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RESIDUES, BENEFICIAL MICROBES, DISEASES, AND SOIL MANAGEMENT IN COOL, EAST SLOPE, ROCKY MOUNTAIN LODGEPOLE PINE ECOSYSTEMS

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ABSTRACT: Manipulation of forest residues has the potential to cause substantial changes in forest floor depth and composition. Such changes alter microbial communities and the accumulation, availability, or loss of soil nutrients. Forest floor changes can also alter risk factors for certain diseases and activities of ectomycorrhizal and nitrogen-fixing microbes. Alterations of soil composition or structure are likely to have both long- and short-term impacts. Natural regulation of forest floor thickness, composition, and associated processes, primarily through wildfire, generally causes extreme fluctuations in microbial activities, nutrient storage. and nutrient release. The latter is usually poorly coordinated with forest stand needs. Silvicultural systems, stand prescriptions, and regeneration methods should be directed to improve long-term nutrient storage, and to coordinate nutrient release with stand needs. Harvesting should incorporate disease sanitation, where appropriate, and limit residual stand damage.

INTRODUCTION

Development of a knowledge base for dealing with the cold, infertile ecosystems typical of the Rocky Mountain crest, particularly eastern slopes, has generally lagged behind that for warm, more productive systems. However, sufficient information is available for preliminary interpretations of advantages and disadvantages of dealing with soils and microbes in east-side Rocky Mountain sites likely to be forested with dense stands of lodgepole pine (Pinus contorta var. latifolia Enqelm.). Before discussing soil-soil microbe interactions and growth of this tree species, it is desirable to examine specialized adaptations of the genus Pinus, and to a lesser extent other conifers, that enable productive growth in low-fertility ecosystems. It is also helpful to review some of the more influential environmental Characteristics of the Rocky Mountains.

Members of the genus Pinus, particularly lodgepole pine and closely related species, are well adapted for, and highly successful in, low-productivity, infertile ecosystems (Miller and others 1979). Three particularly important characteristics of conifers in general, and pines in particular, make them well suited to infertile, moisture-limited environments: (1) pines are strongly mycorrhizal, a characteristic that enables them to acquire moisture, nitrogen (N), and phosphorus when quantities are too low to be available to many other plants (Harley 1969); (2) in the absence of intense competition (Worrall and others 1985). pines normally have a relatively high root/shoot ratio throughout their lives, thus maximizing soil exploration and mycorrhization to enhance nutrient and moisture acquisition (Chapin 1980; Hiller and others 1979); (3) pines are adept at storing nutrients within tissues, then remobilizing and transporting them to growing tissues in times of general shortage or during temporary interruptions of supply (Chapin 1980). These properties enable pines to tolerate, even thrive, in low fertility, periodically disturbed ecosystems with limited moisture typical of east-slope Rocky Mountain sites. Periodic stress caused by wide climatic fluctuations, both long- and short-term, is also typical of these environments, as are periodic insect and disease problems (Fellin 1980; Saestedt and Crossley 1984).

Lodgepole pine is frequently found on impoverished soils such as cold-wet or cold-dry, young soils (Cochran 1985). Soils on the east slopes of the Rockies are skeletal (young) soils, low in organic matter and nutrients (particularly nitrogen and phosphorus), and are moisture limited. Various soils of low water permeability and high density are also common (Cochran 1985).

Considerable genetic variation exists within the population of lodgepole pine occupying east-slope Rocky Mountain ecosystems. Differentiation within this widespread population occurs across relatively minor environmental gradients, particularly for cold hardiness, periodicity of shoot elongation, and disease resistance (Hoff 1985; Rehfeldt 1985). There is a strong elevational factor in this

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variation (Rehfeldt 1985). Thus, in a highly diverse climatic, physiographic, and geological environment, tree adaptation to local conditions is important for good performance and for moderating pest-related problems.

Lodgepole pine is usually considered a fire-maintained seral species, although its characteristics vary considerably. It is an aggressive species, highly suited to pioneering environments. Cone serotiny provides an excellent means of storing and protecting genetic materials in a fire-dominated ecosystem. However, periodic stand replacement by fires is common, serotiny is variable, and fuel accumulations are sometimes high (Lotan and others 1985). Therefore, genetic materials are likely often at risk. At least local, and perhaps extensive, maladaptation of lodgepole populations in some environments is probably common though perhaps of short duration.

