Conservation Assessment for Fungi Included in Forest Service Region 6 Sensitive and BLM Oregon and Washington Special Status Species Programs

Originally created July 2007
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TABLE OF CONTENTS

Overview

This Conservation Assessment (CA) was prepared to address the fungi included in the Oregon and Washington Bureau of Land Management Special Status and Region 6 Forest Service Sensitive Species Programs. This assessment does not make any commitment or allocation of resources nor does it represent a management decision by the US Forest Service or Bureau of Land Management. Although the best scientific information available was used, and appropriate experts were consulted, significant new information may arise, and the assessment may need to be revised. Questions or information updates related to this document should be directed to the Interagency Special Status and Sensitive Species Conservation Planning Coordinator (FS Region 6 and BLM OR/WA) in Portland, Oregon: http://www.fs.fed.us/r6/sfpnw/issssp/contactus/ .

Species covered in this Conservation Assessment include all of those listed as Sensitive by the BLM and Forest Service in Oregon and Washington, as well as those fungi species listed as Survey and Manage, as of April 2020. This document provides an overview and general discussion of the fungi addressed in Appendices I and II. Appendix I has been modified in this April 2020 update, to reflect the current list of Sensitive fungi species in Oregon., Each of the Sensitive species have individual Species Fact Sheets that have been created that are located on the Interagency Special Status and Sensitive Species web site: http://www.fs.fed.us/r6/sfpnw/issssp/ .

Executive Summary

Management Status

Appendix I lists those species currently listed by the agencies as Sensitive through the BLM Special Status or Forest Service Sensitive Species Programs. Appendix II covers Survey and Manage fungi species (as of April 2020).

Classification and Description

Fungi are a large, diverse group of non-photosynthetic organisms belonging to the Kingdom Fungi, which is distinct from either the Plant or Animal Kingdom. Sensitive and Survey and Manage species belong to a number of taxonomic groups and can have a variety of sporocarp (fruiting body) forms and phenologies. Listed fungi include saprobes, mycorrhizae, and parasites that occupy a diversity of specific substrates and habitats across the Northwest. Information on taxonomy, biology and ecology is presented in Appendix II, the Species Fact Sheets, and Appendix III.

Range

All of the species covered in this Conservation Assessment are known or suspected to occur within all or a portion of the Northwest Forest Plan area of Washington, Oregon, and California. In addition, some of these species are known or suspected to occur in other portions of Washington, Oregon, or California or other parts of the United States.

The range and general occurrence information for each species is summarized in Appendix II and in Species Fact Sheets.

Abundance, Sampling, and Population Trends

Typically fungal sampling entails searching for above ground or below ground sporocarps. For a variety of reasons, this can be unreliable and there is a significant amount of uncertainty on the actual abundance of each species. The uncertainty is compounded with resampling so there is very little information on how any populations are changing through time.

Modern molecular techniques include methods that can characterize the entire fungal community within a sample or identify a specific species. These methods can be much more reliable in identifying a species, but they also have their own drawbacks and limitations. More work needs to be done before these methods can be efficiently applied across the landscape, but it may allow for a better understanding of population sizes and trends.

Habitat

Most of the species in this Conservation Assessment are associated to some degree with forest floor litter, down woody material, host tree or shrub species, or some combination thereof. While this association is known, details about the requirements for forest floor litter or down woody material for most fungal species are not well understood, and host specificity is not often known beyond the broad categories of conifers, hardwoods, or plant families within these categories. Down woody debris and forest floor litter are direct food sources for fungi that play a role in decomposing organic material. Host trees (or shrubs in some cases) provide necessary carbohydrates to some fungi through transference of carbohydrates from the roots of the host to the fungus via an underground network termed mycelia.

The size and scale of down woody material influence the range in size of fungal individuals. Fungal colonies can range in size from microscopic to many acres and can persist for years or decades. Fungi are typically patchily distributed, in part due to patchy distribution of substrate (e.g. living host plants, down wood).

Threats

Management activities may pose direct or indirect threats to fungal individuals or populations, depending on the timing or intensity of the activity. Threats and impacts to fungi may occur at multiple scales including at the regional or global scale, at the landscape scale, and at the local habitat scale. This document focuses on project level impacts that affect fungi at a local habitat scale.

Some examples of these activities (depending on scope and intensity) may include:

- Timber harvest, both clear-cutting and thinning
- Wildfire, prescribed burning, and fire suppression activities

- Construction of roads, facilities and energy infrastructure
- Revegetation practices like herbicide application and slash disposal
- Recreational use
- Harvest of mushrooms or other special forest products

Results from Research on Management Practices

High quality experiments on fungal communities are relatively uncommon, and studies including sensitive or Survey and Manage species are even rarer. Despite this, there are studies that do provide information that is useful for some species. Results from studies that included listed species or closely related species are listed in appendix IV. Results from ecosystem scale forestry experiments that included fungal communities as a response variable are detailed in appendix V.

Management Considerations

Knowledge of life processes, as well as the nature of fungal habitat requirements or preferences, remains elusive for most fungi species. Although the research data needed to describe habitat parameters or environmental conditions that might provide for fungi persistence are still lacking, the following represent key considerations in managing known fungi sites:

- Identify the appropriate area to manage based on the substrate and life history of the organism. Fungi that rot woody stems often are limited to 3 to 14 m segments of logs. Root rot fungi can disperse between trees and can extend beyond 800 m. Litter decomposers that occupy a continuous habitat may extend up to 150 m. Mycorrhizae species have different exploration types and growth forms with some species occupying an area less than one m across to individuals that extend over 40 m.
- Maintain gene flow between patches by considering the dispersal ability of the species and the distribution of sites across the landscape.
- Use buffers or harvest patch retention areas to prevent activities from directly impacting the fungal site.
- During timber harvest, use thinning and other green tree retention practices to prevent the creation of large gaps in the forest canopy. This generally means keeping gaps to less than about 10 to 20 m across.
- Preserve old trees and wood as well as remnant old growth stands.
- Conserve adequate woody debris and organic matter.
- Maintain the mycorrhizal network by maintaining old trees that can host large numbers of fungi species, minimizing gap size, and preserving alternate host understory trees and shrubs.
- Avoid applying fire retardant or building fire breaks through known sites.
- Build burn piles outside of known sites.
- Reduce prescribed burn intensities through spring burning, appropriate ignition strategies, fuels management, or waiting until after significant rains for fall burning.
- Avoid adding deep mulch or slash cover to known sites of soil inhabiting species.

- Avoid building recreational facilities near known sites, and discourage recreational use around known sites where possible.
- Encourage best practices for mushroom harvest, particularly discouraging raking of the forest floor or requiring replacement of the litter if raking cannot be avoided.
- Limit fungi collection permits in areas managed for fungal persistence.

Additional considerations for fungal habitat where species presence/absence has not been determined are also included in the text of the Conservation Assessment.

Research, Inventory and Monitoring Opportunities

Information is needed on the general biology and ecology of the species including their dispersal ability, specific habitat, substrate or host range, genet longevity, and fire adaptations. Further research on molecular sampling to determine optimum protocols will increase the utility of this promising field to forest managers. The use of molecular sampling in inventories could provide more definite information on species' range, relative abundance, and distribution. Revisiting known sites that have been subject to potential impacts or mitigation practices could provide information on the true nature of the threats and the efficacy of the mitigation practices.

Introduction

Goal

The goal of this Conservation Assessment is to summarize existing knowledge regarding the biology and ecology of fungal species included as Sensitive in the Forest Service Region 6 Sensitive or Oregon/Washington BLM Special Status Species Programs (SSSSP), and those identified as Survey and Manage species, as of March 2020. Threats to and management considerations for these species are also discussed to aid federal management in species conservation. According to the best current information, most of these species are of concern because of low abundance, restricted distribution, or both. Frequently, information about their habitat preferences or needs is limited or unavailable. The extent to which these species may be affected by land management actions is often poorly understood. Some of the fungi included as Survey and Manage are more abundant, more well known, yet are still on the Survey and Manage list due to the lack of an adaptive management effort to review and potentially remove them.

Management of the fungi species listed in Appendix I follows Forest Service Sensitive Species (SS) policy (FSM 2670), and/or BLM Special Status Species (SSS) policy (BLM 6840 and Oregon/Washington state supplements). Under these programs, fungi are distinctly different than most of the other species: they are not practical to survey for, and they grow below the soil surface making it difficult to accurately define an occupied site. The Agencies seek to manage the known sites and habitat across the landscape in such a way that SS and SSS fungi will persist across their range on federal land in Oregon and Washington in compliance with SS and SSS policy. Forest Service SS policy requires the

agency to maintain viable populations of all native and desired non-native wildlife, fish, and plant species in habitats distributed throughout their geographic range on National Forest System lands. Forest Service management "must not result in a loss of species viability or create significant trends toward federal listing" (FSM 2670.32) for any identified sensitive species. For Oregon and Washington BLM administered lands, SSS policy details the need to manage for species conservation.

