Rocky Mountains Cooperative Ecosystem Studies Unit (RM-CESU)
RM-CESU Cooperative Agreement Number: H1200040001

PROJECT COVER SHEET

TITLE OF PROJECT: Investigation of Mycorrhizal fungi associated with whitebark pine in Waterton Lakes-Glacier National Parks Ecosystem.

NAME OF PARK/NPS UNIT: Glacier NP

NAME OF UNIVERSITY PARTNER: Montana State University

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COST OF PROJECT:

Direct Cost: $ 1000.00

Indirect Cost (CESU overhead): $ 175.00

Total Cost: $ 1,175.00

NPS ACCOUNT NUMBER: 1430-7077-634

NAME OF FUND SOURCE: IMR-IMRICO

PROJECT SCHEDULE, FINAL PRODUCTS, AND PAYMENTS

Date of Project Initiation: May 1, 2007

List of Products: (1) Field collection of ectomycorrhizae from Whitebark pine and identification of this fungi, (2) final report due on March 31, 2008.

Payment Schedule: Invoices as received from the University.

End Date of Project: May 1, 2008

GLACIER NATIONAL PARK
Investigation of Native Mycorrhizal Fungi with Whitebark Pine
Final Report 2009

Cathy Cripps, Montana State University (ccripps@montana.edu)

INTRODUCTION

Whitebark pine is a picturesque, long-lived tree of high mountain landscapes in much of the American West. It is a "keystone" species supplying food and shelter for wildlife and often holding the snow and rocky soils in places where other trees cannot grow. Now, however, in about half of its natural range, including Waterton-Glacier NP, whitebark pine is mostly dead or dying, due to an introduced blister rust disease and replacement by competing trees as a result of fire exclusion (Schwandt 2006, Tomback & Kendall 2001, Kendrick & Keane 2001). Waterton-Glacier NP has been involved with a whitebark pine restoration program for a number of years and has need of additional information on how and where to replant resistant nursery seedlings.

Glacier National Park has considerable need for assistance with determination of ectomycorrhizal fungi associations with the critical issue of decline of whitebark pine forests in the Waterton Lakes-Glacier National Parks ecosystem. The goal is discovery, collection, and recording mycorrhizal fungi in whitebark pine forests with particular emphasis on visiting accessible areas with significant seedling regeneration. Gaining information on the mycorrhizal fungi is potentially crucial to survival of this tree species and discovery of native fungi useful for nursery inoculation is also a goal (although outside the scope of this project). If nursery seedlings require inoculation for successful establishment in areas devoid of fungi, it will be necessary to use native fungal species for national parks to preserve ecosystem integrity. This is the final report for this technical assistance.

National Park Service Substantial Involvement in Project

As noted in the introduction, the project included substantial involvement by Glacier National Park (GLAC) which provided information about locations of previously planted sites (with Whitebark pine) and observations about existing WBP populations with and without disease. Park staff assisted the MSU cooperator with logistics, issued a permit for collections, and will review this final report. A separate report was sent to Cyndi Smith, ecologist for Waterton National Park, and there is some overlap in reports.

METHODS

The goal to collect ECM fungi associated with whitebark pine was accomplished at several ecosites in WGIPP with particular emphasis on accessible areas with significant seedling regeneration. For Waterton Lakes National Park (WLNP), collecting sites included the Summit Lake-Carthew Trail, Tamarack Trail, and Ruby Ridge areas; and for Glacier National Park (GNP), the Siyeh Bend area and an isolated whitebark pine forest past Scenic Point were examined. Trips of a few days each were made in June, July and September to Waterton and Glacier Parks.

Table 1. Sampling sites for ectomycorrhizae.

