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The Possible Presence of Mycorrhizae in the Chuckanut Marsh Wetland and the Lamentable

Absence of Personality in Scientific Communication

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Abstract

A surge in research about mycorrhizae over the past few decades has revealed mycorrhizal associations to be critical to plant ecosystems. They are present in over 90% of plant species and allow them to share nutrients and information through fungal mycelia. The question of how pervasive mycorrhizae are in different habitats receives ever-changing answers as research continues. In this literature review, I explore what mycorrhizal species are likely to be present in a local ecosystem with diverse plant communities: the Chuckanut marsh estuary. I explain how I cross-referenced a plant species list from a Chuckanut marsh characterization study with plant species list that survey mycorrhizal status. I also reviewed literature about both mycorrhizal presence in wetland habitats and history of the study of mycorrhizae. I argue that Suzanne Simard can be credited with the popularity of the topic of mycorrhizae, through her scientific research but especially through her creative methods of communication to the public.

The Possible Presence of Mycorrhizae in the Chuckanut Marsh Wetland and the Lamentable
Absence of Personality in Scientific Communication

Invisible and everywhere. So you could describe mycorrhizae, the symbiotic association between plant roots and fungal mycelia through which plants share resources. The physical structures of the connections are varied but are always the site of exchange for nutrients, minerals, waters, and signaling compounds. Originally thought to be an occasional symbiotic association, mycorrhizae have now been found in over 90% of all plant species and are present in many different kinds of ecosystems (Bonfante, 2018). The presence of mycorrhizae in even the most unexpected places, like mangrove forests, prompted me to investigate what the mycorrhizal community looked like in the nearby Chuckanut marsh wetland, an area of local ecological interest. This paper summarizes the ensuing journey I took through the ever-growing body of published research about mycorrhizae. Before I discuss the mycorrhizal of my specific habitat, however, I will briefly summarize both the current scientific understanding of mycorrhizae and the history of the study of this topic.

Mycorrhizae are an association between plant roots and fungal mycelia. The mushroom structure which we commonly associate with fungi is only a temporary structure of some fungi. The primary structure of a fungi is a mycelium, which is a complex network of branched hair-like structures, called hyphae, which spread through a medium. The function of the mycelium is to absorb as much water and nutrients as possible from the soil, and the many thin hyphae give the fungi lots of surface area with which to do this. In mycorrhizal fungi, the mycelia grow through the soil and around and into plant roots. Mycorrhizae colonize the plant roots in many different ways, but always for the same reason: to take sugar that the plant has photosynthesized.

In return, the fungi provides the plant with water and nutrients from the soil and compounds from other plants.

The reason a fungi can provide compounds from other plants is because one individual fungus is often connected to multiple plants (and vice versa). In a pivotal study in the 90's, forest ecologist Suzanne Simard tracked radioactive carbon moving between different plants through mycorrhizal networks (Simard, 2016). In other words, a mycorrhizal fungus acts as a middleman between plants. The many different connections between plants and fungi link hundreds to thousands of plants together, forming a network that spans entire ecosystems. The sharing of resources between plants is not limited to carbon compounds. Many other nutrients are also shared through fungi, including signaling molecules that convey information. For instance, one study discovered that Douglas Firs, when invaded by budworms, sent a signal through the root-mycelium network to neighboring trees, alerting them to the presence of the budworms and allowing them to prepare chemical defenses (Song, 2015).

The formal scientific study of mycorrhizae began in the 19th century by German botanists. However, awareness of the function of mycorrhizae has been part of many indigenous cultures throughout the world. Robin Wall Kimmerer (2013, p. 19) explains that “in the old times, our elders say, the trees talked to each other. They’d stand their own council and craft a plan. But scientists decided long ago that plants were deaf and mute, locked in isolation without communication.” Traditional farming methods from Benin involved planting crops together that shared resources through mycorrhizae (Saidou, 2006). Finally, mushroom harvesters have known from time immemorial to look for certain mushrooms under certain trees. The German botanists, of the 19th century, however, were the first to notice the physical structures of mycorrhizae. Although at first they described them without realizing what they were; Theodor Hartig

described the fungal mantle in 1841 but did not recognize it as a fungi. Albert Bernard Frank is considered a champion in the field for being the first to interpret the Hartig net as a structure for mutualistic exchange between plants and fungi (Trappe, 2005).

