FOREST MANAGEMENT AND THE DIVERSITY OF WOOD-INHABITING FUNGI

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A Short Description of the Project

Since the summer of 1996, a project has been underway at the University of Wisconsin–Madison,Dept. of Plant Pathology, to determine how different forest management regimes can affect the diversity of fungi found in northern hardwood forests. This report is an introduction to this project's goals, objectives and methods. A particular group of fungi, the wood-inhabiting polyporoid and corticioid fungi (commonly known as the polypores and the crust fungi), was chosen for this project. To date, fruiting bodies have been sampled for two years in forest stands in northern Wisconsin and the adjacent upper peninsula of Michigan. Data analysis has begun in earnest only within the last year, so future reports will address the specific results of these investigations.

Introduction

During the past ten years, the issue of maintaining species diversity has received a great deal of attention from the scientific community.[1] Most of this work has concentrated on the more prominent species in communities, especially such organisms as vertebrates and vascular plants. Although these types of organisms dominate conservation efforts, less obvious species such as fungi, bacteria, nematodes, arachnids, *etc.*, typically dominate terrestrial ecosystems in terms of species richness. Fungi in particular play vital roles in forest ecosystems, acting as mutualists (symbionts wherein both partners benefit), parasites, and saprophytes of virtually all plant species, yet very little work has been done to determine how human actions may be affecting microbial populations such as fungi. In this project, we are examining whether human actions in the form of forest management may be affecting the diversity of fungi that produce fruiting structures on woody substrates. In order to investigate the effects that current forest management practices may be having on the wood-inhabiting fungal community, we are examining the diversity of polyporoid and corticioid fruiting bodies (Basidiomycota, Aphyllophorales) in forest stands that have been subjected to different for-

[1]During the period from 1990 to 1998, over 250 journal articles were published with the words "diversity" or "biodiversity" and "conservation" in their titles. During the entire preceding decade, fewer than ten such articles were published and less than half of these actually dealt with the subject of organismal species conservation (Biological Abstracts 1998).

est management regimes. By sampling fruiting body occurrence of these fungi in replicate stands with differing management histones, we will be able to determine if there is a relationship between certain types of forest management and the diversity of the reproductive structures of these fungi.

Our investigations are being conducted in northern hardwood forest stands in northern Wisconsin and the adjacent upper peninsula of Michigan. Diversity of polyporoid and corticioid fungi is being assessed by collecting fruiting structures in stands with three different types of management history. The first group of stands is comprised of old-growth forest that has no history of management, the second group of stands is comprised of forest that has been selectively harvested to produce uneven-aged stands, and the third group consists of forest that has been clear-cut and allowed to regenerate in an even-aged fashion. Species richness (density) of polyporoid and corticioid fruiting bodies is being assessed in these stands over a two year collection period. Species abundance data will also be analyzed, and, if appropriate, overall species diversity measurements of fruiting bodies will be calculated and compared among stands. An overall analysis of trends in species composition, diversity and spatial patterning of fruiting bodies will allow us to determine how this important community of organisms differs in forest stands that have been subjected to different management regimes.

Current Status of Field

Although forest management practices can be important sources of disturbance in forest ecosystems, most of the research to determine how forest management affects fungal communities in North America has been limited to ectomycorrhizal fungi in the northwestern United States (see Pilz and Molina, 1996). This area of study is still in its infancy, though, because studies of how forest management affects ectomycorrhizal species can take years, if not decades. One of the greatest problems is that mycorrhizal fruiting body production can be sporadic both within and between seasons, and can be strongly influenced by weather conditions. Studies such as the Oregon Cantharellus Study (Norvell, *et al.* 1996; Norvell, 1995) have been designed to last 10 years, yet the authors speculate that more time may be needed before definite answers can be given as to whether human actions can affect these fungal populations. In fact, in a study of agarics and boleti from a Caledonian pine forest in Britain, Tofts and Orton (1998) concluded that even 21 years of data collection were insufficient to characterize a community that includes mycorrhizal macromycetes.

