After the Burn

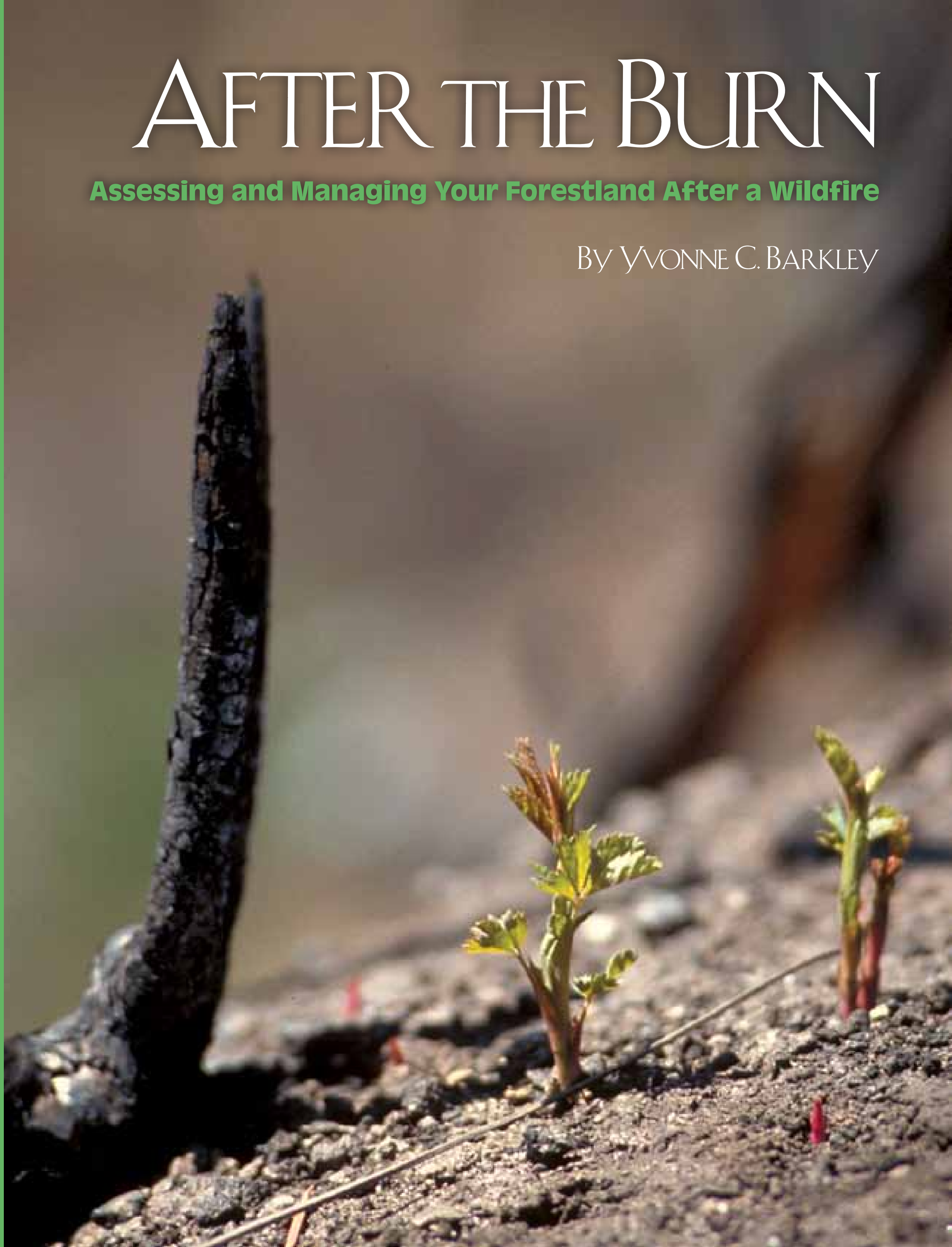
Assessing and Managing Your Forestland After a Wildfire

By Yvonne C. Barkley

Station Bulletin No. 76
May, 2011

Idaho Forest, Wildlife and
Range Experiment Station
Moscow, Idaho

Director
Kurt S. Pregitzer



University of Idaho
Extension

Acknowledgements

After the Burn was written by Yvonne C. Barkley, Associate Extension Forester, University of Idaho Extension.

Special thanks to the following people for their professional review of this publication:

Steve Cook, Associate Professor - Forest Entomology, University of Idaho, Moscow, ID

Deb Dumroese, Research Soil Scientist: Project Leader, U.S. Department of Agriculture, Forest Service, Moscow, ID

Gregg DeNitto, Forest Health Protection: Group Leader, U.S. Department of Agriculture, Forest Service, Missoula, MT

Dennis Ferguson, Research Scientist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Moscow, ID

Mary Fritz, Private Forestry Specialist, Idaho Department of Lands, Orofino, ID

Frank Gariglio, State Forester, Natural Resource Conservation Service, Lewiston, ID

Nick Gerhardt, U.S. Department of Agriculture, Forest Service, Nez Perce National Forest, Grangeville, ID

Terrie Jain, Silviculturist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Moscow, ID

Tim Kennedy, Private Forestry Specialist, Idaho Department of Lands, Boise, ID

Brian Kummet, Fee Lands Forester, Nez Perce Tribal Forestry, Lapwai, ID

Ron Mahoney, Professor and Extension Forester, University of Idaho, Moscow, ID

Marci Nielsen-Gerhardt, U.S. Department of Agriculture, Forest Service, Nez Perce National Forest, Grangeville, ID

Jeff Olson, Associate Director, Publications, University Communications & Marketing, University of Idaho, Mosocw, ID

Kerry Overton, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Boise, ID

David Powell, Silviculturist, U.S. Department of Agriculture, Forest Service, Umatilla National Forest, Pendleton, OR

Peter R. Robichaud, Research Engineer, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Moscow, ID

Sue Rodman, Forester, Anchorage Fire Department, Anchorage, AK

Bruce Sims, Regional Hydrologist, U.S. Department of Agriculture, Forest Service, Missoula, MT

Mark Story, U.S. Department of Agriculture, Forest Service, Gallatin National Forest, Boseman, MT

Pamela Town, Private Wildlife Consultant, Anaconda, MT

Jill Wilson, U.S. Department of Agriculture, Forest Service, Panhandle National Forest, Coeur d'Alene, ID

Photography:

Special thanks to Karen Wattenmaker Photography, Wison, WY for her generous support.
Cover photo: Karen Wattenmaker

Design and Production:

Beth Case, University of Idaho, Creative Services

This publication was supported by a grant from the U.S. Department of Agriculture, Forest Service and by the Renewable Resource Extension Act (RREA).

Table of Contents

Introduction **3**
The Inland Northwest 3
Moist Forests 4
Cold Forests 4
Dry Forests 5

Fire in the Forest **6**
Fire-Based Ecosystems 6
Fire Regimes 7
Fire Suppression 8

Fire Mechanics & Behavior **9**
Wildland Fuels 9
Conduction, Radiation & Convection 10
Climate 11
Topography 11
Fuel Volatility 11
Stages & Types of Wildfires 12

Fire & Vegetation **13**
Adaptive Traits 13
Plant Mortality 13
Fire & Vegetative Regeneration 15
Fire & Plant Reproduction 16
Postfire Plant Communities 17

Fire & Wildlife **18**
Mortality 18
Habitat Modification 18
Invertebrates 19

Fire & Soils **20**
Physical Changes 20
Chemical Changes 21
Biological Changes 22
Productivity 22

Fire & Watersheds **23**
The Hydrologic Cycle 23
Erosion 24

Fire & Aquatic Environments **26**
Pulse Disturbances 26
Channel Erosion & Sedimentation 27
Nutrients, Dissolved Oxygen
& Temperature 27
Large Woody Debris 27

After the Burn **28**
Damages vs. Benefits 28
Emergency Rehabilitiation Treatments 29
Assessment 29

(continued on next page)

Table of Contents (continued)

Postfire Assessment **31**
- General Information 31
- Unit Evaluation 33

Postfire Management **37**
- Salvage Logging 37
  - Bark beetles 38
  - Fungi 39
  - Other Forms of Deterioration 40
  - Rates of Deterioration 40
- Reforestation 41
  - Species Selection 42
  - Type of Stock 43
  - Number of Trees Needed 43
  - Ordering Trees 43
  - Site Preparation 44
  - Planting 44
  - Maintenance 46
- Weeds 46
- Fuel Management 47

Conclusion **49**

Appendix I – Using Individual Tree Characteristics to Predict Mortality **50**
- Ponderosa pine 50
- Western larch 52
- Douglas-fir 53
- Grand fir 54
- Lodgepole pine 55
- Engelmann spruce 56
- Subalpine fir 57
- Western white pine 58
- Western redcedar 59
- Western hemlock 60
- Quaking aspen 60

Appendix II – Erosion Control **62**
- Hillslope Treatments 62
  - Mulch 62
  - Barriers 63
  - Water Repellent Soils 65
  - Seeding & Revegetation 65
- Channel Treatments 70
  - Barriers 70
  - Channel or Stream Clearing 72
  - In-channel Felling 73
  - Debris Basins & Dams 73
- Road Treatments 73
  - Culverts, Rolling Dips, Waterbars & Cross Drains 73
  - Ditches & Armored Crossings 74

References **75**

Footnotes **77**

AFTER THE BURN

Yvonne C. Barkley

"My husband, Jim, and I stood on the rock platform of the old fire lookout with our student interns, taking in the big view of the surrounding Frank Church River of No Return Wilderness. In all directions, mountain peaks punctured the sky. On this blue-sky August day in the year 2000, we counted six mushroom clouds of smoke rising from forest fires." Holly A. Akenson[1]

The Inland Northwest

Fire in the forest. Though a natural part of the ecosystems of the Inland Northwest, it is one of the most feared, fought and controversial components of our physical environment. Encompassing a large portion of the interior Western United States, the landscapes of this region were born of volcanic eruptions, molded by glaciers and floods, and refined by frequent wildfires. Topography is often rough, complex and includes a variety of forest settings ranging from steep slopes in narrow V-cut canyons to gentle rolling hills with wide river valleys. The climate in the region is influenced by moist marine air from the Pacific Ocean, and when combined with the rugged topography, results in a mosaic of diverse forests, which can be classified in three ways: moist forests, cold forests or dry forests.

Karen Wattenmaker

The landscapes of the Inland Northwest were born of volcanic eruptions, molded by glaciers and floods, and refined by wildfires.

Moist Forests

The ***moist forests*** of the Inland Northwest are located in the Cascade Mountains east of the Cascade Crest in Washington and Oregon, the northern Rocky Mountains of northeastern Washington and Oregon, northern Idaho, and western Montana from sea level to 7,550 feet in elevation. The topography is typically steep and broken, with V-shaped and round-bottomed valleys. Precipitation ranges from 28 to 60 inches, with most occurring from November to May. Summers are typically hot and dry, with a distinct dry period in July and August when precipitation totals can equal less than one inch a month. Soils are a mix of sedimentary, metamorphic, and igneous parent material, overlain with a deep layer of ash, making them very fertile. The floor of moist forests will have large accumulations of coarse woody debris and surface organic layers that can contain deep pockets of rotten wood.

Common tree species include:

- Northern Rocky Mountains – western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and grand fir (*Abies grandis*). Also included are western white pine (*Pinus monticola*), western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*), and ponderosa pine (*Pinus ponderosa*).
- Eastern Cascades - western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*), white fir (*Abies concolor*), Pacific silver fir (*Abies amabilis*), Port-Orford cedar (*Chamaecyparis lawsoniana*), incense cedar (*Libocedrus decurrens*), and noble fir (*Abies procera*). Also includes some lodgepole pine (*Pinus contorta*), Sitka spruce (*Picea sitchensis*), Douglas-fir (*Pseudotsuga menziesii*), and ponderosa pine (*Pinus ponderosa*), and less commonly western white pine (*Pinus monticola*) and western larch (*Larix occidentalis*).

Understory vegetation is lush and typically includes:

- Vine maple (*Acer circinatum*), Rocky mountain maple (*Acer glabrum*), Sitka alder (*Alnus sinuate*), devils club (*Oplopanax horridum*), rose (*Rosa* spp.), gooseberry (*Ribes* spp.), huckleberry (*Vaccinium* spp.), willow (*Salix* spp.), baneberry (*Actaea rubra*), pathfinder (*Adenocaulon bicolor*), wild ginger (*Asarum caudatum*), queencup beadlilly (*Clintonia uniflora*), bunchberry dogwood (*Cornus canadensis*), and golden thread (*Coptis occindentalis*).

UI Extension Forestry File Photo

Moist forest.

Tim Prather, University of Idaho

Cold forest.

Cold Forests

The ***cold forests*** of the Inland Northwest generally occur at higher elevations (99 percent are at 4,000 feet or above) in northern and central Idaho, and in the northern Cascade Mountains of Washington. Growing seasons are short - from 90 days at the lower elevations to just a few weeks at the highest levels - and frosts may occur any time during the year. Growth in these forests is further limited by poorly developed soils and, in some areas, low moisture. Most precipitation occurs from late summer to late spring, mainly as snow, sleet and snow, and amounts range from more than 100 inches in the Cascades of northern Washington to just 24 inches in the mountains of central

Idaho. Soils are often shallow and poorly developed, with parent material being mostly glacial in origin. Decomposition is slow and needles and other debris accumulates into thick, dense mats. Coarse woody debris amounts vary with stand age.

Common tree species include:

- Subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmanii*), and mountain hemlock (*Tsuga mertensiana*). Also, lodgepole pine (*Pinus contorta*), western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*), western white pine (*Pinus monticola*), western redcedar (*Thuja plicata*), and grand fir (*Abies grandis*).

Understory vegetation is usually lush and can include:

- False huckleberry (*Menziesia ferruginea*), sitka alder (*Alnus sinuate*), huckleberries (*Vaccinium* spp.), pinegrass (*Calamagrostis canadensis*), elk sedge (*Carex geyeri*), beargrass (*Xerophyllum tenax*), round-leaved violet (*Viola orbiculata*), queencup beadlily (*Clintonia uniflora*), gooseberry (*Ribes* spp.), and pinemat manzanita (*Arctostaphylos nevadensis*).

David Powell, USDA Forest Service

Dry forest.

Dry Forests

Dry forests in the Inland Northwest can be found on a wide range of elevations in northeastern Washington, northeastern and south-central Oregon and central and south Idaho. The limiting factor for growth in these forests is water availability. Precipitation varies from 11 to 30 inches, with most moisture occurring in the fall and winter months. Very dry summers, with less than one inch of precipitation received, are normal during the months of July through September. Soils are derived from igneous, metamorphic, and sedimentary parent materials.

Disturbances such as fire, insects, diseases, snow, ice and competition traditionally keep dry forests thinned, while regular surface fires prepare the forest floor for regeneration. These continual disturbances keep the dry forests of the Inland Northwest in a variety of structural and successional stages. For example, records show that up to 18 percent of the area occupied by dry forests are in a grass, forb and shrub stage for long periods of time, in some areas, for hundreds of years.

Decomposition is slow and needle shed from long-needled pines are a major component of the surface litter. Without fire, accumulations become deep and shade out understory grass and forb species. Coarse woody debris is very low compared to moist and dry forests.

Common tree species include:

- Ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), and Douglas-fir (*Pseudotsuga menziesii*). Also quaking aspen (*Populus tremuloides*), lodgepole pine (*Pinus contorta*), and grand fir (*Abies grandis*).

Understory

- Kinnikinnick *(Arctostaphylos uva-ursi)*, ceanothus *(Ceanothus* spp.), bitterbrush *(Purshia tridentata)*, snowberry *(Symphoricarpos albus)*, spiraea *(Philadelphus lewisii)*, ninebark *(Physocarpus malvaceus)*, a mix of grasses *(Calamagrostis rubescens, Bromus vulgaris)*, and sedges *(Carex* spp.).

Fire in the Forest

"Late last night, a dry cold front passed over Central Idaho igniting about 200 lightning-caused fires. By this afternoon, wisps of smoke began to appear". Blake Swanson[2]

For the past century, fire in the forest has been viewed as damaging to ecosystems rather than as a natural process of renewal. Beginning in the late 1800's, our nation's economy began to depend on the forests of the West to supply a growing population with the raw materials needed to meet increasing demands for all types of forest products – from the small, such as toothpicks and matchsticks, to the large, such as ship masts, railroad ties and building materials. Intensive forest management favored western white pine (*Pinus monticola*), western redcedar (*Thuja plicata*), western larch (*Larix occidentalis*), ponderosa pine (*Pinus ponderosa*), and Douglas-fir (*Pseudotsuga menziesii*). All other species were considered "weeds" and were removed to provide space for more valuable species.

Early in the 20th century, federal and state agencies began suppressing wildfire as a political response to catastrophic events such as the 1910 burns in Idaho and surrounding states in an effort to protect timber values. This effort became increasingly effective after World War II as planes, helicopters and other modern equipment and technologies were added to the battle against wildfire. From 1946 to 1979, wildfires in the West were held at low acreages through both wet and dry weather cycles – reflecting an era when human capacity outpaced environmental effects.

UI Photo Archives

Logs being moved downhill in a flume.

By the late 1970's however, wildfire acres began to grow in spite of increasingly sophisticated firefighting techniques. In 1994, this led the National Commission on Wildfire Disasters to conclude that it was no longer possible to hold wildfires in check by improving the sophistication and capacity of firefighting technology. The irony of wildfire control is that every success in suppressing fire has resulted in growing fuel supplies.

Fire-Based Ecosystems

Our recognition of fire's role in a forested ecosystem comes from studies of past vegetation, identification of charcoal layers in the soil, fire scars on trees, the even-aged character of some forests and records of explorers. Up until the beginning of the 1900's, fire occurred in many Inland Northwest forests at regular intervals and was a natural component of what are termed **fire-based or fire-dependent ecosystems** - ecosystems that depend on periodic fires to maintain their structure and function.

Fire Regimes

Fire severity combined with how often it occurs (**frequency**) and when it occurs (**season**) define an area's **fire regime**. A fire regime is a generalized description of the role fire plays in an ecosystem. Systems for describing fire regimes may be based on the characteristics of the disturbance, the dominant or potential vegetation of the ecosystem in which ecological effects are being summarized, or the fire severity based on the effects of fire on dominant vegetation. Each type of forest (moist, cold and dry) has a fire regime that is "normal" for that ecosystem.

Three general fire regimes are commonly recognized. **Low intensity surface fires** burn along the forest floor and leave canopies alive. These non-lethal burns can consume little to most of the organic material on the forest floor. Historically, these types of fires burned in dry forests as frequently as every five, but more regularly, every 20 years. Low intensity surface fires can be quite large, often burning for weeks or months. Soil burn severities range from low to high. Because of changes in weather patterns, fuels and fire exclusion, these fires are now much less frequent in the dry forests of the Inland Northwest, but occur with the same historical frequency in moist and cold forests.

Stand-replacing fires kill all canopy layers across stands and/or burn areas that are five acres or more in size. Soil burn severity is highly variable and can be low to high. Stand-replacing fires are considered lethal and historically occurred at intervals of 100 years in cold forests to more than 300 years in moist forests. Currently, stand-replacing fires are more prevalent in dry forests of the area than they were historically.

Mixed severity fires historically occurred in all three forest types at a variety of intervals, with a usual range of 25 to 100 years, and maintained diverse mixes of vegetation and stand structures. Mixed severity fires are a combination of stand-replacing and low intensity surface fires and can occur in small patches or cover entire landscapes that burn for weeks. Currently, mixed severity fires have increased in dry forest types and have decreased in moist and cold forest types.

Natural fire regimes provide a multitude of benefits to the forested ecosystems of the Inland Northwest. Natural fire regimes enable species that are best suited to fire-based ecosystems maintain a competitive advantage over less suited species. Less competition reduces stress, which in turn can reduce outbreaks of insects and disease. Fire stimulates understory vegetation, which is important to wildlife and biodiversity, and helps maintain or provide opportunities for niche dependent species. Natural fire regimes also provide a stimulus for the reproductive cycle of many plants while preparing suitable seedbeds for new seedlings.

Karen Wattenmaker

Low intensity surface burn.

Karen Wattenmaker

Results of a stand -replacing fire.

Karen Wattenmaker

Mixed severity burn.

Many areas of the Inland Northwest have slow rates of decay and decomposition and depend on wildfire for recycling biomass and nutrients, and redirecting carbon and nutrients back into forms usable by growing plants. Without fire, nutrients can remain unavailable in dead woody material for decades.

Fire Suppression

Today, ecosystems that are unaffected by fire suppression are extremely rare. Due to suppression, today's fires can be very different from those in the past, and we must take into consideration what fire will do in such altered ecosystems. It is currently recognized that natural fire regimes cannot be perpetuated in unnatural communities. The introduction of exotic insects, diseases and plants, the alteration of the characteristics and processes of traditional plant communities, and the conversion of forested acreages to agricultural and urban use have all changed the environment surrounding and influencing our forests and rangelands.

When fire is suppressed for periods of time that are greater than the natural fire regime, changes in forest structure and function occur. As time passes, you begin to see an increasing number of shade tolerant species, such as Douglas-fir and true fir, in a stand, which replace more adapted and shade intolerant species such as pines and western larch. Stand densities increase and multi-layer canopies begin to develop. By changing the immediate environment, these shade tolerant species begin to alter traditional plant communities. For example, where there once was a savanna-like ponderosa pine forest, interspersed with clumps of aspen and birch, you now have a thick Douglas-fir/grand fir forest. Competition for light, nutrients and moisture increases, not only because of increased stand densities, but because shade-tolerant species require and use more moisture and nutrients than the species they replaced.

When shade tolerant species replace shade intolerant species on drier sites, you begin to see other forest health problems. Douglas-fir and true firs are not as well adapted to dry sites as are ponderosa pine and western larch, and consequently suffer physiological stress when subjected to the hot, dry summers of the Inland Northwest. Stressed trees are more likely to succumb to insect and disease problems such as bark beetles and root rot. Insect outbreaks that would normally not reach epidemic proportions can spiral out of control with the addition of stressed and dying off-site species that offer increased food to sustain populations.

Stressed and dying trees contribute to the already large amounts of live and dead organic matter that accumulate as a result of fire suppression and increasing amounts of shade tolerant species. These now dangerous amounts of fuel often produce high severity fires. In areas where low intensity or mixed severity fires once occurred, you now have stand-replacing fires. After a severe burn, a summer thunderstorm can increase erosion by an order of magnitude, the incidence of windthrow increases, and high heat encountered by roots, cambium and crowns have further reduced a tree's resistance to insect and disease problems, drought stress and nutritional imbalances. When you remove fire from the jigsaw puzzle of Inland Northwest ecosystems, you remove a piece that changes the entire picture.

FIRE MECHANICS & BEHAVIOR

"Fires have been burning for weeks. About an hour before first light, the smoke plume shifted directly over the ranch. It had turned an ominous reddish color and those evacuating by air observed lightning in the smoke plume. The remaining two people [at the ranch] refueled the water pumps one more time and then took the rest of the stock and rode out, headed upstream." Blake Swanson[3]

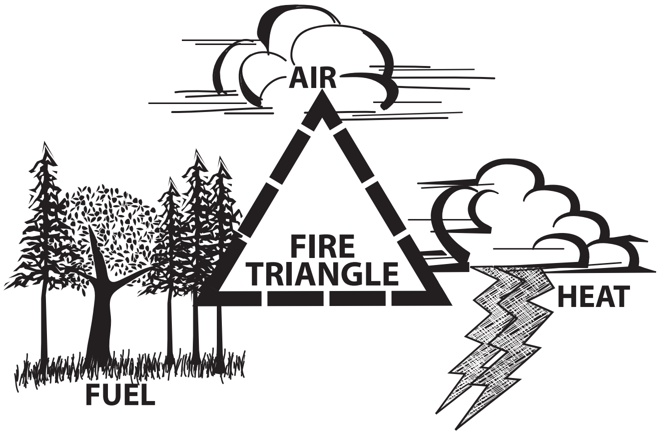


Figure 1. *Fire is a rapid oxidation process that occurs under high temperatures as compared to the slower oxidation processes of decay and decomposition. You need three things to start a fire: fuel, oxygen and heat (ignition).*

Wildland Fuels

Wildland fuels are defined as combustible plant materials, both living and dead, that are capable of burning in a wildland situation. All vegetation can become fuel, with the single most important factor controlling flammability and consumption being moisture content. Human activities have complicated the problem, and combined with fire suppression, have changed the amounts and characteristics of fuels. For example, more people are building homes in the wildland/urban interface, so much so that this wildland fire/building mixture is now considered a separate fuel type.

Fuels are classified in a variety of ways. Fuel size is used to describe the diameter of down, dead, woody fuels, with each class assumed to have similar wetting and drying properties and preheating and ignition rates.

- **Fine fuels** are small in diameter (less than three inches), usually located near the soil surface, and include grass, leaves, needles and twigs.
- **Heavy fuels** are dead logs and branches with diameters of three inches or larger.

Fuels also can be classified by location, configuration, condition or source.

- **Surface fuels** are those that contact the ground and are composed of leaf and needle litter, cones, bark, dead branches and downed logs.

Karen Wattenmaker

Wildland fuels surrounding a home in the wildland/urban interface.

UI Extension Forestry Photo

Lightning strike.

- **Aerial fuels** are those that are located above surface fuels and include lichens, mosses, vines and both the living and dead portions of the crowns of trees and shrubs.
- **Ladder fuels** can carry a fire from the surface fuel layer into aerial fuels via the rungs of a vegetative ladder, such as a tree with branches that extend all the way to the ground or a layered canopy where fire moves from needle litter to shrub to sapling and into the crowns of mature trees.
- **Carrier fuels** are those that support the flaming front of a fire.
- **Live fuels** are living plants in which seasonal moisture is controlled by a plant's physiological processes.
- **Dead fuels** are those in which moisture content is entirely governed by relative humidity and precipitation.
- **Activity fuels** are those that result from, or are altered by, land management practices.
- **Naturally created fuels** are those that result from natural processes or phenomenon.

