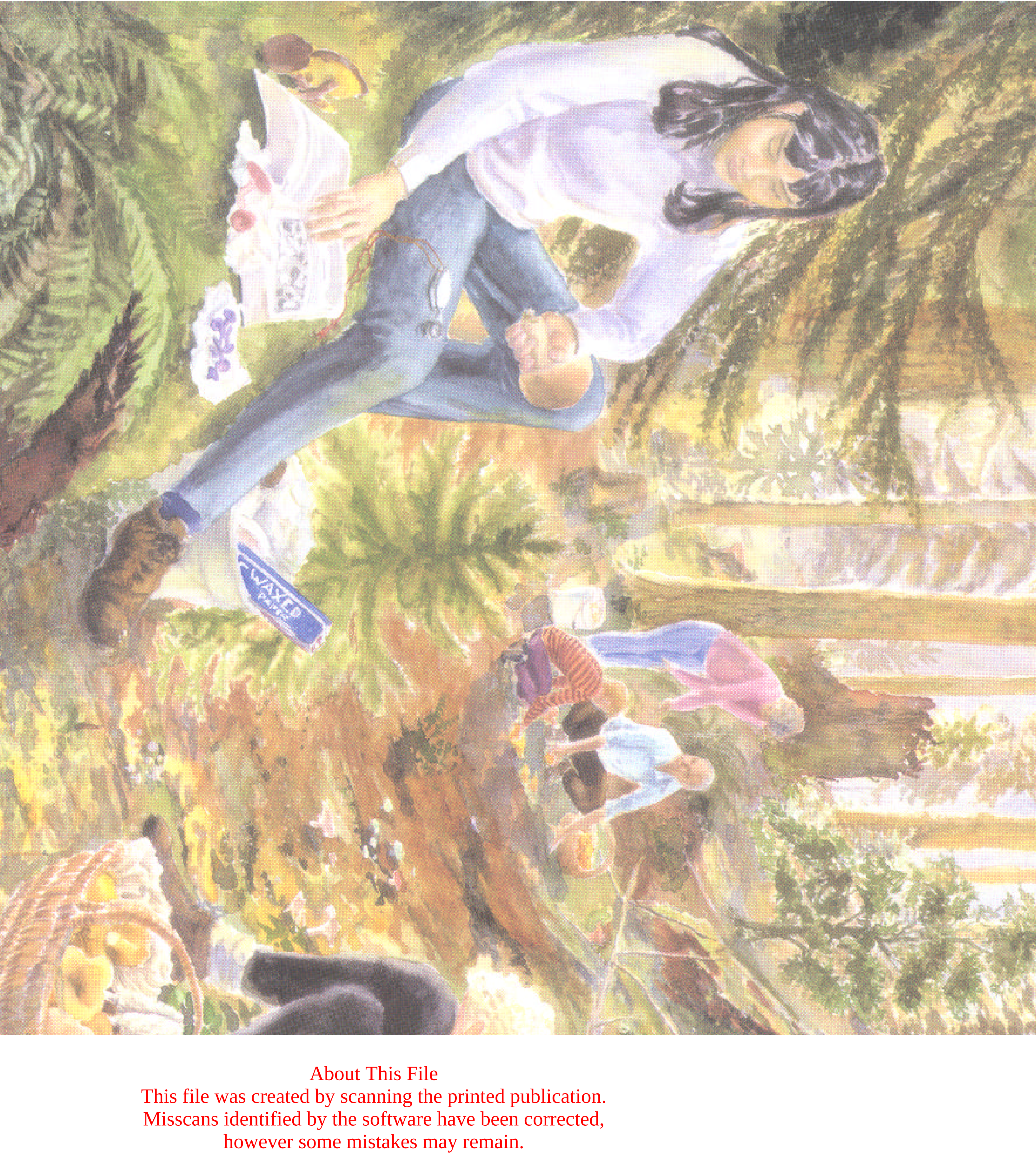
WAXED
PAPER

Key to the Front

1. *Boletus* spp. 2. *Lactarius* spp. 3. *Inocybe* spp. 4. *Tricholoma magnivelare* camouflaged by maple leaf. 5. *Sparassis crispa*. 6. *Hypholoma* spp. 7. *Strobilurus trullisatus*.

Editors

DAVID PILZ is a botanist and RANDY MOLINA is a research botanist and mycology team leader, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR

Managing Forest Ecosystems to Conserve Fungus Diversity and Sustain Wild Mushroom Harvests

David Pilz and Randy Molina, Editors

Ecosystem Management of Forest Fungi:
Inventory, Monitoring, and Biodiversity
Assessment

LaSells Stewart Center, Oregon State
University,
Corvallis, Oregon
May 3-4, 1994

U. S. Department of Agriculture
Forest Service
Pacific Northwest Research Station
Portland, Oregon
General Technical Report PNW-GTR-371
May 1996

Abstract

Pilz, D.; Molina, R., eds. 1996. Managing forest ecosystems to conserve fungus diversity and sustain wild mushroom harvests. Gen. Tech. Rep. PNW-GTR-371. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 104 p.

Ecosystem management is the dominant paradigm for managing the forests of the Pacific Northwest. It integrates biological, ecological, geophysical, and silvicultural information to develop adaptive management practices that conserve biological diversity and maintain ecosystem functioning while meeting human needs for the sustainable production of forest products. Fungi are important components of forest ecosystem management because they perform essential ecological functions, many species are associated with late-successional forests, and commercial harvest of wild edible mushrooms contributes significantly to the regional economy.

Inventory and monitoring provide essential information for improving management decisions, but fungi present a unique set of sampling challenges. To address these unique challenges, a conference entitled "Ecosystem Management of Forest Fungi" was convened May 3-4, 1994, in Corvallis, Oregon. This publication describes the forest management context of fungus inventory and monitoring issues, summarizes the mycological studies presented at the conference, and provides a synopsis of audience discussion. A common understanding of the challenges encountered when studying forest fungi will facilitate the planning and accomplishment of inventory and monitoring activities by improving communication among concerned individuals, interest groups, and land managers.

Keywords: Fungi, mushrooms, ecosystem management, forest management, inventory, monitoring, biodiversity, special forest products, mycorrhizae.

Contents

Introduction

The Pacific Northwest (a geographical region encompassing southeast Alaska, British Columbia, Washington, Oregon, Idaho, western Montana, and northern California) has long been recognized for its rich mycota (fungus biota), particularly the macrofungi that produce large, showy, fleshy sporocarps (fruiting bodies of mushrooms, truffles, conks, puffballs, and cup fungi). Much of that richness is directly related to the region's expansive forest communities, diverse weather patterns, and numerous tree species. Forest tree species form beneficial root symbioses (called mycorrhizae) with specialized fungi, and this factor contributes significantly to the diversity of fungi in the Pacific Northwest. Indeed, many of the mushrooms seen on the forest floor during late summer and autumn are the reproductive structures of mycorrhizal fungi that obtain their carbohydrate nutrition via the roots of host trees. The wood of live and dead trees and the abundance of other organic debris on the forest floor provide rich resources for numerous saprobic (decomposer) and parasitic fungi. Fungi also feature prominently in the complex forest food web, providing sustenance for organisms from microbes to mammals. These four major roles of fungi-mutualisms (especially mycorrhizal), nutrient cycling, pathogenesis, and food web resource–are cornerstones in the dynamic functioning of forest ecosystems, contributing to overall resiliency and diversity. If we are to succeed at managing forest ecosystems in their entirety, we must integrate the biological and functional diversity of forest fungi into future management plans.

Over the last decade, the extensive commercial harvest of several species of edible, forest mushrooms has heightened awareness and concern for forest fungi by both the public and resource managers. Schlosser and Blatner (1995) estimate that wild mushroom harvests contributed approximately $40 million to the economies of Oregon, Washington, and Idaho in 1992. Along with the economic benefits, however, came conflicts between recreational and commercial mushroom harvesters, and concerns about the potential overharvest of wild mushrooms and the impact of mushroom harvesting on forest ecosystems. Public outcry in the region led to enactment of legislation to regulate the commercial harvest of wild mushrooms on public lands in Washington (Washington State House Bill 2865, 1992) followed shortly by similar legislation in Oregon (Oregon State House Bill 2865, 1993). Since then, the U.S. Department of Agriculture (USDA), Forest Service, and U.S. Department of the Interior (USDI), Bureau of Land Management, have implemented permit systems for commercial and recreational harvest of wild forest mushrooms as one of several "special forest products." Users of the resource claimed that the regulations were arbitrary and based on little factual data regarding sustainability of the wild mushroom harvest.

A lack of knowledge regarding the biology and ecology of these unique forest organisms contributed to this controversy. The nature of the commercial industry was likewise a mystery. Users and managers disagreed on how best to manage and regulate the mushroom resource given the lack of harvest impact data. To bring interested parties together for sharing information, the Forest Service and Oregon State University sponsored a regional workshop in Springfield, Oregon, in November 1991 titled "Biology and management of wild, edible mushrooms in Pacific Northwest ecosystems"; over 300 attended. The objectives were to educate managers on the biology and ecology of forest fungi (particularly the commercially harvested species), discuss the social and economic issues of the commercial harvest, provide a forum for sharing concerns, and develop an information network for future mycological collaboration. Molina and others (1993) synthesized the findings of that workshop and set the groundwork for long-term regional management and monitoring of commercially harvested fungi.

The enactment of President Clinton's forest plan for the Pacific Northwestern United States, as detailed in the Forest Ecosystem Management Assessment Team (FEMAT) report (1993), provided new urgency for integrating forest fungi into the new ecosystem management paradigm. Five hundred and twenty-seven fungus species were identified as rare or old-growth-forest dependent and, therefore, potentially in need of protection under the regional plan. The viability of these species was evaluated as part of nine management alternatives. The final record of decision (USDA and USDI 1994) listed 234 fungus species as requiring immediate attention under the four survey-and-manage strategies of the plan. Among the eight groups of organisms listed (fungi, lichens, bryophytes, amphibians, mammals, mollusks, vascular plants, and arthropods), fungi was the largest. Two fungus species received the highest protected status; surveys for these organisms must be conducted before any new ground disturbance. Surveys and management of known sites for listed organisms must begin in 1995, and long-range plans call for regionwide mycological surveys over the next 10 years. The record of decision also emphasizes the need to manage and monitor special forest product species, such as edible mushrooms, within the emerging regional plan.

The FEMAT guidelines mandate an unprecedented study of fungi in the forests of the Pacific Northwest. Although FEMAT specifically addresses forests within the range of the northern spotted owl (*Strix occidentalis caurina*) in the United States, the surveys it mandates have added impetus to fungus studies throughout the geographical region. Professional mycologists and forest managers are concerned about the availability of knowledge and skilled individuals to conduct the fungus surveys and develop monitoring programs. We organized the workshop, "Ecosystem Management of Forest Fungi," to begin meeting these urgent training needs. Our primary objectives were to:

- Review the fundamental ecological roles of fungi in forest ecosystems
- Discuss concepts of biological diversity and conservation for forest fungi
- Discuss the ecology, productivity, and sustainability of commercially harvested forest fungi
- Discuss challenges and specific procedures for assessing fungus diversity and productivity
- Provide an update on current, relevant mycological research in the Pacific Northwest
- Provide opportunities to coordinate regional FEMAT-related surveys and monitoring activities
- Develop an ecosystem management and long-term monitoring framework for forest fungi

The workshop focused on mycorrhizal and some saprobic fungi because these groups encompass the valuable commercial species and those listed in the record of decision. Pathogens received only limited discussion and microfungi, none.

This publication documents the main presentations of the workshop and summarizes many of the issues. The first two sections address diversity and conservation of forest fungi and productivity and sustainable harvest of commercially valuable wild mushrooms, including the historical context of these issues and the unique challenges and considerations researchers face. Current studies presented at the conference are used to illustrate approaches to meeting these challenges, and are referenced in the discussions. Several authors have expanded their original presentations, added comments, answered questions brought forward by participants, and incorporated new data.

Finally, the principles of ecosystem management are illustrated with examples of managing forest fungi and a discussion of practical approaches for integrating forest fungi into ecosystem management. We view this workshop publication and its recommendations as essential first steps in the adaptive management process (Bormann and others 1994), whereby newly acquired information is continuously incorporated into revised management plans. Many of the survey and monitoring protocols are in their early years of field testing, and management recommendations are based on the best available information. As new monitoring information and field techniques become available, they should likewise be evaluated within the adaptive process. Managers can thus build on and use an ever-increasing store of shared experience and knowledge in their efforts to monitor and manage this critical resource.

Literature Cited

Bormann, B.T.; Cunningham, R G.; Brookes, M. H. [and others]. 1994. Adaptive ecosystem management in the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-341. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

Forest Ecosystem Management Assessment Team. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Portland, OR; U.S. Department of Agriculture; U.S. Department of the Interior [and others]. [Irregular pagination].

Molina, R.; O'Dell, T.; Luoma, D. [and others]. 1993. Biology, ecology, and social aspects of wild edible mushrooms in the forests of the Pacific Northwest: a preface to managing the commercial harvest. Gen. Tech. Rep. PNW-GTR-309. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 42 p.

Oregon State House Bill 2865. 1993. Chapter 167, Laws and Resolutions of 1993, 67th Oregon Legislative Assembly, Effective June 24, 1993.

Schlosser, W.E.; Blatner, K.A.1995. The wild edible mushroom industry of Washington, Oregon and Idaho: a 1992 survey. Journal of Forestry. 93(3): 31-36.

U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl. [Place of publication unknown]. 74 p.

Washington State House Bill 2865.1992. Chapter 184, Laws of 1992, 52nd Washington Legislative Assembly, Effective June 11, 1992.

Biological Diversity

Diversity and Conservation of Forest Fungi

Thomas E. O'Dell, Jane E. Smith, Michael Castellano, and Daniel Luoma[1]

Biological diversity has several meanings; most commonly it means the number of species in a particular location or habitat (species richness). It may also include the genetic diversity within species. This topic has immense practical importance to the sustainability and quality of human life and to human impacts on the environment.

Although human beings depend on other organisms for our survival, we have no accurate inventory of all species for any location. Our knowledge is directly proportional to the conspicuousness of a group of organisms; we know more about large vertebrates than about invertebrates and more about forest trees than forest fungi. Paradoxically, the "charismatic megafauna," about which we have the greatest understanding, depend (as do humans) on the poorly understood and inconspicuous groups such as fungi and bacteria. We know the least about the diversity of those organisms most fundamentally important to our existence.

The microbial world challenges our ability to describe diversity. A thimbleful of soil may contain 5 billion bacterial cells, perhaps 500,000 (about 0.1 percent) of those cells will grow in culture and have a chance of being identified to species. Perhaps 1 percent of the many thousands of types of fungi in that soil grow in culture. Because estimates of microbial diversity depend on growing cultures to identify species, our knowledge of soil microbial diversity lacks detail.

[1] **Thomas E. O'Dell** is with the Botany Department, University of Washington, Seattle, WA 98195; **Jane E. Smith** and **Michael Castellano** are with the USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331; and **Daniel L. Luoma** is with the Department of Forest Science, Oregon State University, Corvallis, OR 97331.

Soil fertility depends on bacteria for nitrogen fixation and fungi to release nutrients from organic matter, maintain soil structure, and aid plant nutrient and water uptake. These vital processes sustain agricultural and forest productivity; hence the effect of land management practices on soil microbial communities directly impacts resources needed by humans.

Genetic diversity within species, populations and individuals is arguably the most valuable natural resource available to humanity. The development of new crop varieties and plants with disease resistance uses germ plasm from wild relatives of the crop plants. Similarly, the multibillion dollar global pharmaceutical industry uses natural products, or chemicals derived from them, for many medicines (Farnsworth and Soejarto 1985, Groombridge 1992). An especially salient example for foresters in the Pacific Northwest is the anticancer drug "taxol," recently derived from the Pacific yew tree (*Taxus brevifolia* Nutt.) (Campbell 1991). Yet around the world, this biological inheritance is being diminished. The demand for natural resources is degrading terrestrial and aquatic ecosystems while depleting biological diversity at an alarming rate. Rates of species extinction currently approach the "mass extinctions" of the fossil record. In some groups of plants, it is estimated that up to one-half of the species may become extinct during the next 50 years (Smith and others 1993).

Many people believe that all organisms (including fungi) have an inherent right to exist. This premise is expressed by religions teaching that humans should act as responsible stewards of the land (Berry 1982) and that organisms have intrinsic value (Cobb 1988). This sense of responsibility for nature led to legislative protection of outstanding or scenic ecosystems (National Parks and Wilderness Areas) and prominent species (the Endangered Species Act, U.S. Laws 1973). There is growing recognition, however, that all species are valuable in the web of life and that the only practical means of conserving diversity is through appropriate management of representative habitats.

Fungus Diversity

Why care about fungi, forest fungi in particular? Why are they important? What do we know about their diversity in natural ecosystems? How can we broaden our understanding? What steps are necessary for protecting their diversity?

We cannot include all fungi in this discussion; they simply are too numerous. We will focus on mushrooms, truffles, puffballs, and shelf and cup fungi, a group that produces large sporocarps and encompasses many important ectomycorrhizal, saprobic, and parasitic species. The many other types of fungi critically important to the function of healthy ecosystems include molds, yeasts, lichen symbionts, endophytes, and endomycorrhizae. These fungi are more difficult to study, however, especially in natural settings, and their sheer numbers can overwhelm scientists and managers alike. In contrast, scientists have a century of observations about the rarity or commonness of large sporocarp production in natural settings, and some of the current concern about fungi in forest ecosystems is engendered by the large-scale harvest of a few commercially valuable species.

Some ectomycorrhizal fungi form long-lived symbioses with the roots of higher plants (for reviews see Allen 1991, Harley and Smith 1983, O'Dell and others 1993). The fungi can extend the nutrient-absorbing surface area of the roots, produce extracellular enzymes that increase phosphorous and nitrogen availability, increase host drought tolerance, and protect against pathogens (Trappe and Fogel 1977). In return, the fungi receive host photosynthate as their main source of carbon. Some sources estimate 50 to 70 percent of the net annual productivity of trees may be translocated to roots and associated mycorrhizal fungi (Fogel and Hunt 1979, Norton and others 1990, Vogt and others 1982). Exudates and hyphae of ectomycorrhizal fungi form a major link between aboveground producers and soil food webs, providing an energy source for a wide range of bacteria, protozoa, arthropods, and microfungi. Many large edible mushrooms, such as chanterelles (*Cantharellus* species) and matsutake (*Tricholoma* species) are sporocarps of mycorrhizal fungi.

Saprobic fungi perform essential ecosystem functions by decomposing organic matter and cycling nutrients. Some species, such as the *Armillaria mellea* complex, may originally infect trees as parasites and then continue to decompose trees after death. Many saprobic macrofungi can decompose cellulose, chitin, and lignin, essential abilities for decaying wood (Moorhead and Reynolds 1992). By decomposing coarse woody debris, these fungi soften the interiors of snags and logs, which allows birds and small mammals to burrow into them and create nests and dens (Harmon and others 1986; Maser and others 1978, 1988; Perry 1994; Thomas and others 1979). Well-rotted coarse woody debris also retains large quantities of water during dry weather, and this reserve is tapped by mycorrhizal fungi and tree roots that grow through it. Several saprobic species produce edible sporocarps commonly collected by humans, including oyster mushrooms (*Pleurotus ostreatus*), angel wings (*Pleurotus porrigens*), lion's mane (*Hericium abietis*), and sulfur-shelf (*Laetiporus sulphureus*) (Arora 1986).

Pathogenic fungi contribute to habitat diversity in forests by killing trees that later become snags and logs inhabited by wildlife and a variety of other organisms. Gaps in the canopy develop when diseased trees die and fall, and shade-intolerant plants flourish in these openings (Holah and others 1993). Thus, pathogenic fungi increase plant species diversity and create wildlife habitat. Some fungal parasites of tree roots produce mushrooms that humans eat, such as the honey mushroom (*Armillaria mellea* complex) (Arora 1986).

Mushrooms and truffles are important wildlife food (Carey 1991, Fogel and Trappe 1978, Maser and others 1978). They are consumed by deer, elk, bear, small mammals, and mollusks. Some rodents, such as the California red-backed vole (*Clethrionomys califomicus*) and northern flying squirrel (*Glaucomys sabrinus*), rely on these sporocarps for over 90 percent of their food supply (Hayes and others 1986, Maser and others 1985) and are, in turn, primary prey for species such as the northern spotted owl. Insects also consume sporocarps and are affected by sporocarp diversity and abundance (Fogel and Peck 1975, Worthen and McGuire 1990).

The commercial harvest of forest fungi in the Pacific Northwest has become a multimillion dollar industry. Recreational pickers also take to the woods to seek tasty morsels for the dinner table. Details of the wild mushroom harvest can be found in Molina and others (1993) and Schlosser and Blatner (1995) and will be discussed later in this publication.

Fungi remain an untapped reservoir of potential medicines. Many contain promising immune-stimulating and anticancer substances and have long been esteemed in Asian pharmacopoeias. Western medicine is beginning to examine fungi for treatment of AIDS, other viral diseases, and some cancers (Jong and Donovick 1989).

Given these many reasons to value and conserve fungus diversity, concern is growing over its possible loss. European studies provide salient documentation for this concern; decreased or discontinued fruiting has been noted among many species of macrofungi, coincident with widespread forest decline (Gulden and others 1992) and loss of forest habitat. In several long-term studies, diversity of ectomycorrhizal species has diminished by half since the 1950s (Arnolds 1991). Fungus species associated with late successional forests show the greatest decline.

In the Pacific Northwest, habitat alteration, principally due to logging, and the potential impacts from commercial harvest of mushrooms are the primary concerns. Exclusion of fire from habitats where it is a normal disturbance also may have impacted fungus species. Logging and other management activities affect fungi differently (some species increase, others decrease), and impacts on particular species or fungus diversity as a whole require further investigation (study 2, this document; North 1993; O'Dell and others 1992).

Much of the controversy surrounding the management and harvest of late successional forests in the Pacific Northwest during the last decade has centered around the northern spotted owl and its listing as a threatened species under the Endangered Species Act (U.S. Laws 1973). Legal challenges to forest management plans emphasized that many other species also depend on this declining habitat. Managing portions of the forest for each individual species that may be threatened is not generally practical and habitat needs overlap considerably. Preserving biological diversity requires holistic management of forest ecosystems, including the physical processes and biological interactions that sustain viable populations of numerous species over time.

Conservation of Fungi and the President's Northwest Forest Plan

Following President Clinton's April 2, 1993, forest conference in Portland, Oregon, the Forest Ecosystem Management Assessment Team (FEMAT; 1993) developed management alternatives (within the context of environmental laws) to balance forest conservation with the economic and social needs of people in the Pacific Northwest. The team focused on the maintenance and restoration of biological diversity, particularly in late successional and old-growth forests within the geographic range of the northern spotted owl. FEMAT evaluated the likelihood of maintaining sufficient well-distributed habitat on Federal lands to provide for continued viability of 1,119 fungus, plant, and animal species associated with old-growth forests. The panel of mycological experts identified 527 fungus species (47 percent of all species listed) as strongly associated with old-growth forests or their legacy (for example, coarse woody debris).

The Final Supplemental Environmental Impact Statement (FSEIS; USDA and USDI 1994a) shows additional analysis on late successional- and old-growth-related species. It focuses on public comments to the preferred alternative (alternative 9) and addresses the following objectives: (1) identify species needing additional consideration and analysis, (2) gather pertinent information on potential impacts of forest management on these species, and (3) discuss specific mitigation measures, including their benefits and costs of implementation.

Of the 1,119 species initially considered, 715 had adequate habitat protection or were not expected to be adversely affected by the cumulative effects of anticipated land management activities, so were dropped from further consideration. Of the 214 fungus species that remained on the list after this screening, 129 are known from only one or a few sites. Eighty of these are endemic to the Pacific Northwest. The FSEIS specifies site management for all type localities to ensure continued viability of each species. Additional research on the population biology of these species will facilitate efficient management of these sites.

The final record of decision (USDA and USDI 1994b) is the document that specifies how the FSEIS will be implemented. Table C-3 in that document lists 234 fungus species deemed "of special concern." These species were analyzed and classified into four survey categories. Survey strategy 1 requires management of known sites for all species shown in table C-3. Sites with rare and endemic fungus species will have 64.8 hectares (160 acres) temporarily withdrawn from management activities until those sites can be thoroughly surveyed and site-specific management measures prescribed. One particular fungus, the "noble polypore" *(Oxyporus nobilissimus),* will have 240 hectares (600 acres) of habitat preserved at each known fruiting location. Survey strategy 2 requires surveys before the occurrence of any ground-disturbing activities. Only two fungus species require this strategy: *Oxyporus nobilissimu* and *Bondarzewia Montana* [note: *B. Montana* (Quel.) Sing. will be changed to *B. mesenterica* (Schaeff.) Kreisel in the near future]. Survey strategy 3 requires conducting extensive surveys to find high-priority sites for species management. All 234 fungus species are included in survey strategy 3, and protocols are currently under development. The general regional surveys of strategy 4 are designed to provide further information about little-known species not yet designated as rare and endemic. These regional surveys must begin before 1997 and are expected to take 10 years to complete.

The FSEIS survey strategies apply to all Federal lands in the range of the northern spotted owl, and Federal research agencies are developing the monitoring protocols. The Pacific Northwest Research Station represents the U.S. Department of Agriculture, Forest Service, in this program. Research activities of land management agencies within the U.S. Department of the Interior (National Parks, Bureau of Land Management, and Fish and Wildlife Service) were recently merged into the National Biological Service and given the mission "to gather, analyze, and disseminate the information necessary for the wise stewardship of our Nation's resources *...."* Immediate priorities include establishing or expanding research and inventory programs in biologically diverse areas or in unique ecosystems, and documenting which species live in the United States, where they live, and how they are related to one another in an evolutionary sense. A report of the National Research Council (1993) recommends inclusion of macrofungi; however, funding is generally not yet available to survey and monitor them.

The FEMAT report, the FSEIS, and the final record of decision have set the initial course for conservation of forest fungi in Pacific Northwest forests by stipulating management of known sites and initiating long-term, regionwide surveys on the distribution and abundance of listed fungi. Researchers and managers must collaborate to develop practical field procedures and information protocols for monitoring and protecting wild fungi.

Research Challenges and Considerations

Investigators who study fungus diversity and the ecosystem functions of macrofungi must consider a unique set of research challenges and practical considerations when designing and implementing their survey, monitoring, and research activities.

Detection of Species

The thallus (literally "body") of a fungus typically consists of a web of hyphae (filaments or threads of cells) collectively called "mycelium." This mycelium grows immersed in its substrate (wood, host tissue) or habitat (soil) and thus is concealed from casual observation. An individual fungal thallus (also "mycelium" or "mycelial colony") may live for many years in one spot yet produce sporocarps infrequently. We currently depend on the occurrence of these ephemeral and sometimes sporadically produced sporocarps to demonstrate the presence of a species at a site, with the exception of perennial woody conks. Therefore, a site must be repeatedly scrutinized to survey or monitor species of interest. Failure of a species to fruit for several years evokes uncertainty about whether the colony has died, lies dormant, or is merely not fruiting.

Phenology

Although some species, (for example, *Coprinus comatus)* can fruit whenever environmental conditions are appropriate, most species fruit in a particular season. Within that season, a particular set of environmental conditions generally is necessary to trigger fruiting. For example, chanterelles and russulas can start fruiting in early to mid summer given sufficient moisture, but other species, such as matsutake, rarely fruit until temperatures cool in the autumn, even if moisture is available earlier. Mushrooms that fruit in a particular season may still fruit at different times of the year in different locations. For instance, matsutake fruits in August in northern British Columbia, September and October in the Oregon Cascade Range, and November in the Siskiyou Mountains. Even in nearly the same location, different habitats can influence fruiting phenology. In the Oregon Dunes National Recreation Area, matsutake can start fruiting in August in the fog zone within a few kilometers of the coast, or as late as November slightly further inland.[2] Ammirati and others (1994) illustrate the strong phenological component of field mycological studies. They visited a site weekly from April through December for 2 years. Species differed in the months in which they were encountered, and from year to year, given species were observed in different months. About half of the autumn species were observed in either September or October but not in both months. About a third of the autumn species would have been missed by sampling in a single month, more if fewer samples were taken per month.

Fungi produce sporocarps in response to environmental and physiological factors, especially adequate moisture and appropriate temperatures, and general descriptions of seasonal fruiting patterns are available for many species. Spring fruiting usually occurs with the onset of warm days and nights. Plant species that depend on warm temperature rather than increasing day length for flowering, such as *Linnaea borealis* (twin-flower), are useful indicators of spring fruiting. Such indicator species are particularly useful for less easily observed hypogeous (underground-fruiting) species that form truffles. After dry summers, autumn fruiting typically begins 10 to 14 days after the first rain that is sufficiently heavy to wet the top few centimeters of soil beneath a forest canopy. Fruiting diminishes with snowfall or heavy frosts. The specific local combination of moisture and temperature that initiates fruiting, however, has been described for wild species in only a few cases (Hosford and Ohara 1995, Norvell and others 1995).

---

[2] Personal communication. 1994. Dan Seggotta, botanist, Oregon Dunes National Recreation Area, Siuslaw National Forest, Reedsport, OR 97467.

Timing of seasonal fruitings and response to weather conditions also are influenced by site-specific factors. For instance, forests at high elevations experience more dew and fog drip than those at low elevation, thereby allowing fungi to fruit at high elevations during otherwise dry summer months. Likewise, forest stands with relatively open canopies may allow brief rain showers to penetrate and wet the forest floor more readily than stands with dense canopies. Other than these general observations, few data exist on the fruiting responses of fungi to site-specific conditions.

Long-term phenological studies that correlate site and weather factors with patterns of fruiting are needed to allow researchers and managers to reliably predict sporocarp production. It is even possible that multiple-year patterns in the physiology of host trees (similar to 5- to 7- year cycles in conifer cone-production levels) may influence annual fruiting of mycorrhizal fungi.

Sampling Frequency

Given the large variation in fruiting phenology among species and our current inability to predict annual fruiting patterns, repeated sampling is required to fully characterize fungus diversity in forests. Sampling in both spring and autumn is necessary to capture the dichotomy in seasonal fruiting patterns among many species. Thorough species inventories require at least 5 years of monthly to weekly visits during potential fruiting seasons. Selecting study sites that will not experience timber harvesting, mushroom picking, or other disturbances during this initial period provides baseline data uncomplicated by such extraneous influences. Regular sampling visits are costly, so conveniently located sites are important. Sampling objectives may be modified to capture diversity only at the peak fruiting season, but this limitation should be clearly noted in reported results.

Sampling Design

The most important consideration in planning any study is a clear objective. If the objective is to locate a specific rare fungus, then a "walk-through" by a trained mycologist may be most efficient. If a landowner merely wants a list of species occurrences, then a foray by a mycology club could be useful. Quantitative surveys of species frequency and abundance require systematic sampling methods, and if goals include the comparison of multiple sites or response to treatments (for example, timber or mushroom harvesting) then careful experimental design is essential.

Field sampling designs originally developed to inventory vegetation do not take into account the unique characteristics of fungi (Villeneuve and others 1989, Winterhoff 1992), particularly the patchy distribution of sporocarps. If the study encompasses multiple sites being visited weekly (equal areas should be examined with equal frequency at each site), several field crews may be needed or the sampling area at each site reduced. Sample area and sampling frequency deemed adequate to characterize diversity on a given site, or among compared sites, must be balanced with available personnel and fiscal resources through careful study design.

Fungi that occur on a particular, discrete substrate (for example, dung, leaf, log, or twig) can be sampled by treating the natural unit (leaf, cone, and so forth) as a sampling unit. Dividing a site into selected microhabitats and scrutinizing a subsample of each is referred to as "stratified" sampling, an efficient sampling design for substrate-specific groups of fungi.

Mushrooms, especially ectomycorrhizal species, often fruit in clusters or patches. Sampling designs with plots immediately adjacent to each other are likely to underestimate species diversity (O'Dell and others 1995), but widely spaced plots are more time consuming and costly to sample. Plot size and shape also influence sampling efficiency and practicality. Studies comparing the usefulness of various sampling designs for meeting different study objectives are needed to expedite fungus surveys, monitoring, and research.

Sampling Methods and Units of Measure

Study objectives also determine which sampling methods may be used. Documenting the presence of a rare species may be as simple as photographing, collecting voucher specimens, and ascertaining the fruiting location. Species lists, systematic surveys, long-term monitoring, and assessments of ecological niche or functioning require progressively more elaborate sampling methods.