Scope

The geographic scope and applicability of this assessment encompasses consideration of the known and suspected range of all included species within Washington and Oregon in their entirety. Some new information has been generated regarding these species in the last few years, especially with respect to distribution and habitat. Interagency strategic and pre-disturbance surveys have provided some new information for some species. Still, significant gaps in the understanding of the basic ecology, abundance, and distribution for these species remain, and updates may be necessary to keep this assessment current.

Threats discussed in this document are those currently known or suspected, and may change with time and additional information. Management considerations discussed in this assessment may be applied to specific sites, though some large-scale issues, such as population connectivity, and range-wide concerns are also discussed. Throughout the document, uncertainty and inference are acknowledged where appropriate, and care has been taken to limit considerations to those supported by current literature or research.

Management Status

Appendix I lists those species currently identified as Sensitive through the BLM Special Status or Forest Service Sensitive Species Programs in Oregon and/or Washington. Appendix II covers Survey and Manage fungi species. Except for six species in Appendix I, all of the species in both Appendices are Survey and Manage species under the Northwest Forest Plan.

Species status may change, as species are added and removed from Agency lists in response to new information. For FS Region 6 and Oregon/Washington BLM, current species lists, species-specific maps, number of sites by physiographic province, and other conservation tools are available on the Interagency Special Status Species website: www.fs.fed.us/r6/sfpnw/issssp/ .

Additional information and updated Global, State and Heritage List ranks can be found at State Heritage Programs websites.
For Oregon: https://inr.oregonstate.edu/orbic
For Washington: hhttps://www.dnr.wa.gov/NHPspecies

Classification and Description

Systematics and Taxonomy

Fungi are a large, diverse group of non-photosynthetic organisms belonging to the Kingdom Fungi, which is distinct from either the Plant or Animal Kingdom. There are several major groups of fungi, the most familiar are the two main groups of macrofungi, the Basidiomycota (which include gilled mushrooms, polypores, chantrelles and other mushroom forms), and the Ascomycota (which include morels, cup fungi, and most lichens). The majority of listed fungi are members of these two groups, but among the Survey and Manage species, *Glomus radiatum* is a member of the Glomeromycota and two species of *Endogone* are members of the Zygomycota. Among the Ascomycota the 23 listed species belong to four different classes and five orders. The 166 listed Basidiomycota species represent two different classes and nine orders. Taxonomic information for each species is provided in Appendix II, Appendix III, and in Species Fact Sheets.

Species Description

The vegetative portion of the fungi consists of numerous fungal hyphae that make up the mycelium. The mycelium grows throughout the substrate that saprobes decompose, connects root tips to nutrient sources for the mycorrhizae, and infects host tissue for the parasites. Mycelium can develop into specialized structures including thread like rhizomorphs that extend through the soils, ectomycorrhizal mantles that colonize root tips, mycorrhizal mats that occupy patches of soil in a forest, and different structures that release asexual spores. For the most part, fungal mycelia forms are poorly described and not generally used for species level identification. That is despite the fact that the mycelium is generally more extensive and longer lasting than the fruiting body (sporocarp). However, the mycelium contains DNA and other chemicals that can be identified in soil or wood core samples using modern molecular methods.

Fungi have a diversity of sporocarp forms. The listed species in the Zygomycota (two species of *Endogone*) and the Glomeromycota (*Glomus* sp.) have relatively nondescript fruiting bodies that rarely get larger than several mm across, but sporocarps of the Ascomycota and Basidiomycota are more diverse. Among listed species, the most common growth form, with 62 listed species, is a gilled mushroom with the typical stalk and cap with thin gills on the underside. Underground, truffle-like sequestrate fungi make up 51 listed species, while species with a gastroid growth form (somewhat transitional between a sequestrate fungi and a stalked mushroom) make up another seven species. Twenty-seven Survey and Manage *Ramaria* species are coral fungi with many cylindrical branches arising from a common base. Ten listed species are conk like or crustose polypores that grow out of wood. There are 21 additional Basidiomycota species, which instead of gills have ridges, pores, teeth, or other smooth surfaces that release the spores. Eight Ascomycota species are cup-like or modified cup apothecias. Five species of Ascomycota have club like sporocarps. Finally, there is one parasitic species, which has sporocarps that grow out of the surface of the infected host mushroom. Descriptions for

each species, and the references from which they came, are included in Appendix II or in Species Fact Sheets.

Biology and Ecology

Fungal Growth and Reproduction

Most macrofungi reproduce via spores with one set of chromosomes (the haploid karyotype). These spores grow into hyphae, long continuous threads of cells with nuclei that may flow through the lumen. The hyphae grow into mycelium that can vary in terms of breeding type (Hansen and Hamelin 1999). These homothallic mycelia (made up of hyphae containing one type of haploid nuclei) can grow somatically and in a few species produce fruiting bodies. Other species need to fuse with a mycelium of a complementary mating type before producing fruiting bodies. When two homothallic mycelia of different mating types fuse, they form a heterothallic dikaryon with two sets of haploid nuclei throughout its hyphae (Douhan et al. 2011). Among Basidiomycetes, the heterokaryotic mycelia is the dominant stage and monokaryons are thought to be short-lived, while Ascomycetes tend to form persistent monokaryons that only fuse shortly before fruiting (Douhan et al. 2011).

Once spores are produced, how far the spores disperse can depend on the type of fruiting body. For a potentially rare polypore from Sweden (*Fomitopsis rosea),* researchers found short-term sporocarp recruitment was absent in areas without sporocarps within 3.5 to 7.5 km, and spore fall was about 5% of the level in woody debris rich stands that had live sporocarps. Differences in spore dispersal can influence the distance between genetically distinct populations. Above ground species with airborne spores can have populations that are relatively homogenous (presumably with significant interbreeding) for over 100 km. Hypogeous truffles with animal dispersed spores form much smaller genetically homogenous populations and show significant genetic diversity within about 10 km (Douhan et al. 2011). Some hypogeous fungi that may not be dispersing spores over a long distance can produce long-lived spores, creating a spore bank that persists through time (Bruns et al. 2002c)

Together, all of the mycelia that are genetically identical is called a genet, or genetic individual. Genets range from microscopic up to what may be the largest organism on earth, the humongous fungus of the Malheur National Forest of Oregon, which occupies more than 960 ha and may have lived for millennia (Schmitt and Tatum 2008). Genets can maintain their individuality via mating type interactions for homothallic mycelia or somatic incompatibility for heterothallic dikaryons (Douhan et al. 2011). Genetic individuals can also become separated via various processes like landslides or death and decay of connecting sections into different bodies of mycelia called ramets (Dahlberg and Mueller 2011). In a large ramet there may even be more than one fusion event producing a section of mycelia that is a different genet but the same body of mycelia. This is assumed to be a short-lived phenomenon (Hansen and Hamelin 1999). Additionally, other processes in some species can result in more than two sets of nuclei within a

heterokaryotic mycelium; this may be an adaptation to increase the phenotypic plasticity of the organism (Douhan et al. 2011).

How the mycelia will develop depends on interactions with the physical and biological environment. These interactions can be highly complex and quite variable among different species of fungi. One way to understand the ecology of the diverse group of species included in this document is to characterize them based on morphological, physiological, or ecological traits. Some important traits that could influence how these species respond to threats in their environment include their phenology, their nutrition source and substrate, and their habitat and range. A table of all of the listed species, their taxonomic classification and their morphological and ecological traits is included in Appendix III.

Phenology

Phenology describes the seasonal changes a species goes through over the year. The phenology of at risk species determines the biological window for surveys, may influence the impacts of management actions on fungal communities, and may help predict how fungi respond to global climate change. For fungi, the most obvious phenological cycle is the season when fruiting bodies are produced. Each fungal species has a separate set of environmental variables that will trigger the production of fruiting bodies. The timing of mushroom development (and thus organism detection) varies according to species, and depends on light, soil temperature, pH, and moisture, among other variables (Hunt and Trappe 1987, Luoma 1991). In the northwest, many species are classified as either fall or spring fruiters, with some other species that can fruit in more than one season depending on conditions. While there is limited information, it appears that some species may also have seasonal cycles in their mycelial growth and their interactions with hosts or substrate. For example, a study in Alaska (Treseder et al. 2004) found different amounts of colonization of roots by mycorrhizal fungi at different points of the growing season while a study from Pennsylvania did not find seasonal variation in root colonization, but did find variability in detection frequency in soil samples (Koide et al. 2007). What is known about the phenology of each listed species, and the relevant references, are included in Appendix II or in Species Fact Sheets.

Nutrition Source and Substrate

Fungi are heterotrophic and must absorb nutrients from organic material or other host species on which they live. Fungi obtain organic energy in a number of ways, as saprobes, as mycorrhizae, as parasites, as endophytes, as lichens, or even as microscopic predators (Vidal-Diez de Ulzurrun and Hsueh 2018). Lichens are included in the ISSSS program as a separate group, but in the fungal program, listed species include saprobes, mycorrhizae, and parasites.