In the decades that followed Frank's publications, discoveries were made and discussed by a few interested study centers, however they remained outside the public awareness. The hypotheses made by these early scientists included most of the topics under discussion today: the colonization of multiple species by one fungus, the exchange of nutrients, and even signaling through the fungal networks. The progress of study was slow, however, perhaps because the topics only interested experts. All this has changed in the last few decades. Bonfante (2018, p. 997) describes a "crucial change in the perception of mycorrhizal symbiosis" that has recently taken place, in which mycorrhizae are now "perceived as relevant not only by researchers, but also by society." What are the reasons for the crucial change? New tools in the study of mycorrhizae may be part of the answer. Genetic sequencing has confirmed many of the early hypotheses and allowed for deeper analysis. Bonfante (2018) suggests that the popularity of environmentalism is another reason the public cares more about mycorrhizae now. The hitherto overlooked reason, however, is that mycorrhizae have recently been talked about in engaging and accessible ways.

Suzanne Simard, the above-mentioned forest ecologist, has explained her scientific research in a lot of popular writing, a TED talk, and multiple documentaries. When addressing the public, she describes the ecological systems with phrases like, "mother trees," "send[ing] messages of wisdom," and "a world of infinite biological pathways" (2016). Her poetic language makes some scientists uncomfortable, perhaps reminding them of the infamous book *The Secret Life of Plants* that mixed scientific findings with accounts of mystical experiences to argue that

plants had souls (Jabr, 2020). Ectomycologist Jason Hoeksema (as cited in Jabr, 2020) has said that although “there is value in getting the public excited... sometimes the speculation goes too far.”

The excitement of the public, however, is the reason so many opportunities exist for scientists to test this speculation, which Bonfante (2018) explains, though she does not trace public excitement to Simard or popular writing. I would argue that Simard’s creativity in communicating about mycorrhizae is responsible for the popularity they now enjoy. Her ideas were extended through fiction in the 2009 film *Avatar* and Richard Powell’s movie *The Overstory* (Jabr, 2020). Though the “tree of souls” in the movie *Avatar* was certainly not presented as scientific fact, fiction goes a long way in creating categories for ideas in our minds.

The example of Suzanne Simard and the topic of mycorrhizae teaches us that letting personality or creativity show in your explanations of science has profound effects. It involves risk, certainly, however the possible pay-off is that thousands more people will agree that your research is important and interesting. Ecologist and science-writer Richard Hobbs (2018, p. 49) suggests that if communicating science was not synonymous with “squeezing any hint of creativity and individual expression out of the process... science might actually resonate more with a broader audience.” He adds, “in a world increasingly enamored with anti-scientific sentiment, there’s a lot to lose if we don’t get it right.” The study of mycorrhizae has tremendously benefited from a scientist allowing her fascination to be infectious. It infected me in high school, when I watched the documentary “How Plants Communicate & Think” in biology class. My continued interest in the topic grew into this project: I wanted to know what the “world of infinite biological pathways” looked like locally in the Chuckanut marsh wetland.

Three main reasons make the Chuckanut marsh a location of special ecological interest. First, it is a palustrine wetland, an environment whose anaerobic conditions and salinity could make things difficult for fungi. Still, to varying extents they have been found in similar environments, including completely saltwater ecosystems like mangrove forests (Gehring et al., 1998; Wang et al., 2010). Second, the wetland has six different plant communities within its varying topography: Upland Forest, Palustrine Forest, Upland Shrub, Palustrine Shrub-Scrub, Palustrine Emergent, and Estuarine Emergent. These different plant communities are habitats for several valued species, including spawning Chinook salmon and Great Blue Herons. Third, it is a wetland that has seen considerable human-caused disturbance: a road and culvert built into the wetland, and a stone railroad causeway across the northern end of Chuckanut bay (Northwest Ecological Services, 2008). Any possible effects of these disturbances are outside the scope of this project, but they were features that attracted me to studying this location.