WATERTON	2007	GPS Location	Elev.
Cameron Lake Trail	6/14	49 00.976 N, 114 01.955 W	1905 m
Summit Lake - Carthew Trail	6/16	49 00.976 N, 114 01.955 W	1914 m
Rowe Trail	6/17	49 05.245 N, 113 87.406 W	2130 m
Summit Lake-Carthew Trail-	6/18	49 00.725 N, 114 01.715 W	1975 m
Carthew Trail	9/21	49 00.101 N, 114 00.010 W	2060 m
Ruby Ridge	9/22	49 07.373 N, 113 99.570 W	2086 m
GLACIER PARK			
Siyeh Bend	7/25	48 69.953 N 113 67.199 W	1900 m
Scenic Point	7/26	48 29.093 N, 113 18.855 W	2207 m

Sporocarps (mushrooms, truffles) of fungi known to be ectomycorrhizal (ECM) were collected in whitebark pine forests and identified by their morphology. Sporocarps were tissue-cultured when possible on MMN agar media. Drought conditions preceding the study and the mixed condition of stands limited this approach particularly in Glacier Park. A second approach was devised that consisted of taking root samples using minimally destructive techniques (small portions of root segments were removed). Roots were washed and assessed for mycorrhizal fungi on roots. Mycorrhizae were sorted into morphotypes (fungal species) using a dissecting scope and identified by molecular analysis (sequencing the ITS region, Berkeley, CA and using BLAST search) when necessary (methods in Mohatt 2006, Mohatt et al. 2008, Trusty & Cripps, in prep). Approximately 27 root samples consisting of hundreds of ectomycorrhizae were assessed. Information on taxa of sporocarps and mycorrhizae are recorded along with ecological and site information on the database provided to C. Smith for WLNP. No sporocarps were found in Glacier Park, but molecular identification of fungi on roots samples was used and results are reported here.

RESULTS

SPOROCARPS: In total 20 species of native ECM fungi with potential to associate with whitebark pine were recorded from WGIPP and 12 are confirmed on roots of whitebark pine. Sporocarps were rare in whitebark pine areas of WLNP and absent from GNP during the collecting trips due to preceding drought conditions. However, sporocarps of nine taxa of ectomycorrhizal fungi known to associate with whitebark pine in the GYE were recorded in mixed forests in WLNP (Tab. 2). In addition, two *Rhizopogon* fruiting bodies were found in WLNP, one with lodgepole pine and one with limber pine. The lodgepole sample is likely specific for 2-needle pines and we do not know if limber (*Pinus flexilis*) and whitebark pine share the same mycorrhizal associates. Deer truffles (*Elaphomyces*) were discovered in a whitebark pine forest however spores did not germinate in culture. *Suillus sibericus* was recorded as a sporocarp from Parker Ridge in Jasper National Park (from a C. Wong photo) showing it is a component of this ecosystem as in Greater Yellowstone Ecosystem (GYE).

Table 2. Native ectomycorrhizal Fungi recorded in WGIPP with potential to associate with whitebark pine. Fruiting bodies (+) are from mixed stands; confirmation on white-bark pine roots (*) is by molecular ID. Confirmation of association is either by occurrence in pure stands (GYE/WGIPP) or on roots (last column). Additional GYE species are listed in Mohatt et al. (2008).

Species	WGI PP	GYE	Confirmed pure/ roots
BASIDIOMYCOTA AGARICALES			
HYGROPHORACEAE			
Hygrophorus subalpinus	+	+	+/-
TRICHOLOMATACEAE			
Tricholoma moseri	+	+*	+/+
CORTINARIACEAE			
Cortinarius duracinus	+*	+*	+/+
Cortinarius flavoroseus	+	+	+/-
Cort. cf subolivescens	+	+	+/-
Cortinarius spp.	*	*	-/+
Dermocybe crocea	+	+	+/-
Inocybe fuscomarginata	+	-	-/-
Inocybe sp.	*	-	-/+

Species	WGI PP	GYE	Confirmed pure/ roots
BOLETALES ***Rhizopogon sp. 2***	+	-	-
Suillus sibiricus	+	+*	+/+
Suillus cf variegatus	-*	+*	-/+
Suillus sp.	-*	-*	-/+
APHYLLOPHORALES			
Amphinema sp.	-*	-*	-/+
Piloderma sp.	-*	-*	-/+
Pseudotomentella nigra	-*	-*	-/+
ASCOMYCOTA			
Cenococcum geophilum	-*	-*	-/+
Elaphomyces granulatus	+	-	-/+
Hydnotrya sp	-*	+	-/+
TOTAL SPECIES	20	44 species confirmed	

Fig. 1. a. Whitebark pine forest beyond Scenic Point in Glacier National Park where root samples were taken. B. Careful removal of root sample from whitebark pine seedling.