Saprobic fungi

Saprobes feed on dead and decaying organic material and play a vital role in decomposition and nutrient recycling. Fungal saprobes decompose a variety of substrates including litter and wood and can sometimes transition between parasitism and saprobic life cycle as conditions change. Wood decomposers with their long-lived substrates can undergo community succession and increase in species richness as freshly fallen wood is decomposed into soft, rotten logs (Renvall 1995, Lindblad 1998).

Understanding the specific substrate and decomposition niche of fungal species can be important to conservation. Wood rotting species can specialize on woody debris of different sizes or decay classes (Abrego and Salcedo 2013). Species that specialize on fresh wood may be quicker to respond to treatments meant to increase the woody debris in a stand such as girdling or felling trees than species that specialize on more decomposed wood (Pasanen et al. 2014). Substrate will also separate species depending on whether a mycelium may be restricted to a single log and dependent on spores for dispersal, or may occupy a more continuous habitat and can spread over areas of the forest floor up to 150 m in diameter as in some litter decomposers (Hansen and Hamelin 1999).

Among ISSSSP listed species there are 43 species that are saprobes, 10 of which are reported to decompose wood, another 3 that may decompose wood or litter, and 29 that are reported to decompose litter. Additionally, one species that appears to decompose moss. The moss decomposer and one wood decomposer may also infect live plants, suggesting the species may also be a parasite. Among the litter decomposers, some are clearly restricted to a specific type of litter, such as *Gelatinodiscus flavidus* which is only found on *Chamaecyparis nutkatensis* cones and needles, but for most of the species, only general associations with habitat types have been noted and it is still not clear if they are specializing on a specific component or successional stage of the litter or wood. The most up to date information for substrate and habitat requirements each species, and the references from which they came, are included in Species Fact Sheets.

Mycorrhizal Fungi

Mycorrhizal fungi form interdependent relationships with their living host plants, and contribute beneficially to the arrangement through plant roots. The fungus obtains carbohydrates from the host plant’s photosynthate, while the host plant obtains mineral nutrients and water transferred through the fungus to the host plant's root system (for reviews see Allen 1991, O'Dell et al. 1993, and Smith and Read 1997). About 95% of vascular plant species belong to families that are mycorrhizal (Trappe 1977, Trappe 1987), depending on mycorrhizal fungi for nutrient and water uptake. The fungal network vastly extends the plant roots, increasing the surface area and absorption capacity far beyond the roots' own physical limits.

Estimates of dozens of mycorrhizal fungi species on the same host plant are commonly reported (Douhan et al. 2011). Many fungi also can form mycorrhizal associations with a number of plant species in the community (Amaranthus and Perry 1994, Stendell et al.

1999). This creates a below ground network where plant roots can link different fungal species and mycelia, and fungal mycelia can link different plant species and different age cohorts within species (Beiler et al. 2010). This network confers resistance to disturbance when plants that host a diverse fungal community, such as old trees, survive and continue to host the fungi, which in turn, are there to support new plant seedlings. (Beiler et al. 2010).

Three basic types of mycorrhizal fungi are recognized: ericoid mycorrhizal, ectomycorrhizal, and arbuscular mycorrhizal (Nilsson et al. 2005). Ericoid mycorrhizal fungi are strongly associated with shrubs of the heath family at high latitudes or high elevations while ectomycorrhizal fungi are most commonly associated with the trees of boreal and temperate coniferous forests (Nilsson et al. 2005). Arbuscular mycorrhizal fungi are best represented in temperate deciduous forests, grasslands, agricultural ecosystems, and tropical forests (Nilsson et al. 2005). Ericoid mycorrhizal and ectomycorrhizal fungi are similar in their association with plant communities with low tree productivity and decay-resistant litter, and soils with low availability of nutrients (especially N and P) and low pHs (Nilsson et al. 2005, Toljander et al. 2006). Arbuscular mycorrhizal fungi are associated with plant communities with readily degradable litter and nutrient-rich soils with high pHs (Nilsson et al. 2005, Toljander et al. 2006).

In the Pacific Northwest most tree species associate with ectomycorrhizal fungi, these include members of the Pinaceae like *Pseudotsuga*, *Tsuga*, and *Abies* species, along with members of the Fagacaea like *Quercus* and *Lithocarpus* or members of the Betulaceae like *Betula* and *Alnus*. Consequently, there are 144 listed species which form ectomycorrhizal associations. Little is definitively known about the species of trees many of these fungi associate with beyond the types of forest stands in which they occur; see the Sensitive Species Habitat Summary document (Appendix VI), the individual species fact sheets, or Appendix II for details on each species. Some species have relatively restricted habitat ranges, and therefore it is easier to deduce which trees they associate with, while others are found in a number of different habitat types and therefore may be somewhat generalist in their host associations.

Many herbs associate with arbuscular mycorrhizal fungi as do trees such as *Acer* species or members of the Cupressaceae like cedars and redwoods. There is one listed species that forms AM associations (*Glomus radiatum*) which is presumed to be symbiotic with *Chaemaecyparis* and *Sequoia*.

Shrubs in the Ericaceae can associate with ericoid mycorrhizal fungi, and the conversion of a fungal community to Ericoid mycorrhizal may be one factor in the formation of ericaceous shrub lands following wild fire or logging that prevent reestablishment of conifer forests (Malik 2003). However, some Ericaceae shrubs and trees, such as *Arctostaphylus* spp. or *Arbutus* sp. also associate with ectomycorrhizal fungi and can help some ectomycorrhizal fungi species persist on a landscape after the loss of the forest canopy so they can quickly recolonize new ectomycorrhizal tree seedlings (Amaranthus and Perry 1994, Stendell et al. 1999). None of the listed fungi species form ericoid mycorrhizal associations.

Beyond the morphology of the mycorrhizal association, and the plant host range, these fungi can differ in how the mycelium exploits the soil to gain water or nutrients. At least some species have been observed to associate with particular types of forest debris (Smith et al. 2000). Additionally, the morphology of the mycelium as it extends away from the root tips can vary in characteristic ways. Some researchers have described several "exploration types", which may represent distinct foraging strategies, and have classified ectomycorrhizal species into groups (Agerer 2001). Exploration types include groups like "long distance" or "short distance" that differentiate on how far the mycelium spreads out from the roots and "medium distance mat" and "medium distance fringe" that distinguish based on how the mycelia branch and proliferate. An online fungal traits database had species specific information on only 5 listed ectomycorrhizal species, but since closely related species tend to have the same exploration types, it is possible to deduce the probable exploration type for another 102 species (www.deemy.de). Three listed species have a "contact" exploration type where the mycorrhizal mantle is in close contact with the surrounding substrate. Six species have the "short distance" exploration type consisting of emanating hyphae but no rhizomes. There are 16 species with "medium distance fringe" type consisting of simple rhizomorphs with emanating hyphae that make extensive contact with the soil and 40 species with "medium distance mat" exploration type with simple rhizomorphs connecting areas where emanating hyphae form a mat. Seven species have the "medium distance smooth" type consisting of simple rhizomorphs with few emanating hyphae. Thirty species have the "long distance" type with differentiated rhizomorphs that extend through the soil. Four species have either "contact", "short", or "medium distance" types. One last species could have either "contact" exploration type or the "pick a back" type where the fungus can also grow within the rhizomorphs or mantles of other ectomycorrhizae. This pick a back growth form suggests that the ectomycorrhizal fungal community may be more complex that the one to one mutualist model implies.

Parasitic fungi

Parasitic fungi depend on a living host; some may kill their host, while others do not. Some continue to live as saprophytes after the host has died. Relatively few fungi are parasitic, but included among them are several serious fungal pests (Arora 1986). Parasites play an important role in forest ecology by culling weaker trees, creating gaps as the trees fall, softening heartwood cavities and creating wildlife habitat, thus adding to a more diverse forest. Parasitic species are generally relatively host specific so conserving an at-risk species means managing for their host species as well. Four listed species are obligatory parasites on other fungi (mostly on species in the family Russulaceae), and are unable to survive without the living host tissue (Alexopoulos et al. 1996). One additional species may be either parasitic on live mosses, or saprobic on dead mosses and one wood decomposing species appears to colonize live trees so may be somewhat parasitic.

Habitat Associations and Range

An association of a fungus with a particular habitat may depend on the presence of a particular substrate or host species, the presence of appropriate microclimatic conditions, or be the result of competition or other interactions with species beyond the mycorrhizal or parasitic host. The range of the species depends on the extent of favorable habitat types or microclimates across the region. Information on the habitat associations and ranges of the listed species can be found in species fact sheets, Appendix II, or Appendix VI.