For example, as described by Romme and Knight (1981), midslope fires are more common than low- or high-elevation fires. If a hot, seed-destroying, midslope fire occurs, reforestation is likely to result from high- or low-elevation seed not well adapted to the midslope site. Thus, fire history may control local adaptation and even localized maladaptation may lead to poor performance and pest damage.

East-slope Rocky Mountain lodgepole pine represents a genetically fine-tuned, aggressive species operating on slim resources in a disturbance-prone, harsh, highly variable environment where constant physiological and genetic adjustments are required. In short, it is a highly dynamic system where trees are likely to be responsive to plant-microbe interactions, either positively or negatively. In discussing these interactions, we will emphasize microbial processes involved in the nitrogen economy of the soil (primarily fixation and mineralization, see table l), uptake of nutrients (especially nitrogen) by pine root systems through the formation and activity of ectomycorrhizal fungi, and activities of specific pathogens (primarily endemic root rots) as exemplified by species of Armillaria. Other pathogens in lodgepole pine ecosystems, some more important than root rots, have been discussed elsewhere (Krebill 1975: van der Kamp and Hawksworth 1985).

NITROGEN DYNAMICS AND SOIL ORGANIC MATTER

Most site N reserves are incorporated into the molecular structure of soil organic matter (OM). The remainder is incorporated into living or dead plant bodies. Aspects of how N is brought into and moves within soil, root, and aboveground components of an ecosystem are useful in determining how best to deal with a nutrient usually limiting to tree growth. Table 1 defines terminology required to examine N dynamics.

Active N conversion processes are common to all ecosystems, but rates, quantities, and distributions are variable. Management options can be limited by any of these three factors. East-slope lodgepole ecosystems are most likely to be constrained by low amounts of total N accumulation (either from fixation or

Table 1--Definition of terms used to describe aspects of the nitrogen economy of forest soils

Term	Definition
Fixation[1]	Conversion of atmospheric N to soil N.
Nonsymbiotic	By organisms (bacteria and algae) living free in soil and other environments.
Symbiotic	By organisms (bacteria) within root nodules of living plants.
Available N	That portion of soil N in a form usable by plants.
Immobilized N	That portion of soil N tied up in organic compounds of living or dead organisms and not available for uptake by vegetation.
Mineralization[1]	Process of converting immobilized N to available N through microbial decay (bacteria and fungi).
Ammonia	NH_3, a preferred form of available N for lodgepole pine.
Nitrate	m_3, a form of available N subject to leaching loss.
Nitrification	Process of converting NH_4 to NO_3 by nitrifying organisms (bacteria).
Total N[1]	Total amounts of organic and inorganic N, all forms (N storage).

[1]potentially most limiting to N economy of lodgepole ecosystem.

atmospheric pollution) and slow rates of conversion (mineralization) into a form suitable for uptake by pine roots (Yavitt 1984; Yavitt and Fahey 1986). Both are temperature and moisture limited — major considerations on Rocky Mountain sites.

Table 2 shows the distribution of total nitrogen in two contrasting lodgepole stands in Wyoming; one is a typical small-stem, doghair stand, the other an open-grown stand. These data show that soil On, including decayed woody debris, stores well over half the total N on these sites. Most of the rest is contained in small branches, twigs, foliage, or fine roots. Stem components have relatively small amounts of N, although the doghair stand has more N in bolewood than the open-grown stand (Yavitt 1984). Thus, harvesting or site preparation methods that destroy, displace, or remove nonbolewood components are likely to impose significant losses on N reserves.

Minor losses of nitrogen are probably not a great problem on many sites with good sources of N input, either biological (fixation) or via air pollutants. However, most east-side lodgepole pine sites have neither. Table 3 provides some estimates of major inputs and losses of N to an east-side forest soil, again based on a study in a Wyoming lodgepole stand. These data emphasize that rates of external input are low and that most of the N available for tree growth comes from internal cycling processes (Yavitt 1984). Any substantial losses of N reserves will be replaced slowly and are likely to cause productivity loss (Flinn and others 1980; Weber and others 1984). Because most of the site N reserves are contained in soil On layers, depth variations from site to site or On losses are likely to be reflected in growth rates of the trees (Graham and others in press; Weber and others 1984).

