Environmental Impacts and Mitigation Measures
for Biomass Harvest Forest Thinning

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Background

This portion of the report discusses the environmental effects of biomass removal from dry forests using ground based small and intermediate sized equipment. Impacts include those from thinning, hand piling and burning, thinning and broadcast burning, broadcast burning only and wildfire events that occur as a consequence of allowing stands to become overstocked and fuel-laden.

Biomass harvest involves production of energy and economic by-products from leaves, bark, stems and roots of undecayed plants. In North-central Washington, an available source of biomass is readily available from forest trees and bark, exclusive of needles, treetops and interspersed shrubs and deciduous species.

Thickets of suppressed small diameter trees with very little if any understory vegetation will be priority sites for biomass to energy projects. The condition of these low and mid-elevation sites is the result of fire suppression and in some cases past high grade logging activity.

The abundance of low- or no-value small diameter trees and a relative lack of merchantable larger diameter trees, combined with low growth rates precludes tree farming strategies that are economically viable. Thinning and treating slash at $500 to $1000 per acre cannot be justified when a merchantable tree takes 80 years to grow.

Reducing the cost of thinning and slash treatment through biomass utilization will require the most cost effective harvest methodologies while minimizing negative environmental impacts. Ground based mechanical harvesting with small and intermediate sized equipment is a way to meet the economic criteria, but it will result in soil impacts.

Biomass removal can be part of a management activity that accomplishes multiple objectives such as fuel reduction, thinning for improved forest health, and restoration of historic stand conditions. Thinning is a fuel reduction activity that addresses the consequences of 100 years of fire exclusion. Fire exclusion in dry forests has disrupted the natural recycling of carbon, producing an excess of biomass with the potential to cause forest fires and poor forest health.

The impacts considered here are those that would occur from a forest thinning program with low impact equipment. Two standard prescriptions are considered, both designed for dry site forests. One prescription is primarily for dry and south-facing ponderosa pine sites with a low severity, high-frequency fire regime. The target stand density for these stands is to have under

100 trees per acre (tpa) is of 7-inch-plus stems, with the eventual goal of reducing the density to 25-50 tpa. The other prescription maintains up to 100 tpa on cooler sites or north slopes.

Processing wood for energy production involves a number of steps. The removal process begins with felling and yarding of trees, which may also be done for other objectives such as fuel reduction or stimulation of forest health. Trees can be felled by chainsaws or by wheel- or track-mounted vehicles. Yarding can be done with cables, heavy machinery or manually (if the wood is small and hauling trucks are close by). Yarding impacts are often modified to reduce impacts using a variety of methods such as yarding over frozen ground or using high lead cables, or by using lightweight vehicles and careful operators, well-designed skid trails or articulated machinery to grapple the stems.

A road system and designated skidding and yarding areas are often used and these contribute to the impacts. Additional impacts could potentially occur if drying or chipping facilities will be on site, but these are not analyzed here.

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1. Soils

Biomass removal has direct and indirect short and long term impacts on soil structure and soil chemistry. Impacts will vary by soil type, slope, aspect, soil moisture levels, temperature, understory vegetation and harvest technology. Impacts to soils can occur due to changed soil structure from heavy machinery use or by changes that predispose soils to flooding, erosion, changed hydrologic regimes, or even debris flows initiated during extreme weather events.

1.a. Soils: Direct impacts

Direct impacts to soils include bulk compaction at depth, rearrangement of litter, duff and logs, and disaggregation (exposure of mineral soil due to shear). Disaggregation, or simply “soil disturbance”, can be defined and measured by the amount of bare ground exposed as a result of activities. These impacts are primarily due to heavy machinery and yarding. The soil type and slope has a strong influence on the type and magnitude of soil impacts.

Soil compaction and disturbance damage soil structure. Soil structure is formed from clumps of soil particles held together by chemical bonds and biological materials. These clumps are called peds and form an aggregate that increases the overall available pore spaces in the soil. Developed forest soils have peds that persist through seasonal weather fluctuations and provide habitat for a diverse biotic community.

Soil compaction is the consolidation of individual soil particles following loads applied to the soil surface. Compaction reduces the pore space between soil particles that hold water and provide for gas exchange and habitat for soil biota that are important for nutrient cycling. Extensive areas of compacted soils exhibit lower infiltration rates and increase surface runoff and erosion. Compaction resulting from woody biomass removal is highly variable depending on soil type, moisture levels, temperatures, soil surface, type of machinery and the number of passes over a particular location.

Heavier clay and silt soils can be very susceptible to compaction particularly when soil moisture levels are high. Water acts as a lubricant between soil particles allowing them to slide easily against each other and pack tightly together. Coarser sandy gravelly soils are less susceptible to compaction and in some cases soil surface loading and the minimal resulting compaction can increase water retention by decreasing pore size.

Soil temperatures that go below freezing greatly reduce or eliminate compaction if soil moisture levels are high enough to bind the upper soil layers with ice. Soil duff and downed woody debris along with woody shrubs can also limit compaction of forest soils.

