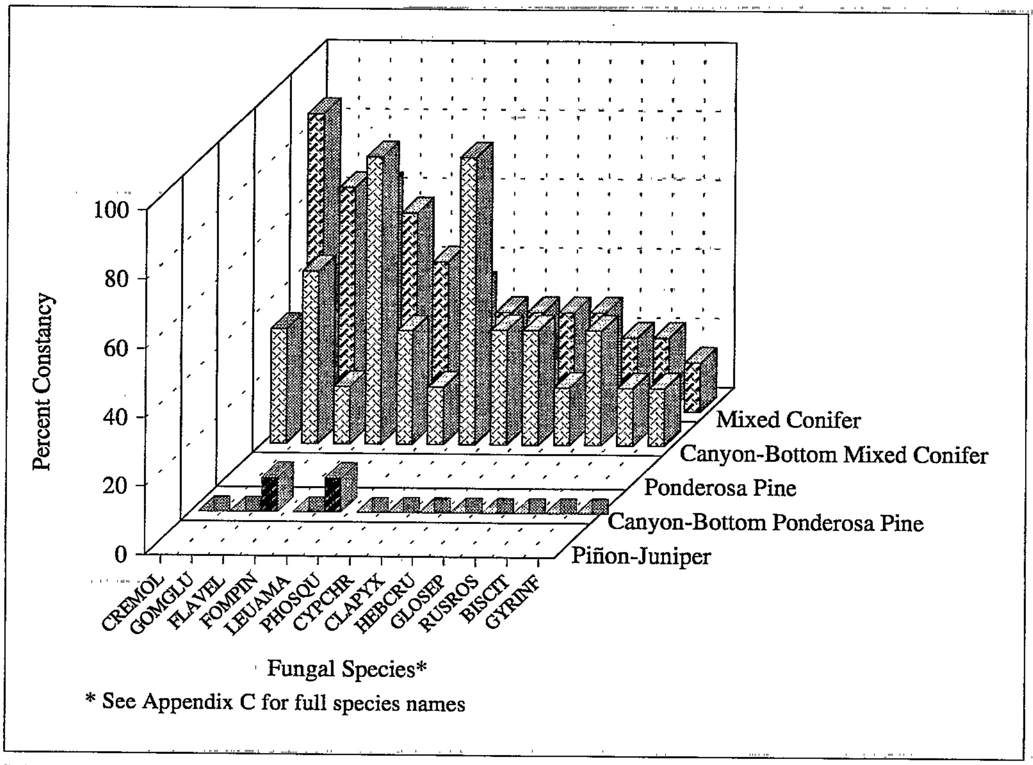

Figure 2. Fungal species found in canyon-bottom mixed conifer and mixed conifer habitat.