Conduction, Radiation & Convection

The vast majority of wildfires are ignited by one of two sources – lightning or humans. As many as 44,000 thunderstorms occur on earth daily, and though the average number of thunderstorms per year is less in the Inland Northwest, the average number of lightning-caused fires is higher because less precipitation accompanies the thunderstorms. Once fuels have been ignited, heat is moved from one piece of fuel to another by **conduction.** Larger fuels must usually be in contact with, or in close proximity to, each other or conduction will not transfer enough heat for kindling to occur. **Radiation** allows the lateral transfer of a fire and contributes to the spread of a fire by preheating and drying small fuels to their ignition points. A third phenomenon, **convection**, preheats surface and vertical fuels, and contributes greatly to the spread of a fire by transporting embers that can ignite spot fires far ahead of the main burn.

"During the morning hours, thick smoke created an inversion, effectively trapping heat and preheating the lower two miles of the drainage. By early afternoon, the relative humidity had dropped to three percent and the wind was gusting above 40 miles per hour."

Blake Swanson[2]

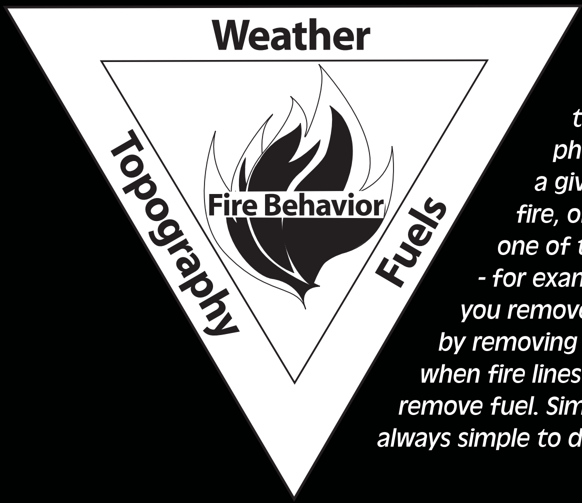


Figure 2. *Any particular fire's behavior will be determined by the weather, topography and available fuel in a given area. To suppress a fire, one need only remove one of the necessary elements - for example, by applying water you remove oxygen and heat, and by removing vegetation (such as when fire lines are constructed) you remove fuel. Simple in theory, but not always simple to do.*

Climate

Climate is defined as the meteorological conditions of a particular region and plays a large role in determining the productivity of an area's vegetation. **Weather** is the day-to-day or even hour-to-hour changes in atmospheric conditions and includes temperature, wind, relative humidity, cloud cover, precipitation and air stability. Weather has both direct and indirect effects on wildfire, determines how and when fires burn, and plays an important role in the behavior of a wildfire. Rainfall and high relative humidity increase fuel moisture and decrease the likelihood of fuels igniting. These factors also decrease the rate at which fuels will combust and slow the spread of a fire. On the other hand, wind and high temperatures increase the rate at which fuel dries. Wind also increases the amount of oxygen available for combustion, aids in preheating and igniting fuels in advance of the front, can produce ignition far ahead of the fire front by transporting flaming brands, and increase the size of the fire front when it changes direction. In many cases, a wildfire will generate its own wind. When the upward convection of heated gases draws air in from around the center of a burn, the fire front can spread outward into this self-generated wind as a back fire.

Topography

Topography provides variations in local climate and partially determines the distribution of plant communities that can have very different flammabilities. Slope position and steepness will affect a particular fire's behavior by determining the amount of exposure to wind and solar radiation. For example, the upper third of a slope will have more exposure to wind and sun than the rest of the slope and south- and west-facing slopes are more exposed and drier than north- and east-facing slopes. The rate at which a fire front spreads on a flat surface can be expected to double on an 18 percent slope and double again on a 36 percent slope. Narrow openings such as box- or v-shaped canyons create funnels that act like chimneys and move a fire quickly up a draw. Narrow and/or steep canyons and draws also allow radiant heat to transfer fire across slopes more easily than broad canyons or valleys.

Fuel volatility

The size and type of fuel involved are very important in the characteristics of a fire. **Fuel volatility** refers to ignitability and flammability associated with a variety of plant chemicals that have relatively low boiling temperatures. For example, grasses, most herbaceous plants and deciduous litter are considered low volatility fuels, whereas species such as chaparral and conifer foliage, which can burn explosively, are considered highly volatile fuels.

"As the flames rose to more than 300 feet above the ponderosas, the tremendous heat caused the trees ahead of the main fire to combust. Investigators theorize that a 1,500°F gas ball, which likely glowed orange, received a fresh supply of oxygen as the firestorm roared out of the Pistol Creek drainage and into the Middle Fork canyon. Within minutes, the prevailing winds drove the 600 foot gas ball up 4,000 feet and four miles east. Simultaneously, the downstream Middle Fork wind steered part of the gas ball along the right side of the Middle Fork." Blake Swanson[2]

Stages & Types of Wildfires

There are four stages of a wildfire. In the first stage, **preheating**, moisture is vaporized and chemicals with low boiling points are volatilized. The second stage, **combustion**, occurs when temperatures go above 575° F and ignite fuels. In this stage, flaming is dependent on the amount and mix of volatilized chemicals, the amount of water vapor present, and the availability of oxygen. Flame temperatures can exceed 1,000°F. The third stage is when **residual charcoal** produced during combustion is burned, and the last stage is **cooling**. Low intensity fires often do not create enough charcoal to have a phase three.

Wildland fires are described in a number of ways.

- **Surface fires** burn surface litter, dead woody fuels, other loose debris on the forest floor, and some small vegetation.
- **Ground fires** not only burn surface fuels, but also burn the organic material in the soil layer.
- **Crown fires** are those that advance by moving from crown to crown of neighboring trees and shrubs.
- **Heading fires** are fires in which the flaming front moves rapidly. The fire may be pushed by wind and/or be moving up a slope. Heading fires burn relatively hot and move quickly through fuels. The flaming front moves forward before all fuel can be completely consumed by fire, and often leaves a large area of smoldering fuel.
- **Backing fires** are those that burn into the wind or down slopes. Because the flames move more slowly, a higher proportion of fuel is consumed in the flaming zone of the fire and less fuel is left to smolder after the fire has passed.
- **Fire whirls** are spinning vortex columns of ascending hot air and gases rising from a fire and carry smoke, debris and flame aloft. Fire whirls range from a foot or two in diameter to small tornadoes in size and intensity. They may involve the entire fire area or only a hot spot within the area.
- **Firestorms** are large, continuous areas of intense fire and are characterized by violent surface drafts near and beyond the perimeter of the fire and sometimes by tornado-like fire whirls.

Fire & Vegetation

"The riparian, grassland, sagebrush and forest are 99 percent burned…Riding up Big Creek was ghostly with many trees and stumps burning and smoldering on the south side of the stream. It is an amazing landscape…charred and black."

Jim and Holly A. Akenson[3]

A wildfire's effect on the vegetative component of a landscape can be dramatic and is usually what pulls hardest at the heart of observers. But, in fire-based ecosystems, all that is blackened and brown is not dead. The damage a wildfire causes to vegetation will be dependent on the characteristics of individual plant species, the type and duration of the fire, temperatures reached and the return frequency of burning.

Adaptive traits

For a plant, an important factor for surviving a fire is how well it is protected from heat. Characteristics such as thick bark and cone scales and air spaces between bud scales provide insulation from extreme temperatures. Some trees have very large buds that have a high heat capacity; others have characteristics that make them inaccessible from fire, such as a high crown base, subterranean buds, and/or the size and shapes of their trunks or crowns.

A tree's fire resistance generally increases with age. Among conifers, trees with large buds and thick bark are more resistant to fire damage than those that do not have these characteristics.

Karen Wattenmaker

Ponderosa pine has thick, fire resistant bark.

Thick-barked trees such as ponderosa pine, mature Douglas-fir and western larch can be heavily scorched without much damage to the cambium, and crown injury is most often the cause of mortality. In thin-barked trees such as lodgepole pine and subalpine fir, the cambium is usually dead beneath any charred bark and is a more likely cause of death. Fire scars occur where cambium is killed and often are not evident until the dead bark sloughs from the tree.

Plant mortality

Plant mortality is often the result of a combination of direct and indirect effects and may not occur for several years after a burn. Direct effects are determined by the temperature and duration of the fire. Indirect effects result from plants and trees being stressed by the direct effects of a fire and, because of this, are more susceptible to insect and disease outbreaks and

Karen Wattenmaker

Scorched foliage.

Karen Wattenmaker

"Eddy effect" — uneven char on bole.

environmental pressures such as drought. The amount of damage individual trees can sustain and still survive is determined by species characteristics such as needle length, bud size and bark thickness, as well as by individual characteristics such as diameter, height and level of health and vigor.

Fire intensity affects scorch height and determines how much of the canopy is consumed. Trees will be killed if crown scorch exceeds a certain percentage and these percentages vary with species. The percent of scorched foliage is often used to measure the amount of remaining live foliage. Crown scorch is a widely used predictor of tree mortality for some species such as Douglas-fir and true firs, while crown consumption is thought a better indicator of mortality for fire-resistant conifers such as ponderosa pine, lodgepole pine, western white pine and western larch. Fire heated air can dry vegetation and branches to lethally low moisture content and often the difference between desiccation and scorch is indistinguishable.

When a fire approaches a tree bole, it rarely produces an even distribution of heat around the stem. The lee side of the tree is more likely to receive higher heat loads at the bark surface. This is a result of the eddy effect created by the cylindrical shape of a tree bole. This uneven distribution of heat will sometimes result in the death of the cambium on one side of the tree, creating a fire scar; in other cases, enough heat penetrates the bark to kill the cambium around the entire circumference. Once a tree's cambium is injured by fire it becomes more susceptible to additional injury, both because the bark is thinner near existing fire scars and because pitch is often found near wounds which, when ignited, burns hotter. Areas of oozing pitch give an almost immediate sign of injury. Heat-killed cambium will brown within a few days, with bark cracking and separating from the underlying wood.

The temperature at which plant tissue dies is dependent on the moisture content of the plant at the time of the burn. Instantaneous heating to 140°F or 10 minutes or more of 120°F will kill the cambium of most plants. Tissues with higher moisture content will be killed at lower temperatures and in shorter time intervals, meaning

Karen Wattenmaker

Burnt, smoldering roots.

Karen Wattenmaker

Vegetative sprouting.

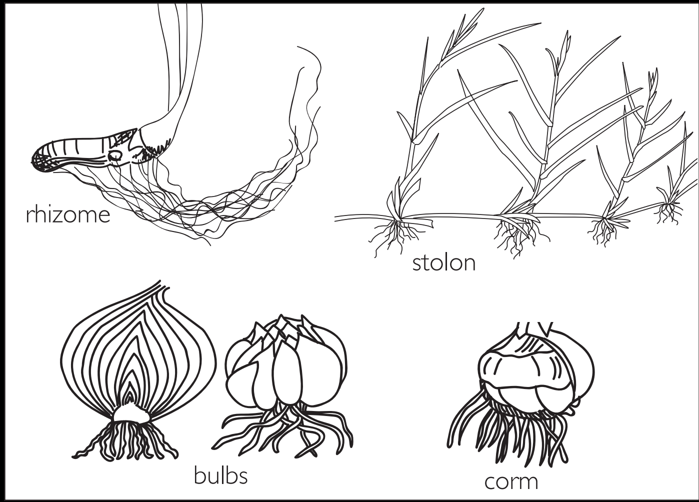


Figure 3. *Vegetative structures.*

that plants that are actively growing are more easily killed than dormant plants. Because of this, late summer/fall burns are better for survival than late spring/early summer burns.

Plant roots are sensitive to both the duration and the temperature of heating - the deeper the roots, the better the insulation. Moist soils are a better conductor of heat than dry soils. When roots are in dry soil one-half to one inch below the surface, they likely will not be damaged by soil heating unless the fire is of long duration.

Fire and vegetative regeneration

Whether herbaceous plants recover after fire depends largely on whether their regenerative structures are exposed to lethal temperatures. Similar to woody plants, their survival depends on the depth of the structure below the surface, whether they are located in combustible material, and the subsurface moisture regime at the time of the fire.

Though very rare in conifers, the capacity to sprout from below ground buds is wide-spread in deciduous plant species. Fire initiates vegetative regeneration in sprouting species by removing existing plant parts that inhibit the growth of latent and subterranean buds, which are well insulated by soil from lethal fire temperatures.

Some woody species, such as aspen, have dormant buds located along roots from which new shoots can originate. Herbaceous plants vegetatively regenerate in a number of ways. For example:

- Blue huckleberry *(Vaccinium globulare)*, thimbleberry *(Rubus parviflorus)*, chokecherry *(Prunus virginiana)*, Labrador tea *(Ledum glandulosum)*, western yarrow *(Achillea millefolium)*, heartleaf arnica *(Arnica cordifolia)*, showy aster *(Aster conspicuus)*, wild sarsaparilla *(Aralia nudicaulis)*, star-flowered Solomon's seal *(Smilacina stellata)*, and bracken fern *(Pteridium aquilinum)*, to name a few, regenerate by **rhizomes**, which are horizontal underground stems with dormant buds that can produce new shoots and adventitious roots.
- **Perennial forbs** are broad leaved species that completely regrow their leaves and stems each year after dying back during winter cold or summer drought. Forbs have similar regenerative structures as woody plants, but also some that are unique. Some have **stolons**, which are stems of herbaceous species that grow on or near the surface of the ground and produce plants with roots at the nodes, such as strawberries *(Fragaria virginiana)*. The **dormant buds** of fireweed *(Epilobium angustifolium)* are located on roots far below the surface and can produce significant numbers of sprouts even after severe burns.

Karen Wattenmaker

Naturally regenerating seedling.

- A **caudex** is a largely underground, often woody stem base that persists from year to year and produces leaves and flowering stems. This structure is found in species such as Indian paintbrush *(Castilleja* spp.), lupine *(Lupinus spp.)*, columbine *(Aquilegia* spp.), and arrowleaf balsamroot *(Balsamorhiza sagittata)*. Other buried reproductive structures include **bulbs** found in common camas *(Camassia spp.)* and death camas *(Zigadenus* spp.) and **corms** of glacier lily *(Erythronium grandiflorum)* and gayfeather *(Liastris spicata)*.

Fire and plant reproduction

While vegetative regeneration allows new growth from individual existing plants, seeds represent the genetic future of a plant by producing new individuals from two parents. The variation that results in a combination of genetic traits from two individuals provides populations with increased resiliency, resistance from adverse conditions and attacks from insects and disease, and also allows for advantageous adaptations to evolve over time.

In fire-based ecosystems around the world, many plant species store seeds in insulated cones, woody capsules or persistent, woody flower-like structures that only open and release seed en-masse after a fire. This condition is known as **serotiny**. In North America, serotiny occurs exclusively in conifers, and where it occurs, these trees often dominate the plant communities in which they live. There is a general association of serotiny with large crown fires. Lodgepole pine, one of the most wide-ranging and variable of the western conifers, has both serotinous cones, which need heat to melt the resin that bonds cone scales shut, and open-coned forms that release seed as cones mature. Most populations of lodgepole pine are dominated by one cone type over another. Closed-cone types usually dominate in areas that experienced large stand-replacing fires and open-coned types dominate where trees have established themselves in tree-fall gaps with an absence of fire.

Other plant species "store" their seeds in the soil (**soil-stored seeds**) and need fire to stimulate germination. The length of time soil-stored seed remains viable varies considerably with some species, such as ceanothus (*Ceanothus* spp.) which remain viable for up to 200 years. Seeds with extremely hard seed coats, called **hard seededness**, need to be scarified, cracked, heated or treated by the acidic process of passing through the digestive tracts of animals in order to be able to germinate. Germination of hard seeds can only occur after the seed coat cracks, which allows water to enter. Chemical cues are another mechanism for the release of soil-stored seed and charred wood and smoke are common chemical cues.

Many of the seeds present in soil seedbanks are often shade-intolerant species, which may not have been present as adults in the preburn forest. Germination of soil-stored or other seed is often dependent on the post-fire seed environment. For some shade-intolerant species, the only time that seedlings can establish is after a burn, when fire has removed all surface litter and exposed bare, mineral soil. The condition of the seedbed, which includes the temperature, percent humidity, amount of shade and potential competition from other plants, will determine the success of a seed's germination and survival. Moss, litter and duff are poor seedbeds in many climates because they frequently dry out in the summer, often resulting in the death of seedlings whose roots have not yet reached mineral soil.

Postfire plant communities

The plant community that occupies your forest today is one that is constantly in transition, with each species responding to changes in the local environment in their own particular time and manner. Depending on the intensity of a burn, postfire plant communities can be similar to, or very different from, the prefire communities they replace.

The classical definition of succession, where a plant community moves in a linear fashion from one stage to the next towards a final, static climax stage, has been replaced with the realization that plant communities are dynamic and continually change in response to disturbances. Fire is one of the few disturbances that regularly kills mature plants. This is an important function of succession that provides opportunities for vegetation change. Fire affects plant competition by changing the number and types of plants in a community and altering site conditions so large numbers of plants must re-establish themselves on a site.

A postfire plant community will be made up of individuals that survived the fire or re-establish themselves vegetatively, and by those that germinate from seed dispersed on-site from surviving plants (usually trees), seed brought in by wind or animal and soil-stored seed stimulated by heat and chemical cues. Those plants that must develop from seed are disadvantaged, as they must develop new root systems. Plant species that reproduce vegetatively by basal or root sprouting or sprouting from underground structures such as dormant buds or rhizomes recover quickly, taking up water and nutrients from established root systems.

Karen Wattenmaker

Postfire plant community.

Fire & Wildlife

"As we walked upstream the damage from the fire became more extreme. Here, the firestorm had created a landscape best likened to the moon. We came across the skeleton of a large animal, probably a deer...". Yvonne C. Barkley[4]

Karen Wattenmaker

Wildlife in stand replacing burn the following spring.

Mortality

The ability of animals to survive a fire depends on their mobility and on the uniformity, severity, size and duration of a fire. Many people believe that all wildlife flees before the flames of a fire like the animated characters in the movie *Bambi*. Evidence contrary to this belief has been observed by animal behavioral scientists during the 1988 burns in the Greater Yellowstone area. No large animals were observed fleeing a fire, and most appeared indifferent even to crowning fires. Bison, elk and other ungulates were observed grazing and resting within sight of flames, often 300 feet or less from burning trees. Large animal mortality occurs most often in very large, active fires that have wide flaming fronts, active crown fires, and thick ground smoke. It was found that most of the large animals killed in the Yellowstone fires of 1988 died of smoke inhalation. Animals with limited mobility living above ground are most vulnerable to fire-caused injury and mortality, whereas animals that live in moist habitats are least likely to be affected. Amphibians and reptiles avoid direct effects of fire by either moving away from it or burrowing into the soil. Smaller mammals and most birds that do leave their habitat while it is burning usually return within hours or days. Not only is the type of fire important, but also the season in which it occurs, with burning during the nesting season being the most damaging.

Habitat modification

Though occasionally killed by smoke inhalation and burning, the biggest effect fire has on wildlife is the modification of habitats. Wildlife habitats, like forests, are not static, but evolve and respond to disturbances as do other natural systems. Fire changes the proportion, arrangement and characteristic of habitats across a landscape. Immediately after a fire there can be temporary loss of food and shelter, and once hidden runways and burrow openings become exposed which increases predation. Wildlife populations in these areas may shift from species that prefer cool, moist conditions to species that prefer warm, dry conditions. Unburned areas adjacent to burned areas supply a mosaic of habitats and provide opportunities for wildlife to choose from a range of vegetative conditions from which to select food and cover.

A particular successional stage or structure is important to many wildlife species when looking for a place to hide, feed or reproduce. Species will immigrate to new areas when the food and cover they require are not available after a burn. The time it takes for a particular species to return to an area will depend on how much a fire altered the habitat structure and food supply.

Herbivores and species that prefer herbaceous vegetation for cover prefer early successional, grass/forb habitats or broad-leafed forests that often become established after a burn. Depending on the vegetation type, burning can increase or improve forage for wildlife from a few years to as long as 100 years. In some cases, the nutritional content and digestibility of plants will temporarily increase as well. In the short-term, dead wildlife becomes food for scavengers, including grizzly and black bears, coyotes, bald and golden eagles, crows and ravens. Fire-killed trees become food for millions of insect larvae and provide perches for raptors.

As succession continues, conifers succeed broad-leafed trees, which become snags and add to dead wood accumulating on the ground. Snags and down, woody debris provide important habitat for cavity nesters, reptiles, small mammals and even large mammals like bears. Openings created by downed and dead trees are soon invaded by shrubs and saplings, and when interspersed with dense patches of shrubs and trees in long-unburned areas, provide excellent food and cover for ungulates. By suppressing fire, this mosaic of habitats that are borne from disturbance cease to exist and wildlife species dependent on early and mid-successional stages move away.

Wetlands are less likely to burn, and when they do, burn less severely than upland sites. Wetlands provide a refuge from fires for many species of wildlife and activities such as breeding by aquatic species may be carried out with little interruption. Fire in wetland areas usually increases areas of open water and stimulates an increase in vegetation favored by many aquatic and semiaquatic species.

Invertebrates

Overall, invertebrate populations tend to decrease after a fire because eggs, food supplies and/or shelter are destroyed. Flying insects are especially vulnerable because they are attracted to fire by heat or smoke and are incinerated in great numbers. Surface insect populations, such as grasshoppers, also tend to decrease. Other insect populations, especially bark beetles, increase after a fire, as trees damaged or killed provide large amounts of suitable habitat. Ants also tend to increase after fires and can eat large amounts of seed. Soil dwelling and aquatic invertebrates generally suffer little immediate damage, though indirect and long term effects are less understood or unknown. Earthworms generally live four to eight inches under the soil surface and are probably protected from the direct effects of heating.

Karen Wattenmaker

Osprey nesting in a snag.

Fire & Soils

"One thinks of black as the sole color after a fire. But we found many colors, especially in the areas that had gone through the firestorm. There were long narrow areas of reddish-gray on the forest floor, the ghosts of fallen logs. Others areas were light gray, white or even a yellow ocher..." [8] Yvonne C. Barkley[4]


Karen Wattenmaker

A burned mountainside devoid of vegetation has a limited ability to retain or absorb water.

Wildfire directly affects forest soils by altering physical, chemical and biological soil properties. The amount of change in any particular situation will depend on the soil type, amount of vegetation destroyed, the intensity and duration of the fire and intervals between fires.

Physical changes

Water repellency slows the movement of water through soil and results in altered substrate water recharge, quicker streamflow delivery and increased potential for surface erosion. Many forest soils are naturally water repellent when dry, but hydrate once soil moisture is increased. In the absence of fire, water repellent layers can form in forest, sage, grass and shrublands, and agricultural soils. When the organic carbon in these soils dry completely, hydrogen bonds form and create an impermeable surface – think about dried peat moss and how difficult it is to rehydrate it.

A burned mountainside devoid of vegetation has a limited ability to retain or absorb water. Wildfire can create or enhance water repellent soil conditions. Wildfires create water repellent layers by partially volatilizing soil organic compounds that then condense onto cooler soil particles deeper in the soil profile. Fires that heat soils to intermediate temperatures are more likely to cause the formation of water repellent layers — very high temperatures (above 500°F) destroy the distilled compounds while low temperatures do not initiate their formation. Water repellency is most often seen after moderate to severe fires, and often is more severe on dry, sandy soils and least severe on wet, fine textured soils. Generally, water repellency weakens with each rainfall and does not persist for longer than two to four years after a burn.

Fire further alters physical soil properties by destroying organic matter, which is essential for maintaining soil structure. The removal of organic matter can increase soil bulk density and decrease porosity, resulting in decreased infiltration and storage as well as increased runoff and erosion. Organic matter also is a basic reservoir for nutrients and, when removed, decreases the nutrient status of a site.

Chemical changes

Fire can greatly alter nutrient cycles of forest ecosystems depending on fire severity, fire frequency, vegetation and climate. Individual nutrients respond differently to fire. Nitrogen (N) is considered to be the most limiting nutrient in wildland ecosystems of the Inland Northwest. Nitrogen is the only soil nutrient that is not supplied to the soil by chemical weathering of parent material. Natural sources of N are supplied to ecosystems physically by precipitation, lightning, dust particles, pollen, air pollutants and/or organically by N-fixation by legumes and other nodulated plants and by free-living N-fixing bacteria that occur in soil and plant residues. Most ecosystems in the Inland Northwest have few N-fixing plant species and rely primarily on free-living soil bacteria and physical inputs of N. The cycling of N involves a series of interrelated complex chemical and biological processes. It has been estimated that 99 percent of volatilized N is converted to N_2 gas during a fire. Although a large percent of N is lost from fire igniting organic matter, it is a small amount of the total pool. But, even small losses of N can adversely affect the long-term productivity of N-deficient ecosystems.

Nitrogen availability can temporarily increase after a fire, enhancing postfire plant growth. However, temporary increases in available soil N following fire is usually rapidly utilized by plants and micro-organisms in the first few years after burning and studies have shown that this increased fertility decreases after a year or two.

Carbon (C) is held mostly in organic debris, down wood and soil wood and because of this, a fire can remove a larger proportion of C than other nutrients. Scientists estimate that five to 80 percent of C can be lost during a fire, depending on the forest type and length of fire suppression activities.

Variable amounts of sulfur (S), phosphorus (P) and chromium (Cr) can be lost during a fire through volatilization. As N and S volatilize at low temperatures and are limiting in many ecosystems, large losses can adversely affect long-term fertility. On the other hand, relatively large amounts of P can be found in ash on the soil surface following a fire, offsetting that lost to volatilization. Percent loss of S is intermediate to losses of N. The quantity and availability of potassium (K), calcium (Ca) and magnesium (Mg) tend to increase temporarily in the upper mineral soil when organic material burns. Most macronutrients (potassium, phosphorus, calcium, magnesium and sodium) are derived from soil parent material, so it may take hundreds of years to replenish these nutrients that are lost during a wildfire.