Compaction can result from the removal of the cushioning surface materials that distribute weight prior to multiple passes over a location. The weight per area transferred by forest machinery to the ground surface is one measure of the compaction that can be expected following harvest operations.

Another major cause of soil disturbance is shear or disaggregation. This can result from “spinning out” and digging ruts caused by inexperienced operators or extreme conditions or topography. When the surface of the soil is exposed to bare mineral soil, it loses tensile strength. When following precipitation and runoff reaches disturbed soils, the effect can initiate a widening cycle of soil erosion that can culminate in a landslide or "debris flow". The impacts from exposure of mineral soil are discussed in more detail in this section under hydrology.

1.b. Soils: Indirect impacts

Indirect impacts to soils can arise from a number of different sources. Following canopy reduction, there is an increased susceptibility to raindrop impacts on soils that have been disturbed. Disturbed soils will have changed permeability to rainfall. There is an increase in the likelihood of rain-on-snow events due to greater accumulation of snow, and reduced rain and snow intercept. Thinning favors early seral species including noxious weeds, that initially have poorly developed roots with little resistance to erosion. Loss of organic material from a forested stand will result in changed amounts of nutrient cycling.

Indirect impacts include changes to the microclimate that can affect how soil develops following disturbance. Opening the canopy will increase soil temperatures and soil drying in the short term due to increased solarization and wind exposure. Exposure of mineral soil exposure will tend to increase the survival of young conifer trees.

As the stand develops over time, the roots of early seral species will decrease solar exposure, and increase the amount of living root tissue in the soil. There is usually a flush of fungal fruiting following disturbance. There will be a greater percentage of annuals that will increase the available forage for ungulate grazers and seed-caching rodents, and these will in turn disseminate fungal spores, while spreading fungal hyphae and vascular plant seeds across the landscape.

Sollins and others found that decayed logs in Cascades forests averaged 350% moisture content in the winter, and 250% in the summer. The water contained in downed wood provides a microhabitat for the establishment of new plants following fire. It is important to provide enough coarse wood on a site after harvest to provide continuous replenishment of wildlife habitat.

The amount of coarse woody debris (CWD) retained after treatment should take into account whether there is an acceptable amount of fuel reduction, and whether the amounts of CWD resembles that of historic stands that existed at the site. In general, open pine stands had low amounts of CWD, however the amount of CWD in riparian areas was highly variable due to the fact that most riparian areas had a mixed-severity fire regime. Mixed severity fire regimes are those that vary between low-intensity and high severity (Hessburg and others 2004).

Brown and others (2003) presented an optimum range for retention of CWD lying between the point where fuel reduction was accomplished and wildlife habitat needs were met. This between 5-20 tons/acre for warm dry forest types and 10-30 tons/acre for cool and lower subalpine forest types. They proposed that the needs of riparian systems were largely unknown, but could be met by providing a 60- to 100-ft wide strip on each side of streams, provided that fuel loads were below 30 - 40 tons per acre. They also stressed that optimum ranges such as the ones they proposed should incorporate a wide diversity of loading.

1.c. Soils: Site productivity and nutrient cycling

The effect of biomass harvest on soil organic matter depends on the relative inputs (through growth and mortality) and outputs (through removal, burning and decomposition) characteristic of a given forest ecosystem and climate.

Sustainable forest ecosystems depend on the interaction of soil microflora and macroinvertebrates to maintain soil fertility, forest health and site productivity (Freckman 1994, Seastedt 1984). The soil and litter food web is the most biologically diverse part of the terrestrial ecosystem in both numbers and species. Arthropods are essential through their role as plant shredders and their grazing on bacteria and fungi that regulate the rate of nutrient mineralization and microbial populations (Niwa and others 2004).

An important element of forest soils is contained in the microbiotic (or "cryptobiotic") community, including fungi, lichens, bacteria, algae, small plants and small invertebrates. Many fungi have symbiotic relationships with trees and plants. These mychorrizal fungi interact with roots providing nutrients to the plant while absorbing sugars from the host.

Disturbances that affect soil structure may reduce the ability of the soils to support a healthy microbiotic soil community. This can lead to deleterious ecosystem changes and increase the incidence of trees to disease. Pathogenic fungi are also part of forest soils. Much like bacteria present in healthy humans, a vigorous tree can tolerate endemic levels of pathogenic fungi. However when tree vigor is reduced fungi such as those in the honey mushroom (*Armillaria*) group, can become virulent, resulting in tree mortality.

Long term site productivity is dependent on healthy soil. The soil crust and vegetative cover is important for increased soil stability, water infiltration, and soil fertility (Belnap and Gardner 1993) and reduces the susceptibility of the soil to wind and water erosion (Wilshire and Nakata, 1976). Increased erosion can result in a decline in water quality due to an increase in sediment and dissolved matter (Miller, 1970). In addition, a reduction in soil water content influences the activity of the soil biota, with an influence on the nitrogen cycle (Torbert and Wood, 1992), as well as on vascular plant vigor and reproduction (Crawford 1979; Skujins, 1984), and decomposition rates of soil organic matter (West, 1981).