Examining an annual root zone N budget is instructive for analyzing N transfers within an ecosystem. Table 4 shows that most of the N in the root zone is contained in soil organic materials or in tree roots, and that movement of nitrogen among soil components and plant

Table 2--Total nitrogen distribution in contrasting 80-to 100-year-old *Pinus contorta* ecosystems of Wyoming, calculated from Yavitt (1984)

	Doghair stand		Open stand	
	- - - - Percent - - - -			
Trees				
Foliage	[1]10		[1]7	
Branch and twig	[1]6		[1]7	
Bole	[1]8		[1]6	
Root crown	1		1	
Lateral roots	5		1	
Fine roots	11		7	
Total	41		29	
Debris				
O_1 horizon	[1]17		[1]14	
O_2 horizon	[1]37		[1]40	
Total	54		54	
Dead fall	5		0	
Dead wood	0	—	[1,2]17	—
Total	5	[3]83	17	[3]91
Total for all soil OM to 100-cm depth	570g/m²		650 g/m²	
Ecosystem total	618g/m²		735 g/m²	

[1]Sources of N highly vulnerable to burning or mechanized removal.
[2]Where a previous old-growth stand was terminated by wildfire and substantial volumes of bole wood remained, N storage in the decayed wood component can exceed that stored in the other debris components by two to three times (Fahey 1983).
[3]Total percentage of N that is vulnerable to burning or mechanized removal.

Table 3--Some major soil nitrogen gains and losses from a typical, 80-year-old Wyoming lodgepole pine stand, calculated from Yavitt (1984)

Source	Percentage annual N budget
Gains	
Rain	5
Snow	2
Throughfall	8
Nonsymbiotic fixation	<1
Symbiotic fixation	3
Litter fall	17
Mineralization release from soil OM	25
Losses	
Immobilization in soil OM	14
Vegetation uptake	25
Leached to or below subsoil	<1

uptake are slow (Yavitt 1984). In particular, mineralization activities are extremely slow. Although this is a potential advantage from the standpoint of nitrate loss below the root zone (Vitousek and others 1982), it also shows that the temperature and moisture limitations of these soils inhibit the decay process and make it difficult to get N released from soil OM. Not only is it difficult to get N on these sites, it is also a problem to get the N released in a form suitable for uptake and use by the trees (Fahey 1983; Yavitt and Fahey 1986; Yavitt 1984).

Although the process of nonsymbiotic nitrogen fixation contributes little to N input in an 80-year-old Wyoming lodgepole pine stand (Yavitt 1984; table 31, this process is active in western Montana forest ecosystems (Jurgensen and others 1979; Larsen and others 1980). Also, at least under relatively warm, moist, midsummer conditions, nonsymbiotic N-fixation rates at a high-altitude, western Wyoming site can be substantial (Jurgensen and others 1982). Rates of fixation and daily accumulation can be at least as high as those in western Montana (table 5). However, warm, mist conditions are infrequent in east-side forests, so annual accumulations from thio source are likely small.

Because N-fixing organisms can be effective in east-side lodgepole pine soils under appropriate conditions, management actions that increase soil moisture or temperature should enhance nonsymbiotic nitrogen fixation (and mineralization). Because decayed and decaying wood can be particularly active sites of nonsymbiotic N fixation (Larsen and others 1980), modest quantities of postharvest woody residues left on site should further enhance nitrogen input, as would encouraging symbiotic N-fixers as components of the understory vegetation (Jurgensen and others 1979, 1982; Yavitt 1984).

Rates of wood decay reported for Montana and Wyoming sites (Fahey 1983; Harvey and others 1981) indicate that substantial decay should occur within 60 to 100 years and that decayed wood in contact with the soil can become an important site for nitrogen storage (table 6). Large- diameter residues, if in contact with the soil, may decay faster than small ones that rapidly dry out because of the limited summer moisture on many east-side sites. This has been reported for a variety of forest ecosystems in Washington (Erickson and others 1985). Leaving large-diameter residues is also a consideration for encouraging ectomycorrhizal activities in Northern Rocky Mountain forest soils (Harvey and others 1978, 1979, 1986).