MYCORRHIZAE ON ROOTS: At least 12 species of ECM fungi are confirmed on roots of whitebark pine seedlings in WGIPP and eight at Scenic Point (Fig. 1, Table 3). These fall in to two main ecological groups: generalists not restricted to a particular host (that form mycorrhizae with pine, spruce and fir) and fungi that are host specific on some level (occurring only with pines, 5-needle pines, or only stone pines). The non-host specific fungi include: *Cenococcum geophilum, Amphinema byssoides, Piloderma fallax* and *Pseudotomentella nigra*. All have also been confirmed on whitebark pine from the GYE. *Cenococcum geophilum* occurs on many hosts and was prolific on some seedlings, producing hundreds of mycorrhizae and covered roots on two samples from seedlings. The host specific fungi are the suilloids and here include: Rhizopogon subbadius, Suillus variegatus and unknown types of suilloids. Descriptions of ectomycorrhizae on root samples and a brief ecology of the fungi are listed in Table 3 and color photographs of representative samples are shown in Fig. 2.

Table 3. Native ectomycorrhizal fungi found on roots of whitebark pine at Scenic Point, Glacier National Park. All were identified by molecular techniques (ITS sequencing and BLAST search).

Ectomycorrhiza	**description**	**hosts**	**ecology**
Amphenima byssoides	Golden, stringy, rhizomorphs	generalist: spruce, pine, fir	open or disturbed soil
Cenococcum geophilum	Black, black emanating hairs	generalist: spruce, pine, fir	drought conditions
Hydnotrya cf variiformis	Smooth, thin, golden/redbrown	?	ascomycete
Piloderma cf fallax	White, stringy, rhizomorphs	generalist: spruce, pine, fir	associated with wood
Pseudotomentella nigra	Yellowish/dark, surrounded by cloud of blue black mycelium	generalist: spruce, pine, fir	open or disturbed areas with seedings
Rhizopogon subbadius	Whitish with pink/yellow tints, coralloid clusters, rhizomorphs	Host-specific: 5-needle pine	nitrogen acquisition
Suillus cf variegatus	Large coralloid clusters, whitish with golden yellow interior, covering, rhizomorphs	Host-specific: 5-needle pine	nitrogen acquisition
Suilloid type-unknown	Small white coralloid clusters	Host-specific: pine	nitrogen acquisition

Fig. 2. Ectomycorrhizal root tips of whitebark pine (*Pinus albicaulis*) on beyond Scenic Point in Glacier National Park. A. *Rhizopogon* type. B. *Suillus* coralloid type (2 cm diameter). C. Clustered Suilloid type. D. *Hydnotrya* type. E. *Pseudotomentella nigra*. F. *Piloderma* root system with rhizomorphs.

Overall, the number of mycorrhizal types (species) on whitebark pine averaged 2.3±1.7 types per seedling (Tab. 4) with a higher diversity of types on mature root systems. IN the search for mycorrhizae, an unintentional result was a comparison of the mycorrhizal status of seedlings in various microhabitats, including those a) in beargrass under-story b) under the canopy of mature forests with an "open" under-story and c) on nurse logs. Seedlings on nurse logs hosted the highest diversity of mycorrhizal fungi (3.5±0.6), followed by those in an open under-story (2.4±0.2), with a significantly lower diversity for seedlings in beargrass (0.4±0.4) as shown in Fig. 3.

Table 4. Number of types of ectomycorrhizal fungi on roots of whitebark pine roots for several sites in WGIPP for three conditions: seedlings in O= open understory, BG=beargrass & NL= nurse logs.