Van Belle and Temmerman (2001) noted that biomass harvest may lead to reduced nutrient cycling, particularly of available nitrogen, but also potassium (Staff and others 1994). Van Belle and Temmerman (2001) claimed the loss of nutrients can range from 50 to 90%. Their recommended mitigation measures are to use longer rotations (50 to 100 years) and use fertilizers when conducting harvest on poor soils. They suggested this can be obtained as the ash from combustion.

Nitrogen is the primary limiting nutrient in forest ecosystems. The source of nitrigen is primarily due to soil microbiota except where nitrogen fixing plants such as alder (*Alnus* spp.) or Ceanothus (*Ceanothus* spp.) are present. Nonsymbiotic fixation depends on the presence of organic matter for energy (Harvey and others 1989). Changes in uptake and cycling of soil nutrients have resulted from elimination of cryptobiotic crusts, which accompany species changes resulting from soil disturbance (Bolton and others 1993).

Nitrogen is mineralized from decomposing organic matter in forest ecosystems. The supply and demand of mineralized nitrogen shifts critically between short-term peaks after fires, and more stable, but lower levels maintained as trees mature. Disturbances caused during harvest accelerate nitrogen mineralization in excess of that required by young stands at the expense of the nitrogen balance maintained in closed stands (Dyck and Skinner 1990).

A 200-year study of rotting logs Oregon State University is underway in the Oregon Cascade Range at the H.J. Andrews Experimental Forest near Blue River, Oregon. The studies are now 20 years old. The research has demonstrated that there is ecological benefit in leaving debris in the forest. Key findings include (1) as much as one-third of the nitrogen in Pacific Northwest forests comes from nitrogen fixation processes within rotting logs; (2) the "brown rot" fungi that cannot break down lignin in trees leaves structural material behind that builds future soil; (3) there is a 10-fold difference in wood decay rates among dead trees; (4) even within a single log, decay patterns are complex and cannot be easily summarized by considering the "average" condition of the wood.

Significant indirect impacts can occur both to and from the presence of heavy duff and litter loads, particularly when a stand is treated with fire. Numerous researchers confirm that fire suppression has produced unprecedented accumulations of litter and duff and humus under trees (Hood and Sharon 2007). The greatest accumulations of loose litter occurs under long needle conifers such as ponderosa pine and in areas with dry climates. While organic matter is vital to healthy soils, too much duff and litter can increase fire hazards, and result in severe tree mortality during burning.

Bowen (1984) demonstrated that a large part of net primary production occurs in roots that are continually decomposing within the soil. He reported that loblolly pine root production was 2.8 times greater than normal wood production. He found that more than 50% of assimilated carbon dioxide by *Pinus sylvestris* is used for fine root production.

The chemistry of a soil is dependent on inputs and outputs over hundreds or thousands of years. Timber harvest can alter this in a number of ways, for instance by increasing the amount of organic material in the soil. Over the long term this makes soil richer, but in the short term it ties up available nitrogen. Plants adapted to poor soils are naturally adapted to do with less nutrients. Altering the soil chemistry can change the trajectory of a stand radically, for instance in favoring reestablishment of a new species (stand conversion).

Forest soils tend to be acidic, due in large part to the contribution of tannins over long periods. In contrast, non-forested stands in the arid west tend to be basic, due to accumulated calcium and magnesium over time. It has been demonstrated that the harvesting of forest residue can lower soil pH (Van Belle and Temmerman 2001). Mitros and others (2002) showed that the pH as well as the total nitrogen of regularly burned oak woodlands was higher than comparable unburned areas.

Little and Klock (1985) studied the effect of biomass removal and post-harvest fire on the distribution of nitrogen and sulfur in the Cascades of Oregon. They found that nutrients removed for biomass were small compared with nutrients removed in harvesting merchantable timber.

1. d. Soils: Fire and fire suppression

Fuel and forest health treatments accompanying biomass harvest may involve cutting and felling small diameter stems, pruning understory branches, re-introduction of fire, piling and burning slash, raking duff away from the boles of legacy leave trees (Fulé and others, 2001), rearranging fuels where legacy trees are limiting, and allowing creeping burns to burn into riparian areas to protect coarse woody debris (CWD).

If prescribed fire or pile burning follows biomass harvest this can create additional impacts. Controlled burning creates localized soil disturbances with changed chemistry, and reductions or changes in soil microflora that can take many years for recolonization to occur. Most of these changes are beneficial in the long term, but there can be short-term negative impacts, such as increased susceptibility to weed invasion. Several studies observed increased mortality to retained trees following prescribed burning (Kaufmann and Covington 2001). Deep accumulations of litter and duff can smolder and burn at high temperatures (Hood and Sharon 2007).