During the early phases of the project's conception, I narrowed my study to ectomycorrhizae, one of the two most common subtypes of mycorrhizae. The other is arbuscular mycorrhizae. The main difference between the two types is their physiological connection to plant roots. Ectomycorrhizae fungal hyphae grow between root cells without penetrating the cells, whereas arbuscular mycorrhizae penetrate the cells and form structures inside them. Ectomycorrhizae also form dense sheaths around roots called Hartig nets. Arbuscular mycorrhizae are most abundant, present in 72% of vascular plants compared to ectomycorrhizae which only colonize 2% (Bonfante, 2018). However, there is more species diversity in the ectomycorrhizae group: around 20,000 species are ectomycorrhizae of the current estimate of 50,000 species for mycorrhiza total (Heijden et al., 2015). Ectomycorrhizae also include the fungi that form fruiting bodies, the structure we traditionally know as mushrooms. Having

macroscopic above-ground structures made this group more accessible for field work, which was at one point an element of this project. Even after field work became unfeasible, the diversity of ectomycorrhizae made for very interesting (if also overwhelming) results.

To determine what ectomycorrhizal species were likely present in the Chuckanut marsh wetland, I first used the Species List in Appendix F of the “Chuckanut Village Marsh Wetland Characterization” to determine what plants were present in the marsh. This study was published by Northwest Ecological Services (2008) in preparation for habitat restoration work by the city of Bellingham in 2011. I also used Wang & Qiu's (2006) survey of over 3000 land plants to determine the mycorrhizal status of plant species in Chuckanut marsh wetland. I read the articles referenced by Wang & Qiu to find any species names associated with the plant species. Many of their referenced articles were themselves similar compilations of other studies. As the amount of relevant literature grew, I narrowed my search to six trees, having learned that ectomycorrhizae associate most with tree species (Heijden et al., 2015). The six chosen species are *Abies grandis*, *Pseudotsuga menziesii*, *Betula papyrifera*, *Picea sitchensis*, *Populus tremuloides*, and *Populus trichocarpa*, their common names being Grand Fir, Douglas Fir, Paper Birch, Sitka Spruce, Quaking Aspen, and Black Cottonwood.

From the papers reviewed, I found that there at least 45 genera and 126 species that have been found in association with these six tree species. These species are reported in Table 1. The three genera with the most species listed are: *Russula*, *Amanita*, and *Cortinarius*. The plant communities in which these tree species are found are not surprisingly the Upland Forest and Palustrine Forest. This likely represents only a fraction of the species that are associated with these six trees, much less the wetland as a whole, since several hundreds of fungal species can be

found in a forest with even just a few plant species (Heijden et al., 2015). However, the list gives us a glimpse at the mycorrhizal biodiversity in just one area of the wetland.

As I was reading through the articles looking for species names, several potential problems with my method came to my attention. The studies used to make the table took place in many different habitats and regions. Some studies have reported that the fungal mycorrhizae composition for the same plant species was different based on habitat and altitude even if the locations were otherwise in the same biogeographic realm (Jacquemyn et al., 2016; Becklin & Galen, 2018). Could we expect to see any of the species from Table 1 in the Chuckanut marsh wetland, since the studies were in different regions and habitats?

The reasons I am reasonably confident that many species listed are likely in the wetland is the pervasiveness of fungal species throughout biogeographic regions and the coupled relationship of their diversity with plant species. Similar fungal species have been found in so many places of the world that early mycologists concluded fungal growth was something like spontaneous generation: if climatic conditions were correct for a certain fungi, there the fungi would be. More research has determined that fungi distribution is, of course, more complex than that (Peay et al., 2010). However, it remains true that many of the same fungi species are found throughout biogeographic regions. Changes in fungi composition are usually determined by climate and latitude (Peay et al., 2010). These factors often also determine the distribution of plant species. Although in general fungal diversity is not geographically coupled with plant diversity, ectomycorrhizae prove the exception due to their symbiosis and possible co-evolution with plants (Tedersoo et al., 2014). For these reasons, plant species throughout the world likely have at least some fungal associates in common.

The question of habitat-driven variety also complicates but does not discredit Table 1. Becklin & Galen (2018) describe one fungal community as an underground mosaic that matched the pattern of alternating meadowland and forestland above ground. However, the difference between ectomycorrhizae communities was the relative abundance of the same and similar species, rather than having all different species (Jacquemyn et al., 2016; Becklin & Galen, 2018). So again, though the Chuckanut marsh wetland is a different habitat from those studied in the articles I read, likely many genera and some species in them are the same.