W=Waterton G=Glacier	**Tree no.**	**Micro-habitat**	**No. types**	**Ectomycorrhizal fungi on roots**
W: Rowe Tr.	A	O	3	I, Cg, C
W: Summit Lake	A	BG	0	NM
	B	BG	0	NM
	C	BG	0	NM
	D	BG	3	I (few), old types
	E	O	1	Cg (hundreds)
	F	NL	4	S, Sd, others
	G	NL	2	Cg, P
	H	NL	3	Cg, others
W: Rowe Trail	A	BG	0	NM
	B	BG	0	NM
	C	O	3	Cg, types 1 & 2
	D	O	3	Cg, Sd, type 2
	E	BG	0	NM
	F	NL	5	Cg, P, Sd, I, other
W: Ruby Ridge	G	O	1	Cg (hundreds)
	H	O	3	Cg(lots), Sd, type 2
	I	O	2	Cg, P
	J	O	2	Cg (hundreds), P
	K	O	3	Cg, P, type 3
	L	O	2	Sd, Type 5
	M	O	3	Cg, Sd, type 1
G: Scenic Point	A	O	2	Pn, type 1
	B	O	1	Pn
	C	O	5	Cg, Sd, A, Type 4
	D	O	4	Cg, S, R, Sd
	E	O	6	Cg, P, Sd, H, other
			2.3±1	**12-15 types minimum**

*****NM=no mycorrhizae recorded**,** A=Amphinema, Cg=Cenococcum geophilum, C=Cortinarius, H=Hydnotrya, I=Inocybe, P=Piloderma, Pn=Pseudotomentella nigra, R=Rhizopogon, Sd=Suilloid, S=Suillus, Type 1 white, Type 2 golden, Type 3 copper, Type 4 turquoise, Type 5=woolly.

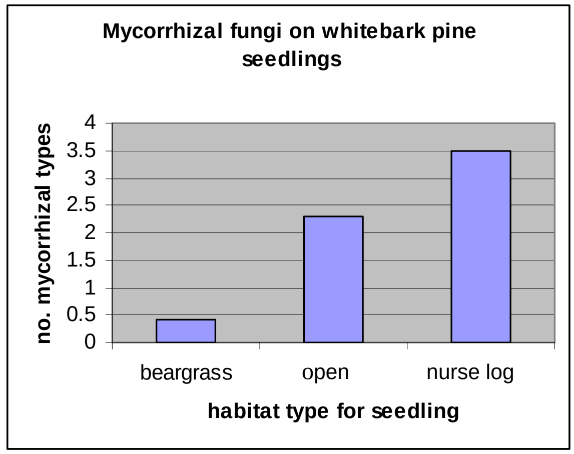

Fig. 3. Number of mycorrhizal types on whitebark pine seedlings situated in beargrass (n=7), under the canopy of mature whitebark pine forests with an open understory (n=11) and on nurse logs (n=4). Samples from mature roots not included.

DISCUSSION

A diversity of native ectomycorrhizal fungi were found to occur with whitebark pine in WGIPP. While many of these fungi are generalists that can form mycorrhizae on pine, spruce and fir, a subset of suilloid fungi were discovered in both Glacier and Waterton Park. *The importance of the discovery of suilloid fungi in WGIPP whitebark pine forests cannot be over-stated because of their unique role in the establishment of pine seedlings and the sustainability of pine forests.* The suilloid fungi (*Suillus, Rhizopogon*=pogies) discovered are specific for the genus *Pinus*, and are likely specific for 5-needle pines and possibly for stone pines (Mohatt et al. 2008). The implication is that pines have an advantage in forest systems where suilloids are present. When only generalist non-host specific fungi are the only ones available in the soil, pines do not have an advantage over other conifer species such as spruce and fir. Suilloid fungi (primarily *Suillus* and *Rhizopogon*) are known to be critical for establishment and sustainability of other pine species (Smith & Read 1997, Read 1998), and this appears to be true for *Pinus albicaulis* as well.