2. Plant communities

2.a. Forest stand dynamics

Biomass harvest and associated logging alters the structure and composition of forest stands in many ways. Some of the effects of logging include: (1) reducing the number of stems; (2) opening the canopy; (3) exposing understory plants and young trees to release; (4) altering the stem diameter distribution; (5) altering the spacing distance and evenness of spacing; (6) generating slash; (7) changing species composition both directly and in the future by favoring early seral species establishment or release. All of these effects have consequences in the way future stands will develop. Mitigation measures should emphasize a thorough plan and long-term design.

Fire suppression has profoundly affected dry forests by removing stocking level controls of small trees at the expense of large, old trees. Along with climate change, and expansion of forest diseases, fire suppression is part of a syndrome of declining forest health that is occurring across western North America. Thinning to improve forest health or reduce fuels may include a number of silvicultural practices and logging techniques beyond the removal of logs and slash for biomass, e.g., targeting small-diameter trees, providing for controlled fire, favoring early-seral species, etc.

In dry forests east of the Cascades forestry activities are designed to accomplish objectives that fulfill management goals for a site as well as following state Forest Practices regulations. Some of the more important goals for stand management in dry forests east of the Cascades include:

- Economic goals that target sound merchantable timber and long-term site sustainability.
- Socio-economic goals to employ forestry workers.
- Silvicultural goals to improve forest stand health. Silvicultural goals may focus on curing disease, such as reducing mistletoe infestation, or on the maintenance of forest health, for instance in using thinning to reduce competition.
- Fuel reduction goals that make stands less liable to catastrophic loss during wildfire and ensuring the safety of adjacent homeowners and firefighters in the event of wildfire. A related goal is the re-introduction of controlled fire in fire-prone ecosystems.

The latter two eco-centric goals above can be referred to as forest health objectives. Forest health projects are often designed in the context of knowing how the stand functioned normally, generally characterized by the presettlement condition, or "*range of historical variability*" (HRV), usually taken by how the stand functioned in the early 1900s, prior to fire suppression. The target stand condition is sometimes designed as a modification of the HRV to a "desired future condition" or DFC.

In harvests designed to accomplish forest health objectives, the structure, arrangement and species makeup of leave-trees is often considered to be just as important or more so than that of the trees removed.

2.b. Biodiversity and landscape-level ecosystem management

Forest health is defined here as a forest condition in which natural processes are balanced and interdependent and biodiversity is maintained over the long term. Forest health should be assessed over a large landscape, typically a watershed or subwatershed, and over long times. The specific stand attributes that may or may not be present on a stand at any given seral stage do not need to represent the full range of biodiversity present in the landscape. Rather the landscape should include a representative balanced of stand ages, structures and species. For example, old growth conditions may only be naturally present on a stand at the climax of stand development representing a small fraction of the total landscape. Maintenance of forest health means providing for future forests by ensuring that there is a continuous balance of all species, structures and stages across a watershed at any given time.

INSEE (2004) recommends authoritatively that biomass harvest must not lead to a decrease of biodiversity. Protection of biological diversity goes beyond the protection of individuals or economic resources or species of concern. Biodiversity is defined by the total number of species capable of occupying a site, however this number varies over time depending on the condition of individual stands.

In sustaining biological diversity on a site it is important to provide for habitat capability of wide-ranging species that may move in and out of a site over time. Many species occur in cyclic patterns. Long time intervals may ensue between times when a stand offers suitable habitat for species requiring temporally limited or uncommon habitats. For example, black-backed woodpeckers are normally uncommon in eastern Washington. But following the 8,000 acre Thunder Mountain Fire in 1994 they became common as the availability of preferred prey such as flat-headed borers exploded. But five years after the fire, the flat-headed borer populations crashed, and the black-backed woodpeckers became scarce again. Thus the normal cycle of black-backed woodpeckers rises and falls over the average fire-return interval of lodgepole pine, about 80 years.

Maintenance of biological diversity through human intervention requires some sort of ecosystem management (EM). Ecosystem management involves understanding how different species interact. EM can be use to sustain biodiversity by managing the interaction of species for their mutual benefit. EM involves deliberate control of ecosystem elements so that the inputs and outputs of matter and energy are balanced over the long term, and the cycle of stand disturbances can provide continuous habitat capability over space and time.

Riparian systems are extremely important for ecosystem function. Although riparian zones of the western U.S. are only a minor proportion of the landscape, they have relatively more plant and animal biomass than the remainder of the area and they are a critical source of diversity, which tends to be highest at the land/water ecotones (Thomas 1979, Odum 1978).

Riparian vegetation produces up to 90% of the organic matter necessary to support headwater stream communities (Cummins and Spengler 1978). Up to 99% of the energy input of headwater streams is imported from bordering riparian vegetation and only 1% is produced within the stream itself from photosynthesis (Cummins 1974).

Van Belle and Temmerman (2001) noted that biomass harvest has the potential to alter species compositions due to reduced shade and changes in the nutrient status of soil. Measures to preserve biodiversity are ongoing in Sweden, including increased use of selective cutting, increasing the proportion of old trees and dead wood, and preserving areas with high species diversity. They cited guidelines to leave 10 to 30 % of the logging residues on the felling site (Brjesson, 2000).

