APPENDIX E
Fires Effects on Soils

Appendix E

Fires 2000 Assessment

FIRE EFFECTS ON SOILS

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I. GENERAL DISCUSSION

The following discussion will provide some information on the effects of fire on the soil ecosystem. The emphasis is placed here because the long-term effects of fire may be more critical to soil organisms, (especially mychorrizae) are very important to forest productivity and community dynamics (Molina and Amaranthus 1990). There are many sources related to "managed" fires but very few documents concerning natural fires. Even though timing and intensity may vary, the assumption is made that there is little difference between the effects relating to the two types of fire. Visible effects of fire are very obvious--charred vegetation, litter absence, black stems, red needles on trees, bare mineral soil, etc. The more subtle impacts can occur on or beneath the soil surface. This discussion will deal with impacts related to fire disturbances on or beneath the soil surface.

A. Definitions

The following definitions are necessary to better understand activities occurring beneath the soil surface:

Mycorrhiza (means "fungus root")- represents the intimate association between the fine roots of plants and specialized symbiotic fungi (Molina and Amaranthus 1990, Peyronel et al. 1969).

- Ectomycorrhizal - the fungus develops only outside the root cells.
- Endomycorrhizal - the fungus only grows within the root cells.
- Ectendomychorrizal – the fungus forms outside the root cells and also penetrates to grow within them.

Rhizosphere - islands of intense biological activity centered at the root (especially fine roots) surface and adjacent soil. This is where the majority of soil nutrients are recycled and retained (Molina and Amaranthus 1990).

Soil Ecosystem -the community of soil organisms and the nonliving environment in which they reside.

Symbiosis - close physical association when two organisms interact (Borchers and Perry 1990).

B. Fire intensity (see * and ** below)

1. Surface Soil Impacts

Fire intensity in relation to surface organics and soil impacts can be rated many ways. Two methods are listed below.

a) Unburned is that surface condition, which for one reason or another escaped the fire,

b) Light burn is defined as that surface condition in which fire has charred the surface of organic litter but has not removed all litter from the soil surface,

c) Severe burn is defined as that surface condition in which fire has removed all organic litter from the ground surface and in addition has baked the mineral soil to a highly colored, crusty state, **AND**

a) Low intensity is that condition in which fire has not destroyed soil surface litter and humus:

1) root crowns and surface roots will resprout,
2) potential surface erosion has not changed as a result of fire,
3) fuels up to ¼ inch and less than 40 percent of the brush canopy are burned,
4) a sparse layer of dark ash is present, and
5) the surface litter is singed.

b) Medium intensity is where, on up to 40 percent of the area, soil surface litter and humus, have been destroyed by fire and the A horizon has had intense heating:

1) some crusting of soil surface can produce accelerated surface erosion,
2) intensively burned areas may be water repellent,
3) many of the root crowns will resprout,
4) some surface roots of grasses in the intensively burned area are dead and will not resprout,
5) surface litter is charred but not ashed, and
6) surface ash is dark in color.

c) High intensity is where, on more than 40 percent of the area, soil surface litter and humus have been completely destroyed by fire and the A horizon has had intense heating:

1) crusting of soil surface produces accelerated surface erosion,
2) intensively burned areas may be water repellent,
3) many root crowns and surface roots of grasses in the intensively burned area are dead and will not resprout,
4) no residue or only a few ashes remain on the soil surface, and
5) fuels greater than ¾ inch and more than 80 percent of the plant community have been consumed.

** The Unburned, Light, and Severe grouping is from Tarrant 1956. The Low, Medium, and High grouping is from the Burned-Area Emergency Rehabilitation Handbook 2000 (FSH 2509.13).*

*** It should be noted that the author has observed all of these conditions on all natural fires on the Kootenai. However, the amount of each condition varies from fire to fire, from year to year, and from vegetation type to vegetation type. On the fires this summer (2000), as well as those observed during the past 30 years, three to six percent of a fire area fall in the high category. Percentages in the other categories vary depending on the intensity and duration of the burn as affected by the aspect, elevation, wind, vegetation type and density, moisture content of the surface organics and surface soil. Both the severe or high conditions have been very limited and don't pose a threat to the lands of the Kootenai. Even Tarrant (1956) generally did not observe severe burn exceeding five percent.*

2. Above Ground Vegetative Effects

On the Kootenai National Forest the surface soil definitions are supplemented with the implications of impact on the vegetation. The above-ground vegetation information comes from USDA 2000 and contains a low, medium, and high grouping also. In low intensity areas, depending on the species and the age, 20 percent or less of the overstory is killed. A very patchy burn pattern occurs with little or no tree damage visible in some areas. In medium intensity areas, 20 to 70 percent of the overstory is killed depending on the species and age; 50 percent of the

aboveground understory vegetation is "killed back"; and less than 25 percent of the understory is killed. In high intensity, 70 to 100 percent of the overstory vegetation is killed. The same percent of above-ground under story vegetation is removed, while 50 percent of the understory plants are killed.