Suilloid fungi were primarily recorded on Ruby Ridge in WLNP and beyond Scenic Point in GNP in contrast to other sites. At the latter site, mycorrhizae were of large size (up to 2 cm across) and were prolific along larger root systems of mature pines (Fig. 2b). The higher prevalence of suilloids at these sites could possibly be due to the presence of more pure, intact whitebark pine forests that include both mature trees and seedling regeneration. In contrast, suilloids were rare at other sites with a mixed forest type where whitebark pine was more sporadic and interspersed with other conifers. It is likely that as whitebark pine declines, these suilloids will decline as well. While there is some evidence that spore-banks of suilloids can exist for a period of time in the soil after burns, it is not known how long they might remain viable in the soil of ghost forests after complete mortality of the whitebark pines.

The discovery of suilloid fungi specific to 5-needle pine (including western white pine) and stone pines is of interest for North America. *Suillus sibericus* and *Suillus variegatus* occur with stone pines in Europe and Asia, revealing a long co-evolutionary history (Moser 2004) and we now report both species from WGIPP (and Jasper for *S. sibiricus*). These *Suillus* species appear to match up with those found in the Greater Yellowstone Ecosystem (Mohatt et al. 2008, Cripps & Mohatt 2005) although molecular analysis was not definitive to species. The same is true for *Rhizopogon* species. An important point is that these species have associated with stone pines for hundreds, if not thousands of years. Their importance in stone pine systems is known in Europe where suilloids have been used to inoculate the European stone pine (Pinus cembra) for over 50 years successfully increasing seedling survival at high elevations. Some taxa from WGIPP have value for inoculation of nursery seedlings of whitebark pine.

Overall, the number of mycorrhizal types (species) on whitebark pine averaged 2.3±1.7 per seedling and this is on par with the diversity on whitebark pine seedlings in the GYE (2.2±1.3) (Mohatt et al. 2008). The low number of fungi on one seedling suggests that survival of a particular seedling depends on only one or two fungi and mycorrhizal fungi differ in their physiology, ecology and specific benefits to their host (Table 3 & 4, Fig. 3). In addition to host specificity, some fungi occur solely on seedlings and others are restricted to mature trees. The mycorrhizal community typically changes (mycorrhizal succession) as a tree matures or as the soil in a forest gains organic matter, nutrients and shade. Suilloids are one of the few sets of fungi that bridge this gap and are important to both pine seedlings and mature pines. In addition, suilloids are known to play a role in nitrogen acquisition, unusual for most mycorrhizal fungi. This could be of high importance to pines in high-elevation nitrogen-limited environments.

Suilloids have a unique ecology in other ways. *Rhizopogon* and *Suillus* spores are distributed by large and small mammals that consume the fruiting bodies. Fungi can be up to 80% of the diet of small mammals at certain times of year. We observed a deer eating *Rhizopogon* on Dunraven Pass in YNP and many of our collections were nibbled on by squirrels. The presence of these vectors (mice, voles, squirrels and deer) is an important consideration for restoration of whitebark pine as mammals can move spores directly to seedlings from distant source. Certain mammals may depend on particular species for food that are identified by odor, therefore it is important to exclude exotic mycorrhizal fungi i.e. those not native to the system.

Generalists such as *P. nigra* were found on seedlings in open habitats away from trees and the fungus also occurs on whitebark pine seedlings in burns (Trusty and Cripps, in prep). This fungus may have a preference seedlings in disturbed or open habitats. The generalist *Cenococcum geophilum* proliferates under drought conditions which could explain its predominance in some areas and on some seedlings. It can also confer a drought tolerance to its host plant. It occurs primarily within the canopy of forests since it does not disperse by long distance spores. *Piloderma* species are usually associated with mature forests since they have some ability to decompose the organic matter available is this habitat. All of these species can colonize spruce and fir as well as pine.