Soil pH increases in direct proportion to the amount of material burned and is dependent on the original soil pH, amount and chemical composition of ash, and the wetness of the climate. Soil pH changes will decrease with depth and are usually short-lived (two to three years).

Soil changes can occur as a direct result of fire itself (soil heating), the residual effect of ash deposited on the soils surface, or a combination of both. The amount and type of ash varies with the nature of fuels combusted, fuel densities, soil water content, total amount of fuel load consumed and severity of burning. Ash can range from small amounts of charred dark-colored pieces of wood to large amounts of white ash. If soil temperatures are high enough, organic matter in the soil matrix may actually burn, leaving it the consistency of powder. Soil mineral particles will become reddish in color in extreme cases of soil heating and can even be fused together under extreme temperatures maintained for long periods of time. The result is highly erodible soil that is vulnerable to overland flow. The chemical nature of ash affects soil by increasing the pH, changing the solubility of organic matter and associated minerals, and by the addition of available nutrients for microbial populations.

Biological changes

Soil is a living thing. It is inhabited by millions of micro-organisms that provide a multitude of functions and benefits. Microbiota (algae, protozoa, fungi, bacteria and cyanobacteria) and macrobiota (insects, earthworms and plant roots) contribute to soil productivity by enhancing decomposition, plant nutrition and function, cycling nutrients, and contributing to humus formation.

Duration of heating, maximum soil temperatures and soil water content are the most important factors affecting the response of soil organisms to soil heating. Many soil macro- and micro-organisms are easily damaged by soil heating. For example, it has been found that severe burning temporarily (two years) inhibits the development of fungal mycorrhizae on tree seedlings and encourages some root rots while inhibiting others. Fungal mycorrhizae are an important component of many forested ecosystems and play an important role in the uptake of essential nutrients by trees, and also possibly improve water absorption by roots and protect root tips from invasion by pathogens.

Chipmunks are an important agent for the dispersal of mycorrhizae after a fire. These animals eat fruiting bodies of the fungi in adjacent unburned areas and spread spores in burned areas when they defecate. Downed logs provide important travel lanes and home sites for chipmunks. Therefore, the presence of residual logs after a wildfire enhances the re-establishment of mycorrhizal fungi, both by providing habitat for chipmunks and providing suitable microsites for mycorrhizae establishment and growth.

Productivity

Changes in site productivity after a burn can be positive or negative, and can vary with the type of ecosystem, the composition of the pre- and postfire plant communities, and the extent of the burn. It is difficult to assess potential for loss of soil productivity after a fire because there is no easy way of calculating long-term productivity declines resulting from the loss of soil material or nutrients. Site productivity changes can be long-term or temporary. If a fire is within the natural range of variation for an ecosystem, and that ecosystem was otherwise healthy before the burn, productivity changes should be short-lived and acceptable. If a fire is outside the natural range of variation and intensity, and if that ecosystem was significantly altered or unhealthy, long-term soil productivity is more likely to be at risk. Methods that consider only the lost value of harvestable timber may underestimate the loss of productivity to other ecosystem components.

Karen Wattenmaker

Log ghosts.

FIRE & WATERSHEDS

Flying into the Frank Church River of No Return Wilderness from Cascade, Idaho. "On this clear day, we could see the results of the year's fires for many miles, including several watersheds. There was a variety of effects, from small, lightly burned patches to large, blackened patches with reddish-gray, ghostly shadows of fallen trees." Yvonne C. Barkley[4]

Karen Wattenmaker

A watershed denuded by wildfire.

The area of land that drains water, sediment and dissolved materials to a common outlet at some point along a stream channel is called a **watershed**. The term **watershed condition** is used to indicate the health of a watershed in terms of its hydrologic function and soil productivity. **Hydrologic function** is the ability of a watershed to receive and process precipitation into streamflow without ecosystem deterioration and is intimately tied to the processes that make up the hydrologic cycle and those that contribute to erosion.

The hydrologic cycle

The hydrologic cycle is made up of interrelated components that are difficult to evaluate individually. Fire and its effects on interception, transpiration, evapotranspiration, infiltration, soil water storage and runoff will affect both the quantity and quality of water within a watershed.

Precipitation is an important influence on flows in forest streams. Defined as water from the atmosphere that reaches plants, the ground or water bodies, precipitation is deposited in many forms, including rain, snow, sleet, hail and condensation such as dew and frost. **Interception** is the process whereby a portion of all precipitation is caught before it reaches the ground. Both natural and constructed surfaces intercept precipitation and each surface has different characteristics and abilities to intercept moisture. For example, waxy conifer needles and rough surfaces intercept water more efficiently than broad leaves and smooth surfaces. Leafless periods provide less interception than a full canopy during the growing season and dense vegetative structures more so than sparse. Water at interception sites eventually changes to water vapor and is lost to the atmosphere in the **evaporation** process.

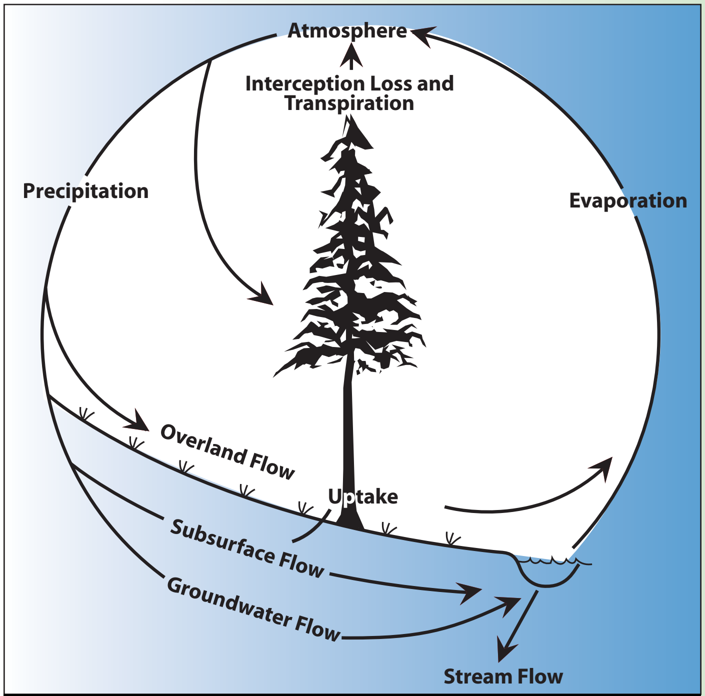


Figure 4. *Forest hydrologic cycle.*

Transpiration is the uptake of soil water by plants and its evaporation to the atmosphere through leaves and other plant surfaces. Transpiration can be likened to breathing. Plants "inhale" water through their roots and "exhale" water vapor through leaves to the atmosphere. **Evapotranspiration** is the loss of water to the atmosphere by the combined effects of interception, transpiration and direct evaporation from ground surfaces and water bodies. **Infiltration**, which is the amount of water that can be absorbed by soil in a given time period, is determined by the percent ground cover, vegetative cover type, soil volume-weight and amount of dead organic material and other protective cover. **Overland flow** or **surface runoff** is water from precipitation that moves over the ground surface, and **subsurface** or **groundwater flow** is any water that flows through the soil and underground rock crevices.

A healthy watershed will allow precipitation to infiltrate into the soil, which limits overland flow and erosion. Transpiration and interception are often reduced after a wildfire, while the rate at which water can be infiltrated into the soil can decrease. This sets the stage for increased overland flow and erosion.

Because melting snow has slower soil percolation rates than water, Inland Northwest snow packs contribute significantly to soil-stored moisture. Snow accumulation has been found to be inversely proportional to the amount of vegetative cover, and in smaller openings, more snow will accumulate on the ground during the winter than in the surrounding forest. This can be beneficial if spring melting is gradual, but if involved in a rain-on-snow event or rapid heating, has greater potential to cause flooding and catastrophic events such as mudslides and debris avalanches. However, when burned areas are approximately four times larger than the height of the surrounding cover, snow accumulations can decreased due to wind scour, further decreasing contributions to stored-soil moisture.

Erosion

Erosion is a natural process occurring on landscapes at different rates and scales, depending on geology, topography, vegetation, climate and weather, and is defined as the movement of individual soil particles by wind or water. Erosion is a function of the forces available, the amount of protection to the soil surface, and the type of the soil, and is usually described by three components: detachment, transport and deposition. **Detachment** is influenced by the ease which individual soil particles are detached (soil erodibility), slope gradient and slope length. Overland flow, gravity, wind and animal activity **transports** detached soil particles from one place to another, which settle (**deposition**) at the bottom of slopes, in areas of vegetation and surface litter, behind rocks or in streams or rivers.

The amount of erosion after a burn will be dependent on each storm event, the severity of the burn, the slope, soil type and condition of the watershed before the burn. Erosion may be fast or may continue to occur over several years after a burn as the root systems of burnt vegetation decay, further decreasing soil stability.

Surface erosion is the movement of individual soil particles, usually by water flowing over exposed soil surfaces, and occurs when precipitation exceeds soil infiltration rates. Some soil types are more susceptible to erosion than others, either because

Karen Wattenmaker

Erosion – Surface erosion.

Karen Wattenmaker

Erosion – mass wasting or debris flow.

particles are more easily detached and moved or because of lower infiltration rates.

Mass wasting includes debris flows and debris avalanches. Debris flows and avalanches are dramatic forms of mass wasting and can deliver massive amounts of sediment to streams. **Debris avalanches** are rapid, shallow soil mass movements from steep hillslope areas. If enough water is present, debris avalanches become **debris flows**, which are rapid downslope mass movements of a slurry of soil, rocks and organic debris directly to stream channels. The terms are often combined or used interchangeably because most debris avalanches are initiated by excess soil water and almost immediately turn into debris flows. When debris avalanches/flows reach steep stream channels, they become a mass movement of large volumes of water mixed with soil, rock and organic material called **debris torrents**. **Slumps** and **earthflows** are slow mass movements that usually occur in areas with deep, fine-textured soils, moving only inches per year.

Another type of erosion, called **dry ravel**, is best described as dry grain flowing downhill. Occurring in semiarid ecosystems, gravity moves soil grains, aggregates and rock material down-slope, often in huge quantities. Dry ravel can be triggered by animal activity, earthquakes, wind, and even by the thermal expansion of soil grains, and often settles in dry streambeds, where it is easily transported into streams during subsequent precipitation events.

Fire & Aquatic Environments

"Though the fire blackened many miles along the Middle Fork of the Salmon River, today the water is sparkling in the sun and flowing clear. We see a fish swirl to the surface and snag a bite to eat …" Yvonne C. Barkley[4]

Karen Wattenmaker

The health and wealth of a stream environment are reflections of the condition and function of the surrounding land.

Over the last 200 years, many changes have been made to most of the aquatic environments of the Inland Northwest. In a period from 1811 to 1859, beaver were essentially removed from these environments through extensive trapping for the fur trade. Mining, grazing, logging and farming caused further change, as did the expansion of industry and urban areas. Today, many aquatic and riparian environments of the Inland Northwest are substantially, and perhaps irreversibly, changed in both physical and biological structure and function.

Pulse disturbances

The health and wealth of a stream environment are reflections of the condition and function of the surrounding land. Good hydrologic conditions are preserved in watersheds that have greater than 75 percent ground cover, with two percent or less of rainfall becoming surface runoff, resulting in little erosion. Streamflow response to precipitation is slow and streamflow is sustained between storms. Riparian vegetation provides shade, which aids in temperature regulation of stream water, intercepts excess nutrients before they can enter the stream environment, and prevents or decreases deposition of soil and silt into the water.

The intensity of a fire will have different effects on stream environments and the five-year period after a major wildfire is one of transition in aquatic ecosystems. Wildfire effects are often described as **pulse disturbances** — initially severe but generally short-lived. High-intensity burns usually result in increased streamflow and sedimentation. Higher stream water temperatures result from lost riparian vegetation that provided shade and erosion protection. Increased light combined with increased nutrient levels often results in a temporary increase in primary production and a shift in the aquatic invertebrate communities from species that process leaf litter and debris to species that scrape and graze attached algae from rocks and gravel. The full recovery of aquatic communities often is dependent on the presence of intact communities upstream and downstream from the burned areas. Fish will generally reoccupy fire-affected areas rapidly when their movements are not limited by barriers such as poorly designed road crossings and culverts, diversions or dams.

Channel erosion and sedimentation

Unmanaged stream ecosystems are altered by episodic floods, droughts and the periods in between, and are in a constant state of adjustment. Erosion is a natural and on-going process and its effects on a stream are highly variable. The addition of eroded material into streams is a common result of fire and increases stream sediment deposition. This added material combined with increased streamflow then leads to increased channel erosion. Over time, these two forces result in the stream environment shifting to a new and different equilibrium.

Although sediment occurs naturally in streams, changes in the amount and type can severely affect aquatic communities. Excess fine sediment can fill in pore spaces between cobbles where fish lay their eggs, and in some cases, clog and abrade fish gills and suffocate eggs and aquatic larvae living on the bottom. In some regions, more than 60 percent of total landscape sediment production is fire-related. Much of that sediment loss can occur the first few years after a wildfire, though in some cases, sediment accumulations may take decades or even longer to recover to prefire conditions.

Nutrients, dissolved oxygen and temperature

There can be a dramatic increase in in-stream nutrient levels the first year after a burn. Nutrients such as nitrogen, phosphorus and potassium are needed for plankton and algal growth, plants that form the food base for fish. But, excess amounts of these nutrients can cause algae blooms, which, when alive, decrease light penetration, and when dead and decomposing, decrease amounts of dissolved oxygen.

Dissolved oxygen is a basic requirement for healthy aquatic ecosystems. Most fish and aquatic insects "breath" oxygen dissolved in the water. Water absorbs oxygen directly from the atmosphere and from plants as a result of photosynthesis. The ability of water to hold oxygen is influenced by temperature and salinity, and decreases with increasing water temperatures.

Temperature also governs many biochemical and physiological processes in cold-blooded aquatic organisms, and increased temperatures can increase metabolic and reproductive rates throughout the food chain. The water temperature at a particular spot is determined by the temperature of the water upstream, processes

David Powell, USDA Forest Service

Large woody debris in a healthy stream.

within the stream reach, and the temperature of overland flow and runoff. Many aquatic species can only tolerate a limited temperature range, and a shift of minimum and maximum temperatures within a stream can have critical effects on species composition.

Large woody debris

Nutrient concentrations also can increase from the addition of large amounts of woody debris to the stream environment. Large woody debris plays a role in hydraulics, sediment routing and channel morphology of streams and is an important component of fish habitat. It also can cause dissipation of energy that is generated by flowing water. Inputs of leaf and needle litter may decline within the first five years if the canopy and surrounding riparian vegetation has been completely burned or removed. Large woody inputs often increase in the short-term as a result of windthrow but generally remain stable during the first decade or more. Recruitment from dead standing wood in riparian areas is critical to maintain large in-stream wood in the long-term. If all the trees in a particular area are killed, it could take hundreds of years before the next generation of large woody debris begins to fall into a stream channel.

In some cases, excess burnt debris may need to be removed to protect infrastructure such as culverts and bridges, but generally, postfire woody debris should be left in the stream environment. Removal could result in changes in channel morphology, scouring of the channel bed, increases in streamflow velocities and sediment loads, an export of nutrients out of the ecosystem, and a deterioration of biotic habitats.

After the Burn

"I still work to reconcile my belief that fire is a beneficial part of the natural environment with my sense of loss when I gaze at the burned landscape. I find the altered landscape fascinating, but not beautiful…In this monochrome environment, colors become vibrant: the perky yellow balsamroot framing the Taylor Ranch in the spring, the fragrant pearly blooms of syringa on the rocky hillsides in the summer, the peach and red and yellow hues of hawthorn and Rocky Mountain maple and cottonwoods growing along Big Creek in the fall, and the clumps of enormous white snowberries in winter. Ash from the fire provides nourishment for all." Holly A. Akenson.[1]

Yvonne C. Barkley, University of Idaho

Damage assessments should be done as soon as possible after a wildfire.

Forest ecosystems are extremely resilient, and in the Inland Northwest, are supremely adapted to disturbance by fire. By living in fire-based ecosystems, we become part of those ecosystems and influence the landscape by our activities in and around forestlands. In this light, the time after a burn can be an excellent time to achieve specific management objectives for a particular piece of ground. Perhaps a change in the species composition to one more suitable for the site would be appropriate, or increasing wildlife habitat, controlling noxious weeds and improving forest health conditions.

Damages vs. benefits

From a management perspective, **damages** are defined as the unfavorable effects of fire-caused changes that make management objectives difficult to achieve or unobtainable. **Benefits** are the favorable effects of fire-caused changes and are factors that contribute to the realization of management objectives. All effects must be looked at with reference to the overall short- and long-term management objectives of any particular piece of land. The effects of fire in an ecosystem that is being managed for wilderness or habitat objectives may be viewed differently from those being managed primarily for timber production.

Emergency Rehabilitation Treatments

The fire-based ecosystems of the Inland Northwest have a long history of fire and as you now know, native species have one or more mechanisms for surviving fire and/or reproducing after a burn. **This is important** — **emergency rehabilitation will not be necessary for many burned areas of a forest**. Much or most of these areas will recover normally without intervention and well-intentioned **rehabilitation efforts could actually interfere with natural recovery responses**.

Rehabilitation treatments should be considered only if the risks to life, property or other resource values are high. Federal land agencies use the Burned Area Emergency Response (BAER) system for assessing and treating large areas of burned land. The Forest Service has done most of the research and collected most of the available information on burned area rehabilitation. Fires that require an immediate assessment of site conditions are visited by assembled teams, which usually include soil scientists, hydrologists and others with a wide range of knowledge and experiences as needed on any particular fire. Burned areas under 300 acres are rarely considered for treatment, and satellite images are commonly used to identify treatment areas. Threats to life, property and water quality are the main reasons given for BAER treatments. Other reasons for emergency rehabilitation treatments are to repair facilities for safety reasons, stabilize biotic communities and prevent the degradation of critical known cultural sites and natural resources.

Treatment effectiveness will depend greatly upon appropriate treatment selection, which in turn depends on accurately identifying emergency conditions. Once rehabilitation treatments are in place, monitoring is very important in order to determine if additional treatments are needed and to evaluate and improve treatment effectiveness.

"We spent a lot of time walking the land, trying to determine if trees were alive, if soil was water repellent, if understory vegetation would come back. Suddenly, we saw a sprig of green. Just 10 days after this area had experienced the very hottest part of the firestorm, an aspen was sending up new sprouts." Yvonne C. Barkley[4]

Assessment

As a private forest landowner or manager who is dealing with smaller acreages, the best way for gathering the necessary information will be by walking the property. Assessment and treatment may be more accurate and effective if adjacent properties are included. Damage assessment should be done as soon after the burn as possible so as to allow time for emergency postfire treatments, **if necessary**. Emergency erosion treatments

Karen Wattenmaker

Vegegation sprouting after a burn.

need to be installed before the first rains of the fall for best effects. **Be very careful when first entering burnt areas. Trees with partially burnt trunks and root systems, called hazard trees, are common and can fall without warning.**

Before you begin your assessment, review your management objectives. An initial inventory of damages will be easier if you already have records of preburn conditions and characteristics of your land. Photographs are a valuable part of management plans and should be updated any time a change has occurred on the landscape. Establishing set photo points throughout your land will help you compare conditions and changes over time.

The information you gather will be more manageable if you assess your land by unit. Units are areas similar in landform and vegetative communities. A map of the unit will be needed. You can photocopy a topographic map or an aerial photograph and enlarge the unit area or you may sketch a map of the unit. Color-coding your information will make interpreting your maps easier. For example, use green for areas that have experienced no to light damage, yellow for moderate damage, and red for severe damage. Make several copies of the unit map, as you will have different types of information to collect. When you are through, I recommend that you have all but your base map photocopied onto clear acetate. You can then overlay the maps and see where areas of greatest concern are, as well as use them to look for patterns and compare characteristics and differences.

Landowners are encouraged to check with local land management agencies for information and expert visits. You can glean a lot of general information from your local county soil survey, which is available to you from the U.S. Department of Agriculture Natural Resource Conservation Service. To find the office nearest you, check your local listings or go to their Web Site at **www.nrcs.usda.gov**.

Karen Wattenmaker

Beware hazard trees.

POSTFIRE ASSESSMENT

Observer(s): ________________________________ **Evaluation Date:** ______________

Unit Identification. Owner' Name(s): ____

Unit Description: ____

____

Property Legal Description: ______________________ Sec. ______ T _____ R _____ _____ M

Nearest Town: ____________________________ County: ________________ State: ______

General Information

The following information may be gathered from aerial photographs, topographical maps, and soil and vegetation surveys and then verified in the field.

Aerial photograph numbers/Topographic map numbers. List map names and numbers. Include both aerial photos and topographic maps.

Aerial photograph #s: ______________ Topographic maps: ______________

Make sure your photos have the date they were taken on them – this provides a valuable reference point. Aerial photos and topographic maps are available from the U.S. Geographic Survey. To find the office nearest you, check your local listings or go to their Web site at **www.usgs.gov**.

Size of unit (acres): ________________ **Elevation:** Min.: _______ft. Max.: _______ft. Average : _______ft.

Aspect. Record the overall aspect of the slope: ________________ Varies from ________ to ________

Soil type(s). Record the dominant soil types of your unit using a U.S. Department of Agriculture Natural Resource Conservation Service soil survey for your area. Note additional information provided in the soil survey such as:

- Soil type(s): ______________________
- Natural vegetation: ______________________
  ____
- Average annual precipitation: ______________________
- Average annual air temperature: ______________________
- Average frost-free days: ______________________
- Soil permeability: ______________________
- Water capacity: ______________________
- Runoff rates: ______________________
- Erosion potential: ______________________
- Effective rooting depth: ______________________
- Best uses (pasture, farm, forests, etc.): ______________________

Forest type: Record prefire forest type (if known):

- Moist _____
- Dry _____
- Cold _____
- Mixed _____

Accessibility of inventoried unit and surrounding landscape. Record the type and access to and within the unit. Indicate the amount and type of traffic on each type of road and trail. Describe any constraints on new or redesigned roads.

Condition codes: Excellent (E); Good (G); Fair (F); Poor (P)

Inventoried Unit	Surrounding Area	Accessibility	Usage
__________	__________	Main road (1st class)	Heavy ___ Moderate ___ Light ___
__________	__________	Hauling road (2nd class)	Heavy ___ Moderate ___ Light ___
__________	__________	3rd class skid road	Heavy ___ Moderate ___ Light ___
__________	__________	Foot trails/skidder roads	Heavy ___ Moderate ___ Light ___
__________	__________	ATV/snowmobile trails	Heavy ___ Moderate ___ Light ___
__________	__________	Gated	Year round ______ Seasonal ______

Constraints on road building: ____

____

Current land-use of inventoried unit and surrounding area. Record the dominant prefire land uses of the unit and surrounding landscape (this may include neighboring properties).

Primary (1); secondary (2), etc.

Inventoried Unit	Surrounding Area	Land Use	Inventoried Unit	Surrounding Area	Land Use
__________	__________	Timber production	__________	__________	Agricultural – idle (fallow, CRP, etc.)
__________	__________	Recreation – foot traffic	__________	__________	Grazing
__________	__________	Recreation – vehicle traffic Type : ________________	__________	__________	Aesthetics
			__________	__________	Residential and Urbanization
__________	__________	Wildlife management	__________	__________	No active management
__________	__________	Agricultural – crops	__________	__________	Other: ____________________ ________________________

Attach map of landscape use and unit location. Show scale and arrow pointing north.

Unit Evaluation

The following information will be collected and mapped in the field and will be most useful when applied to a specific forest stand or other homogenous unit.

Burn severity. All assessment and management decisions after a burn will be based on burn severity. You most likely will have a mosaic of burn severities throughout a unit. Determine and map burn severities. Indicate areas of low (green), moderate (yellow), and high (red) burn severities using the criteria in the table provided to the right.

Table 1. Burn severity classification*.

Soil and Litter Parameters	***Burn severity***		
	Low	*Moderate*	*High*
Surface Organic Horizons (litter, humus and rotten wood)	Scorched, charred, blackened but with definable plant parts; 40 to 85 percent litter cover remains.	Partially consumed; less than 40 percent litter cover remaining, much covered with black char.	No surface litter remains.
Small Woody Debris (<3" diameter)	Surface burned; some unburned areas.	Charred; partially to wholly consumed.	Fully consumed.
Large Woody Debris (>3" diameter)	Blackened with unburned areas.	All blackened; char goes into wood.	Only large, deeply charred logs are left.
Stumps	Stumps intact but blackened.	Burned deep enough to form charcoal.	Stumps gone; hole in ground where stumps and root systems were.
Soil Heat Pulse	32° to 350°F (0 to 177°C)	125° to 750°F (50 to 400°C)	350° to >575°F (177 to >300°C)
Mineral Soil/Ash	Exposed mineral soils may be unchanged or blackened, with isolated areas gray to orange where downed logs burned.	Black, gray, and/or orange mineral soil dominates area, with little to no unburned areas; gray ash present in patches covering <20 percent of area.	Black, gray and orange mineral soil dominates area; gray ash layers may be deep and extensive.
Indicates:			
Soil Organisms	Soil microbes and organisms intact.	Soil microbes and organisms absent except in isolated areas.	Little to no soil organisms remain.
Nutrient Status	Unaffected.	Some to much volatilization of nitrogen has occurred.	Nitrogen likely absent, some to little of other nutrients present.
Water Repellant Layers	None.	Water repellent layers possible.	Water repellant layers likely.
Erosion Potential	Low.	Erosion possible on susceptible soils.	Susceptible to overland flows and catastrophic erosion events.

***Compiled from Hungerford 1996, DeBano et al. 1998, Jain, 2005.**

Predicting mortality. Map predicted mortality. For a mixed-species stand, you may want to map each species' mortality on separate pages.