Studies involving wood-inhabiting fungi may require less time to implement. Fruiting body production by wood-inhabiting fungi is often more consistent than that of ectomycorrhizal and litter-decomposing species, both from year to year and within a season (Renvall et al. 1991a,b; Wästerlund and Ingelög, 1981). Although researchers have noted that wood-inhabiting fungi from the families Polyporaceae, Corticiaceae, and Hymenochaetaceae make up a relatively stable community, little work has been done in North America to determine how forest management may be affecting this important guild of fungi. Work done in Northern Europe, however, suggests that certain forest management practices can strongly affect the diversity of wood-inhabiting fungi (Bader et al. 1995, Høiland and Bendiksen, 1997, Ohlson *et al.* 1997,

Wästerlund and Ingelög, 1981). In a recent paper reviewing the distribution of macrofungi in Sweden, Rydin *et al.* (1997) concluded that one of the main threats to macrofungi in Sweden was modem forestry, and that "the high proportion of threatened macrofungi in spruce forests of Sweden indicates how strong the impact of forestry and management has been on the Swedish landscape..." They also noted that there was a significantly higher proportion of aphyllophoroid species, the majority of which inhabit wood, in threatened than non-threatened categories, and commented on the fact that seven of the eight species of macrofungi considered extinct in Sweden were wood-inhabiting. Wästerlund (1989) concluded that although the total production of fungi in Scandinavian coniferous forests was not necessarily decreased, there were qualitative changes that usually resulted in a decrease in species diversity.

Such Northern European studies have led to a common conclusion: intensive management of a forest is associated with a decrease in the diversity of fruiting bodies of wood-inhabiting fungi. This appears to be due to the correlation of species diversity with both the quality (in terms of diameters and decay classes) and the total quantity of wood at a site (Bader *et al.* 1995; Høiland and Bendiksen, 1997; Ohlson *et al.* 1997; Wästerlund and Ingelög, 1981).

To our knowledge, the only studies in North America that have tried to address the question of how forest management relates to the amount of coarse woody debris in a stand, and therefore the diversity of fungi found in the stand, have been conducted in the Pacific Northwest on hypogeous fungi (truffles) (Amaranthus *et al.* 1994, but see also Colgan *et al.* 1996). Amaranthus *et al.* found that mature *Pseudotsuga menziesii* (Mirb.) Franco forest fragments had a greater percent frequency of occurrence of truffles than plantations, and that truffle number and dry weight were also greater in mature forests. They also noted that coarse woody debris had a significant effect on the numbers and biomass of truffles in mature forest, and concluded that forest management practices "...that emphasize the retention of mature trees and coarse woody debris promote the abundance and diversity of truffles..."

One other fungal species in North America has received a significant amount of attention because of its dependence on large woody debris. This fungus is *Bridgeoporus (=Oxyporus) nobilissimus* (Cookel Burdsall, Volk, and Ammirati, the "Noble Polypore" (Burdsall *et al.* 1996). Both *B. nobilissimus* and another polypore, *Bondarzewia mesenterica* (Schaeff.) Kreisel (formerly *B. montana* [Quel.] Sing.), are considered sufficiently rare to warrant protection from disturbances caused by forest management. Forest management guidelines in the Pacific Northwest stipulate that surveys for these fungi are required before "any ground-disturbing activities" (O'Dell *et al.* 1996). Although no fungus species are currently listed on the Federal Register as officially threatened or endangered, *Bridgeoporus nobilissimus* has been included on the Natural Heritage Program list due to its reliance on large-diameter *Abies* spp., in particular *Abies procera,* for its nutrition and reproduction (Burdsall *et al.* 1996; Pilz *et al.* 1996). Because of the rarity of this substrate, the United States Forest Service forest management guidelines of the Pacific Northwest require that 240 hectares (600 acres) be preserved at each known fruiting locality (O'Dell *et al.* 1996).