2.c. Noxious weeds and invasive species

Thinning has high potential to cause detrimental invasions of invasive species. Many invasive species are classed in a legal sense as "noxious weeds", having a mandatory control requirement. Invasive species are associated with soil disturbance, canopy reduction, road building and burning, all of which can occur in association with thinning.

The effects of invasive species can be devastating to economies and ecosystems. In a well-studied case, Vitousek (1986) documented that over 95% of the vegetation cover in Hawaii is introduced, leading to imperilment of many native species.

Brooks (in press) described a range of ways that invasive species can affect fire behavior, and increase following fire. Monocultures of invasive species can lead to changes in fundamental ecosystem processes on a site. Invasions of annual grasses such as cheatgrass (*Bromus tectorum*) in southern Oregon have increased fire frequency and severity (Young and Evans, 1978).

Site disturbances are the largest contributor to invasions of noxious weeds. In a study of invasive species distributions in the Chewuch Watershed done by Pacific Biodiversity Institute in Winthrop Washington in the late 1990s, invasive species presence was inversely correlated with distance from roads and the majority of invasive species were within several feet of the edge of a road.

Once a disturbed site is invaded by noxious weeds, these species inhibit beneficial restoration processes and lead to more disturbance. For instance, bull thistle (*Cirsium arvense*) inhibits the germination of trees. The effect of vegetation removal on test plots resulted in increased sediment yields of 216% and 126% on bunchgrass and knapweed sites respectively (Lacey and others, 1989).

Wooten and Renwyck (2001). Cited a number of necessary changes in plans, policies and programs that have the potential to reduce noxious weeds. Mack and others (2000) stressed that the control of biotic invasions is most effective when it employs a long-term, ecosystem-wide strategy rather than a tactical approach focused on battling individual invaders. Prevention of invasions is much less costly than post-entry control.

Wooten (1999) briefly compiled over 50 ways to treat noxious weeds without herbicides. In their review, Wooten and Renwyck (2001) recommended changes in forest planning and policy as the most important hurdle for successful programs of invasive species control. Effective control measures are in many cases compromised by political intervention to protect the chemical industry, that can benefit from invasive species.

The use of herbicides can be controversial and increase the project costs and potential for impacts. Wooten and Renwyck (2001) noted that the loss of soil microflora can result from using herbicides. In a well-documented case in Oregon, herbicide loss of shrubs led to the conversion of productive forestland to permanently unforested openings (Perry and Amaranthus, 1994; Amaranthus and Perry, 1987; Perry, 1984). Herbicides kill a broad range of non-target vegetation, which can lead to altered ecosystems, beginning with raised site temperatures as a result of loss of cover (Holtby and Baillie, 1987).

Whenever possible it is better to contain or control a noxious weed without the use of herbicides. An EPA funded study of community weed control efforts was administered by Aileen Jeffries of Winthrop, Washington over a five-year period in the 1990s. She found that alternatives to herbicides were more effective than roadside spraying at less cost. This project evaluated a number of methods for controlling noxious weeds including hand pulling, sheep grazing, plowing, introduction of biological controls. Biological controls can be extremely effective at low cost. In the case of diffuse knapweed, biological controls were able to reduce the amount of plants to only 14% of untreated stands in just three years (Seastedt 2003).

3. Hydrology and effects on riparian areas

The hydrology of a watershed and of streams adjacent to harvest sites is an important consideration in the design of harvests. Hydrology can involve the movement and storage of water over long distances and involve large masses; thus the scope for addressing this issue should extend to the larger landscape. Riparian areas are often key ecosystem components in an area, with a magnitude of higher value to both humans and wildlife.

Understanding the normal function of a hydrologic system and its relative health are important to know before starting a land management project. It is important to know whether the hydrologic system is functioning normally, is at-risk, is non-functional, or is a lost cause. Specific issues that need to be considered in order to protect hydrologic and riparian function include the following:

- Healthy riparian function depends vitally on the input and movement and character of organic debris in the system (Bilby and Likens 1980, Ward and Aumen 1986).
- The structure and arrangement of large woody debris (LWD) within channels is important (Bragg and Kershner 1999), as is knowing the structure and arrangement of coarse woody debris (CWD) in adjacent uplands (Gurnell and others 1995)
- Flow characteristics of the stream are important, particularly peak flows (Fetherston and others 1995).
- Channel morphology and fluid dynamics are important, beginning with classification of the stream by order or class, and knowing whether a stream is perennial or intermittent, and whether key aquatic species are present or not (Bryant and Sedell 1995, Bren 1993, France 1997).
- The height of subsurface water tables and aquifers and their relationship within a watershed may be important to know (Sedell and others 2000).
- The normal and exceptional climate and precipitation regime should be known.

The impacts of logging, thinning and biomass harvest on hydrology is primarily indirect, but has a high potential for severity. The effects can be far-reaching and include increased risk of flooding, erosion, sediment delivery to streams and debris flows.