It is important to determine which trees are dead and which trees are alive and to assess the percent of live trees that will die from secondary effects such as bark beetle invasion, fungal infections and/or a decline in wood quality. There are so many variables involved in assessing postfire tree mortality that it is impossible to apply a formula or standard set of characteristics, making this process more of an art than a science. You will get the most accurate results by using a combination of methods. **Appendix I** (page 50) provides information on predicting mortality using individual tree characteristics, percent crown scorch volume and cambium condition.

Method used to predict mortality by percent crown scorch volume:

- Determine the species of the tree.
- Measure diameter of tree at breast height (dbh).

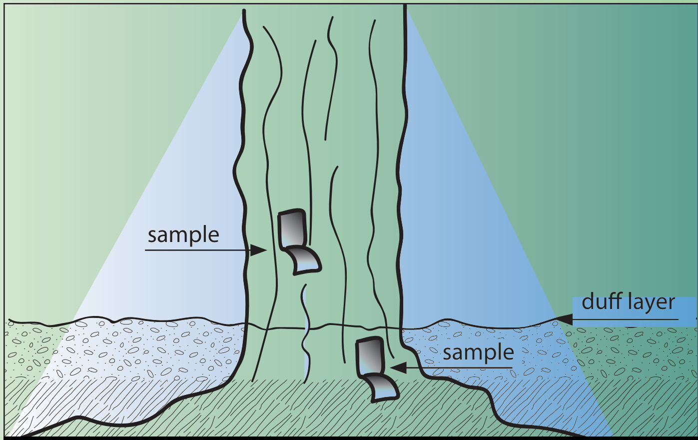


Figure 6. *Assessing cambium condition.*

- Look for brown, dried, or burned foliage. Estimate the amount of foliage scorched; be sure to look at all sides of the crown. Use the tables in **Appendix I** (page 50) for the species being assessed to estimate mortality based on crown scorch volume.

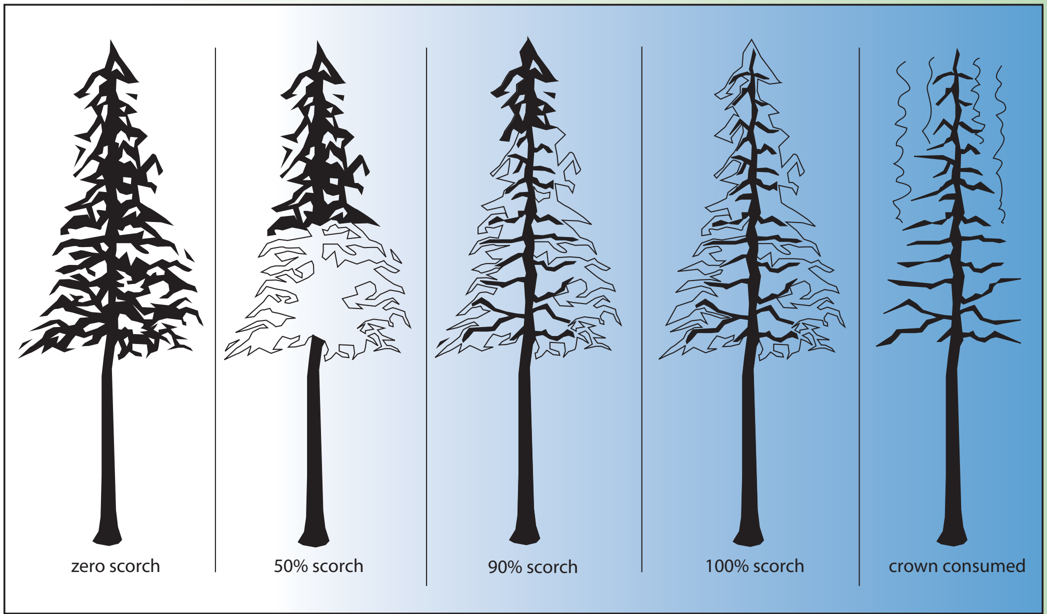


Figure 5. *Assessing percent crown scorch.*

Method used to assess cambium condition:

- Remove a small section (about one-inch square) of bark down to the sapwood near the base of the tree. Check at four sites around the circumference of the trunk. This will allow you to determine the amount of live cambium.
- Check the condition of the inner bark at or below the duff layer using the same method as above.
- Use the criteria provided in **Appendix I** for the species being assessed to predict mortality based cambium condition.

Record soil conditions. Locate water repellent areas and indicate on unit map. See page 65 in **Appendix II – Erosion Control**, for ways to test for and treat water repellent soils.

Estimate postfire potential for erosion. A common initial concern after a wildfire is erosion and flooding. Some soils are more erodible than others. Postfire erosion rates will be dependent on a number of factors, some measurable (percent slope) or known (soil type), some that can be estimated (burn severity), some that we have control over (vegetative cover) and others we do not have control over (postfire weather patterns). In general, erosion hazard will increase as slope increases and vegetative cover decreases.

To be safe, assume that all drainages in steep, hilly areas are capable of carrying debris flows and are especially vulnerable after a wildfire. Areas burned at moderate to high severity are of greatest concern due to lack of cover and the development of water repellent layers.

Using your county soil survey (available from the Natural Resource Conservation Service):

- Determine your soil type. If you have a mosaic of soils in your unit, repeat the process for each soil type.
- Record burn severity.
- Determine the corresponding erosion hazard.
  - o Slight hazard– slopes ranging from 0 to 5%.
  - o Moderate hazard – slopes ranging from 3 to 12%.
  - o High hazard – slopes ranging from 7 to 35%.
  - o Very high hazard – slopes ranging from 20 to 65%.

Indicate results on unit map using the following:

Hazard rating +	*Burn severity*
Slight	light (green) moderate (green) severe (yellow)
Moderate	light (green) moderate (yellow) severe (yellow)
High	light (yellow) moderate (red) severe (red)
Very high	light (red) moderate (red) severe (red)

Note unique unit features such as draws, rocky outcrops, etc. Even areas with low erosion hazard ratings can experience rill and gully erosion if denuded of vegetation and challenged with a short duration, high intensity storm event. For recommendations on erosion control, go to **Appendix II – Erosion Control** (page 62).

Estimate post-fire potential for weed establishment. Assess the potential for weed establishment and/or spread on burned areas. By the summer of postburn year two, you will know if you have a weed problem, but by then it may be too late to achieve good control economically. Note areas that have experienced moderate to severe burning that have little to no vegetation. These areas will be especially susceptible to weed establishment from seed blown in from surrounding areas, as will areas that had weeds previous to burning. Walk the perimeter of your land and see if neighboring lands have weeds present and note where these populations are. Monitor these areas closely as weeds can spread to your property from adjacent populations by wind blown seed or by rhizomes and other vegetative structures. See page 46 in the **Postfire Management** section for more information on weed control measures.

Note that where weeds are concerned there are no areas of low concern. A successful weed management program will consist of an annual weed assessment conducted in the late spring/early summer each year, and very aggressive control of low populations of weeds in order to halt the establishment or spread at a low-cost investment.

For More Information

For those that would like or need a more complete erosion potential analysis than is available here, refer to the U.S. Department of Agriculture, Forest Service FSWEEP erosion prediction tools available on the Web at: **http://forest.moscowfsl.wsu.edu/fsweep**.

Landowners and managers interested in a comprehensive evaluation of wildlife habitat and riparian zones should refer to **Evaluating Wildlife Habitat for Managing Private Forest Ecosystems in the Inland Northwest.** 1996. Pamela Town and Ronald L. Mahoney. Station Bulletin No. 60, Idaho Forest, Wildlife and Range Experiment Station, University of Idaho. Moscow, ID. For a comprehensive evaluation of the condition of streams and rivers, please refer to **Are Your Streams Healthy? Stream Quality Survey for Managing Private Forest Ecosystems.** 1996. Pamela Town and Ronald L. Mahoney. Station Bulletin No 61. Idaho Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, ID. Both of these publications are available from Extension Forestry, PO Box 441140, College of Natural Resources, University of Idaho, Moscow, ID 83844-1140. TEL: (208) 885-6356. E-mail: extfor@uidaho.edu.

Postfire Management

"While we were at Pistol Creek, the landowners and ranch manager were very interested in learning about what they should do postfire. They wanted to know if they could expect a bark beetle outbreak. Trees needed to be removed – when should that be accomplished so they could still use the wood to rebuild cabins and for firewood? They wanted to plant trees – what kind? How many? When should we plant? And they wanted to minimize their fire risk – what are the best ways to manage fuels? From the various questions asked, I realized that some people see the time after a burn as the end of a good book, while others see it as the beginning of the next chapter." Yvonne C. Barkley[4]

Karen Wattenmaker

Salvage cuts should be done as soon as possible after a burn — by year three much or all of the value has been lost.

Salvage logging

Once you have assessed the status of your land, you will need to make some short- and long-term management decisions. One of the first will be to decide if you will harvest your dead and dying trees. Standing dead trees (called **snags**) serve a multitude of purposes, the primary one being habitat for many woodland species of birds and mammals, and as reserve nutrients as they fall to the forest floor over the coming years. But lots of standing dead trees can be too much of a good thing.

Salvage cuts are often initiated after a disturbance (fire, wind, insect or disease kill) to recover the value of damaged trees and remove hazard trees. Salvage operations usually are not done unless the material taken out will at least pay the expense of the operation. But economics and safety are not the sole factors in deciding to salvage log – forest health considerations also play a role in the decision to harvest postfire stands. Increased bark beetle populations may occur in fire-damaged trees, which then serve as reservoirs for future generations of beetles to spread into adjacent healthy stands. Standing dead and dying timber is also fuel and can increase future fire risks. Do the math, look at your land and your management objectives, and make the decision. Salvage cuts should be done as soon as possible after a burn – by year three, much or all of the value is lost.

Bark beetles

Nothing loves a stressed tree more than a bark beetle – unless it's thousands and thousands of bark beetles. Several conditions must exist for bark beetles to take advantage of fire-damaged hosts and because all the conditions must be met for an outbreak to develop, beetle epidemics following wildfires are a possibility, not a given.

First, there must be a sufficient supply of undamaged inner bark (**phloem**) in fire-damaged trees to sustain new and growing beetle populations. If the phloem has been heated until dry and darkened, beetles can neither feed nor deposit eggs in it. Second, fires must occur at a time of year when beetles are in the adult stage and can quickly infest susceptible trees. And third, because bark beetles are not very strong flyers, there must be a population of beetles within a reasonable distance to take advantage of weakened trees that become available.

If all of the above criteria are met and a bark beetle population does move in or increase in size, amounts of damage will vary with the severity of the burn. In areas that were lightly burned, the amount of bark beetle attraction depends mostly on the amount of root collar damage. Most thick-barked species, such as mature Douglas-fir, western larch and ponderosa pine, will have low mortality and not attract beetles unless smoldering duff significantly damaged roots or root collars. On the other hand, thin-barked species, such as true firs, can tolerate little damage at ground level without significant stress, making them much more susceptible to bark beetle attack. In areas that have experienced a light burn, look for trees that have little apparent bole or crown damage, but may be completely girdled at the root collar.

Trees in areas that have experienced moderately severe burns are at the greatest risk of bark beetle infestation. The degree to which mature Douglas-fir are attacked will again depend on the amount of damage to the root collar, though it has been found that bole scorch on more than half of the tree's circumference will likely produce a strong attraction for Douglas-fir beetles.

Few severely burned trees will be infested by bark beetles or woodborers. Severe heating and charring destroys and dries the phloem, resulting in an unsuitable habitat for invading insects. Even most woodborers that feed in the sapwood require relatively fresh phloem for newly hatched larvae. Look for severely burned trees that have lost all of their foliage, as they will tend to have a higher moisture content than those with attached dead foliage. This can be a controlling influence on bark beetle populations – studies have shown survival of beetle larvae is higher in standing trees with foliage than without.

Three classifications of beetles that attack fire-damaged and fire-killed timber are phloem feeders, sapwood feeders and heartwood feeders.

UI Extension Forestry File Photo

Bark beetle.

Phloem feeders work inside the bark, cambium, and outer layers of the sapwood, and include bark beetles and some of the woodborers. All species of bark beetles are very small, usually one-quarter inch long. Life cycles vary among species, but all are a variation on the following example, using the Douglas-fir beetle.

Adult beetles attack injured or weakened Douglas-fir trees in late spring or early summer. Areas that experienced a burn in late

Douglas-fir beetle gallery.

Long-horned beetle.

Piles of sawdust indicate presence of Ambrosia beetles.

summer or fall will not be attacked until the following spring. The potential for attack is related to the severity of the fire and the amount of damage sustained by each individual tree. Douglas-fir beetles can only reproduce in trees with fresh phloem tissue, so dead trees are not attractive to this species.

Douglas-fir beetles do not destroy wood by themselves. Once inside the tree, the adult beetles build tunnels (called **galleries**) under the bark and mine the cambium. Fire-blackened areas in the lower portion of the stem have been found to be most attractive to beetles, and attacks commonly move from the base of the tree to the top, often being most abundant along the midbole. Eggs are laid alternately along opposite sides of the galleries. Larvae mine outward from the egg galleries towards the outer bark. Most Douglas-fir beetles overwinter as adults in the outer bark and emerge in the spring to fly and infest new trees, when the cycle begins anew. The primary attack season for this species is mid-April to June. Those beetles that overwintered as larvae emerge later, usually sometime in midsummer.

Sapwood feeders include flat-headed (or metallic) beetles and roundheaded (or long-horned) beetles and some wood wasps. Woodborers are much larger insects than bark beetles and often have long antennae. Larvae are large, fleshy grubs with a rounded head that is often darker than the body. The larval stage is the most destructive stage, making large, extensive galleries into the sapwood and sometimes the heartwood of the tree.

As always, there is an exception to the rule. Ambrosia beetles, sometimes called pin-hole borers, are as small or smaller than bark beetles and their larvae look very similar. Ambrosia beetles usually are the first to attack the sapwood and frequently the first to attack fire-killed trees. These beetles will attack weakened or recently dead trees. Each beetle will produce one brood per tree the first season after death. The presence of ambrosia beetles can be identified by small piles of white sawdust around the base of a tree. Decay tends to be more advanced around ambrosia beetle holes, as the beetles introduce stain fungi, on which their larvae feed.

Heartwood borers move radially through a tree and mine in and through sapwood and ahead of rot. Heartwood borers only breed in dead trees and continue to develop even after trees are felled and logs are milled, which causes increased loss value.

Fungi

As fungal spores cannot penetrate bark, insect infestations that take place after a burn often provide entry points for fungi. Fungi require certain levels of temperature, moisture and oxygen to become established and thrive. When the moisture content of wood falls below 15 percent, fungi become inactive. Some species of fungi do not die at this point, but go dormant and become active again when conditions become favorable. Excessive moisture decreases oxygen supplies, and when wood is completely saturated, oxygen levels are not sufficient to sustain fungal growth. On dry sites, deterioration often occurs on the lower bole where moisture conditions are more favorable. On wet sites, moisture conditions will be more favorable higher up in the stem.

It is important to detect decay in fire-killed timber early, as it takes very little loss of cell wall material to significantly decrease wood strength. While insect damage and stain lower log quality, decay reduces strength properties, which render the wood useless from a structural standpoint and thus decreases log value.

In the first year after a fire, stain is the most important form of deterioration. Blue stain in the sapwood of trees is one of the first signs of degradation in log quality, and when conditions are favorable for blue stain fungi they also are favorable for other fungi. Stains in softwoods cause little damage to the wood structurally, but do cause loss in grade because of appearance.

There are many types of decays and rots that affect fire- and beetle-killed trees. Here is a summary of the most common in the Inland Northwest:

- Pouch fungus (*Cryptoporus volvatus*) is a sapwood decayer. It may appear as soon as one year after death and produces a light tan discoloration that is difficult to detect on the end surface of a log.
- *Fomitopsis officinalis* deteriorates both sapwood and heartwood. It is more common in older burns and discoloration is yellow or pink to light reddish-brown but also may appear purple.
- *Fomitopsis pinicola*, also called red belt fungus, decays both sapwood and heartwood. In early stages, it appears as a pale yellow to light brown streaking in the sapwood and results in brown cubical rot, which in advanced stages causes wood to crumble easily.
- *Ganiderma applantum* limits activity to the sapwood in the butt log. Discoloration is tan to brown, sometimes purplish-brown to violet stain, and has exacting moisture requirements. It is uncommon except in hemlock.
- *Gloeophyllum sepiarium* is a brown rot that rapidly destroys sapwood and heartwood. Discoloration occurs in patches and is pale tan to brown. This fungus often is found on drier sites.
- *Trichaptum abietinum*, also called purple fungus, causes a white rot responsible for a majority of sapwood deterioration in fire-killed Douglas-fir. Discoloration appears after the first or second year after a fire and is light yellow to tan.

David Powell, USDA Forest Service

Fruiting body of red-belt fungus.

Other Forms of Deterioration

Moisture and temperature also contribute to weather checking. Weather checking generally happens in the top log (top eight feet) of larger trees where there is less volume to be lost. Smaller trees and those with thin bark are more susceptible to weather checking, and checking will be more extensive on hot, dry or windy slopes. Checking can provide an entryway for fungi.

Breakage in felling is another form of degrade that results in volume or value loss. Fire-killed trees tend to have more breakage than green trees. A decrease in pulp chip volume due to char and decay is yet another source of loss due to fire.

Rates of Deterioration

Insect damage is generally classified as limited deterioration with the resulting wood products, such as lumber or veneer, being lower in grade but still usable. Stain also is classified as limited


Jacques Regad, Département de la Santé des Forêts, France

Blue stain fungi.


Robert L. Anderson, USDA Forest Service

Heartwood decay in pine.


Randy Cr, GREEN TREE Technologies

Fully deteriorated tree coverd by lichens.

deterioration but has a major economic impact by lowering the value of products graded for appearance. The presence of decay fungi results in a classification of general deterioration with a resulting loss in volume. Each stand and each tree is unique, but some generalizations have be made:

- blue stain will appear in susceptible trees within the first year;
- by the second year, some of the heartwood will be decayed; sapwood decay will be increasing;
- after three years, the sapwood of most softwoods has deteriorated beyond use for structural timber products.

Reforestation

All states in the Inland Northwest have **Forest Practices Acts** (FPA), which are laws set to guide landowners on basic forest practices and outline minimum management requirements. These laws usually include reforestation standards. It is important to be familiar with your state's FPA laws. They sometimes are vague and misinterpretation is not an excuse for noncompliance. To be sure, contact your local state land's office for a copy of your state's rule and for any clarification you may need on particular laws.

Reforestation is the process of renewal during which a new stand of trees is regenerated on a previously forested site following a disturbance such as fire. **Afforestation** is similar to reforestation but involves establishing trees on sites that have

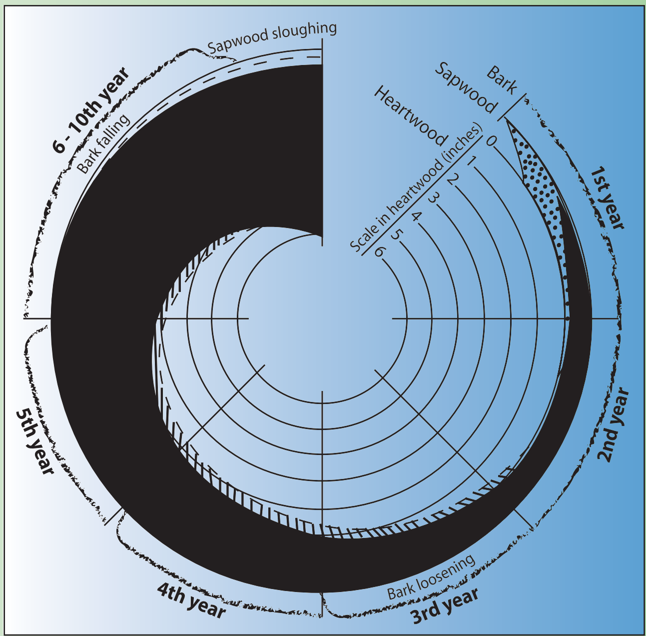


Figure 7. *Progress of deterioration in the trunk of an average young-growth, fire-killed Douglas-fir tree. Stippling represents limited deterioration by blue-staining fungi and ambrosia bettles in the sapwood. The black area represents general deterioration by all causes. The cross hatching represents limited deterioration by borers in the heartwood.* *Diagram from Kimmey and Furniss (1943).*

Natural regeneration.

Tree planting in burned area.

been used for other purposes, such as farm fields or old pasture lands that were never forested.

The method of reforestation you choose, as well as the species of trees, will depend on your site assessment, management plans and financial resources. **Natural regeneration** is when you let nature handle the job. In a managed forest, openings created by harvesting usually include a reforestation strategy to prepare the site for the next crop. For instance, you can use a seed tree or shelterwood cut to remove all of the trees except those of the preferred species, or enhance seedling establishment by preparing the seedbed. Natural regeneration will likely be the most cost-effective means of reforesting your property – seedlings are "free", genetically adapted to the site and you have no transplant shock. But success will be dependent on the abundance of seed available after a burn, both in surviving species and in the soil seedbank. Species selection is often not a choice, nor are stocking levels and spacing. Often, successful germination and establishment will need to be followed up with thinning, and you will need to do weed and brush control.

When a wildfire removes some, most or all of the vegetation from a site, a reforestation strategy is often not feasible and landowners are left with fewer options. **Artificial regeneration** is when you bypass nature and seed or plant the site yourself. In general, direct seeding is not recommended for artificial regeneration. The toll taken by predators such as rodents, birds and insects can drastically affect regeneration success and incur additional follow up costs for fill-in planting, brush control and thinning. By planting seedlings, you can select favored species and get a one- to-five-year head start on other plants that will sprout from local seed.

A successful reforestation project will require a considerable amount of planning and preparation. You must accomplish the following steps well before your first planting day. By following these steps, your planting project will be more efficient, successful and stress-free.

Selecting the species you want to plant

Match the species to the site. Consider soil type, amount of precipitation, slope aspects and frost pockets. Look at past management records to see what species did well and what did not. Consider a mix of conifers, and if necessary, some shrubs, forbs and grasses for the understory.

Look at your management objectives. Do you have multiple goals? Perhaps some areas will be primarily for timber production, others are riparian areas, and yet others designated as wildlife habitat areas. Do not forget to take into consideration other, more non-tangible needs such as recreation, aesthetics and view sheds.

Trees that are grown from seed gathered at sites with similar conditions to yours will do better. The most commonly used criteria for matching seed zones in the Inland Northwest is elevation, and reputable nurseries should be able to tell you what elevation their seed was collected from for each species. Some nurseries will even have a selection of elevational sources within a species. You should try to get seedlings grown from seed that was collected at your approximate elevation.

Selecting the type of stock you want to use

The most important characteristic of your planting stock will be the caliper (diameter) of the stem. The larger the caliper, the stronger and more resilient the seedling. Attention should also be paid to the shoot to root ratio. You need a sufficient amount of top to support the root system with "food" from photosynthesis and a sufficient amount of root system to support the top with moisture and nutrients. "Good" shoot to root ratios for different types of planting stock are listed below.

Planting stock comes in two basic forms:

- **Bareroot stock** are grown in nursery seedbeds, lifted and transplanted to field sites. As the name implies, this type of stock has no rootball of soil around the roots – they are bare. Another type of bareroot seedling commonly available is a plug + 1. Plug + 1's are trees that are grown in containers the first year, transplanted out into beds the second year and then lifted and transplanted again to the planting site. Bareroot stock is the most commonly found stock and is usually available in larger sizes at a lower cost. Some species of trees, such as hemlock, do not grow well in nurseries as bareroot stock and will not be readily available. Bareroot stock also is more susceptible to stresses such as heating and drying during storage and shipping. Good shoot to root ratios for bareroot stock are 2½ - 3 (shoot) to 1 (root).
- **Plug, or container grown, stock** are grown in containers. This type of seedling retains the plug of soil it is grown in and usually experiences less transplant shock, though they usually cost more than bareroot stock. They are becoming more readily available and some nurseries offer a variety of sizes. Frost heaving is more of a problem with container grown stock than bareroot trees. Good shoot to root ratios for containerized stock are 1-1½ (shoot) to 1 (root).

Determining the number of trees you will need

The answer to this question, as so many others when addressing natural resource management issues, is "it depends." It depends on the burn severity, number of trees and species present before the burn, management objectives, site characteristics and the carrying capacity of any particular piece of ground. Tree planting recommendations are offered as number of trees per acre or as a specified spacing. But these recommendations are not very useful to landowners who are faced with planting areas that have experienced a mosaic of burn severities, characteristics and conditions. And restocking your land to mimic preburn densities is not a good guideline either. Chances are good that you had too many trees per acre before the burn – most people do.

This is one area where the art of forestry comes into play. Reforestation companies commonly plant 435 trees per acre at 10' x 10' spacing on clearcut sites that will experience high mortality from harsh conditions (dry sites, sites with south- or west-facing aspects or high animal depredation). Numbers decrease with better conditions and will decrease again when you have residual trees. A distance of 16 feet between trees will give you approximately 170 seedlings per acre; 20 foot spacing will result in 110 seedlings per acre.

The best I can offer is this. Use your management objectives, the characteristics of each area you want to plant, and your state's reforestation requirements to determine the number of trees you want to have per acre when they reach maturity, subtract the number of surviving trees per acre and add 10 percent to compensate for mortality. If your site is particularly harsh or you expect a lot of animal depredation, add 25 percent for mortality. For a more specific recommendation, and to ensure you are compliant with state laws, contact your local department of lands service forester or a forestry consultant.

Ordering your trees

Finding and selecting a nursery is the same process as finding and selecting a contractor. Locate several nurseries and visit them, if possible, to see the quality of their stock. Compare availability of species and types of stock and compare costs. **Order early!** Ordering your trees the fall before you plant is not too soon.

Site preparation

Site preparation is done to ready the soil to receive seed or seedlings, reduce fire hazard, and/or control pest and diseases. Preparation may include salvage logging, clearing, burning or breaking up slash or windfall. Removing competing vegetation or exposing mineral soil creates a favorable seedbed. Fortunately, even low intensity burns will leave you with partially prepared seedbeds by decreasing or removing duff layers and competing vegetation and exposing mineral soil.