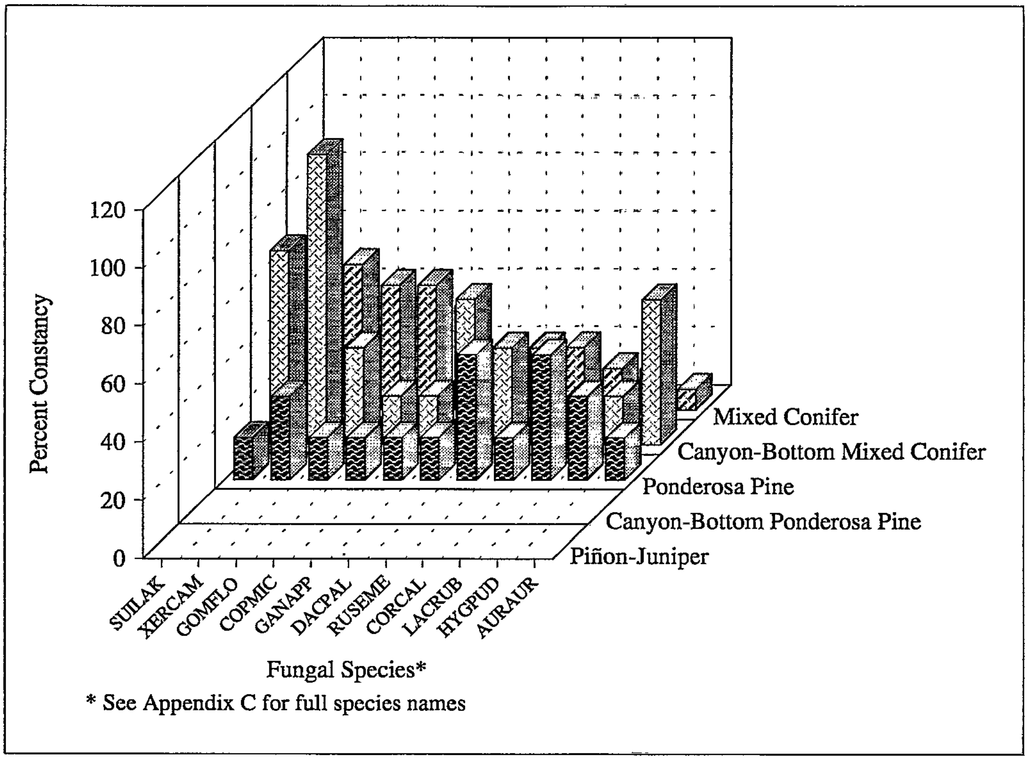

Figure 3. Fungal species found in ponderosa pine, canyon-bottom mixed conifer, and mixed conifer.

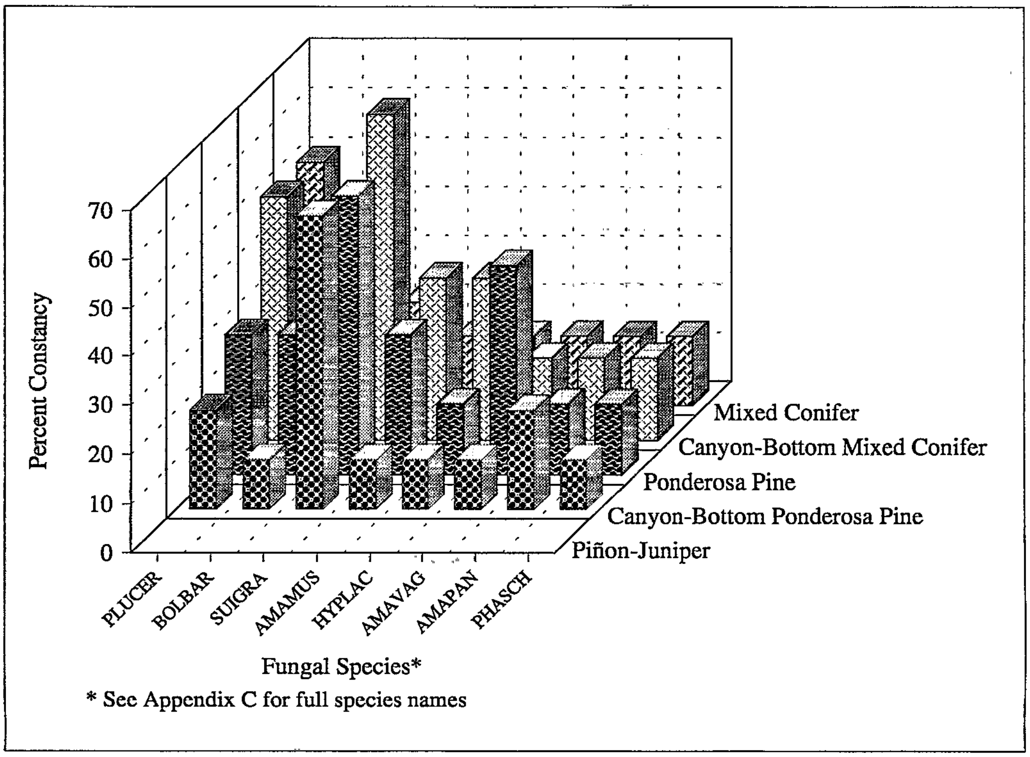

Figure 4. Fungal species foung in all habitats except piñon-juniper.