Changes in hydrologic inputs and outputs are exacerbated by soil disturbance (Beschta and others 1995). Soil disturbances modify the surface permeability to water in complex ways, sometimes decreasing permeability and causing channeling, and at other times increasing permeability and raising water tables.

The removal of trees reduces the amount of evapo-transpiration that occurs in a stand. Trees respire large amounts of water through their tissues and removing them allows this water to raise ground water tables. The impact of raised water tables can have beneficial effects on stands.

Ingalsbee (undated) described a cascade of effects that can result from canopy removal alone or combined with fire and/or post-fire harvest (salvage logging). The removal of forest and understory canopy and soil litter and duff increases the impact of raindrop penetration to the soil surface. This can lead to increased susceptibility to sheetwash erosion. Removing or killing trees decreases evapotranspiration which increases the height of the water table, and this in turn changes the hydrologic regime. Removal of canopy allows a greater buildup of winter snow, with an increased risk of a rain-on-snow event.

All of these changes can result in increased surface water runoff, increased water yields and increased peak stream flows, with increased potential for erosion, landslides and floods, and subsequent sedimentation of streams. Val Belle and Temmerman (2001) comment that changes in soil productivity can result from inadequate soil drainage caused by soil puddling and loss of soil porosity as well as increased acidity and salinity caused by modification of water tables.

Water quality can be impacted indirectly or directly by forest harvest activities. Important water quality parameters include turbidity, sedimentation, increased presence of fecal coliforms, and movement of synthetic chemicals or hazardous materials. Sedimentation is frequently assessed by fisheries biologists on fish bearing streams, but turbidity and fecal coliforms are seldom measured unless the water is also a direct source for drinking water.

The loss of logs or snags that would otherwise become logs can cause increased erosion and sedimentation of streams. Large-diameter logs help store water, and release it over longer time periods. Logs in streams help trap sediment and dissipate energy of streams (Sedell and others 1988). Logs also provide important aquatic habitats wildlife and aquatic species.

If there are cattle allotments adjacent to the harvest activities, there may be indirect impacts due to increased cattle grazing in riparian areas. This can occur if fences are knocked over or if passive barriers such as dense timber stands are removed. Mosely and others (1998) noted that, "Cattle grazing in riparian areas affects nutrients, fecal bacteria, sediments, streambanks, and vegetation in the riparian ecosystem, with associated effects on water quality." These researchers recommend that salt grounds and water developments should be located at least 12 to 20 feet from surface waters to protect water quality.

4. Wildlife

Thinning can have impacts on wildlife species. Amid calls for multi-species protection measures, the Endangered Species Act (ESA) nonetheless remains as the primary last resort for species threatened with extinction or extirpation.

Protection of wildlife requires that thorough site surveys are conducted. Because many wildlife species are only observed infrequently, an important component of wildlife surveys involves conducting pre-field literature reviews and consulting with the state Priority Habitats and Species (PHS) program. Reviews of historic wildlife sightings are appropriately done at watershed scales.

Wildlife surveys are often based on an assessment of habitat quality, in the absence of positive identification of sought-for species. Knowledge about the likelihood of key species on a site is combined with knowledge about the limiting factors that control that species abundance. To adequately survey for habitat quality, wildlife surveyors should be familiar with the botany and ecology of a site as well knowing the biology of likely species of concern.

An important group of species that should be included in wildlife surveys are keystone species that provide indispensable ecosystem functions, for example beavers that thin aspen trees and maintain water tables. Another keystone species group that should always be surveyed for are primary cavity excavators such as woodpeckers that provide nests for a wide number of other species that do not build their own homes. Other keystone species include important prey species such as snowshoe hares; important predators such as raptors that control rodent populations; rodents that disperse seeds and fungi; migratory songbirds that disperse seeds and control insects; ungulate browsers that can significantly affect the understory vegetation. Many other examples could be cited of mutualistic species that ultimately confirm that the most important wildlife protection measure is the maintenance of biodiversity.

Another important group of species to survey for are indicator species that are strongly tied to a certain habitat attribute and can act as a surrogate indicator for the presence of other species or their habitats. Ideally, an indicator species should be reasonably common. An example of an indicator species could be spotted frogs that require moist, relatively pristine habitats, and freedom from toxic chemicals. Another example is water quality that is now routinely assayed using standardized bioassays of commonly occurring aquatic macroinvertebrates.

Washington state maintains a list of species of concern that encompass one or more of all the above attributes. When conducting ground-disturbing projects on public lands, consultation with a biologist is required. Where federally protected Threatened or Endangered (T & E) species are known to occur on a site, projects may require formal consultation with federal biologists. When a project is likely to affect T & E species, it may require completion of a Habitat Conservation Plan, which is the equivalent of an EIS for protecting that species.

On private lands there are less stringent requirements to protect T & E species as their presence is largely unknown and unlikely. Some common exceptions to this in Eastern Washington are protection of raptor nest trees, known spotted owl centers, and waterways containing T & E fish stocks. Otherwise, the minimum environmental survey may be only a DNR forestry permit required for cutting trees larger than 6 inches in diameter. Obviously, for a landowner to seek only the minimum protection is like buying the cheapest insurance policy. Landowners should seek to go beyond state minimum forestry requirements for their own benefit.