Rationale and Significance

The goal of full ecosystem management is being adopted to sustain the health, productivity, and integrity of resource producing ecosystems. Unless forest management issues are addressed at ecosystem scales, it is possible that many harvesting operations within U.S. forests will not be sustainable in the long term (Leaf, 1979). Full ecosystem management will necessitate the inclusion of inconspicuous organisms such as fungi into forest management guidelines (see Pilz and Molina, 1996). Although seldom investigated, wood-inhabiting fungi are a tremendously diverse and abundant component of forest ecosystems. It is estimated that fungal species make up the second largest major group of organisms on earth (Cannon and Hawksworth, 1995), and that in terrestrial ecosystems fungi can comprise the second largest amount of biomass (Pimentel *et al.* 1992). Wood and bark account for over 90% of the aboveground biomass in all major forest types (Cooke and Rayner, 1984), so wood-inhabiting fungi occupy a critical position in the nutrient cycle of forests. Fungal pathogens often invade the woody tissues of living trees and can adversely affect a wide range of valuable timber species (Gilbertson and Ryvarden, 1986). In addition, wood-inhabiting plant pathogenic fungi are also very important ecologically. By selectively killing susceptible tree species these fungi can: (1) have a significant impact on the direction of forest succession (Holah *et al.* 1997), (2) influence composition and diversity of understory vegetation in a stand (Ingersoll *et al.* 1996; Holah *et al.* 1993), and (3) affect the microbial biomass and decomposition rates in forests (Cromack *et al.* 1991). Such fungi often continue to saprophytically decay woody tissue following the death of a tree, softening the wood as they mineralize complex substrates such as cellulose, hemicellulose, and lignin. Fungi, specifically the brown rot and white rot basidiomycetes, are the only organisms capable of efficiently releasing the energy stored in this vast supply of lignified cellulose and hemicelluloses (Gilbertson, 1980; Hawksworth *et al.* 1995; Cooke and Rayner, 1984). Fungi often must decay wood to a specific stage before other creatures such as beetles, mammals, and birds will be able to utilize the wood as a suitable habitat (Samuelsson *et al.* 1994). Fungi therefore play many vital roles in forests and are intricately linked to many other organisms.

The lack of research done on wood-inhabiting fungi is unfortunate, especially in light of the fact that the majority of fruiting body species are usually found on wood *(e.g.,* in a Norway spruce forest, approximately 58% of the fruiting body species were collected from wood [de vires, 19901). In particular, the polyporoid and corticioid species that inhabit wood appear to be a good group with which to work (Czederpiltz, 1998). These species are diverse, often tremendously abundant in forests, and appear to be one of the most stable fungal communities. Researchers such as Renvall *et al.* (1991a,b) have noticed that fruiting body production is more consistent for wood-inhabiting fungi than for mycorrhizal or litter-decomposing macrofungi. Penttilä and Kotiranta (1996) explain this phenomenon by pointing to the work of Cooke (1948), who showed that environmental conditions such as temperature and moisture are more constant in tree trunks than in the ground. In addition, in a study of wood-inhabiting fungi in Norway, Høiland and Bendiksen (1997) found that overall environmental conditions at a site seem to have little or

no effect on species number, but that species numbers are highly correlated with the particular conditions of each individual piece of substrate. This suggests that it is the relatively constant environmental variables of the log itself that significantly influence fruiting body production.