Abundance and Population Trends

Range and Abundance

This conservation assessment focuses on two lists of fungi, all of which are known to occur within all or a portion of the Northwest Forest Plan area of Oregon, Washington, and California. Some species also occur in other areas of North America outside of the Northwest Forest Plan area or elsewhere around the world. The Sensitive species list focuses on species that are known to be rare in the northwest. The Survey and Manage list focuses on species thought to be dependent on old growth forest and at risk from timber harvest and other disturbance. The sensitive species tend to have fewer known occurrences and a more restricted range, while some of the Survey and Manage species are more common and widespread. The Survey and Manage list has not been reviewed since 2003, a review of more recent location data is likely to find that Survey and Manage status is not warranted for a number of fungi. Additionally, some of the Survey and Manage species that are relatively nondescript are under collected and may be more common than the records indicate (Norvell and Exeter 2004). The Sensitive and Survey and Manage lists may be occasionally updated to reflect new information about the range and abundance of each species. The range and general occurrence information for each species is summarized in Appendix II and in Species Fact Sheets.

Fungal Sampling

Surveys for species presence are often difficult, because fungi can be seen only when fruiting bodies are produced. Visual surveys focused on sporocarps are easy to implement over a large area with trained personnel, but results can vary depending on a number of environmental and biological factors. Above ground fungi are easier to find than fungi that fruit underground. While hypogeous fungi may be discovered with a visual survey of a larger area, intensive sampling of the duff and surface soil in smaller plots targeted in likely microsites or around holes that may have been dug by fungivorus mammals is often more effective at discovering species in an area (Castellano et al. 2004).

Even with above ground fruiting bodies present, their correlation with the extent and abundance of the fungal organisms underground is poorly understood (Straatsma and Krisai-Greilhuber 2003). Studies that delineated individual mycelial genets and counted the number of sporocarps produced have found a wide range in the number of sporocarps

per genet and found that across species, sporocarp production was not related to genet size or relative abundance (Dahlberg and Stenlid 1995, Bonello et al. 1998, Douhan et al. 2011).

Patterns of fruiting body occurrence and abundance can be influenced by several variables that are difficult to separate: (a) environmental conditions; (b) type, amount and distribution of substrate; and (c) ecological succession (Straatsma and Krisai-Greilhuber 2003). Work by Luoma (1991) and Smith et al. (2002) documented that proportions of species differ annually, as does species composition. O'Dell et al. (1996) suggest that in order to maximize detection with sporocarp surveys, monthly surveys in spring and autumn over a minimum 5-year period are necessary, but in a later work (Odell et al. 2004) suggested 10 years would be preferable and cited a study where new species were encountered in the same area each year of a 21 year study.

Methods have also been developed to visually distinguish species based on the ectomycorrhizal root tip morphology (Agerer 1991). Unfortunately, the species resolution is poor. However, genetic sequencing methods have been developed that can much more reliably identify the species of ectomycorrhizal samples (Cline et al. 2005, Kranabetter et al. 2013).

There are a number of methods that are used to sample genetic sequences within fungal tissue (Classen et al. 2018). Sequencing often focuses on particular parts of the genome that can be replicated with different Polymerase Chain Reaction (PCR) primers that bind to a particular series of base pairs and begin the PCR replication process. In fungi, the Internally Transcribed Spacer (ITS) region of the RNA strand that is in the fungal ribosome is most often targeted because it has enough diversity to reliably separate most fungal species (Schoch et al. 2012). However, primer sets that target other regions of the genome can also be used (Gordon and Apple 2011). Older studies often have used the Restriction Fragment Length Polymorphism (RFLP) method where replicated sequences of the ITS region are cut with restriction enzymes. These enzymes cut at a specific base pair sequence, which ends up creating different sized genetic fragments for each species. These fragments can be separated through gel electrophoresis (Cline et al. 2005). More recently, it has become easy enough to determine the entire base pair sequence in the genome region for each species, which can be compared to other known sequences and identified in the Basic Local Alignment Search Tool (BLAST) process (Kranabetter et al. 2013).

Using these methods on soil, duff, or wood samples makes it possible to identify all of the species in the samples. However, it generates an incredibly large data set that needs to undergo error checking and quality control processes. Researchers often use the term Operational Taxonomic Unit (OTU) in these sorts of studies because they often can only match a subset of the sequences to a known species (Taylor et al. 2014). It may be possible to identify the OTU at a higher taxonomic level (like the Genus or Family), which could alert a manager to the possibility of one of the listed species being present. Additionally, more fungi genomic sequences are continually added to the databases so it is likely that the proportion of species that can be identified will increase over time.

Sequencing sporocarps of the target species can also guarantee that the species can be identified in the BLAST process.

A molecular sampling method that focuses on reliably detecting a particular species in a sample of soil, wood, or fungal tissue can be more straightforward than whole community sequencing. One strategy involves developing PCR primer sets that amplify specific genetic sequences and then using gel electrophoresis to separate the fragments into bands of different sizes on the gel plate (a marker). Once the marker is identified, it is relatively inexpensive to identify the species in a sample, making it a somewhat efficient way to delineate populations and locate new locations of a target species, even when there are no sporocarps present (Gordon 2008, Gordon and Apple 2011, Gordon and Van Noman 2014).

When molecular methodology is compared with sporocarp sampling, each method is shown to have particular strengths and weaknesses. The use of species-specific markers allows detection of locations of a target species even in the absence of sporocarps, but visual surveys can cover a much greater area (Gordon 2008, Gordon and Van Noman 2014). Studies that compiled species lists for an area with both sporocarp surveys and molecular sampling generally find a large number of species that are only discovered by one methodology (Varenius et al. 2016, Kranabetter et al. 2013). It is likely that the sporocarp sampling misses species that were not producing a visible sporocarp during the sample event. The few studies on the subject suggest molecular methods may also be somewhat dependent on seasonal and annual cycles of mycelial growth (Izzo et al. 2005, Koide et al. 2007). However the bigger negative when compared with sporocarp surveys may be the limited proportion of the landscape that can be sampled and the resulting blindness to species that do not happen to occur in the discrete soil, litter, or wood samples (Bruns et al. 2002b, Izzo et al. 2005, Anderson et al. 2014). Additionally, only species that have been sequenced can be identified. The management objectives of the survey need to be considered before sampling protocols are developed. PCR based methods may be most effective when specific areas or habitat components can be targeted, but repeated sporocarp surveys may be the best way to survey extensive areas for a large number of species.

Population Trends

Due to the difficulty of sampling and the many unknowns about the structure and function of fungal communities, very little is known about population trends for many species, especially rare species with only a handful of known sites. This lack of knowledge could be addressed with projects that resample known sites. Including both robust sporocarp sampling methods (several surveys per year over at least 5 years) and appropriate molecular sampling methods in the relocation efforts would allow direct comparisons between the methods that could be useful in optimizing survey protocols. Resampling that focuses on sites within historic project areas can provide information on how the species respond to impacts and mitigation efforts. Resampling of undisturbed sites may provide information on species persistence and general trends. All these efforts need to be pursued to develop rigorous information on the population trends of these species.

Conservation

Threats to Species

Threats and impacts to fungi may occur at multiple scales including at the regional or global scale, at the landscape scale, and at the local habitat scale.

Larger scale effects that impact species globally or across regions include global climate change and air pollution. If climate change alters temperature and moisture patterns or fire severity, it clearly could have a major effect on fungal communities (Fernandez et al. 2017, Hopkins et al. 2018). However, climate change vulnerability assessments generally require more information about habitat requirements of individual species than is generally available for fungi. Air pollution in the Pacific Northwest is mostly minimal. Heavy metal pollution is limited to a few regions near point sources like mines or other industrial sites. Nitrogen pollution is a problem across more areas in the northwest, generally near concentrations of non-point sources like vehicle exhaust in urban areas or dust from farmland (Geiser and Neitlich 2007). Nitrogen addition has been shown to influence fungal communities, particularly for ectomycorrhizae (Lilleskov et al. 2001, Berch, et al. 2006). Areas with naturally different levels of nitrogen can have very different fungal communities, which suggests that changes in atmospheric deposition of nitrogen could have significant long-term effects on the fungal community (Trudell and Edmonds 2004). It is important to understand these large-scale threats, but the management recommendations addressed in this document are not adequate to effectively mitigate these threats, which should be addressed at other levels.

Landscape scale threats could be related to global threats such as if climate change results in a greater proportion of the landscape experiencing a severe fire, or they could be an emergent effect related to a number of local effects across the landscape. District or forest wide planning can be used to mitigate this effect such as developing a fuels management strategy to limit the extent of high severity burns. Planning should also take into account the cumulative effect on each species with respect to gene flow and dispersal type. It has been found that animal dispersed hypogeous fungi tend to have high spore loads in a local area, but genetically distinct populations can be separated by as little as five to ten kilometers, while wind dispersed epigeous fungi can be a part of a relatively homogenous population spreading up to 100 km (Douhan et al. 2011). Invasion of exotic plant species across the landscape can also influence fungal communities, so management to prevent the spread of weeds may also preserve fungi habitat (Wolfe et al. 2008, Shannon et al. 2014).