Indices that combine numbers of species present (richness) with the abundance of each species are commonly used when the ecological implications of species diversity are studied. Three measures of sporocarp abundance are commonly employed: counts, frequency (percentage of plots in which the species is present or absent), and biomass. The choice of how fungi are measured directly affects which species is considered most important. To illustrate: consider measuring a plot containing one boulder weighing 10 kilograms (22 lbs), three cobbles totaling 5 kilograms (11 lbs), and 10 pebbles totaling 1 kilogram (2 lbs). All are equally frequent (one plot), pebbles are most numerous, and boulders have the most mass. Bear in mind that "abundance" (however defined) of sporocarps is an unknown reflection of the size and extent of the thallus of a given species. Sporocarp biomass may partially reflect annual changes in the energy reserves of a given fungus, but large genetic differences likely exist among species in the relative percentage of resources allocated to sporocarp production. Frequency reflects the area colonized by a species and therefore is a useful indicator of distribution. Numbers of sporocarps reflect neither resource allocation nor extent of mycelium but, like biomass, reflect annual variation in productivity within a species. A combination of measures may be most descriptive. Studies should explain why particular measures of abundance were selected.

Different sampling methods are needed for different types of fungi; for example, sporocarps of hypogeous (belowground) fungi, such as truffles, are generally produced below the soil surface. Their detection requires excavation and this causes sufficient habitat disruption that subsequent fruiting in the same location does not represent undisturbed conditions; typically, therefore, new plot locations are selected each sampling period. Epigeous (aboveground) sporocarps, such as mushrooms, are more easily located, but researchers must decide whether to simply count them, count number of plots where they are present, pick and weigh them (with potential impacts on subsequent fruiting), or count and measure their size. Study objectives and practical concerns dictate whether permanent or new plot locations are used.

Studies of ectomycorrhizal species diversity also can sample ectomycorrhizal root tips directly–a procedure described in study 3. Counting ectomycorrhizal root tips in soil cores estimates the extent to which various ectomycorrhizal fungi are colonizing root tips in a natural setting, thereby providing a more direct measure of mycelial abundance and ecological function than sporocarp production. To date, most studies of field ectomycorrhizae have relied on visually characterizing morphological types. The advent of quick, easy, and inexpensive molecular techniques for genetic identification will allow these types to be verified and identified to species. This advance will, in turn, allow researchers to correlate sporocarp abundance with mycorrhiza abundance (Gardes and Bruns 1991, 1992, 1993; Gardes and others 1991).

Sample processing methods depend on both the material collected and the planned analyses. Identification is essential to diversity assessment; hence, specimens that cannot be recognized immediately must be handled appropriately for subsequent examination. The identification of some species is facilitated by promptly noting fresh characteristics that quickly fade. Some mushrooms and most truffles can be refrigerated for several days, but other species decay overnight. Familiarity with identification keys and sporocarp characteristics is essential for knowing how to handle each specimen. Where identification cannot be conducted promptly, the typical procedure is to note fresh characteristics and dry the specimens for later examination. Some molecular techniques of genetic analysis can use dried material, but other procedures require fresh or frozen material. For measures of abundance that use biomass, collected mushrooms and truffles may be weighed fresh but commonly are dried to obtain comparable biomass data, because water content of sporocarps differs widely. Ectomycorrhizal root tips in soil cores can be refrigerated for weeks and separated for microscopic examination as needed.

Taxonomy

Collecting mushrooms and truffles is a relatively easy (albeit methodical) process, but identification often is challenging. Many mushrooms are easily identified, but many others can be reliably identified only by experts who prefer to examine fresh rather than dried specimens. Because most refrigerated collections remain fresh for only a few days, drying is necessary if timely examination by a taxonomist is not possible. Field personnel must be familiar with important features used in fungus keys so that they can take adequate notes on fresh characteristics for subsequent identification of dried samples.

Identification guides have only limited usefulness for some groups of North American fungi. For example *Cortinarius*, the most diverse mushroom genus, received its most thorough North American treatment over 50 years ago (Kauffman 1932). Consequently, collected species are often of unknown taxonomic affinity; that is, possibly described (but not in easily accessible literature), undescribed (that is, new to science), or not previously reported from North America. Distinctive species often can be readily identified by using popular field guides, but because of taxonomic difficulties, identifications of many species are frequently unreliable. Any investigation of fungi should document identifications with voucher collections deposited in an herbarium (Ammirati 1979).

Studies of fungus diversity are hampered by a shortage of trained mycological taxonomists, especially individuals with broad experience. Suggestions for resolving this difficulty are discussed in the last section of this publication.

Habitats and Forest

Conserving species diversity and sustaining the functional roles of fungi in forest ecosystems requires maintenance of diverse habitats for the growth and reproduction of numerous species. Although habitat requirements overlap among many species, others need specific or unique habitats to survive. We typically know little about these requirements; our ignorance often results from the difficulties of studying fungi and limited resources to do so.

The principles of conservation biology also are based on maintaining genetic diversity within species. This is accomplished by preserving numerous populations and ensuring gene flow among them. Ignorance of the population and reproductive biology of most fungi currently hinders conservation efforts. We poorly understand, for example, how long colonies live, how often new colonies are established, or how far apart they can be and still mate. These data are necessary to determine the size and distribution of appropriate forest habitats necessary for conserving fungus diversity.

Studies to fill the gaps in our knowledge may be either taxon or habitat based. Taxonbased studies target particular species. For example, *Oxyporus nobilissimus* and *Bondarzewia montana* are uncommon fungi requiring taxon-based inventory of habitats throughout their range. Study 5 in this document describes inventory and conservation measures for rare taxa.

A habitat-based approach correlates species distribution with environmental factors. Study 1 examines fungus diversity in several old-growth forest communities differing in annual rainfall. Species composition of ectomycorrhizal fungus communities also changes as forests mature; some species are more prevalent in young, others in older stands (Arnolds 1991, Deacon and Fleming 1992, Hinitikka 1988, Termorshuizen and Schaffers 1987). Study 4 examines relative fungus diversity in stands of varied age. Comparisons of mycological data from disturbed (harvested or burned) and undisturbed (old-growth) forests are needed to understand fungus community dynamics. Correlating site habitat factors such as coarse woody debris, stand age and density, understory vegetation, and soil conditions with fungus sporocarp occurrence will increase our knowledge of the effects of forest management practices on fungus diversity. Study 3 is an integrated research project addressing these issues.

Experiments with forest management treatments (for example, forest thinning or leaving coarse woody debris in areas that are clearcut) are useful for examining the response of fungi to management practices. These projects use many of the sampling methods discussed in this section, but sampling is conducted within the context of larger integrated research programs studying many ecosystem components. Studies 2, 3, and 6 are examples of this approach.

Cooperation

Taxonomic and sampling difficulties need not discourage us from learning more about distributions of macrofungi. Much empirical data exist for Europe (Arnolds 1992), and many investigations are underway in the Pacific Northwest. Cooperation among research institutions and land management agencies ensures that taxonomic, experimental design, statistical, and publication expertise is combined with practical field experience, and that results will be incorporated into updated management plans. Members of mycological groups, as well as graduate students in botany, forestry, and other natural resources, often provide invaluable field assistance; studies discussed in the next section have relied heavily on their support and will continue to benefit from their efforts.

Fungi perform indispensable ecosystem functions and have the potential to provide a broad range of sustainably produced commercial products. If diligently pursued, knowledge, conservation, and use of the diverse fungi in our region will reward society .

Literature Cited

Allen, M.F. 1991. The ecology of mycorrhizae. Cambridge, United Kingdom: Cambridge University Press. 184 p.

Ammirati, J. 1979. Chemical studies of mushrooms: the need for voucher collections. Mycologia. 71: 437-441.

Ammirati, J.; Ammirati, S.; Norvell, L. [and others]. 1994. A preliminary report on the fungi of Barlow Pass, Washington. McIlvainea. 2: 10-33.

Arnolds, E. 1991. Decline of ectomycorrhizal fungi in Europe. Agriculture, Ecosystems and Environment. 35: 209-244.

Arnolds, E. 1992. Mapping and monitoring of macromycetes in relation to nature conservation. McIlvainea. 10: 4-27.

Arora, D. 1986. Mushrooms demystified: a comprehensive guide to the fleshy fungi. Berkeley, CA: Ten Speed Press. 959 p.

Berry, W. 1982. The gift of good land. San Francisco: North Point Press. 281 p.

Campbell, S., ed. 1991. Pacific yew final environmental impact statement. [Place of publication unknown]: U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management; Food and Drug Administration. Appendices 1 and 2.

Carey, A.B. 1991. The biology of arboreal rodents in Douglas-fir forests. Gen. Tech. Rep. PNW-GTR-276. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 46 p.

Cobb, J.B., Jr. 1988. A Christian view of biodiversity. *In*: Wilson, E.O., ed. Biodiversity. Washington, DC: National Academy Press. 481-485.

Deacon, J.W.; Fleming, L.V. 1992. Interactions of ectomycorrhizal fungi. *In*: Allen, F.A., ed. Mycorrhizal functioning: an integrative plant-fungal process. New York: Chapman & Hall: 249-300. Chapter 8.

Farnsworth, N.R.; Soejarto, D.D. 1985. Potential consequences of plant extinctions in the United States on the current and future availability of prescription drugs. Economic Botany. 39(3): [pages unknown].

Fogel, R.; Hunt, G. 1979. Fungal and arboreal biomass in a western Oregon Douglas-fir ecosystem: distribution patterns and turnover. Canadian Journal of Forest Research. 9: 245-256.

Fogel, R.; Peck S.B. 1975. Ecological studies of hypogeous fungi. I: Coleoptera associated with sporocarps. Mycologia. 67: 741-747.

Fogel, R.; Trappe, J.M. 1978. Fungus consumption (mycophagy) by small animals. Northwest Science. 52: 1-31.

Forest Ecosystem Management Assessment Team. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Portland, OR; U.S. Department of Agriculture; U.S. Department of the Interior [and others]. [Irregular pagination].

Gardes, M; Bruns,T.D. 1991. Rapid characterization of ectomycorrhizae using RFLP patterns of their PCR amplified ITS. Mycological Society of America Newsletter. 42: 14.

Gardes, M.; Bruns, T.D. 1992. Molecular sampling of mycorrhizae: opposing views from above- and below-ground. Mycological Society of America Newsletter. 43: 22.

Gardes, M.; Bruns, T.D. 1993. ITS primers with enhanced specificity for basidiomycetes-application to the identification of mycorrhizae and rusts. Molecular Ecology. 2: 113-118.

Gardes, M.; White, T.J.; Fortin, J. [and others]. 1991. Identification of indigenous and introduced symbiotic fungi in ectomycorrhizae by amplification of nuclear and mitochondrial DNA. Canadian Journal of Botany. 69: 180-190.

Groombridge, B. 1992. Global biodiversity: status of the Earth's living resources. London: Chapman and Hall: 434-436.

Gulden, G.; Høiland, K.; Bendiksen, K. [and others]. 1992. Macromycetes and air pollution: mycocoenological studies in three oligotrophic spruce forests in Europe. Bibliotheca Mycologica. 144: 1-81.

Harley, J.L.; Smith, S.E. 1983. Mycorrhizal symbiosis. London: Academic Press. 483 p.

Harmon, M.E.; Franklin J.F. ; Swanson, F.J. [and others] 1986. Ecology of coarse woody debris in temperate ecosystems. Advanced Ecological Research. 15: 133 320.

Hayes, J.P. ; Cross, S.P ; McIntire, P. W. 1986. Seasonal variation in mycophagy by the western red-backed vole, *Clethrionomys califomicus,* in southwestern Oregon. Northwest Science. 60: 250-257.

Hinitikka, V. 1988. On the macromycete flora in oligotrophic pine forests of different ages in south Finland. Acta Botanica Fennica. 136: 89-94.

Holah, J.C.; Wilson, M.V ; Hansen, E.M. 1993. Effects of a native forest pathogen, *Phellinus weirii,* on Douglas-fir forest composition in western Oregon. Canadian Journal of Forest Research. 23: 2473-2480.

Hosford, D.; Ohara, H. 1995. Ecological study of *Tricholoma magnivelare* shiros in central Washington. *In*: Schnepf, C., comp., ed. Dancing with the elephant: Proceedings: The business and science of special forest products—a conference and exposition; 1994 Jan. 26-27; Hillsboro, OR. [Place of publication unknown]: University of Idaho Extension Service: 111-116. Sponsored by: Northwest Forest Products Association; Western Forestry and Conservation Association.

Jong, S.C.; Donovick, R. 1989. Anti-tumor and anti-viral substances from fungi. Advanced Applied Microbiology. 34:183-262.

Kauffman, C.H. 1932. *Cortinarius.* North American Flora. 10: 282-348.

Maser, C.; Cline, S.P. ; Cromack, K., Jr. [and others] 1988. What we know about large trees that fall to the forest floor. *In*: Maser, Chris; Tarrant, Robert F.; Trappe, James M.; Franklin, Jerry F. From the forest to the sea: a story of fallen trees. Gen. Tech. Rep. PNW-GTR 229. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 25-46.

Maser, C.M.; Trappe, J.M.; Nussbaum, R.A. 1978. Fungal-small mammal interrelationships with emphasis on Oregon coniferous forests. Ecology. 59: 799-809.

Maser, Z.; Maser, C.; Trappe, J.M. 1985. Food habits of the northern flying squirrel *(Glaucomys sabrinus)* in Oregon. Canadian Journal of Zoology. 63:1084-1088.

Molina, R.; O'Dell, T.; Luoma, D. [and others]. 1993. Biology, ecology, and social aspects of wild edible mushrooms in the forests of the Pacific Northwest: a preface to managing commercial harvest. Gen. Tech. Rep. PNW-GTR-309. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 42 p.

Moorhead, D. L.; Reynolds, J.F.1992. Modeling the contributions of decomposer fungi in nutrient cycling. *In*: Carroll, G.C.; Wicklow, D.T., eds. The fungal community: its organization and role in the ecosystem. New York: Marcel Dekker: 691-714.

National Research Council. 1993. A biological survey for the Nation. Washington, DC: National Academy Press. 205 p**.**

Norton, J.M.; Smith, J.L.; Firestone, M.K. 1990. Carbon flow in the rhizosphere of ponderosa pine seedlings. Soil Biology and Biochemistry. 22: 449-455.

Norvell, L.; Kopecky, F.; Lindgren, J.; Roger, J.1995. The chanterelle *(Cantharellus cibarius):* a peek at productivity. *In*: Schnepf, C., comp., ed. Dancing with the elephant: Proceedings: The business and science of special forest products–a conference and exposition; 1994 Jan. 26-27; Hillsboro, OR. [Place of publication unknown]: University of Idaho Extension Service: 117-128. Sponsored by: Northwest Forest Products Association; Western Forestry and Conservation Association.

O'Dell, T.E.; Castellano, M.A.; Trappe, J.M. 1993. Biology and application of ectomycorrhizal fungi. *In*: Metting F.B., ed. Soil microbial ecology: applications in agricultural and environmental management. New York: Marcel Dekker: 379-416.

O'Dell,T.E.; Luoma, D.L.; Molina, R.J. 1992. Ectomycorrhizal fungal communities in young, managed and old growth Douglas-fir stands. Northwest Environmental Journal. 8: 166-168.

O'Dell, T.E.; Schreiner E.G.; Ammirati, J.F. 1995. A comparison of aggregated and dispersed sampling for species richness of ectomycorrhizal fungi. Supplement to the Bulletin of the Ecological Society of America. 76 (3): 371.

Perry, D.A. 1994. Forest ecosystems. Baltimore: The Johns Hopkins University Press: 203-207.

Schlosser, W.E.; Blatner, K.A. 1995. The wild edible mushroom industry of Washington, Oregon and Idaho: a 1992 survey. Journal of Forestry. 93: 31-36.

Smith, F.D.M.; May, R.M.; Pellew, R. [and others]. 1993. Estimating extinction rates. Nature. 364: 494-496.

Termorshulzen, A.J.; Schaffers, A. P 1987. Occurrence of carpophores of mycorrhizal fungi in selected stands of *Pinus sylvestris* in the Netherlands in relation to stand vitality and air pollution. Plant and Soil. 104: 209-217.

Thomas, J.W.; Anderson R.G., Maser, C.; Bull, E.L. 1979. Snags. *In*: Thomas, Jack Ward, tech. ed. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Hand. 553. Washington, DC: U.S. Department of Agriculture, Forest Service: 60-77.

Trappe, J.M.; Fogel, R. D.1977. Ecosystematic functions of mycorrhizae. *In*: Proceedings: The below-ground ecosystem: a synthesis of plant-associated processes; [dates of meeting unknown]; [location of meeting unknown]. Range Sciences Department Science Series *25.* Boulder, CO: Colorado State University: 205-214.

U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994a. Final supplemental environmental impact statement on management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl. [Place of publication unknown]. 2 vol.

U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994b. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl. [Place of publication unknown]. 74 p. [plus Attachment A: standards and guidelines]

U.S. Laws, Statues, etc. Endangered Species Act of 1973 (as amended) 16 U.S.C. 1531-1543.

Villeneuve, N.; Grandtner, M.M.; Fortin, J.A. 1989. Frequency and diversity of ectomycorrhizal and saprophytic macrofungi in the Laurentide Mountains of Quebec. Canadian Journal of Botany. 67: 2616-2629.

Vogt, K.A.; Grier, C.C.; Meier, C.E.; Edmonds, R.L. 1982. Mycorrhizal role in net primary production and nutrient cycling in *Abies amabilis* ecosystems in western Washington. Ecology. 63: 370-380.

Winterhoff, W. 1992. Fungi in vegetation science. [City unknown], The Netherlands: Kluwer Academic. 258 p.

Worthen, W.B.; McGuire, T.R. 1990. Predictability of ephemeral mushrooms and implications for mycophagous fly communities. American Midland Naturalist. 124: 12-21.

Conference Presentations on Diversity and Conservation of Forest Fungi

Study I: Ecology of Ectomycorrhizal Fungi in Old Growth **Pseudotsuga menziesii-Tsuga heterophylla** *Forests of Olympic National Park*

Thomas E. O'Dell and Joseph F. Ammirati [1] [2]

Context

Despite their importance in many ecosystem processes, the ecology of ectomycorrhizal fungi in unmanaged habitats is little studied in North America (Klironomos and Kendrick 1993). A few investigators have documented fungus species distributions in hardwood versus coniferous forests in eastern North America (Bills and others 1986, Nantel and Neuman 1992, Villeneuve and others 1989). In northwestern North America, such studies (except for that of Cooke 1955) have focused on hypogeous (truffle-like) fungi (Fogel and Hunt 1979, Hunt and Trappe 1987, Luoma and others 1991). Hypogeous fungi, while ecologically important, comprise a small fraction of ectomycorrhizal species.

Although *Pseudotsuga menziesii* is estimated to host over 2,000 species of ectomycorrhizal fungi, little is known of the variation in fungus species richness between stands or habitats where it occurs (Molina and others 1993, Trappe 1977). Old-growth *P. menziesii-Tsuga heterophylla* (Douglas-fir–western hemlock) forests were selected for this study because the correlation between understory vegetation and climate is well documented (Franklin and Dyrness 1973, Henderson and others 1989, Zobel and others 1976), and the forest types are regionally important.

---

[1] Authors are with the Botany Department, University of Washington, Seattle, WA 98195.

[2] Cooperating was E.G. Schreiner, Olympic National Park, National Biological Service, U.S. Department of the Interior. Funds were provided in part by the National Science Foundation, DEB-9203262.

The Olympic National Park, with large areas of native forests and steep environmental gradients, is ideal for studying ectomycorrhizal fungi in relation to environment. The Olympic Mountains, rising steeply from the surrounding coastal plain and foothills, create a barrier to moisture-laden air from the Pacific Ocean. This geography creates a steep precipitation gradient with average annual rainfall of up to 600 centimeters (236 in.) in west-side valleys, compared to less than 50 centimeters (20 in.) in the rain shadow to the east. The western hemlock zone is the most common forest zone on the peninsula (see Houston and Schreiner 1994, for thorough discussion of climate, vegetation, and geology of the Olympic Peninsula).

Objectives

1. Describe occurrence of mycorrhizal fungus species in a range of old-growth *P. menziesii–T. heterophylla* forest types.

2. Determine whether mycorrhizal fungus species show preference for different plant associations.

3. Estimate standing crop of mycorrhizal fungus sporocarps in these associations.

4. Determine environmental factors that correlate with species diversity and sporocarp production.

5. Describe the spatial patterns of sporocarp production.

Methods and Rationale

Communities of ectomycorrhizal fungi, mushrooms, and their allies, were examined in the *P. menziesii–T. heterophylla* zone, in autumn 1992 and 1993 and spring 1993 and 1994. Within this zone, three understory vegetation types were studied and two to three stands from each type were sampled. A stand sample consisted of two parallel 245-meter-long (268-yd-long) transects, 5 meters (16 ft.) apart, each with one hundred, 4-square-meter (43-ft.^{2}) circular plots at 5-meter (16-ft.) intervals for a total area of 400 square meters (480 yd^2). Sporocarps were collected and vegetation data recorded for each plot. Sporocarps were identified, dried, and weighed to determine biomass. Species observed in the stand, but not in plots, were collected for species richness estimates, but were not included in biomass calculations. Percentage of cover by all perennial plant species and large woody debris was estimated in each plot. The diameter at breast height of all woody stems over 1 centimeter (0.39 in.), height of canopy dominant trees, and increment cores to obtain age and growth data for all size classes of trees were measured in two 500- or 1000-square-meter (600-1200-yd^2) plots (the minimum size necessary to include at least 30 stems) in each stand.

Plant communities for sampling were selected from field reconnaissance for common understory vegetation types. Multiple stands of each type were sampled to determine whether species of fungi prefer particular plant communities. Only putative ectomycorrhizal species, those producing above-ground sporocarps, were sampled, because of resource limitations; adding truffles or other groups of fungi would have restricted the study to fewer sites. Multiple samples were taken each season to increase the chance of detecting species that fruit for short times. The use of small sampling plots dispersed along transects was chosen on the assumption that a greater proportion of species in a stand would be detected than by using large plots divided into continuous subsamples. This sampling design also allowed testing for spatial patterns of sporocarp production. Plots were used to standardize the area sampled so that the different sites could be compared. Transects were moved for each sample period to avoid disturbance effects due to removing sporocarps. Plant associations were classified according to Henderson and others (1989.)

About 70 percent of species observed were actually collected in plots using this design. A few plots had extremely large biomass (over 10 grams [0.35 oz.] dry weight), while most had little or no biomass (that is, no sporocarps were present). Because of the large number of plots with no biomass, spatial pattern analyses are unreliable.

Unique Considerations

1. Funding limitations restricted research to 2 years, with one person working full-time on the project. No funds were available to hire additional field assistants.

2. A special challenge was identifying the great diversity of fungi encountered, particularly in the genus *Cortinarius*.

2. Lead investigator Thomas O'Dell had the opportunity to improve his mushroom
3. identification skills from collaboration with coinvestigator and expert mushroom taxonomist, Joseph Ammirati.

4. Access to Olympic National Park, where substantial old-growth forests are protected and extreme environmental gradients occur, was a unique opportunity.

Suggestions for future improvements in similar studies include:

1. Increased duration. The difference between the two years was extreme; a longer study would provide better comparisons among habitats, stands, and species.
2. Increased sampling frequency and area. Several species were observed in the stands but outside the sampled area, thus indicating the need to sample a larger area, or do more intensive sampling (more plots in the same total area). Ideally, one should sample weekly to fortnightly to detect most species.
3. Improved replication of habitats. Old-growth vegetation is highly variable. Conducting fungus studies of stands where the vegetation is already mapped would facilitate finding stands with similar vegetation, hence minimizing within-habitat variation. More stands of each type also could be sampled to compensate for existing within-habitat variation.

Current Status

Data analysis, problem identifications, and manuscript preparation are continuing. Sampling will continue at two sites for an additional project comparing sporocarp abundance and ectomycorrhizal dominance.

Literature Cited

Bills, G.F.; Holtzmann, G.I.; Miller, O.K., Jr. 1986. Comparison of ectomycorrhizal basidiomycete communities in red spruce versus northern hardwood forests of West Virginia. Canadian Journal of Botany. 64: 760-768.

Cooke, W.B. 1955. Fungi, lichens and mosses in relation to vascular plant communities in eastern Washington and adjacent Idaho. Ecological Monographs. 25: 119-180.

Fogel, R.; Hunt, G. 1979. Fungal and arboreal biomass in a western Oregon Douglas-fir ecosystem: distribution patterns and turnover. Canadian Journal of Forest Research. 9: 245-256.

Franklin, J.F.; Dyrness, C.T. 1973. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-8. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 417 p.

Henderson, J.A.; Peter, D.H. ; Lescher, R.D.; Shaw, D.C. 1989. Forested plant associations of Olympic National Forest. Tech. Pap. R6-001-88. [Place of publication unknown]; U.S. Department of Agriculture. Forest Service, Pacific Northwest Region.

Houston, D.B.; Schreiner, E.G. 1994. The Olympic Mountains and environs. *In*: Houston, D.B.; Schreiner, E.G.; Moorehead, B.B., eds. Mountain goats in Olympic National Park: biology and management of an introduced species. Sci. Monogr. NPS/NROLYM/NRSM-94/25. [Place of publication unknown]: U.S. Department of the Interior, National Park Service. Chapter 2.

Hunt, G.A.; Trappe, J.M. 1987. Seasonal hypogeous sporocarp production in a western Oregon Douglas-fir stand. Canadian Journal of Botany. 65: 438- 445.

Klironomos, J.N.; Kendrick, W.B. 1993. Research on mycorrhizas: trends in the past 40 years as expressed in the 'MYCOLIT' database. New Phytologist. 125: 595-600.

Luoma, D.L.; Frenkel, R.E.; Trappe, J.M. 1991. Fruiting of hypogeous sporocarps in Oregon Douglas-fir forests: seasonal and habitat variation. Mycologia. 83: 335-353.

Molina, R.; O'Dell, T.; Luoma, D. [and others]. 1993. Biology, ecology, and social aspects of wild edible mushrooms in the forests of the Pacific Northwest: a preface to managing commercial harvest. Gen. Tech. Rep. PNW-GTR-309. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 42 p.

Nantel, P.; Neuman, P. 1992. Ecology of ectomycorrhizal basidiomycete communities on a local vegetation gradient. Ecology. 73: 99-117.

Trappe, J.M. 1977. Selection of fungi for ectomycorrhizal inoculation in nurseries. Annual Review of Phytopathology. 15: 203-222.

Villeneuve, N.; Grandtner, M.M.; Fortin, J.A. 1989. Frequency and diversity of ectomycorrhizal and saprophytic macro-fungi in the Laurentide Mountains of Quebec. Canadian Journal of Botany. 67: 2616-2629.

Zobel, D.B.; McKee, A.; Hawk G.M.; Dyrness, C.T. 1976. Relationship of environment to composition, structure and diversity of forest communities of the central western Cascades of Oregon. Ecological Monographs. 46:135-156.

Study 2: Response of Ectomycorrhizal Fungi to Forest Management Treatments: Implications for Long-Term Ecosystem Productivity

Daniel L. Luoma, , Joyce L. Eberhart, and Michael P. Amaranthus[1] [2]

Context

Much of the interest in maintaining site productivity relates to a desire for nondeclining flows of timber harvest. On public lands, timber production is being integrated, however, into ecosystem management regimes where all the values we derive from forests are being managed interactively. Ectomycorrhizal fungi are important strands in the web of life in the soil and are essential for nourishing trees (Trappe and Fogel 1977).

This study examines critical aspects of the ecology of ectomycorrhizal fungi and will have strong management implications. The integrated research and extended perspective offered by this study will, for the first time, produce information on long-term interactions among mycorrhizal fungi, sustainable ecosystem productivity, and forest management practices.

This study was initially targeted for the Siskiyou Integrated Research Site in southwestern Oregon. Insight gained about the relations between disturbance effects, ectomycorrhizae, and site productivity will enable important interregional comparisons with the work of Harvey and others (1976, 1991) in the northern Rocky Mountains. Intraregional comparisons of sporocarp production will be possible with Fogel (1976), Hunt and Trappe (1987), Luoma (1991), Luoma and others (1991), and O'Dell and others (1992).

Objectives

This study is part of a large integrated research experiment on long-term ecosystem productivity (LTEP). It is designed to examine how vegetation structure in three classes (early, mid, and late seral stage) and coarse woody debris (CWD) at three relative levels of retention (low, medium, and high) interact to influence various ecosystem processes. Three important objectives of this study are to compare among early and late seral vegetation stage and low and high coarse woody debris treatments as follows:

1. The richness and relative abundance of ectomycorrhizal types as extracted from soil cores.
2. The species richness and biomass of ectomycorrhizal fungus sporocarp production.
3. The correlation between ectomycorrhizal type richness and sporocarp production.

---

[1] **Daniel Luoma** and **Joyce Eberhart** are with the Department of Forest Science, Oregon State University, Corvallis, OR 97331; and **Michael Amaranthus** is with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Grants Pass, OR 97526.

[2] Cooperating was Robyn Darbyshire, Siskiyou Integrated Research Site, Chetco Ranger Disuic, Siskiyou National Forest, Brookings, OR 97415.

The study is not intended to inventory or estimate total ectomycorrhizal species or type richness. Rather, the objectives are tailored to the framework of the experimental design. We are interested in characterizing species richness and biomass from representative samples in a manner that allows for testing of treatment effects.

Methods and Rationale

This study benefits from the opportunity to obtain pretreatment data. Although this is the ideal situation, such data cannot always be obtained. Pretreatment data were gathered in stands that will receive high and low CWD treatments within each early and late successional treatment. This is a 2- by 2-split-plot design. Including the untreated control stand, this design yielded five sample stands per block of the LTEP study design. Based on experience from studies in progress, previous work (Luoma 1991), and anticipated technical support, available resources were deemed adequate to sample three blocks for a total of 15 sample stands. Sampling the midsuccessional treatment was considered less critical because sporocarp production studies are underway in even-aged managed stands at the H.J. Andrews Experimental Forest (study 4).

Intensive sampling was conducted to provide high-quality data with useful levels of statistical precision. At least 2 years (preferably 3 years) of pretreatment sampling are necessary (Arnolds 1981, Fogel 1981, Lange, 1948, Luoma 1991, Richardson 1970) to establish reliable baseline data. These data quantify pre-existing variation within and among experimental units, thus clarifying interpretation of treatment effects and strengthening resultant inferences.

Each stand was sampled once each spring and autumn from spring 1992 through spring 1994. Ectomycorrhizal fungus community structure, as reflected by sporocarp production, has a strong seasonal aspect in our region (Fogel 1976, Hunt and Trappe 1987, Luoma and others 1991). Presumably, this seasonal response reflects aspects of ectomycorrhizal dynamics. Sporocarp sampling is timed to coincide with peak seasonal fruiting. Root sampling also centered on the fruiting season but may be extended over a longer part of the season. Post-treatment sampling (in 3-year increments) should occur during years 0-2, 4-6, 9-11, 14-16, 19-21, 29-31, and 49-51 and every 20 years thereafter. Luoma (1989), O'Dell and others (1992), and our studies in progress show differences in ectomycorrhizal fungus community structure by comparing stands at ages of 25 and 50 years and between 80, 160, and 400+ years. Little is known of mycorrhizal dynamics during the first 20 years after disturbance.
Ectomycorrhizal mushroom species were sampled by using 2- by 50-meter (6.56- by 164-ft.) strip plots. Treatment units were stratified into upper, middle, and lower slope positions. Three strip plots were permanently installed in each treatment stand sampled, one in each slope position. Three transient mushroom strip plots also were surveyed in each sample period, one in each slope position. At each sample period, hypogeous sporocarp production (truffles) was assessed in 25 systematically placed 4-square-meter (43 ft.^{2})plots. The truffle plots were established in conjunction with the transient mushroom plots along three transects with eight, nine, and eight plots each. Truffle plots were placed every 6 meters (19.7 ft.) along the center line of the transient mushroom plot. The transient mushroom plots were sampled only once with three new plots established each sample period.

Ectomycorrhizae were sampled by use of 6- by 15-centimeter (2.3- by 5.9-in.) soil cores. Cores were taken at each end of each permanent mushroom strip plot and a subset of transient plots. Three to six cores per treatment unit were obtained in each of three sample periods. Each core was washed in an elutriator and screened with 2-millimeter and 250-micrometer sieves. The coarse fraction was spread evenly in a 25.4-square-centimeter (4.06 in.^{2}) tray divided into 36 compartments with a plastic insert. Within each compartment, each ectomycorrhizal type encountered was recorded. This procedure provided the determination of relative frequency for each ectomycorrhizal type within the core. The mean number of types and relative frequency of each type will be used for treatment comparisons. The correlation between ectomycorrhiza abundance and sporocarp biomass will be tested.