The final question regarding habitat is whether fungi could exist in an environment that is saline and anaerobic, two characteristics of the Chuckanut marsh wetland. In terms of salinity, several studies have shown that ectomycorrhizae can in fact enhance plant tolerance to salinity. If this is true, then ectomycorrhizae are indeed likely present in the palustrine areas of the wetland, and are perhaps the reason that plants exist there at all (Gehring et al., 1998; Guerrero-Galán et al., 2019). In fact, one species from Table 1, *Rhizopogon roseolus* has been studied specifically in regards to salinity, and was found to be resistant to salinity when grown in saline culture (Gao et al., 2018). Concerning the wetness of the wetland, anaerobic conditions may indeed have negative effects on the presence of mycorrhizae. A study that counted ectomycorrhizae sheaths on root tips found that only 2% of root tips had sheaths in wetlands compared to the 28% in uplands (Vasilas et al., 2004). Another study of ectomycorrhizae in uplands versus wetlands found greater diversity in upland forests, although some species existed at every location studied. Assuming their discoveries about moisture gradients to be universal, we could expect to see fewer species in the Palustrine Forest community than in the Upland Forest community.

To summarize, the list of species in Table 1 is not presented as a comprehensive or correct list, but as a starting point. Becklin & Galen (2018) use the analogy of a mosaic to describe how the variation of a mycorrhizal community mirrors the variation of above-ground plant communities. Assuming the same to be true in the Chuckanut marsh wetland, we could expect that belowground the wetland has six ectomycorrhizal communities which correspond to the six plant communities. With Table 1, we have a list of some likely components of the ectomycorrhizae network in the Upland Forest and Palustrine Forest plant communities. We can also predict that the Upland Forest mycorrhizal community will likely be much denser than the Palustrine Forest mycorrhizal community.

Many different field techniques could cement and expand what we know about the ectomycorrhizae of the wetland. These techniques could involve anything from Geiger counters, soil cores, or surveys of fruiting bodies. For more research using already published literature, the list of fungi species could be edited to only include species that have been found in this region. Information about fruiting bodies could be added to the table. And of course, more papers exist and are continually being written about mycorrhizae that include species found in the wetland. A similar approach to mine could also be taken with arbuscular mycorrhizae of the Chuckanut marsh wetland. The smaller number of arbuscular mycorrhizae species might make the resulting list more reliable, and a study on arbuscular mycorrhizae would likely involve more of the wetland's plant communities since arbuscular mycorrhizae usually associate with shrubs and herbaceous plants.

The lack of definite answers about which ectomycorrhizae are in the wetland is both frustrating and exciting. The complexity of ecological systems makes them hard, but so important, to study. Each of the species listed in my table, plus hundreds more, have unique

characteristics and functions. An appreciation and even awe for this level of diversity, which found in any ecosystem, is the biggest motivator for good environmental stewardship.

Taxonomist Frank Rheindt explains that “we can only conserve what we know” (quoted in Gregg, 2020, par. 13). Appreciating the unity, as well as the diversity, of ecosystems is important for conservation. Suzanne Simard helped people shift their understanding of forests from a collection of individuals to a “wood wide web” (Simard 2016). Removing individual plants is more than simply removing individual plants; it is the removal of parts from a whole. This knowledge should shape the way we approach land use. Whether we manage wetlands, plan cities, plant gardens, or walk along trails, may we be mindful of the connections underground.

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Table 1: List of Genera and Species Found with *Abies grandis*, *Pseudotsuga menziesii*, *Betula papyrifera*, *Picea sitchensis*, *Populus tremuloides*, and *Populus trichocarpa*