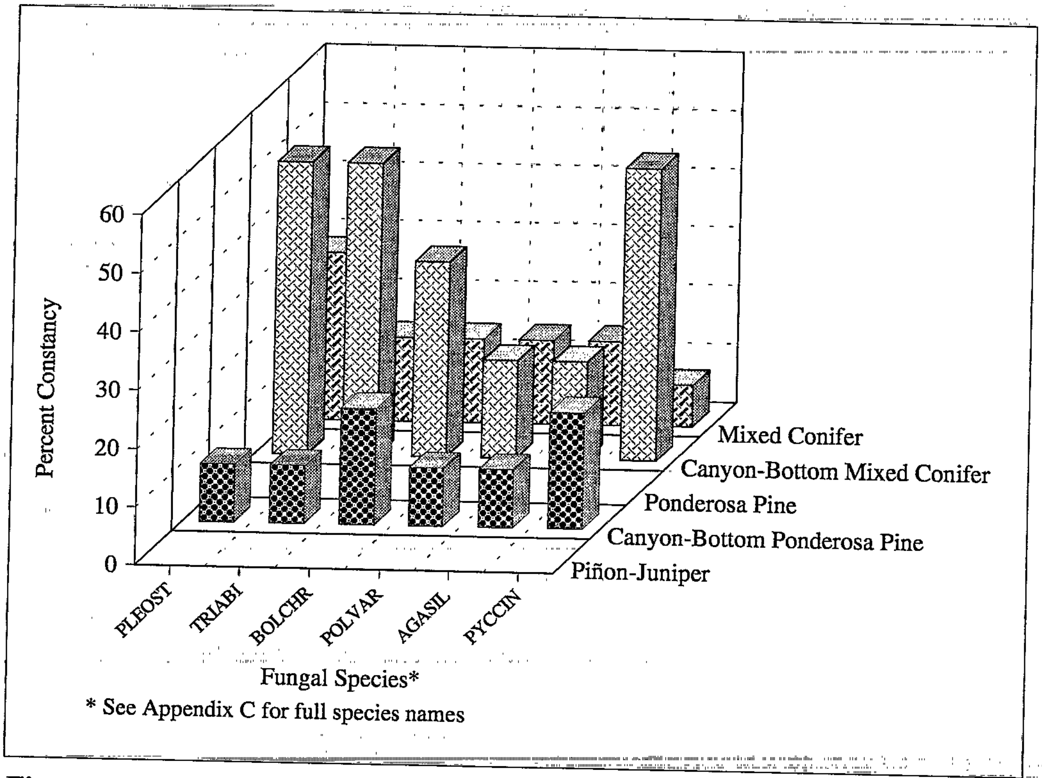

Figure 5. Fungal species found in canyon-bottom ponderosa pine, canyon-bottom mixed conifer, and mixed conifer habitats.