This document focuses on project level impacts that affect fungi at a local habitat scale. Local impacts or threats can be grouped into three basic types. Management actions can destroy the fungal organism, destroy or remove the substrate or host that the fungus grows on, or can alter the microclimate and habitat conditions beyond what the species can tolerate. Management actions that may threaten fungal populations include: 1.) a variety of timber harvest strategies, 2.) natural and prescribed fire, 3.) construction of

roads, trails, facilities, and energy distribution infrastructure, 4.) some silvicultural practices including fertilizer application, use of pesticides, and mulching, 5.) recreational activities, and 5.) the harvest of special forest products, particularly mushrooms.

Timber Harvest

Timber harvest can remove mycorrhizal host plants and substrate for saprobic fungi. The removal of forest also can create a microclimate that is unfavorable to the fungi. Harvest activities may also kill or destroy the fungal organism. Clear-cutting is the type of timber harvest that results in the largest change in the vegetation and microclimate of the site and there is an large amount of research that demonstrates it can reduce the richness and abundance of the fungal community (Bradbury et al. 1998, Kranabetter and Wylie 1998, Durrall et al. 1999, Hagerman et al. 1999, Byrd et al. 2000, Durrall et al. 2006, Fischer et al. 2012, Juutilainen et al. 2014). Other studies have not found any differences in species richness between clear-cut stands and undisturbed forest, but they found large changes in the fungal community composition (Mah et al. 2001, Jones et al. 2003, Barker et al. 2013, Varenius et al. 2016). Both results suggest that clear-cutting poses a major threat to the persistence of the listed species at their known sites.

Thinning forests has a smaller effect on the plant community and the microclimate at the site and would be expected to have a smaller effect on the fungal community. Some studies of light thinning treatments (leaving between 70% to 50% of original canopy) have failed to find an effect of thinning on fungal species richness (Waters et al. 1994, Kranabetter and Kroeger 2001, Norvell and Exeter 2004), but others have found a negative effect (Linblad 1998, Colgan et al. 1999, Edman et al. 2004, Meyer et al. 2005, Hart et al. 2018, Lohmus 2011, Kebli et al. 2012).

Fire Effects

Fire affects fungi in a variety of ways and management decisions must weigh a number of conflicting processes and account for tradeoffs of each decision. Wildfire can cause large and long-lasting changes in fungal communities including killing fungi and reducing diversity or ectomycorrhizal colonization rates (Visser 1995, Bradbury et al. 1998, Bruns et al. 2002a, Treseder et al. 2004, Kipfer et al. 2011, Barker et al. 2013). The effects of some wildfires can be minimal, and it will often depend on fire severity (Dahlberg 2002, Cairney and Bastias 2007, Rincon and Pueyo 2010). However, even if the impact of a wildfire is minimal overall, it could have a larger effect on some rare species (Glassman et al. 2016).

Preventing wildfire often involves using prescribed burning to manage fuels, which can itself threaten fungi. A review of fire effects on fungi found a consistent negative effect of prescribed fire on above ground sporocarp production (Taudierre et al. 2016). This observation seems to be a relatively short-term reduction in sporocarps (Meyer et al. 2005) or mycelia in surface soil layers (Smith et al. 2005), but often there is survival in deeper soil (Stendell et al. 1999) and over time the sites can recover (Hart et al. 2018). This is especially true for low severity prescribed fires; high intensity prescribed fires can have large effects on the fungal community (Penttila and Kotrianta 1997).

Practices that reduce fire severity during prescribed burning can limit the negative effects on the fungal communities. Fall burns are often more severe than spring burns and can lead to negative effects on the fungal community that are not found after spring burns (Smith et al. 2004, Trappe et al. 2009b). Higher fuel loading can also increase fire severity, which can lead to a greater impact on the fungal community (Dahlbeg et al. 2001, Cowan et al 2016). The nature of the forest may also influence the impact of the fire. Stands dominated by tree species that are easily killed by fire (ex. *Thuja* or *Picea sitchensis*) may harbor fungi that are more sensitive to fire while stands dominated by fire adapted tree species (ex. *Pinus ponderosa)* are more likely to harbor fungal species with adaptations that allow it to persist in burned landscapes.

Fire suppression can also be a threat to fungi. Ammonium and Phosphate fertilizers are an ingredient in many wildland fire retardant mixtures and ectomycorrhizal fungi are known to be sensitive to fertilizer application (Berch et al. 2006, Lilleskov et al. 2001). The soil compaction and removal of the forest floor during fire line creation may also impact fungal communities (Hartmann et al. 2012, Hartmann et al. 2014, Wilhelm et al. 2017).

Construction Effects

There are limited studies addressing the effects of construction on fungal communities, but it is likely that road building and facility construction would involve severe compactions similar to what has been shown to reduce abundance of many fungal groups during timber harvest (Hartmann et al. 2014). Roads and facility construction would also be likely to destroy any fungi and the habitat it needs if the plant community is replaced with constructed infrastructure. Trail construction would likely pose a similar risk to fungi, but with less extreme compaction and a smaller footprint. Construction of energy infrastructure like pipelines and electrical transmission corridors can also threaten fungi. Digging a trench to lay a pipeline would clearly destroy any mycelia that was disturbed. Power line corridors need to stay open so in forested areas they typically involve a drastic change in the vegetation community. If the resulting community is dominated by herbs and other non-ectomycorrhizal species, it can result in a large change in the fungal community (Hopkins et al. 2018).

Revegetation Practices Effects

Mycorrhizal fungi provide trees with better access to soil nutrients, so in sites with supplemental mineral nutrients there often is a reduction ectomycorrhizal richness (Berch et al. 2006, Lilleskov et al. 2001). However, it may be possible for fungal communities to recover several years after the nutrient addition (Wright et al 2009).

Herbicides can kill plants, which would have an indirect effect on fungi that depend on the plants, but often the direct effects are minimal (Chakravarty and Chatarpaul 1990, Busse et al. 2003, Ratcliff et al. 2006). In some lab studies, there were effects on fungi in culture, but not in soils (Chakravarty and Sidhu 1987, Estok et al. 1989, Busse et al. 2001). Trappe et al. (1984) did an extensive review of the effects of a variety of

herbicides, fungicides, and pesticides on mycorrhizal fungi and found a range of effects depending on the product.

Logging typically creates abundant slash that can be left in place or managed in some way, typically by burning or mastication. Leaving slash in place will increase the amount of woody debris and organic matter on a site, which may provide substrate for some species. However, in one study in a Norway spruce forest, removing slash increased the number of ectomycorrhizal root tips and soil mycelial growth (Majdi et al 2008). Since the layer of slash will help conserve soil moisture, the effects in northern Europe may differ from northwest forests with limited precipitation over the growing season. Pile burning can drastically effect the soil community (Jimenez-Esquilin et al. 2007, Cowan et al. 2016), but the impacts tend to be patchy and limited in extent. Mastication and mulching have been shown in a study from Alberta, Canada to hasten the decline of aspen roots and their mycorrhizal associates in harvest units, which would limit their ability to recolonize seedlings, but that short-term study was again in a northern forest with a different moisture regime than many parts of our region (Visser et al. 1998).

Recreation

In addition to construction effects, recreation sites can include compaction from pedestrians and off road vehicles. One study that looked at historic recreation sites in Crater Lake National Park noted that there were no sporocarp collections at the most disturbed parts of the campgrounds. However, the sampling was at a broad scale and included relatively undisturbed areas within the campgrounds that resulted in the study not finding differences in the sporocarp community (Trappe et al. 2009a). A study from Switzerland that compared edible mushroom production in areas that were harvested normally and areas harvested from a system of catwalks (to avoid trampling the soil) over 29 years documented a reduction in biomass production, but not species richness (Egli et al. 2006). These studies suggest that human traffic can negatively impact fungal communities.

Special Forest Products

The harvest of any type of special forest products can influence the forest community and thus the fungi, but mushroom harvest is the most likely to have a direct effect on the listed species. *Chantaellus subalbidus* is the most commonly sought after edible mushroom among the listed species, but *Sprassis crispa*, is also a prized edible and the two species of *Tuber* may be targeted along with the more common Oregon white truffle (*Tuber oregonense*).

Long-term studies in both Oregon and Switzerland have found the actual harvest of the fungal sporocarp does not tend to reduce future sporocarp production (Pilz and Molina 2001, Egli et al. 2006), but the Swiss study found that the associated trampling did reduce abundance. Some mushroom foragers will rake up the litter and soil to get at hypogeous truffles or immature Matsutakes (*Tricholoma murillanum*). The raking is a much bigger disturbance than simply picking the sporocarp. Raking is assumed to damage truffle production (Pilz and Molina 2001) and has been shown to reduce Matsutake yield

(Luoma et al. 2006). It is likely raking would also be detrimental to other listed fungi that are not targeted by foragers but happen to be in a harvest area.

