Commercial Harvest of Edible Ectomycorrhizal Fungus Sporocarps from Pacific Northwestern Forests: Ecological and Management Implications

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Summary. - Edible sporocarps of many ectomycorrhizal fungi are highly prized by different cultures. The decline of favorite edible species in some countries, however, has created a market demand for these wild fungi from countries where they remain plentiful. These economic forces have led to development of a multimillion dollar industry of wild mushroom harvest from the extensive ectomycorrhizal forests of western North America; approximately 1,800,000 kg were harvested in 1992. This paper discusses ecological and management implications of this commercial harvest on ectomycorrhizal fungi and focuses on current research aimed at developing management guidelines for protecting the mushroom resource and ensuring a sustainable harvest.

Keywords: mushrooms, sustainability, forest management, Cantharellus, matsutake

Introduction

Early research on ectomycorrhizal fungi was stimulated by interest in the production of delicious, wild forest fungi. In the 1880s, pioneering mycorrhizologist A. B. Frank (3) was commissioned to promote the possibility of truffle cultivation in the Kingdom of Prussia. A century later, artificial "truffle culture" has succeeded in France, Italy, Spain, New Zealand and the United States. Much of that success resulted from decades of field observation and study of the natural biology and mycorrhiza formation of valuable *Tuber* species. Research on other edible ectomycorrhizal fungi has not been as comprehensive as for *Tuber* species. Although we may have general understanding on geographic range, host associations, and mycorrhizal characteristics of important edibles such as *Cantharellus* (2), we poorly understand their ecology and productivity in natural forests, an understanding essential to conserving and managing the use of these fungi.

Edible sporocarps of many ectomycorrhizal fungus species are highly prized by different cultures and local markets for their commercial sale are common around the world. However, the decline of favorite edible species in Europe (1) and Japan (4) has created a market demand for wild fungi from regions where the species remain abundant and a modern infrastructure (forest roads and nearby airports) provides quick access to and export of the fresh product. These economic forces have led to development of a multimillion dollar industry of wild mushroom harvest from the extensive ectomycorrhizal forests of western North America (5). This paper discusses ecological and management implications of this commercial harvest on ectomycorrhizal fungi and focuses on current research aimed at developing management guidelines for protecting the mushroom resource and ensuring a sustainable harvest.

Commercial mushroom harvest in the Pacific Northwest

A small entrepreneurial wild mushroom industry began in the early 1980s in Oregon and Washington, harvesting small volumes of mushrooms and shipping them to gourmet restaurants in the United States. Then, with the decline of chanterelle (*Cantharellus*) productivity in Europe, a new export market developed; harvested chanterelles were packed in brine and shipped to canneries in Germany. This new market vastly increased the volume of mushrooms harvested and led to development of a system of harvesters, buyers, processors, and brokers for the expanding industry. Later in the decade, the industry returned to a primarily fresh export market.

Schlossner and Blatner (6) extensively surveyed of the wild mushroom industry in Oregon. Washington and Idaho for 1992. They report that the industry employed about 11,000 people and contributed \$41.1 million to the regional economy; nearly 1,800,000 kg of wild mushrooms were harvested. Twenty five species are commercially harvested but the most economically important are chanterelles (mostly *Cantharellus cibarius* Fr. but also *C. subalbidus* Smith & Morse), pine mushroom or American matsutake (*Tricholoma magnivelare*

(Peck) Redhead), king bolete (*Boletus edulis* Bull: Fr.) and several *Morchella* species. Twenty-eight percent of all exports went to Japan and 25 percent to European markets (primarily France and Germany).

The most abundantly harvested ectomycorrhizal fungi are the chanterelles and American matsutake, with 454,000 kg of the former and 375,000 kg of the latter harvested in 1992. Importing countries reflect cultural tastes and regional availability of preferred fungus species. Nearly half of all harvested chanterelles were air-shipped to Europe; chanterelles are popular throughout Europe, but productivity has declined in some regions (1). For similar reasons, 70 to 90 percent of harvested American matsutake went to Japan, where it supplements the highly revered Japanese matsutake (*Tricholoma matsutake* (Ito et Imai) Sing.). Over the last 50 years productivity of *T. matsutake* in Japan has declined dramatically to 10 percent of previous yields (4).