DISTRIBUTION AND ACTIVITY OF MYCORRHIZAE

Mycorrhizal infection of root systems is considered an important adaptation of pines for normally infertile ecosystems (Harley 1969;

Table 4--Annual soil root zone nitrogen budget, in percentage of total for 1 year, from typical 80-year-old Wyoming lodgepole pine stand, calculated from Yavitt (1984)

Root zone N		N conversions		Vegetation use of N	
Roots	42				
Soil organic matter (to 100-cm depth)	40	Mineralized	5		
				Vegetation uptake	5
Soil solution	3	Immobilized	4		
To and below subsoil	1				
Totals	86		9		5

Table 5-- Comparative nonsymbiotic nitrogen fixation rates and amounts (among soil components) between a moderate, 250-year-old, west-slope subalpine fir stand in Montana and a cool, 160-year-old, east-slope lodgepole pine stand in Wyoming (midsummer measurements) after Jurgensen and others (1982)

Soil component	Rate/day (gN[X10^{-9}]g^{-1})		Amount/day (gN/ha)	
	Montana	Wyoming	Montana	Wyoming
Humus	0.3	2.1	<0.1	0.1
Decayed wood	28.1	35.9	1.2	.2
Mineral transition layer[1] (0 to 5 cm mineral)	2.1	2.7	2.9	3.8
Mineral (5 to 30 cm mineral)	[2]0.7	.8	5.1	2.3

[1]Mineral transition layer described as first 5 cm of mineral soil; mineral includes the rest of the mineral soil in core sample to a 30-cm maximum depth.
[2]Based on an assumed one-third of mineral transition layer rate.

Miller and others 1979). Formation and activity of mycorrhizal root systems on lodgepole pine seems particularly important for pioneering environments with young trees (Grossnickle and Reid 1982). Lodgepole appears typical of all Pinus spp. in that it is responsive to the presence and activity of mycorrhizal fungi (Grossnickle and Reid 1982) and in some instances it may be particularly responsive to selected species of mycorrhizal fungi (Molina and Trappe 1982).

Old decayed logs deposited on or incorporated in forest soils are an important organic constituent of east-side soils. Up to 15 percent by volume of western Montana forest soils (top 30 cm) can be made up of decayed wood (Harvey and others 1976). High concentrations of ectomycorrhizal activities in soil wood have been reported during dry seasons (Harvey and others 1978) and on dry sites (Harvey and others 1979). Thus, deposits of decayed wood derived from large residues in forest soils should enhance productivity of the site for lodgepole pine in moisture-limited areas. We currently recommend that 10 to 15 tons of 6-inch+ residues/acre (2.4 to 3.6 tons of 15 cm+ residues/ha) be left on the site after harvesting (Harvey and others 1986a,b in press).

Table 7 compares the distribution of ectomycorrhizal activities between a western Montana (west side of Continental Divide) and north Western Wyoming (east side) site. These data show organic soil layers are extremely limited on the east-ride site when compared to the west-side site and that, despite this limitation, ectomycorrhizal activities are also concentrated in the sparse organic layers of east-slope soils.

Because organic layers constitute a shallow horizon on the soil surface, usually less than 1.7 inches (4 cm) in Northern Rocky Mountain forests, feeder root activities are usually a surface phenomenon (Harvey and others 1986). The concentration and turnover of conifer fine roots near the soil surface, particularly in organic horizons rich in nutrients (Coutts and Philipson 1977), make significant contributions to soil OM (Vogt and others 1983). Their shallow nature also makes feeder roots subject to potential disruption by management activities that disturb the soil surface (Harvey and others 1986; Perry and others 1982). Therefore, conservation of soil OM, including old, decayed residues and stumps, appears desirable in mort lodgepole pine forests. However, where such materials might serve as a potential disease inoculum source, different rules must be applied.

DISTRIBUTION, ACTIVITY, AND DAMAGE POTENTIAL OF SELECTED PATHOGENS

Although it is our intent to emphasize aspects of root disease pathology in this report because of the relationship with residue and OM management, we will also review some other aspects of pathology potentially important to east-side lodgepole pine management. This review will be brief because lodgepole pine disease relationships have been discussed in recent literature (Krebill 1975; van der Kamp and Hawksworth 1985).