Unique Considerations

Results from this study demonstrated utility of pretreatment sampling (Eberhart and others, in press; Luoma and others, in press). Because observed post-treatment differences could have origins in pretreatment conditions, baseline data enable analysis of post-treatment data with a broader range of tests than otherwise would be possible. These tests provide increased confidence and inferential power during interpretion of results. Sampling both sporocarps and ectomycorrhizae enables researchers to make complementary treatment comparisons and will provide insights into the relations between ectomycorrhiza abundance and sporocarp production.

Current Status

Pretreatment data collection is finished. Harvest treatments will be implemented in 1996.

Literature Cited

Arnolds, E. 1981. Ecology and coenology of macro-fungi in grasslands and moist heathlands in Drenthe, The Netherlands. Vaduz, Liechtenstein: J. Cramer. 410 p.

Eberhart, J.L.; Luoma, D.L.; Amaranthus M.P. [In press]. Response of ectomycorrhizal fungi to forest management treatments–a new method for quantifying morphotypes. *In*: Proceedings, 4th European symposium on mycorrhizae; 1994 July 11-14; Granada, Spain. [Place of publication unknown]: [Publisher unknown].

Fogel, R. 1976. Ecological studies of hypogeous fungi. II: Sporocarp phenology in a western Oregon Douglas-fir stand. Canadian Journal of Botany. 54: 1152-1162.

Fogel, R. 1981. Quantification of sporocarps produced by hypogeous fungi. In: Wicklow, D.T.; Carroll, G.C., eds. The fungal community, its organization and role in the ecosystem. New York: Marcel Dekker: 553-568.

Harvey, A.E.; Larsen, M.J.; Jurgensen, M.F. 1976. Distribution of ectomycorrhizae in a mature Douglas-fir/larch forest soil in western Montana. Forest Science. 22: 393-398.

Harvey, A.E.; Page-Dumroese, D.S.; Graham, R.T.; Jurgensen, M.F. 1991. Ectomycorrhizal activity and conifer growth interactions in western-montane forest soils. *In*: Proceedings, Management and productivity of western-montane forest soils; [dates of meeting unknown]; [location of meeting unknown]. Gen. Tech. Rep. INT-280. [Place of publication unknown]; U.S. Department of Agriculture, Forest Service: 110-118.

Hunt, G.A.; Trappe, J.M. 1987. Seasonal hypogeous sporocarp production in a western Oregon Douglas-fir stand. Canadian Journal of Botany. 65: 438-445.

Lange, M. 1948. The agarics of Maglemose. Dansk Botanisk Arkiv. 13: 1-141.

Luoma, D.L. 1989. Biomass and community structure of sporocarps formed by hypogeous ectomycorrhizal fungi within selected forest habitats of the H.J. Andrews Experimental Forest, Oregon. Corvallis, OR; Oregon State University. 173 p. Ph.D. thesis.

Luoma, D.L. 1991. Annual changes in seasonal production of hypogeous sporocarps in Oregon Douglas-fir forests. *In*: Ruggiero, L.F.; Aubry, K.B.; Carey, A.B.; Huff, M.H., tech. coords. Wildlife habitat relationships in old-growth Douglas-fir forests. Gen. Tech. Rep. PNW-GTR-285. Portland, OR;: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 83-89.

Luoma, D.L.; Eberhart, J.L.; Amaranthus M.P. [In press]. Response of ectomycorrhizal fungi to forest management treatments–sporocarp production. *In*: Proceedings, 4th European symposium on mycorrhizae; 1994 July 11-14; Granada, Spain. [Place of publication unknown]: [Publisher unknown].

Luoma, D.L.; Frenkel, R.E.; Trappe, J.M. 1991. Fruiting of hypogeous fungi in Oregon Douglas-fir forests: seasonal and habitat variation. Mycologia. 83: 335-353.

O'Dell, T.E.; Luoma, D.L.; Molina, R.J. 1992. Ectomycorrhizal fungal communities in young, managed and old-growth Douglas-fir stands. Northwest Environmental Journal. 8: 166-168.

Richardson, M.J. 1970. Studies of *Russula emetica* and other agarics in a Scots pine plantation. Transactions of the British Mycological Society. 55: 217-229.

Trappe, J.M.; Fogel, R.D. 1977. Ecosystematic functions of mycorrhizae. *In*: Proceedings of the below-ground ecosystem: a synthesis of plant-associated processes; [dates of meeting unknown]; [location of meeting unknown]. Range Sciences Department Science Series 25. Boulder, CO: Colorado State University: 205-214.

Study 3: Community Structure and Dynamics of Ectomycorrhizal Fungi in Managed Forest Stands: Demonstration of Ecosystem Management Options (DEMO) Program

Daniel L. Luoma, Joyce L. Eberhart, and Michael P. Amaranth us [1] [2]

Context

The demonstration of ecosystem management options (DEMO) program will gather data to test assumptions in standards and guidelines that currently direct forest ecosystem management in the Pacific Northwest. Treatments that implement various levels of live tree retention will be examined. The demonstration design consists of six approaches representing diverse retention strategies ranging from predominantly evenaged to uneven-aged systems. These experimental treatments are described in detail by Ford and others (1995) and White and Esterholdt (1995). Research on ectomycorrhizal fungi is an important part of the study.

Studies from the Pacific Northwest indicate that forest management activities can reduce abundance of ectomycorrhizal fungi and forest regeneration (Amaranthus and Perry 1989, Amaranthus and others 1990). In these studies, the abundance and rapidity of ectomycorrhiza formation were critical to seedling survival and growth, especially on harsh sites; however, across the Pacific Northwest the degrees of reduction of ectomycorrhizal fungi and impact on forest regeneration differ widely and depend on many factors. Ectomycorrhizal fungus species differ in their ability to provide particular benefits to their host, and their presence and abundance change during forest succession (Mason and others 1983, Trappe 1977). Recent research (Amaranthus and others 1994) indicates that previously clearcut young stands produce fewer sporocarps than intact mature forest fragments. No information is available, however, over a range of partial forest harvests and silvicultural systems.

Vegetational and structural changes during succession in Douglas-fir forests are well known (Franklin and others 1981, Spies and others 1988), yet we know little of ectomycorrhizal fungus community structure and diversity (Luoma and others 1991). Such data are essential to predict impacts of disturbance and management on ecosystem productivity. This study will integrate vegetation, wildlife, watershed, and economic responses with knowledge of ectomycorrhizal fungi and their underground functions. Critical aspects of ectomycorrhiza ecology that have strong management implications will be emphasized.

[1] **Daniel Luoma** and **Joyce Eberhart** are with the Department of Forest Science, Oregon State University, Corvallis, OR 97331; and **Michael Amaranthus** is with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Grants Pass, OR 97526

Objectives

The objectives of this study were:

1. To compare among no harvest and 75 percent, 40 percent, and 15 percent basal area retention treatments:
    - A. The species richness and biomass of ectomycorrhiza sporocarp production. (Sporocarp richness and biomass will be correlated with small mammal frequency and abundance, and with changes in plant community composition and structure, including coarse woody debris.)
    - B. The richness and relative abundance of ectomycorrhizal types. (Ectomycorrhizal richness and relative abundance will be correlated with changes in plant community composition and structure.
    - C. The correlation between ectomycorrhizal type richness and sporocarp species richness.
    - D. The importance of mycophagy in the diet of small mammals.

2. To compare within the 40- and 15-percent green tree retention treatments, the effect of dispersed and aggregated retention patterns on:
    - A. Species richness and biomass of ectomycorrhizal sporocarp production. (Sporocarp richness and biomass will be correlated with small mammal frequency and abundance and changes in plant community composition and structure.)
    - B. Richness and relative abundance of ectomycorrhizal types. (Ectomycorrhizal richness and relative abundance will be correlated with changes in plant community composition and structure.)

The study is not intended to inventory or estimate total ectomycorrhizal species or type richness. The objectives are tailored to the framework of the experimental design. We are interested in characterizing species richness and biomass from representative samples in a manner that will allow for testing of treatment effects.

Methods and Rationale

The integrated DEMO project is designed to replicate six live-tree retention treatments in eight geographic locations (blocks). These treatments consist of four levels of live-tree retention (15-, 40-, 75-, and 100-percent of existing live-tree basal area), with two patterns of retention (aggregated and dispersed) applied to the 15- and 40-percent retention treatments). The aggregated pattern consists of residual trees retained in clumps of about 1 hectare (2.47 acres) and the dispersed pattern has residual trees homogeneously dispersed throughout the unit. For the 75-percent retention treatment, all of the cut will occur in about 1-hectare (2.47-acre) patches dispersed throughout the unit. The 100-percent retention represents the control. Based on experience from studies in progress, previous work (Luoma 1989, 1991; Luoma and others 1991; O'Dell and others 1992), and anticipated technical support, sampling will be limited initially to three of the replicated blocks.

This study benefits from the opportunity to obtain pretreatment data. Although this is the ideal situation, such data cannot always be obtained. At least two years (preferably three years) of pretreatment sampling are necessary (Arnolds 1981, Fogel 1981, Lange 1948, Luoma 1991, Richardson 1970, Vogt and others 1992) to establish reliable baseline data. These data quantify pre-existing variation within and among the experimental units, thus clarifying interpretation of treatment effects and strengthening resultant inferences.

Ectomycorrhizal fungus community structure, as reflected by sporocarp production has a strong seasonal aspect in our region (Fogel 1976, Hunt and Trappe 1987, Luoma and others 1991). Each stand will be sampled once each spring and autumn. Sporocarp sampling will be timed to coincide with seasonal peak fruiting. Root sampling also will center on the fruiting season but may be extended over a longer part of the season. Mycorrhizal typing will generally follow the methodology of Eberhart and others (in press). Posttreatment sampling (in 3-year increments) should occur during years 0-2, 4-6, 9-11, 14-16, 19-21, 29-31, 49-51, and every 20 years thereafter.

Ectomycorrhizal mushroom species will be sampled by use of six strip plots (2 by 50 meters [6.5 by 164 ft.]) per treatment unit. Long, narrow, strip plots reduce trampling impacts within the plots and intercept a wider variety of microsites than circular plots of the same area (Luoma and others, in press; Mehus 1986; Ohenoja and Metsänheimo 1982; Ruhling and others 1984). During the pretreatment sampling phase, three strip plots will be permanently located within the treatment grid. Strip plot placement will be stratified by upper, middle, and lower slope position. In stands with gentle slopes, plots will be systematically placed in a dispersed pattern.

Sporocarps of each ectomycorrhizal fungus species will be collected separately for each square meter of the permanent strip plots. Three temporary mushroom strip plots will be established anew with each sampling. Sporocarps of each ectomycorrhizal species from the temporary strip plots will be treated as a single collection for that plot. In the laboratory, sporocarps will be identified, dried, and weighed to the nearest 0.01 gram to determine biomass. Following tree harvest in the dispersed and aggregated retention treatment areas, additional strip plots will be systematically assigned within undisturbed patches of residual forest. Post-treatment plot location and sampling will be closely coordinated with vegetation sampling to broaden the scope of interpretive inference.

Hypogeous sporocarp production will be sampled by using twenty-five 4-square-meter (43-ft.^{2}) plots placed every 6 meters (19.7 ft.) along the temporary mushroom plots in the upper, middle, and lower slope strata. For truffle fungi, a species collection is defined as a group of sporocarps of the same species that form a cluster with a radius < 10 centimeters (3.9 in.). In the laboratory, sporocarps will be further identified, dried, and weighed to the nearest 0.01 gram to determine biomass. In each plot, exposed mineral soil, cover of coarse woody debris (CWD), and decay class of the CWD will be recorded to enable analyses for correlation with truffle production (Amaranthus and others 1994). Distance from plot center to, and decay class of, the nearest piece of CWD > 8 centimeters (3.1 in.) in diameter and = 250 cubic centimeters (21.3 in.^{3}) in volume will be compared with distance from each species collection center to the nearest coarse woody debris with the same minimum size criteria. The percentage of cover of *Piloderma bicolor* (including related species) also will be recorded in truffle plots because it is most readily detected in its vegetative (mycorrhizal) state. *Piloderma* sp. are frequently found in soil with well-decayed woody material, but fruiting structures are rarely found; hence, excavation is the most efficient means to quantify relative abundance.

Unique Considerations

As part of a large integrated research project, experimental design and sampling methods must conform to the research and management needs of the entire project. The resulting benefit is that a wide variety of associated information will be available from other concurrent investigations. Data will be entered into the Forest Science Data Bank for permanent storage and use in long-term research. Representative voucher collections with the original field labels will be deposited in the Oregon State University Herbarium for long-term reference.

Current Status

Pretreatment baseline data collection is continuing.

References

Amaranthus, M.P.; Perry, D.A. 1989. Interaction effects of vegetation type and Pacific madrone soil inocula on survival, growth, and mycorrhiza formation of Douglas-fir. Canadian Journal of Forest Research. 19: 550-556.

Amaranthus, M.; Trappe, J.M.; Bednar, L.; Arthur, D. 1994. Hypogeous fungal production in mature Douglas-fir forest fragments and surrounding plantations and its relation to coarse woody debris and animal mycophagy. Canadian Journal of Forest Research. 24: 2157-2165.

Amaranthus, M.P.; Trappe, J.M.; Molina, R.J. 1990. Long-term forest productivity and the living soil. *In*: Perry, D.A.; Meurisse, R.; Thomas, B. [and others], eds. Maintaining the long-term productivity of Pacific Northwest forest ecosystems. Portland, OR: Timber Press: 36-52.

Arnolds, E. 1981. Ecology and coenology of macro-fungi in grasslands and moist heathlands in Drenthe, The Netherlands. Vaduz, Liechtenstein: J. Cramer. 410 p.

Eberhart, J.L.; Luoma, D.L.; Amaranthus M.P. [In press]. Response of ectomycorrhizal fungi to forest management treatments–a new method for quantifying morphotypes. *In*: Proceedings, 4th European symposium on mycorrhizae; 1994 July 11-14; Granada, Spain. [Place of publication unknown]: [Publisher unknown].

Fogel, R. 1976. Ecological studies of hypogeous fungi. II: Sporocarp phenology in a western Oregon Douglas-fir stand. Canadian Journal of Botany. 54: 1152-1162.

Fogel, R. 1981. Quantification of sporocarps produced by hypogeous fungi. *In*, Wicklow, D.T ; Carroll, G.C., eds. The fungal community, its organization and role in the ecosystem. New York; Marcel Dekker: 553-568.

Ford, E.D; Aubry, K.B.; White, J.D. [and others]. 1995. Demonstration of ecosystem management options: revised draft study plan. 28 p. On file with: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3625 93d Ave., Olympia, WA 98512-9193.

Luoma, D.L. 1989. Biomass and community structure of sporocarps formed by hypogeous ectomycorrhizal fungi within selected forest habitats of the H.J. Andrews Experimental Forest, Oregon. Corvallis; Oregon State University. 173 p. Ph.D. thesis.

Luoma, D.L. 1991. Annual changes in seasonal production of hypogeous sporocarps in Oregon Douglas-fir forests. *In*: Ruggiero, L.F.; Aubry, K.B.; Carey, A.B.; Huff, M.H., tech. coords. Wildlife habitat relationships in old-growth Douglas-fir forests. Gen. Tech. Rep. PNW-GTR-285. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 83-89.

Luoma, D.L.; Eberhart, J.L.; Amaranthus M.P. [In press]. Response of ectomycorrhizal fungi to forest management treatments–sporocarp production. *In*: Proceedings, 4th European symposium on mycorrhizae; 1994 July 11-14; Granada, Spain. [Place of publication unknown]: [Publisher unknown].

Luoma, D.L.; Frenkel, R.E.; Trappe, J.M. 1991. Fruiting of hypogeous fungi in Oregon Douglas-fir forests: seasonal and habitat variation. Mycologia. 83: 335-353.

Mason, P.A.; Wilson, J.; Last, F.T.; Walkem, C. 1983. The concept of succession in relation to the spread of sheathing mycorrhizal fungi on inoculated tree seedlings growing in unsterile soils. Plant & Soil. 71: 247-256.

Mehus, H. 1986. Fruit body production of macro-fungi in some north Norwegian forest types. Norwegian Journal of Botany. 6: 679-701.

O'Dell, T.E.; Luoma, D.L.; Molina, R.J. 1992. Ectomycorrhizal fungal communities in young, managed and old growth Douglas-fir stands. Northwest Environmental Journal. 8: 166-168.

Ohenoja, E.; Metsänheimo, K. 1982. Phenology and fruiting body production of macro-fungi in subarctic Finnish Lapland. In: Laursen, G.A.; Ammirati J.F., eds. Arctic and alpine mycology. Seattle: University of Washington Press: 371-389.

Richardson, M.J. 1970. Studies of Russula *emetica* and other agarics in a Scots pine plantation. Transactions of the British Mycological Society. 55: 217-229.

Ruhling, A.; Bååth, E.; Söderström, B. 1984. Fungi in metal-contaminated soils. Ambio. 13: 34-36.

Spies, T.; Franklin, J.F.; Thomas, T. 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. Ecology. 69:1689-1702.

Trappe, J.M. 1977. Selection of fungi for ectomycorrhizal inoculation in nurseries. Annual Review of Phytopathology 15: 203-222

Study 4: Measuring Fungal Succession in Douglas-Fir Forests

Jane E. Smith, Randy Molina, Donaraye McKay, Michael Castellano, and Daniel Luoma[1] [2]

Context

The importance of ectomycorrhizal fungi to many ecosystem processes is well established, yet little is known about community structure and dynamics of ectomycorrhizal fungi in natural vegetation. This study was undertaken to determine whether ectomycorrhizal fungus communities differ between successional stages of Douglas-fir forests. Describing fungus communities by sampling sporocarps will provide data essential for predicting impacts of disturbance and management on forest health. Study results will provide information about factors critical to maintaining the diversity of ectomycorrhizal fungi regionally. Correlations between fungus populations and factors such as vegetation associations, soil types, stand age, stand density, or harvesting methods could be used to estimate sporocarp production in similar habitats during periods typical of forest succession. Insights about the relations among forest succession, disturbance, and ectomycorrhizal fungal diversity will provide for comparisons of sporocarp production in forests of the Pacific Northwest (Amaranthus and others 1994; Ammirati and others 1994; Fogel 1976; Fogel and Hunt 1979; Hunt and Trappe 1987; Luoma 1989, 1991; Luoma and others 1991; Waters and others 1994), the northern Rocky Mountains (Harvey and others 1987, 1991), Europe (Arnolds 1981, Gáper and Lizon 1995, Mehus 1986, Mikola 1962, Ohenoja and Metsänheimo 1982), and the United Kingdom (Dighton and others 1986). Because mushrooms and truffles are important food for small mammals, predictability of sporocarp production will influence forest management decisions directly affecting wildlife populations. Knowledge about the comparative ecological functions of various ectomycorrhizal fungi that colonize tree roots during different seral stages of forest succession is lacking and deserves additional investigation.

Objectives

The objectives of this study were to compare the following among young, rotation-age, and old-growth Douglas-fir stands:

1. Species richness and biomass of epigeous ectomycorrhizal fungus sporocarp (mushroom) production.

2. Species richness and biomass of hypogeous ectomycorrhizal fungus sporocarp (truffle)

---

[1] **Jane Smith, Randy Molina, Donaraye McKay**, and **Michael Castellano** are with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR 97331; and **Daniel Luoma** is with the Department of Forest Science, Oregon State University, Corvallis, OR 97331.

[2] Cooperators included Jim Mayo, USDA Forest Service, Willamette National Forest; Cascade Center for Ecosystem Management; and Oregon State University.

2. Percentage of cover of *Piloderma* bicolor, a widespread ectomycorrhizal fungus that does not produce mushrooms or truffles but can be identified by its thick, bright yellow mycelium in the soil. *(Piloderma* bicolorcoverage will be correlated with abundance and decay class of coarse woody debris, because it is thought to be associated with old-growth forests.)

Methods and Rationale

Species diversity and sporocarp production of ectomycorrhizal mushrooms and truffles were examined from plots in three replicate stands each of old-growth (>400 years old), rotation-age (45-60 years old), and young (25-30 years old) Douglas-fir in and near the H.J. Andrews Experimental Forest along the west side of the Cascade Range in Oregon.

Stands were sampled once each in spring and autumn, 1991-94. Sampling in both spring and autumn was necessary to capture the dichotomy in seasonal fruiting patterns typical of the Pacific Northwest (Fogel 1976, Hunt and Trappe 1987, Luoma and others 1991). Sporocarp production varies annually so stands must be sampled for several years to detect fluctuations. Sporocarp sampling was timed to coincide with the peak of seasonal fruiting determined from weather reports and reports of field cooperators.

Ectomycorrhizal mushroom sporocarps were collected from a total area of 700 square meters (7,535 ft.^{2}) per stand from strip plots (2 by 50 meters [6.6 by 164 ft.]) and circular truffle plots (study 3). Three of six strip plots were permanently located within each stand. Sporocarps of each ectomycorrhizal mushroom species were collected separately for each square meter of the permanent plots. Three temporary mushroom strip plots were positioned in the upper, middle, and lower slopes of each stand. Sporocarps of each ectomycorrhizal mushroom species were treated as a single collection for each temporary plot. Sporocarps were identified, dried, and weighed to the nearest 0.01 gram.

Truffles were collected from twenty-five 4-square-meter(43-ft.^{2}) circular plots (a total area of 100 square meters [1,076 ft.^{2}] per stand) located at 25-meter (82-ft.) intervals along three transects (eight, nine, and eight plots each, in the upper, middle, and lower slope strata, respectively). In each truffle plot, the percentage of cover by exposed mineral soil, coarse woody debris by decay class, and *Piloderma* bicolor mycelium was recorded. Data pertaining to coarse woody debris were measured according to methods described in study 3 with the exception that coarse woody debris = 10 centimeters (3.9 in.) rather than 8 centimeters (3 in.) diameter was the criterion for this study. Truffle plots were marked with a flag to avoid repeat sampling of the same area in subsequent seasons. Sporocarps were identified, counted, dried, and weighed to the nearest 0.01 gram.

Unique Considerations

Sufficient rainfall is necessary to initiate autumn fruiting; hence, scheduling fieldwork then was more difficult than during spring, because predicting the onset of autumn rains or season-ending heavy frost or snowfall is not possible. The spring fruiting season is longer and more predictable than the autumn season.

Sampling was accomplished mostly with volunteer help, and many volunteers were available for only 1 or 2 days. Collecting is labor intensive and a crew of four to six people was required each sampling season (3 to 4 work weeks). This high degree of volunteer turnover required that more time be allotted to training and ensuring that data collection was consistent. The amount of time required to sample differs with crew experience, weather conditions, and density of understory vegetation.

Current Status

Statistical analyses are in progress, as are final taxonomic determinations of problem taxa. Sampling will likely continue in subsequent years to substantiate trends reflected in this 4-year sample period.

Literature Cited

Amaranthus, M.; Trappe, J.M.; Bednar, L.; Arthur, D. 1994. Hypogeous fungal production in mature Douglas-fir forest fragments and surrounding plantations and its relation to coarse woody debris and animal mycophagy. Canadian Journal of Forest Research. 24: 2157-2165.

Ammirati, J.; Ammirati, S.; Norvell, L. [and others]. 1994. A preliminary report on the fungi of Barlow Pass, Washington. McIlvainea. 2: 10-33.

Arnolds, E. 1981. Ecology and coenology of macro-fungi in grasslands and moist heathlands in Drenthe, The Netherlands. Bibliotheca Mycologica. 83: 1-407.

Dighton, J.; Poskitt, J.M.; Howard, D.M. 1986. Changes in occurrence of basidiomycete fruit bodies during forest stand development: with specific reference to mycorrhizal species. Transactions of the British Mycological Society. 87: 163-171.

Fogel, R.; Hunt, Gary A. 1979. Fungal and arboreal biomass in a western Oregon Douglas-fir ecosystem: distribution patterns and turnover. Canadian Journal of Forest Research. 9: 245-256.

Fogel, R. 1976. Ecological studies of hypogeous fungi. II: Sporocarp phenology in a western Oregon Douglas-fir stand. Canadian Journal of Botany. 54: 1152-1162.

Gáper, J.; Lizon, P. 1995. Sporocarp succession of mycorrhizal fungi in the Norway spruce plantations in formerly agricultural land. *In*: Baluska, F. [and others], eds. Structure and function of roots. [City unknown], The Netherlands. Kluwer Academic Publishers: 349-352.

Harvey, A.E.; Jurgensen, M.F.; Larsen, M.J.; Graham, R.T. 1987. Relationships among soil micro-site, ectomycorrhizae, and natural conifer regeneration of old-growth forests in western Montana. Canadian Journal of Forest Research. 17: 58-62.

Harvey, A.E.; Page-Dumroese, D.S.; Graham, R.T.; Jurgensen, M.F. 1991. Ectomycorrhizal activity and conifer growth interactions in western-montane forest soils. *In*: Harvey, Alan E.; Neuenschwander, Leon F., eds. Proceedings: Management and productivity of western-montane forest soils; [Dates of meeting unknown]; [Location of meeting unknown]. Gen. Tech. Rep. INT-280. [Place of publication unknown]: U.S. Department of Agriculture, Forest

Luoma, D.L. 1991. Annual changes in seasonal production of hypogeous sporocarps in Oregon Douglas-fir forests. *In*: Ruggiero, L.F.; Aubry, K.B.; Carey, A.B.; Huff, M.H., tech. coords. Wildlife habitat relationships in old-growth Douglas-fir forests. Gen. Tech. Rep. PNW-GTR-285. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 83-89.

Luoma, D.L.; Frenkel, R.E.; Trappe, J.M. 1991. Fruiting of hypogeous fungi in Oregon Douglas-fir forests: seasonal and habitat variation. Mycologia. 83: 335-353.

Mehus, H. 1986. Fruit body production of macro-fungi in some north Norwegian forest types. Nordic Journal of Botany. 6: 679-701.

Mikola, P. 1962. The bright yellow mycorrhiza of raw humus. *In*: Proceedings of the 13th Congress of the IUFRO; 1961 September; Vienna, Austria. [place of publication unknown]: [publisher unknown]: Part 1, 24-4: [page numbers unknown].

Ohenoja, E.; Metsänheimo, K. 1982. Phenology and fruiting body production of macro-fungi in subarctic Finnish Lapland. *In*: Laursen, G.A.; Ammirati, J.F, eds. Arctic and alpine mycology. Seattle; University of Washington Press: 390-409.

Waters, J.R.; McKelvey, K.S.; Zabel, C.J.; Oliver, W.W. 1994. The effects of thinning and broadcast burning on sporocarp production of hypogeous fungi. Canadian Journal of Forest Research. 24: 1516-1522.

Study 5: Inventory and Monitoring of Rare Fungus Species: A Case Proposal

James Trappe and Michael Castellano [1] [2]

Context

Protection of rare fungi and their habitat is a responsibility of forest managers and researchers alike. Inventory of populations of target fungi is the first step in a protection program, and monitoring for changes in populations is an important followup. The President's plan (USDA and USDI 1994) for Federal land management within the range of the northern spotted owl specifically directs the National Forests and Bureau of Land Management districts to survey for rare fungus species before implementing disturbance activities. These survey procedures are currently being designed. We have selected an area to exemplify proposed methods for inventory and monitoring of rare fungi: the Lamb Butte Scenic Area in the Willamette National Forest. Similar procedures can be adapted to other sites of rare fungi.

Objectives

Objectives of the study are to:

1. Provide reasonable interim protection to areas with known rare fungi.
2. Test procedures for surveying known populations of rare fungi for mapping population boundaries and establishing appropriate reserves.

Methods and Rationale

The Lamb Butte Scenic Area contains at least two rare, local endemics *(Chroogomphus loculatus* and *Gastroboletus imbellus)* and other rare but not locally endemic species (Trappe, unpublished data). A stepwise approach is proposed. **Year 1:** Examine, define, and map habitat types characteristic for the rare species over the entire ridge system that connects Lamb Butte with nearby Ollalie Ridge Research Natural Area. All areas in the ridge system with the appropriate habitat types plus 40-meter (1,300-ft.) buffer strips will be temporarily withdrawn from management activities. The withdrawal will continue until inventories reveal the extent of the populations of the rare fungi and the habitats in which they occur. Populations of the rare species will be inventoried in either the spring or autumn fruiting season, depending on the life-cycle of the particular fungus. The mapped habitats, buffer strips, and areas adjacent to clearcut edges or encircling roads will be carefully searched for the target species. All finds of rare fungi will be entered on the habitat type maps. Weather patterns before and during the fruiting season of target species will be recorded. **Year 2:** Repeat inventory as for year 1. **Year 3:** Repeat inventory as for year 1 unless populations of the target fungi have been well defined. **Year 4:** Define boundaries of area to be withdrawn and complete withdrawal process for a mycological preserve; include rare fungi in inventories of watersheds in the general area. **Years 5 and thereafter:** Monitoring will be continued in year 5 and at periodic intervals thereafter, depending on weather patterns found to be favorable for fruiting of the target fungi by previous inventories.

---

[1] **James Trappe** is with the Department of Forest Science, Oregon State University, Corvallis, Oregon; and **Michael Castellano** is with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, Oregon.

[2] Cooperators were Willamette National Forest, Oregon Mycological Society, North American Truffling Society, and the Native Plant Society.

Unique Considerations

Fruiting differs from season to season and year to year. We cannot presently predict when a given fungus species will fruit. Hence, inventory must begin as soon as the sites become wet enough to sustain autumn fruiting, 2 weeks after the first wetting rains, and every 2 weeks thereafter until the first hard freeze or snow covers the ground. Spring-fruiting species should be monitored at 2-week intervals from time of snowmelt until summer drought. If the summer is wet, inventory may continue through the summer at manageable intervals. If populations of the target or other rare fungi have been discovered and mapped in years 1 and 2, withdrawal can be completed in year 3. If the populations have not been defined by the end of year 3, the withdrawal area will be defined by habitat type of the type localities with 400-meter (1,300-ft.) buffer strips.

Research and National Forest personnel must collaborate to ensure that all individuals involved in the inventory and monitoring are adequately trained and provided with written descriptions and illustrations of the target fungi and other rare fungi that have been found in similar habitats elsewhere. Interested individuals from the mycological and native plant societies will be recruited to help; otherwise the limited available personnel from research institutions and National Forests may not be able to complete the program in an acceptable intensity and time.

As managers of the area, personnel of the Willamette National Forest will be responsible for organizing and implementing inventories, withdrawing and protecting areas involved, and subsequent monitoring. One professional mycologist or more will work closely with National Forest personnel to train assistants and oversee mycological aspects of inventory and monitoring.

Unknown factors, presumably including history, geology, soils, vegetation, and climate, have combined to produce an unusual concentration of rare and locally endemic fungi in the Lamb Butte-Ollalie Ridge area. Probably the same combination of factors has provided habitat for other rare organisms as well. Unknown factors complicate definition of the area to be preserved. Target fungi are known only from single-type collections, so extent of soils, mycorrhizal hosts, and habitat types are unknown. Sporocarps of the target fungi are short-lived, and weather patterns that induce and shut down fruiting are difficult to determine; hence 2-week sampling periods may be inadequate to encounter fruitings of these species.

Many areas of the Western United States contain rare fungi, and each area will have its own distinctive characteristics. This example can serve as a starting point for inventory and monitoring of rare fungi, but can be modified to meet the individual circumstances of other areas.

Current Status

On July 5 and 6, 1994, a meeting of western professional mycologists convened in Corvallis, OR, to discuss the implications of growing interest in the surveying of rare fungus species, especially the shortage of taxonomists and the training that will be required for field crews. Currently, a Federal interagency team is finalizing standard protocols for surveying rare fungi on Federal lands in the Pacific Northwest. Amy Rossman, Director of the National Fungus Collection, Agricultural Research Service, Beltsville, MD, sponsored a workshop on October 15-19, 1995, to begin work on a book outlining sampling protocols for all fungal taxa.

Literature Cited

Miller, O.K.; Trappe, J. 1970. A new *Chroogomphus* with a loculate hymenium and a revised key to section *Floccigomphus.* Mycologia. 62: 831-836.

Thiers, H.T.; Trappe, J.M. 1969. Studies in the genus *Gastroboletus.* Britonia. 21: 244-254.

U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994. Final supplemental environmental impact statement on management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl. [Place of publication unknown]. 2 vol.

Study 6: Influence of Thinning, Plant Diversity, and Mycophagous Mammals on Mycorrhizal Fungi

Wes Colgan III, James Trappe, Randy Molina, Andrew B. Carey, and David Thysell[1 2]

Context

The northern flying squirrel is the major food of the northern spotted owl in the Puget Sound area of Washington. The squirrel feeds almost exclusively on hypogeous sporocarps (truffles and truffle-like fruiting bodies) of fungi that are ectomycorrhizal with Douglas-fir and western hemlock. As part of an integrated study, "Experimental manipulation of managed stands to provide habitat for spotted owls and to enhance plant and animal diversity," at the Fort Lewis Military Reservation, WA, we are examining short-term effects of thinning, provision of nest boxes, and a combination of the two on diversity and productivity of hypogeous ectomycorrhizal fungi and their use as food by northern flying squirrels.