Results from Research on Management Practice

Ideally, managers would like to base their decisions on the results of multiple controlled experiments, on each management action, in each relevant plant community. However, this sort of research on the listed fungi is limited due to the difficulty of doing ecosystem scale controlled experimentation, the difficulty in accurately monitoring fungal populations, and the low likelihood of including rare or uncommon species in these studies. Despite this, there are studies that do provide information that is useful for some species. Additional studies address fungal communities in general or include species closely related to the listed species. Often fungal community studies document the effect of treatments on species richness. It is likely that actions that conserve richness overall would conserve the listed species, but each species has unique habitat requirements and may respond to treatments differently from other species. Closely related species often will have similar habitat requirements and responses to treatments, but even at the genus level there may be habitat partitioning between species (Taylor et al. 2014), and there may be differences between different clades of species within a genus (Wilhelm et al. 2017).

There are a number of ecosystem scale experiments and studies that have looked at fungal communities in the greater northwest region, or similar forests elsewhere. The fungal sampling method delimits what information can be gleaned from the results. Sporocarp surveys have the inherent limitations listed above. Additionally, due to how microclimatic changes from things like fires and timber harvest could influence sporocarp formation, and how surviving mycelia may respond to the loss of host trees (Waters et al. 1994, Colgan et al. 1999), sporocarp productivity may not track changes in below ground communities (Kranabetter et al. 2013). Below ground sampling can include bioassay seedlings to test the mycorrhizal community that can colonize new plants. A few studies sampled all fungi in soil cores, which can be a very powerful tool to determine the species composition of an area, but one that will document microfungi and other species groups that are not represented among listed species. For these studies, it is important to look at which species and taxonomic groups increase and decease rather than simply the richness values.

Species Specific Results

There are a number of sporocarp based studies that have included sites of listed species or their congeners that provide information on how the species may respond to different management actions. Additionally a few studies have done whole community sampling of the mycelial genomes and identified some listed species based on genomic sequence matching. Some of these studies have also summarized results by higher taxonomic levels in supplementary data so for listed species that were not present, it is possible to see how other members of the genus or family responded. Results from each study are reported for each listed species in table form in Appendix IV.

Ecosystem Scale Experiments

Despite the difficulty of implementing forest mycology experiments at the stand scale, there have been a number of forestry experiments that have included fungal communities as a response. The results need to be interpreted in the context of the characteristics of the ecosystem and plant community of the site, the fungal sampling methodology, and the amount of time the fungal community developed after the experimental treatment was applied. See Appendix V for a short description of each study and a synopsis of the results.

Management Considerations

Management Considerations are actions or mitigations that a deciding official can use as a means of providing for the continued persistence of the species' site. These management considerations may be appropriate to use to protect specific known sites. Additionally, including these actions or mitigations can preserve the fungal community in general, which may include listed fungus sites that have not been discovered due to the difficulty of fungal surveys. These considerations are not required and are intended as general information that field level personnel can use and apply to site-specific situations.

Identifying an Area to Manage

Delimiting the Occupied Patch

Occupied fungal locations are generally first documented by the presence of one or more fruiting bodies. Beneath these structures lies a complex system of mycelia, associated with living plant parts, wood, or the soil, which constitute fungal individuals. Molecular methods can be used to delimit the size of fungal individuals or populations, but if the mycelium is patchy, it may take a large number of samples. If the only information is sporocarp locations, it may be possible to predict the size of the fungal individual based on other species with a similar life history. Fungi that rot woody stems often are limited to 3 to 14 m segments of logs (Hansen and Hamelin 1999). Root rot fungi can disperse between trees and can extend beyond 800 m and litter decomposers that occupy a continuous habitat may extend up to 150 m (Hansen and Hamelin 1999). Mycorrhizae species have different exploration types and growth forms with some species occupying an area less than one m across to individuals that extend over 40 m (Dahlberg and Stenlid

1995, Dahlberg 1997, Bonello et al. 1998, Redecker et al. 2001, Bergeman and Miller 2002, Douhan, et al. 2011).

Gene Flow between Patches

The objective of managing a fungal site is typically to maintain habitat conditions so that species viability will be maintained at an appropriate scale, in accordance with agency policies. Fungal sites are made up of single or clustered genets forming a patch that interacts with other patches of genets elsewhere on the landscape. Patches can persist through long-lived genets that can expand and move over time, or through recruitment and turnover of short-lived genets. Sites should be managed as a part of a population that has internal gene flow. Species with only short distance spore dispersal like truffles may exhibit significant genetic diversity within an area less than ten km across, indicating a limit of significant gene flow (Douhan 2011). For these species, it may be important to maintain habitat connectivity for small mammal dispersal agents to ensure gene flow between sites. Above ground sporocarps with airborne spores may have gene flow over distances up to 100 km (Douhan 2011), so it may be possible to maintain genetic diversity between sites with less habitat connectivity. Ideally, research tailored to each of the Sensitive and Survey and Manage species would be used to describe management areas appropriate to the average organism size and habitat needs of that species.

Contribution to Species' Persistence across the Landscape

The value of each site in terms of promoting the persistence of the species across the landscape depends on several factors. Local sites exist within a regional population with some sites representing the edge of the species range, and other cites more central. Sites may be generally protected from management threats due to their co-occurrence with other protected or old growth dependent plant or wildlife species, or the scenic, wilderness, or other resource values of the area. Sites with specific microclimate, landscape position, or stand structure may differ in terms of resistance or resilience to climate change or natural disturbances like wildfire and flooding. Some sites may be larger, healthier, or more productive and therefore more likely to contribute to the species' persistence.

General Management Considerations

An extension document of fungal conservation strategies from British Columbia (Wiensczyk et al. 2002) emphasize some approaches which may help to maintain a diverse community of fungi (in this case ectomycorrhizal) across a landscape. These strategies suggest retaining refuge plants, mature trees, and forest floor integrity during timber harvest and mechanical site preparation; avoidance of high-intensity broadcast burns; minimizing the effects of host species shifts; and managing for coarse woody debris. Incorporating species sites into harvest patch retention areas (as described in the Northwest Forest Plan Standards and Guidelines 1994, C-41) may assist in providing for some of these key habitat elements.

Specific Management Considerations

Protection Buffers / Harvest Patch retention areas

One of the simplest ways to mitigate the threat of timber harvest on listed fungi is to avoid known sites. Protection buffers can both prevent damage to the fungal organism or substrate, and prevent changes to the microclimate that may be detrimental to the fungus. To prevent damage to the fungi or its substrate, it is important to understand the extent of the fungal individual or population either by mapping its extent with molecular sampling of the mycelium, or estimating the extent based on sporocaps and an understanding of how biology and substrate of the organism relates to the size of the fungal individual. Reported estimates of fungal individual extents range from 0.7 m to 150 m for litter decay fungi, between 3 and 14 m along a tree bole for stem decay fungi, between 30 and 884 m for root decay fungi, and 30 m for an ectomycorrhizal species (Hansen and Hamelin 1999).

The biology and habitat of each fungi will also influence how dependent a species is on a stable microclimate. For a species that is very sensitive to temperature fluctuations or desiccation, larger buffers may be required. Sampling at three Washington iterations of the DEMO study reported that 6 or 7 years after harvest, within a retention patch, the level of light decreases with distance from the edge of a clear-cut until it reaches a level similar to undisturbed, 70 to 170 year old forest at around 15 m. However, soil temperature effects extend 20 to 30 m into the forest while air temperature effects were measured up to 60 m in to the forest (Heithecker and Halpern 2007, Aubrey, at al. 2009). A separate study found the impacts of a clear-cut on air temperature and relative humidity extend into stands of old growth Douglas fir forest as far as 240 m and soil temperature up to 60 m (Chen, et al. 1995). These edge effect distances may be shorter if the retention patch is within a thinned unit.

Determining the optimum retention patch size depends on the fungal species, the type of timber harvest prescription in the surrounding unit, and the local climate. In general, larger patches of forest often retain more diversity (Berglund and Jonsson 2003, Rosenvald and Lohmus 2008). Some researchers have estimated the minimum effective patch size for maintaining species richness as 0.5 ha (Kranabetter et al. 2013), while others have modeled a continuous increase in species richness with patch size up to 3.6 ha (Ylisirniö et al. 2016).

Green Tree Retention

Green tree retention is a catch-all term describing timber harvest prescriptions that are less intensive than clear-cutting. It can involve dispersed retention, which would be a form of thinning, or aggregated retention, which involves leaving small or large groups of trees. A 2016 meta-analysis found strong positive effects of green tree retention on fungal richness and abundance and described three general ways green tree retention can help conserve biodiversity: lifeboating, structural enrichment, and landscape connectivity (Rosenvald and Lohmus 2008).

Lifeboating

Lifeboating provides continuity of habitat on a site and can be important to poor dispersers or rare species. A number of studies have shown that seedlings that are planted within about 10 m of leave trees have more abundant and diverse ectomycorrhizal communities than seedlings planted further from any surviving trees (Borchers and Perry 1990, Durall et al. 1999, Kranabetter and Wylie 1998, Kranabetter 1999, Outerbridge and Trofymow 2004, Cline et al. 2005). In some forests, shrubs and non-timber trees may also be hosts for the same ectomycorrhizal species and therefore provide some of the lifeboating effects (Visser 1995, Colinas, et al. 1994). However, not all mycorrhizal species can colonize the shrubs and non-harvested tree species that may remain after timber harvest (Colinas et al. 1994, Massicotte et al. 1994). Ultimately, the possibility of lifeboating on shrubs and leave trees at a fungi site will be contingent on the host or substrate range of the fungi, and the assemblage of plant species in the forest.