C. Soil Organisms

Based on Brady (1984), Richards (1987, Borchers and Perry 1990, and Perry 1994), soil organisms are grouped by size:

1) Macrobiota—(usually more than one cm. in length.)--plant roots that include mycorrhizae, nitrogen-fixing bacteria, and other symbiotic organisms; plant eaters-insects, millipedes, sowbugs, slugs and snails, and earthworms; predatory-insects mites, centipedes and spiders.

2) Mesobiota—(usually 200 um to 1 cm. in length)--nematodes, protozoa, rotifers, springtails, enchytraeid worms, and mites. Most of the soil animals are in this group.

3) Microbiota—(usually 200 um or less in length and invisible to the naked eye)--filamentous fungi, yeasts, and slime molds; actinomycetes and cyanobacteria; green algae and diatoms; and protozoa, nematodes, rotifers, and mites.

Some of the benefits of mychorrizae to plants include enhanced uptake of nutrients (increased surface area) and water (contribute to aggregate formation and stability), protection against pathogens, improved resistance to drought, enlarged root systems, tolerance to heavy metal, and accelerated decomposition of primary minerals (Molina and Amaranthus 1990). Amaranthus et al. (1987), in southwest Oregon, found that mycorrhizae are necessary for drought resistance and general establishment of conifers.

The following is an example of the importance of below surface organisms: Bacteria and fungi alone can amount to 4,000 pounds in some forest soil ecosystems (Bollen 1974). Soil organisms are much more abundant on (in the organic mat) or near the soil surface. This is part of a complex relationship between soil moisture, soil temperature, food supply, and soil aggregation. Soil organisms are affected by the environment around them and in turn affect the environment. Ultimately, they are a major factor in soil formation.

According to Borchers and Perry (1990), soil organisms are not only influenced by soil aggregation, but they are largely responsible for it. In a relatively undisturbed soil, individual particles are usually bound into aggregates. Well-aggregated soil ensures a proper balance between air and water content, which is necessary for root survival. Mycorrhizae, their hyphae, and bacteria are major agents of soil aggregation because they release organic glues that stabilize mineral particles into aggregates. An illustration is: the better the soil aggregation the better the porosity the better the infiltration rate the better the root development the better the vegetative growth.

The benefits of below-ground soil organisms cannot be understated (Molina and Amaranthus 1990). They enhance the uptake of nutrients and water; help protect plants against pathogens; play a large role in enlarging root systems; provide a tolerance to heavy metals; help improve resistance to drought; aid in the decomposition process; release nitrogen in a form available to plants; contribute to soil aggregate formation and stability; and keep nutrients from leaching out of the system, especially soluble nitrogen.

II. FIRE INFLUENCE

Fire affects the soil community directly by immediately killing or injuring organisms. Indirectly, it has longer-term influences on plant succession, soil organic matter transformations, and microclimate (Borchers and Perry 1992). Anything that kills or injures living plants also impacts those organisms that depend on their products for energy, nutrients, or habitat. This is especially true within the rhizosphere. Combustion of coarse woody debris, forest floor litter, and organic matter can have immediate and long-term consequences. Changes in the soil environment include altered acidity, changes in nutrient availabilities, and altered temperature regimes (Graham et al. 1994, Neal et al. 1965, Raison 1979, Woodmansee and Wallach 1981). The soil organisms can be categorized into invertebrates, microbes, and mycorrhizae.

A. Soil Organisms

1. Effect on Soil Invertebrates

Most studies reveal that soil invertebrate activity is decreased from months to several years by fire (Metz and Dindal 1980). Sometimes the diversity changes, yet the overall numbers are still reduced (Metz and Frazier1973). Downward migration may also occur, temporarily increasing these numbers at lower depths (Borchers and Perry 1990). In Montana, Fellin (1980) compared several silvicultural treatments under two residue treatments. Significantly fewer arthropods resulted from both treatments, with about half the loss attributed to burning. The greater the canopy left, the greater the numbers of arthropods. These effects are probably associated with temperature differences. In general, the initial impact can be drastic but transitory.

2. Effect on Soil Microbes

Heat affects microbial types differently; fungi are generally the most susceptible, actinomycetes least, and bacteria intermediate (Borchers and Perry 1990, Ahlgren 1974, Harvey et al. 1976, Wells et al. 1979, Perry and Rose 1983). A post-fire soil environment generally consists of decreased plant competition for nutrients, less acidity, and greater temperature extremes, especially on the surface soil layers (Neal et al. 1965).