Objectives

The objectives are to:

1. Determine seasonal species composition and standing crop biomass of hypogeous and selected epigeous ectomycorrhizal fungus sporocarps in non-thinned, lightly-thinned, heavily-thinned, and open-cut areas, with and without tree cavities and nest boxes, of four treatment blocks.
2. Determine the seasonal diet of flying squirrels live-trapped in non-thinned and thinned stands throughout the year through fecal pellet analyses of the percentage of fungus, plant, and lichen components.

Methods and Rationale

The study consists of 16 stands of 55- to 65-year-old plantations of Douglas-fir. Eight stands have been thinned twice (1972 and late 1980s) and eight have not been thinned since planting. Four of each stand type were thinned in February and March 1993. Biomass production and species composition of hypogeous and epigeous sporocarps in treated and untreated stands are being measured. Diets of flying squirrels in treated and untreated stands are being assessed by analyses of feces collected from live-trapped individuals. Available sporocarps will be compared to those actually consumed by squirrels in the stands to determine if the squirrels prefer certain species.

The sampling method chosen is adapted from Luoma (1991). Statistical analysis will provide estimates of stand-level fungus characteristics (seasonal sporocarp standing crop, annual biomass production, species diversity, and so forth).

Field sampling was done about every 6 weeks from April 1993 through December 1995. At the first sampling, all stands without tree cavities or nest boxes were sampled; at the second sampling 6 weeks later, all stands with tree cavities and nest boxes were sampled. This alternation continued throughout the study. Fungus sporocarps were collected from 10 circular plots, each 4.0 square meters (43 ft.^{2}), located at about 10-meter (32.8-ft.) intervals along randomly placed transects in each of the non-thinned stands of each block at each sampling time. Thinned stands of each block were sampled more intensively to determine if thinning treatments affect sporocarp production differently. Each treatment (light thin, heavy thin, and open cut) was sampled by 10 randomly placed 4.0-square-meter (43-ft.^{2}) plots, totaling 30 plots per thinned stand per sampling period.

Epigeous sporocarps (mushrooms) of species eaten by small mammals (primarily the *Boletaceae* and *Russula* spp.), and other mycorrhizal fungi observed or suspected to be used as food by small mammals, were collected from each plot. Each item was placed in a waxed paper bag with a tag recording plot number, stand number, and other pertinent information. Each plot was then raked to a depth of at least 5 centimeters (2 in.) into mineral soil to expose hypogeous sporocarps. Position in soil profile, distance to nearest coarse woody debris, and field characteristics (bruising reactions, odor, and so forth) were recorded. All plots were marked with a flag and the duff replaced. No plot was sampled twice. All fungus samples were annotated, dried, and returned to the Forestry Sciences Laboratory, Corvallis, OR, for final identification and weighing. Voucher specimens of each species found were deposited in the mycological herbarium at Oregon State University (OSC[3]).

Fecal pellets collected from live-trapped animals at Fort Lewis are being microscopically analyzed for spores and other food remnants. Fort Lewis cooperators preserved the pellets with ethanol and provided animal identification numbers and stand data. Fungus spores were identified to genus or to species when possible. Frequency and relative quantity were estimated. Types of vascular plants and lichens were recorded and identified when possible (Castellano and others 1989).

The ratio of fungi to plants and lichens found in feces of animals will be plotted through the year to determine seasonal variation. Sporocarps present in the field during a given sampling time will be compared to species in fecal pellets collected at the same time. These comparisons will determine whether some species are being found by the animals but not by researchers and whether fungus caches are being used for food.

This study is the first to examine effects of silvicultural manipulation of managed forests on sporocarp production of mycorrhizal fungi and the animals that feed on them. As part of the larger silviculture and wildlife study at Fort Lewis, it is also the first to integrate data on fungus productivity and squirrel feeding behavior. It will greatly enhance understanding of the importance of mycorrhizal fungus sporocarps in forest food webs.

Comparing sporocarps present in stands immediately after thinning to sporocarps found in undisturbed stands will reveal short-term effects of thinning on the fungus community. The data can be compared to a similar study of fungus sporocarp productivity at the Siskiyou National Forest Integrated Research Site in southwest Oregon (study 2). The small mammal mycophagy portion of our study will allow comparisons to data collected in the Olympic Mountains in Washington (Carey, in press) and the Coast Ranges of Oregon (Maser and others 1978).

[3] The original acronym, OSC, for Oregon State College has been retained to refer to the herbarium at Oregon State University (OSU).

Unique Considerations

The study at Fort Lewis is an integrated ecosystem management study. Coordination with the many other researchers is essential. Our study must fit within the goals of the long-term study.

Our study was installed as the thinning was completed. Now, in the third year post-treatment, dense underbrush and weedy species are filling the gaps created by the logging operation. This situation creates undesirable conditions for workers and crew managers. A large brush saw is necessary to clear plots and, often, the paths between them. Field personnel must be made aware that stinging nettle and yellow jacket wasps are hazards often encountered in the field.

Current Status

We continue to analyze fecal pellets, and field data are undergoing statistical analyses. This project would not be possible without the many volunteers from the Puget Sound area. At present, more than 50 species of hypogeous fungi have been collected from study plots; at least 5 are new to science.

Literature Cited

Carey A.B. [In press]. Sciruids in Pacific Northwest managed and old-growth forests. Ecological Applications.

Castellano, M.A.; Trappe, J.M.; Maser, Z.; Maser, C. 1989. Key to the spores of the genera of hypogeous fungi of north temperate forests. Eureka, CA: Mad River Press: 186 p.

Luoma, D.L. 1991. Annual changes in seasonal production of hypogeous sporocarps in Oregon Douglas-fir forests. *In*: Ruggiero, L.F.; Aubry, K.B.; Carey, A.B.; Huff, M.H., tech. coords. Wildlife habitat relationships in old-growth Douglas-fir forests. Gen. Tech. Rep. PNW-GTR-285. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 83-89.

Maser, C.; Trappe J.; Nussbaum, R.A. 1978. Fungal-small mammal interrelationships with emphasis on Oregon coniferous forests. Ecology. 59(4): 799-809.

Productivity and Sustainable Harvest of Wild Mushrooms

Michael Amaranthus and David Pilz [1]

Historical Context

Throughout history, mushrooms have been important sources of food and medicine. In the Pacific Northwest, however, only recently has demand for wild mushrooms grown sharply. About two decades ago, enterprising individuals began harvesting and shipping fresh chanterelle mushrooms to fine restaurants and gourmet shops in California and along the East Coast. It was a small and scattered industry where harvesters sold and shipped the majority of the harvest. The season ranged from 2 to 3 months in autumn, and the volume of mushrooms harvested was relatively small.

Major changes occurred by the late 1980s in the volume and manner in which mushrooms were harvested, sold, and handled. Chanterelles were sold primarily to European markets and canneries rather than restaurants. The industry expanded to a system of harvesters, buyers, processors, and brokers. Harvesters located and picked the mushrooms. Buyers, typically associated with a specific processor, set up buying stations near wooded areas known to produce mushrooms and advertised for harvesters. Processors handled, cleaned, packed, and shipped the product, while providing the cash and field prices. Brokers marketed the processed mushrooms around the world.

During this period, supplemental income from wild mushroom harvesting grew substantially for unemployed timber industry and other rural workers (Chen and others 1993). In 1992 nearly 11,000 people, employed full or part time, contributed over $41.1 million to the economies of Oregon, Washington, and Idaho by harvesting and selling nearly

---

[1] Both authors are with U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **Michael Amaranthus** is at Grants Pass, OR 97526 and **David Pilz** is at Corvallis, OR 97331.

1.82 million kilograms (4 million pounds) of wild edible mushrooms (Schlosser and Blatner 1995). Pickers generally earned from $2 to $100 per pound, depending on species, quality, and supply.

Today, thousands of pickers harvest commercial fungi from private and public lands, yet uncertainty about the ecology of wild edible mushrooms hinders efforts to manage this valuable resource. At the center of the management issue is a lack of information on the ecology of these forest fungi, productivity and habitat requirements, interaction of forest health and mushroom production, and the effects of repeated mushroom harvest on production. Clearly, if wild edible mushroom production is to be sustained, it must be done by understanding these organisms and the social and economic forces behind their harvest (U.S. Department of the Interior 1993).

Species of Mushrooms Harvested

The suitability of a particular mushroom species for commercial harvest depends on many criteria including abundance, shelf life, appearance, texture, flavor, and familiarity to sellers and buyers. Schlosser and Blatner (1995) state that over 25 species are harvested for resale in the Pacific Northwest. The Integrated Resources Policy Branch of the British Columbia Ministry of Forests lists 22 edible mushroom species commercially harvested from their forests (de Geus 1995). Large-scale commercial harvest, however, is concentrated on the following species, given in declining order from greatest to least cash value of the harvest. For more information on the 1992 Pacific Northwest commercial wild mushroom market cited below, see Schlosser and Blatner (1995). For a more detailed discussion of each species and further technical references, see Molina and others (1993).

Matsutake

The American matsutake *(Tricholoma magnivelare) is* cousin to the highly prized Japanese "pine mushroom" (*T. matsutake).* It forms ectomycorrhizae over a broad geographical area in association with a wide variety of tree species in the Pacific Northwest including true firs, pines, Douglas-fir, hemlock, and tanoak *(Lithocarpus).* The North American harvest begins in August, in British Columbia, and continues south to northern California, in January. Small quantities of matsutake mushrooms are harvested in Mexico in *Pinus teocote* forests during summer and autumn.[2] The annual harvest from the Pacific Northwest has increased dramatically in recent years because of the high market value. In 1992, nearly a million pounds were harvested. Price to harvesters ranges greatly, depending on the developmental stage of the mushroom. Japanese buyers, the primary market, prefer young specimens, and prices paid to pickers occasionally reach $100 a pound. The average price in 1992 was over $8 a pound averaged for all stages of development or "grades," but in some years it has been much higher.

Morels

Morels *(Morchella* species) are not generally mycorrhizal (see study 7 for discussion). They seem to fruit most prolifically in open woodlands, mixed-conifer forests, hardwoods, and disturbed areas, especially following fire or tree mortality. In the Pacific Northwest, fruiting begins as early as February in warm areas and continues into June in cool areas. Oregon produced an estimated 400,000 kilograms (900,000 lbs.) in 1992.

[2] Personal communication. 1995. Luiz Villareal, Instituto de Recursos Geneticos y Productividad, Montecillos, Mexico.

The harvest fluctuates greatly from year to year depending on abundance. Many areas are crowded with pickers after fires. For morels, pickers earned about $4 a pound in 1992, but many restaurants pay in excess of $25 a pound for fresh morels.

Chanterelles

The chanterelle *(Cantharellus cibarius* Fr.) is an ectomycorrhizal symbiont with several forest trees. It commonly associates with Douglas-fir and hemlock in the Pacific Northwest. In the United States, commercial harvest begins in August on the Olympic Peninsula of Washington and continues into December in northern California. Over a million pounds are marketed from the Pacific Northwest annually. The picker earned about $3 a pound in 1992. Price for chanterelles leaving the area is considerably higher. Wholesale prices in San Francisco exceeded $20 a pound in autumn 1994. Other areas, such as Poland and Russia, are major exporters of the chanterelle. The percentage of total market demand that is harvested in the Pacific Northwest is unknown.

Boletes

Many species of *Boletus* mushrooms are hunted by recreational pickers. One species, *Boletus edulis,* is highly esteemed by Europeans and therefore commercially valuable. *Boletus edulis* is an ectomycorrhizal symbiont with spruces, pines, Douglas-fir, true firs, and some oaks. Commercial harvest of this mushroom is still limited, but increasing. It fruits most abundantly in early autumn, but spring and early summer fruitings are common in some areas. Price was about $4.50 a pound fresh to harvesters in 1992 but differs with grade. Young specimens generally sell for over $10 a pound.

Truffles

The Oregon black truffle *(Leucangium (Picoa) carthusiana)* has a pleasant odor reminiscent of pineapple and is widely collected in Douglas-fir forests. Over 18,000 kilograms (4,000 lbs.) were collected in Oregon alone, in 1992, and price per pound to pickers averaged $75. The Oregon white truffle *(Tuber gibbosum) is* reminiscent of the Italian white truffle of Europe, although its taste and ecology differ significantly. It is ectomycorrhizal with Douglas-fir. About 32,000 kilograms (7,000 lbs.) were harvested from Oregon and Washington in 1992, with prices averaging about $30 per pound. October through December are peak fruiting periods for these species. Truffles fruit beneath the soil surface, and thus their presence and maturity are hard to detect without the use of trained sniffing animals such as the dogs or pigs used in Europe for truffle harvesting. Regional, national, and international demand for ripe truffles is high, and inoculation of tree plantations with European species of truffles has been attempted in California, Oregon, North Carolina, Texas, New Zealand, and Tasmania (Smith 1995, Trappe 1988). To date, production of European truffles has been verified in the North Carolina, California, and New Zealand plantations.[3] Markets for wild Pacific Northwest truffles have been slow to develop, however, because some early marketing attempts included immature and relatively odorless truffles found by random raking, rather than only ripe and pleasantly aromatic specimens found by trained animals.[4] Ripe specimens of Pacific Northwest truffles are very flavorful, though, and their potential market remains large.

---

[3] Personal communication. 1995. Mike Castellano, USDA Forest Service, PNW Research Station, 3200 Jefferson Way, Corvallis, OR 97331.

[4] Personal communication. 1994. James Trappe, Department of Forest Science, Oregon State University, Corvallis, OR 97331.

Hedgehogs

Hedgehogs *(Hydnum repandum* and *H. umbilicatum* are ectomycorrhizal symbionts with Douglas-fir and other forest trees. Hedgehogs fruit from autumn until late spring. Many consumers are still unfamiliar with hedgehogs, and they have a relatively small commercial trade. About 18,000 kilograms (40,000 lbs.) were harvested in 1992 with the price averaging about $3 per pound. Mushroom companies are seeking to expand harvest of this species.

Economic and Social Factors

Mushroom harvesters range from the curious or avid recreationalist to temporarily unemployed workers needing additional income, to highly skilled commercial harvesters. Individuals who work in forestry or timber harvesting often are familiar with fruiting locations and enjoy being in the woods; hence, they can easily supplement income during periods of slack employment by collecting and selling mushrooms. Recent immigrants, especially Southeast Asians, can harvest mushrooms profitably without the language skills and education required for other jobs. Native Americans claim prior harvesting rights in some instances; the Karuk Tribe in northern Californian and the Nisga'a Tribe in the Nass Valley of northern British Columbia[6] have both claimed prior rights to matsutake harvesting.

Valuable mushrooms (matsutake) or mushrooms that fruit in large flushes (morels) often are harvested by transient mushroom gatherers who travel to new locations as the season progresses; for instance, matsutakes begin fruiting in northern Canada in August and may end in the mountains of coastal California in January. Morels can begin fruiting as early as February in southwest Oregon. In the forests of the intermountain West, morels progressively appear at higher elevations and on more northerly aspects (as late as June and July) as weather warms and snowpacks melt. In contrast, the less valuable chanterelle can fruit for up to 5 months in a single location (study 8) and is typically picked by local harvesters.

Even remote areas may experience commercial harvest of valuable species. Helicopters are routinely used to transport matsutake collected in roadless areas of interior British Columbia (see footnote 6). By comparison, the practicality of selling low-value chanterelles often depends on how far a picker has to drive between the collection site and a buyer; thus relatively inaccessible areas are unlikely to experience significant commercial harvesting when prices are low.

Wild, edible mushrooms from Washington, Oregon, and Idaho are being marketed around the world as well as nationally and locally. Japan is the predominant market for matsutake, followed by Asian communities in the Western United States and Canada. Europe is the largest international market for chanterelles, although imports differ widely by country. Morels are predominantly marketed within the United States, but international markets include Europe, Japan, and Canada (Schlosser and Blatner

---

[5] 0ctober 28, 1993, correspondence by Stephen H. Suagee, Attorney at Law, to Barbara Holder, Forest Supervisor, Klamath National Forest, in reference to the Karuk Tribe's Notice of Appeal and Request for Stay of the October 20, 1993, Decision Notice and Finding of No Significant Impact (FONSI) for [Tanoak] Mushroom Management by District Rangers George R. Harper and Sam Wilbanks for the Happy Camp and Ukonom Ranger Districts, Klamath National Forest, California, respectively. On file with: Klamath National Forest, 1312 Fairlane Road, Yreka, CA 96097.

[6] de Geus, Nelly; Redhead, Scott; Callan, Brenda. 1992. Wild mushroom harvesting discussion session minutes, March 3, 1992. Report on file with: Integrated Resources Branch, British Columbia Ministry of Forests, Pacific Forestry Centre, Victoria, BC.

1995). Barring major disruptions to international trade, markets for wild edible mushrooms are likely to continue growing as human populations increase and become more affluent, and as more people become familiar with the pleasures of their consumption (Molina and others 1993).

Matsutake, morels, and chanterelles are commercially collected elsewhere throughout the Northern Hemisphere, resulting in significant international competition. International markets and prices can fluctuate wildly from year to year, and even within a season, as global weather patterns produce good or poor crops in various locations. Competition or collusion among mushroom buyers and processors can dramatically influence prices paid to local harvesters. Prices paid to pickers can inflate tremendously when mushroom crops are poor elsewhere, good locally, and buyers compete intensely. This is particularly true of high-value mushrooms, such as matsutakes. When prices are high, it is not unusual for large numbers of harvesters to congregate in small areas, sometimes to the consternation of land managers and the local communities.

Although harvester groups, travel arrangements, and market forces fluctuate, mushroom harvesting job opportunities have become important to local and regional economies. Of the estimated 11,000 commercial harvesters in 1992, 35 percent reported that mushroom harvesting was their primary source of income during the fruiting season (Schlosser and Blatner 1995).

We are just beginning to develop quantitative estimates of the commerce in wild mushrooms. Much economic misinformation exists about the mushroom industry. This results from erratic mushroom fruiting patterns from year to year that can greatly influence supply and price. Also, the popular press tends to use high prices present at the beginning or end of the season as a standard for the entire season. This overestimates real cash amounts that harvesters receive. Little information is available about the percentage of family income derived from mushroom harvesting or total dollar amount generated in the region. Mushroom harvest dollars are often part of an "underground" economy in which much of the cash value is not reported. Even though the income is not reported, harvesters spend substantial dollars in a rural communities. Many Asian pickers leave large urban environments and travel long distances to small rural communities where they stay for a few days to several weeks. During this period, harvest dollars benefit local communities.

Harvesting wild edible mushrooms in the Pacific Northwest is attracting international attention as a tourist activity. A "package mushroom tour" for Japanese and other foreign visitors is being developed by one outdoor recreation company in Oregon. International tourists would be guided throughout the Northwest to pick a variety of mushrooms in majestic forests, experience local settings and customs, and have the mushrooms prepared by master chefs. The demand for such activities is likely to increase as harvest of wild edible mushrooms declines in heavily populated areas overseas.

Commercial mushroom harvesting has created regulatory issues across the Pacific Northwest.[7] Concerns include over-harvesting, undesirable harvest methods, competi-

[7] Russell, Kenelm. 1990. Forest fungi manufacturing, marketing, and regulatory considerations. Presented at the special forest products workshop, Portland, OR, February 8-10, 1990. On file with: K. Russell, Washington State Department of Natural Resources, Olympia, WA 98504.

tion among harvesters for "picking rights," wildlife harassment, traffic safety and road repairs, campground crowding and maintenance, littering, trespass, firearm safety, vandalism, and research site security. In response to locally abundant mushroom crops, sudden large influxes of harvesters and buyers can quickly stress community and management resources.

Regulations for protecting the mushroom resource may take the form of implementing harvest rules and permit systems, limiting permit numbers, allocating or rotating collection areas, or providing contracts for exclusive harvest rights. Prevention of inappropriate harvest methods requires communication through meetings, videos, posters, handouts, press releases, presentations, and other public education efforts. Road closures may be necessary to control traffic, road deterioration, and wildlife harassment or to protect research and monitoring areas. Law enforcement is needed to deter unauthorized or illegal activities in the forest. Large numbers of harvesters and avid competition for a valuable commodity can increase the potential for crime, and because buyers often handle large amounts of cash, they are tempting targets for robbery.

Effective management of the commercial mushroom harvest requires anticipating the size of the demand, primary locations of the activity, and expected conflicts. Public land managers must develop means to apportion the harvest fairly, while ensuring that harvesting impacts are minimized. Detailed information from the public is needed to make equitable decisions. Cooperation among Federal agencies to standardize permits, regulations, and procedures will reduce confusion and inconvenience among harvesters facing a maze of regulatory details specific to local forests or management districts. Law enforcement agencies, including Federal, state, county, and local, need access to information about permits, closed areas, and proper harvesting activities.

Most mushrooms harvested by commercial pickers are from Federal and state lands. Boise-Cascade, Weyerhaeuser, International Paper, Plum Creek, Simpson, and other industrial landowners also experience some commercial harvesting on their properties. All land managers play key roles in the future of the industry, because their silvicultural decisions influence the abundance and distribution of wild mushroom crops and they regulate access to their forests. Most managers recognize that wild mushrooms are an important forest product, both economically and ecologically. They also realize that little quantitative information is available as a basis for management decisions.

Human Influences on Edible Mushroom Production

Extensive timber and mushroom harvesting has led to concern about the sustainability of the commercial wild mushroom harvest among a growing number of mycologists, forest managers, recreational pickers, commercial harvesters, buyers, and processors (Molina and others, in press, a). There is additional concern that mushroom harvesting at current rates could adversely affect forest health and productivity or food webs for wildlife species. Unfortunately, few benchmark measurements of commercial mushroom production exist to make comparisons of effects over time. As a result, agencies in the Pacific Northwest, such as the USDI National Park Service, USDA Forest Service, and the Washington Department of Natural Resources, are restricting mushroom harvest in some areas due to uncertainty over mushroom production and harvest impacts. Increased regulation and legislative appeals are likely.

Much concern about the sustainability of the commercial mushroom harvest comes from European studies where a decline in populations of mycorrhizal fungi has been measured over the last three decades (Arnolds 1988, 1991). Arnolds (1988) found, however, no evidence that the collection of mushrooms by harvesters leads to a decline in fungus species abundance. Other factors may be involved; for example, forest habitat altered by agriculture and urban development has led to changes in fungus composition. The dramatic mushroom decline in recent decades has outpaced the loss or alteration of habitat, or changes in forest age, composition, and structure.

The observed fungus decline in central Europe also has been linked to increases in various types of pollution (Arnolds 1988). Decline in *Cantharellus cibarius* has been documented in The Netherlands and correlated to acid rain deposition patterns but not to mushroom harvesting (Danell 1994, Jansen and van Dobben 1987). Acid precipitation, caused by burning high-sulfur coal for power generation, has been linked to European temperate forest decline and directly influences ectomycorrhizal fungi (Dighton and others 1991, Oren and others 1989). Pollutants from heavy industry not only harm trees directly but also damage the soil and mycorrhizal fungi associated with the trees (Kowalski 1987). Heavy industrial pollution and shifts in fungus production have been documented in Germany and the former Czechoslovakia (Vosatka and others 1991). The level of mycorrhizal infection decreased significantly in a survey of conservation sites in Great Britain (Woodin and Farmer 1993). Increasing evidence and concern over decline of fungi in Europe have resulted in a series of international meetings and draft conservation strategies.

European mycologists have alerted their Pacific Northwest counterparts to the need to monitor wild edible fungi; however, sulfur dioxide pollutant levels in the Pacific Northwest are much lower than those observed in Europe, where fungus decline has been noted. American scientists determined that sulfur dioxide levels in the United States and Canada were lower by a level of magnitude compared to central Europe (MacKenzie and El-Ashry 1990). Air pollutant sources of nitrous oxides and ozone can alter mycorrhizal symbiosis and mushroom production (Garner and others 1989, MacKenzie and El-Ashry 1990), yet it is unknown whether observed nitrous oxides and ozone values typical of the Pacific Northwest could influence production of wild edible mushrooms. Wide distribution, natural variability in production and uncertain estimates derived from variable sampling protocols have made it difficult to document changes in production. Assessment is difficult because no accurate species distribution maps are available for wild edible mushrooms, and fungus populations remain unexplored in large areas of the Pacific Northwest.

The impact of improperly harvesting wild mushrooms has received substantial media attention over the last few years (Lipske 1994, McRae 1993, Richards 1993) and studies 8, 9, and 11 in this document assess the impacts of various harvesting techniques. Certain practices such as raking and using leaf blowers to expose the young "buttons" of valuable matsutake have been specifically identified as potentially damaging to the matsutake mycelial mat. Other potentially harmful activities include forest floor compaction and resultant mycelium damage in heavily trampled areas or removing all sporocarps before spores are disseminated. No quantifiable information currently supports claims that these activities reduce production, however. Many mycologists believe that harvesting mushrooms is as harmless as picking fruit off a tree or berries from a bush. Careful and long-term monitoring is needed to determine if raking, trampling, and reduced spore production are damaging to the fungi (studies 9 and 11; Molina and others, in press, b).

Forest age, composition, and structure likely influence wild edible mushroom production, and there is great potential to manage forest stands to produce conditions that favor fruiting of a preferred mushroom species. Matsutake in Japan fruits most abundantly in 30- to 60-year-old pine stands, and Japanese foresters clear out understory vegetation, reduce litter depth, and thin trees to increase matsutake production. Clearly, morel production is stimulated by fire, and Oregon white truffles increased dramatically in size and abundance following the addition of lime to a Douglas-fir plantation.[8] Forest management activities such as weed control, density management, prescribed underburning, and altering forest structure and composition to promote host species for certain wild edible fungi may be used as tools to enhance production in the future. The economic benefits during a rotation could be substantial, especially for highly valued commercial fungi such as matsutake, morels, and the Oregon white truffle.

Clearcutting impacts ectomycorrhizal mushrooms in the short term by killing major photosynthetic hosts and removing much of the energy source for sporocarp production. Either surviving mycelium or spores from elsewhere may colonize the roots of new trees, but several decades typically pass before edible ectomycorrhizal species fruit again. Recent research indicates that clearcutting can decrease hypogeous sporocarp production compared to mature forest fragments (Amaranthus and others 1994). Over time, even-aged young forested stands that develop after clearcutting may, however, produce a greater abundance of some wild edible mushrooms species than the previous older forests (authors, personal observations, and discussions with harvesters).

A variety of wildlife consume matsutakes, chanterelles, and boletes, yet we poorly understand the role of mushrooms in their diets and whether mushroom harvesting by humans consequently reduces their food supplies. If these mushrooms are a significant wildlife food resource, then human competition for them may affect specific wildlife populations. For instance, one forester has asked whether matsutake harvesting should be restricted near northern spotted owl nest sites on the supposition that flying squirrels (a main item of the spotted owl's diet) might feed on the mushroom. Conversely, mycophagy by indigenous wildlife species might be an important spore dispersal mechanism in certain locales. In southwest Oregon, for example, commercial collectors claim that matsutake mushrooms often are found fruiting near dusky-footed wood rat *(Neotoma fuscipes)* nests, and they speculate that new colonies are formed through dispersal of spores in wood rat feces. Deer and elk also actively seek matsutakes and can consume large quantities. The importance of this mushroom in their diet and whether they act as spore vectors are unknown.

Large numbers of mushroom hunters also may impact other resources, and some areas may need protection from mushroom harvesting. Traffic associated with heavy harvesting can have adverse effects on areas prone to high levels of erosion.

[8] Personal communication. 1993. James Trappe, Department of Forest Science, Oregon State University, Corvallis, Oregon 97331.

Matsutake harvesting in the Oregon Dunes National Recreation Area may be threatened by the impact of people walking on the highly erosive sandy soils. Moving slow-growing moss to search for young "buttons" of matsutake mushrooms may significantly disturb habitat in the sandy soils of the Oregon Dunes, whereas moving leaves for the same purpose in the Siskiyou Mountains may be innocuous. Human trampling of locally endemic sensitive plant or fungus species may be a concern in some areas. Special habitats such as wetlands or areas containing habitat for rare plants or animals may need mushroom harvesting restrictions. It may be necessary to set up no-harvest areas as controls to examine the effects of harvest or rotate areas to minimize the impact of continued harvest.

Management concerns about movement of disease organisms also can influence mushroom harvest regulations. An appeal against commercial matsutake harvesting in the Klamath National Forest in northern California was based on fears that large numbers of pickers in the forest would increase the spread *Phytophthora lateralis,* a soil-borne root disease fatal to Port-Orford-cedar *(Chamaecyparis lawsoniana* (A. Murr.) Parl.), into non-infected areas (see footnote 5).

Many management concerns regarding mushroom harvesting are actually concerns about managing people when they visit the forest. Demographic information from collection permits, industry surveys, public meetings, site visits, and interagency communication are all effective means of improving the regulation of human activities and serving the public.

Research Challenges and Considerations

Investigators who study a single species of edible mushroom face a different set of challenges than those studying fungus diversity. Vogt and others (1992) provide an excellent review of factors affecting basidiomycete sporocarp production in forest ecosystems with an emphasis on sampling challenges. This section emphasizes practical field procedures for forest managers to monitor several commercially valuable edible mushrooms.

Site Selection and Security

Selection of study sites depends on the goals of the study. If investigators want unbiased estimates of mushroom production in a given habitat type, then sampling locations must be selected randomly or systematically; that is, without prior knowledge of mushroom occurrence or abundance. These studies can be expensive, because even if chosen sites have appropriate habitat, some sites may not have populations of the selected mushroom. More sites therefore must be chosen, visited, and sampled to obtain adequate estimates. If unbiased estimates of mushroom production across landscapes (with a variety of habitats) are desired, then stratified sampling techniques, based on current knowledge of habitat requirements, can improve efficiency.

Known fruiting sites should be selected when investigators plan to apply experimental treatments, study the biology and ecology of a given mushroom, or measure productivity in areas of particular interest to managers or harvesters. The biased selection of these sites prevents valid extrapolation of productivity estimates across broader landscapes.

Careful site selection becomes particularly important when research addresses commercially valuable mushrooms. Sites must be secure from trespass and unauthorized collection of sporocarps but also readily accessible to field crews. Field personnel often are aware of obscure areas, or areas located on roads having lockable gates to limit access.

Unauthorized harvesting is particularly difficult to prevent on study sites having highly valuable mushrooms such as matsutakes. Harvesters know most fruiting locations and often consider patches as "theirs" because they have harvested them for many years. Ideally, investigators can convince local harvesters to participate in the study and thus avoid conflicts when these sites are selected for research.

Research site security may be enhanced in several other ways. Educating the public about research activities and goals is the most effective way to minimize intrusion and damage. Examples include providing handouts and verbal explanations when individuals obtain permits, showing educational videos, and publishing articles in the local press. "No Mushroom Harvest" signs are essential to inform the public that collection is not allowed in the study area. Because these signs often attract unscrupulous harvesters, they should be posted within the site and not be visible from a road. Signs should be large, brightly colored, and posted low, because mushroom pickers usually have their attention focused on the ground. Illustrations of the most commonly collected mushroom in the area, overlain with the circle and slash symbol, effectively communicate the message to non-English-speaking harvesters. When pickers obtain permits, they should be shown examples of the signs and instructed to avoid harvesting in posted areas.

Frequent visits to research sites by field crews is another effective means of security. Law enforcement officers can visit the site regularly and cite or ticket individuals who are picking illegally. Researchers and officers should greet harvesters politely, explain the purpose of the study and the restrictions, ask them to avoid the area, and solicit their help in informing others. When mushrooms are harvested as part of the study, investigators may choose to cooperate with previous harvesters of the site; the harvesters obtain exclusive access and can sell mushrooms found on the site in exchange for their efforts harvesting the site and providing the data to researchers. If the mushrooms are regularly picked, or marked in a manner that destroys their commercial value, unauthorized harvesters will find the site discouraging.

Field Crews

Studies of edible fungi usually are confined to their fruiting season. The start and duration of the season typically depends on weather, and thus is somewhat unpredictable. Autumn-fruiting mushrooms usually begin to appear soon after the onset of autumn rains and continue until a hard frost. Abundance of fruiting also differs considerably from year to year. Supervisors must be flexible in arranging personnel to implement mushroom studies. Unlike studies of fungus diversity, though, crews do not require extensive training in mushroom identification. Most commercially harvested species are easily recognized.

When volunteers help investigators with field sampling, it is important to recognize their attitudes toward and interest in mushroom harvesting. Recreational pickers may have different opinions than commercial harvesters, and both should be respected. Participation in conducting objective, scientific research is an opportunity for communication among groups with various interests. Volunteers should be rewarded for their efforts whenever possible. Reimbursing their expenses and allowing volunteers to keep collected mushrooms after recording measurements are two possible rewards. Volunteers also may be included in the planning, review, and modification of studies. Significant contributions on their part should be publicly acknowledged.