Structural Enrichment

Trees left behind after a timber harvest increase forest structure both due to the living trees having a different size and shape from new seedlings, and by creating woody debris as they die or loose branches. Structural enrichment in the form of more woody debris or organic matter can benefit mycorrhizal species (Harvey et al 1976, Harvey et al. 1981, Amaranthus et al. 1996, Elliott et al. 2007), but structural enrichment is more often considered a way to provide substrate to saprobes. Structural enrichment can provide habitat for both saprobes that colonize fresh wood soon after a disturbance, and species that utilize older wood in more stable forest stands. A study that looked at the addition of dead wood to a forest via girdling or cutting and leaving trees increased the diversity of polypores, but after 5 years the wood was just beginning to decompose, so species that require well decayed woody debris were not increased (Pasanen et al. 2014). Silvicultural practices that maintain more woody debris on site can increase the subsequent fungal richness in the resulting stands, particularly for the species that exploit fresh wood (Runnel et al. 2013, Toivanen et al. 2012). The quality and variety of woody debris in terms of size and decay stage is important to preserving fungal richness (Abrego and Salcedo 2013). Studies have shown that the fungal diversity is often higher in more decayed woody debris (Fischer et al. 2012), and that larger wood may harbor more fungal species than smaller pieces (Kebli et al. 2012, Juutilainen et al. 2014). The overall habitat the structural enrichment occurs in is also important as the microclimate influenced by the level of canopy cover or distance from an edge may influence the fungal communities (Siitonen et al. 2005). Additionally, the species richness on fresh substrate can be higher in un-managed forest with abundant, diverse substrates (and the fungi that utilize each substrate) than on fresh wood in managed forests with reduced levels of coarse woody debris overall (Lindblad 1998, Lohmus 2011). Likewise, structural enrichment has been shown to be more effective at conserving fungal diversity in sites with existing populations than in more species poor areas (Edman et al. 2004), highlighting the importance of protecting known sites in addition to using conservation forestry practices across the broader landscape.

Landscape Connectivity

Individual trees and patches of forest left within a harvest unit can create connections between unharvested forest areas and other retention patches that allow species to disperse across the landscape. Landscape connectivity can be important for long-term, migration patterns or species with extinction – immigration population dynamics. Spore fall tends to depend on the local fungal community with forest species declining with distance from a forest and wood rotting fungi localized around the colonized piece of wood (Peay and Bruns 2014). A species of *Russula* has been found to have many, small, genets in an old growth forest, suggesting it forms short-lived genets and requires frequent recolonization from spores (Redecker et al. 2001). Similar short-lived species may depend on a network of occupied habitat to maintain their population. Landscape connectivity may also be important for species like truffles that depend on forest animals to disperse their spores, or saprobes that disperse vegetatively.

Reducing Soil Compaction

Soil compaction can alter fungal communities and often reduces the abundance of basidiomycete ectomycorrhizal species (Hartmann et al 2012, Hartmann et al 2014). Designating skid roads and planning felling activities can reduce extent and number of passes that heavy machinery make. Limbing and cutting logs to length for transport at the stump creates a bed of slash that harvest machinery can drive over, spreading the weight out over a larger area and helping to prevent ruts. This has been found to result in significantly less compaction impact than dragging whole trees to a landing and processing the slash there (Han et al. 2009). Different machinery will also have different effects on compaction. Forwarders, machines that carry harvested material to the landing in bins, prevent the soil damage associated with dragging logs across the ground in skidding operations (Bustos and Egan 2011). Additionally, some types of machines or wheel configurations can result in less compaction than other types (McDonald 1997, Bustos and Egan 2011).

Preserve Old Trees and Wood as Well as Remnant Old Growth Stands

Preserving old trees and woody debris along with intact stands of old growth forest is very important for fungal conservation. A number of studies have demonstrated that forest stands increase in diversity with time. Ectomycorrhizal succession often does not involve late seral species replacing early seral species, but rather an accumulation of new species and retention of the early seral species (Bradbury et al. 1998, Kranabetter et al. 2005). Likewise, studies that have looked at sporocarps and genomic analysis of wood cores have found there is often more richness of wood rotting fungi in more decayed logs than fresh logs (Elliott et al. 2007, Fischer et al. 2012, Kebli et al. 2012). Larger woody debris will often harbor more species as well (Juutilainen et al. 2014). Preserving the oldest trees and large woody debris in all decay classes can be important for maintaining the fungal community. Preserving old growth stands with diverse fungal communities is also important as new substrate is more likely to be colonized by a diverse community when spores or other inoculum are abundant (Edman et al. 2004). Inputs of woody debris are often not sufficient to support many species typical of well-decayed wood without

enough time for the wood to decay to a more suitable substrate (Toivanen et al. 2012, Pasanen et al. 2014). Once diversity is lost, it may be slow or impossible to manage young forest to become new sites for listed species, therefore preserving high quality habitat is very important.

Conserve Adequate Woody Debris and Organic Matter

Down woody material has repeatedly been found to support fungal communities. Down woody material may function to retain moisture, allowing root tips to support active ectomycorrhizae (Harvey et al. 1976, Harvey et al. 1978, Amaranthus et al. 1989, Harmon and Sexton 1995). These fallen tree "reservoirs", large limbs, and stumps can provide refugia for seedlings and mycorrhizal fungi, especially in drier forest communities. As stands mature, the availability of downed wood may be crucial for establishment of fungi as well as plant seedlings (Kropp 1982).

Down woody debris is a direct food source for wood-decaying fungi. Studies in Scandinavia and North America indicate that the presence of large down wood promotes higher diversity of wood-decay fungi species (Kruys, 1999, Crites and Dale 1998, Ohlson et al. 1997, Høiland and Bendiksen 1996, Bader et al. 1995, Wästerlund and Ingelög 1981). Høiland and Bendiksen (1996) found that rare wood-inhabiting fungal species occurred primarily on long (average length = 11 meters) and well decayed (average decay Class III) down wood. When surface area is taken into consideration, fine woody debris appears to be equally important to species diversity (Kruys and Jonsson 1999).

Two studies have attempted to quantify the amount of woody debris that is needed to optimize habitat for a diverse fungal community. A study from Montana estimated that maintaining 25-37 tons per ha of woody residue 14 cm in diameter or larger is optimum for ectomycorrhizal fungi (Harvey et al. 1981). A study from Finland estimated that species richness was maximized in stands with more than about 40 m^3 per ha of logs and more than about 8 m^3per ha of snags (Ylisirniö et al. 2016). These estimates were for different regions so what is optimum for the climate and fungal community in Oregon and Washington forests may differ.

Maintain Mycorrhizal Network

Mycorrhizal networks create systems that are resistant to perturbations due to multiple connections to the network via older trees (Beiler et al., 2010). Preserving host plants is key to preserving the mycorrhizal network. Old trees with large root systems that have had a long time to form associations can host a rich community of ectomycorrhizae and create nodes for multiple species to persist on the landscape. Harvest prescriptions that preserve the trees above a certain size can reduce the impact on the ectomycorrhizal community (Meyer et al. 2005). Surveys of the ectomycorrhizae that colonize seedlings have demonstrated that richness and colonization rate are much reduced beyond about 10 m from a forest edge (Durrall, 1999, Outerbridge and Trufymow 2004, Jones et al. 2008, Cline et al. 2005). These results suggest limiting gaps to less than about 10 m radius. In the gaps created by timber harvest, maintaining the understory community can also help maintain the mycorrhizal community as many species of understory shrubs can host some

of the same fungi as the trees (Borchers and Perry 1990, Colinas et al. 1994, Hagerman et al. 2001). Quickly replanting cut over areas can help maintain the network if the new seedlings are in before the roots and mycorrhizae die (Wiensczyk et al.2002). Reducing the extent and severity of soil compaction during harvest can also help maintain the mycorrhizal network.

Avoid Applying Fire Retardant or Building Fire Breaks Through Known Sites

Wildland fire fighting is a complex process requiring quick decision making. Pre-season planning, appropriate training and adequate information can make the avoidance of Sensitive and Survey and Manage fungal sites more likely. Making plans on where to lay out fire lines to avoid sites is something planners can accomplish during the off season so that guidance is available in case a wildfire threatens the area. Training fire managers to be aware of protected fungi sites will prepare them to incorporate avoidance into their suppression strategy. Quickly entering new observation data into agency databases and providing appropriate location data to incident commanders in a clear and easy to understand format will give them the information they need to protect important sites while achieving the suppression objectives.