Treat weeds and remaining undesirable vegetation the fall before planting. This gives you time to see if your treatments were effective and to do any follow up treatments as needed the following spring.

Planting

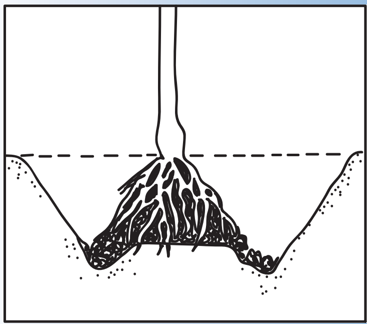
Spring planting conditions are optimal when soil temperatures are 40°F at a depth of four to six inches. But many reforestation projects are started as soon as the snow is off the ground and the site is accessible in order to take advantage of spring moisture before the usual summer drought experienced in most areas of the Inland Northwest.

When your order arrives from the nursery, handle the boxes gently to prevent damaging seedlings. If you cannot plant immediately, ensure seedlings are stored properly. Keep seedlings as cool as possible in the packaging material they arrive in, even if it is only for a day or two. Open the boxes and make sure the roots are moist, if not, add some water, rewrap, and close the box. If you need to store your seedlings for a week or more, put them in refrigerated storage at temperatures as close to 35°F as possible.

Only take as many boxes out to the site as you can plant in one day. If your storage area is close to your planting site, remove boxes in batches throughout the day. Keep boxes and bundles of seedlings out of direct sunlight and be careful how you shade them. Seedlings in a tarp-covered box will be hotter than if placed directly in the sun. The best place for your seedlings at the planting site is in heavy shade under existing trees. If you have no shade at the site, you can create some by suspending a tarp at least three feet above boxes, which will allow air to circulate freely between tarp and boxes.

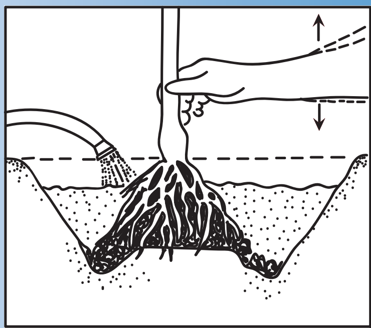
Figure 8. *Bareroot planting*

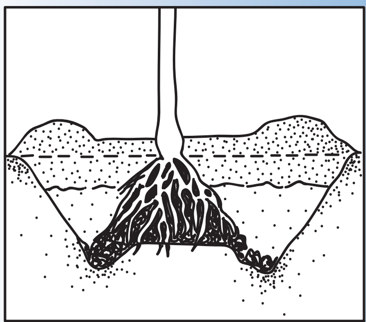
a). For bareroot, non-taprooted species, form a cone of soil in the center of the hole. The top of the cone should reach to nearly the top of the hole. Tamp it with your hands to make it firm.



b). Spread the roots over the cone, pointing the tips away from each other and towards the bottom of the hole. Make sure the biggest root is lying in the direction of the prevailing winds.

c). Fill the hole with the remaining soil, breaking up any clods and discarding rocks and debris. Water if possible.



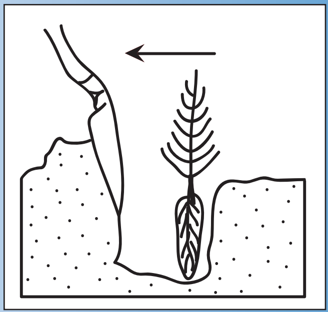


d). Make sure the root collar of the seedling is just below the soil line. The root collar is the area where the soil surface was at the nursery, usually indicated by a change in the color and texture of the bark.

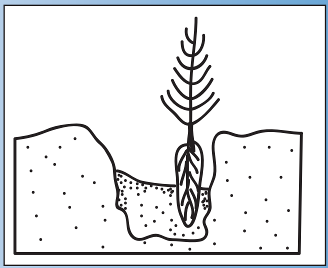
Figure 9. ***Planting container grown stock.***

For container-grown seedlings, insert a shovel vertically with the blade reversed, then pull soil back and out of hole. The hole should be large enough so the entire root plug fits easily into it.

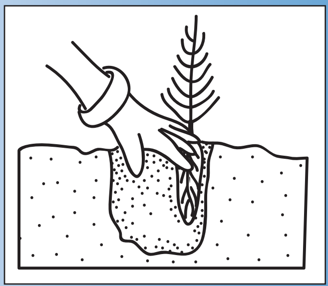
a). Straighten the back of the hole and insert the seedlings at the proper depth. The top of the root plug should be at least 1/2 to 1 inch below the soil line as long as foliage will not be buried.



b). Hold the seedling in place and fill the hole halfway with moist soil.



c). Finish filling the hole with moist soil, tamp with your hand and cover surface with a mulch of loose, dry soil.



d). This properly planted seedling had its original plug buried 1/2 to 1 inch below the soil line. None of its foliage is buried.

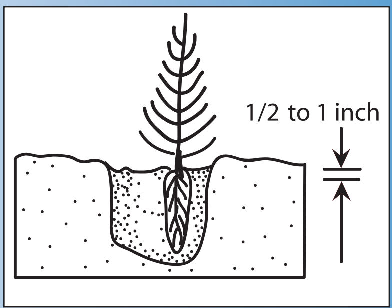
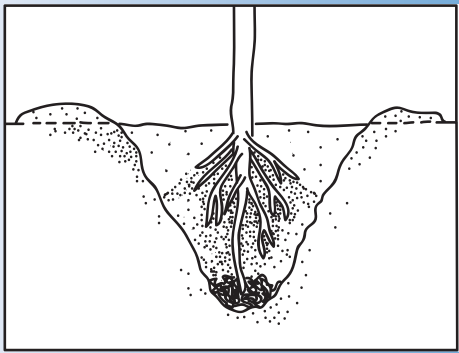


Figure 10. ***Planting species with a tap root.***

For taprooted tree species, make the hole slightly larger than the spread-out root system. Set the seedling in the hole so the root collar is slightly below the top of the hole. Partially fill the hole, breaking up clods and discarding any rocks or debris. Firm the soil around the roots as you continue to fill the hole, making sure the tree is planted straight.



While planting, move seedlings around the site in a planting bag or five-gallon bucket. This not only gives you an easy way to transport them, but also protects them from wind, sun and heat. When possible, plant seedlings on the north or east sides of stumps and logs, which will provide some protection from direct sun.

Dig a good hole. Planting holes should be twice as wide and as deep as the root system or plug. Spades, shovels and hoedads are the tree planters' choice of tools – dibbles are not recommended as they do not create a large enough hole and often contribute to soil compaction. Place the seedling in the hole, making sure you spread roots out if you are using bareroot stock. Backfill, keeping sticks and rocks out of the hole and firm the soil around the seedling with your hand. DO NOT firm the soil around your seedlings by stepping around them – this compacts the soil too firmly and is commonly referred to as "the death stomp."

You may have additional steps after the actual planting, depending on if you have decided to install tree shelters, mulch or shade cards. Tree shelters add protection from animal depredation and also aid in moisture retention. They usually are made of plastic and can be either mesh or solid. You must stake the shelters to secure them. Shade cards can be made out of wood, plastic or heavy duty cardboard, and are placed on the west- and/or south-facing side of a seedling to provide shading on harsh sites.

Hawkweed.

Spotted Knapweed.

Rusk Skeltonweed.

Mulch can be natural, such as bark, leaf litter or duff, or synthetic. Synthetic mulches, also called landscape fabric, comes in rolls or mats and helps retain soil moisture and provide weed control. Mulching is not a common practice in large reforestation plantings and will add a significant cost to your project.

Maintenance

Plan to control weeds and brush for at least three years following planting. If used, inspect tree shelters several times of year. Follow up planting may be necessary if you have significant mortality or animal browse damage.

Weeds

Weed survival after a fire should be expected. Many weeds survive fire via buried seeds. Others reproduce vegetatively from below-ground crowns, roots or rhizomes. For example, the roots of Canada thistle can penetrate the soil 22 feet. Because even the most severe fires typically damage roots only to four inches below the soil, this species has an excellent chance of surviving even very severe fires. New shoots from vegetative root buds are stimulated to grow when fire removes top growth. Fire exposes ground surfaces, causing a flush of nutrients and creates conditions of high light and low shade. Combined with nutrient reserves in roots of rhizomatous and sprouting species, the results are rapid growth and aggressive expansion of weed populations.

Weeds are frequently transported to newly burned areas by wind, equipment, humans and animals, from seeding non-native grasses in rehabilitation efforts, and also from using non-weed free certified products or materials as mulch. Weeds can displace natives by directly out-competing them or by changing fundamental ecosystem processes such as nutrient cycling and disturbance frequencies. Some weeds are transient and have no long-lasting impact while others may persist indefinitely. The worst offenders are those species that are considered **system transformers**. These include the knapweeds, hawkweeds and skeltonweeds, and are species that completely convert and occupy the site to the exclusion of other species.

Weeds will be most abundant in areas that were severely burned, adjacent to established weed populations, and/or in poor ecological condition before the burn. Riparian areas typically have richer and moister soils and so are able to support a greater diversity of plant species. They also serve as natural corridors for transporting seeds via water and animals, and due to seasonal variations in water levels, tend to be highly disturbed systems. In addition to providing ideal growing conditions, riparian zones also are typically restricted use areas for most herbicide use. Over the short-term (approximately five years), this combination of factors makes riparian areas the most vulnerable to weed establishment, and the most difficult to manage aggressively once a weed population has established itself.

Staging areas for the rehabilitation efforts also are very vulnerable to weed invasions. **It is important to use certified weed-free products or materials for rehabilitations efforts.** Areas where straw bales are stored should be monitored over time and when non-certified products are used, can provide an inventory of weed species present in the mulch. Other areas that should be monitored for weeds are roads, trails, dozer lines, areas that received ground-disturbing treatments such as ATV traffic, hazard tree removal, straw bale placement and areas that were seeded or mulched.

Over the longer-term (50 to 100 years), small patches of weeds can be expected to persist on drier sites, in open areas, along roads and trails and in riparian zones. These remnant populations provide seed sources that could aid in the establishment of new populations of weeds following future disturbances such as fire and tree-fall events.

Control methods include hand treatments, herbicide applications, biological controls and changes in grazing prescriptions, with the most commonly used being chemical control. A good source of information for weed control is the Pacific Northwest Weed Management Handbook, available on the Internet at **http://weeds.ippc.orst.edu/pnw/weeds**. This handbook is designed as a quick and easy reference of weed control practices used in various cropping systems or situations in Oregon, Washington and Idaho. A large portion of the handbook is devoted to registered uses of herbicides, crop desiccants and some plant growth regulators. You also can call your Extension office or agricultural and forestry chemical supply company for information and recommendations.

An important component of an integrated weed management plan is often revegetation, which suppresses noxious weeds by introducing competing plants. As a rule, the more severe the burn and the greater the degree of preburn weed cover, the more likely the need for revegetation. Shrublands and grasslands regenerate quickly, whereas forested ground will take more time. But one thing you can count on – empty space will quickly be occupied by vegetation. Your goal is to ensure that the vegetation that occupies the space is the vegetation you want and plan for it. Land managers need to prevent and monitor weed outbreaks – in many states it is the law.

Fuel Management

Research has shown that fuel treatments may reduce wildfire severity in some treated areas. Fuels accumulate over time and increase the potential for fire to ignite, spread and intensify as the time since the last burn lengthens. The goal of fuel reduction is not to fully prevent fires, but to reduce severity and risks associated with natural hazards. Fuel treatments also can be used to restore fire to historic regimes by re-establishing fuel loads to safe management levels and by creating buffer areas between values-at-risk and areas where natural ignitions are allowed to play themselves out. Historic fire regimes may be an important consideration in fuel treatment applications. Among study sites, fuel treatments were most effective in those ecosystems where fires were historically the most frequent.

Fuel management involves reducing, removing and/or rearranging fuels, and/or accelerating decomposition, and can be accomplished by thinning, pruning, grazing, lopping and scattering, and/or prescribed burning. Apply fuel treatments in strategically selected areas where they have the greatest probability of success. A **firebreak** or **fuelbreak** is a strip of land that has been cleared

Karen Wattenmaker

Fuel build-up.

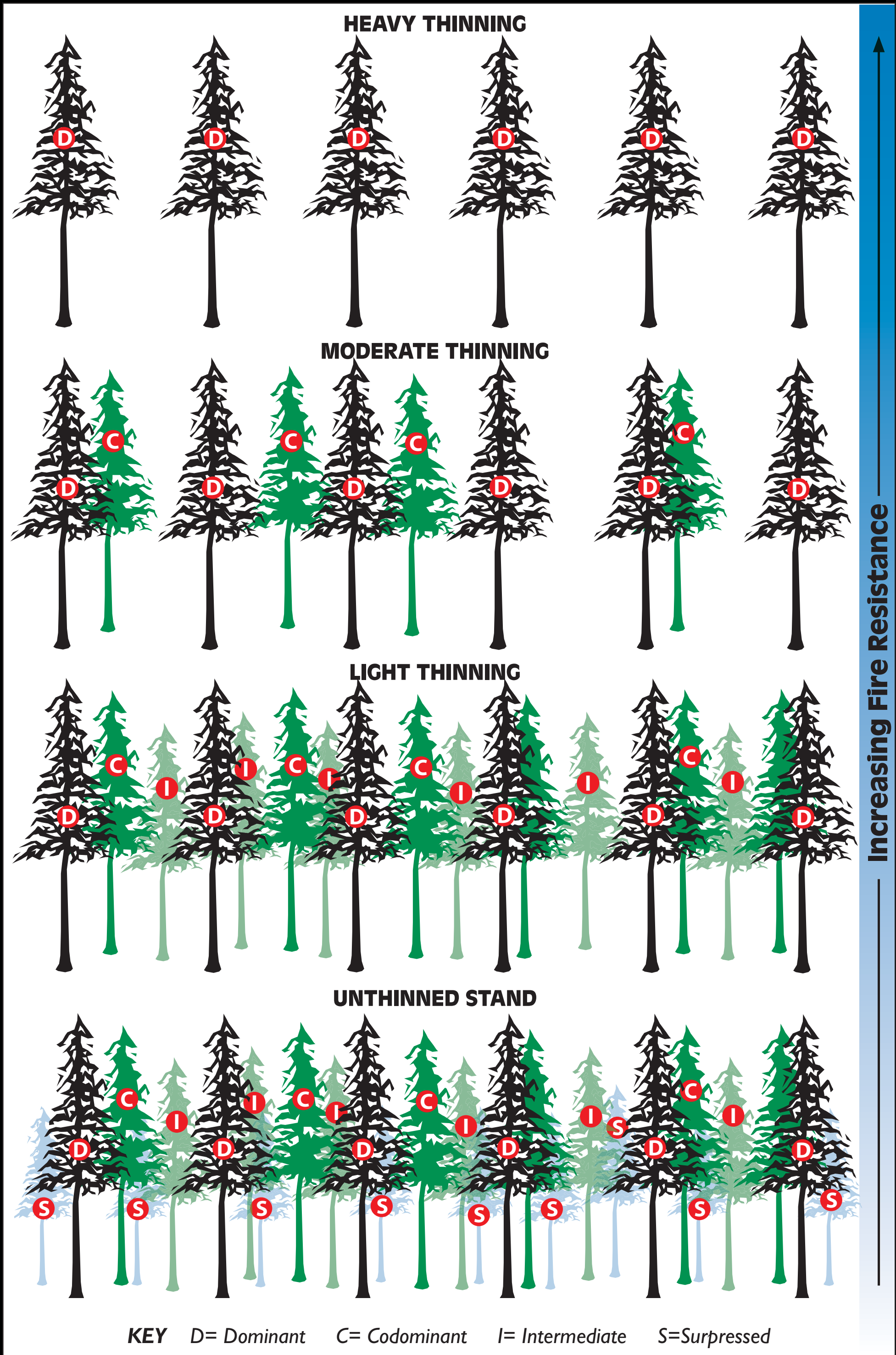


Figure 11. Thinning.

of vegetation down to mineral soil and serves to slow or stop the spread of fires. Natural or other barriers such as roads, rocky slopes or streams often serve as firebreaks. Human-made firebreaks are constructed BEFORE a fire occurs, and are usually located on ridgetops, valley bottoms or other strategic positions. They should be at least 200 to 300 feet wide and must be regularly maintained each year prior to the fire season. Firebreak success will depend on use, location, wind and fuel conditions. In extreme conditions, not even a firebreak will stop a large fire spread by traveling firebrands.

Thinning from below influences fire hazard by changing the arrangement and quantities of live and dead biomass by removing smaller trees and shrubs, decreasing the number of stems per acre. This practice then increases light, moisture and nutrients in the stand, which contributes to increased average diameters of residual trees. This makes for a more vigorous and resilient forest, one that is better able to withstand stress from drought, nutrient deficiencies and attacks from insects and disease. Thinning and pruning also can be used to remove ladder fuels, create shaded fuel breaks and clearings around homes and communities, clear access roads, as a pretreatment for prescribed fire, to maintain or restore forest components such as large trees, snags and downed woody debris, and to remove continuous fuel sources from wildland interface areas. Thinning can be accomplished by hand pulling or cutting, mechanical clearing or by using herbicides.

Hand clearing vegetation includes cutting or pulling out (including most of the root system) individual tree or shrubs. This method is ideal for use near homes and communities to create firebreaks that blend naturally into the forest edge. It also is good for creating mosaics near areas cleared or thinned with heavy equipment, and for steep slopes where machinery would be impractical. Hand clearing operations are slow, labor intensive and expensive. The hand cutting method involves cutting right above the root crown with a brush hook, axe or a chain saw. Small sprouting species can be grubbed out of the soil. Larger species will require hand cutting, heavy equipment or herbicide application depending upon vegetation size and location.

Mechanical clearing is more cost effective than hand clearing, but often has greater environmental impacts, such as soil compaction and increased erosion potentials. Effective brush control will require several years of treatment. Hand and mechanical methods often are combined with herbicide applications to increase the effectiveness of the treatment. **Activity fuels** are those that are generated by management activities, and lopping, scattering, piling, burning, chipping, burying or removing slash are integral to producing forests with low fire hazards.

Grazing animals and fire have co-existed and played major roles in the development and maintenance of naturally occurring savannas throughout North America. A **savannah** is defined as a vegetative cover type of open-grown trees or shrubs with an understory of grasses and grass-like plants. Livestock grazing can be used to control herbaceous vegetation in firebreaks and reduce understory species after initial fuel reduction treatments. Managers using grazing as a maintenance tool should consider the type of animal and determine the amount and types of vegetation that needs to be consumed over the course of a project. For example, goats will eat a wider variety of plant species than will sheep or cattle. For dense brush control, managers recommend confining sheep and goats in a small area. Grazing in confined areas requires monitoring and rotation, and animals will require water and transportation to project sites.

Prescribed burning is the preplanned and controlled application of fire under prescribed conditions of weather, fuel moisture, soil water content and other conditions such as wind speed and direction. These factors will determine heat intensity and are used to determine the rate of spread to achieve the desired objective. Each prescription should establish the conditions necessary to confine the fire to the treated area and create the desired heat intensity to achieve management objectives. Prescribed fire can be used to reduce fire danger, decrease logging residue and slash, prepare seed beds, improve wildlife habitats and aid in weed eradication and species conversion.

Most private forest landowners will not have the knowledge, experience or equipment to carry out prescribed burns themselves. Many states hold landowners financially liable for fires that "get away" – a bill that can run into the millions of dollars. For most, hiring an experienced consulting firm to apply a prescribed burn is the way to go.

Conclusion

Forest ecosystems are resilient, and in the Inland Northwest are particularly adapted to disturbance by fire. It's natural. When viewed strictly from a fire-based ecosystem's structure and function, fire is a good thing. After a burn there is nothing "to fix" – the land will simply follow its own course towards a new equilibrium.

But forest and rangelands do not exist in a bubble, and wildfire raises complex social and economic issues. Humans not only have altered these systems by suppressing fire and changing species compositions, but also have placed economic and personal values on such things as timber, recreation, wildlife and aesthetics. As you can see, the relationship between fire and people is very complex and dynamic.

APPENDIX I

USING INDIVIDUAL TREE CHARACTERISTICS TO PREDICT MORTALITY.

It is important to determine which trees are dead and which trees are alive and to assess the percent of live trees that will die from secondary effects such as bark beetle invasion, and/or fungal infections. Unfortunately, there are so many variables involved that it is impossible to apply a formula or a standard set of characteristics to determine survivability, making this process more of an art than a science.

A few general "rules of thumb":

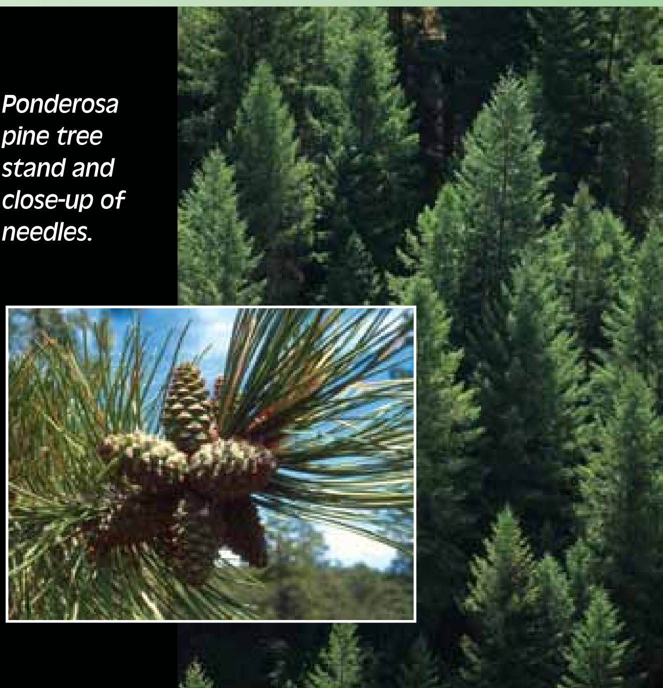
- As the percent crown scorch increases and the thickness of bark decreases, mortality increases.
- Dead branches will retain their dead needles while live branches will tend to shed dead needles.
- Live cambium will be cream colored and juicy; dead cambium will be dry, brown, or gray and have a sour, fermented smell.
- Young, fast-growing trees on good sites will be able to withstand the damaging effects of fire better than overmature, slow-growing trees on poor sites.
- Dormant season burns will result in less damage than early season burns.

Ponderosa pine (*Pinus ponderosa*)

Ponderosa pine is a large tree, growing to 180 feet in height and three to four feet in diameter and has several common names. Young, vigorously growing ponderosa pines often are called bull or blackjack pines, and have dense crowns of deep green foliage and dark brown to black bark. Slower growing, older trees that have developed the characteristic yellow-green foliage and yellow-brown to cinnamon-red platy bark that comes with age often are called yellow pine.

Fire adaptations.

- Thick, nonflammable, exfoliating bark insulates cambium from heat, develops with age and reaches three-plus inches on old trees. Densely grown trees tend to have thinner bark and are less hardy than open grown trees.
- Deep root systems with a large taproot.
- Self-pruning lower branches, resulting in high crowns.
- Long-needles arranged loosely in an open structured crown.
- High foliar moisture content of live needles.
- Large buds enclosed in thin, insulating bud scales.



Ponderosa pine tree stand and close-up of needles.

Karen Wattenmaker

David Powell, USDA Forest Service

Fire effects.

- Low-intensity fires readily kill seedlings less than 12 inches in height, while larger seedlings, saplings and pole-sized trees may be damaged but not killed, especially if the burn occurred during the dormant season. Trees larger than pole-size are quite resistant to low-intensity burns.
- Cambial damage is most likely to occur when high-intensity fires are maintained by deep duff layer surrounding bases of trees.
- Extensive foliar scorching can occur with only light damage occurring to buds, with some trees able to withstand up to 90 percent crown scorch as long as 50 percent of buds and twigs survive.
- Trees producing heavy cone crops are more prone to mortality because nutrients are diverted to cone development and maturation rather than to recovery.
- Damage to cambium is the more important factor in small-diameter classes of ponderosa pine while crown damage is more important in pole-sized and larger trees.
- Cambium must be completely girdled to kill the tree and trees that only are partially girdled have a good chance of survival.
- Bark charring is a poor indicator of cambium damage in ponderosa pine.

Table 2: Probability of fire-induced mortality for ponderosa pine.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	10	20	30	40	50	60	70	80	90	100
5	49%	53%	60%	68%	78%	86%	93%	97%	99%	99%
6	42%	46%	53%	62%	72%	83%	90%	95%	98%	99%
7	36%	40%	46%	55%	67%	78%	88%	94%	98%	99%
8	30%	34%	40%	49%	61%	74%	85%	93%	97%	99%
9	25%	28%	34%	43%	55%	69%	82%	91%	96%	99%
10	21%	24%	29%	37%	49%	64%	78%	89%	95%	98%
12	15%	17%	21%	28%	39%	53%	69%	84%	93%	97%
14	11%	12%	10%	21%	30%	43%	61%	77%	90%	96%
16	8%	9%	7%	16%	23%	35%	52%	71%	86%	94%
18	6%	7%	6%	12%	18%	29%	45%	65%	82%	93%
20	5%	5%	4%	10%	15%	24%	39%	59%	78%	91%
22	4%	4%	4%	8%	13%	21%	34%	54%	74%	89%
24	3%	4%	3%	7%	11%	18%	31%	50%	71%	87%
26	3%	3%	3%	6%	10%	16%	28%	47%	69%	86%
28	3%	3%	3%	6%	9%	15%	27%	45%	67%	85%
30	3%	3%	3%	6%	9%	15%	26%	44%	67%	85%

Sources/Notes: Table developed by David C. Powell, Forest Silviculturist, Umatilla National Forest, Pendleton, OR. These values are probabilities, expressed as a percent, of ponderosa pines of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). See Steele et al. (1996) for a description of the calculation methodology. White values on a blue background denote combinations of crown scorch and DBH with a mortality probability ≥ 50%.

Cambium condition.