Life Histories

The life history of mushrooms is another relevant consideration in designing studies. Most important wild, commercial species are ectomycorrhizal, and this symbiotic relation with forest trees currently makes artificial inoculation and cultivation expensive, time-consuming, and difficult. Truffle plantations in Europe and elsewhere are the best current examples of successfully producing edible sporocarps of an ectomycorrhiza species through artificial propagation. The high value of culinary truffles makes seedling inoculation and intensive plantation management cost-effective. Research on cultivating other ectomycorrhizal species is being conducted in several countries. The Japanese have developed techniques for enhancing production of native matsutake colonies and spreading the fungus to new forest sites (Kawai and Ogawa 1981, Ogawa 1982, Tominaga 1978), and pines in New Zealand are being inoculated with matsutake and bolete species. Efforts to cultivate *Boletus* species in France, *Lactarius sangifluus* in Spain, and *Cantharellus cibarius* in Sweden illustrate the interest in bringing other mycorrhizai species into cultivation in spite of the difficulties. Plantation management may eventually become profitable for cultivation of two Pacific Northwest truffles *(Tuber gibbosum* and *Leucangium (Picoa) carthusiana)* and the American matsutake *(Tricholoma magnivelare),* but harvesting in the wild likely will continue. Some commercial harvest of the less abundant saprobic species (for example, *Pleurotus ostreatus, Hericium abietis,* and *Sparassis crispa)* does occur in the wild, but many prized edible saprobes, such as *Pleurotus* and *Agaricus* species, are relatively easy to grow and fruit in culture.

Ectomycorrhizal species persist for long periods on sites where their tree hosts remain healthy. Study 8 illustrates this point for chanterelles. Markers used to designate sporocarp positions were color coded by year of sampling. After several years, the different colors were tightly clustered, suggesting that fruiting often occurs in the same location. Similarly, Japanese studies of matsutake fruiting demonstrate that sporocarps develop on the leading edge of slowly moving mycelial colonies called shiros (Ogawa 1975, Tominaga 1971). Repeated fruiting in nearly the same location from year to year allows researchers to map clusters of sporocarps. Experimental treatments (such as picking versus no picking) can be applied to these clusters in subsequent years. Studies 8 and 11 illustrate selection of sporocarp clusters for application of experimental treatments. Persistent patches of mushrooms also provide the opportunity to investigate annual sporocarp formation and productivity in response to site conditions, microclimate, mycelial colony characteristics, and mycorrhiza abundance.

In the Pacific Northwest and intermountain West, morels represent yet another life history group of edible mushrooms. Massive, episodic fruitings of certain morel species often occur in response to events such as logging, fire, insect infestations, and ground disturbance. These large fruitings subside dramatically over the next several years after the event, although the magnitude and rate of decline are poorly documented. Persistent fruiting at low levels does occur without disturbance, but large, disturbance-related crops are most cost-effective for commercial harvesting in this region. The episodic nature of fruiting places constraints on the location and timing of studies. The unique life history of morels and related research challenges are discussed in detail in study 7.

Inventories and Monitoring

The term edible mushroom inventories refers to either surveys of occurrence or estimates of sporocarp production (counts or weights) per unit area. We use the term "monitoring" when those inventories are repeated to detect trends. Monitoring also can be used more broadly when it refers to tracking or understanding the health or viability of a resource, as illustrated below in this chapter. Baseline surveys of occurrence and estimates of annual variation in productivity are needed to determine if commercial harvesting diminishes subsequent fruiting or interferes with the reproduction of these fungi over extended periods of time (that is, decades or several timber rotations). Habitats change as forests mature and experience replacement events such as logging or fire, hence baseline inventories must be tied to habitat types if we are to measure and predict long-term trends in occurrence and production across landscapes. All renewable resources have inherent limits to sustainable harvesting, and we are just beginning to theorize about the functional limitations for forest fungi. Creative experiments can test many of our hypotheses, but final verification of sustainable harvesting will result only from careful long-term monitoring.

Total Versus Commercial Production

Investigators must distinguish between total biological production and commercial production when planning inventories. Commercial harvesters use efficient search patterns to obtain the most valuable mushrooms with the least effort; mushrooms too small, damaged, or old are usually not collected. Mushrooms not commercially harvested may be important as food for wildlife or for reproducing the species via spore dispersal. Clear objectives regarding the type of production information needed will determine monitoring methods. For measuring commercial production, managers could give commercial harvesters exclusive access to a defined area and weigh all the mushrooms they collect by commercial grade. If an estimate of total production and animal use of the resource is desired, then thorough sampling designs and searching techniques must be used.

Sampling Designs

Sample plot shape, size, number, and location are important considerations for efficient and accurate mushroom inventories because edible fungi tend to fruit in several clustered arrangements (Vogt and others 1992). Plots are typically shaped as circles, squares, or strips. Strip plots, commonly called transects, are actually elongated rectangular plots located along a transect. Walking along strip plots is quicker than stopping repeatedly for sampling numerous, small, circular or square plots. The perimeters of narrow strip plots are easily measured from a single transect, whereas determining the perimeter of a large circular or square plot is difficult in brushy areas unless borders are permanently marked. For a given sample area and number of plots, strip plots may be more likely to intersect clustered sporocarps and provide a representative sample, but this assumption needs testing. "Adaptive cluster sampling" (Thompson 1992) is a theoretically efficient sampling method for populations that have clustered individuals, but its practicality for mushroom sampling under field conditions has not yet been tested.

Field personnel walking along the center of a strip plot are more likely to detect mushrooms near the center than on the edges. This error (lower probability of detection near the edges) becomes worse with wider strips (Thompson 1992) and brushier sites. When a strip plot is sampled by two individuals walking along either side, the probability of detection greatly increases because partially hidden sporocarps may be observed from either of two angles. If strip plots are sufficiently narrow (2 meters [6.6 ft.] wide or less), field personnel can sample from the sides without stepping into the plots, thus avoiding soil disturbance or compaction within the plot (Mehus 1986, Ohenoja and Metsänheimo 1982, Ruhling and others 1984). Walking repeatedly along the immediate edge of a narrow strip plot does, however, tend to create highly impacted trails that can be erosive on steep slopes. Soil disturbance in these trails may impact mycorrhizal formation or mycelial growth and, consequently, alter fruiting patterns in the immediately adjacent plots. Strip plots 5 to 8 meters (16.4 to 26 ft.) wide allow sampling personnel to walk on the plot in a pattern that changes with each visit, thereby dispersing trampling impacts.

Strip plot widths also must correspond to required sample area. The total sample area needed for adequate productivity estimates is directly related to sporocarp abundance and distribution patterns within a site. Abundance is an especially difficult consideration because it changes from year to year. A sample area large enough to produce a reasonable sample during a year with light fruiting, may yield an overwhelming and unnecessary workload in a year with heavy fruiting. Investigators must either select sample areas that are workable at both extremes or subsample in years of heavy production. Approximations of adequate sample areas for various edible mushroom species are provided in the ongoing studies described here. Unfortunately, even with sample areas of 2,500-10,000 square meters (3,000 to 12,000 yd^2), production estimates for a single mushroom species are frequently imprecise (Pilz and Amaranthus, unpublished data); that is, the estimates have broad confidence intervals (the range of values that have a given statistical probability of including the true value). Two-meter wide (6.6-ft. wide) strip plots would need to be kilometers in length to yield such large sample areas. A reasonable number of circular or square plots covering this area would be so large that personnel would experience difficulty determining where they had already searched unless the plot were elaborately subdivided. Investigators must balance the shape and arrangement of the plots with how much walking is practical, ease of sporocarp observation, site brushiness, and potential for soil compaction or erosion from repeated visits.

Investigators also must decide whether to sample mushroom production at a given site or within a given habitat type. If characterizing mushroom production at a given site (say a logging unit) is desired, systematically located strip plots are easy to establish because beginning and end points are typically located at the edge of the site (commonly a road) and follow parallel compass bearings. All microhabitats, whether suitable for the mushroom of interest or not (that is, logs, streams, rocks, non-ectomycorrhizal host vegetation, and so forth), are included in the sample so that per-unit-area production estimates characterize the site as a whole. If the investigator wants an estimate of mushroom productivity in a given habitat type, then either production estimates must be adjusted downwards by the percentage of inappropriate habitat that falls within the sample plots or sample areas must be selected that exclude obviously inappropriate habitat. For instance, a manager wishing to estimate chanterelle productivity in local Douglas-fir stands would avoid sampling alder thickets along streams (or proportionately adjust production estimates) because alder does not form mycorrhizae with chanterelles. Randomly located plots provide greater assurance of unbiased estimates than systematically located plots, but may require a little more effort to locate, establish, and sample because, to relocate them, they need to be better marked and documented than strip plots starting from the edge of a road. A distance or orientation criterion also must be used to ensure that randomly located strip plots do not overlap.

The scale of the inventory is another important consideration in selecting sampling designs. For instance, strip plots may be practical for sampling mushroom populations in a forest stand or small watershed, but different approaches may prove more useful for characterizing populations over landscapes or regions. For example, many land management organizations have established forest inventory plots (various sizes and shapes) across their landscapes. These inventory plots provide the opportunity to sample mushrooms at sites where the vegetation and environment have already been fully described, thus allowing cost-effective correlations of productivity with habitat factors.

Sampling Methods and Units of Measure

The verb "to mushroom" derives from observations that sporocarps often grow and mature rapidly. To estimate edible mushroom production, we must decide when and how they will be measured. In essence, we are taking snapshots in time of their development.

To estimate total biological productivity of an undisturbed site across a season, one would mark and track individual mushrooms, measuring or weighing them only when they reach maximum size (assuming they did not get picked by humans or eaten by animals first). This procedure would be very labor intensive and for many purposes, unnecessary. Individual sporocarps of chanterelles, for example, persist 2 to 8 weeks in the field, allowing sampling intervals of a week or longer before mature sporocarps are lost to decay. Mushrooms under a certain size can be left for sampling during the next visit, allowing them to mature. Sampling interval and minimum size criteria must be clearly explained to properly interpret the resulting data.

In areas of intensive commercial collection, some harvesters visit sites daily and harvest a mushroom only when it reaches optimum commercial value, as defined by specific size and maturity criteria. Cooperating with collectors using this method provides a very accurate measure of commercial mushroom production at a site.

The simplest way to determine mushroom biomass is to pick and weigh them. Unfortunately, no one has conclusively demonstrated whether picking influences the size, number, or biomass of subsequent sporocarps, either that season or in following years. Study 8 suggests no short-term effects of harvest on subsequent chanterelle production, but carefully replicated comparisons are needed for other mushroom species. Studies 9 and 11 also address this issue, as will the planned morel inventories mentioned in study 7.

Mushrooms readily absorb rainfall and dry quickly, which causes rapid changes in mushroom moisture content. When accurate fresh weights are desired, mushrooms should be protected against excessive drying during transport from the field to the weighing facility. A picnic cooler works well to transport mushrooms. Plastic field collection bags retain moisture too well if the study includes measurements of commercial grades. Fresh mushrooms transpire ("sweat') moisture that condenses inside the bag; they then get wet and rapidly become slimy. Paper bags breath adequately but often tear when wet. Small waxed bags work well for individual mushroom specimens but are too small for the larger collections typical of plot samples. Cloth bags work well because they breath and do not tear when wet. Plastic buckets used by commercial collectors protect mushrooms well in the field but can be cumbersome, especially if multiple buckets are used to collect a separate sample for each strip plot. Mushrooms from each strip plot can be placed in separate cloth bags that are then carried in a single bucket for field protection. Regardless of the collection method, mushrooms must be weighed promptly for accurate fresh weights.

Any inventory of total production should rely on dry weights for comparisons among sites and sampling periods, because mushroom moisture content will change with differences or changes in the weather. If it is impractical to dry all sampled mushrooms, investigators can weigh subsamples, calculate a dry-to-wet weight ratio, and use this ratio to estimate total dry biomass from the total fresh weight.

Estimating the weight of non-harvested mushrooms requires different procedures. Size and dry weight measurements of a representative sample of picked mushrooms can be used to develop regression equations that estimate weight of nonpicked mushrooms from measurements of their size. Various size attributes can be used: maximum, minimum, or average cap diameters (all species); cap height (morels); stem diameter at the annulus (matsutakes); or stem diameter where it meets the hymenium (chanterelles). Bending and kneeling to measure stem diameter in the field is physically difficult, and measuring total height or stem length is problematic if part of the stem or its base is imbedded in duff or soil. Equations currently are being developed to determine best size criteria, or combination of criteria, for estimating the weight of each species. See studies 7, 9, 10, and 11 for examples, and Vogt and others (1992: 569) for a discussion of difficulties with this method.

When sample mushrooms are not harvested, field crews must know which mushrooms were measured during the previous sampling interval to avoid (or keep track of) repeat sampling. Mushrooms can be marked in several ways: with permanent felt-tip markers, paint, nail polish, food coloring, colored toothpicks, or small bulletin board pins with colored heads. Each method has drawbacks. Chemicals in the markers and paint may be toxic and influence sporocarp growth. Food coloring is nontoxic and less likely to affect mushrooms but may not persist in rain. Round toothpicks (the colored party variety) tend to crack open the caps of small sporocarps, and small pins may be lost on the site (to the potential detriment of small mammals) after mushrooms have decayed. The thin, flat variety of wooden toothpick is unlikely to split mushroom caps and may be painted if greater visibility is needed. Markers placed next to (rather than in) measured mushrooms should always be placed on the same side (compass orientation), so they are not mistakenly associated with mushrooms that fruit subsequently.

Studies of Mushroom Harvesting Effects

Some mushroom collectors report that mushroom harvesting influences the size or abundance of mushrooms that fruit later in the season or in following years. Confirming or refuting these anecdotes requires a statistical comparison of harvest and no-harvest treatments; sporocarps are collected and weighed on harvest plots, and counted and measured for size and weight regressions on control plots. Three years of baseline productivity data were collected from plots (selected clusters) in study 8 before harvest treatments were applied. The usefulness of applying harvest treatments with only one year of baseline data will be assessed for matsutake mushrooms in study 11.

Inventory strip plots can be used for harvest impact comparisons, but if harvest and no-harvest plots are adjacent, comparisons could be confounded by the possibility that sporocarps from both plots may be connected by underground mycelia that share responses to harvesting disturbance. Some mushroom harvesting impacts may result from destructive searching techniques used by inexperienced harvesters, such as raking forest duff layers to find immature sporocarps. Examining the impacts of searching techniques is most readily studied in a replicated experimental design using analysis of variance (ANOVA) to compare treatments and possible covariation with environmental factors like soil type (study 11 is an example).

Individual sporocarps do not recur, so they are not appropriate experimental units for measuring the impact of harvesting treatments. Insofar as clusters of mushrooms can be assumed to represent the fruiting of distinct mycelial colonies, they are more appropriate experimental units for measuring the impact of sporocarp harvesting on the fruiting behavior of a fungus individual. Cluster productivity can be measured by numbers of sporocarps, and weight can be measured or estimated. Comparisons should be based on the relative increase or decrease in productivity of treated clusters compared to control clusters, because all clusters will experience annual background variation in fruiting levels related to weather or physiological cycles.

Before application of experimental treatments, clusters of sporocarps must be mapped and delineated. Clusters should contain fairly uniform numbers, biomass, and spacing of sporocarps, so that treatments are applied to similar experimental units. Anticipated covariance also should be kept to a minimum to obtain maximum sensitivity of statistical comparisons. The most likely source of covariance is a physiologically shared response to different treatments by clusters fruiting from a single mycelial colony (individual). Similarly, genetically distinct mycelia of ectomycorrhizal species may share the same host tree, and therefore share common physiological responses to treatments. Clusters receiving experimental treatments should be sufficiently distant from each other to minimize the chance of shared mycelia or hosts. Molecular techniques of genetic analyses will be useful for determining the normal extent of mycelial colonies for different species. This will allow researchers to define adequate separation of clusters without using unnecessarily large distances.

Once clusters are defined, experimental treatments are randomly assigned to them. Replicating experimental treatments requires use of either multiple sites or blocking clusters within a site according to similar microenvironmental factors, or both.

Managers value prompt results to support their decisions; therefore, investigations supported or conducted by land management agencies must carefully consider how many years of baseline data provide adequate precision for their comparisons. Mapping sporocarp locations and abundance for several years before treatment application likely would improve cluster definitions, and several years of baseline data would test the assumption that control and treatment clusters exhibit similar annual variation in production if they are not treated. On the other hand, cluster definition may be adequate after only one year of mapping, and sufficient replication of randomly assigned treatments should compensate for variation among clusters in the annual fluctuations of productivity. Study 11 illustrates these procedures and considerations.

Studies of Forest Management Effects

Forest thinning or clearcutting, soil disturbance, fire, fertilization, cattle grazing, and allowing forest stands to age naturally all potentially influence edible mushroom productivity. Studies of forest management effects will allow managers to predict trends in edible mushroom production as these activities change forest landscapes. Studies can be located where management activities have already occurred (retrospective) or where they are planned (prospective).

Retrospective studies compare inventories in areas affected by a particular land management activity with inventories in non-affected areas (controls). Retrospective comparisons require more careful and extensive replication of inventoried sites than prospective studies because variation in the presence and abundance of mushrooms on the inventoried sites prior to the management activity is unknown.
Prospective studies typically employ baseline inventories of mushroom production to enhance statistical comparisons and simplify interpretation. Although fewer sites may be needed than with retrospective comparisons, replication of the experimental treatments still require multiple sites because management activities are typically applied to entire forest stands.

Stand treatments can be compared by sampling sporocarp production on strip plots, but the power of ANOVA comparisons derives from the degrees of freedom (number of treatment replicates minus one), rather than the number of plots within each treatment. Therefore, plots need not be as large, long, or numerous within each treatment location as is needed to obtain narrow confidence intervals for productivity estimates on a single site. Indeed, one large plot in each replicated treatment (stand or site) would be adequate if the investigator is not concerned about assigning confidence intervals to an estimate of productivity at individual treatment locations.

Experiments on the scale of forest stands are expensive and rarely justified simply to examine effects on mushroom production. Opportunities exist, however, to cooperate with integrated research projects examining the influence of land management activities on various ecosystem components and processes. Cooperating with integrated research restricts mushroom investigators to the overall design and objectives of the project, and field activities must be carefully coordinated. The mushroom portion of the study becomes less expensive, however, and considerable information on site conditions is available. Studies 9 and 12 illustrate edible mushroom monitoring conducted as a component of an integrated research project.

Studies of Biology and Ecology

Interpretation of inventory data or experimental results will be enhanced by an improved understanding of mushroom biology and ecology. A short list of topics and relevant questions worthy of further investigation follows. Study 13 illustrates an approach for investigating some of these topics.

Environment—How do micrometeorological factors (for example, soil temperature and moisture content) influence the onset and progress of sporocarp development? Are patterns of annual variation in sporocarp abundance or size cyclical in nature? If so, what factors regulate the patterns? How uniform are fruiting patterns among populations located in different forest stands, watersheds, landscapes or regions?

Mycelial colonies—What factors influence establishment, growth and decline of the fungal mycelium for a given species? How deep, extensive, and dense is the mycelial colony that produces sporocarps? How quickly does it spread through the soil? Does a fungus reach its maximum vigor or competitiveness in stands of a certain age? What are the preferred host trees for mycorrhizal species? How does the fungus interact with other fungi or soil organisms?

Reproduction—How does the species reproduce? How important is spore dissemination to reproduction, and does commercial picking significantly impact spore dispersal? Are episodic disturbance events necessary for reproduction (for example, fires for morels)? Following a stand-replacement event such as wildfire or logging, do fungi colonize a new forest through resting propagules or persistent mycelia in the soil, by maintaining mycorrhizae on rapidly sprouting brush species, by spores from adjacent forest, or some combination of these?

Genetics—Do colonies consist of genetically distinct, dikaryotic (two different haploid nuclei per cell) individuals? How commonly, and in which species, do monokaryotic (haploid) spores anastomose (fuse) with existing hyphae to produce heterokaryotic mycelia with more than two genetically distinct nuclei per cell (Rayner 1991)? How genetically diverse is the species at different scales (for example, within stands, watersheds, regions, or throughout its range)? Are there locally adapted endemic populations that may need protection?

Although few of these questions are easily answered, we must address them if managers are to regulate commercial mushroom harvests with confidence about long-range impacts. Answering these questions requires creative investigative methods that employ detailed descriptions, long-term correlations of fungus physiology with site conditions, and innovative field and laboratory experiments. Field research sites selected, secured, and mapped for harvesting impact or land management studies are logical locations to conduct detailed, long-term research.

Literature Cited

Amaranthus, M.; Trappe, J.M.; Bednar, L.; Arthur, D. 1994. Hypogeous fungal production in mature Douglas-fir forest fragments and surrounding plantations and its relation to coarse woody debris and animal mycophagy. Canadian Journal of Forest Research. 24: 2157-2165.

Arnolds, E. 1988. The changing macromycete flora in the Netherlands. Transactions of the British Mycological Society. 90: 391-406.

Arnolds, E. 1991. Decline of ectomycorrhizal fungi in Europe. Agriculture, Ecosystems, and Environment. 35: 209-244.

Chen, P.Y.S.; Novy, C.; Rogers, K. [and others]. 1993. *In*: Thomas M.G.; Schumann, D.R., eds. Income opportunities in special forest products: self-help suggestions for rural entrepreneurs. Agric. Info. Bull. 666. [Place of publication unknown]: U.S. Department of Agriculture, Forest Service. Chapter 11.

Danell, E. 1994. *Cantharellus cibarius:* mycorrhiza formation and ecology. Uppsala, Sweden; Acta Universitatis Upsaliensis. 58 p. Ph.D. dissertation.

de Geus, N. 1995. Botanical forest products in British Columbia: an overview. Victoria, BC; Integrated Resources Policy Branch, British Columbia Ministry of Forests. 51 p.

Dighton, J.; Clint, G.M.; Poskitt, J. 1991. Uptake and accumulation of ^{137}Cs by upland grassland soil fungi: a potential pool of Cs immobilization. Mycological Research. 95: 1052-56.

Garner, J.; Pagano H.B.; Cowling, E.B. 1989. An evaluation of the role of ozone, acid deposition, and other airborne pollutants in the forests of eastern North America. Gen. Tech. Rep. SE-59. Asheville, NC; U.S. Department of Agriculture, Forest Service. Southeast Forest Experiment Station.

Jansen, E.; van Dobben, H.F. 1987. Is decline of *Cantharellus cibarius* in the Netherlands due to air pollution? Ambio. 16: 211-213.

Kawai, M.; Ogawa, M. 1981. Some approaches to the cultivation of a mycorrhizal fungus, *Tricholoma matsutake* (Ito et Imai) Sing. *In*: Mushroom science XI, Part 2: Proceedings of 11th international scientific congress on the cultivation of edible fungi; 1981 [day and month unknown]; Sydney, Australia. [Place of publication unknown]: [publisher unknown]: 869-883.

Kowalski, S. 1987. Mycotrophy of trees in converted stands remaining under strong pressure of industrial pollution. Zeitschrift der Vereinigung für Angewantd Botanik. 61: 65-83.

Lipske, M. 1994. A new gold rush packs the woods in central Oregon. Smithsonian. 25: 35-46.

MacKenzie, J.J.; El-Ashry, M.T. 1990. Air pollution: toll on forests and crops. New Haven, CT Yale University Press.

McRae, M. 1993. Mushrooms, guns, and money. Outside. 18: 64-69, 151-154.

Mehus, H. 1986. Fruit body production of macro-fungi in some north Norwegian forest types. Norwegian Journal of Botany. 6: 679-701.

Molina, R.; Amaranthus, M.P.; Pilz, D.; Fischer, C. [In press, a]. Commercial harvest of edible ectomycorrhizal fungus sporocarps from Pacific Northwest forests: ecological and management implications. *In*: Proceedings, 4th European symposium on mycorrhizae; 1994 July 11-14; Granada, Spain. [Place of publication unknown]: [publisher unknown].

Molina, R.; O'Dell, T.; Amaranthus, M. [and others]. 1993. Biology, ecology, and social aspects of wild edible mushrooms in the forests of the Pacific Northwest: a preface to managing commercial harvest. Gen. Tech. Rep. PNW-GTR-309. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Molina, R.; Vance, N.; Pilz, D. [and others]. [in press, b]. Special forest products: integrating social, economic, and biological considerations into adaptive ecosystem management. *In*: Franklin, J.F.; Kolm, K., eds. Creating a forestry for the 21st Century. [City unknown], CA: Island Press.

Ogawa, M. 1975. Microbial ecology of mycorrhizal fungus, *Tricholoma matsutake* (Ito et Imai) Sing. in pine forest. I: Fungal colony ('Shiro') of *Tricholoma matsutake.* Bull. 272. Tokyo, Japan;: Government Forest Experiment Station.

Ogawa, M. 1982. How to produce matsutake mushroom. Nara, Japan; Matsutake Research and Consultation Office, Forest Service Research Station. 158 p.

Ohenoja, E.; Metsänheimo, K. 1982. Phenology and fruiting body production of macro-fungi in subarctic Finnish Lapland. *In*: Laursen, G.A.; Ammirati, J.F, eds. Arctic and alpine mycology. Seattle: University of Washington Press: 371-389.

Oren, R.; Werk, K.S.; Meyer, J.; Shulze, E.D. 1989. Potentials and limitations of field studies on forest decline associated with anthropogenic pollution. *In*: Schulze, E.D.; Lange O.L.; Oren, R., eds. Forest decline and air pollution: a study of spruce *(Picea abies)* on acid soils. Berlin, Germany; Springer-Verlag: 23-46.

Rayner, A.D.N. 1991. The challenge of the individualistic mycelium. Mycologia. 83: 48-71.

Richards, B. 1993. It seems some folks would simply kill for a nice morel. Wall Street Journal. April 11: A1, A12. New York City.

Ruhling, A.; Bååth, E.; Söderström, B. 1984. Fungi in metal-contaminated soils. Ambio. 13: 34-36.

Schlosser; W.E.; Blatner, K.A. 1995. The wild edible mushroom industry of Washington Oregon and Idaho: a 1992 survey. Journal of Forestry. 93: 31-36.

Smith, M. 1995. Tasty trade. Horticulture: The Bulletin. April 18.

Thompson, S. K. 1992. Sampling. New York: John Wiley & Sons.

Tominaga, Y. 1971. Studies on the formation and development of the fruit body of *Armillaria matsutake* (Ito et Imai). Bulletin Hiroshima Agricultural College. 4: 106-122.

Tominaga, Y. 1978. *Tricholoma matsutake. In*: Chang, S.T.; Hayes, W.A., eds. The biology and cultivation of edible mushrooms. New York; Academic Press: 683-697.

Trappe, J.M. 1988. Use of truffles and false-truffles around the world. *In*: Atti del II congresso internazionale sul tartufo: a proceedings; 1988 November 24-27; Spoleto, Italy. [Place of publication unknown]; [publisher unknown]: 19-30.

U.S. Department of the Interior, Bureau of Land Management. 1993. Managing special forest products in Oregon and Washington. [Place of publication unknown].

Vogt, K.A.; Bloomfield, J.; Ammirati, J.F.; Ammirati, S.R. 1992. Sporocarp production by Basidiomycetes, with emphasis on forest ecosystems. *In*: Carroll, G.C.; Wicklow, D.T., eds. The fungal community: its organization and role in the ecosystem. 2d ed. New York; Marcel Dekker: 563-582.

Vosatka, M.; Cudlin P.; Mejstrik, V. 1991. VAM populations in relation to grass invasion associated with forest decline. Environmental Pollution. 73 (special issue): 263-270.

Woodin, S.J.; Farmer, A.M. 1993. Impacts of sulfur and nitrogen deposition on sites and species of nature conservation importance in Great Britain. Biological Conservation. 63: 23-30.

Conference Presentations on Productivity and Sustainable Harvest of Wild Mushrooms

Study 7: Morel Life Histories–Beginning to Address the Unknowns With a Case Study in the Fremont National Forest Near Lakeview, Oregon

Nancy S. Weber, David Pilz, and Carol Carter [1] [2]

Context

In the forested regions of the North Temperate Zone, true morels *(Morchella* Pers. : Fr.) are the premier spring wild mushroom collected for personal and commercial use (Weber 1995). True morels are easily distinguished from other wild mushrooms, but identifying a given collection to species is often frustrating. The modern history of scientific nomenclature for mushrooms begins with the works of the Swedish scientist Linnaeus. Linnaeus (1753) placed what is now called the common, white, or yellow morel *(Morchella esculenta* (L. : Fr.) Pers.) in the genus *Phallus* as *P. esculentus* L. Since the time of Linnaeus, several dozen species and subspecific taxa in *Morchella* have been described and named. Korf's (1973) estimate that there are probably only three good species may be low, but an estimate of a dozen good species may be high. No modern synthesis of the genus giving probable synonymies has appeared. Several studies are underway that may yield insight as to how many species of true morels merit recognition.

---

[1] Nancy **Weber** is with the Department of Forest Science, Oregon State University, Corvallis, OR 97331; **David Pilz** is with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR 97331; and **Carol Carter** is with the Biology Department, Portland State University, Portland, OR 97207. Funds for Weber's work provided in part by the National Science Foundation through grants DEB 9007186 and DEB 9400545.

[2] Cooperating was Betty Charon, USDA Forest Service, Fremont National Forest, Lakeview Ranger District, Lakeview, OR 97630.

For this discussion, we divide the true morels into four informal groups: the half-free morel *(M. semilibera* DC : Fr.); the common, white, or yellow morel(s) *(M. esculenta* and related taxa); the black morel(s) *(M. conica* Pk., *M. elata* Fr. : Fr., and allied taxa); and the fire morel(s) *(M. esculenta* var. *atrotomentosa* Moser, and *M. conica* var. *nigripes* Moser). All four groups are represented in western North America.

The life cycle and life style (mode of nutrition) of true morels differ from those of the matsutake and the golden chanterelle, both of which are believed to be obligately mycorrhizal and are not known to form either sclerotia or conidial states (anamorphs). In contrast, true morels are saprobic or at most facultatively mycorrhizal. They regularly form sclerotia (dense masses of tissue) and conidial states as part of their life cycle (Matrouchot 1892; Molliard 1904a, 1904b, 1905; Ower 1982; Stamets 1993). Furthermore, Ower (1982), working with isolates from California, and Ower and others (1986) established that *M. esculenta* can be cultivated from spores and complete its entire life cycle as a saprobe. Ower (1982) worked with tissue cultures and cultures started from ascospores of a single specimen. In Europe, Buscot (1989, 1992, 1993a, 1993b, 1994), Buscot and Kottke (1990), and Buscot and Roux (1987) have described various types of associations among mycelia of *M. rotunda* (Pers.) Boud. (same group as *M. esculenta*), *M. elata*, and *M. semilibera* and roots of *Picea abies*. Buscot (1994) postulates that morels may be involved in complex ectomycorrhizal relations under some conditions. Successful attempts at pure culture synthesis of morel mycelium and roots of possible hosts have not been reported.

Many questions remain about the mating types and nuclear behavior in morel life cycles. The scheme presented in figure 1 is undoubtedly oversimplified, but will serve as an introduction to the apparent complexity of the morel life cycle. We have drawn on the life cycle presented by Volk and Leonard (1990) and other publications in developing figure 1.

The least complex possible nuclear cycle may involve two mating types (n, n'). Each ascospore and the cells of its products (definitely the primary mycelium and sclerotia and possibly conidiospores and sporocarps if they are formed) contain nuclei of only one mating type (n or n'). For the cycle to be completed, a secondary mycelium (both types of nuclei present in each cell) is formed. The cells in the secondary mycelium may contain both types of nuclei, singly or in pairs (dikaryons) (n, n', n+n'; Volk and Leonard 1990). All the products of the secondary mycelium, except possibly the conidiospores, are likely to share this pattern. We have seen no reports on the nuclear condition of the conidiospores; in many other members of the Ascomycotina, uninucleate and binucleate conidiospores may be formed which results in several possible types of conidiospores (for example, n, n', n and n, Wand n', n and n'). In the ascus, two nuclei of opposite mating type fuse and undergo meiosis producing eight haploid (n or n') ascospores. Other mating systems may occur; for example, Volk and Leonard (1990) interpreted Ower's (1982) work to imply that the progeny of a single spore might complete the cycle (noted with "?" in fig. 1).