Biological and management concerns

The magnitude of the commercial mushroom harvest in the Pacific Northwest has raised controversy about conservation of the mushroom resource, particularly regarding harvest effects on species viability and ecosystem function. As part of a comprehensive research program for managing commercial mushroom harvests, we have conducted several public workshops to gather information on the primary concerns of resource managers, the mushroom industry and general public. Those concerns fall into four categories; we present them as a series of questions so readers can envision the scale and complexity of needed mycorrhiza research.

Production and distribution. How many fruiting bodies are being produced? How are they distributed across the landscape or within a given area? How does production vary during a season and from year to year? What is the actual or potential commercial productivity of a given area? What proportion of forest habitat is available and accessible for harvesting? What factors determine productivity and how might they be managed?

Mushroom harvesting. How can the sustainability of mushroom harvesting be assured? What proportion of the crop can be harvested without unacceptable impacts on the fungus itself or other resources? What techniques will mitigate those impacts; does mushroom harvesting increase or decrease subsequent production? Is spore dispersal reduced by removal of immature mushrooms, and, if so, does it impair reproductive success? Is fungal mycelium and subsequent mushroom production affected by search and harvest techniques such as raking, moving woody debris, or digging? Are mushrooms harmed by numerous harvesters trampling the forest floor? How important are commercially valuable species as food for wildlife, and is human competition for the resource significant?

Land management. How do various timber harvesting methods (clear-cutting, thinning to various densities, host species selection) affect subsequent mushroom production over time? What is the impact of soil compaction or disturbance from logging activities? What are the relationships between fire and subsequent mushroom production, especially for morels? How does the intensity and timing of fire influence edible mushroom production? What impacts do grazing, fertilization, or pesticide application have on production? Can mushroom production be improved through habitat manipulation, for example: planting tree seedlings inoculated with specific fungi, thinning understory brush for sunlight and rainfall penetration, prescribed burns, and irrigation. Can production be increased across the landscape by managing forests to attain tree age class, structure and composition optimal for fruiting?

Biology and ecology. What are the important reproductive events in the life cycle of a particular fungus species? How are new colonies or populations established and maintained? What causes them to diminish or perish? How important is spore dispersal to reproductive success, population maintenance, genetic diversity, or adaptability to unique micro-habitats? How much genetic diversity exists within and among populations? Are there endemic, narrowly-adapted, or unusual populations of otherwise common species? What are the growth rates of fungal colonies in soil and degree of mycorrhizal development by specific fungi on root systems? To what degree do other mycorrhizal or saprophytic fungi compete with desired fungi for colonization sites on host roots or space in the forest soil?

Answering these questions will require scientific investigations on an array of ecological scales (soil microniches to regional landscapes) and with a variety of investigative methods.

Monitoring needs and methodological considerations

Numerous biotic and abiotic factors influence fruiting of ectomycorrhizal fungi, and sporocarps of different species vary in abundance and distribution from year to year (7). Sporocarps are typically clustered and

associated with particular substrates. Fruiting is generally non-uniform and frequently occurs in arcs or patches of a few to numerous sporocarps. The distribution of patches can also vary widely from a few scattered groups to concentrated clusters. Commercially harvested species such as American matsutake, *Cantharellus* species, and *Boletus edulis* also associate with a broad range of host tree genera in the Pacific Northwest (*Abies, Arbutus, Lithocarpus, Pinus, Pseudotsuga, Quercus, Picea,* and *Tsuga*) and occur over a range of forest habitats and tree age classes. This broad spatial and temporal variability of sporocarp occurrence, combined with insufficient ecological knowledge of the mycorrhizal fungi, presents a formidable challenge for mycorrhizal and mycological research.

The first step to meeting this challenge is establishing long-term monitoring of the fungal resource over the regional land base. Three types of monitoring are required: detection, evaluation and research. Each type addresses different concerns and provides data to meet specific management objectives.

Detection monitoring addresses questions of productivity and distribution. It documents the current production of commercial fungi and variability with space and time. This baseline information is essential to assess whether production is declining, increasing or remaining stable. Because annual fruiting typically occurs over a short period and varies from year to year, sampling must be repeated at least weekly throughout the fruiting period and over several years to assess total production. Numbers of mushroom and their weights must be recorded as well as commercial quality and current market prices, so that total commercial value can be determined. Detection monitoring also requires establishing "control areas" where mushroom harvest is restricted.