The five major disease classes and their relative importance to the lodgepole pine resource are: (1) dwarf mistletoe, (2) native rusts (primarily stem rusts), (3) root and stem decays, (4) stem cankers, and (5) foliar disease. (table 8). Dwarf mistletoe is a widespread, highly destructive disease. Perhaps as many as 50 percent of the lodgepole pine stands on east-slope sites are infested (van der Kamp and Hawksworth 1985). Fortunately, management methods to reduce damage from this disease are available, although applying them is often difficult.

Table 6 - Decay and nitrogen content in dead lodgepole pine bole wood and residue suspended above and lying on soil in Wyoming, after Fahey (1983)

Residue description	Weight loss	Age	Specific gravity	N. content	N gain
	Percent	Yr	(g/cm³)	- - - Percent	- - -
Standing dead	20	110	--	--	--
Suspended deadfall	10	80	0.41	0.065	0
Deadfall on ground (cylindrical)	60	[1]55	0.34	0.085	[2]31
Deadfall on ground (compressed)	--	--	0.24	0.20	208

[1]Assumes falldown occurred at 15 years.
[2]Increase over suspended stage.

Table 7 - - Comparative distribution of ectomycorrhizal activity (among soil components) between a moderate 250 - year - old, west - slope stand in Montana and a cool 160 - year - old, east - slope stand in Wyoming. The latter supports primarily lodgepole pine; both are classified within the subalpine fir habitat series

Soil component	Soil component volumes		Number of active short roots	
	Montana[1]	Wyoming[2]	Montana[1]	Wyoming[2]
	- - - - - - - - - - -	Percent	- - - - - - - - - - -	
Litter	2^{a3}_{x}	2^{a}_{x}	0^{a}_{-4}	6^{a}_{x}
Humus	13^{a}_{y}	3^{a}_{x}	74^{b}_{x}	37^{a}_{y}
Decayed wood	14^{a}_{y}	1^{a}_{y}	19^{a}_{yz}	28^{a}_{y}
Mineral transition layer[5] (0 to 5 cm mineral)	16^{a}_{y}	16^{a}_{x}	6^{a}_{y}	28^{a}_{y}
Mineral (5 to 30 cm mineral)	55^{a}_{z}	78^{a}_{z}	1^{a}_{z}	1^{a}_{x}
All organics combined	29^{a}_{x}	6^{b}_{x}	93^{-}_{x}	71^{-}_{x}
All minerals combined	71^{a}_{y}	94^{b}_{y}	7^{-}_{x}	29^{-}_{x}

[1]Montana data derived from Harvey and others (1978).
[2]Wyoming data derived from Jurgensen and others (1982); data from both States at estimated site maximum (late spring), see Harvey and others (1978).
[3]Differing letters indicate significant differences between sites (a,b) or within site (x, y, z), based on two-sided t-test.
[4]Indicates comparison not possible or available.
[5]Mineral transition layer described as first 5 cm of mineral soil; mineral includes the rest of the mineral soil in core sample to a 30-cm maximum depth.

Table 8--Fungus-caused diseases, by class, listed in approximate descending order of risk to lodgepole pine, after Ives (1983), Krebill (1975), and van der Kamp and Hawksworth (1985) (taxonomic designations as currently accepted)

a. Stem rusts

Endocronartium harknessii (J.P. Moore) Y. Hirats

Cronartium coleosporioides Arth.

C. commandrae Peck

C. comptoniae Arth.

b. Root decays

Armillarea mellea (Vahl:Fr.) Quel.

Inonotus circinatus (Fr.) S.C.Teng (=Polyporous tomentosus var. circinatus)

Phaeolus schweinitzii (Fr.) Pat. (=Polyporous schweinitzii)

Inonotus tomentosus (Fr.) S.C.Teng (=Polyporous tomentosus)

Phellinus weiri (Murr.) Gilberts.(=Poria weirii)

Verticicladiella wageneri Kendr. (=Ceratocystis wageneri)

Heterobasidion annosum (Fr.) Bref. (=Fomes annosus)

Mixtures and others

c. Stem decays

Phellinus pini (Bros.:Fr.) A. Ames(=?Phellinus vorax)

Peniophora pseudo-pini Weres. et Gibson

Coniophora puteana (Schum.:Fr.) Karst.