A comparison of the mycorrhizal status on whitebark pine seedlings in various microhabitats found that seedlings on nurse logs hosted the highest diversity of mycorrhizal fungi, followed by those in an open under-story, with a significantly lower diversity for seedlings in beargrass (Cripps et al. 2008) . Sample numbers were limited, but this trend is apparent, and may have functional significance (Fig. 3). The whitebark pine seedlings situated in the beargrass under-story were primarily from the Summit Lake-Carthew Trail area of WLNP. Observation of healthy seedlings in beargrass (*Xerophyllum tenax*) suggests these species can co-exist. However, it was difficult to sample roots since the mats of grass rhizomes were several cm thick and needed to be sawed through. Examination with a dissecting scope revealed grass rhizomes pressed tightly against primary tree roots in a dense mass devoid of soil. Secondary lateral roots of the pine spread into the matt and thinned to attenuated points devoid of mycorrhizae. One cluster of mycorrhizal roots was located just at ground level hugging the main root of the pine seedling, but in all other cases, mycorrhizae were either absent or could not be located on seedlings in beargrass. Given that mycorrhizal fungi need oxygen to function, it is possible that an alternate physiology is at work here or fungi might be deeper in the soil.

Perkins (1999) found that for whitebark pine neither seed germination nor survival differed among seeds planted with different under-story neighbors, but in burned plots the average seedling dry mass was significantly lower in association with *Xerophyllum tenax* (P=.03, .019). She further states that this species produces dense root masses which can have a negative effect on conifer establishment referencing Landhausser et al. (1996). The latter study shows the grass *Calamagrostis canadensis* to be problematic for regeneration of other conifers. Izlar (2007) also noted beargrass to have a negative effect on planted *Pinus albicaulis* seedling survival. Competition from native and seeded grasses reduced mycorrhizal formation on sugar pines planted after a burn in Oregon (Amaranthus et al. 1993). Therefore, if fire is a restoration strategy in certain areas, the dynamics of beargrass recovery after fire should be taken into account in context with that for whitebark pine seedlings.

In areas of WLNP with dense beargrass, numerous seedlings were located on nurse logs. These are assumed to be from bird-planted seeds since many were in clusters. Hypothetically, nutcrackers might have a higher seed recovery rate for those planted on nurse logs rather than in a sea of beargrass. These seedlings hosted numerous healthy-looking ECM rootlets situated within the decomposed wood of the nurse log. Izlar (2007) also observed green, healthy whitebark pine seedlings established on nurse logs in her survey. *Cenococcum geophilum* and suilloid fungi were both recorded on seedlings on the ground and on nurse logs. With the low sample size, it is difficult to say if particular fungal species have a preference for certain microhabitats, although this is known to occur (Iwanski & Rudawska 2007). Reduction of nurse logs is another consequence of fire that should be taken into account in particular areas for reforestation. We do not know if they are an actual reservoir for mycorrhizal fungi or if the roots and fungi arrive and proliferate together.

Additional ecological roles of ECM fungi in regard to the soil became apparent during the course of this investigation. Dense masses of mycorrhizae along roots aggregated the soil into large clumps which held moisture around the roots system. This was particularly evident in the argillite soil of Ruby Ridge in WLNP and the soils at Scenic Point in GNP (Fig. 4). Rhizomorphs (shoe-string like strands) of some fungi aggregated even gravel size particles. Mycelium was observed in close contact with granitic particles, and it is possible these fungi produce phosphatases that can access inorganic phosphate in minerals. The large coralloid mycorrhizae (Fig. 2b) from mature roots beyond Scenic Point in GNP have potential to host N-fixing bacteria, but this remains to be discovered in these systems.