Polyporoid and corticioid fungi are also amenable to quantitative analysis because many of these fungal species produce perennial or long-lived fruiting structures (Gilbertson and Ryvarden, 1986), meaning that when a fungus does produce a fruiting structure, it produces a record of its presence that will be observable for a long time. Many wood-inhabiting species also possess no known mechanism other than spore dispersal to move from one piece of wood to the next, so when their nutrient base is depleted, fruiting bodies must be produced for survival (Cooke and Rayner, 1984). The long-lived nature of these fruiting bodies, along with their regular production, suggests that it should be possible to characterize this fungal community with considerably less effort than is required for most other groups of fungi and, in addition, a significant amount of work has been done on their taxonomy (Gilbertson and Ryvarden, 1986; Ginns and Lefebvre, 1993). This will be the first study in North America to quantitatively approach the question of whether forest management affects the diversity of fungi that produce fruiting bodies on wood.

General Research Methods

We are sampling polyporoid and corticioid fruiting bodies in five old-growth stands, five uneven-aged stands, and three even-aged stands. Originally the design of the study was balanced, with five stands of even-aged forest. After sampling it was discovered that two of the five even-aged stands had been thinned. The data for the two even-aged thinned sites will be analyzed, but it is unlikely that two sites are enough to fully characterize this fourth category of management history.

—Location and site characteristics

All fifteen of our sampling sites were located in mesic northern hardwood stands in northern Wisconsin and the adjacent upper peninsula of Michigan. For a description of the area's soils, climate and landscape classification, see Goodburn and Lorimer (1998), a study that used many of the same sites used in this project. Stands were dominated by sugar maple, but also contained significant amounts of yellow birch, basswood, ironwood, and often a component of hemlock (less than 30% hemlock dominance). All sites were located on medium rich soils with the same or similar soil series and similar geomorphology. Similarity of soils and habitat characteristics was controlled by locating all sites in the same forest habitat type classification (see Kotar *et al.*, 1988 and Coffman *et al.*, 1983). All stands were classified as *Acer-Tsuga-Dryopteris* (ATD), although a few may have been transitional between ATD and *Acer-Viola-Osmorhiza* (AViO) or *Acer-Tsugu-Maianthemum* (ATM), (Goodburn and Lorimer, 1998).

Each sampling site is situated within a unique forest stand, defined as an area with similar site potential, and therefore managed as a unit by the man-

agement agency. Stands were located from aerial photographs, and the plot center was located randomly within each stand. All old-growth stands were greater than 20 ha in size, and were located in the Sylvania Wilderness Area on the Ottawa National Forest, Michigan. The Sylvania Wilderness is a block of land almost six miles by six miles in dimension, and contains over 6,000 ha of old-growth forest (USDA, 1964). Only localized cutting has been done for personal use in Sylvania, and tree ages range up to approximately 350 years (Goodburn and Lorimer, 1998). To qualify as old-growth, a stand had to have at least 34% of its basal area in large trees (>46cm dbh, or diameter at breast height), and at least 67% of its total basal area in mature and large trees (>26 cm dbh). Uneven-aged, selectively managed sites were chosen based on "... previous management by the selection system on a cutting cycle of 8-15 years, a minimum residual basal area of 16.1 m^2ha (70 ft^2/ha), and a maximum residual tree diameter >45 cm dbh" (Goodburn and Lorimer, 1998). All uneven-aged stands have been "actively managed to fulfill forestry objectives," but have not been cut within the previous four years. Such stands generally do not contain trees greater than 200 years old (Cole and Lorimer, 1994). Even-aged sites were located in second growth stands that had regenerated from clear-cutting and have a relatively simple, skewed distribution of tree ages. The even-aged stands have not been thinned and are dominated by sugar maple trees 65-75 years of age (Goodburn and Lorimer, 1998).