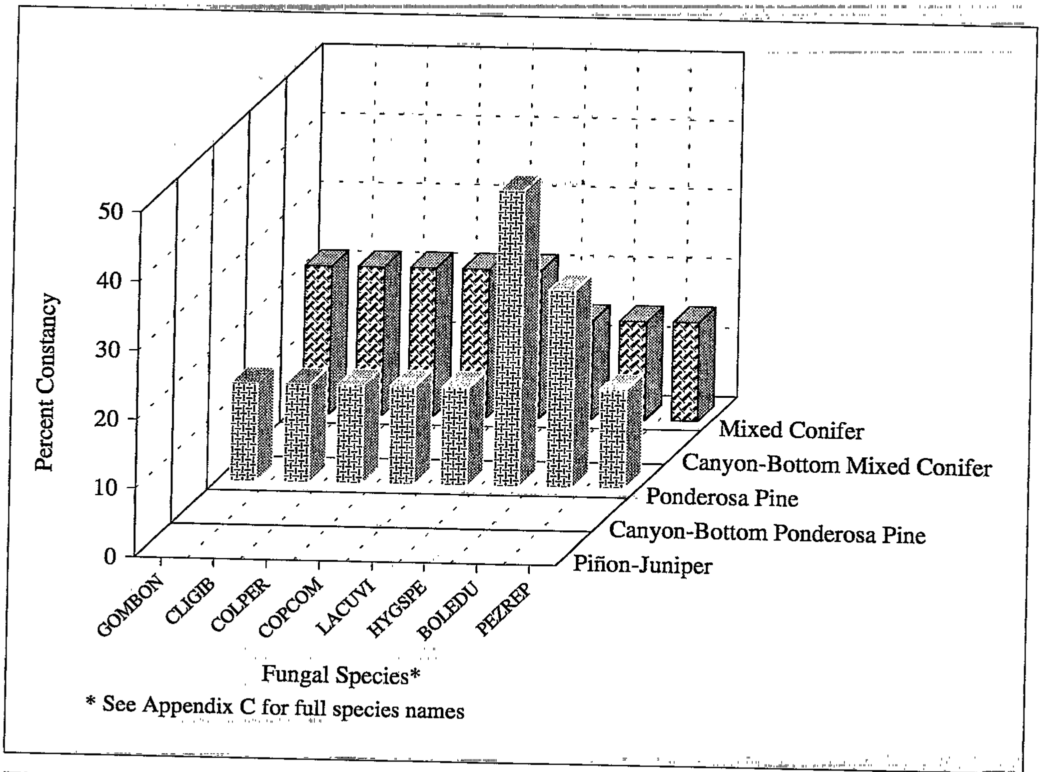

Figure 6. Fungal species found in the ponderosa pine and mixed conifer habitats.

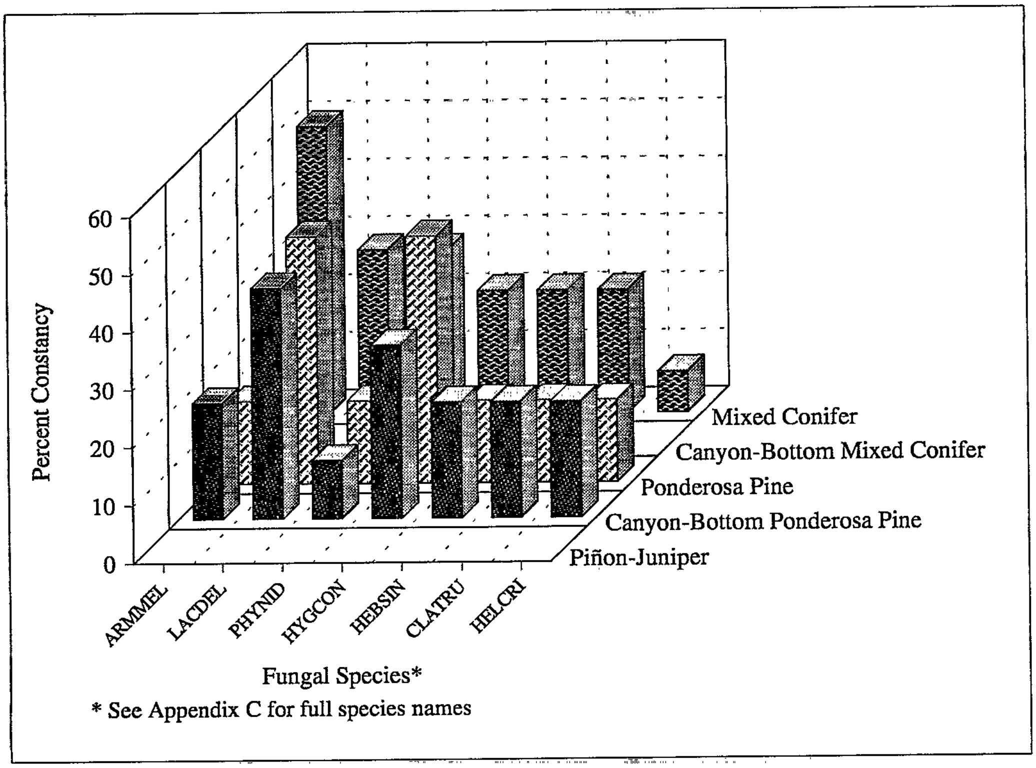

Figure 7. Fungal species found in the canyon-bottom ponderosa pine, ponderosa pine, and mixed conifer.