The scattered distribution of fungal sporocarps in forest stands, and the extensive land area that needs sampling present the greatest difficulty for establishing a regional monitoring program. Most mushroom detection sampling designs use either transects or quadrats; each approach has strengths and weaknesses (7). We use a variety of transect methods. Some transects serve as permanent plots and are repeatedly sampled throughout the fruiting season for several years. Others are temporary, with either randomly chosen locations, or locations chosen to systematically sample a given land area, e.g numerous parallel transects. They allow search of extensive areas for sporocarps. Once located, sporocarp distributions can be mapped for later ecological study of the fungal colonies. Compared to square or circular quadrat sampling plots, transects increase the likelihood of detecting mushrooms in areas where fungal fruiting is patchy or responding to fine-scale changes in abiotic or biotic conditions within a stand. Narrow transects 1 to 2 meters wide reduce trampling effects and human-error in detection, because the harvester can easily see and reach into the plot without disturbing the soil. Unfortunately, the use of narrow transects may reduce the chance of detecting mushrooms, especially in periods where the abundance and distribution of mushrooms is limited or patchy. We are testing transects of variable width and length to determine which best assess mushroom productivity and distribution in different forest habitats and topographic conditions.

Evaluation monitoring addresses questions pertaining to the effects of mushroom harvest and forest management practices. It relies on trends in data from detection monitoring. For example, if detection monitoring indicates declining levels of mushroom harvest, additional evaluation monitoring is needed to determine the extent and cause of the impact. Evaluation monitoring focuses on specific concerns such as mushroom harvest level, type and intensity of site disturbance or changes in forest structure and composition. Forest managers can use results from evaluation monitoring to assess impacts of these activities and then modify management approaches accordingly. Evaluation monitoring can also include studies that evaluate strategies for increasing production of commercial mushrooms.

As an example, to evaluate the effects of various mushroom harvest techniques on future mushroom productivity and to develop potential methods for enhancing productivity of commercially harvested American matsutake, we are conducting evaluation monitoring studies in four areas in Oregon. Specific treatments in order of increasing soil and mycelium disturbance include: 1) no mushroom harvest control; 2) mushroom harvest with minimal disturbance of soil and fungus mycelium; individual mushrooms are located and gently pulled from the soil; 3) after a matsutake colony is located, the litter and humus are removed over the entire colony by raking the surface organic material to the depth of the mycelium and pulling it to the side of the colony; the mushrooms are then pulled from the soil and the litter and duff replaced over the colony; 4) same procedure as treatment three but the litter and duff are not replaced over the colony; 5) same procedure as treatment four but deep raking occurs throughout the mycelium, thus completely disrupting the roots and fungal network. An additional treatment of adding five liters of water per square meter of fruiting area at two week intervals throughout the fruiting season is also planned as an enhancement technique.

Research monitoring examines basic biological and ecological phenomena and presents a myriad of investigative opportunities for mycorrhiza research. In addition to specific studies on their mycorrhizal ecology, research would examine the functional roles of these fungi in forest ecosystems. For example, how do these fungi contribute to nutrient cycling, soil aggregation, and overall site productivity? These investigations can be conducted concurrently within detection and evaluation monitoring sites where environmental and forest stand data are available. Modern methods and techniques such as molecular DNA tools and *in vivo* root observation chambers can be used to great advantage in these studies to better understand mycorrhiza dynamics.

Conclusions and future challenges

The difficulty in assessing cause and effect for the decline for some ectomycorrhizal fungi in Europe emphasizes the need for establishing long-term fungal inventory and monitoring programs. The intense commercial harvest of edible ectomycorrhizal fungus sporocarps heightens this need in the Pacific Northwest. Long-term monitoring is essential to assess the "carrying capacity" of the land and to develop ecological models to predict future mushroom productivity. Changes noted in mushroom productivity can also serve as biological indicators of large scale changes in forest health due to management practices, pollution, or global climate change.

The greatest challenge in this endeavor for mycorrhizologists and mycologists is dealing with broad landscape and regional-scale questions. Most field studies of sporocarp production and fungal species diversity focus at the stand level and are of short duration (7). Few fungal community studies address questions of habitat disturbance or effects of mushroom harvest on future sporocarp production, so available data relate little to managing commercial harvest. To meet these challenges and provide the essential information needed to wisely manage fungal resources, mycologists and mycorrhiza researchers must work closely with other scientists and forest managers to conduct cooperative studies within an ecosystem framework. Several such integrated studies are underway in the Pacific Northwest (see Luoma *et al.*, this volume).

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