Wildlife mitigation measures need to consider the biology of the species that occur on a site. Sometimes one species will benefit at the expense of another. For instance, the well-studied decline of the spotted owl was hastened by rapid increases of a competing species, the barred owl, that benefits from denser stands characteristic of overstocked forests.

Kauffman and Krueger (1984) noted that livestock abuse of riparian areas can severely impact terrestrial wildlife habitat and decrease wildlife numbers. They divided the impacts of herbage removal from riparian systems into two categories: woody and herbaceous vegetation. The effect on woody species has a critical impact in riparian ecosystems because of the importance of woody vegetation to wildlife habitat and also because of its influence on riparian microclimate.

Heiken (undated) noted that dead trees play an important role in a healthy forest and provide a wide variety of ecological functions. A large number of wildlife species use dead wood. Over 30% of all Oregon bird species use dead trees for nesting, foraging, roosting, and communication.

Hautala and others (2004) studied changes in CWD after retention felling and mechanical site preparation (scarification) in mature Picea abies-dominated boreal forest. Felling caused the loss of 8% of the total pre-treatment volume of CWD whereas scarification resulted in a 67% loss. The authors recommend partial cutting over clearcutting, reduced use of scarification and placing retention trees in patches as a source of future CWD and species diversity with high amounts of CWD.

Niwa and others (2004) studied long-term sustainability of terrestrial ecosystems in Oregon. They noted that burning in association with harvest had both positive and negative effects on arthropods, the former from production of new CWD habitats, and the latter from both direct mortality as well as loss of habitat. These researchers found that microclimatic changes from clearcutting were more disruptive to soil- and litter-dwelling arthropods than shelterwood cutting was. They found that species richness of arthropods was richer in regenerating sites than in mature forests. Soil compaction did not appear to reduce soil microarthropod abundance, but it did decrease litter-inhabiting soil microarthropods, and this effect was most pronounced in the East Cascades. Subsoiling to reverse compaction was not studied, but the authors warned against it as likely to break roots and disturb fungal mats and potentially affect water and thermal relations.

5. Fire behavior

In response to severe impacts from wildfires that have run across developed lands, fuel reduction has become the primary goal of many forestry projects. When these projects overlap private lands, they are referred to as being within the wildland-urban interface, or WUI. There is federal funding for WUI fuel reduction projects under the National Fire Plan (NFP). The NFP requires that participating collaborators have a Community Wildfire Protection Plan in place. Collaborators should include both agency personnel as well as non-governmental agencies and community members. A community wildfire protection plan should be based on sound science and availability of the plan to the public.

In discussing fuel reduction there is an important distinction between fire hazard and fire risk. Fire hazard is a physical situation (fuels, weather, and topography) with potential for causing harm or damage as a result of wildland fire (Scott and Reinhardt 2001). Fire risk pertains to sources of or causative agents for wildfires. Risk deals with the likelihood or probability of an ignition source occurring. Examples of risk sources and causative agents include lightning, equipment use, smoking, campfires, debris burning, railroads and power lines, etc. Fire hazard is the focus of the discussion presented here, although statistical studies show that fire risk is increased with increased road access.

The basis for a fuel reduction project begins with sound knowledge about the fire regime of an area (Agee 1998, Metlen and Fiedler 2006), and the existing condition of fuels on those lands that determine the expected fire behavior under given weather conditions (Agee 1993, Anderson 1982). Fuel reduction can be an effective way of managing expected fire behavior, although extreme climatic events such as drought, dry lightning, and high winds can override most reasonable protection measures (Ohlson 1996, Fahnestock 1973).

There is wide acceptance that the cause of elevated fuel loads and fire hazards across the west is in large measure due to fire suppression. Wherever forests have missed several cycles of wildfire, it is likely that fuels have built up to a point where fires will be uncharacteristically severe. Fire suppression has the greatest effect on ecosystems such as ponderosa pine stands and lower elevation Douglas fir that have fire regimes characterized by frequent low-severity fires or patchy fires with some low-severity cycles. In these ecosystems, fuel loads are so high that when fire does comes to these stands as it eventually will, there is high mortality and severe structural damage.

Three of the most important fire behavior characteristics that can be modified by fuel reduction and rearrangement are severity, crown fire potential, and fire spreading rate. Severity is a measure of the expected stand mortality that can be expected during a wildfire and it correlates roughly with the total energy released per unit area (Demyan and others 2006). This in turn depends on a combination of the intensity and duration of a fire, as well as the sensitivity to mortality damage of the affected plants (or structures) affected. There are exceptions to this relationship, depending on the duration of fire and the highest temperatures attained, however. For instance, smoldering duff can have a relatively low total energy output but still cause high mortality because the duff is at high temperatures for a long enough time in close contact with living roots. High severity fires are most likely in stands with both high amounts of biomass as well as sufficient fine fuels and "ladder fuels" (vertical fuels that can carry fire from the surface into the tree crowns) to carry the fire throughout the stand.