The important lesson of this complex life cycle is that there are many potential points at which management decisions may impact future crops of morels. The possibility that sclerotia produced by the primary mycelium (haploid, monokaryotic mycelium) might

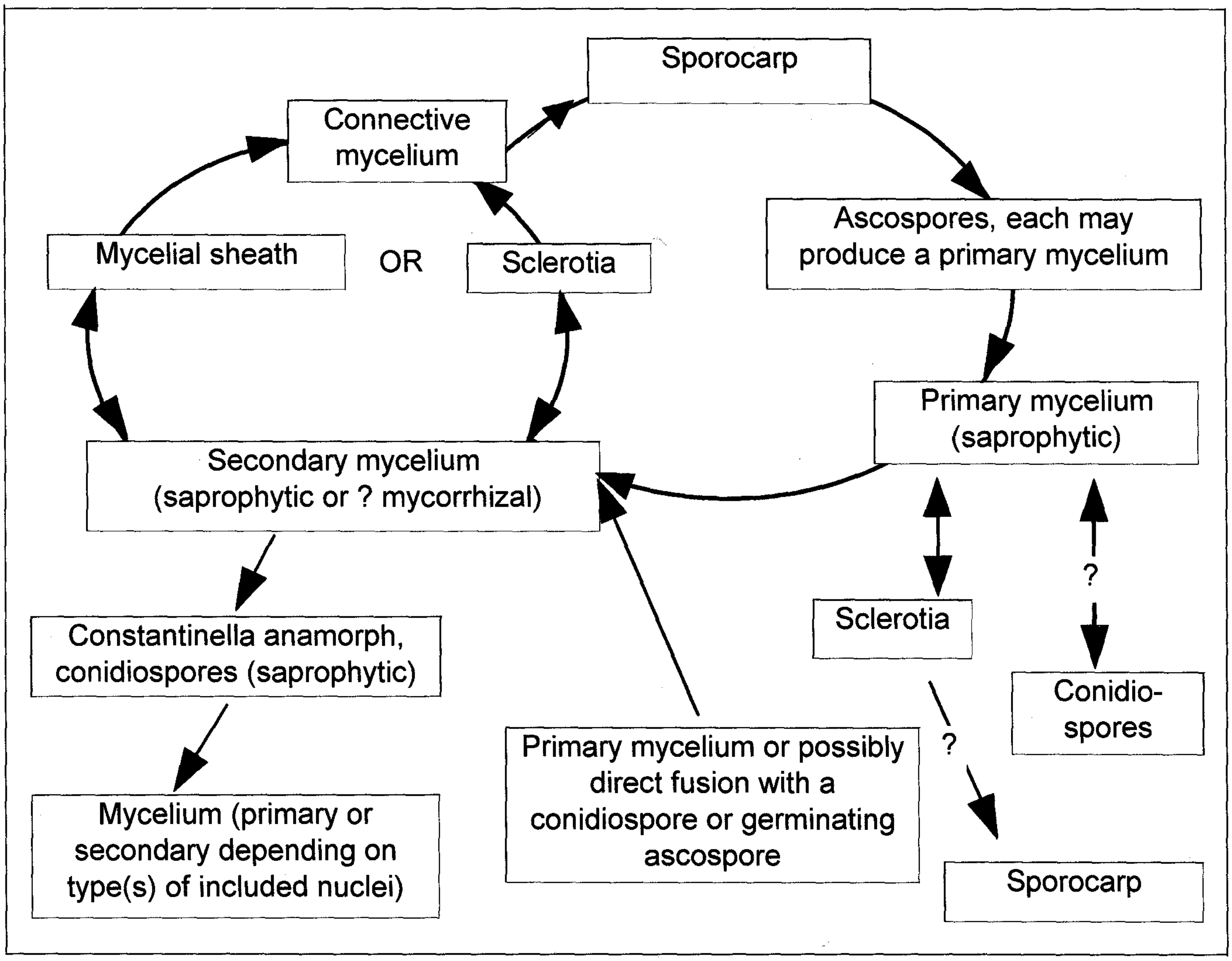

Figure 1—Composite life cycle of true morels. The primary mycelium is thought to be saprobic; *M. esculenta* may complete its life cycle as a saprobe; the secondary mycelium of some other species (see text) may be at least facultatively mycorrhizal. Sclerotia produced by the secondary mycelium and mycelial sheaths may be two manifestations of the same phase.

form sporocarps was inferred from Ower's (1982) work and remains an area of uncertainty. The role and behavior of the conidiospores also remains unresolved. The primary and secondary mycelia are the vegetative stages of the organism, responsible for obtaining nutrients and so forth; the sclerotia may function as storage organs or tide the organism over unfavorable conditions.

Each of the four groups of morels appears to have different ecological preferences. The common and half-free morels occasionally fruit abundantly in mechanically disturbed (but likely not burned) areas. They also may fruit regularly, if less abundantly, in relatively stable habitats in association with broad-leaved trees in the Rosaceae, Salicaceae, Fagaceae, and possibly the Ericaceae. In western North America, black morels are most abundant in coniferous forests, especially those attacked by insects, and in burned areas. Fire morels are the least well known; they may be restricted primarily to severely burned coniferous forest at moderate to high elevations. The black and fire morels from burned areas are the backbone of the commercial morel crop in western North America.

Several papers (Coombs 1994, Duchesne and Weber 1993, Miller and others 1994) contain information that could lead to the development of methods for predicting or enhancing the morel crop. Duchesne and Weber (1994) report that in May following a prescribed burn in September 1990 in Ontario, Canada, a massive fruiting of morels developed in the burned area but not in the adjacent forest. Coombs (1994) describes the initial stages in an experiment where morel sclerotia were introduced into a burned area to see if such inoculation would increase the crop. Miller and others (1994) found what they identify as morel sclerotia in soils burned in the 1988 fires in Yellowstone National Park. Perhaps some way of estimating the potential crop based on the density of sclerotia could be developed.

Informed management of wild morels is possible only if we know which organisms are involved, agree on what to call them, and understand their biology and ecology. Areas in need of attention include (1) defining the species and arriving at a stable set of names for them, (2) gathering baseline data on natural fruiting patterns for each species, with emphasis on those gathered in commercial quantities, and (3) confirming the life cycle and life style variations for at least the major species. Studies of macroscopic and microscopic changes in sporocarps as they mature, population structure at the molecular level, and productivity over a period of years are just some of the topics awaiting attention.

As a result of contacts made during the conference, the authors initiated a study on morel fruiting patterns. The Lakeview Ranger District, Fremont National Forest, in south-central Oregon was chosen because of interest in the project by local staff and an abundant fruiting of morels in the area.

The objectives of this preliminary study included:

Objectives

1. Testing selected ways of quantifying information on abundance of sporocarps per unit area.
2. Developing regression formulae relating sporocarp weight and size.
3. Gathering baseline estimates of productivity for use in comparing future fruiting levels.
4. Gathering samples for morphologic, taxonomic, and population genetics studies.

ethods and Rationale

We developed a method for setting up random strip plots to count morel sporocarps. Using a belt-chain and compass, we established a line 183 meters (600 ft.) long. We sampled morels within a band 1 meter (3.2 ft.) wide on each side of the line. All morel sporocarps were gathered by gently detaching the intact sporocarp from its mycelium (with a minimal amount of adhering debris). Sporocarps from each transect were placed in separate, labeled kraft bags. For each transect, sporocarps were sorted into four size categories approximating commercial grades. Within each grade and transect grouping, sporocarps were counted, weighed, and placed in a dehydrator (Trappe 1982). After drying, they were weighed again.

Sporocarps close to, but outside, the edge of the transect were gathered, kept in separate individual bags, and labeled with their position along the transect (distance and whether right or left of median line). Size and weight measurements of these sporocarps were used for the regression formulae. The next day, the sporocarps were cut in half longitudinally; one-half of each sporocarp was used for molecular studies of population genetics, and the other half was kept as a voucher sporocarp for studies of sporocarp morphology.

ique Considerations

Data collected over a period of years will provide an estimate of population fluctuations and can be used in conjunction with various types of habitat manipulation to ascertain effects on fruiting patterns of morels. Because we observed morels to be clustered on the landscape, strip plots may show great variability in numbers of sporocarps encountered. Multiple strip plots must be sampled within a short period to provide precise estimates of site productivity. Genetic and morphological analyses of specimens will be used to determine variation within and among populations and species.

A three-person field crew is optimal. When morels are abundant, only two or three strip plots can be completed in a standard working day. This schedule includes travel time, taking notes on sporocarp morphology, and sorting, counting, weighing, and drying sporocarps as well as preparing samples for molecular analysis. Crews need to be trained in the survey technique, in identification of morels, and in techniques for recording data and processing sporocarps. Several crews could be trained together in a 1- to 2-day workshop, with part or all of one day spent in the field.

Each crew should have:

- standard safety equipment
- compass
- belt-chain (preferably calibrated in meters)
- dowel, rod, or stick cut to 1 meter in length
- supply of large (standard grocery size) and small (lunch bag size) kraft bags
- basket for carrying supplies and samples (paper bags may tear when wet)
- indelible markers
- knives, trowels, or other implements for easing sporocarps from their substrate
- cooler(s) to hold sporocarps and prevent overheating or desiccation during travel time

In the laboratory, facilities are needed for sorting, weighing, and drying the sporocarps. Home food dehydrators, available in many markets for about $60-100, are recommended. Those with adjustable temperatures and a fan are preferred. Sporocarps to be dried are cut in half lengthwise, placed in a single layer on each screen, and clearly labeled. The sporocarps should become as crisp as a fresh potato chip in 12 to 16 continuous hours of dryer operation. A steady drying temperature in the range of 35 to 50 °C (about 95 to 120 °F) and good air circulation are recommended to prevent collapse of the sporocarps. When sporocarps are removed from the dryer, the dry weights are determined and each set of sporocarps is placed in a clean bag, labeled, and stored in an insect-proof place for further morphological study. During the drying process, mature morels release large quantities of spores. These spores may cause allergic reactions in some people, thus the dryers should be located in a well-ventilated area or under an exhaust fan, so that the spores will not affect workers. Sporocarps for molecular studies are labeled, placed in small coolers with a block of artificial ice, suitably packed so that the sporocarps are not damaged, and express shipped to the laboratory. They also may be frozen and shipped later.

Morel season in a given area and elevation usually lasts only a few weeks, although by moving from lower to higher elevations, or from warm to cool exposures, morels can be found over several months in some mountainous areas. The season starts after snow melt when rains are relatively regular and the soil warms; generally, nights are cool and days warm at the start of morel season. The season can end abruptly with the arrival of hot, dry weather. Trying to schedule crews for a particular time and place more than a few weeks in advance is not recommended. Rather than have one or two crews responsible for survey in several dispersed districts or forests, each organization may prefer to have a local trained crew that can be assigned to morel duty on a few days notice.

Current Status

The principal investigators have begun an expanded and replicated study of morel productivity, ecology, taxonomy, and population genetics following wildfires and tree mortality in the mountains of northeastern Oregon. Michael Amaranthus (Pacific Northwest Research Station, Grants Pass, OR) is concurrently installing a case study of morel responses to site conditions and tree mortality in a recently burned area of southwestern Oregon.

Literature Cited

Buscot, F. 1989. Field observations on growth and development of *Morchella rotunda* and *Mitrophora semilibera* in relation to forest soil temperature. Canadian Journal of Botany. 67: 589-593.

Buscot, F. 1992. Ecological and biological strategies of morels. Cryptogamie – Mycologie. 13: 171-179.

Buscot, F. 1993a. Mycelial differentiation of *Morchella esculenta* in pure culture. Mycological Research. 97(2): 136-140.

Buscot, F. 1993b. Synthesis of two types of association between *Morchella esculenta* and *Picea abies* under controlled culture conditions. Journal of Plant Physiology. 141: 12-17.

Buscot, F. 1994. Ectomycorrhizal types and endobacteria associated with ectomycorrhizas of *Morchella elata* (Fr.) Boudier with *Picea abies* (L.) Karst. Mycorrhiza. 4: 223-232.

Buscot, F.; Kottke, I. 1990. The association of *Morchella rotunda* (Pers.) Boudier with roots of *Picea abies* (L.) Karst. New Phytologist. 116: 425-430.

Buscot, F.; Roux, J. 1987. Association between living roots and ascocarps of *Morchella rotunda.* Transactions of the British Mycological Society. 89: 249-252.

Coombs, D. 1994. Come spring, this project may make a lot of sense. Mushroom, the Journal of Wild Mushrooming. 13(46): 12-13.

Duchesne, L.C.; Weber, M.G. 1993. High incidence of the edible morel *Morchella conica* in a jack pine, *Pinus banksiana,* forest following prescribed burning. Canadian Field-Naturalist. 107: 114-116.

Korf, R.P. 1973. Discomycetes and tuberales. *In*: Ainsworth, G.C.; Sparrow, Frederick K.; Sussman, A.S., eds. The fungi, an advanced treatise. Vol. IV: A taxonomic review with keys: Ascomycetes and fungi imperfecti. New York; Academic Press: 249-319.

Linnaeus, C. 1753. Species plantarum. Holmiae. [Place of publication unknown]: [Publisher unknown]. 1,200 p.

Matruchot, L. 1892. Recherches sur le développement de quelques mucédinées. Paris: [Publisher unknown].

Miller, S.L.; Torres, P.; McClean, T.M. 1994. Persistence of basidiospores and sclerotia of ectomycorrhizal fungi and *Morchella* in soil. Mycologia. 86: 89-95.

Molliard, M. 1904a. Forme conidienne et sclérotes de *Morchella esculenta* Pers. Revue Générale de Botanique. 16: 209-218.

Molliard, M. 1904b. Mycélium et forme conidienne de la morille. Comptes Rendus Hebdomadaires des Séances de l'Academie des Sciences. 138: 516-517.

Molliard, M.1905. Production expérimentale de l'apareille ascosporé de la morille. Comptes Rendus Hebdomadaires des Séances de l'Academie des Sciences. 140: 1,146-1,148.

Ower, R. 1982. Notes on the development of the morel ascocarp: *Morchella esculenta.* Mycologia. 74: 142-144.

Ower, R.; Mills, G.L.; Malachowski, J.A.; inventors, Neogen Corp., assignee. 1986. Cultivation of *Morchella.* U.S. patent 4,594,809. June 17. 7 p. Int. CI.4A01G 1/04.

Stamets, P. 1993. Growing gourmet and medicinal mushrooms. Berkeley, CA: Ten Speed Press. 552 p.

Trappe, J.M. 1982. Alternative methods for drying fungi and controlling insects in herbaria. Mycologia. 74:1,014-1,015.

Volk, T.J.; Leonard, T.J. 1990. Cytology of the life-cycle of *Morchella.* Mycological Research. 94: 399-406.

Weber, N.S. 1995. A morel hunter's companion. Lansing, MI: Two Peninsula Press. 209 p.

Study 8: Oregon Cantharellus *Study Project 1986-96*

Lorelei Norvell, Judy Roger, Janet Lindgren and Frank Kopecky [1] [2]

Context

During an economic recession in the 1970s, many unemployed workers discovered that edible wild mushrooms could be harvested and profitably sold for export to Europe and Japan. Unfortunately the resulting increase in wild mushroom harvesting coincided with several drought years. Edible species became increasingly difficult to find, and recreational mushroom pickers began to fear that overpicking would lead to a disappearance of many species. They pointed to a severe decline in many popular edibles in Europe where fungi have been picked for centuries (Jansen and others 1985).

The perceived decrease in yellow chanterelles *(Cantherellus cibarius)* provoked the greatest concern. Commercial harvesters believed that picking the sporocarps did not endanger the organism, but no scientific evidence existed to support this belief. Members of the Oregon Mycological Society decided to conduct a pioneer 10-year study to investigate the impact of intensive chanterelle harvest on future chanterelle productivity.

The Oregon *Cantharellus* Study Project began in 1986 in cooperation with the U.S. Department of Agriculture, Forest Service, and the City of Portland. An unfunded study, all materials and labor have been donated by over 60 volunteers.

Objectives

The objectives were to:

1. Determine the effects of long-term, intensive, chanterelle harvesting on subsequent fruiting.

2. Assess associated fungus and plant diversity on the chanterelle site through biweekly inventory of all epigeous fungi (excluding lichens) and semiannual inventory of vascular and nonvascular plants.

The study is in a 100-year-old *Tsuga heterophylla* and *Pseudotsuga menziesii* forest within the buffer zone of the City of Portland's Bull Run Watershed, Mount Hood National Forest (Corbett and Zig Zag Ranger Districts), Oregon.

Methods and

In 1986, the research team established 10 separate study plots (ranging from 16 to 64 square meters [172 to 690 ft.^{2}) around clusters of fruiting chanterelles; the intent was to encompass one chanterelle clone per plot. Before harvest treatments were applied, workers mapped and measured chanterelles for 3 years to acquire baseline data. In 1989, each plot (subdivided into 4-meter-square [43 ft.^{2}] subplots for mapping purposes) received one of three treatment designations: (1) control (no removal of chanterelles), (2) pull-harvest (chanterelles pulled from ground), or (3) cut-harvest (chanterelles

---

[1] **Lorelei Norvell** is with the Department of Botany, University of Washington, Seattle, WA 98195; and **Judy Roger, Janet Lindgren,** and **Frank Kopecky** are with the Oregon Mycological Society, Portland, OR. Frank Kopecky served as coordinator, 1985-87, Janet Lindgren as instigator, Lorelei Norvell as project designer and coordinator, 1988-91, and Judy Roger as coordinator, 1992 to present.

[2] Cooperators were Dick Hardman, Rex Holloway, Molly Sullivan, Kathleen Walker, and Todd Parker; Corbett and Zig Zag Ranger Districts, Mount Hood National Forest; and Jim Robbins, City of Portland Water District.

removed by cutting at ground level). All treatments were replicated in three blocks (one block has two small control plots).

Plants and other mushrooms are inventoried in all plots. Tree age will be determined from growth ring increment cores and soil will be analyzed at the conclusion of the study to provide additional ecological information. Daily temperature and precipitation data are provided by the Bull Run Watershed Headwork's weather station 5 kilometers (3.1 mi.) away.

Three to four volunteer researchers visit the site every 2 weeks from early July until the season is ended by snow in late November to early December. In no-harvest control plots, researchers place color-coded plastic pickup sticks with numbered flags next to each new chanterelle and map them by triangulation. Coordinates are obtained from metric tapes secured to dowel rods inserted into plastic pipes driven into the ground at all subplot corners. Workers determine cap diameter, stem diameter, and height of each chanterelle and report their measurements to another individual who records them. Measurements are repeated at each successive visit until the chanterelle disappears or the season is complete.

In harvest plots, all chanterelles greater than 1 centimeter (0.39 in.) in diameter are removed (in an attempt to duplicate "heavy" harvesting). Researchers place harvested specimens into (waxed) paper bags, and note the date and subplot. At completion of each day of fieldwork, the project coordinator measures, dries, and records biomass (dry weight in grams) of each chanterelle. All specimens are stored at the University of Washington fungal herbarium (WTU) for future molecular analysis. From 1986 to 1993, 2,893 chanterelles were tracked on the control and harvest plots.

During each visit, other fungus species also are inventoried on subplots (but no mapping, measurements, or enumerations are made). New or unrecognized species are collected in aluminum foil or plastic tackle boxes, and field identifications and distinctive characters are recorded by experienced field taxonomists. All fresh collections are then described, dried, and stored at WTU for later microscopic examination. Both plants and fungi also are inventoried during spring months. Since 1986, 215 fungus, 39 vascular plant, and 16 bryophyte species have been recorded.

Unique Considerations

Selection and training of conscientious qualified volunteers able to conduct a scientific investigation of this magnitude has been our most important consideration. Fortunately the approximately 80 years of taxonomic experience (Lindgren, Norvell, and Roger) and 40 years of forestry experience (Kopecky) brought to the study by the primary investigators have been augmented by additional expertise from over 50 enthusiastic volunteers. Despite a seemingly large volunteer pool, we found it easy and most efficient to use a relatively small work force composed of the same trained reliable individuals. The labor-intensive nature of our primary research-field work alone requires at least 15 annual visits (with an estimated 24 staff-hours per visit) for each of 10 projected years–leads almost inexorably to worker burnout, particularly as strict adherence to a biweekly sampling regimen often necessitates working in extremely unpleasant (wet and cold) weather. Dependence on a volunteer work force also has dictated the small scale of our study. If the chanterelles were only harvested and weighed (not measured, mapped, or tracked), or if only two treatments were applied (pull-harvest versus no-harvest), time spent on site could be reduced.

Preliminary data indicate no difference between cut-harvest and pull-harvest. Our data agree with that of Egli and others (1990), who observed no difference between cutting or pulling of 15 other edible species. The fact that our study (comparing treated and control plots over time) was the first of its kind, however, dictated that we attempt to provide as much baseline data as possible for future studies.

Although we are getting excellent data, they may not be applicable to other sites. Given the small scale of the study, we may be seeing harvest effects on only closely related, if not genetically identical, chanterelles in one forest location. Larger studies should be conducted and results compared.

The study's location behind locked gates in the Bull Run Watershed (first suggested and facilitated by Kopecky and the USDA Forest Service) has protected its integrity. We strongly suggest establishing any study of an economically valuable fungus (for example, chanterelle, matsutake, and morel) in similarly protected preserves when possible. The relative proximity of such a protected site to a metropolitan area also proved helpful: all microscopic examination and drying can be done in established labs rather than in temporary work stations.

Our greatest challenges have involved unknowns, uncontrollable variables, and unforeseen omissions. When we began the study, we did not know the age of our chanterelle mycelia, whether mycelia require spore influx to remain viable, or whether chanterelles have innate fruiting cycles. Although 8 years of data (5 years of harvesting data) indicate no statistically significant correlation between chanterelle harvesting and subsequent fruiting, the weather has been so variable as to make any conclusions premature and unreliable. Preliminary data do suggest a statistically significant correlation between warm summer temperatures and high chanterelle numbers (this correlation also has been cited by Danell 1994, Largent and others 1994, Ohenoja 1993), but this is the only factor among many yet to be analyzed. Recent studies (Kotilova-Kubickova and others 1990a, 1990b, 1990c; Largent and others 1994; Vogt and others 1992) indicate that micrometerological data would prove more informative in tracking sporocarp production of Basidiomycetes than the generalized weather data we have obtained thus far. In spite of these problems, this study is the oldest continuing examination of chanterelle production and picking impacts.

Current Status

After the 1996 field season, we intend to perform a full statistical analysis of the first 10 years of data and determine the genetic composition of the population through molecular techniques. Because even a 10-year study is too short to provide definitive answers, we hope to continue the study.

Literature Cited

Egli, S.; Ayer F.; Chatelain, F. 1990. Der Einfluss des Pilzsammelns auf die Pilzflora. Mycologia Helvetica. 3(4): 417-428.

Danell, E. 1994. *Cantharellus cibarius:* mycorrhiza formation and ecology. Uppsala, Sweden: Acta Universitatis Upsaliensis. 58 p. Ph.D. dissertation.

Jansen, E.; van Dobben, H.; de Wit, T. 1985. Achteruitgang van de cantharel in Nederland. Wetenschappelijke Mededeling Koninklijke Nederlandse Natuurhistorische Vereniging. 167: 59-69.

Kotilova-Kubickova, L.; Ondol, J.P.; Priban, K. 1990a. Phenology and growth of *Dermocybe uliginosa* in a willow carr. I: Phenology of fruiting. Mycological Research. 94: 762-768

Kotilova-Kubickova, L.; Ondol, J.P.; Priban, K. 1990b. Phenology and growth of *Dermocybe uliginosa* in a willow carr. II: Fruiting duration and performance. Mycological Research. 94: 769-773.

Kotilova-Kubickova, L.; Ondol, J.P. ; Priban, K. 1990c. Phenology and growth of *Dermocybe uliginosa* in a willow carr. III: Fruit-body growth and biomass production. Mycological Research. 94: 774-780.

Largent, D.; Hewlett, S.; Sime, D. 1994. Influence of environmental factors on fruiting of edible, mycorrhizal mushrooms. [Place of publication unknown]: [publisher unknown]; Final report; [contact unknown]. Prepared for: California Department of Forestry and Fire Protection.

Ohenoja, E. 1993. Effects of weather conditions on the larger fungi at different forest sites in northern Finland in 1976-1988. Oulu, Finland: University of Oulu. Ph.D. dissertation.

Vogt, K.A.; Bloomfield, J.; Ammirati, J.F.; Ammirati, S.R. 1992. Sporocarp production by Basidiomycetes, with emphasis on forest ecosystems. *In*: Carroll, G.C.; Wicklow, D.T, eds. The fungal community, its organization and role in the ecosystem. 2d ed. New York: Marcel Dekker: 563-582.

Study 9: Effect of Environmental Factors and Timber and Mushroom Harvest on Cantharellus *Production on the Olympic Peninsula, Washington State*

Michael Amaranthus and Kenelm Russell [1,2]

Context

Changes in forest composition and structure likely affect fruiting of chanterelle *(Cantharellus)* species. Recent research (Amaranthus and others 1994) indicates that clearcutting can decrease truffle sporocarp production for two decades as compared to mature forest fragments. Luoma and others (1991), O'Dell and others (1992), and study 4 of this publication show differences in ectomycorrhizal fungus community structure among stands aged 25, 50, 80,160, and 400+ years. Forest thinning can reduce productivity of hypogeous fungi in 60- to 70-year old Douglas-fir stands." Little information, however, exists on chanterelle responses to forest thinning and various silvicultural systems. Such data are essential to predict impacts of forest harvest on mushroom production.

This study is on the Olympic Peninsula within 60-year-old stands dominated by western hemlock, Douglas-fir, and Sitka spruce and is an Integrated Research Site of the Long-Term Ecosystem Productivity Program of the USDA Forest Service. The integrated research and extended perspective offered by this study will produce needed information on interactions among chanterelle fruiting, environmental factors, mushroom harvesting, and forest density management.

Objectives

Objectives were to:

1. Compare subsequent fruiting among plots where chanterelles are harvested and not harvested.
2. Correlate sporocarp production with soil temperature, air temperature, and moisture variables.
3. Compare chanterelle production in stands thinned to produce forest composition and structure typical of early, middle, and late seral stages (and a no-timber-harvest control).

Methods and Rationale

Including the no-timber-harvest control, the study design consists of 4 treatment stands in each of 3 blocks for a total of 12 treatment stands. Chanterelle production is sampled once monthly from mid-August to mid-December. Chanterelle sporocarp production has a strong seasonal aspect in our region, and sampling over a 5-month period will ensure capturing not only biomass production but also changes in soil

[1] **Michael Amaranthus** is with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Grants Pass, OR 97526; and **Kenelm Russell** is with the Washington Department of Natural Resources, Olympia, WA 98504.

[2] Cooperators were David Arthur, Siskiyou National Forest, Grants Pass, OR 97526; and Richard Bigley and Jim Arthurs, Washington Department of Natural Resources, Olympia WA 98504.

[3] Upublished data. 1995. James Trappe and Wes Colgan III Department of Forest Science, Oregon State University, Corvallis, OR 97331.

moisture and temperature on the site. Two years of baseline data on chanterelle production have been collected, and timber-harvest treatments were scheduled for spring 1995. Post-treatment chanterelle sampling will occur at years 1, 2, 3, 5, 10, and 20 and every 20 years thereafter.

Chanterelle mushrooms are sampled within four strip plots (8 by 100 meters [26 by 328 ft.]) located in each forest harvest treatment. One-half of each transect (4 by 100 meters) was randomly selected as either a chanterelle-harvest or no-harvest treatment. In the chanterelle-harvested portion of each transect, all mushrooms are cut at the soil surface with a knife and placed in sealed plastic bags in a cooler. Size and weight are measured within 24 hours of collection. Cap width (at widest point), total mushroom height, and basal stem diameter (where cut) are measured to the nearest millimeter, and fresh weight recorded to the nearest one-tenth of a gram. A subsample of mushrooms is dried and weighed to determine average moisture content during each sampling period. In the no-harvest half of each strip plot, cap diameter and mushroom height are measured in the field for each chanterelle mushroom. Regression equations (derived from the harvested mushrooms) of size, fresh weight, and dry weight will be used to estimate chanterelle biomass in the measured, but not harvested, portions of each plot.

Additional data collected include fruiting of chanterelle species other than *C. cibarius* and *C. subalbidus* (the commercially harvested species), mycophagy, and forest floor vegetation and litter (moss, salal, decayed wood, and so forth). For future identification, a colored plastic toothpick is inserted in each inventoried, but not harvested, mushroom. During each visit, soil moisture and temperature are determined at a 10 centimeter (3.93-in.) depth at the end points of two center strip plots in each stand. Air temperature and soil surface temperature also are recorded at each of the three blocks.

Unique Considerations

Most other studies of chanterelle production have lacked integration with investigations of other ecosystem components. Other research activities on the site and the extended perspective offered by this integrated project will produce information on interactions between fruiting of mycorrhizal fungi and environmental factors, such as soil compaction, stand conditions, and timber harvesting.

Current status

Two years of pretreatment data (autumn 1993 and 1994) have been collected. Total and monthly production was much higher in autumn 1994 than in autumn 1993. Chanterelle numbers and total dry weight have been significantly greater, during both seasons, in areas with only moss on the forest floor than in areas covered with sparse salal, dense salal, or decayed wood. Chanterelle harvest has not yet significantly affected *chanterelle* numbers or dry weight. Timber harvest began in summer 1995, and chanterelles were again sampled that autumn.

Literature Cited

Amaranthus, M.P.; Trappe, J.M; Bednar, L.; Arthur, D. 1994. Production of hypogeous fungi in managed and unmanaged habitats of southwest Oregon. Canadian Journal of Forestry Research. 24: 2,157-2,165

Luoma, D.L.; Frenkel, R.E.; Trappe, J.M. 1991. Fruiting of hypogeous sporocarps in Oregon Douglas-fir forests: seasonal and habitat variation. Mycologia. 83: 335-353.

O' Dell, T.E.; Luoma, D.L.; Molina, R.J. 1992. Ectomycorrhizal fungal communities in young, managed and old growth Douglas-fir stands. Northwest Environmental Journal. 8: 166-168.

Study 10: Matsutake Productivity and Ecology Plots in Southern Oregon

David Pilz, Chris Fischer, Randy Molina, Michael Amaranthus, and Daniel Luoma[1] [2]

Context

The production of the Japanese matsutake mushroom (*Tricholoma matsutake)* has declined in Japan (Kawai and Ogawa 1981) while demand continues to increase (The Japan Trade Development Division 1990). Korea supplies much of the matsutake market, but harvesting of the American matsutake *(T. magnivelare)* in the Pacific Northwest also has expanded dramatically. They are now harvested from northern British Columbia and southeast Alaska, south through coastal pine forests and the eastern crest of the Cascade Range in Washington and Oregon, to the Siskiyou and Klamath Mountains of southwest Oregon and northwest California. In Oregon alone, about 204,545 kilograms (450,000 pounds) valued at $4,350,000 were harvested in 1992 (Schlosser and Blatner 1995). Much of the Oregon harvest of matsutake mushrooms is collected from Federal lands on the east side of the Cascade Range near Chemult and in the Siskiyou Mountains of southwest Oregon. Burgeoning mushroom harvest activities preceded monitoring of matsutake productivity and adequate understanding of its ecology. Matsutake fruiting differs greatly from year to year, so quick establishment of baseline productivity study sites was deemed essential to begin gathering inventory and ecological data. The applicability of fungus diversity sampling methods to the measurement of a single species of edible mushroom also needed evaluation.

Objectives

Objectives were to:

1. Determine biomass production of matsutake sporocarps from permanent plots in designated study areas and from watersheds where matsutakes are commercially harvested.

2. Correlate sporocarp production with vegetation, soil, and temperature parameters.

4. Develop cost-effective methods to inventory, predict, and compare productivity of edible mushrooms in different regions.

Methods and Rationale

This study was installed in Oregon on the Chemult Ranger District of the Winema National Forest, the Illinois Valley Ranger District of the Siskiyou National Forest, and the BLM Medford District. Each long-term study site is 225 by 225 meters (740 ft.) for a total area of 5 hectares (12.4 acres). These sites were located in inaccessible areas wherever possible, and signs restricting recreational or commercial collecting were

---

[1] **David Pilz, Chris Fischer,** and **Randy Molina** are with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR 97331; **Michael Amaranthus** is with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Grants Pass, OR 97526; and **Daniel Luoma** is with the Department of Forest Science, Oregon State University, Corvallis, OR 97331.

[2] Cooperators were Gerry Smith, Chemult Ranger District, Winema National Forest; Rudy Wiedenbeck and David Arthur, Siskiyou National Forest; and Kathy Browning, Medford District, Bureau of Land Management.

posted. At Chemult, three sections (square miles) were designated for study purposes. Matsutake production was evaluated within six permanent 2- by 50-meter (6.6 by 164-ft.)strip plots located systematically and oriented randomly within each study site for a total sample area of 600 square meters (6,460 ft.^{2}) per site. Study sites were selected on different aspects and elevations within the dominant plant community types to allow extrapolation of results to a broader landscape context.