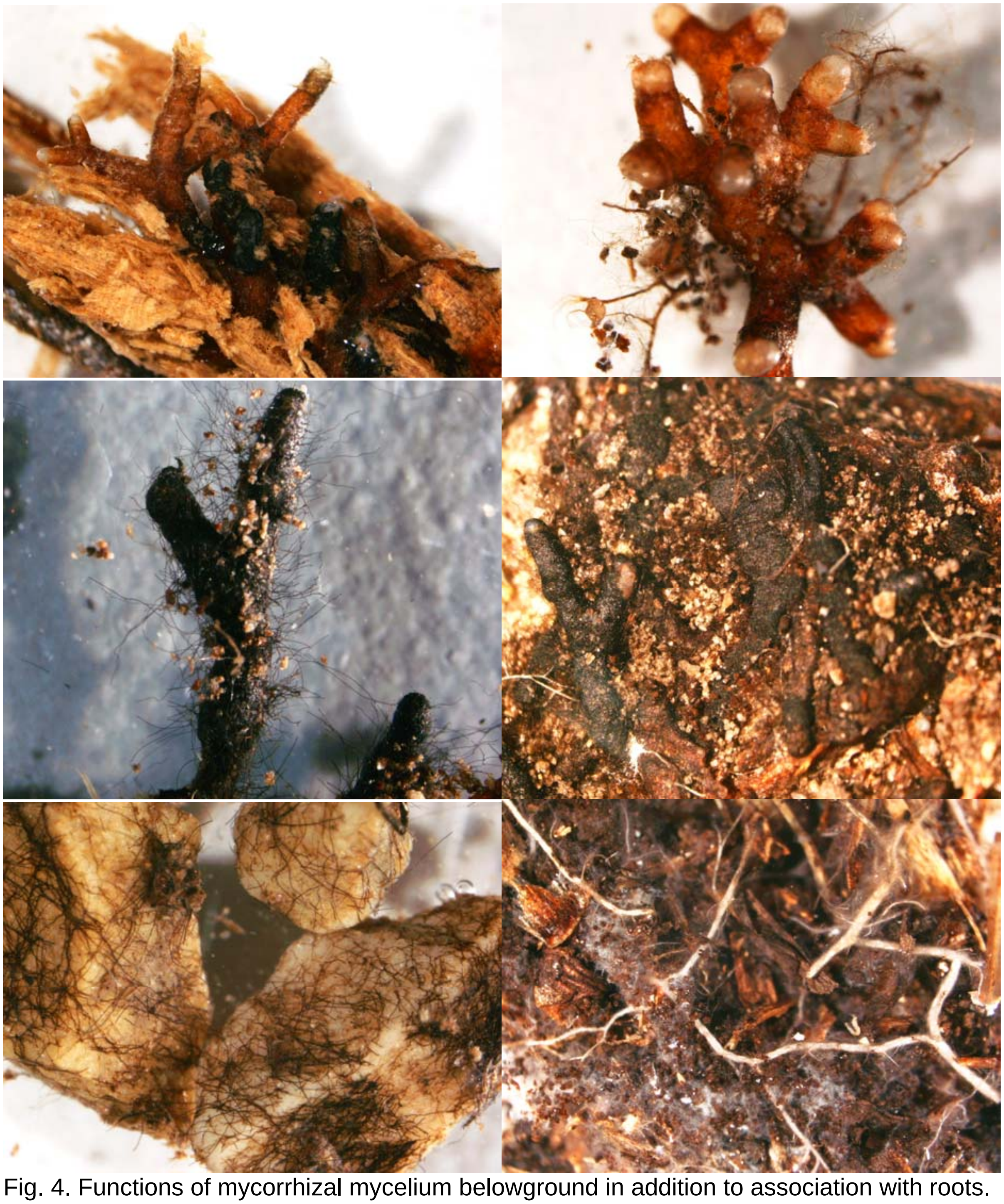

Fig. 4. Functions of mycorrhizal mycelium belowground in addition to association with roots. A. Mycorrhizae in wood with possible decomposition function. B. *Pseudotomentella nigra* with extramatricular hyphae. C. *Cenococcum geophilum* with radiating hairs. D. *C. geophilum* aggregating soil on root systems. E. Mycorrhizal mycelium growing over gravel, possible phosphatase activity and gravel aggregation. F. Mycelial matt of ectomycorrhizal and saprophytic fungi holding organic matter together enhances moisture retention.