Build Burn Piles Outside of Known Sites

Severe fire intensity created under burn piles can be lethal to soil fungi (Jiménez Esquilén et al. 2007) and create negative effects on the fungal community (Dahlberg et al. 2001, Reazin et al. 2016). In fuels management projects involving pile burning, piles can be restricted to outside of buffer areas around known sites. If that is not possible, minimizing the spatial density so less of the landscape is affected may reduce the impact. Keeping piles to less than two meters across can also allow for relatively rapid recolonization from the fungal communities surrounding the pile (Cowan et al 2016).

Reduce Prescribed Burn Intensities Through Spring Burning

Soil and fuel moisture levels are often considerably higher during spring than fall and spring burning has been shown to preserve more of the forest floor and have fewer negative effects on fungi (Smith et al. 2004, Trappe et al. 2009b). Other measures that serve to reduce burn severity, such as an appropriate ignition strategy, gathering some fuels from near fungal sites and burning them in piles off site, or postponing the burn until after significant rains, can also help protect fungal communities during fall burns (Waters et al. 1994, Meyer et al 2005, Hart et al. 2018).

Avoid Deep Mulch or Slash Cover

Despite the uncertainty about effects from deep mulch or slash cover in Oregon and Washington forests, mulching treatments may not be appropriate at Sensitive or Survey and Manage sites. At a minimum, mulching treatments should avoid the covering the ground in areas occupied by the mycelium of soil dwelling Sensitive or Survey and Manage fungi.

Discourage Recreational Use around Fungal Sites

To prevent compaction of the soil within fungal sites, recreational activities should be discouraged in the area. Avoid building trails or other facilities through sites to prevent additional compaction threats. If existing recreational infrastructure or assets threaten sites, it may be possible to reroute or build new trails that take users around the site, close parts of campgrounds or picnic areas, or create structures that discourage visitors from accessing the site.

Discourage Raking During Mushroom Harvest / Encourage Litter Replacement

Identifying and encouraging the use of best harvesting practices can reduce the impact of mushroom harvesting on fungal sites. These may include cutting mushrooms off at the base, or gently rocking the mushroom loose to minimize disturbance of the mycelium. Raking of the forest floor is very damaging and should be strongly discouraged. If it cannot be totally eliminated, raking should always be followed by replacement of the forest floor to reduce the impact (Luoma et al. 2006). Dogs can be trained to locate hypogeous fungi by smell and can be an efficient way to locate truffles without raking. Outreach to commercial and personal use mushroom harvesters to explain the importance of using best practices may help limit the threat. Regulations mandating best harvest practices can also be promulgated.

Limit Fungi Collection Permits in Areas Managed for Fungal Persistence

Since mushroom foragers may not always use the best practices for harvesting fungi, and soil trampling by foragers can reduce productivity (Egli et al. 2006), it may be appropriate to limit fungi collection in Sensitive and Survey and Manage fungi sites. This is especially true if the mushroom targeted by the foragers is a truffle or matsutake, which are often harvested by raking.

Other Resources

Additional tools to assist in assessing project impacts and potential mitigation can be found on the interagency (Region 6 Forest Service and Oregon/Washington BLM) Special Status and Sensitive Species website: www.fs.fed.us/r6/sfpnw/issssp/planning-tools/ .

Research, Inventory, and Monitoring Opportunities

General Biology and Ecology

For most of the listed fungi, there are significant knowledge gaps on basic aspects of life history and ecology. Dispersal ability, specific habitat, substrate or host range, genet longevity, and fire adaptations each should be understood for all of the listed species.

Fungi can disperse both vegetatively and through spores. The relative importance of each method will determine how different management actions will affect the long-term survival of the species.

For most species there is some information on what forest types it can be found in. There needs to be more definite information on the ecological amplitude in terms of forest type and range, but also in terms of particular components of the stand, such as if it mostly occurs in organic horizons or mineral soil and whether it is associated with woody debris. Understanding how the species responds to changes in microclimate will help managers decide how large protection buffers should be and whether the species may tolerate things that open up the canopy like thinning or fire.

The main mycorrhizal host or basic substrate type is known or suspected for most species. However, it would be better to know all of the plants that can host the mycorrhizae so it is possible to predict whether the fungi would be able to persist on shrubs or different tree species left after timber harvest. For saprobes, understanding what size and decay class wood or litter that the fungi decomposes is also important.

Some fungi are long-lived and can get very large, while others are short-lived and only occupy relatively small areas (Redecker et al. 2001). Information on the size and longevity of fungal genets can help managers understand the relative importance of protecting known sites and maintaining good habitat that the species can colonize. Knowing which environmental cues trigger sporocarp formation will give more context to location information based on sporocarp observations.

Like other taxonomic groups, fungi can be more or less adapted to wildfire (Taylor and Bruns 1999). Fuels management projects often try to treat the whole landscape so fuel buildups in one area do not cause a lower intensity fire to grow to a severe fire. With knowledge of how sensitive each fungi is to fire, it will be possible to which mitigation practices are most appropriate for each species.

Along with this basic information, there are any number of questions of how each species respond to specific management actions in specific regions or plant communities.

Sampling

Fungi sampling remains a difficult task to do well. Due to various factors that determine fungal fruiting there is always uncertainty in the results of sporophyte surveys. Molecular

sampling can help reduce some of that uncertainty, but it too can be difficult and expensive. For modern molecular sampling to be effective, the first step is for each listed species to have a genomic sequence from a positively identified specimen entered into a database such as Genbank. Researchers who use sequencing to identify fungi typically compare the sequences to genomic databases of sequences of positively identified specimens. If all listed species are sequenced and entered into the genomic databases, any future study that encounters a listed species would be able to identify it. When a species is sequenced, it may also be possible to cross reference sequences that were reported as unidentified in older studies. It would then be possible to go back to those studies and see the results for the species. It may also be beneficial to develop methods to identify the listed species with molecular markers that may be easier to apply to a large number of samples than typical genomic sequencing (Gordon and Van Norman 2014).

In addition to developing methods to sample for each species, it would also be good to develop protocols for sampling the fungal community in general. Comparisons with sporocarp sampling should be made to get a better understanding on the relative costs and benefits of each type of sampling. With this information it may be possible to develop guidelines to determine which sampling methods are most appropriate for different situations.

Inventory

There has been considerable effort in fungal sampling in forests included in the Northwest Forest Plan. Areas outside of the range of the northern spotted owl have had much less fungal inventory work. A number of listed species have historical records both west of the Cascades and in northern Idaho. The Blue Mountain region of northeast Oregon / southeast Washington is generally drier than those regions, but fungal inventories could discover sites of listed species in that region.

Most historic surveys have been sporocarp surveys, so it is impossible to be certain about a negative result. While it is difficult to predict how a season will turn out while planning surveys, in retrospect many surveys may have been an inefficient use of resources due to interannual variation in weather and sporocarp production. Molecular methods have their own limitations, but they do not depend on the production of ephemeral sporocarps and tend to be more consistent. Establishing a systematic inventory of fungi on National Forest Lands using molecular methods to generate full species lists would give managers a much better picture of the true range and abundance of listed and non-listed fungi. Surveys using species-specific molecular markers in targeted habitat could be another way to determine how rare or widespread a species is.

Known Site Revisits

In the decades of pre-disturbance fungi surveys conducted by the Forest Service and Bureau of Land Management, many new sites have been found. Many of those sites were in project areas and various modifications to prescriptions and unit boundaries have been made to protect the known sites. Revisiting those sites to relocate sporocarps, or to identify the species in soil or wood cores with molecular methods will provide invaluable

information on the efficacy of the mitigation actions. It would also be wise to re-sample previous ecosystem scale forestry experiments that had only short-term sampling (such as the DEMO study) to see what the longer term effects were. Using molecular methods to identify the entire fungi community could give another level of information than was collected during the original sampling.

Acknowledgements

This Conservation Assessment built on a number of previous publications of the ISSSSP fungal program, which can be found at can be found on the interagency (Region 6 Forest Service and Oregon/Washington BLM) Special Status and Sensitive Species website: www.fs.fed.us/r6/sfpnw/issssp/planning-tools/. Much of the format and some text is from the previous version of the Conservation Assessment created by Rob Huff and Kathy Cushman in 2007 and updated by Rob Huff, Helen Lau, and Rick Dewey in 2013. The description of basic mycorrhizal types was adapted from the document "Mycorrhizal fungi: Biological/ecological information and effects of selected types of forest management actions", prepared by Rick Dewey in 2012. The document, "Effects of Commercial Thinning and Associated Activities on Habitat and Distribution of Fungi", prepared by Jenny Lippert and edited by Rob Huff in 2014 provided valuable insight as did the document "Effects of Prescribed Fire on Sensitive Fungi Species" prepared by Clint Emerson and edited by Rob Huff in 2014.

Much of the research was initially compiled in the "Annotated Bibliography of Information Potentially Pertaining to Management of Rare Fungi on the Special Status Species list for California, Oregon, and Washington" document and associated spreadsheets first created by Katie Grenier and Jenifer Ferriel in 2013, updated by Katie Grenier in 2016 and 2107, by Sallie Herman in 2018, and Erica Heinlen in 2019.

Caitlin Lawrence helped with some of the literature review for this document.

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