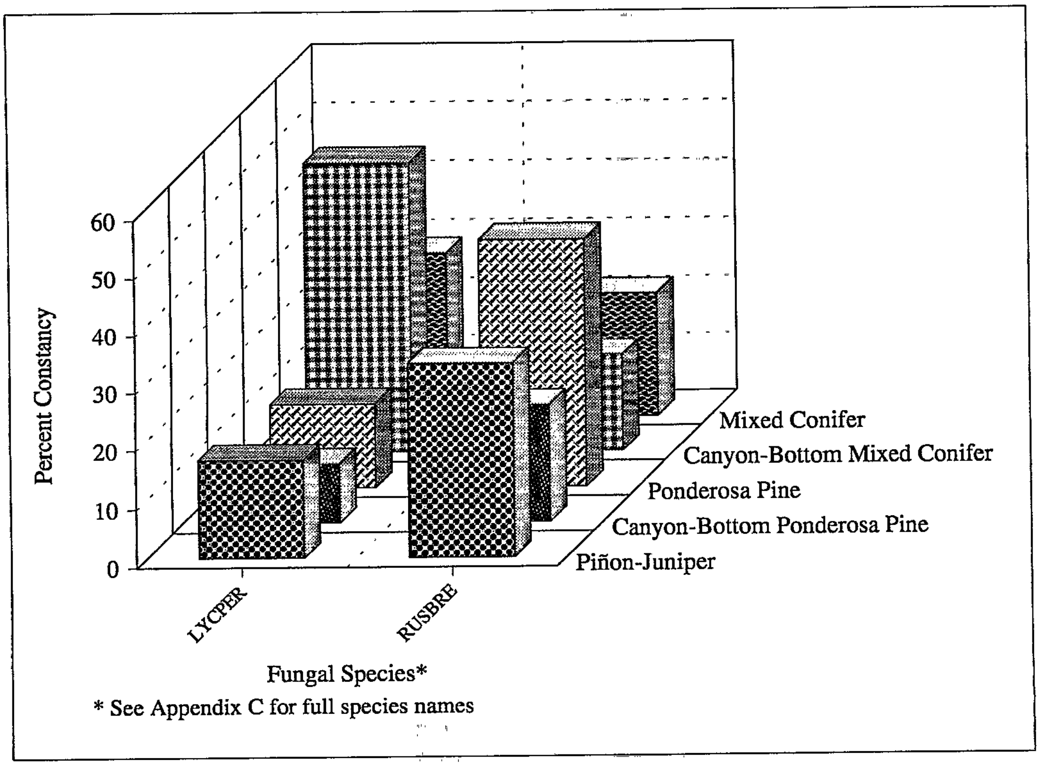

Figure 8. Fungal species found in all habitats.