MANAGEMENT CONSIDERATIONS

Information on the mycorrhizal fungi important to whitebark pine is valuable to the extensive efforts currently underway to restore whitebark pine forests using a combination of management strategies such as fire, logging, and the planting of rust-resistant nursery-grown seedlings (Keane and Arno 2001, Burr et al. 2001, Tomback et al. 2001). Inoculation with native fungi may be necessary where the fungi are missing or where seedlings need a 'jump-start' for survival until appropriate fungi arrive. Currently it is estimated that only 42% of seedlings survive on out-planting and in some areas there is 100% mortality (Izlar 2007). The preservation and cultivation of suilloid fungi is particularly important so that native species are available for national parks and where exotic fungi are unsuitable. *Commercial inocula with non-native fungi should not be applied to any whitebark pines.* Systems are sensitive, and native fungi not only have unique physiological and mechanical roles, but they are also part of the food chain and addition of alien fungi risks cascading ecological effects. Douglas fir hosts several thousand species of mycorrhizal fungi; in contrast our research that shows whitebark pine associates with a much more limited set of fungi. Suilloid fungi have now been discovered in WGIPP and this could be of critical importance to the ecology of this tree in peril. These fungi need to be preserved within this habitat. If trees are killed by fire, clear-cutting or mortality due to blister rust or beetles this can remove the inoculum source and plantings should follow quickly while viable spore banks still exist in the soil. Monitoring can reveal if seedlings are at risk from lack of mycorrhizal colonization to determine where/when inoculation is necessary.

PRODUCTS FROM THIS RESEARCH:

1) Field collection of mycorrhizae 2) Identification of mycorrhizal fungi from Glacier Park 3) Final report and 4) Journal article: Cripps, CL, Smith, Cyndi, Caroli, Tara & Joyce Lapp 2008. Assessment of Ectomycorrhizal Fungi with Whitebark Pine: Waterton-Glacier International Peace Park. Nutcracker Notes 14:12-14.

FUTURE DIRECTIONS:

We are currently working on inoculation of whitebark pine seedlings in the nursery (through another grant) and have had successful colonization with particular strains of native ectomycorrhizal suilloid fungi at MSU (Fig. 5). We are now working on development of inoculation methods that are consistent and amenable to practical nursery conditions. We are interested in working with the GNP Native Plant Nursery in the future to inoculate (a few) whitebark pine seedlings that might remain in the nursery long enough for colonization to take place before out-planting. Alternatively a few seedlings grown from Glacier seed at the Coeur d'Alene nursery could be transferred to MSU for inoculation and maintenance before out-planting. Monitoring is also possible in areas where seedling survival is low.

Fig. 5. First whitebark pine seedlings colonized by native mycorrhizal fungi (suilloid) under greenhouse conditions at Montana State University Plant Growth Center.

AKNOWLEDGMENTS

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SUBSTANTIAL INVOLVEMENT BY THE NATIONAL PARK SERVICE:

Check the following to indicate the appropriate types of substantial involvement by both the NPS and the cooperator. In addition, the substantial involvement must be detailed within the attached Scope of Work:

x **The National Park Service and cooperator will jointly participate in project research and/or fieldwork.**

x **Project findings will be incorporated into National Park Service operations and/or planning efforts.**

CONTRIBUTION OF PROJECT TO OBJECTIVES OF CESU:

The NPS RM-CESU Research Coordinator indicates, by initials here, that this project contributes to the purpose of the CESU and is consistent with the approved Mission Statement, Strategic and/or Annual Work Plan.

X **Initialed by Kathy Tonnessen, RM-CESU Research Coordinator, on August 6, 2007**

FINAL REPORT

Upon the completion of the project, a copy of the final report (electronic required; paper copy optional) must be submitted to the NPS Research Coordinator and to the RM-CESU host university. Send electronic copies to rmcesu@forestry.umt.edu **and Kathy_tonnessen@nps.gov. Mail paper copies to RM-CESU, The University of Montana, College of Forestry and Conservation, Missoula, MT 59812.**

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