The relationship between the various microbes is usually altered. In relationship to each other, bacteria often increase greatly over fungi. If some of the bacteria are the nitrifying kind, nitrification will result in a loss of nitrogen from the ecosystem unless intercepted by regrowing vegetation (Vitousek et al. 1979). CWD plays a role in the forest ecosystem as habitat for non-symbiotic, nitrogen-fixing bacteria that is needed (Silvester et al. 1982). It appears that maintenance of CWD, especially on the high intensity burn areas, is an important management activity.

3. Effects on Mycorrhizae

Generally, mycorrhizal fungi are dependent on their hosts to complete their life cycle. For this reason, complete removal of vegetation from a site does not favor their continued presence. Similarly, commercial tree species require fungal partners, especially as seedlings in harsh environments. Various studies have found that trees growing in soils from burned clearcuts have fewer mycorrhizae than trees found in soils from unburned clearcuts or undisturbed forests (Borchers and Perry 1990). It should be noted that some shrubs act as banks, holding mycorrhizae until recolonization.

Harvey et al. (1980a) noted that even in low consumption burns, active mycorrhizae were significantly lower. As the intensity of burn increased, the number of active mycorrhizae was

further reduced--to the extent of being absent after severe burns (Harvey et al. 1980b, Wright and Tarrant 1959). This is probably the result of an alkaline shift in soil reaction, high nutrient flux, and a reduction in soil organic matter. All these are detrimental to mycorrhizal development if they are extreme. Vegetation succession could be directly affected as well. Some species of mycorrhizae (e.g., species symbiotic with lodgepole pine) are more tolerant of increased fire temperatures. However, those symbiotic with Douglas-fir and ponderosa pine are not. This may help explain those sites where lodgepole pine is the dominant or only overstory species. Such sites are scattered across the Kootenai.

Reinnoculation with active mycorrhizae may depend on decomposing logs (Borchers and Perry 1990) or shrubs, i.e., (Ceanothus genus). In all likelihood, however, many organisms survive fire within incompletely burned logs.

B. Soil Properties

1. Physical

Physical properties are probably less affected than chemical properties, but those that are will recover slower. Light burning has little or no effect on physical soil properties. Severe burning reduces macropore volume and percolation rate and increases micropore volume and bulk density (Tarrant 1956) with the overall effect of decrease water uptake.

2. Chemical

Upper surface soil becomes less acidic with increased burn intensity. In other words, the amount of change in soil pH is related to the severity of burn (Bissett 1980). Light burning stimulates nitrification, but severe burning strongly reduces the nitrogen content of soil (Harvey et al. 1989, Niehoff 1985, Nielsen-Gerhardt 1986). Light burning also increases the amount of acid soluble P2O5 and exchangeable potassium. Severe burning increases, even more greatly, the available supply of these nutrients. Light burning has no appreciable effect on cation exchange capacity, but severe burning strongly reduces this property (Tarrant 1959).

In order to apply a time scale to fire effects three groupings are listed below:

1. Immediate changes:
    - Loss of surface vegetation (from zero to 100 percent)
    - Loss of surface litter and humus (from zero to 100 percent)
    - Vaporization and mineralization of soil organic matter in severely burned areas
    - Volatilization of nutrients
    - Release of nutrients

2. Short-term changes:
    - Higher day time or summer surface soil temperatures
    - Lower night time or winter surface soil temperatures
    - Loss of nitrogen
    - Decomposition rate of cellulose fiber is much higher
    - Respiration rates decrease
    - Reduction in infiltration rates
    - Reduction of moisture holding capacity
    - Higher temperatures increase decomposition rate
    - Snow melts faster

- Increase in exchangeable bases
- Increase in surface soil pH
- Mean Summer Soil Temperature is higher.

3. Longer-term changes:
    - Regrowth of surface vegetation
    - Gradual temperature moderation
    - Rebuilding of microbial populations
    - Slow increase in water holding capacity
    - Melt rates gradually change
    - Temperatures slowly moderate

C. Soil Heating

Temperatures at the soil surface can exceed 700 degrees centigrade, while litter surface temperatures have exceeded degrees centigrade (Agee 1994). Duration of high temperatures depends on the type of fuel, amount of fuel, and fuel moisture. Soil heating by fire lasts a short time, but soil heating from loss of vegetative cover and surface organics lasts longer. Below are some effects related to intensity levels:

1. Low Intensity
    - Loss of some surface litter
    - Loss of some seedlings
    - Release of nutrients
    - Surface kill of some shrubs

2. Medium Intensity
    - Loss of most litter and much of the humus
    - Loss of most seedlings and many of the overstory depending on the species
    - Release of nutrients
    - Loss of most surface vegetation

3. High Intensity
    - Loss of all litter and humus
    - Loss of all seedlings and most overstory depending on species
    - Loss of all surface vegetation
    - Loss of soil organics
    - Potential increase in soil bulk density
    - Loss of soil porosity
    - Loss of soil structure
    - Reduction of soil organisms, especially macrobiota
    - Decreased infiltration rate (water repellency)
    - Volatilization of nutrients

There is a direct correlation of numbers of mycorrhizae with live tree roots and amount of organic matter. As fire intensity increases the number of mycorrhizae decrease (Harvey et al. 1980a and Harvey et al. 1980b). The cooler the burn the quicker the mycorrhizal activity will return to preburn conditions.