Stereum sanguinolentum (Alb. et Schwein.:Fr.)Fr.

Inonotus tomentosus (Fr.) S.C. Teng

Dichomitus squalens (Karst.) Reid (=Polyporus anceps)

Mixtures and others

d. Stem cankers

Atropellis piniphilla (Weir) Lohman et Cash

A. pinicola Zeller et Good.

Dasyscyphus sp. Gray

Tympanis sp. Tode

Diplodia sp. Fr.

Valsa sp. Fr.

Others

e. Foliar diseases

Lophodermella concolor (Dear.) Darker

L. montivaga Petrak

Elytroderma deformans (Weir) Darker

Lophodermium pinastri(Schred.ex.Hook.)Chev.

Scirrhia pini Funk et Parker (=Dothiostroma Pini)

Coleosporium asterum (Diet.) Syd.

Others

f. Stains

Amylostereum sp. (Boid.) (=Stercum)

Ceratocystis sp. Ell. et Halst(=Ophiostoma)

Europhium sp. A. K. Parker

Leptographium sp. Lagerb. et Melin

Verticicladiella sp. S. Hughes

Others

Native rusts (Cronartium spp.) are also widespread and capable of inflicting heavy damage (Krebill 1975). However, geographic, site, and habitat type factors limit the distribution of several important native rusts (Beard and others 1983; Geils and Jacobi 1984). Also, in cases where an alternate host is required, there is the additional requirement for conditions suitable to support the alternate host in proximity to susceptible forest stands (Krebill 1975). Thus, distribution of many rust diseases tends to be highly discontinuous. Those that do not require the alternate host, for example gall rust. tend to be more widespread. In general, thinning, spacing, and pruning are effective controls, except where damage (and risk) is high. Under such conditions, stocking levels should be high enough to offset mortality. Genetic resistance to native rusts has been noted (Hoff 1985) and will eventually play a significant role as an aid in controlling theme diseases in high-damage, high-risk circumstances.

Potentially, the most damaging root rot pathogen is likely to be Armillaria (James and others 1984; Krebill 1975; Morrison 1981; van der Kamp and Hawksworth 1985). However, recent work at the Intermountain Research Station indicates that Armillaria distribution and damage is strongly constrained by habitat type (climate) throughout most of the Inland Northwest, including many habitats likely to support east-side lodgepole pine stands (McDonald 1985, personal communication). Table 9 shows the distribution of this inportant pathogen, and damage patterns, on a number of east-slope sites. These data, though limited, indicate high potential for damage due to Armillaria activity only in relatively productive habitat types for the area (ABLA/CLUN, ABLA/MEFE, ABLA/VAGL, PSME/PHMA, PSME/VAGL). A substantial portion of east-slop. habitat types may be beyond the environmental latitude of this organism and are, therefore, not likely at risk.

Table 9--Status of Armillaria on 0.04-ha plots (all conifer species)[1] located in subalpine fir and Douglas-fir habitat series in the Northern Rocky Mountains. listed in approximate order of decreasing risk to disease damage. after McDonald and others [in press]

Habitat type	Climatic characterization	Number of plots	Percentage with Armillaria	Percentage with pathogenic Armillaria
Abies lasiocarpa series[2]				
ABLA/CLUN	Cool/moderate	5	80	100
ABLA/MEFE	Cold/moderate	6	83	60
ABLA/VAGL	Cool/dry	3	100	33
ABLA/ALSI	Cold/moderate	2	100	0
ABLA/ACGL	Cool/dry	1	100	0
ABLA/CACA	Cold/wet	1	0	--
ABLA/STAM	Cold/wet	1	0	--
ABLA/VACA	Frost pockets	2	0	--
ABLA/XETE	Cold/dry	6	0	--
ABLA/VASC	Cold/dry	8	0	--
Pseudotsuga menziesii series				
PSME/PHMA	Warm/dry	6	67	75
PSME/VAGL	Cool/dry	2	100	50
PSME/VACA	Frost pockets	1	0	--
PSME/JUCO	Hot/dry	2	0	--
PSME/CARU	Hot/dry	6	0	--

[1]Lodgepole pine can be considered moderately susceptible to damage by this important disease.
[2]Habitat series designations as reported in Pfister and others (1977).