- Trunk, roots and root collar:
  - 3-4 sites are pale, green and moist – alive.
  - 2 sites are brown and dry – marginal condition.
  - 3-4 sites are brown and dry – dead.

Postfire response.

- Post-fire regeneration is exclusively through seed. Even though trees with scorched foliage may not live long, they serve as important seed sources.
- Fire creates a favorable seedbed for this species by removing competing vegetation and exposing bare mineral soil. Seedling establishment is best when a good seed crop coincides with above average rainfall.
- Post-fire release of nutrients, primarily nitrogen, contributes to successful regeneration.

Chris Schnepf, University of Idaho

Chris Schnepf, University of Idaho

Western Larch tree stand and close-up of needles.

Table 3: Probability of fire-induced mortality for western larch.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	10	20	30	40	50	60	70	80	90	100
5	49%	53%	60%	69%	78%	86%	93%	97%	99%	99%
6	43%	47%	53%	62%	73%	83%	91%	96%	98%	99%
7	36%	40%	47%	56%	67%	79%	88%	94%	98%	99%
8	31%	34%	41%	50%	62%	74%	85%	93%	97%	99%
9	26%	29%	35%	44%	56%	69%	82%	91%	96%	99%
10	22%	25%	30%	38%	50%	64%	78%	89%	95%	98%
12	15%	17%	22%	29%	39%	54%	70%	84%	93%	97%
14	11%	13%	16%	21%	31%	44%	62%	78%	90%	96%
16	8%	9%	12%	16%	24%	36%	53%	72%	86%	95%
18	6%	7%	9%	13%	19%	30%	46%	65%	82%	93%
20	5%	6%	7%	10%	15%	25%	40%	59%	78%	91%
22	4%	5%	6%	8%	13%	21%	35%	54%	75%	89%
24	3%	4%	5%	7%	11%	18%	31%	50%	71%	87%
26	3%	3%	5%	6%	10%	17%	29%	47%	69%	86%
28	3%	3%	4%	6%	9%	16%	27%	45%	67%	85%
30	3%	3%	4%	6%	9%	15%	26%	44%	67%	85%

Sources/Notes: Table developed by David C. Powell, Forest Silviculturist, Umatilla National Forest, Pendleton, OR. These values are probabilities, expressed as a percent, of western larches of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). See Steele et al. (1996) for a description of the calculation methodology. White values on a blue background denote combinations of crown scorch and DBH with a mortality probability ≥ 50%.

Western larch (*Larix occidentalis*)

Western larch, also called tamarack, is the largest of the American larches, and is one of the few deciduous conifers. Western larch is considered to be the most fire resistant tree species in the northern Rocky Mountains and Inland Northwest. It is very long-lived, enabling it to persist in a stand until fire creates openings and new seedbeds, where larch seedlings will quickly occupy the site and grow rapidly.

Fire adaptations.

- Thick bark with little resin content – at ground level the bark is often 6 inches thick on mature trees.
- High, open canopies with foliage that has low flammability.
- A tolerance for defoliation.
- Deep root systems.

Fire effects.

- Mature western larch are able to withstand most fires.
- Pole-sized trees are able to withstand low to moderate fires, while seedlings and saplings are readily killed by fire.
- Cambial mortality will depend on the duration of the fire and thickness of the bark.

Cambium condition.

- Trunk, roots and root collar:
  - 3-4 sites are pale, green and moist – alive.
  - 2 sites are brown and dry – marginal condition.
  - 3-4 sites are brown and dry – dead.

Postfire response.

- Some individuals will survive even large severe fires, becoming seed trees for rapid restocking.
- Fires that precede a good seed crop especially favor western larch, as seedlings grow best on burned seedbeds.

Douglas-fir *(Pseudotsuga menziesii)*

Second in the country only to the giant sequoias of California, Douglas-fir is the largest tree in the Inland Northwest. Found in mixed stands with ponderosa pine, western larch and grand fir, Rocky Mountain Douglas-fir *(Pseudotsuga menziesii* var. *glauca*) is more drought tolerant than its coastal cousin and is found more often in the more arid Inland Northwest. Though the name may imply it, Douglas-fir is not a true fir.

Fire adaptations.

- Trees develop thick, corky, fire-resistant bark at approximately 40 years of age in the northern Rockies, although the benefits of this adaptation often are offset by low-growing branches that often are retained even when shaded out and no longer green.

Fire effects.

- Trees in the pole and sapling stages are extremely susceptible to fire as their bark is photosynthetic and resin-filled.
- Mature trees can survive moderately severe surface fires.
- Obvious fire scars often are formed and trees can survive several centuries after injury. These fire scars have proven to be an important record of the history of understory fire regimes.
- Rocky Mountain Douglas-fir most often is killed by crown fires, with bud and fine twigs being particularly susceptible.
- Deep humus layers add to susceptibility by increasing heating of roots and lengthening heating times of the lower bole.
- Generally, Rocky Mountain Douglas-fir with greater than 60 percent crown scorch do not survive.

Bill Cook, Michigan State University

Bill Cook, Michigan State University

Douglas Fir tree stand and close-up of needles.

Table 4: Probability of fire-induced mortality for Douglas-fir.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	10	20	30	40	50	60	70	80	90	100
5	**52%**	**56%**	**62%**	**70%**	**79%**	**87%**	**93%**	**97%**	**99%**	**100%**
6	45%	49%	**56%**	**65%**	**75%**	**84%**	**91%**	**96%**	**98%**	**99%**
7	39%	43%	49%	**59%**	**70%**	**81%**	**89%**	**95%**	**98%**	**99%**
8	33%	37%	43%	**53%**	**64%**	**76%**	**87%**	**94%**	**97%**	**99%**
9	28%	32%	38%	47%	**59%**	**72%**	**84%**	**92%**	**97%**	**99%**
10	24%	27%	33%	41%	**53%**	**67%**	**80%**	**90%**	**96%**	**98%**
12	17%	20%	24%	32%	43%	**58%**	**73%**	**86%**	**94%**	**98%**
14	12%	14%	18%	24%	34%	48%	**65%**	**81%**	**91%**	**97%**
16	9%	11%	13%	18%	27%	40%	**57%**	**75%**	**88%**	**95%**
18	7%	8%	10%	14%	21%	33%	**50%**	**69%**	**84%**	**94%**
20	5%	6%	8%	11%	17%	27%	43%	**63%**	**81%**	**92%**
22	4%	5%	7%	9%	14%	23%	38%	**57%**	**77%**	**90%**
24	4%	4%	6%	8%	12%	20%	34%	**53%**	**74%**	**89%**
26	3%	4%	5%	7%	11%	18%	30%	49%	**71%**	**87%**
28	3%	3%	4%	6%	10%	16%	28%	47%	**69%**	**86%**
30	3%	3%	4%	6%	9%	16%	27%	45%	**67%**	**85%**

Sources/Notes: Table developed by David C. Powell, Forest Silviculturist, Umatilla National Forest, Pendleton, OR. These values are probabilities, expressed as a percent, of Douglas-firs of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). See Steele et al. (1996) for a description of the calculation methodology. White values on a blue background denote combinations of crown scorch and DBH with a mortality probability ≥ 50%.

Cambium condition.

- Trunk, roots and root collar:
  - 3-4 sites are pale, green and moist – alive.
  - 2 sites are brown and dry – marginal condition.
  - 3-4 sites are brown and dry – dead.

Postfire response.

- Low resistance to fire in its younger years coupled with slower growth rates puts Rocky Mountain Douglas-fir at a definite disadvantage in post-fire environments, especially when in competition with western larch and ponderosa pine.
- This species depends on wind-dispersed seed to colonize burned areas. Seedling establishment is best on bare mineral soil and usually is restricted to within a few hundred yards of seed trees surviving in, or adjacent to, the burned area. On drier sites, seedling establishment is more successful in shade.
- Though thinning via fire can increase growth of residual trees, radial growth can be greatly reduced for up to four years following a burn.

Grand fir (*Abies grandis*)

One of the true firs found in the Rocky Mountains, grand fir is found most frequently on deep, moist soils in gulches, along streams, and on gentle mountain slopes, and is tolerant of shade.

Fire adaptations.

- Thick bark at maturity provides moderate protection against frequent surface fires. Young trees have thin bark and are readily killed by fire.

Fire effects.

- Grand fir has low, dense branching habits, flammable foliage and a tendency to develop dense stands with heavy lichen growth, which contributes to the likelihood of torching and mortality from crown fire.
- Will not survive crowning or severe fire.
- Ground fires burning in heavy duff can injure shallow roots and kill mature trees.

Chris Schnepf, University of Idaho

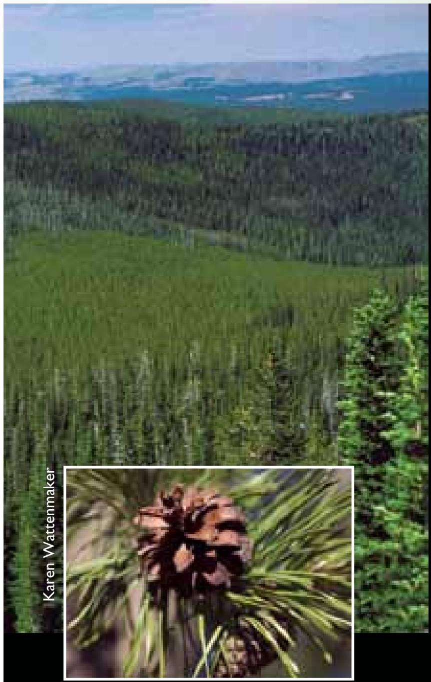
Chris Schnepf, University of Idaho

Grand Fir tree stand and close-up of needles.

Table 5: Probability of fire-induced mortality for grand fir.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	10	20	30	40	50	60	70	80	90	100
5	**68%**	**71%**	**76%**	**83%**	**88%**	**93%**	**96%**	**98%**	**99%**	**100%**
6	**65%**	**68%**	**74%**	**80%**	**87%**	**92%**	**96%**	**98%**	**99%**	**100%**
7	**61%**	**65%**	**71%**	**78%**	**85%**	**91%**	**95%**	**98%**	**99%**	**100%**
8	**58%**	**62%**	**68%**	**75%**	**83%**	**90%**	**95%**	**98%**	**99%**	**100%**
9	**54%**	**58%**	**65%**	**73%**	**81%**	**89%**	**94%**	**97%**	**99%**	**100%**
10	**51%**	**55%**	**62%**	**70%**	**79%**	**87%**	**93%**	**97%**	**99%**	**100%**
12	44%	48%	**55%**	**64%**	**74%**	**84%**	**91%**	**96%**	**98%**	**99%**
14	38%	42%	49%	**58%**	**69%**	**80%**	**89%**	**95%**	**98%**	**99%**
16	33%	36%	43%	**52%**	**64%**	**76%**	**86%**	**93%**	**97%**	**99%**
18	28%	31%	37%	46%	**58%**	**71%**	**83%**	**92%**	**97%**	**99%**
20	23%	26%	32%	41%	**52%**	**67%**	**80%**	**90%**	**96%**	**98%**
22	20%	22%	27%	35%	47%	**62%**	**76%**	**88%**	**95%**	**98%**
24	17%	19%	24%	31%	42%	**57%**	**72%**	**85%**	**94%**	**98%**
26	14%	16%	20%	27%	37%	**52%**	**68%**	**83%**	**92%**	**97%**
28	12%	14%	17%	23%	33%	47%	**64%**	**80%**	**91%**	**96%**
30	10%	12%	15%	20%	29%	43%	**60%**	**77%**	**89%**	**96%**

Sources/Notes: Table developed by David C. Powell, Forest Silviculturist, Umatilla National Forest, Pendleton, OR. These values are probabilities, expressed as a percent, of grand firs of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). See Steele et al. (1996) for a description of the calculation methodology. White values on a blue background denote combinations of crown



David Powell, USDA Forest Service

Karen Wattenmaker

Lodgepole tree stand and close-up of needles.

Table 6: Probability of fire-induced mortality for lodgepole pine.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	10	20	30	40	50	60	70	80	90	100
5	77%	79%	83%	88%	92%	96%	98%	99%	100%	100%
6	75%	78%	82%	87%	92%	95%	98%	99%	100%	100%
7	74%	77%	81%	86%	91%	95%	97%	99%	100%	100%
8	73%	76%	80%	86%	91%	95%	97%	99%	99%	100%
9	72%	75%	79%	85%	90%	94%	97%	99%	99%	100%
10	70%	74%	78%	84%	90%	94%	97%	99%	99%	100%
12	68%	71%	76%	82%	88%	93%	96%	98%	99%	100%
14	65%	68%	74%	80%	87%	92%	96%	98%	99%	100%
16	62%	66%	71%	78%	85%	91%	96%	98%	99%	100%
18	59%	63%	69%	76%	84%	90%	95%	98%	99%	100%
20	56%	60%	66%	74%	82%	89%	94%	97%	99%	100%
22	53%	57%	64%	72%	80%	88%	94%	97%	99%	100%
24	50%	54%	61%	69%	79%	87%	93%	97%	99%	100%
26	48%	52%	58%	67%	77%	86%	92%	96%	98%	99%
28	45%	49%	55%	64%	75%	84%	91%	96%	98%	99%
30	42%	46%	53%	62%	72%	83%	90%	95%	98%	99%

Sources/Notes: Table developed by David C. Powell, Forest Silviculturist, Umatilla National Forest, Pendleton, OR. These values are probabilities, expressed as a percent, of lodgepole pines of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). See Steele et al. (1996) for a description of the calculation methodology. White values on a blue background denote combinations of crown scorch and DBH with a mortality probability ≥ 50%.

Cambium condition.

- Trunk, roots and root collar:
  - 3-4 sites are pale, green and moist – alive.
  - 2 sites are brown and dry – marginal condition.
  - 3-4 sites are brown and dry – dead.

Postfire response.

- On many sites, grand fir will be the dominant species only if fire is excluded.
- Trees that survive fire are susceptible to decay fungi that enter through fire wounds and scars. Grand fir wood does not contain decay-inhibiting properties or exude pitch over wounds, two very important mechanisms for excluding or delaying fungal and/or insect invasions.
- Survivors will provide on-site seed sources from canopy seedbanks. Grand fir seedlings prefer bare mineral soil for germination. Seedlings are not as drought tolerant as other species and establishment can be slow or delayed.
- Grand fir usually establishes itself in areas 20 to 30 years after a burn, and as a shade tolerant species, will continue to establish itself in stands until canopy closure.

Lodgepole pine (*Pinus contorta* var. *latifolia*)

Lodgepole pine is a widespread, medium-sized species found from 1,500 to 11,500 feet in elevation. Growing in moist, but well-drained sandy or gravelly soils, this species is intolerant of shade and is aggressive and hardy. Lodgepole pine is an excellent colonizer and is capable of forming dense, often pure stands in remarkably short periods of time, especially in areas opened up by fire.

Fire adaptations.

- Lodgepole pine is considered a fire evader because of its serotinous cones. This species has the ability to produce seed at a young age and store it in the canopy for long periods of time. When the heat from the next fire melts the resin holding the cones shut, lodgepole pine then releases a staggering number of seeds that quickly repopulates a site.

David Powell, USDA Forest Service

David Powell, USDA Forest Service

Engelmann spruce tree stand and close-up of needles.

Table 7: Probability of fire-induced mortality for Engelmann spruce.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	10	20	30	40	50	60	70	80	90	100
5	73%	76%	81%	86%	91%	95%	97%	99%	99%	100%
6	71%	74%	79%	85%	90%	94%	97%	99%	99%	100%
7	69%	72%	77%	83%	89%	94%	97%	98%	99%	100%
8	67%	70%	76%	82%	88%	93%	96%	98%	99%	100%
9	65%	68%	74%	80%	87%	92%	96%	98%	99%	100%
10	62%	66%	72%	79%	86%	92%	96%	98%	99%	100%
12	58%	62%	68%	75%	83%	90%	95%	98%	99%	100%
14	53%	57%	64%	72%	80%	88%	94%	97%	99%	100%
16	49%	53%	59%	68%	77%	86%	93%	97%	99%	99%
18	44%	48%	55%	64%	74%	84%	91%	96%	98%	99%
20	40%	44%	51%	60%	71%	81%	90%	95%	98%	99%
22	36%	40%	47%	56%	67%	79%	88%	94%	98%	99%
24	33%	36%	43%	52%	64%	76%	86%	93%	97%	99%
26	29%	33%	39%	48%	60%	73%	84%	92%	97%	99%
28	26%	29%	35%	44%	56%	70%	82%	91%	96%	99%
30	23%	26%	32%	41%	52%	67%	80%	90%	96%	98%

Sources/Notes: Table developed by David C. Powell, Forest Silviculturist, Umatilla National Forest, Pendleton, OR. These values are probabilities, expressed as a percent, of Engelmann spruces of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). See Steele et al. (1996) for a description of the calculation methodology. White values on a blue background denote combinations of crown scorch and DBH with a mortality probability ≥ 50%.

Fire effects.

- Lodgepole pine has thin bark that makes it very susceptible to fire-kill from cambium heating, though mature trees can withstand some low-severity burns.
- Crown scorch followed by basal scorch is the best predictor of mortality.

Cambium condition.

- Trunk, roots and root collar:
  - 4 sites are pale, green and moist – alive.
  - 3 sites are pale, green and moist – marginal condition.
  - 2-4 sites are brown and dry – dead.

Postfire response.

- Lodgepole pine is a prolific seeder and produces fertile seed as young as 10 years of age. Heavy seed crops occur at two to three year intervals and can be stored in the canopy in serotinous cones for as long as 15 to 20 years.
- This species also has high seed viability, high seedling survival and rapid growth.

Engelmann spruce (*Picea engelmannii*)

Engelmann spruce commonly occurs in pure stands and is found throughout the Inland Northwest. It is a moderately shade tolerant species and produces large seed crops every three to six years. The average maximum age for this species is 400 years, and suppressed Engelmann spruce can live in the understory for 50 to 100 years and quickly recover once released.

Fire adaptations.

- None. Easily killed because of thin bark, a moderate amount of resin in the bark that is readily ignitable, a very shallow root system, low-growing branches, moderately flammable foliage and a tendency to grow in dense stands that supports heavy lichen growth.

Fire effects.

- Trees commonly escape burning because they occur in moist pockets where fire spread is slowed or stopped.
- Engelmann spruce is rated as very fire sensitive and is often killed in even low-intensity burns. Crown fires typically kill Engelmann spruce.

Cambium condition.

- Trunk, roots and root collar:
  - 3-4 sites are pale, green and moist – alive.
  - 2 sites are brown and dry – marginal condition.
  - 3-4 sites are brown and dry – dead.

Postfire response.

- Re-establishment is through wind-dispersed seed from trees in adjacent habitats or individuals that have survived in unburned pockets. Success will depend on the availability of seed and will be best on moist surfaces where fire has consumed most or all of the duff, exposing bare mineral soil.

Subalpine fir (*Abies lasiocarpa*)

Subalpine fir has a narrow, spire-like, pyramidal crown and commonly has branches that extend all the way to the ground. A tree of great beauty, subalpine fir grows best at elevations from 3,500 to 9,500 feet, often in pure stands. Partially because of its inaccessibility, this species has little commercial importance, but does play an important ecological role as a cover tree on high elevation watersheds.

Fire adaptations.

- None. Subalpine fir are very fire sensitive and high mortality rates from even low-intensity burns are common. It is considered to be the least fire-resistant western conifer species. It has thin, non-insulating and readily ignitable bark, a shallow root system, low-growing branches, a tendency to grow in dense stands, highly flammable foliage and moderate to heavy lichen growth.

UI Extension Forestry File Photo

David Powell, USDA Forest Service

Subalpine fir tree stand and close-up of needles.

Table 8: Probability of fire-induced mortality for subalpine fir.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	10	20	30	40	50	60	70	80	90	100
5	76%	79%	83%	88%	92%	95%	98%	99%	100%	100%
6	75%	78%	82%	87%	91%	95%	97%	99%	100%	100%
7	74%	77%	81%	86%	91%	95%	97%	99%	100%	100%
8	72%	75%	80%	85%	90%	94%	97%	99%	99%	100%
9	71%	74%	79%	84%	90%	94%	97%	99%	99%	100%
10	69%	73%	78%	83%	89%	94%	97%	99%	99%	100%
12	66%	70%	75%	82%	88%	93%	96%	98%	99%	100%
14	63%	67%	73%	79%	86%	92%	96%	98%	99%	100%
16	60%	64%	70%	77%	85%	91%	95%	98%	99%	100%
18	57%	61%	67%	75%	83%	90%	95%	97%	99%	100%
20	54%	58%	64%	72%	81%	88%	94%	97%	99%	100%
22	51%	55%	62%	70%	79%	87%	93%	97%	99%	100%
24	48%	52%	59%	67%	77%	86%	92%	96%	99%	99%
26	45%	49%	56%	65%	75%	84%	91%	96%	98%	99%
28	42%	46%	53%	62%	72%	83%	90%	95%	98%	99%
30	39%	43%	50%	59%	70%	81%	89%	95%	98%	99%

Sources/Notes: Table developed by David C. Powell, Forest Silviculturist, Umatilla National Forest, Pendleton, OR. These values are probabilities, expressed as a percent, of subalpine firs of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). See Steele et al. (1996) for a description of the calculation methodology. White values on a blue background denote combinations of crown scorch and DBH with a mortality probability ≥ 50%.

David Powell, USDA Forest Service

UI Extension Forestry file photo

Chris Schnepf, University of Idaho

Western White Pine tree stand and close-up of needles.

Table 9: Probability of fire-induced mortality for western white pine.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	10	20	30	40	50	60	70	80	90	100
5	77%	79%	83%	88%	92%	96%	98%	99%	100%	100%
6	75%	78%	82%	87%	92%	95%	98%	99%	100%	100%
7	74%	77%	81%	86%	91%	95%	97%	99%	100%	100%
8	73%	76%	80%	86%	91%	95%	97%	99%	99%	100%
9	72%	75%	79%	85%	90%	94%	97%	99%	99%	100%
10	70%	74%	78%	84%	90%	94%	97%	99%	99%	100%
12	68%	71%	76%	82%	88%	93%	96%	98%	99%	100%
14	65%	68%	74%	80%	87%	92%	96%	98%	99%	100%
16	62%	66%	71%	78%	85%	91%	96%	98%	99%	100%
18	59%	63%	69%	76%	84%	90%	95%	98%	99%	100%
20	56%	60%	66%	74%	82%	89%	94%	97%	99%	100%
22	53%	57%	64%	72%	80%	88%	94%	97%	99%	100%
24	50%	54%	61%	69%	79%	87%	93%	97%	99%	100%
26	48%	52%	58%	67%	77%	86%	92%	96%	98%	99%
28	45%	49%	55%	64%	75%	84%	91%	96%	98%	99%
30	42%	46%	53%	62%	72%	83%	90%	95%	98%	99%

Sources/Notes: Table developed by David C. Powell, Forest Silviculturist, Umatilla National Forest, Pendleton, OR. These values are probabilities, expressed as a percent, of white pines of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1996). See Steele et al. (1996) for a description of the calculation methodology. White values on a blue background denote combinations of crown scorch and DBH with a mortality probability ≥ 50%.

Fire Effects.

- The fuel structure in subalpine fir dominated stands promotes highly destructive, stand-replacing fires. Fuel loads are usually greater at high elevations due to the decrease in decomposition rates.
- Once fire reaches the highly flammable crowns, it travels easily between the densely spaced canopies.

Cambium condition.

- Trunk, roots and root collar:
  - 4 sites are pale, green and moist – alive.
  - 3 sites are pale, green and moist – marginal condition.
  - 2-4 sites are brown and dry – dead.

Postfire response.

- In subalpine habitats, subalpine fir will survive in unburned areas of broken and rocky terrain. These individuals serve as seed trees for subsequent generations.
- Subalpine fir seedlings readily establish themselves on burned mineral seedbeds, but burned, high-elevation subalpine fir stands may remain open for decades following a fire, due to the harsh environment near the treeline.

Western white pine *(Pinus monticola)*

King of Inland Northwest forests until the introduction of white pine blister rust, western white pine is but a shadow of its former glory. Fire suppression combined with mortality from white pine blister rust has decreased western white pine stocking levels from 44 percent in 1941 to five percent in 1979.

Fire adaptations.

- Mature western white pine has moderately thick bark and moderately flammable foliage.
- Lichen growth and resinous bark can decrease resistance to fire.
- Young trees have thin bark and are very susceptible to fire.

Fire effects.

- Fire of any intensity will usually damage the cambium layer of young trees, resulting in death.
- Low intensity burns will kill scattered mature western white pines, while leaving others with only scarring.
- Moderate to high intensity burns often results in cambium damage and crowning, followed by the death of the tree.
- Deep humus layers add to the susceptibility by increasing heating of roots.

Cambium condition.

- Trunk, roots and root collar:
    - 4 sites are pale, green and moist – alive.
    - 3 sites are pale, green and moist – marginal condition.
    - 2-4 sites are brown and dry – dead.

Postfire response.

- Western white pine will reseed itself from adjacent trees or surviving trees within the burned areas from canopy seedbanks.
- This species is a fire-dependent, seral species, needing fire to create openings and remove competing vegetation for regeneration to occur.
- Western white pine seed stored in the duff may remain viable for two to three years. If the duff is not consumed, the seed can germinate and establish natural regeneration.

Western redcedar (*Thuja plicata*)

Under favorable conditions, western redcedar can become true giants of the forest, reaching 150 to 200 feet in height and four to eight feet in diameter. Western redcedar's broad, buttressed and fluted bole combined with its lush horizontal and drooping branches makes this species distinct in northern Inland Northwest forests.

Fire adaptations.

- Western redcedar has a very shallow root system, thin bark, a low-growing branching habit and highly flammable foliage, with a fire resistant rating of moderate. Despite these traits, older trees often survive fire because of their large size.

Chris Evans, University of Georgia

UI Extension Forestry file photo

Western redcedar tree stand and close-up of needles.

Fire effects.