To estimate biomass of the matsutakes without harvesting them, the following measurements were made after the veil of each mushroom had broken: (1) cap diameter, (2) stem diameter at point of annulus attachment, and (3) vertical distance from annulus to top of cap. Once measured, each mushroom was marked so that it would not be remeasured. Other matsutakes were collected outside the plots to develop correlations between size and weight, so that the biomass of unharvested sporocarps within the plots could be estimated from their size measurements. Plots were surveyed weekly through the fruiting season until no new sporocarps were located or the site was covered with snow. A percentage of volume removed was estimated for partially eaten sporocarps. Data on fungus consumption by animals will provide valuable information about potential effects of human competition for a wildlife food resource.

Distance to the nearest tree or shrub species also was determined for each mushroom. These data may reveal fungus-host associations important for managers to understand for long-term maintenance of matsutake populations. Weekly temperature and moisture data will be obtained from the nearest weather station and correlated with estimates of matsutake biomass production.

At the Illinois Valley Ranger District, we also attempted to weigh all mushrooms collected by harvesters from a discrete watershed having only one access road. A station was set up to monitor what collectors brought out at the end of each day.

Unique Considerations

Many valuable lessons were learned from field experience during autumn 1993. These study plots were too expensive and time consuming to use for randomly sampling productivity of likely habitats without foreknowledge of fruiting on the site. The sample area of the strip plots on each site was far too small to adequately sample a single mushroom species, except in areas of known heavy fruiting, such as the Chemult sites. Many study sites were compromised by illegal picking unless they were located far beyond a road gate. Some "no picking" signs were simply ignored because the matsutakes are so valuable. Some sites were intentionally harvested by indignant local pickers, and one gate was even pulled out of the ground. Weighing the commercial harvest from a given watershed was problematic because the weighing station was time consuming to operate and intimidating to harvesters, among whom prior arrangements had not been made. Correlations of fruiting with weather may be stronger if data were collected on the site rather than from distant weather stations (especially in mountainous and forested terrain where microclimate variations are great over small distances), but local stations are expensive.

Current Status

Dry weather limited fruiting in the Siskiyou Mountains during the 1993 season and only a few matsutakes were found on two of the nine sites. The Illinois Valley Ranger District study sites were abandoned to free personnel for pursuing more cost-effective monitoring approaches. One of the BLM sites was monitored in 1994, but dry, cold weather prevented fruiting. The Chemult sites were sampled from 1993 to 1995 and data are being analyzed.

Literature Cited

Kawai, M.; Ogawa, M. 1981. Some approaches to the cultivation of a mycorrhizal fungus, *Tricholoma matsutake* (Ito et Imai) Sing. *In*: Mushroom science XI, Part 2: Proceedings of 11th international scientific congress on the cultivation of edible fungi; 1981 [day and month unknown]; Sydney, Australia. [Place of publication unknown]; [publisher unknown]: 869-883.

Schlosser; W.E.; Blatner, K.A. 1995. The wild edible mushroom industry of Washington, Oregon and Idaho: a 1992 survey. Journal of Forestry. 93: 31-36.

The Japan Trade Development Division. 1990. The mushroom market. Export Opportunities in Japan Series [no. unknown]. Ottawa, ON: External Affairs and International Trade Canada.

Study 11: Matsutake Inventories and Harvesting Impacts in the Oregon Dunes National Recreation Area

David Pilz, Randy Molina, Michael Amaranthus, Daniel Segotta, and Frank Duran [1] [2]

Context

The Oregon Dunes National Recreation Area (ODNRA) of the Siuslaw National Forest is located along the central Oregon coast between Florence and Coos Bay. Matsutake mushrooms have been commercially harvested for decades from shore pine *(Pinus contorta* var. *contorta)* forests on the dunes, but harvesting pressure increased dramatically in the last 5 years as the value of matsutakes became widely known. To manage the resource appropriately, the Siuslaw National Forest dedicated funds in 1994 and 1995 for monitoring production and examining harvest impacts. After considering a variety of monitoring methods, the ODNRA decided to participate in a matsutake monitoring program designed by Michael Amaranthus and described here. To compare results regionally, this study design is also being implemented at the Diamond Lake Ranger District, Umpqua National Forest; the Chemult Ranger District, Winema National Forest; the Boswell Mine near Cave Junction; and the Medford District BLM.

Objectives

Objectives were to:

1. Determine matsutake production (sporocarp biomass) and value from long-term study plots in a known matustake fruiting area.
2. Evaluate the effects of various mushroom harvesting techniques on matsutake production.

Methods and Rationale

In 1994 we delineated clusters of matsutakes for application of experimental treatments in subsequent years. Mushrooms were individually collected, graded, and weighed, and each tenth mushroom was dried and weighed. We mapped each mushroom relative to a reference tree. We then used Global Positioning System equipment to pinpoint these trees so that clusters could be mapped relative to each other and easily relocated. First-year mapping and weighing allowed us to (1) choose clusters of sporocarps for application of experimental treatments in subsequent years, (2) determine per-unit-area productivity of matsutake mushrooms on the study site, and (3) identify surplus clusters for use in other field studies, such as examination of matsutake physiology, reproduction, population genetics, and response to microclimatic variables.

Treatments were implemented in 1995. Clusters were defined to include mushrooms no further than 0.5 meter (1.6 ft) apart with distances between clusters being greater than 2 meters (6.6 ft). Replicated blocks of clusters were used to examine the influence of vegetation type on mushroom productivity and response to treatments. Within each of three blocks, six clusters with similar matsutake production were selected and randomly assigned one of the six following treatments:

---

[1] **David Pilz** and **Randy Molina** are with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR 97331; **Michael Amaranthus** is with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Grants Pass, OR 97526; and **Daniel Segotta** and **Frank Duran** are with the Siuslaw National Forest, Corvallis, OR.

[2] Cooperating were Ed Strawn and Dwight Reindle, commercial matsutake harvesters from the Oregon Dunes.

1. No harvest control.
2. Harvest with minimal disturbance (gentle rocking and pulling) and replacement of duff.
3. Total removal of litter and duff layer by raking (to the surface of the matsutake mycelial layer), sporocarp removal, and **careful replacement of the duff.**
4. Total removal of litter and duff layer by raking (to the surface of matsutake mycelial layer) sporocarp removal, and **no replacement of the duff.**
5. Total removal of litter and duff layer by raking (deep raking through the matsutake mycelial layer), sporocarp removal, and **duff replacement.**
6. Total removal of litter and duff layer by raking (deep raking through the matsutake mycelial layer), sporocarp removal, and **no replacement of the duff.**

These treatments are designed to answer questions about the impact of harvesting itself and the potential damage of searching techniques used by some harvesters to locate the valuable small mushrooms that have not yet emerged through the forest duff layer.

To characterize climatic differences among the study sites, maximum and minimum soil and air temperature will be determined at 1-week intervals beginning August 1 and extending 2 weeks past the fruiting period in each location.

Unique Considerations

Mapping individual sporocarp locations was labor intensive but provided a valuable foundation for long-term studies, because sporocarps occur in nearly the same spot each year. In Japanese studies, matsutake sporocarps appear in arcs on the leading edge of mycelial mats called *shiros* that advance through the soil only a few centimeters per year (Ogawa 1975, Tominaga 1971). Our initial mapping indicated that fruiting patterns of the American matsutake may be more diffuse than those of the Japanese matsutake. Selection of clusters for application of experimental treatments was based on proximity of sporocarps to each other rather than the excavations of mycelial mats needed to define shiros. Fruiting in 1994 was sufficiently heavy to proceed with cluster selection and application of experimental treatments in 1995. Rapidly increasing demand for commercial matsutake harvest privileges has lent urgency to obtaining results of harvest impacts.

Security of the study site is a major consideration. We have cooperated with commercial collectors throughout the study to keep the surrounding area thoroughly harvested, thus discouraging unauthorized harvesters. Our cooperators are skilled at noting evidence of visits by other harvesters. During application of the experimental treatments, mushrooms left in the control clusters were marked to destroy their commercial value. Arrangements for regular visits by dedicated law enforcement officers was necessary to reduce vandalism of the study site. In 1995, the study site was closed to the general public during the fruiting season to allow officers to cite anyone found in the area, because it was often difficult to catch unauthorized harvesters with mushrooms in their possession.

Commercial production (rather than total biological) will be measured in this study because treatment applications and sampling procedures are designed to mimic what typically occurs during commercial harvesting activities. Annual production of matsutake differs greatly, and conclusions about averages, extremes, and trends must be based on data collected over many years. Likewise, the potentially harmful effects of experimental treatments may not become apparent for several years. This study will provide increasingly valuable insights as new data accumulate from each season.

Current Status

The 1994 field season at the Dunes study site was productive. Nearly a hundred reference trees were used to locate from 20 to 100 sporocarps each. The season began in early November, peaked in early December, and finished in early January. At least half of the clusters (temporarily defined by the reference trees) showed evidence of tampering by unauthorized harvesters, but we had sufficient undisturbed clusters to apply experimental treatments in 1995. Site security was enhanced in 1995. Results of the mapping and first-year treatment applications will be published in 1996.

Study activities are proceeding concurrently at the Diamond Lake site. Mapping began in 1995 at the Chemult, Boswell Mine, and Medford sites, and treatments will be applied in 1996.[3]

Literature Cited

Ogawa, M. 1975. Microbial ecology of mycorrhizal fungus, *Tricholoma matsutake* (Ito et Imai) Sing. *In:* pine forest 1: Fungal colony ('Shiro') of *Tricholoma matsutake*. Bull. 272. Tokyo, Japan: Government Forest Experiment Station.

Tominaga, Y. 1971. Studies on the formation and development of the fruit body of *Armillaria matsutake* (Ito et Imai). Bulletin Hiroshima Agricultural College. 4: 106-122.

---

[3] Concurrent studies are being coordinated by Rick Abbott, USDA Forest Service, Diamond Lake Ranger District, Umpqua National Forest, Idleyld Park, OR 97447; Jerry Smith, USDA Forest Service, Chemult Ranger District, Winema National Forest, Chemult, OR 97731; and Mike Amaranthus, USDA Forest Service, Pacific Northwest Research Station, Grants Pass, OR 97526. Cooperating on these sites is Andy Moore, commercial matsutake harvester, Cave Junction, OR 97523.

Study 12: Chanterelle Production Responses to Stand Thinning

David Pilz, Randy Molina, and Jim Mayo [1] [2]

Context

Norvell and others (1995) (also see study 8) examine the impact of harvesting chanterelles and David Largent and others (1994) correlate the fruiting phenology of chanterelles with microenvironmental variables. This study and study 9 are the only known examinations of timber management impacts on chanterelle productivity.

This study was added to an integrated research project, "Young Stand Thinning and Diversity Study," an administrative study sponsored by the USDA Forest Service, Willamette National Forest, in the central Oregon Cascade Range. The project was designed to examine how various stand-thinning techniques and leave-tree densities affect site conditions and ecological responses, including the production and quality of special forest products such as chanterelles.

Objectives

Objectives were to:

1. Determine how large an area must be sampled to produce adequate estimates of chanterelle productivity on a given site.

2. Examine the impacts of stand thinning on subsequent chanterelle production.

Methods and Rationale

Four young (30 to 50 years old) Douglas-fir stands in the Oakridge, Blue River, and McKenzie Ranger Districts of the Willamette National Forest were selected as study blocks. At each location, three logging treatments are being examined that include an unthinned control and two thinning intensities (124 residual trees per hectare [50/acre] and 297 residual trees per hectare [120/acre]). Productivity is being estimated by collecting chanterelles along systematically located strip plots. The effects of thinning will be assessed by comparing the relative increase or decrease from baseline fruiting in thinned stands to the seasonal increase or decrease from baseline fruiting in unthinned stands. We will also compare the impact of stand thinning operations by sampling permanently marked areas of dense chanterelle fruiting.

Unique Considerations

Annual fruiting patterns are highly variable, so supervisors must be flexible in scheduling work crews. We designed our sampling for what we considered feasible in a year with heavy production and will undertake optional tasks when fruiting is light. Facilities, space, and equipment must be arranged to regularly sort, weigh, and dry large numbers of chanterelles.

[1] **David Pilz** and **Randy Molina** are with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR 97331; and **Jim Mayo** is with U.S. Department of Agriculture, Forest Service, Willamette National Forest, Blue River Ranger District, Blue River, OR 97413.

[2] Cooperators were John Tappeiner, Department of Forest Science, Oregon State University, Corvallis, OR 97331; USDA Forest Service, Willamette National Forest, the Blue River, McKenzie, and Oakridge Ranger Districts; and the Cascade Center for Ecosystem Management.

Permanently marking mushroom patches so that they can be located after logging operations is difficult. Nearest leave trees were identified, located, and marked. Plot centers were marked with rebar driven into the ground to avoid puncturing logging tractors tires. If necessary, metal detectors can be used to relocate the rebar. Planned skid trails were avoided as chanterelle patches were selected. Some patches may be damaged or destroyed by slash burn piles, or slash may have to be moved to facilitate sampling. Slash also may make walking on inventory strip plots difficult after logging. Other researchers were informed not to pick chanterelles for personal use.

We benefit from work performed by other cooperators; our methods and design were limited, however, by choices made by the original designers of the integrated research project. Coordination is required to uniquely mark plot locations, because many other studies are occurring in the same stands. Timber harvest studies on National Forest lands may encounter legal challenges that prevent or delay logging.

Current Status

Only 1 year of baseline productivity data on fruiting patterns (1994) was obtained, but chanterelles were found in all stands. Commercial thinning operations were/are scheduled for 1995 and 1996. Only control stands were sampled in 1995. The first season of post-logging surveys is scheduled for autumn 1996.

Literature Cited

Largent, D.; Hewlett, S.; Sime, D. 1994. Influence of environmental factors on fruiting of edible, mycorrhizal mushrooms. [Place of publication unknown]; [Publisher unknown]; final report; [contact unknown]. Prepared for: California Department of Forestry and Fire Protection.

Norvell, L.; Kopecky, F.; Lindgren, J.; Roger, J. 1995. The chanterelle *(Cantharellus cibarius):* a peek at productivity. *In*: Schnepf, Chris, comp., ed. Dancing with the elephant: Proceedings: The business and science of special forest products–a conference and exposition; 1994 Jan. 26-27; Hillsboro, OR. [Place of publication unknown]; University of Idaho Extension Service: 117-128. Sponsored by: Northwest Forest Products Association; Western Forestry and Conservation Association.

Study 13: Shiro Analysis of Matsutake in the Central Washington Cascade Range

David R. Hosford [1 2]

Context

As harvests of native matsutake diminished, Japanese importers began looking to the U.S. Pacific Northwest to supply similar mushrooms. As a representative of their interests, H. Ohara, a matsutake specialist, came to the Pacific Northwest in 1980 to assess the quantity and quality of matsutake, "pine mushroom," in Washington State. It was during his visit that we first met and together located matsutake "shiros" (literally, castle or domain of the fungus) in central Washington. Later, during my visit to Japan, we laid the foundation for future collaboration. In 1985, we began a 5-year study of *Tricholoma magnivelare* in central Washington using the Kyoto or "Shiro" method developed principally by Hamada (1955), Ogawa and Hamada (1965), Ohara (1966), and Ohara and Hamada (1967).

As the commercial value of matsutake became more widely recognized, our study attracted the attention of forest researchers, managers, and harvesters specifically interested in mycorrhizae, sporocarp productivity, and habitat management. This study, the first of its kind in the Pacific Northwest, has provided baseline information on the ecology of matsutake and has led to new studies throughout the region.

Objectives

Objectives for each Shiro analysis were to:

1. Mark the seasonal location of each sporocarp.
2. Map the horizontal and vertical position of the mycelium.
3. Calculate total sporocarp productivity per season.
4. Determine the maturation interval in days from primordia to fully opened sporocarps.
5. Collect and identify associated species of mushrooms.
6. Identify all associated plant species and determine plant community structure and composition.
7. Determine soil type, profile, pH, temperatures, and moistures.
8. Collect roots, soil, and young sporocarps for study of mycorrhizae, microbial populations, and somatic cultures, respectively.

Methods And Rationale

The shiro is defined here as the soil microhabitat that is influenced by mycelial growth and mycorrhizal development; it is the fundamental ecological unit in the study of mycorrhizal fungi. From studies of *T. matsutake* shiros, Japanese researchers have developed forest management techniques to establish new shiros in pine forests or to

[1] David Hosford is with the Department of Biological Sciences, Central Washington University, Ellensburg, WA 98926.

[2] Cooperators were Hiroyuki Ohara, Laboratory of Biology, Doshisha Women's University, Kyoto, 602, Japan; Makoto Ogawa, Biological Environmental Institute, Kansai Environmental Engineering Center, 8-4 Ujimatafuri, Uji, Kyoto, 611, Japan; and the Wenatchee National Forest, Cle Elum Ranger District.

enhance sporocarp productivity in established shiros (Ogawa 1982). With this management possibility in mind, we began our baseline study of *T. magnivelare* shiros to better understand its ecology and productivity.

In autumn, 1985, four sites with 19 shiros, were located in the central Washington Cascade Range. Each site was described in detail including topography, climate, soil type, and vegetation. From late August through mid-November, each shiro was monitored one to three times per week for the appearance of matsutake and other mushrooms species. Numbers of sporocarps were counted and their position in the shiro marked by color-coded flags; different colors represented different years. The relative position of fungal mycelium and host roots to the flags was determined, and annual growth or advancement of the mycelium mapped. Flags also provided an accurate reference point for obtaining mycorrhizae or soil samples from the active mycorrhizal zone and from immediately adjacent soil (Ohara and Hamada 1967). Harvested sporocarps were weighed and either dried for later study or used to obtain somatic cultures and spore prints. Mature (fully opened) and decaying sporocarps were counted and marked, but left in place.

Unique Considerations

For long-term study, selected shiros should ideally be close to the research facility to allow frequent monitoring, yet distant to regular public access so that they are protected from unwanted visitors. Such criteria are difficult to meet. Our 19 shiros were scattered in four sites with some on private and others on public lands. Unfortunately, by the end of the study only nine shiros remained as a result of clearcut logging. Cooperation among land owners, managers, and researchers is needed to dedicate research sites for such long-term study. Low levels of fruiting in the dry seasons in 1987 and 1989 also impacted our study.

Shiro analysis involves flagging, collecting, identifying, weighing, and curating samples, extremely time consuming and labor intensive activities. At the beginning of our study, we monitored 19 shiros one to three times per week. Each trip took about 10 hours in the field, including travel time, followed by 10 to 16 hours of laboratory study. We averaged 46 hours per week per researcher the first season. From 1986 to 1989, I worked alone and had to reduce field trips to one per week and monitoring to two shiros per site (total of eight). Even so, the work load was overwhelming. Those interested in this type of research need field staff adequate to the task of monitoring the selected number of shiros.

Current Status

Study results have been summarized by Hosford and Ohara (1986, 1990, 1995). From 1990 to 1993, the nine remaining sites were visited sporadically; productivity was low due to extreme drought. In 1994, we began regular monitoring of shiros for sporocarp productivity and soil microbiology. Daily weather conditions, precipitation, and soil temperatures are now recorded year-round. Future collaboration with colleagues in Japan and the USDA Forest Service on mycorrhizae, DNA, and microbial populations is anticipated. Based on our initial forest habitat analysis, preliminary GIS (Geographic Information Service) mapping of potential matsutake sites in the central Washington Cascade Range is underway.

Literature Cited

Hamada, M. 1955. [Title not translated]. Kanzume Jiho. 34: 1-7. In Japanese.

Hosford, D.; Ohara, H. 1986. Shiro analysis of mycorrhizal fungi. [Abstract]. *In*: Roots in forest soils: biology and symbioses: Meeting of the IUFRO working party on root physiology and symbioses (S2.01-13); 1986 August 4-8; Victoria, BC. [Place of publication unknown]: [publisher unknown].

Hosford, D.; Ohara, H. 1990. Ecological characterization of American matsutake. *In*: Abstracts: bacteriology and mycology. Osaka, Japan: International Union of Microbiological Societies Congress.

Hosford, D.; Ohara, H. 1995. Ecological study of *Tricholoma magnivelare* shiros in central Washington. *In*: Schnepf, C., comp., ed. Dancing with the elephant: Proceedings: The business and science of special forest products–a conference and exposition; 1994 Jan. 26-27; Hillsboro, OR. [Place of publication unknown]; University of Idaho Extension Service: 111-116. Sponsored by: Northwest Forest Products Association; Western Forestry and Conservation Association.

Ogawa, M. 1982. How to produce matsutake mushroom. Nara, Japan: Matsutake Research and Consultation Office. Forest Service Research Station, Nara, Japan: 158 p.

Ogawa, M.; Hamada, M. 1965. [Title not translated]. Transactions of the Mycological Society of Japan. 6: 67-71. In Japanese.

Ohara, H. 1966. [Title not translated]. Proceedings of the Japan Academy. 42: 503-506. In Japanese.

Ohara, H.; Hamada, M. 1967. Disappearance of bacteria from the zone of active mycorrhizas in *Trlcholoma matsutake* (S. Ito et Imai) Singer. Nature. 213: 528-529.

Forest Fungi and Ecosystem Management

David Pilz, Randy Molina, Michael Amaranthus, Michael Castellano, and Nancy S. Weber [1]

Illustrated Principles of Ecosystem Management

What exactly is "ecosystem management"? Simply put, it is a holistic approach to managing land. It is based on understanding and maintaining the components (for example, species), interactions (for example, food webs), and processes (biological, chemical, and physical) of ecological systems, while simultaneously producing products and services for society. As applied to Federal forests in the United States, a goal of ecosystem management is full implementation of forest management directives found in Federal legislation. (For a concise review of pertinent laws, see Cubbage and others 1993: 528-539.) Previous efforts to implement this body of legislation have been challenged repeatedly with administrative appeals, lawsuits, and laws that preclude judicial review. Nevertheless, their basic tenets are widely accepted among scientists, managers, and the general public: namely, public forests should provide a wide variety of amenities and uses in perpetuity.

In recent decades, the public has demanded a broader spectrum of recreational opportunities and commercial goods from public forests. Concurrently, scientists have expanded our understanding of the critical role that biological diversity plays in sustaining long-term production of many services and commodities we derive from forest ecosystems. Fungi are essential functional components of forest ecosystems and directly provide humans with valued products.

---

[1] **David Pilz, Randy Molina,** and **Michael Castellano** are with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331; **Michael Amaranthus** is with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Grants Pass, OR 97526; and **Nancy Weber** is with the Department of Forest Science, Oregon State University, Corvallis, OR 97331.

In this chapter, we briefly describe the following principles of ecosystem management and illustrate them with examples of managing forest fungi:

- Conserving diversity is essential to sustaining ecosystem productivity
- Management must account for the dynamic nature of ecosystems
- Ecosystem processes must be managed across multiple scales and land ownerships
- People are an integral part of ecosystems and their successful management
- Adaptive management requires continuous monitoring and research

These principles are excerpted from recent publications that discuss in detail the meaning of ecosystem management and its application to public forests (Bormann and others 1994, Jensen and Everett 1994, Kaufmann and others 1994, Marcot and others 1994, Moote and others 1994, Overbay 1992). After discussing examples of how these principles relate to forest fungi, we examine methods for integrating the management of forest fungi into the larger context of ecosystem management.

Conserving Diversity

An underlying premise of efforts to preserve diversity is the recognition that we cannot know all the functional roles each organism, population, or species has in an ecosystem. In many cases, their importance is clear and their functions invaluable, but scientists are continually surprised with discoveries about the significance of unusual, obscure, or seemingly minor species. Although species frequently exhibit overlapping functions in ecosystem processes, a given species can be specially adapted to a narrow environmental niche, thereby allowing it to function more effectively than competitors. In ecosystems with diverse biota, numerous species with precise adaptations use the physical environment more efficiently than a few species with imprecise or general adaptations, thus enhancing ecosystem productivity. We are just beginning to understand how important the diverse fungus community of Pacific Northwest forests is to the growth of trees and the vast array of other forest organisms.

No officially threatened or endangered fungus species is currently listed on the Federal Register, but through the Forest Ecosystem Management Assessment Team (FEMAT 1993) process, and in the general mycological community, many fungus species are considered rare, uncommon, or threatened, *Oxyporus nobilissimus* was listed with the Natural Heritage Program in Oregon by John Christy.[2] to 1994, Joseph Ammirati[3] submitted "A preliminary list of uncommon, sensitive, rare, and/or endangered macrofungi in Washington State" to the Washington Department of Natural Resources Natural Heritage Program, but no official action was taken on it. Rare or endangered fungi need to be listed if they are to be protected within the context of our forestry practices. Germany, the Netherlands, and Sweden have developed such "red" lists for fungi whose abundance has declined dramatically (Arnolds 1991, 1992). The list created from the FEMAT process is a logical starting point, but habitats outside the range of the northern spotted owl and within other ownerships must be considered when determining the status of each species

---

[2] John Christy, Wetlands and Aquatics Ecologist, Oregon office, The Nature Conservancy, 821 SE 14th Avenue, Portland, OR 97214.

[3] Joe Ammirati, head of the Botany Department, University of Washington, Seattle, WA 98195.

Well-documented species distinctions are requisite to accurate listing, and valuable for managers designing measures to protect rare species. Fungi have complex mating-compatibility factors, and many are difficult or impossible to culture and mate in vitro; thus the biological species definition of mating compatibility (with fertile offspring) within, but not among, species is difficult to verify in most cases. Currently, most fungus species are predominantly defined by sets of morphological characteristics, but mycological taxonomists constantly debate meaningful criteria for defining a unique species, and are sometimes referred to as "lumpers" or "splitters," depending on how many species they recognize. Molecular techniques of genetic analysis are providing additional information for resolving some species concepts.

In addition to accurate species distinctions, the process of listing fungi should detail criteria for determining rareness and assigning threatened status, as well as removing species from protection lists as new information becomes available or populations expand. We can adopt much of the process that the native plant societies have used for vascular plants. A panel of regional experts, using agreed upon criteria, should annually evaluate species for addition to, or removal from, lists. Information used by the panel should be widely disseminated, so that managers can judge the importance of conserving local populations.

Conservation of diversity is important for sustaining the harvest of wild, edible fungi as well. The wide variety of edible fungi with their individual habitats and fruiting seasons provides opportunities in the Pacific Northwest to gather mushrooms or truffles throughout most of the year. Genetic diversity within edible fungus populations likely allows specific adaptations to local habitats and, consequently, greater sporocarp production than if fungus populations were genetically uniform. Appropriate management of edible fungi will require a greater understanding of diversity within and among populations and the importance of that diversity to survival, reproduction, sporocarp production, and long-term viability of each species.

Dynamic Nature of Ecosystems

All populations of living organisms are influenced by a wide range of factors such as climate, soil, disturbance processes, other plants and animals, and people. These factors are unpredictable and fluctuate in a manner that greatly influences the abundance and distribution of mushroom species and populations. As with all organisms, local extinctions, invasions, migrations, or successions of mushroom taxa inevitably occur without any human influence (Groombridge 1992) but can be greatly accelerated or interrupted by human activities (Arnolds 1991).

Forests change slowly and incrementally as they age. Sporocarp studies suggest that groups or guilds of ectomycorrhizal fungi shift in composition as forests age (see citations in study 4), and parasitic and saprobic fungi find more habitat as trees reach maturity and woody debris increases in a forest (Arnolds 1989). Edible mushrooms can occur in all stages of coniferous forest stand development; however, edible ectomycorrhizal species such as chanterelles, matsutake, and boletes occur most abundantly in mid-successional stages of development.

Forests also change rapidly and dramatically when disturbed by storms, wildfires, or logging. Disturbance (and the process of recovery from disturbance) is common to all ecosystems, and fungi have evolved responses. For example, some form ectomycorrhizae with brushy hosts that sprout quickly after logging or a fire that kills coniferous hosts (Amaranthus and Perry 1989, 1994; Molina and others 1992), thereby enabling the fungi to persist on the site until new trees become established. While clearcutting is an efficient means of timber harvest, and mycelial colonies of ectomycorrhizal fungi, such as chanterelles, boletes, and matsutakes, could conceivably persist on a site if new conifer hosts become promptly established, fruiting is likely to be greatly reduced or eliminated until the new stand accumulates sufficient carbohydrates from photosynthesis to support sporocarp production. In the southern Cascade Range of Oregon, chanterelles can be collected in partially harvested stands. Matsutakes were abundantly produced in some ashfall areas of the Mount St. Helens eruption in Washington where host trees were not killed (Amaranthus, unpublished data). Some morel species are known to fruit prolifically in response to disturbances such as fire, soil movement, or tree mortality. On the other hand, disturbances that differ in type, frequency, or severity from historical patterns (for example, industrial pollution) may endanger fungus diversity and sporocarp production by commercial species (Arnolds 1991, Jasen and others 1985).

Managers must characterize the typical dynamics of change for their particular ecosystem and adopt practices that provide sufficient habitat for species to perpetually reproduce or migrate. For instance, *Rhizopogon exiguus* (a species listed in the FEMAT report [1993]) has been found only in late-successional forests. If, indeed, it depends on some characteristic of older forests for its existence, then its long-term survival depends on its ability to colonize new appropriate habitats when its original habitat changes. Its spores are disseminated by small mammals that rarely wander deep into new clearcuts, except where they can find sufficient cover from predation under coarse woody debris. Unless there is significant connectivity among stands of late-successional forest or their structural components, this fungus may eventually become threatened as remaining patches of old-growth forest inevitably encounter stand-replacement disturbance events such as fire or logging.

Multiple Scales

Ecosystem processes occur on various scales, from specific habitats to forest stands, landscapes, and regions. Effective ecosystem management must integrate plans or activities for a given scale with management considerations for other scales. Ecological or geographic boundaries rarely correspond completely with ownership, administrative, or political boundaries, therefore ecosystem management also must operate across these divisions.

Some species of fungi have very particular habitat needs. *Oxyporus nobilissimus,* for instance, occurs only on large-diameter trees, snags, or stumps of *Abies* species, especially *Abies procera.* Continual recruitment of old noble firs is needed for this fungus to persist.

Likewise, many edible ectomycorrhizal fungi flourish with particular species and ages of host trees. The American matsutake now fruits abundantly in shore pine *(Pinus contorta* var. *contorta)* stands planted 40 years ago to stabilize dunes on the Oregon Coast ,[4] and Korea is the world's largest producer of Japanese matsutake mushrooms because it has extensive young pine stands that developed after the Korean war.[5]

[4] Personal communication. 1993. Dan Segotta, botanist, Oregon Dunes National Recreation Area, Siuslaw National Forest, Reedsport, OR 97467.

[5] Personal communication. 1993. Yun Wang, mycologist, Crop and Food Research, Mosgiel, New Zealand.

Similarly, *Boletus mirabilis* forms mycorrhizae only with hemlock (*Tsuga*) species, and its sporocarps are found growing only from thoroughly rotted wood containing hemlock roots.

At the scale of forest stands, silvicultural practices can be used to enhance fungus diversity. The Final Supplemental Environmental Impact Statement (FSEIS; USDA and USDI 1994a) that resulted from President Clinton's forest plan, designates large areas of Federal forest lands as "late-successional reserves." For areas within this designation that have been clearcut during the last four decades, the primary management goal is using silvicultural manipulations (for example, thinning or snag creation) to speed the development of late-successional structure and habitat in regenerated forest stands, and thereby enhancing ecosystem diversity. Several recent studies (Amaranthus and others 1994, study 4) suggest that older forest habitats support a greater diversity of truffles and ectomycorrhizal morphotypes, as well as more unique species, than do adjacent young forest plantations. Research that examines the response of fungus communities to silvicultural manipulations and changing forest structure and composition will be essential to evaluate progress towards this goal (studies 2 and 3).

Silvicultural practices used to speed development of late-successional characteristics also may have implications for some commercial mushrooms. Although *C. cibarius* and *C. subalbidus* are commonly found in younger stands, they were placed on the FEMAT list of old-growth-associated species out of concern that populations occurring in old-growth forests may be genetically unique, and that commercial harvesting pressures might harm them. *Cantharellus tubaeformis,* on the other hand, was listed in FEMAT because it is more typically found in older forests, and, may be associated with coarse (large-diameter) woody debris that remains as a legacy from previous old forests. If this observation is verified, then maintaining or creating this legacy in late-successional reserves would improve its habitat. Likewise, increasing the amount of coarse woody debris will provide additional habitat for less frequently collected saprobic mushrooms such as sulfur shelf *(Laetiporus sulphureus),* lion's mane *(Hericium abietis),* angel's wings *(Pleurotus porrigens),* and *Ganoderma* species.