In areas of high damage potential, residue management practices may affect this disease. Armillaria uses stumps, root systems, and perhaps logging slash as a food base from which to infect living trees. Thus, a reduction of food base materials should be of somebenefit, at least to heavily impacted areas. This may also be the case in moderate-hazard habitat types with visible damage. Disturbance frequently leads to increased Armillaria damage (McDonald and others, in press; McDonald 1985 personalcommunication). However, lodgepole pine is only moderately susceptible to this disease, and most other root rots as well (Hobbs and Partridge 1979; James and others 1984; McDonald and others, in press). Therefore, the primary damage and benefits frommanagement would likely be in fir and spruce components of mixed stands.

Other root rot and stem decay organisms also have discontinuous distribution patterns (Bella 1985; Vyse and Navratil 1985; Whitney and others 1983). In these cases, our knowledge of distribution patterns is fragmentary and not helpful for assessing potential risk in the absence of diagnosed damage in or near a stand to be harvested. Root rots, other than Amillaria, are not likely to be affected by residue management methods. Phallinus root rot management has been attempted in the Pacific Northwest with removal of infected stumps (Theis and Russell 1984). Results do not appear cost effective, particularly for low- productivity sites. It is, however, unlikely that Phellinus will cause significant damage to lodgepole pine and of the ContinentalDivide. Residue removal may reduce inoculum load (spores) for stem decay organisms likely to produce fruiting bodies on logging slash. However, only 16 fungi have been reported to decompose logging slash and cause significant losses in live, standing timber (Spaulding and Hansbrough 1944), and many of these are not common in the Rocky Mountains. In most cases, spores arriving from outside harvested stands are probably sufficient to cause infection of residual trees if historical damage in the stand has been high.

As with Armillaria, the incidence of other root and stem decays, and other diseases as well, can be increased with partial cutting (Bella 1985; Johnstone 1981). In most cases, the affected diseases are those already evident in the stand before harvest. In the case of high hazard Armillaria sites (table 9), damage might not be evident before harvest. In high-hazard habitat types, it would be prudent to treat as if postharvest damage by Armillaria is likely--favor resistant species and remove any infected slash.

There are potentially important root decay scenarios with lodgepole pine that involve interactions between the respective pathogens and insect pests or fire. In one, insects (Dendroctonus spp.) simply act as a vector (carrier) for black root stain (Verticicladiella spp.). This disease has considerable potential to damage lodgepole pine in the Interior West (Bertagnole and others 1983, Hobbs and Partridge 1979; James and others

1985). Fortunately, it does not persist in dead root systems, so it can be managed with appropriate harvesting.

In another scenario, fire damage to roots provides infection courts for root and stem decay organisms in Oregon. Infection predisposes trees to insect attack (Dendroctonus ponderosae Hopk.), providing dispersal trees that increase insect damage and mortality, eventually leading to return of fire (Gara and others 1985). Presumably, managing such stands (fuel) to limit fire could break this cycle and, in turn. reduce root rot, decay, and insect damage.

Lastly. a significant and consistent association between infection of the root pathogen Armillaria and incidence of infestation of mountain pine beetle (Dendroctonus ponderosae Hopk.) in lodgepole pine has also been documented in Utah. In this case it was suggested that survival of the insect during its low-population cycle may be favored by the presence of Annillaria root disease (Tkacz and Schmitz 1986). An association with fire-damaged roots as a predisposing factor, as noted by Gara and others (1985) was not observed. However, damage by dwarf mistletoe (Arceuthobium americanum Nutt. ex Engelm.) and comandra rust (Cronartium comandrae Pk.) were noted as possible predisposing factors.

There are also two decay-related disease scenarios where exclusion of pathogens may became an important management consideration for east-side lodgepole pine. One pertains to annosus root rot (Heterobasidion annosum, see table 8). This pathogen, thus far, is relatively rare in lodgepole pine stands of the western United States and Canada. However, it causes a great deal of damage in other parts of the world. The organism native to our area may not be as pathogenic as elsewhere (van der Kamp and Hawksworth 1985). If so, excluding more pathogenic strains may be critical. If imported, more damaging strains may have potential to become established and cause extensive damage.