- Shallow roots under duff are often scorched when duff layers burn and even moderate fires may kill trees.
- The most common causes of fire mortality are root charring and crown scorching.
- No **Probability of fire-induced mortality** table is available for this species.

Cambium condition.

- Trunk, roots and root collar:
    - 4 sites are pale, green and moist – alive.
    - 3 sites are pale, green and moist – marginal condition.
    - 2-4 sites are brown and dry – dead.

Postfire response.

- Western redcedar will readily establish itself after a burn on bare mineral soil from off-site seeds dispersed by the wind.

Chris Schnepf, University of Idaho

Western hemlock and close-up of branches.

- Fire-killed trees deteriorate slowly. Bark will remain on trees for up to five years, no immediate reduction of wood strength on fire-killed trees is reported in redcedar poles, and some large trees will remain salvageable for almost 100 years after being killed by a fire.

Western hemlock (*Tsuga heterophylla*)

In the wetter areas of its native range, western hemlock is the largest of the four American hemlocks. Reaching heights of 125 to 175 feet and two to four feet in diameter, western hemlock is very shade tolerant and has an open, pyramidal shaped crown that features a drooping terminal leader.

Fire adaptations.

- None. Western hemlock has low fire resistance due to thin bark, shallow roots, highly flammable foliage, a low-branching habitat, tendency to form dense stands and is often lichen covered.

Fire effects.

- Western hemlock is commonly killed by fire, with even light burns scorching its shallow root systems.
- No **Probability of fire-induced mortality** table is available for this species.

Cambium condition.

- Trunk, roots and root collar:
    - 4 sites are pale, green and moist – alive.
    - 3 sites are pale, green and moist – marginal condition.
    - 2-4 sites are brown and dry – dead.

Postfire response.

- Postburn mortality is common due to fungal infections of fire wounds.
- Western hemlock is a secondary colonizer of burned sites, relying on off-site trees to provide seed.

Quaking aspen (*Populus tremuloides*)

The most widely distributed tree in North America, quaking aspen is fast growing and relatively short-lived. This species is very intolerant of shade and has a wide spreading root system that root suckers freely.

Due to years of fire suppression, aspen stands are on the decline throughout North America. In the Inland Northwest, 94 percent of aspen stands are mature or overmature, and young stands are becoming very uncommon.

Fire adaptations.

- Quaking aspen has thin bark and is easily top-killed by fire.
- This species is a prolific root, stump and collar sprouter and will send up shoots for several years after a burn. Sprouts grow rapidly, easily out-competing other vegetation for existing light, moisture and nutrients.
- Even if the prefire plant community had few aspens, it will often dominate a site after a fire, with a new, even-aged stand of aspen taking only a decade to develop.

Fire effects.

- Small diameter quaking aspen is usually killed by even a low intensity burn, but resistance increases with the age and diameter of individuals. Moderate severity burns will usually top-kill all ages and sizes of aspen. Severe burns may kill shallow root systems, but those deeper in the soil profile will live and be able to sucker.

- Deteriorating stands have less root biomass and store less carbohydrates in their root systems than younger, more vigorous stands, and because of this, are at a greater risk of mortality.
- Mortality may not occur immediately after the burn, with some trees able to leaf out prior to dying and wounded trees often invaded by wood rotting fungi.
- No **Probability of fire-induced mortality** table is available for this species.

Postfire response.

- Aspen regenerates by root, stump and collar sprouts. Many clones in the west originated several thousand years ago. Deteriorating clones produce fewer suckers as they mature.
- Fewer than 500 suckers per acre in mature stands are considered to be a signal that this species is undergoing regeneration problems.
- At least 90 percent of the live aspens in a stand must be killed in order to stimulate regeneration.
- Dense suckering in young stands is sustained by frequent fires. Low intensity fires result in thinning of older aspen stands and development of an all-aged condition. High intensity fires result in stand replacement and a return to vigorous sprouting and suckering and subsequent stand renewal.
- Seeds are wind-blown, short-lived, but vigorous germinators, and germinate best on a moist, bare mineral soil seedbed.

David Powell, USDA Forest Service

Paul Wray, Iowa State University

Quaking Aspen and close-up of branches.

Karen Wattenmaker

Aspen sprouting from roots.

APPENDIX II
EROSION CONTROL

Erosion control is probably one of the most common rehabilitation activities after a burn, with success often measured in the quality of the stream at the bottom of the hill. In some regions, more than 60 percent of total sediment production over the long-term is fire-related. Much of that sediment loss occurs in the first year after a wildfire, though in some cases, sediment accumulations and incision may take decades or even longer to recover to prefire conditions. Erosion control only should be used if you are trying to protect downstream values at risk and rehabilitation treatments that have an impact the first year will be important in minimizing damage to both soil and watershed resources.

Karen Wattenmaker

Straw mulch applied to a burned site.

Hillslope treatments

Hillslope treatments are intended to reduce surface runoff and keep soil in place. These treatments are regarded as the first line of defense against postfire erosion and unwanted sediment deposition. Common hillslope treatments are mulching, barriers such as contour-felled logs, straw wattles, silt fences and sandbags, and grass seeding.

Mulch

Mulch is used to cover the soil, thereby reducing rain impact, overland flow, soil erosion and the effects of water repellent soils while increasing soil water content. Research has shown that mulching is the only treatment that consistently and significantly reduced erosion rates by immediately increasing the percent ground cover, compared to gradually increasing cover from growing vegetation.

There are many types of mulching materials to choose from. **It is very important to use certified weed-free products or materials.** Mulch often is used in conjunction with grass seeding to provide ground cover in critical areas.

- **Straw** is the most commonly used mulch. The effectiveness of using straw mulch will depend on how evenly and consistently it is applied. This treatment is most effective on gentle slopes and in areas where high winds are not likely to occur. Mulch is best used in high-value areas, such as above or below roads, above streams or below ridge tops. Rated as the most cost effective type of mulch, straw is superior in protection to hydraulic mulches and comparable to expensive fabrics. Straw should be clean barley or wheat straw – using uncertified straw can introduce invasive plant species.

  Straw mulch is labor intensive to apply correctly and can be difficult to maintain. On gentle slopes, hand broadcasting to a uniform depth of two to three inches is the best method of application. On steep slopes, the straw can be blown onto slopes at the same depths. The Forest Service uses one ton

Bob Brown, USDA Forest Service

Straw mulch anchored into soil by punching.

of straw per acre, which provides about 70 percent ground cover.

Mulch should be applied to the entire seeded or bare area and extend into existing vegetation. If the treatment area is prone to high winds, it may be necessary to punch the mulch into the soil with a spade, roller or crimper. Mulch should be stabilized on all sides to prevent damage that starts at the edges. Hand punching mulch involves using a spade or shovel to punch straw into the slope until all areas have straw standing perpendicularly to the slope and embedded at least four inches deep every 12-inches apart. You can achieve the same effect by using a roller puncher equipped with straight studs that is rolled over the slope. Crimpers have serrated blades four to eight inches apart that force the straw mulch into the soil. Crimping should be done in two directions with a final pass across the slope.

- **Slash spreading** is a common practice after timber sales, but can also be used on burned slopes where dead vegetation is present, and on firebreaks and dozer lines. This treatment is most effective on gentle slopes. Slash spreading provides many of the same benefits of straw, with the additional benefit of keeping and recycling nutrients back into the site. Sufficient material is usually available on-site in low- to moderately-burned areas, especially after salvage logging operations. Intensely burned areas may not have sufficient on-site material. Application can be labor intensive. Using material that is smaller than three inches in diameter can mitigate concerns that slash will attract or harbor insects and/or add to fuel loads. Consult your state's Forest Practices Act for allowable amounts of residual slash. Slash will need to be cut small enough so that it has good contact with the soil. Avoid mechanically treating and spreading slash on wet soil as this will contribute to soil compaction.
- **Fabric mulches.** Geotextile fabric mulches are used to cover the ground and control erosion in high risk areas such as extremely steep slopes, above roads or structures, or along stream banks. Geotextiles come in different grades with ultraviolet inhibitors that determine how long they will last in the field.

Karen Wattenmaker

Log barriers.

Barriers

Barriers are installed on hillslopes along the contour to slow water flow, increase infiltration and trap sediment.

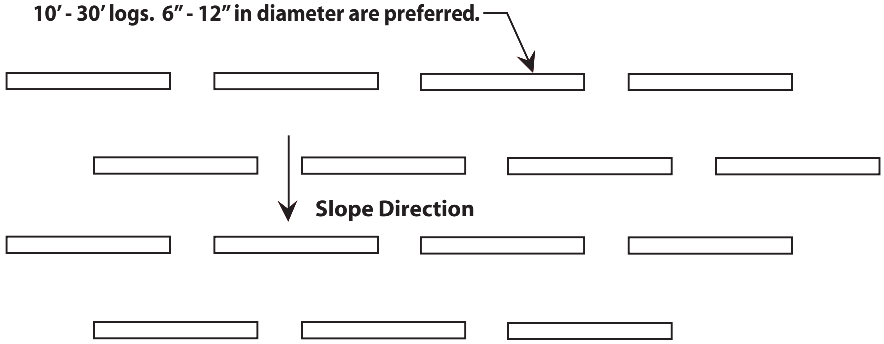
- **Log barriers.** Felling, placing and anchoring logs on the contour of a burned slope provides immediate protection and contour-felled logs are often used in the first year after a burn where erosion rates are expected to be high. This treatment is appropriate for slopes of less than 40 percent. Failures are common where water flows under logs. Placement along the contour is important. Studies have shown that misplacement

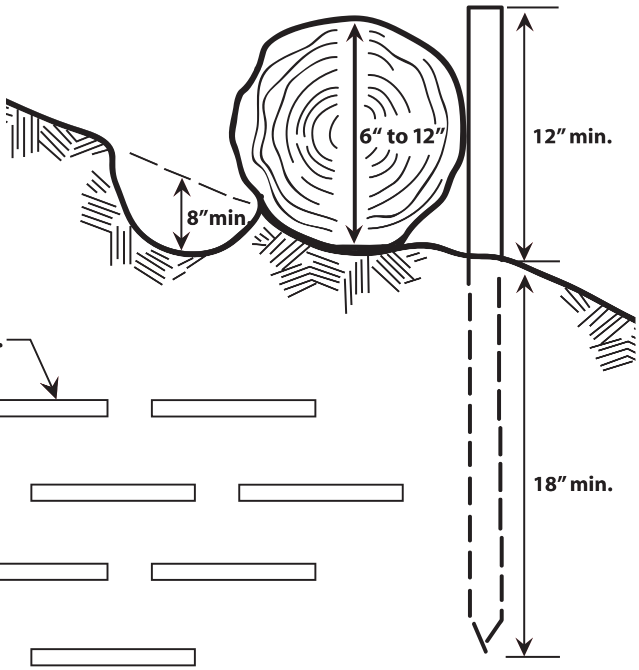
Figure 12. Installing contour-felled logs.

Recommended Horizontal Spacing

Slope Gradient	Low Fire Intensity	Medium Fire Intensity	High Fire Intensity
<5%	250 feet	160 feet	130 feet
5-10%	200 feet	120 feet	90 feet
10-20%	120 feet	60 feet	40 feet
20-50%	60 feet	30 feet	20 feet
>50%	40 feet	20 feet	20 feet

With contour log felling, trees are placed directly on the ground and staked in or wedged behind stumps.





of logs at more than two to five degrees off contour causes trap efficiency to decrease by 20 percent. Log barriers should be viewed as a short-term fix, with some structures filling in with sediment the first storm event after a burn, while others may take one to two years to fill.

In order to be economically feasible, you must have an adequate numbers of 15- to 30- foot long logs that are six to 12 inches in diameter available on the site. Install felled logs on the contour with good ground contact and proper anchoring. Establish good ground contact by delimbing beneath each log while leaving other branches intact and positioned downhill. Trenching to seat contour-felled logs will provide additional stability. Use wooden or re-bar stakes to anchor logs. Steep, shallow and/ or rocky soils and uneven ground surfaces make anchoring difficult, so take extra care to ensure that logs are adequately secured. Berms made of piled up soil at the ends of logs will increase storage capacity by about 10 to 15 percent and are recommended.

- **Straw wattles.** In areas where you do not have a sufficient number of logs available, straw wattles may provide an alternative to contour-felled logs for breaking up slope length. The last two to three feet of the straw wattle should be turned upslope to prevent water and sediment from going around the structure and will increase storage capacity. Straw wattles also can be used in small drainages and on side slopes for catching sediment. The cost of installing straw wattles is about half that of contour-felled logs.
- **Sandbags.** You can construct an inexpensive temporary barrier by stacking sand or earth-filled sandbags one to two feet high. Sandbags can be positioned to divert mud and small debris flows away from buildings and roads, but they will not seal out water. They should be viewed as a short-term fix as they deteriorate when exposed to continued wetting and drying for several months.
- **Silt fences.** Silt fences are made of woven wire and fabric filter cloth and are used as a temporary barrier to catch sediment-laden runoff from swales, small ephemeral drainages

or along hillslopes. They provide temporary sediment storage and cannot handle large debris flows or heavy sediment loads.

Water repellent soil

Water repellency slows the movement of water through soil and results in altered substrate water recharge, quicker streamflow delivery and increased potential for surface erosion. Wildfire creates water repellent layers by partially volatilizing soil organic compounds that then condense onto soil particles deeper in the soil profile.

To check for water repellent soil, scrape away the ash layer to expose the mineral soil. Place one drop of water on the soil surface. If water droplets bead on the surface for 10 to 40 seconds, it is considered moderately water repellent. If it beads for more than 40 seconds, it is considered strongly water repellent. Sometimes, the water repellent layer is a few inches under the soil surface. In these cases, scrape away a one-half to one inch of soil and repeat the test to find the upper boundary of the water repellent layer. Continue testing the soil by scraping away additional layers of soil (one-half to one inch at a time) until non-water repellent soil is reached. This will give you the location and depth of water repellent layers. Water repellency is more severe on dry, sandy soils, and occurs least on wet, fine textured soils. Areas of high severity burns are more likely to have fire-induced water repellency.

Fallen logs can be placed across slopes to slow runoff and intercept sediment. Hand rakes or hoes have been used on gentle to moderate slopes to break up water repellent layers and allow infiltration. On steeper slopes, scatter straw mulch to protect soil from erosion.

Seeding and Revegetation

Though not the most successful method, grass seeding is the most commonly used treatment after a burn. Grass seed is applied to burned sites from the ground or by air with the intention of increasing vegetative cover on the site during the first few critical years after a fire and by doing so, decreases or prevents erosion. Grasses are particularly suited for this purpose because their extensive fibrous root systems increase water infiltration and hold soil in place. This treatment is able to treat large areas at a reasonably low cost per acre, and for decades was used for range improvement with the purpose of gaining use from land that would not produce timber for many years.

Seeding treatments may not be needed as often as currently thought, and successful establishment can actually displace native plant regeneration. As one of the most used and most studied treatments used by the Forest Service's Burned Area Emergency Response (BAER) teams, a great deal is known about the effectiveness of grass seeding. Erosion was decreased by seeding in only one out of eight (12.5 percent) first year studies; benefits were not apparent until the second year after a fire and had greatest value during the second and third rainy seasons. Forest silviculturalists also have expressed concerns about the impacts of grass seeding on conifer regeneration. The use of native grass species over non-native annuals such as cereal grains does not necessarily evade this problem. Not only are native grasses expensive and not widely available, but well-adapted native perennial grasses could provide as much or more competition with tree regeneration as the non-native annual species currently in use.

If you decide to seed grass, know that the success of this treatment is highly dependent on the timeliness of seed application, choice of seed, applicator skill, protection from grazing, and luck in getting gentle rains to stimulate seed germination before wind or heavy rains blow or wash soil and seed away. Often times, the most successful grass crops are often where they are needed the least – at the bottom of the hill.

- **Aerial seeding** grasses, and occasionally legumes, is typically done over large areas where erosion hazard is high and the native plant seed bank is thought to be destroyed or severely depleted by fire. Seed is applied by fixed-wing aircraft or helicopter. In some situations, it is best to drop seed directly into dry ash before any rain falls, while in others, seed is best applied after the first snow so that it will germinate in the spring. Both of these conditions, as well as applying straw mulch over seeded grass, can reduce loss of seed to rodents, increase available moisture for germination and growth, and protect seed from being washed or blow off site. Arrangements for aerial application of seed in a timely manner after a burn can be difficult, as there are few aircraft operators in any given area and supply may not equal demand. Obtaining a sufficient supply of seed, especially if you want or need to use native grass species, also can be difficult, and in the case of native species, expensive as well.

- **Broadcasting seed** from all-terrain vehicles or by hand is less expensive and is commonly done in localized areas of high burn severity where re-establishing plant cover quickly is essential, such as riparian areas and above lakes and reservoirs. Broadcast seeding delivers a more even application than aerial seeding.
- **Hydroseeding** is an application of a slurry of water, wood fiber, seed and fertilizer to treatment sites. Hydroseeding is best used on short, steep, highly erodible slopes that have been partially or completed denuded of vegetation. It is fairly expensive and often is reserved for areas close to roads, bridges, homes and other structures. Slope lengths of 100 to 200 feet can be treated. Small landowners will need to hire out this service – check listings in the Yellow Pages under landscape contractors.

Seed Mixes. Fast-growing, annual or perennial non-native grasses and cereal grains typically are used. These species are inexpensive and regularly available in large quantities. Cereal grains such as barley, rye, oats and winter wheat appear to show great promise for producing cover that does not persist. Legumes are able to increase available nitrogen in the soil after postfire nutrient flushes and are often added to mixes. BAER teams have recommended nonreproducing annuals, such as cereal grains or sterile hybrids that provide quick cover and then die out in order to let native vegetation reoccupy the site. There are legitimate concerns that grass seeding may introduce weed species even in certified seed. For example, cheatgrass can germinate and become established while lying on top of the soil and germinates earlier than other grass species, giving it a competitive advantage.

When considering grass seed mixes, first determine why you are reseeding the area. Different mixes will be used for erosion and noxious weed control than for establishing range to graze cattle or for planting with trees. For example, if you are planting trees, you will want to seed shorter grasses, as taller grass species tend to lay down on seedlings when wet or covered with snow and bend the seedlings over. You also may want to choose bunch grasses versus those that grow in thick mats. Voles and mice thrive in the protective covering provided by matting grass species while they eat your seedlings.

Plant several species of grasses and forbs to allow you to cover a range of site conditions and increase your chance for success. The NRCS recommends a minimum of three species in a mix. Use certified seed of a known variety and make sure it also is certified as weed free. Fertilization is not recommend the first year of seeding, but should be done in subsequent years until vegetation is established.

Table 10. Revegetating Burn Areas West of the Continental Divide and Foothills/Mountains East of the Divide.

***Seedling rates by zone.** The below rates are "pure stand" seeding rates for each species expressed as pure live seed (PLS) per acre. **Rates should be doubled for severely burned acres**.

	Grass/forb species	**lbs(PLS) ac@40seeds/sq.ft***
Zone 1 – Dry, warm sites. Open grasslands and woodland benches at low elevations on all aspects and on south- and west-facing slopes at higher elevations; dry Douglas-fir and ponderosa pine habitat types with a significant bunch grass component in the understory.	Slender wheatgrass	12
	Thickspike wheatgrass	12
	Streambank wheatgrass	11
Native tree/shrub species.	Bluebunch wheatgrass	12
Trees: ponderosa pine, Douglas-fir.	Big bluegrass	2
Shrubs <4 ft: snowberry, Woods rose, antelope bitterbrush, skunkbush sumac.	Pubescent wheatgrass	22
Shrubs >4 ft: mountain mahogany, mockorange, chokecherry.	Sheep fescue	3
	Hard fescue	3
	Yellow sweet clover	> ½ lb/ac
	Dryland alfalfa varieties	> ½ lb/ac

Table 10. (continued)

	Grass/forb species	lbs(PLS) ac@40seeds/sq.ft*
Zone 2 – Moist, warm sites. Moderate environments receiving more effective precipitation than dry, warm sites. Found on north- and east-facing slopes on lower elevations, all aspects at mid-elevations, and on south-and west-facing aspects at higher elevations. Douglas-fir and ponderosa pine habitat types. **Native Tree/Shrub species.** **Trees:** ponderosa pine, Douglas-fir, western larch. **Shrubs <4 ft:** snowberry, Woods rose, currant. **Shrubs >4 ft:** serviceberry, Rocky Mountain maple.	Slender wheatgrass	12
	Thickspike wheatgrass	12
	Streambank wheatgrass	11
	Beardless wheatgrass	12
	Big bluegrass	2
	Mountain brome	27
	Intermediate wheatgrass	22
	Nevada bluegrass	2
	Sheep fescue	3
	Hard fescue	3
	Orchardgrass	4
	Timothy	2
	White Dutch, red or white clover	2
	Yellow sweet clover	> ½ lb/ac
	Alfalfa	> ½ lb/ac
	Sanfoin	> ½ lb/ac
Zone 3 – Moist, cool sites. Found predominately on north- and east-facing slopes at mid-elevations and on all aspects at high elevations. Douglas-fir with blue huckleberry in the understory along with grand fir, western redcedar, western hemlock habitat types. **Native Tree/Shrub species.** **Trees:** Douglas-fir, western larch, Engelmann spruce **Shrubs >4 ft:** Scouler's willow, red-osier dogwood, alder, Rocky Mountain maple.	**Grass/forb species**	**lbs(PLS) ac@40seeds/sq.ft***
	Slender wheatgrass	12
	Beardless wheatgrass	12
	Big bluegrass	2
	Tufted hairgrass	1
	Mountain brome	27
	Intermediate wheatgrass	22
	Orchardgrass	4
	Sheep fescue	3
	Hard fescue	3
	Nevada bluegrass	2
	Timothy	2
	Alsike, red, or white clover	> ½ lb/ac
	Birdsfoot trefoil	> ½ lb/ac
Zone 4 – Riparian areas. Stream bottoms, wet meadows. These sites are subirrigated or wetter for at least a portion of each growing season. **Native Tree/Shrub species.** **Trees:** black cottonwood, quaking aspen, Engelmann spruce. **Shrubs <4 ft:** snowberry, Woods rose. **Shrubs >4 ft:** native willow species, red-osier dogwood, chokecherry, mockorange, Rocky Mountain maple, water birch, alder serviceberry.	**Grass/forb species**	**lbs(PLS) ac@40seeds/sq.ft***
	Slender wheatgrass	12
	Basin wildrye	2
	Meadow foxtail	2
	Birdsfoot trefoil	> ½ lb/ac
	Alsike clover	> ½ lb/ac

This information is excerpted from Wiersum, T. J. Fidel, NRCS and T. Comfort. 2003. Revegetating After Wildfires. NRCS, Missoula, MT.

Natural Resource Conservation Service

Rye is one of the many species of grass you can choose to sow after a burn.

To calculate a mix, divide the individual species rate by the number of species in the mix. Then take the lbs./acre and multiply by the total acres to be seeded.

Example: Mix of five grasses to be seeded on 10 acres. Divide the lbs./acre for each species by 5 and then multiply by 10. For slender wheatgrass this would be (12/5)10 = 24.

Contact your local Extension, state lands, Natural Resource Conservation Service (NRCS), or Forest Service office for further information about grass seed mixes appropriate for your area.

Installation. The best time to seed is late fall before winter rain or snow begins. If mulching, apply straw at a rate of one ton per acre and anchor by punching with shovels or crimping equipment. Note that a 74-pound bale of straw will cover about 800 square feet.

The Natural Resource Conservation Service (NRCS) recommends the following steps for grass seeding:

Equipment and materials needed:

- One hand operated cyclone seed spreader for each person.
- A scale to weigh seed – at least 20 lb capacity.
- At least two plastic buckets.
- Seed targets. At least two pieces of two by two foot soft cloth or cardboard with corrugations exposed, nailed to wooden frame or at least four pieces if one by one foot soft cloth attached to an open wire frame.
- Four grocery bags and two markers.
- Inoculant (specific type for each legume). Omit if seed is coated by supplier. Inoculating legumes enables them to fix nitrogen, which improves the health of plants and provides additional fertility for other plants. Inoculate alfalfa and other legumes the night before or early on seeding day so seed will dry by seeding time. Re-inoculate seed coated over 30 days ago or seed that hasn't been kept cool and dry.

Purchase seed. The total amount of seed needed will equal the acres burned multiplied by the recommended seeding rate per acre. Include roads and firebreaks in the burned areas. Seed supplies of each species should be obtained in separate bags and kept cool and dry.

Check seed tags for species and the percent germination and purity. Increase the seeding rate if percent germination multiplied by the percent purity shows less than 80% Pure Live Seed (PLS).

> *Example 1*. Low PLS adjustment. Recommended seed rate is 10 pounds per acre. The seed you bought is 90% pure and has a 70% germination rate.
>
> *90% x 70% = 63% Pure live seed.*
> *Adjustment factor is 90/63 = 1.3*
> *Adjusted seeding rate is 1.3 x 10 lbs/acre = 13 lbs/acre.*

Coated seed adjustment is needed if the seed is coated by the supplier with inoculant or other materials. No adjustment is needed when you inoculate alfalfa or other legume seeds at the site. Recommended seeding rates are based on uncoated seed and need to be adjusted as shown in this example after making any adjustment for low PLS:

> *Example 2.* Alfalfa seed or other small legume seed.
> *Adjustment factor = 1.5*
> *Adjusted seeding rate is 1.5 x 9 lbs/acres = 13.5 lbs/acre.*

Calibrating your spreader:

- Adjust seed spreader according to the manufactures directions based on half the seeding rate when doing arid seeding and on the full rate when doing a single once-over seeding.
- Set out two seed targets 10 feet apart and offset 10 feet.