D. Reburns

The previous discussion relates to fires that burned an area that hasn't been burned in more than over fifty years. The concept of reburn is one that needs to be discussed. Many examples exist on the Forest where at least one or more reburns occurred within 20 to 40 years of each other, i.e., dense lodgepole pine stands where little or no dominance is occurring. Those areas that naturally burn every 5 to 40 years are lightly affected by reburns. Where fire frequency was much longer, specifically 200 to 300 years, reburns can have a significant effect.

The areas that had previously experienced a light burn, where a minimal amount of the overstory was killed, most likely will not be strongly affected by a reburn. In those areas, where the original burn was medium to high intensity and much of the overstory vegetation died, the potential for severe impact is much greater. The greatest impact will occur in medium intensity areas. When these areas reburn, the amount of high intensity will increase to over 50 percent. The following changes combine to create reduced plant reproductivity and vigor. Soil invertebrates, soil microbes, and soil mycorrhizae will be altered; nitrogen content will be strongly reduced; pH change can be significant; the cation exchange will be reduced; and other nutrients will be reduced. Many of the soluble nutrients will be lost, since initial plant reproduction will be greatly reduced. The hotter the burn, the greater the changes that occur. Low intensity burns will have little effect.

E. Coarse Woody Debris

Coarse woody debris (CWD) plays such an important role in our ecosystems a few items need to be mentioned. This discussion of CWD will relate to woody residue larger than 3 inches (Graham et al. 1994). In forested ecosystems such as ours (Kootenai National Forest), CWD can persist for many years (greater than 200). It has greater longevity in moist ecosystems (those dominated by western hemlock and western redcedar) than in drier ones (those dominated by ponderosa pine). The amount of CWD varies on these diverse systems. Graham et al. (1994) found that an average of 10.3 tons/A of CWD accumulated in ponderosa pine forests, while 29.4 tons/A accumulated in the cedar/hemlock forests.

Coarse woody debris serves many chemical, biological, and physical functions. Nitrogen input, as well as phosporous and sulfur, from logs with advanced decay is very important to the forest ecosystem. Logs in the advanced stages of decay often contain high volumes of plant roots. These sites are very favorable for root growth as they hold large amounts of water, can release large amounts of nutrients, and are excellent sites for the development of mycorrhizae (Graham et al. 1994). Often seedlings, especially Engelmann spruce, western hemlock, western red cedar, and Douglas-fir, are seen growing in decayed CWD. Coarse woody debris can help to protect the forest floor from erosion and mechanical disturbances. For these and other reasons, it is essential that a portion of CWD be maintained.

III. CONCLUSIONS

Many changes occur to soil organisms as a result of fire. The higher the intensity, the more damaging the effect. Not all effects are negative, however. Many of the newly-released nutrients can be utilized by new vegetative growth (if it occurs within two years of the fire); and while microbial populations are reduced, they have the ability to rebuild. There are a variety of effects that occur as a result of fire. These effects can be beneficial and/or detrimental-- depending on the intensity and duration. Based on my observations of fire on the Kootenai National Forest over the past 30 years, many of the aforementioned effects are temporary. In the same respect, others are not. The following considerations will minimize the subsequent effects of fire on soil organisms:

1) Minimize cumulative additions to the existing disturbance level with salvage or other activities.

2) Maintain <u>all</u> remaining surface litter and humus in the medium- and high-intensity portion of the burns. Since most of the soil productivity is related to the organic matter, it is critical to keep that which remains. This could mean using a cool spring burn to remove the slash created during any salvage operations.

3) Maintain at least the minimum tonnage recommended by Graham et al. (1994),a minimum of 5 tons of CWD on Douglas-fir/ninebark (drier sites) and a minimum of 17 tons on western hemlock (moist sites). This includes both standing and down, but not stumps.

4) The decision to replant should be made the first season after the fire to take advantage of newly released nutrients.

5) Make no or very few changes in slope hydrology, especially in the yellow and red watersheds (USDA 1993). The organic mat plays a significant role in dissipating surface water flow. Removal of large portions of this will allow overland flow to occur with greater frequency and with a much greater chance for surface erosion.

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