The second pathogen is the organism responsible for Armillaria root rot. Armillaria mellea (table 8) has been generally assumed to be the damage-inciting culprit. However, there is increasing evidence that several Armillaria species may be involved or that there may be variation within the species that affects the distribution and damage patterns shown in table 9 (McDonald 1985, personal communication). If this turns out to be the case, local and regional exclusion or measures specific to Armillaria species present may be helpful for limiting this disease in the future.

Most other common diseases of lodgepole pine (table 8) are only locally important and infrequently inflict major damage. Atropellis canker and several foliar pathogens can cause serious damage, but the damage is usually limited to small areas. If economical, development of resistance is a viable approach for dealing with many of these relatively minor pathogens. In some instances, thinning can reduce infection levels (Stanek and others 1986; Whitney and others 1983). Table 10 summarizes disease damage potential and possible controls for east-side lodgepole pine stands. All in all, our pathological problems generally appear less limiting than insect, soil productivity, silvicultural, or economic problems. However, the presence of disease damage potential, particularly by dwarf mistletoe, root rots, or native rusts, complicates other limitations because management actions that solve one problem frequently complicate or enhance others.

THE TRADEOFF PROBLEM AND SITE-SPECIFIC MANAGEMENT

Management of east-side lodgepole pine frequently presents choices in offsetting values, particularly with respect to manipulating microbial actions. For example, residue reduction (inoculum removal) for Armillaria, control reduces N reserves, OM, and N-fixation. Similarly, fuel management involves short-term reductions of OM. However, long-term protection against excessive losses of OM, and retaining high- N-content foliage and twigs may increase inoculum for foliar pathogens. Broadcast burns that protect N reserves may not be intense enough to control competition or provide adequate site preparation. On the other hand, too much site preparation may result in high seedling density, but reduces early root proliferation and extension.

Table 11 is provided as a reminder of some hypothesized estimates of major tradeoffs to emphasize that the manager is slave to many masters. The determination of which master is most critical to a particular site is the most difficult assessment. This becomes particularly difficult in instances where time since disturbance can completely change potential impact, for example, decay of fine fuels versus large fuels. If properly determined, conflicts can be minimized, and those that remain can be addressed with reasonable confidence in an appropriate outcome.

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Table 10--Relative damage and treatments for fungus-caused diseases of lodgepole pine, after Ives (1983), Krebill (1975), van der Kamp and Hawksworth (1985), Whitney and others (1983)

Disease class	Potential control	Damage potential
Stem rusts	Selective removal	Generally moderate, but locally high
	Alternate host control for *Cronartium* sp.	
	Resistance	
Root decays	Clearcut	Generally moderate, but locally high
	Stump removal or treatment	
	Broadcast burn?	
	Species conversion or mix	
	Avoid or treat high hazard sites	
	Guard against import or movement of disease organisms?	
	Use resistance if it becomes available? Do not use highly susceptible species on high hazard sites	
Stem decays	Reduce residual stand damage	Generally low, but locally high
Stem canker	Stand opening	Locally moderate
	Avoid or treat high hazard sites	
Foliar diseases	Use resistance if it becomes available?	Generally low, but locally and temporally moderate

Table 11--Some examples of hypothesized tradeoffs between beneficial (+) and detrimental (-) environmental effects of some selected stand treatment alternatives on lodgepole pine ecosystems

Treatment alternatives	Environmental effect			
	Fire hazard	Pest hazard	Symbiont[1] activity	Nutrient supply
Clearcut (conventional utilization)	+-[2]	+-	+-	++
Clearcut (intensive utilization)	+	++	-	+-
Thin (heavy)[3]	+-	+-	+-	+
Thin (light)[3]	+-	+-	0	+
Mechanical site prep.	++	+	-	--
Prescribed burn	+	+	-	+
Pile and burn	+	+	-	--
Windrow and burn	+	+	-	-
Wildfire (hot)	++	++	--	--
Planted tree regeneration	0	+	+	0
Natural tree regeneration	0	+-	+	0

[1]Includes both ectomycorrhizal and free living, N-fixing bacterial activities based primarily in soil organic layers.

[2](+-) indicates effect depends on time, local conditions, or degree of treatment; (0) indicates no effect; (++ or --) indicates effect is very strong.

[3]For example, one-third and two-thirds stand density reduction (thinning) treatments described in STEM field site descriptions (this proceedings).