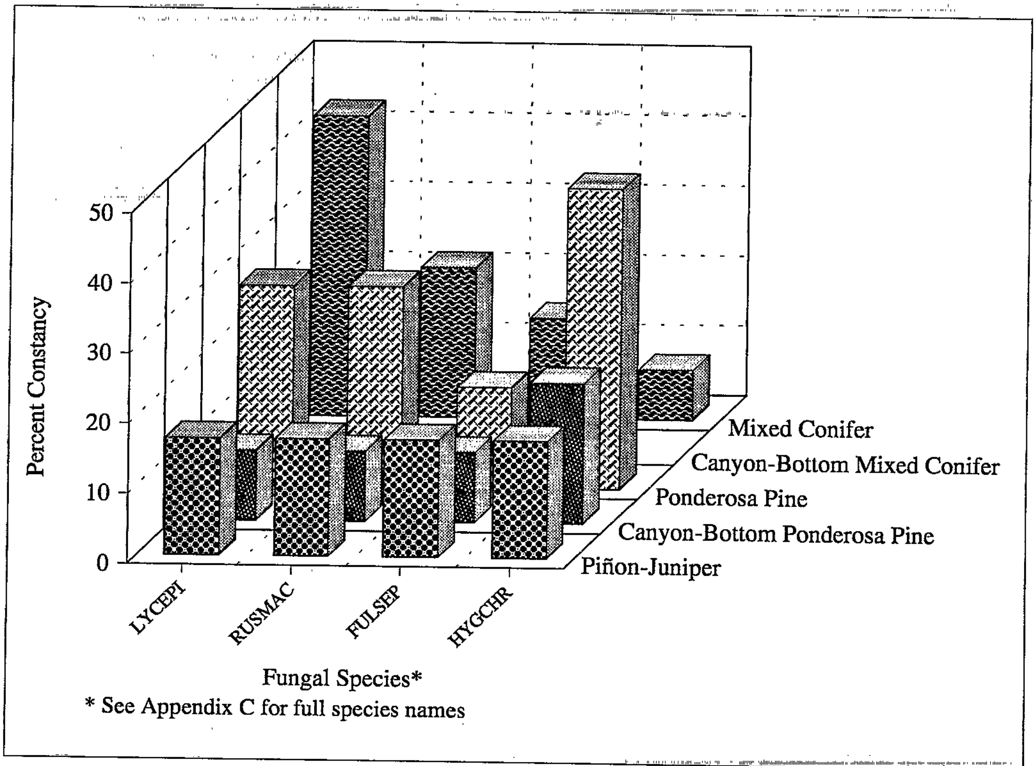

Figure 9. Fungal species found in piñon-juniper, canyon-bottom ponderosa pine, ponderosa pine, and mixed conifer.

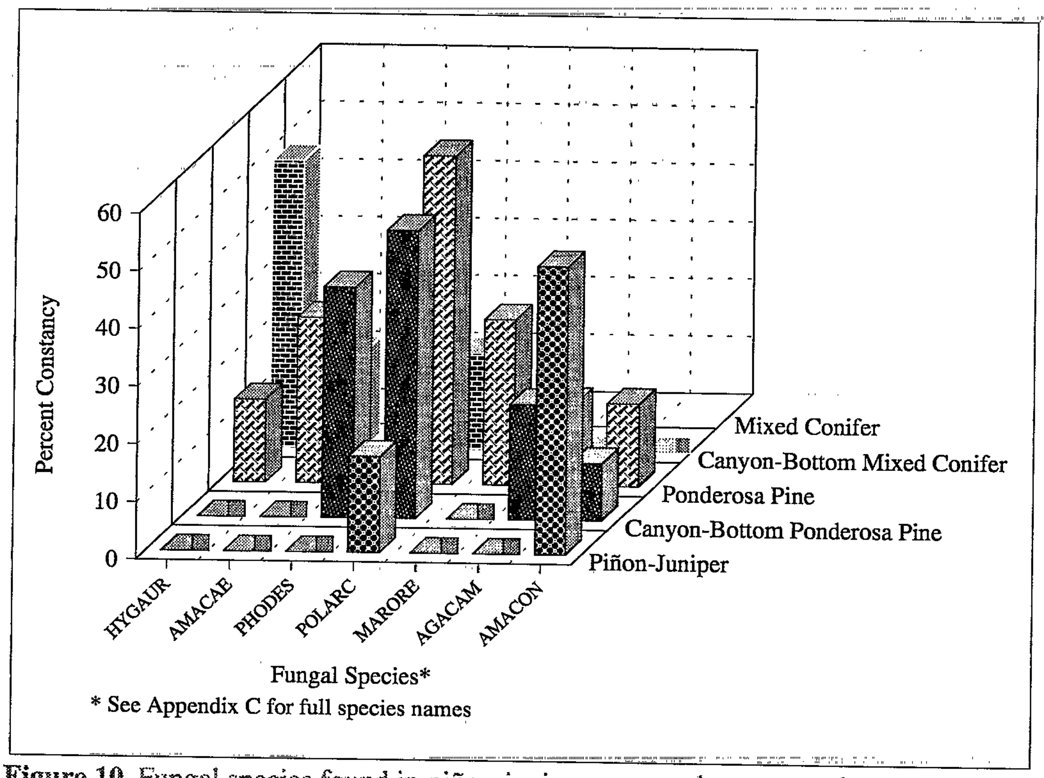

Figure 10. Fungal species found in piñon-juniper, canyon-bottom ponderosa pine, and canyon-bottom mixed conifer habitats.

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