—Plot layout and sampling schedule

To quantify fruiting body occurrence of polyporoid and corticioid fungi in each stand, plots 100m by 60m were constructed at each sampling site (Fig. 1). Each plot ran east-west and was composed of three contiguous

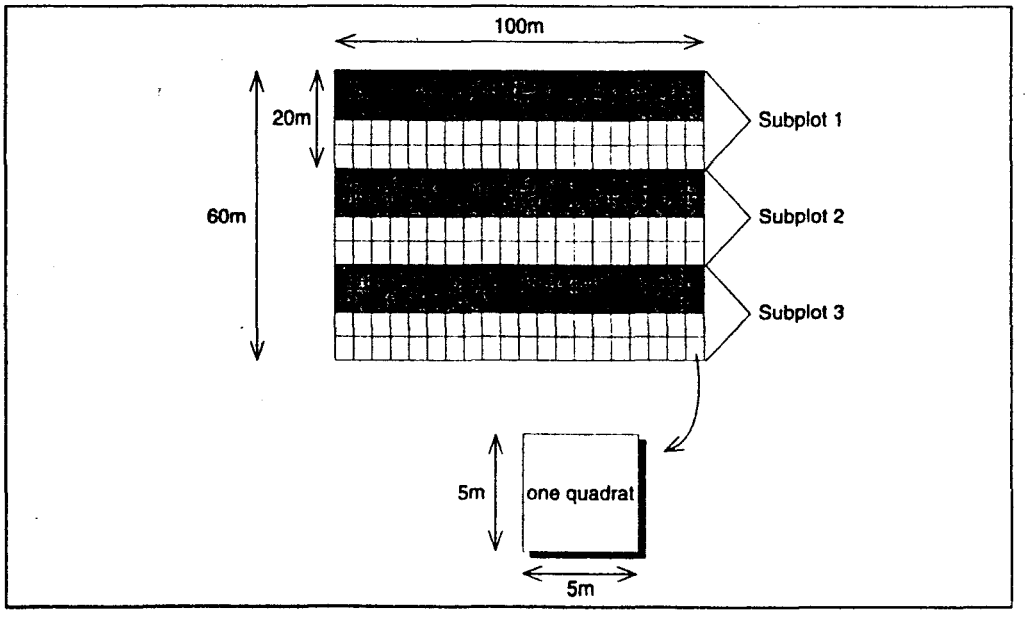

Fig. 1. Diagram of the plot constructed at each site for one year of sampling. There were two sampling periods each year, and shaded quadrats represent the area that was sampled during one sampling period. Shaded quadrats with an "x" represent area that was smapled for small diameter debris as well as large diameter debris. See text for a full description of sampling procedures.

subplots 20m by 100m. The entire plot was divided into 5m by 5m quadrats, and fluorescent flags were placed at the corners of each quadrat. Sites were sampled in two periods during the summer and because sampling is destructive (specimens must be collected and all logs and debris must be turned and examined), a split-plot design was employed. In this system, half of the area in the plot is left undisturbed during the first sampling period of the year in order that it can be sampled during the second sampling period. All sampling was done from the ground level to a height of 2.5m. During the first of the two sampling rounds, the northern or southern 10m by 100m strip was randomly chosen from each subplot and all large woody substrates greater than or equal to 15 cm in diameter were examined for fruiting bodies. Then, within each 10m by 100m strip sampled for large debris, either the northern or southern 5m by 100m strip was randomly chosen to have all small woody substrates less than 15 cm in diameter examined for fruiting bodies. For each piece of large diameter substrate in each quad, all known polyporoid and corticioid species were recorded, while all unknowns were collected. The quantity of fungus on each piece was recorded as either the total number of caps present for pileate species, or as an estimate of the hymenial surface area for resupinate species. After the two summer sampling periods, all large woody substrates within the plot had been examined, while for small substrates, our stratified random sampling procedure had covered half of the area of the plot.

Substrate data were also recorded for each piece of large diameter woody substrate in each quadrat. Information taken for large woody debris included substrate species, diameter, length (within each quadrat), height off the ground, form *(e.g.,* log, tree, snag, stump, suspended log), amount of moss coverage, amount of bark, and decay class. Decay classification was based on the procedures employed by Goodburn and Lorimer (1998). During the first sampling period, substrate information was recorded for all large woody substrates whether or not fruiting bodies were present, while during the second sampling period such data were only taken on wood with fruiting bodies. The amount of small woody debris within each quadrat sampled for fruiting bodies was estimated on a scale of 1-5, and the diameter of each fungal bearing piece was estimated as being either less than 15 cm but greater than 10 cm, less than or equal to 10 cm but greater than 5 cm, or less than or equal to 5 cm.