Some portions of Federal forests are designated as "matrix" lands, where timber production is emphasized. Silvicultural practices used for enhancing timber production typically employ clearcut harvesting timed to occur when rate of increase in mean annual increment of tree volume (derived from diameter and height growth) starts to decline. Although stands approaching harvestable age, (using this criterion) produce abundant quantities of commercially valuable ectomycorrhizal mushrooms and truffles, fruiting of these fungus species is typically negligible during early stages of stand regeneration. Areas managed for short timber harvest cycles will have a greater proportion of their forest stands in early seral stages than areas managed for longer timber rotations; therefore overall production of edible mycorrhizal species across a landscape or ownership may be diminished with short timber harvest cycles. If edible mushroom production is correlated with vigorous growth of host trees (young or mature), then studies of commercially thinned middle-aged stands may provide valuable information about sustaining high levels of mushroom production (studies 9 and 12) while producing timber.

Japanese foresters manipulate forest stands specifically to improve matsutake production (Tominaga 1978); they clear understory growth, reduce litter depth, and thin trees. Practices such as mild controlled burns or density management may improve matsutake fruiting in the Pacific Northwest. Changes in matsutake production may depend mainly on how litter is removed or thinning is conducted. Thinning intensity and patterns, soil compaction and movement, and slash disposal all may have significant effects. With an understanding of these effects, thinning can be designed to maintain or enhance mushroom production.

On a landscape scale, Bormann and Likens (1979) describe the northern hardwood forest as a shifting mosaic of irregular patches, differing in composition and age, and driven by disturbance, growth, and decay. This seems a good way to envision most, if not all, natural forested landscapes, although the characteristic spatial and temporal scales of the mosaic will differ. The species and abundance of fungi respond to this shifting mosaic of forest conditions (Mehus 1986). A primary objective for managing fungi on a landscape level is to create (or maintain) sufficiently large and connected habitats to sustain viable populations of all species. Within this goal, managers also may wish to assure a steady supply of readily accessible habitat that produces abundant crops of edible mushrooms.

Three aspects of habitat that influence fungus communities and mushroom production are most relevant at the scale of landscapes: (1) different major forest types, (2) different successional stages within a given forest type, and (3) microhabitat diversity within each forest type and successional stage. Forest types, successional stages, and unique microhabitats harboring rare or endemic species, accommodating high fungus diversity, or supporting high levels of edible mushroom production need to be identified, mapped, and inventoried. Basic inventories are essential because they provide benchmarks for future comparisons and allow managers to predict how fungus communities or edible mushroom productivity will change overtime as the mosaic of forest conditions are manipulated.

Regional lists of rare fungi depend on identification of unique fungus species or endemic populations that deserve protection. During evaluations of fungus species for inclusion on such lists, their abundance, distribution, range, variation among populations, and local adaptations need to be considered.

Commercial harvest of edible fungi significantly contributes to the regional economy. Transient harvesters can work throughout most of the year if they follow a seasonal route through the Pacific Northwest, as various species fruit at different locations or elevations. Managers can better regulate the harvests on their own lands if they communicate regularly with managers in other portions of the region about timing and sizes of mushroom crops, harvester activities, and purchase prices.

Management activities or plans at any given scale invariably affect management considerations on adjacent scales. Regional listing of a rare fungus species could shift timber harvest away from sites having appropriate habitat for that fungus. Silvicultural manipulations of many individual stands will affect the mosaic of forest conditions on the landscape and may result in increasing or decreasing mushroom crops.

Effective ecosystem management requires coordination among landowners and regulatory agencies and integration of plans at different scales. For example, if public lands provide adequate habitat for fungi associated with late-successional forests, short-rotation timber management can be practiced on private forest lands with less risk of extirpating species of concern. On the other hand, many industrial forest landowners are closing their land to the public to prevent problems with fire, vandalism, and garbage dumping; hence private timberlands may act as reserves where edible fungi are not subject to human harvests and can freely disseminate spores.

People and Ecosystems

In most forests, human management plays a dominant role in shaping the landscape, and human activities have become an integral component of ecosystem processes (for example, fire suppression, timber harvests, and livestock grazing.) Ecosystem management of public forests presents us with the challenge of obtaining human amenities in a manner that mimics naturally evolved patterns, thereby conserving species, interrelations, and processes that ensure the forest will produce a wide variety of amenities and useful products in perpetuity.

Human uses of forest ecosystems shift in response to economic conditions, technological advances, and changing social values; therefore, the public must be included in the planning process if results are to reflect current social values and economic needs. The increasing value that society is placing on biological diversity has prompted conservation organizations, such as The Nature Conservancy, to create databases of rare species and their habitats on private lands. Integrating databases for private lands with similar databases for public lands allows managers to examine species occurrence and rareness across whole ecosystems rather than just ownerships, thus enabling more effective, less expensive, and less restrictive conservation efforts. Public agencies would benefit from efforts by local mycological societies to extend species databases to fungi, just as native plant societies have for plants.

The recent increase in the number of people commercially harvesting edible mushrooms is another example of how people play a constantly changing role in ecosystems. Some of the increase came from forest workers who lost employment when logging was restricted on Federal lands to protect the northern spotted owl. Mushroom harvesting increased quickly, and many managers were caught unprepared; hence, newly instituted regulations and permit systems needed refinement. The public has provided valuable input regarding commercial mushroom gathering during the last several years by helping managers revise permits, improving the fairness and efficacy of harvest regulations, and ameliorating conflicts between commercial and recreational pickers. As with the harvest of any wild organism, mushroom collectors are concerned about sustaining the resource, and increasingly recognize the relation between mushroom production and appropriate forest habitats. Their input (in conjunction with opinions of the interested public as a whole) should be considered when designing how forest conditions will change across the landscape over time.

Adaptive Management

To be effective, ecosystem management must be "adaptive," that is:

- The best information currently available should be used for immediate decisions
- Monitoring and research activities should be started to address critical areas of ignorance
- Management strategies should be adapted (modified) as improved information becomes available

These principles have been incorporated into the survey and management guidelines described in the FSEIS (USDA and USDI 1994a). and adopted in the record of decision (USDA and USDI 1994b). The first surrey strategy is managing known sites of rare species. The second is surveying sites where ground-disturbing activity is anticipated. The third is conducting surveys of specific likely habitat for presumed rare species, and the fourth is conducting general regional surveys. The information acquired while implementing each strategy will be used to modify the others. For instance, a database of herbarium specimens of the FEMAT fungi has been compiled and made accessible to managers so that collection locations can be used to protect "known" sites of occurrence. Habitat and location information will be used to refine our understanding of habitat requirements for each species. This information can then be used to determine which species are potentially present in a particular area before ground-disturbing activities occur, and where to look for other populations. Information from the first three steps will be used to create a habitat-stratified sampling scheme for the general regional surveys.

A good example of the adaptive management process for edible mushrooms is the potential use of research on the fruiting patterns of morels in response to fire. If the timing and intensity of fires is related to subsequent levels of morel fruiting, managers may be able to reduce dangerously high fuel loads with controlled burning, while enhancing production of this special forest product.

Integrating Forest Fungi Into Ecosystem Management

Successfully implementing the principles of ecosystem management we have just illustrated will entail:

- Conducting relevant monitoring and research activities
- Using the best information available to develop and continuously update models for predicting the results of management choices
- Improving information access and transfer
- Developing regional strategies to enhance cooperation among land owners, managers, researchers, and the interested public

Monitoring and Research

Monitoring and research are absolutely essential, but can be expensive. Managers and researchers must cooperate to design cost-effective monitoring and research programs that provide information useful for supporting management decisions. They also must develop technology transfer systems that disseminate research results promptly, so that further decisions are based on the most current information. Management and monitoring (including research) can be envisioned as a feedback loop with each activity continuously refining and improving the other. Acquiring and disseminating critical information may appear a daunting task, but if it is approached logically and systematically, managers will obtain pertinent knowledge in a timely manner.

A step-wise approach to monitoring and research activities would include the following elements:

- Identify subjects of critical concern and assign priorities to them
- Identify management options for addressing these concerns
- Identify information required to choose among options

- Assess the resources available to procure needed information

- Choose creative and cost-effective methods of acquiring information

- Share the costs of data gathering with cooperators

- Assure that information becomes quickly and readily available to managers

- Verify that new information is incorporated into management activities

Researchers have developed several ways to examine fungus diversity and sporocarp production (Arnolds 1992, Vogt and others 1992), but these procedures have not been adapted to regional biodiversity surveys or edible mushroom monitoring projects in the United States. Standardized protocols for measuring and monitoring fungi will ensure compatibility of data sets for comparison and evaluation. They must be sufficiently broad to accommodate differences among fungus species and the specific goals of a survey, monitoring, or research project.

National Forest managers must implement the selected protocols on a large scale to meet survey strategies 2, 3, and 4 of the record of decision (USDA and USDI 1994b). In addition to the standardized protocols being development by the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, national efforts are also underway. A book is expected to be published by the National Biological Survey and the National Museum of Natural History on how to collect samples, culture isolates, and monitor diversity of fungi from terrestrial and aquatic substrates.[6] Rather than concentrate on particular taxa, the book will be divided into five major sections: (1) macrofungi on soil, wood, leaves, lichens, and other substrates; (2) readily culturable microfungi; (3) fungi associated with animals; (4) aquatic fungi and protoctistan organisms formerly treated as fungi; and (5) general topics–for example, herbarium management, culture collections, database management, and appropriate molecular techniques. Each section will feature a complete range of sampling protocols for each fungus group.

These protocols will provide essential tools for environmental assessments of fungi on public lands in the range of the northern spotted owl. Protocols will be tested by field personnel and evaluated by land managers for feasibility and cost. Because nonspecialists often implement the fungus survey protocols (at least portions that do not require taxonomic expertise), the protocols will thoroughly describe unique aspects of assessing fungus populations. Prior training of field personnel will be requisite.

The mycology team at the USDA Forest Service, Pacific Northwest Research Station, in Corvallis, Oregon, is currently developing practical field procedures that can be used by managers for monitoring the production of edible mushroom sporocarps. These procedures are a subset of the sampling protocols for fungus diversity; they concentrate on a single fungus species and management considerations regarding sporocarp harvests. Special emphasis will be placed on practical, economical, valid methodology

[6] Draft title: "Standard methods for fungi" as a volume in the "Measuring and Monitoring Biological Diversity Series" being published by the National Biological Survey and the National Museum of Natural History. Editors are Greg Mueller, Field Museum of Natural History, Chicago, IL 60605; Gerald Bills, Merck Research Laboratories, Rahway, NY 07065; Amy Rossman, Systematic Botany and Mycology Laboratory, Beltsville, MD 20705; and Harold Burdsall, U.S. Department of Agriculture, Forest Service, Center for Forest Mycology, Madison, WI 53705.

usable by nonspecialists to implement monitoring programs wherever commercial harvesting of wild mushrooms is a significant activity.

Managers and researchers need to cultivate a clear understanding of each other's needs and goals if they are to develop useful monitoring and research plans. Managers can be frustrated by lack of precise information when they need to make decisions, and scientists often perceive a lack of appreciation among managers for the rigor of the scientific method. Managers and researchers will fully realize the limitations and opportunities each faces only by cooperating to achieve mutual objectives. Constraints are commonly inherent in funding mechanisms or institutional goals, and these barriers to shared endeavors must be altered to allow effective cooperation. The conference that this publication summarizes was specifically intended to bring together managers and researchers to develop an integrated approach to monitoring and managing fungi in forest ecosystems.

Modeling

Researchers and managers must cooperate in developing models that theoretically, mathematically, and geographically predict ecosystem responses to the management choices. Mycologists and other researchers should be involved in the early stages of modeling the role of fungi in forest ecosystems, because they have the greatest familiarity with distributions, habitat requirements, reproductive mechanisms, and life histories of important fungus species, as well as their functional roles in the ecosystem and interrelations with other biotic and abiotic components. The theoretical exercise of developing models for the occurrence, persistence, and function of fungi in forests provides useful insights about additionally needed data, how important the missing information is, and how readily it may be acquired. This information allows us to design the most useful monitoring and research programs for improving the predictive power of our models.

Because fungi are so numerous and ecologically diverse, monitoring and managing them species by species is impractical in many cases. Effective use of new models and technologies for implementing ecosystem management must be tied to evolving concepts of preserving adequate representative habitats (continuously over time) for the long-term viability of all species, including those beyond our ability to specifically consider (Marcot and others 1994). The challenge in this case, is defining what constitutes "adequate representative habitats." The first step in modeling the relations between fungi and habitats is developing conceptual models that postulate how groups of fungus species (guilds) with similar ecosystem functions or life histories are related to various habitats or their components. Conducting regional surveys over an extended period is the next step in identifying species or guilds that indicate adequate habitat for a large number of associated species. The third step is evaluating how species with similar reproductive mechanisms will respond to various forest management regimes. The final step is developing predictive models to quantify how indicator species and guilds of fungi will respond to anticipated changes in the landscape mosaic of forest habitats. The authors are not aware of any examples where this has been attempted with fungi, so this endeavor will be challenging.

Modeling may be applied to specific rare fungi as well. Those listed in the FEMAT

Geographic Information System (GIS) map layers will help identify locations with especially rare habitat, reveal the status of connectivity among habitats, and suggest opportunities for creating appropriate habitat (for example, structural components) in other areas.

Habitat modeling of fungus diversity or rare species occurrence is only in the early conceptual stages; substantial work (regional monitoring and empirical studies) is needed to develop and test useful predictive relations for our models. Nevertheless, conceptual models will be useful for inferring unusual, significant, or rare habitats in greatest need of short-term protection and assigning priorities to needed research.

Predictive models that relate edible mushroom productivity to habitat factors will allow managers to assess how planned forest management activities influence mushroom crops and may suggest means for enhancing mushroom production. Salient habitat factors that can be manipulated include tree species, plant communities, stand age, stand density and structure, abundance of coarse woody debris, fire frequency, and soil compaction, movement, or drainage. Although some important habitat factors are not readily altered (for example, aspect, climate, or soil type), managers can chose to encourage fruiting in accessible locations where mushroom production is most likely to improve in response to management activities.

On a larger scale, if mushroom production per unit area can be correlated with stand characteristics, such as tree species, age, or structure, then different management regimes and objectives (with their associated silvicultural assumptions) could be used to create scenarios of mushroom productivity across watersheds, forest, or regions.

Information Access

Although new monitoring programs will be essential for ongoing adaptive management plans, much useful information on edible fungi already exists, and references are being compiled for fungi listed in the FEMAT report (1993). A logical first step is summarizing current information from diverse or obscure sources and making it available in a convenient form. The next step is using every means available, especially new information-transfer technologies, to provide easy and quick access to summarized knowledge and new monitoring or research information.

Unlike plants and many groups of animals, no complete guide to the macrofungi of the Pacific Northwest currently exists, and many genera of fungi still lack definitive monographs and keys. Even when comprehensive treatments exist, they often need revision. Even so, several good identification books are available. Where descriptions are lacking for rare fungi, researchers should give high priority to publishing useful descriptions and keys.

Mycologists have been collecting Pacific Northwest fungi as specimens for herbaria for nearly a century. Herbarium archivists are presently converting huge datasets from note cards or data books to electronic format. This is a slow, tedious, underfunded process that will take years to complete, but it has been expedited for FEMAT-listed fungi. Recent Federally funded contracts have supported visits by taxonomic experts to significant herbaria where specimens were verified and collection data electronically remote locations to acquire information about specimens of interest. As with the FEMAT species, specimen identification should be verified and information recorded in a standardized format.

The procedure for extending surveys of fungus diversity beyond herbarium records also can benefit from past efforts and experiences. For instance, cataloging rare vascular plant species, locating their populations, and preserving their habitats began nearly 15 years ago in Oregon (Meinke 1982). The experiences and ideas of individuals and organizations (for example, State Natural Heritage programs, The Nature Conservancy) with experience in this process will be invaluable for designing and conducting efficient fungus surveys.

Useful information is available for important species of wild edible fungi, but few efforts have been made to synthesize knowledge from diverse sources, especially as they relate to forest habitats and management. Molina and others (1993) summarize information concerning the harvest of commercially valuable, wild, edible species in the Pacific Northwest. In cooperation with experts on each species, a series of more detailed publications is in progress, each summarizing current knowledge about a given species of commercial importance (for example, matsutake, chanterelles, and morels).

Managers struggling to regulate the rapid increase in commercial harvesting of mushrooms can find a comparable precedent in the brief, but intense, harvest of Pacific yew (Taxus brevifolia Nutt.) bark for taxol production (Campbell 1993, Hartzell 1991). The rapid development of yew biomass as a special forest product and concerns about its sustainability are in many ways analogous to the development of mushrooms as special forest products. Mushrooms have been used medicinally in Asia for millennia (Stamets 1993), and if active ingredients are isolated from fungi and proven effective by pharmaceutical companies, new species of wild fungi may suddenly experience intense harvest pressure in their native habitats. Managers will benefit from familiarity with previous examples of urgently-needed harvest regulations.

In addition to synthesizing current knowledge and learning from past experiences, effective ecosystem management of forest fungi must use the full array of new technologies now available for handling large quantities of information. The recent increase in electronic communication capabilities and software, especially the Internet, will transform the accessibility and utility of information. Large databases of recent literature citations are already available on-line from most universities. Electronic mail allows virtually instantaneous global communication among colleagues. Bulletin boards provide interactive discussions on almost any topic of mutual interest. Recent developments in World Wide Web browsing programs allow keyword searches of international resource indices that direct the user to "home-page" sites (providers) that maintain and continuously update pertinent information for public access and use. Advances in personal computer hardware, increases in data transmission rates, and standardizing of data transfer protocols are expanding our ability to share information, especially images. Individuals or organizations with specialized knowledge will be able to provide on-line resources that support interactive inquiries.

Advances in computer science also provide managers with several ways to model ecosystems. The GIS databases are powerful tools for applying model predictions to decisions about changing forest landscapes; for example, creating electronic databases of pertinent collections of fungi in herbaria was the essential first step for implementing new survey plans on Federal lands. Placing appropriate location information on shared GIS databases will allow managers to determine if herbarium specimens of significant fungi have been collected from lands they manage, and evaluate the precision of relevant location information. If location data are vague or the sites have been disturbed since the specimens were collected, the sites should be revisited. Satellite trilateration using the Global Positioning System (GPS) can record the precise location of newly discovered populations or habitats on a GIS data layer so that future activities will account for their presence.

Organizations conducting diversity assessments of fungi will likely benefit from the development of on-line mushroom identification services. Either dichotomous or synoptic keys could be accessed electronically and designed for easy use. Users could point and click on images of key features to clarify their choices. Synoptic keys use a set of shared characteristics described for each taxon, and the combination of selected characters narrows the alternatives to appropriate taxa. Synoptic keys are most efficient when all selected characteristics are described for each taxon in the key, and some subset of characteristics is unique for each taxon. Dichotomous keys also can incorporate a "point-and-click-to-learn-more" format incorporating illustrations of mushroom characteristics, glossaries, common and scientific name indices, and color images. This technology has the potential to make mushroom identification entertaining as well as educational.

Regional Strategies

The FEMAT report (1993) and subsequent documents implementing its analysis (USDA and USDI 1994a, 1994b) were pivotal initiatives for instituting ecosystem management on Federal forests in the Pacific Northwest and incorporating fungi in the process. These initiatives should be considered the beginning of efforts to fully survey, monitor, manage, and sustain fungus diversity and edible mushroom harvests throughout the region on all land ownerships. Progress towards this goal will be augmented if managers and the mycological community cooperate to develop regional strategies that:

- Expand the level of mycological expertise

- Involve the public in the process of ecosystem management

- Coordinate the efforts of all interested parties

Ecosystem management and assessments of biological diversity will be possible only if we can identify the organisms comprising the web of life. Several approaches are needed to alleviate the current and anticipated shortage of professional mycologists trained in taxonomy. Universities and funding agencies should support more graduate programs and students in this fundamental science and hire them when they graduate. The recent announcement of the "Partnership for Enhancing Expertise in Taxonomy" by the National Science Foundation strongly supports this effort.

Training of individuals with strong mushroom identification skills is needed as well. Many Federal land management agencies have staff botanists who are assigned management of fungi as yet another responsibility. Most botanists have training in the principles of taxonomy and use of taxonomic keys, but some are unfamiliar with the vocabulary used to describe the characteristics of fungi. Agency botanists commonly express interest in learning more about mushroom identification, and would benefit from training programs sponsored by experts. One such program is the 2-day "Mushrooms and Managers" short course sponsored by the Oregon State University College of Forestry and the Pacific Northwest Research Station. Another approach would be a "mycological institute" similar to the "silvicultural institute" held periodically at Oregon State University. Institute training could provide an intensive 1- or 2-week, hands-on session with specific training in mushroom identification and field sampling protocols. Much of the course could be taught by invited specialists.

In most parts of the country, and especially the Pacific Northwest, many people have a strong interest in macrofungi; they form the membership of numerous mushroom clubs and mycological societies. Although most members became interested in macrofungi as a source of food and recreation, some have expanded their interests into more technical aspects of mycology and have the interest, time, and technical knowledge to help with research. Examples of their efforts include the landmark chanterelle project by the Oregon Mycological Society (study 8) that includes identification of all mushrooms at a site in the Mount Hood National Forest, the extensive survey of fungi at Barlow Pass, Washington, conducted by members of the Puget Sound Mycological Society in cooperation with several research mycologists (Ammirati and others 1994), and the long-term research contributions of the North American Truffling Society (Rawlingson and others 1995). The Pacific Northwest Key Council provides a forum for amateur mycologists with a scientific bent to hone their skills in taxonomy; however, only a few dozen people in the region have sufficient time, interest, and knowledge of macrofungi to participate effectively in sampling fungus diversity. It is unrealistic to think that the mushroom club closest to a given National Forest district or other administrative unit harbors the expertise to conduct complex inventories or identification tasks. Most clubs have limited funds for libraries and microscopes, and the majority of club members are not experienced in using technical literature and microscopic features of macrofungi to make definitive identifications. Nevertheless, if the skills, resources, and commitment of local volunteers is carefully assessed, managers and researchers can usually find appropriate ways to use their help. Certainly, when talented mycologists do volunteer, every effort should be made to support their participation.

Commercial mushroom harvesters are another group with extensive experience. Their knowledge of ideal habitat for abundant fruiting of edible mushrooms is probably unequaled. They also are skilled at reading marks or signs in the forest indicating mushroom consumption by animals or collection by other humans. Although often secretive and wary of land managers, many commercial harvesters are keenly interested in learning more about the mushrooms they collect, and support efforts to ensure the sustainability of the resource. Managers and researchers benefit greatly from soliciting their cooperation in designing, conducting, and evaluating edible mushroom monitoring projects.

Coordination

Like "ecosystem management," "coordination" and "cooperation" are often considered good-sounding buzzwords infrequently put into practice. Several examples, however, should demonstrate their applicability to the study of fungi.

We noted earlier that no complete publication currently identifies all the macrofungi in the Pacific Northwest (that is, a "mycota" similar to a “fora" for plants). Even if taxonomists reach agreement on species distinctions, ample work remains to describe each species and provide keys for each genus. Publication of a complete mycota for the region might be delayed for decades while issues are resolved and identifications completed or updated. The advent of on-line references provides another alternative. An extensive (not necessarily complete) mycota would still involve considerable cooperation among taxonomic experts worldwide, as well as significant institutional and financial support; but on-line keys, descriptions, references, and citations can be continuously updated, gaps noted, and unresolved issues explained. Given sufficient enticement, interested parties could begin cooperating immediately to design and implement this resource.

Studies that examine fungi and their responses to forest management activities throughout the range of relevant habitats constitute another endeavor that significantly benefits from coordination. Regional research may initially be more expensive than local case studies, but the broad applicability of the results provides significant savings in the long run. Mixed ownership of forest lands in the Pacific Northwest lends itself readily to regional studies that involve cooperative investigations among organizations with different interests and management goals. Mushroom fruiting is so variable that long-term monitoring is necessary to gather meaningful data. Regional investigations conducted by several collaborators are more likely to be maintained for extended periods than local case studies because more organizations have a stake in their continuity.

Successful surveys of fungus diversity and studies of edible fungi will inevitably require open communication and cooperation from a wide range of forest owners, managers, scientists, resource specialists, mycological societies, and harvesters.

Closing Remarks

The "fungophobic" cultural tradition our society inherited from British immigrants (Arora 1986) induces many managers to disregard fungi and evokes derogatory opinions from others. Although fungi have been recognized as belonging to a separate taxonomic "kingdom" of life for over 20 years, many people still consider them plants. Mycologists are often hired as botanists. These examples illustrate the difficulties mycologists and mushroom enthusiasts face in obtaining resources to manage our forests for more than just the trees. As concepts of forest management evolve, however, ecosystem management is becoming a reality. Fungi play such vital roles in forest ecosystems that they cannot be ignored in management plans, yet resources available for monitoring fungi are likely to remain limited. Meeting the challenge of doing more with less requires managers and mycologists to pursue creative options for investigating and managing forest fungi in an ecosystem context.

Ecosystem management of forest fungi will require hard work, patience, new technologies, innovative solutions, extensive cooperation, and shared resources, but the elements of success are in place. Given the enthusiasm, excitement, and optimism

Literature Cited

Amaranthus, M.P.; Perry, D.A. 1989. Interaction effects of vegetation type and Pacific madrone soil inocula on survival, growth, and mycorrhiza formation of Douglas-fir. Canadian Journal of Forest Research. 19: 550-556.

Amaranthus, M.P.; Perry, D.A. 1994. The functioning of ectomycorrhizal fungi in the field: linkages in space and time. Plant and Soil. 159: 133-140.

Amaranthus, M.P.; Trappe, J.M.; Bednar, L.; Arthur, D. 1994. Hypogeous fungal production in mature Douglas-fir forest fragments and surrounding plantations and its relation to coarse woody debris and animal mycophagy. Canadian Journal of Forest Research. 24: 2,157-2,165.

Ammirati, J.; Ammirati, S.; Norvell, L. [and others]. 1994. A preliminary report on the fungi of Barlow Pass, Washington. McIlvainea. 2:10-33.

Arnolds, E. 1989. Changes in frequency and distribution of macromycetes in the Netherlands in relation to a changing environment. *In*: Fungi Atque Natura (Funghi ed Ambiente) Atti del IV: Convengno Internazionale di Micologia del; 1987 September 27-30; [location of meeting unknown]. [Place of publication unknown]; [publisher unknown]: 163-232.

Arnolds, E. 1991. Decline of ectomycorrhizal fungi in Europe. Agriculture Ecosystems and Environment. 35: 209-244.

Arnolds, E. 1992. Mapping and monitoring of macromycetes in relation to nature conservation. McIlvainea. 10: 4-27.

Arora, D. 1986. Mushrooms demystified: a comprehensive guide to the fleshy fungi. Berkeley, CA: Ten Speed Press. 959 p.

Bormann, B.T.; Cunningham, P.G.; Brookes, M.H. [and others]. 1994. Adaptive ecosystem management in the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-341. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

Bormann, F.H.; Likens, G.E. 1979. Pattern and process in a forested ecosystem. New York: Springer-Verlag. 253 p.

Campbell, S. 1993. Pacific yew final environmental impact statement. 1993-790-110 / 80002 Region No. 10. Portland, OR; U.S. Department of Agriculture, Forest Service. Pacific Northwest Region.

Cubbage, F.W.; O'Laughlin, J.; Bullock III, C.S. 1993. Forest resource policy. New York: John Wiley & Sons: 528-539.

Forest Ecosystem Management Assessment Team. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Portland, OR; U.S. Department of Agriculture; U.S. Department of the Interior [and others]. [Irregular pagination].

Groombridge, B. 1992. Global biodiversity: status of the Earth's living resources. London, England; Chapman and Hall: 192-205. Chapter 16.

Hartzell, H., Jr. 1991. The yew tree: a thousand whispers: the biography of a species. Eugene, OR; Hulogosi. 319 p.

Jansen, E.; van Dobben, H.; de Wit, T. 1985. Achteruitgang van de cantharel in Nederland. Wetenschappelijke Mededeling Koninklijke Nederlandse Natuurhistorische Vereniging. 167: 59-69

Jensen, M.E.; Everett, R. 1994. An overview of ecosystem management principles. *In*: Jensen, M.E.; Bourgeron, P.S., tech. eds. Volume II: Ecosystem management: principles and applications. Gen. Tech. Rep. PNW-GTR-318. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 376 p. (Everett, Richard L., assessment team leader; Eastside forest ecosystem health assessment).

Kaufmann, M.R.; Graham, R.T; Boyce Jr., D.A. [and others]. 1994. An ecological basis for ecosystem management. Gen. Tech Rep. RM-246. [Fort Collins, CO]; U.S. Department of Agriculture, Forest Service, [Rocky Mountain Forest and Range Experiment Station]. 22 p.

Marcot, B.G.; Wisdon, M.J.; Li, H.W; Castillo, G.C. 1994. Managing for featured, threatened, endangered, and sensitive species and unique habitats for ecosystem stability. Gen. Tech. Rep. PNW-GTR-329. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 39 p. (Everett, Richard L., assessment team leader; Eastside forest ecosystem health assessment; Hessburg, Paul., science team leader and tech. ed., Volume III: assessment.)

Mehus, H. 1986. Fruit body production of macro-fungi in some north Norwegian forest types. Norwegian Journal of Botany. 6: 679-701.

Meinke, R.J. 1982. Threatened and endangered vascular plants of Oregon: an illustrated guide. Portland, OR; U.S. Fish and Wildlife Service, Office of Endangered Species, Region 1.

Molina, R.; O'Dell, T.; Luoma, D. [and others]. 1993. Biology, ecology, and social aspects of wild edible mushrooms in the forests of the Pacific Northwest: a preface to managing commercial harvest. Gen. Tech. Rep. PNW-GTR-309. Portland, OR; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 42 p.

Molina, R.J.; Massicotte, H.; Trappe, J.M. 1992. Specificity phenomena in mycorrhizal symbioses: community-ecological consequences and practical implications. *In*: Allen, Michael F., ed. Mycorrhizal functioning: an integrative plant-fungal process. [Place of publication unknown]: Chapman and Hall: 357-423.

Moote, M.A.; Burke, S.; Cortner, H.J.; Wallace, M.G. 1994. Principles of ecosystem management. [Place of publication unknown]: Water Resources Research Center, College of Agriculture, University of Arizona. 14 p.

Overbay, J.C. 1992. Ecosystem management: introduction. *In*: Taking an ecological approach to management: Proceedings, National workshop, 1992 April 27-30; Salt Lake City, UT. WO-WSA-3. [Washington, DC]: U.S. Department of Agriculture, Forest Service: 3-15.

Rawlinson, P. ; Evans, F.; Trappe, J.M. 1995. The North American Truffling Society: introduction to its series on truffles and trufflelike fungi. Mycotaxon. 55: 171-174.

Stamets, P. 1993. Growing gourmet and medicinal mushrooms. Berkeley, CA: Ten Speed Press. 552 p.

Tominaga, Y. 1978. *Tricholoma matsutake. In*: Chang, S.T; Hayes, W.A., eds. The biology and cultivation of edible mushrooms. New York; Academic Press: 683-697.

U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994a. Final supplemental environmental impact statement on management of habitat for late-successional and old-growth forest-related species within the range of the northern spotted owl. [Place of publication unknown]. 2 vol.

U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994b. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl. [Place of publication unknown]. 74 p.

Vogt, K.A.; Bloomfield, J.; Ammirati, J.F.; Ammirati, S.R. 1992. Sporocarp production by Basidiomycetes, with emphasis on forest ecosystems. *In*: Carroll, G.C.; Wicklow, D.T., eds. The fungal community: its organization and role in the ecosystem. 2d ed. New York; Marcel Dekker: 563-582.

Acknowledgments

The excellent technical reviews by Joseph Ammirati, Shannon Berch, Eric Danell, Paul Dunn, and James Trappe are gratefully acknowledged. We thank Doni McKay and Thomas Danner for help with keyboarding. Artwork for the cover was done by Christine Roberts. The conference and proceedings were supported by the Cascade Center for Ecosystem Management, PNW Ecological Framework for Management Program, and the Northwest Forest Plan.

Pilz, D.; Molina, R., eds. 1996. Managing forest ecosystems to conserve fungus diversity and sustain wild mushroom harvests. Gen. Tech. Rep. PNW-GTR-371. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 104 p.

The recent increase in commmercial harvest of edible, forest fungi (mushrooms) and the listing of 237 fungi as needing protection in President clinton's Northwest Forest Plan have heightened concern among resource managers regarding the wise management of these forest organisms. This book resulted from a workshop held in May 1994, "Ecosystem Management for Forest Fungi," and provides summary chapters on conservation issues and fungal diversity, commercial harvest of edible mushrooms, and integration of fungi into adaptive ecosystem management. Summaries of current mycological research, inventory, and monitoring are also provided. Its primary aim is to provide useful background information on the ecology of forest fungi, methods to assess fungal diversity and productivity, and opportunities for resource managers to incorporate fungi into forest plans.

Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890 Portland, Oregon
97208-3890