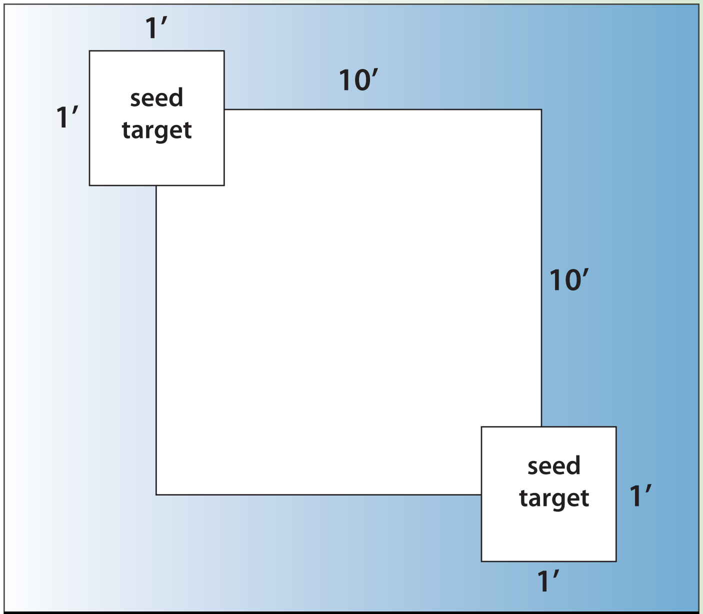


Figure 13. Calibrating your spreader.

- With the hand-operated spreader half full, start broadcasting and walk between the two seed targets.
- Stop and check the seed count at each target. Adjust the seeder and repeat until the number of seeds per square foot agrees with your approximate target of a minimum of 50 seeds per square foot.

Seeding:

- Divide seed of each species into equal amounts and label bags. Keep cool and dry. When seeding a mixture broadcast each species separately, if possible, to get the most uniform distribution of seed.
- Broadcast in two directions to achieve uniform distribution of seed. Using half the seed of a species, broadcast as you walk across the slope, starting at the top of the burn area. Maintain the same walking speed you used while calibrating your spreaders. Notice how far the seed is thrown. When you reach the other edge of the burn, move downslope a distance equal to the width of the throw and make another pass across the slope. Continue broadcasting half of the seed, trying to avoid gaps. Repeat until you reach the bottom edge.
- Using the remaining half of the seed, repeat the process going down the area. On gentle slopes you may be able to broadcast while walking back up the slope. On steep slopes, it is best to broadcast only while walking down the slope because you need to maintain the same walking speed used to calibrate the seeder.
- If you are only able to broadcast in one direction, broadcast half of the seed first and then the other half in the same direction while walking midway between your previous lines of travel.

Visual monitoring should be done for several years after a burn. Temporary fencing may be necessary to keep grazing livestock and wildlife and/or vehicles off of burned areas and riparian zones during recovery periods. In some areas, elk grazing is as problematic as cattle grazing, and the use of the more costly high fences that exclude elk needs to be considered. Elimination of grazing for two years was judged to be very important for achieving hillslope stability.

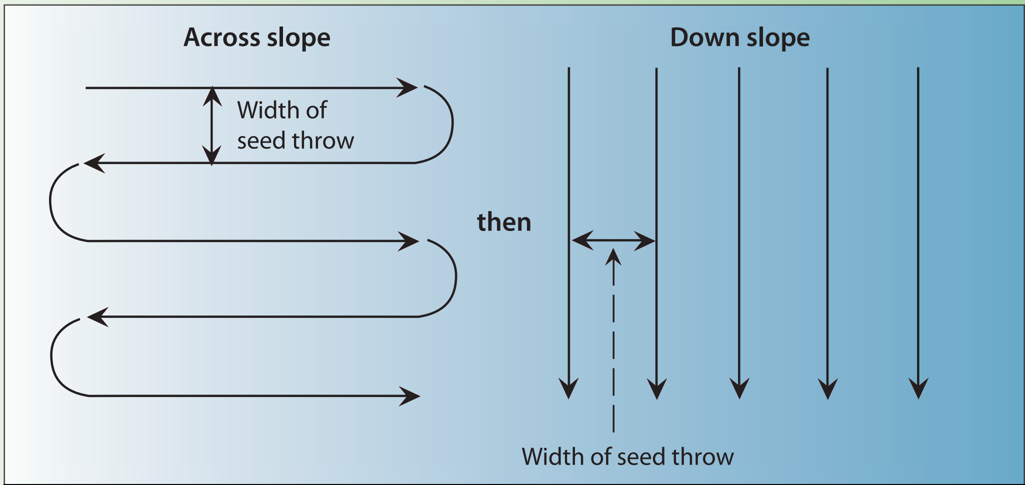


Figure 14. Broadcast seeding in two directions.

Channel treatments

Channel treatments are used to control sediment and water movement in ephemeral or perennial stream channels and to prevent flooding and debris torrents. Some in-channel treatments slow water velocities and allow sediment to settle out and be released gradually as the structure decays; others provide longer-term protection. It is felt that channel treatments should be viewed as secondary mitigation treatments and only should be used if downstream threats are severe. Most channel treatments are expensive and will need to be installed by qualified engineers. In some states, permits may be necessary to do any in-channel treatments. Check with your state lands management agency for the rules. It would be prudent for most landowners to work with an erosion control specialist from the Natural Resource Conservation Service in the design and construction of erosion control barriers in channels or to contract out the installation to an experience professional.

Barriers

Straw bale check dams. Straws bale check dams are temporary sediment barriers constructed of straw bales located across small drainages. These temporary structures decrease water velocity and detain surface runoff long enough for sediment to filter out and be deposit behind dams, thereby reducing the amount of sediment deposited into stream channels.

Straw bale check dams are a very temporary treatment (often filling in after the first few storms) and should not be expected to provide protection for longer than three months. Straw bale check dams have been shown to work best in drier regions, on small drainage areas that have low gradients (less than 30 percent), and in channels that are not incised. They are not intended to provide protection from large storm events or to control debris flows in larger creeks, streams or rivers. Timing of installation can be dependent on the availability of straw bales, which often is not until August of each year. Again, use certified weed-free materials to prevent establishing weeds at and downstream from the structure site.

Straw bale check dams tend to blow out in large storms and failure is common in poorly installed or located structures. To be effective, straw bale check dams must be well designed, properly placed and well built. To install straw bale check dams across small channels:

- **The dam will consist of two rows, an upstream row and a downstream row (see Figure 15 (1)).**
- **Downstream row:**
  Dig a trench across the channel of a size that will result in the top of this row of bales being level with the ground (see Figure 15 (2)). Straw bales in this row will be placed with the longest, widest side down.

USDA Forest Service, Trinity National Forest

Straw bale check dam.

Robert Barkley, Idaho Department of Lands

Failed staw bale check dam.

The tops of the bales across the center of the channel should all be level and set at the same elevation. Stake bales after all bales have been placed into position.

- **Upstream row:**
  Dig another trench across the channel, upstream and immediately adjacent to the downstream row of bales. This trench needs to be wide and deep enough for the straw bales to be placed vertically on their long edges with at least six inches of each bale below the ground, starting with the bale in the middle of the channel (see Figure 15 (3)).

  The trench should be as level as possible so the tops of the bales at the center of the channel are level and water can flow evenly across this portion of the dam.

  Continue the trench up the side slopes of the small channel to a point where the unburied bottom line of the highest bale (point "C" in Figure 15 (4)) is higher than the top of the bales that are in the center of the channel (point "D" in Figure 15 (4)).

- **Anchoring the structure:**
  After you have placed the bales to your satisfaction, they need to be staked. Drive two-inch by two-inch wooded stakes or number four rebar stakes through the bales and one and a half- to two-feet into the ground. The first stake in each bale should be driven toward a previously laid bale to force the bales together (see Figure 15 (4)).

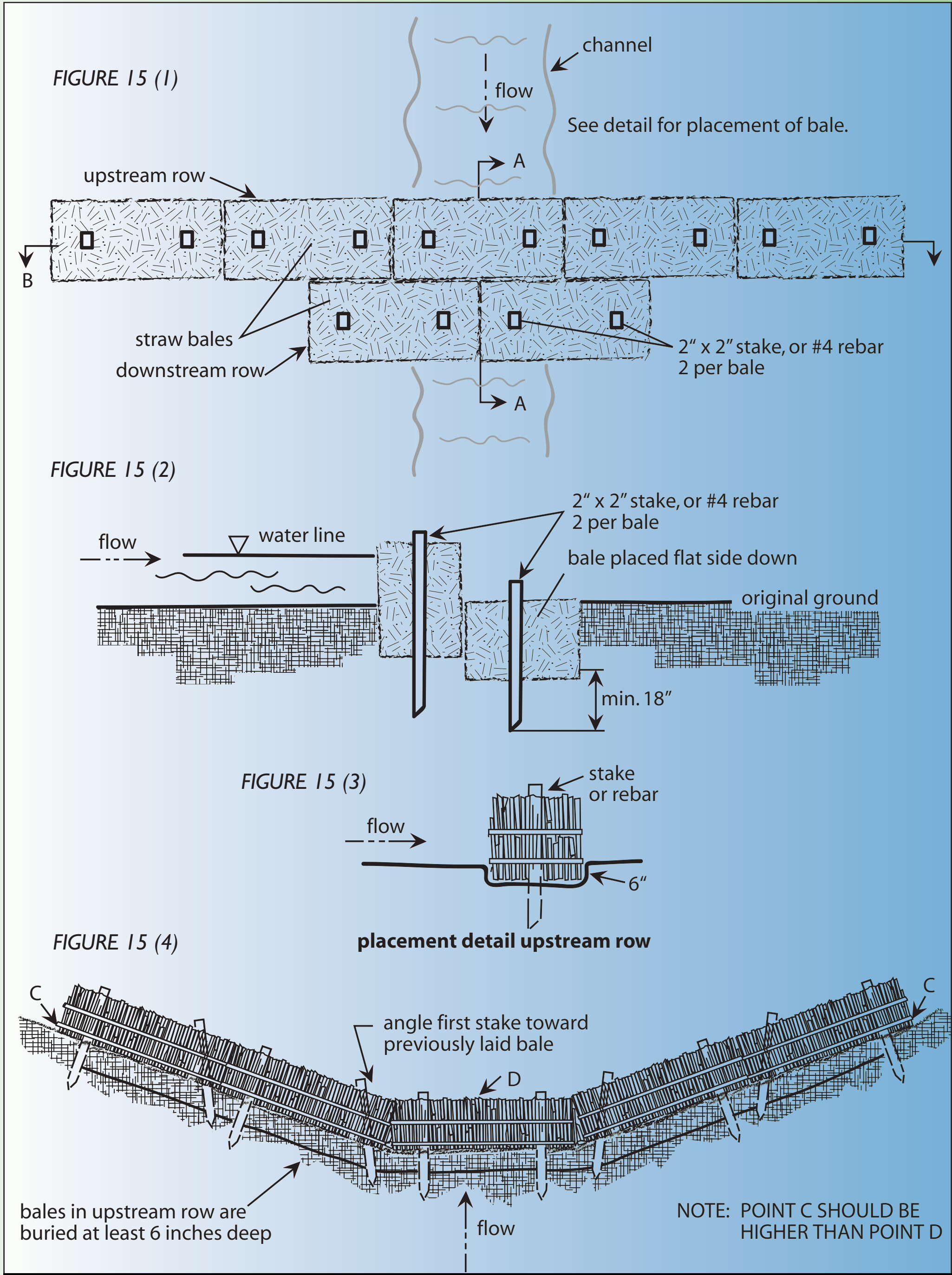


Figure 15. Straw bail check dams.

First year maintenance is critical. Inspect your straw bale check dams after each precipitation event and do necessary repairs immediately.

Log check dams. Log check dams provide the same protection as straw bale check dams, but have the added benefit of being more durable than straw bales and lasting much longer. Research has shown that well built log dams can be 70 to 80 percent effective in trapping sediment and last 15 to 30 years.

Rock cage dams (gabions). Rock cage dams, also known as gabions or rock fence check dams, are used in intermittent or small perennial stream channels to replace large woody debris that was removed from stream environments by fire. Rock cage dams provide grade stability and slow the flow of water enough to trap coarse sediments. This treatment works well on mild gradients, and often will trap enough fine sediments behind the structure to provide a microsite for riparian vegetation re-establishment.

Properly designed and installed rock cage dams are capable of halting gully erosion in denuded watersheds and reducing sediment yields by 60 percent or more. Although these structures are relatively expensive, studies have shown that when used in conjunction with vegetation treatments, they can reduce erosion by 80 percent and suspended sediment concentrations to 95 percent. Installation will depend on the availability of adequate amounts and sizes of rocks, and due to the weight of the cages when filled, should be installed by a commercial contractor. Rock cage dams need to be cleaned out periodically to maintain their effectiveness.

Log grade and rock grade stabilizers. These structures are similar in function to log dams, but the emphasis is on stabilizing the channel gradient rather than trapping sediment. They are expensive and time-consuming to install. Proper design and installation are critical in making log grade stabilizers last and function effectively.

Channel or stream clearing

Channel clearing removes large objects that could become mobilized in a flood. Removing and/or reducing the size of logs and other organic debris and removing sediment deposits from stream channels prevents this material from being mobilized in debris flows or flood events. This treatment is used to prevent the creation of channel debris dams, which can contribute to flash flooding, as well as decrease or eliminate organic debris that can block culverts and cause culvert failure or reduce channel flow capacity.

Karen Wattenmaker

Washed-out road.

In many cases, debris from fire-killed trees does not enter channel systems until two to three years after a burn. Large woody debris plays an important role in stream environments by trapping sediment, dissipating the energy of flowing water, and providing aquatic habitats. In some instances, channel clearing can be more disruptive than the wildfire, and policy is swinging towards reducing the use of or eliminating this practice.

Channel clearing is an expensive and time-consuming operation, and should be reserved for situations where excess debris threatens road culverts, where woody debris might move into

Robert Barkley, Idaho Department of Lands

Properly installed and protected culvert.

Armored stream crossing.

reservoirs, and where sediment must be removed from debris basins and channels to provide adequate sediment storage capacity.

In-channel felling

In-channel felling of streamside trees can provide small sediment trapping structures and large woody debris that traps organic debris and temporarily detains or slows down storm runoff. In-channel felling is commonly done in headwater streams using walking type excavators to place large woody material across the channel where existing wood was consumed by fire.

When falling trees in-channel, tree roots should remain attached and should be partially buried. This will ensure the successful placement of the structures and prevent them from washing downstream. Large woody material diameters should range from 12 to 16 inches with a length of approximately 40 feet or more. Woody material felled into channels often will alter stream gradients, and may cause sediment deposition and channel aggradation.

Debris basins and dams

Debris basins are constructed to regain control of runoff or decrease the deterioration of water quality and threat to human life and property. Debris dams are designed to provide immediate protection from floodwater, floatable debris, sediment, boulders and mudflows. Effective debris dams must be able to trap a minimum of 50 percent and preferably 70 to 80 percent of 100-year flows. A spillway is a necessary part of the construction to insure the safe release of flows in excess of the design storage capacity. This treatment often is used as a last resort because they must be designed by qualified engineers, are extremely expensive to construct, and require annual maintenance.

Road Treatments

While many road drainage systems are usually not affected by fire, adjacent, altered watersheds can affect the functionality of these systems. Road treatments are used to manage and mitigate water's erosive force and move water from undesirable to desired locations. Landowners may need professional assistance to properly design road treatments.

Culverts, culvert overflow/bypass, rolling dips, waterbars, cross drains

All of these treatments are used to provide drainage relief for roads and inside ditches to the downhill side of roads, especially when existing culverts are expected to be overwhelmed. Most landowners will need to hire a commercial contractor to repair and maintain forest roads, especially permanent roads and those that experience heavy and/or seasonal use.

Increasing culvert sizes increases flow capacity and decreases potential for road damage. Installing and maintaining armored culvert inlets and outlets not only maintains flow, but also reduces scouring around culvert entrances and exits, allows large particles to settle out of sediment laden water, and reduces the chance of debris blocking culverts. In some cases, removing undersized culverts, which will fail with increased flows, is the best option. Culvert removal, instead of upgrade, is often done when roads are removed. Frequent storm patrols to check culvert performance are a cost-effective method to reduce road failure due to culvert blockage, and also enable you to close areas as needed. Some areas include early warning systems, such as radio-activated rain gauges or stream gauge alarms, when flows are increased. Check with your local Fish and Game agency for fish passage considerations.

Ditches and armored crossings

Cleaning and armoring ditches will aid water flow capacities and prevent downcutting. Ditches need to be maintained or high water levels can overtop roadways and lead to gully development in the roadbed. Armoring ford crossings provide low-cost access across stream channels on low traffic volume roads and are able to handle large flows. Large riprap is placed upstream and downstream of the actual road crossing area.

References

Agee, J.K. 1993. **Fire Ecology of Pacific Northwest Forests**. Island Press, Washington, D.C. 493 pp.

Anonymous. 2000. **Survivability and Deterioration of Fire-Injured Trees in the Northern Rocky Mountains: A Review of Literature.** U.S. Department of Agriculture, Forest Service, Northern Region State and Private Forestry, Forest Health Protection. Report 2000-13.

Aplet, G.H. 2003. **Fire, Fuel, and Restoration Priorities of the Forest Conservation Community.** Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Bond, W.J. and B.W. van Wilgen. 1996. **Fire and Plants**. Chapman and Hall, London, UK. 263 pp.

Brown, N.C. 1937. **Timber Products and Industries.** John Wiley and Sons, Inc., New York, NY. 316 pp.

Chew, D.C. 2003. **Comparing Two Methods of Identifying Ecological Restoration Opportunities.** Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

DeBano, L.F., D.G. Neary, and P.F.Ffolliott. 1998. **Fire's Effects on Ecosystems**. John Wiley and Sons, Inc., New York, NY. 333pp.

DeBano, L.F. 2000. **The Role of Fire and Soil Heating on Water Repellency in Wildland Environments: A Review.** Journal of Hydrology, 231-232 (2000) pgs. 195-206.

FEIS database. **www.fs.fed.us/database/feis/plants/trees**

Ganz, D.J., D.L. Dahlsten, and P.J. Shea. 2003. **The Post-Burning Response of Bark Beetles to Prescribed Burning Treatments.** Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Graham, R.T. Technical Editor. 2003. **Hayman Fire Case Study**. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-114. Ogden, UT. 396 pp.

Graham, R.T., S. McCaffrey, and T.B. Jain, Technical Editors. 2004. **Science Basis for Changing Forest Structure to Modify Wildfire Behavior and Severity.** U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-120. 43 pp.

Graham. R.T., and T.B. Jain. 2005. **Silvicultural Tools Applicable in Forests Burned by a Mixed Severity Fire Regime.** In: Mixed Severity Fire Regimes: Ecology and Management Symposium Proceedings. November 17-19, 2004. Red Lion Hotel, Spokane, WA. Compiled and edited by: L. Taylor, J. Zelnik, S. Cadwallader, and B. Hughed, Washington State University, Pullman, WA.

Hardy, C.C. and Arno, S.F. Editors. 1995. **The Use of Fire in Forest Restoration: A General Session at the Annual Meeting of the Society of Ecological Restoration**. Seattle, WA. September 14-16, 1995. U.S. Department of Agriculture, Forest Service, Intermountain Research Station General Technical Report INT-GTR-341. June, 1996. 86 pp.

Hardy, C.C. and S.F. Arno. Editors. 1995. **The Use of Fire in Forest Restoration: A General Session at the Annual Meeting of the Society of Ecological Restoration**. Seattle, WA. September 14-16, 1995. U.S. Department of Agriculture, Forest Service, General Technical Report INT-GTR-341. June, 1996. 86 pp.

Harlow, W.M., and E.S. Harrar. 1969. **Textbook of Dendrology**. Fifth Edition. John Wiley and Sons, Inc. New York, NY. 512 pp.

Hawley, R.D. 1935. **The Practice of Silviculture**. Third Edition. John Wiley and Sons, Inc. London, Chaptam & Hall, Limited. 340 pp.

Idaho Forest Practices Act. 1996. Idaho Department of Lands, Boise, ID. 51 pp.

Jain, T.B. **Personal Communication**. 2005. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Moscow, ID 83843.

Kaufmann, M.R., A. Shlisky, and P. Marchard. 2005. **Good Fire, Bad Fire: How to Think About Forest Land Management and Ecological Processes.** U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 16 pp.

Kilpatrick, S., D. Clause, and D. Scott. 2003. **Aspen Response to Prescribed Fire, Mechanical Treatments, and Ungulate Herbivory**. Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Landureth, B.L. for A.W. DuFault. 2001. **Wildland-Urban Interface Fuel Load Reduction Community Level Protection**. Support Document for National Fire Plan Projects in Utah and Nevada, Division of Forestry, Fire and State Lands, Utah Department of Natural Resources, Logan, UT.

Lowell, E.C., S.A. Willits, and R.L. Krahmer. 1992. **Deterioration of Fire-Killed and Fire-Damaged Timber in the Western United States**. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station PNW-GTR-292. 27 pp.

Lynch, D.L., and K. Mackes. 2003. **Costs for Reducing Fuels in Colorado Forest Restoration Projects.** Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Martinson, E.J., and P.N. Omi. 2003. **Performance of Fuel Treatments Subjected to Wildfires**. Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Massman, W.J., J.M. Frank, W.D. Shepperd, and M.J. Platten. 2003. **In Situ Soil Temperature and Heat Flux Measurements During Controlled Surface Burns at a Southern Colorado Forest Site.** Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Neary, D.G., S.T. Overby, and S.M. Haase. 2003. **Effects of Fire Interval Restoration on Carbon and Nitrogen in Sedimentary- and Volcanic-Derived Soils of the Mongollon Rim, Arizona.** Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Ogle, D.G. **Wildfire Recovery Tips.** 2003. U.S. Department of Agriculture Natural Resource Conservation Service, Boise, ID.

Oester, P.T. 2000. **Enhancing Reforestation Success in the Inland Northwest.** PNW 520, Oregon State University Extension Service, Corvallis, OR. 11 pp.

Omi, P.N., Joyce, L.A., technical editors. 2003. **Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings.** April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Peterson, D.L., M.C. Johnson, J.K. Agee, T.B. Jain, D. McKenzie, and E.D. Reinhardt. 2005. **Forest Structure and Fire Hazard in Dry Forests of the Western United States.** U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station General Technical Report PNW-GTR-628. 30 pp.

Pritchett, W.L. 1979. **Properties and Management of Forest Soils.** John Wiley and Sons, Inc. New York, NY. 500 pp.

Reforestation Basics. Small Woodlands Program, British Columbia Forestry. **www.woodlot.bc.ca/swp/myw.html/15_Reforestation.htm**

Reinhart, E.D. and K.C. Ryan. 1989. **Estimating Tree Mortality Resulting from Prescribed Fire.** In: Prescribed Fire in the Intermountain Region: Forest Site Preparation and Range Improvement Symposium Proceedings. Compiled and edited by Baumgartner, D.M., et al

Robichaud, P.R., J.L. Beyers, and D.G. Neary. 2000. **Evaluating the Effectiveness of Postfire Rehabilitation Treatments.** U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station RMRS-GTR-63. 88 pp.

Sanders, K. D. 2000. **How Long Should Rangelands Be Rested From Livestock Grazing Following A Fire?** A Viewpoint. University of Idaho Extension white paper. 4 pp.

Scott, D. and R. Pike. 2003. **Wildfires and Watershed Effects in the Southern B.C. Interior.** Streamline Watershed Management Bulletin, Vol. 7, No. 3. Fall, 2003. FORREX-Forest Research Extension Partnership, Kamloops, B.C., Canada. 4 pp.

Shaver, P. **Fire & Silvopasture**. Inside Agroforestry, Fall, 2002. USDA Natural Resource Conservation Service Grazing Lands Technology Institute, Corvallis, OR. 4 pp.

Smith, D.M. 1962. **The Practice of Silviculture**. Seventh Edition. John Wiley & Sons, Inc. New York, New York. 578 pp.

Smith, J.K., editor. 2000. **Wildland Fire in Ecosystems: Effects of Fire on Fauna**. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-42-Vol.1. Ogden, UT. 83 pp.

Jain, T.B. and R.T. Graham. 2005. **Restoring Dry and Moist Forests of the Inland Northwest.** Pp 463 – 480. In: Restoration of Boreal and Temperate Forests, Stanturf, J.A. and P. Madsen, editors. CRD Press, Baca Raton, FL.

Stephens, S. and J. Moghaddas. 2003. **Fire Hazard and Silvicultural Systems: 25 Years of Experience From the Sierra Nevada**. Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Veblen, T.T. 2003. **Key Issues in Fire Regime Research for Fuels Management and Ecological Restoration**. Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. April 16-18, 2002, Fort Collins, CO. Omi, P. N., and L.A. Joyce, technical editors. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proceedings RMRS-P-29. 475 pp.

Wenger, K.E. 1984. **Forestry Handbook**. 2nd edition. For the Society of American Foresters. John Wiley & Sons, Inc. New York, NY. 1319 pp.

Wiersum, T. J. Fidel, NRCS and T. Comfort. 2003. **Revegetating After Wildfires.** NRCS, Missoula, MT.

Whitson, T.D., et al. 2002. **Weeds of the West.** University of Wyoming, Laramie, WY. 628 pp.

FOOTNOTES

1. Excerpt from ***Jumping from the Frying Pan*** by Holly A. Akenson. In ***Forged in Fire: Essays by Idaho Writers***. 2005. Mary Clearman Belw and Phil Druker, editors. University of Oklahoma Press, Norman, OK. 261 pp.

2. Journal entry from Blake Swanson, landowner, and his chronology of the 2000 Pistol Creek fire, Frank Church River of No Return Wilderness, ID.

3. Journal entry from Jim and Holly Akenson, managers of the University of Idaho Taylor Ranch Wilderness Research Station, Frank Church River of No Return Wilderness, and their chronology of the 2000 Diamond Point and Clear Creek fires.

4. Journal entry from Yvonne C. Barkley, Associate Extension Forester, University of Idaho, from her September, 2000 post-fire visit to the Pistil Creek Ranch, Frank Church River of No Return Wilderness, ID.

University of Idaho
Extension

This publication is issued as contribution No. 951 of the University of Idaho Forest, Wildlife and Range Experiment Station, College of Natural Resources, University of Idaho, Moscow, ID 83844-1130

8,000 8/2006 $15.00