Genus	Species
Acremonium	Acremonium strictum
Amanita	Amanita aspera
	Amanita chlorinosma
	Amanita crocea
	Amanita gemmata
	Amanita muscaria
	Amanita pantherina
	Amanita silvicola
	Amanita strobiliformis
Amanita vaginata	
Amphinema	Amphinema byssoides
Boletellus	Boletellus zelleri
Boletinus	Boletinus amabilis
	Boletinus lakei
Boletus	Boletus edulis
	Boletus erythropus
	Bolletus zelleri
Byssoporia	Byssoporia terrestris
Calodon	Calodon velutinus
Cantharellus	Cantharellus cibarius
	Cantharellus floccosus
	Cantharellus subalbidus
Capronia	Capronia
Cenococcum	Cenococcum geophilum
	Cenococcum geophilum
	Cenococcum graniforme
Chlorophyllum	Chlorophyllum brunneum
	Chlorophyllum oliveri
	Chlorophyllum rhacodes
Choirmyces	Choirmyces meandriformis
Claviadelphus	Claviadelphus fistulosus
Cortinarius	Cortinarius cinnamomeus
	Cortinarius croceocaeruleus
	Cortinarius croceofolius
	Cortinarius decolorcus

	<i>Cortinarius semisanguineus</i>
	<i>Cortinarius uliginosus</i>
Gomphidius	<i>Gomphidius glutinosus</i>
	<i>Gomphidius oregonesis</i>
	<i>Gomphidius smithii</i>
	<i>Gomphidius subroseus</i>
	<i>Gomphidius tomentosus</i>
Hebeloma	<i>Hebeloma crustuliniforme</i>
	<i>Hebeloma longicaudum</i>
Hydnum	<i>Hydnum repandum</i>
Hygrophorus	<i>Hygrophorus chrysodon</i>
	<i>Hygrophorus gliocylus</i>
Hymenoscyphus	<i>Hymenoscyphus erica</i>
	<i>Hymenoscyphus ericae</i>
Inocybe	<i>Inocybe decipientoides</i>
	<i>Inocybe dulcamera</i>
	<i>Inocybe geophylla</i>
	<i>Inocybe glabripes</i>
	<i>Inocybe lacera</i>
	<i>Inocybe umbrina</i>
Krombholziella	<i>Krombholziella aurantiaca</i>
Laccaria	<i>Laccaria amethysteo-occidentalis</i>
	<i>Laccaria amethystina</i>
	<i>Laccaria laccata</i>
	<i>Laccaria tortilis</i>
Lactarius	<i>Lactarius aurantiacus</i>
	<i>Lactarius controversus</i>
	<i>Lactarius deliciosas</i>
	<i>Lactarius deliciosus</i>
	<i>Lactarius pallidus</i>
	<i>Lactarius resimus</i>
	<i>Lactarius rufus</i>
	<i>Lactarius sanguifluus</i>
	<i>Lactarius substratus</i>
Leccinum	<i>Leccinum aurantiacum</i>
	<i>Leccinum nigrescens</i>
Lycoperdon	<i>Lycoperdon gemmatum</i>
Melanoleuca	<i>Melanoleuca melaleuca</i>
Morchella	<i>morchella elata</i>
	<i>morchella esculenta</i>

Oidi dendron	Oidi dendron maius
Paxillus	Paxillus involutus
Phialophora	Phialophora finlandia
Piloderma	Piloderma fallax
Pisolithus	Pisolithus tinctorius
Pseudotsugarhiza	Pseudotsugarhiza baculifera
Rhizopogon	Rhizopogon luteolus
	Rhizopogon parksii
	Rhizopogon roseolus
	Rhizopogon rubescens
	Rhizopogon vinicolor
Russula	Russula virescens
	Russula amoenolens
	Russula delica
	Russula emetica
	Russula foetens
	Russula lepida
	Russula murrillii
	Russula nigricans
	Russula nitida
	Russula placita
	Russula puellaris
	Russula pulchella
	Russula sanguinea
	Russula vesca
	Russula vesicatoria
	Russula xerampelina
	Russulua delica
	Russulua emetica
Scleroderma	Scleroderma bovista
Sebacina	Sebacina
Suillus	Suillus granulatus
	Suillus leteus
	Suillus piperatus
Tomentella	Tomentella sublilacina
Tricholama	Tricholama imbractum
	Tricholama pessundatum
	Tricholama poplinum
	Tricholama sudum
	Tricholoma atrosqmosum

Truncocolumella	Truncocolumella critina
Tuber	Tuber borchii
	Tuber californicum
Tylospora	Tylospora fibrillosa
Volvariella	Volvariella speciosa
Wilcoxina	Wilcoxina
	Wilcoxina mikolae
Xerocomus	Xerocomus chrysenteron
	Xerocomus pulverulentus
	Xerocomus subto mentosus