Plots were established in the spring of 1996, and the first sampling round was started in the beginning of June and ran through mid-July, with one site being sampled approximately every two and a half days. The second sampling round was then started at the beginning of August, and ran continuously for fifteen days with one stand being sampled approximately every day. The second sampling round was much quicker than the first since substrate data were only taken for pieces of wood with fruiting bodies.

The sampling order of sites was blocked by time so that for each three sites sampled (a "block" of sites), there was one stand of each management class. Because two of our even-aged sites turned out to be placed in thinned stands, two of our blocks (the first and the last) are missing the even-aged treatment category. The order in which the blocks were sampled was random, as was the

order of sites within each block. However, as previously mentioned, the sites included within each block were not random. In addition to ensuring that each block contained one site of each management category, we also paired even-aged sites and uneven-aged sites based on geographic location, and then randomly grouped each pair with an old-growth site. Therefore blocking is based on a combination of geographic proximity and time of sampling (seasonality). The order in which the sites were sampled was repeated for the second sampling round of 1996.

In 1997, each site was again sampled in the same way, but new plots were put in at each site contiguous to the 1996 plots. The 1997 field plots were randomly located either east or west of the 1996 plot. In a few cases, plots had to be located randomly either to the north or south of the previous year's plot due to geographic or habitat limitations (trails, marshy areas, areas with too great a component of hemlock, *etc.*)1. The blocking scheme employed during the 1996 field season was repeated during the 1997 field season.

Collection Results from 1996 and 1997

To date, all fungal collections made during the second sampling rounds of 1996 and 1997 have been examined and either identified to species or assigned to a genus and given a species number *(Antrodia* sp. #1). During these two sampling periods, approximately 5,000 fungal samples were collected and 14,781 fungal observations were made (a fungal observation is the Occurrence of a particular species on a piece of substrate within one quadrat). A total of 236 polyporoid and corticioid species have been identified (a list of these species can be obtained by contacting the first author). Voucher specimens have been deposited in the mycological herbarium of the Center for Forest Mycology Research in the USDA-FS Forest Products Laboratory, Madison, Wisconsin.

Preliminary Conclusions

From an analysis of our sampling techniques (see Czederpiltz, 1998), it appears that polyporoid and corticioid fungi make up a community that can be adequately quantified in forest stands by a small number of researchers over a relatively short period of time. The subset of these species that form persistent fruiting bodies is particularly amenable to quantitative analysis and could be used to study how fungi respond to a variety of different disturbance regimes in forests. This group appears quite responsive to disturbances caused by forest management. The response may be due primarily to the dependence of some species on specific types of coarse woody debris. Because modem forest management practices can radically alter the amounts and types of debris found in forests, wood-inhabiting species may be of special interest for conservation efforts.

Management regimes that reduce the quantity or quality of' woody debris could lower the fungal diversity found at a site. Changes in the diversity and abundance of wood-inhabiting fungi could affect the turnover rates of key nutrients in these stands. A less diverse fungal community may function less efficiently than a diverse community, and due to a lack of niche redundancy, a less diverse community may not be as resistant to such environmental stresses as drought or fire. Alterations in the functioning of the fungal community could directly affect the health and productivity of plant communities. Such changes could also influence other organisms that interact with the fungal community, from creatures such as beetles and slugs that are directly dependent on fungi for nutrition, to the vertebrates that eat such organisms. Changes in the composition and functioning of the fungal community could have broad, far-reaching effects on the diversity, health and productivity of our forests.

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