Crown fire potential is the relative likelihood that a fire will torch into the tree canopy and continue to travel as a running crown fire in the crowns of the trees. Reduction of crown fire potential is a high priority in the WUI because crown fires cannot be fought with conventional ground-based equipment required to bring a fire under control. Crown fires are a danger to firefighters and the public. Conditions for high crown fire potential occur when the canopy branches of adjacent trees are interspersed throughout the stand, and ladder fuels are present down to the height at which surface flame lengths would extend.

The spreading rate of a fire is a measure of how fast fire moves across the landscape. It is an important consideration for fire prevention in the WUI for several reasons. Even fires with relatively low severity can cause large amounts of damage if they cover a large area before firefighters arrive to contain the blaze. Fast-moving fires also present a safety hazard because they can move faster than people or animals can run.

Factors that affect spreading rate are the presence of continuous fine fuels, and reduced canopy density that creates higher surface wind speeds, increased solar intensity and increased rates of fuel drying (Countryman 1955, Anderson 1983). Fuel reduction methods designed to reduce fire severity and crown potential tend to increase the fire spreading rate. This is because forest thinning opens the canopy. This in turn increases the rate of drying of fine fuels that carry a fire and increases the wind speeds that can push a fire by up to ten times (see figure). The presence of dry fuels also increases the relative risk that a given ignition will spread rather than go out. The microsite conditions under open stands tend to produce more fine fuels due to the increased solar exposure that favors the growth of fine fuels such as grasses and forbs.

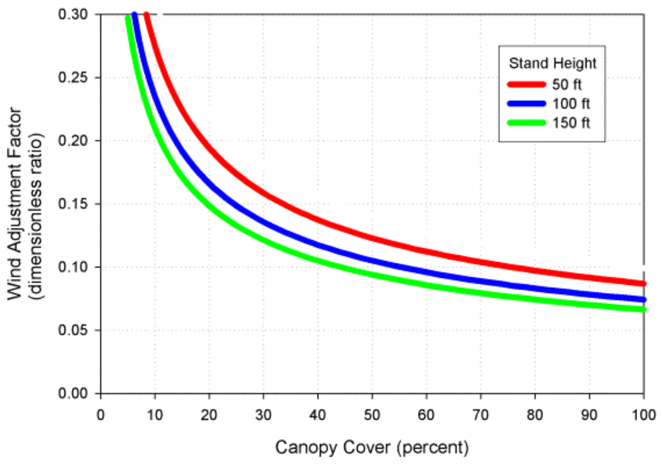

Figure showing the relationship of canopy cover to wind speed, from Finney (1998).

In fire-prone ecosystems east of the Cascades, fire provides important beneficial functions for forests. Under a frequent fire regime, fire naturally thins out competing young conifers and shrubs, and maintains open canopies. Fire stimulates root sprouting of most shrubs and deciduous trees. Fire helps restore forest health by opening the canopy for early seral species that require sunlight to survive. Fire stimulates germination of seeds of many species. After a fire, burned stands are more densely covered with vegetation.

Fire also generates smoke that can have significant impacts. Severe smoke effects occur when wildfires burn unnaturally dense stands caused by fire suppression. With heavy fuel loads, fires are predisposed to burn severely, uncontrollably, unpredictably, and with large amounts of smoke.

Smoke from controlled burning in association with slash removal is regulated federally by the EPA and within Washington state by the Department of Ecology. Air quality statutes limit the amount of controlled burning by area, and when clear weather conditions allow smoke to disperse well. Smoke is highly damaging to air quality and bad for human health. In contrast, recent research has confirmed that smoke is beneficial to the ecosystem by stimulating germination of some plants, and releasing chemical signals to insects that feed in freshly burned forests and provide crucial seral prey for some species.

McNeil Technologies (2003) considered fuel and emissions characteristics from a wide number of organic sources. They noted that it is important to consider the sulfur content of biomass stocks to estimate the amount of sulfur oxides likely to occur in fuel emissions. Sulfates contribute to air pollution and contribute to slag deposition during combustion. They also found that high chlorine content in non-forest fuelstocks would cause undesirable alkali production during pyrolysis.

6. Cumulative effects

Minor impacts that cumulatively add up to large impacts are termed cumulative effects. The effects can be cumulative over time, space or type of impact.

There will be numerous minor impacts during logging harvest due to vehicle emissions and noise. These are a nuisance for adjacent neighbors. Road dust can be a significant problem for adjacent landowners. Road dust should be controlled by watering down roads as often as necessary, or covering the roads with an impervious surface. Road closures and the danger of logging trucks on passenger roads should be appropriately addressed and mitigated. Equipment should be inspected and in good repair.

If cattle grazing is occurring adjacent to or in the logging units, there may be increased grazing use following release of herbaceous species and grasses. Cattle impacts on riparian areas is exacerbated by logging if it opens up access to riparian areas and sensitive sites that may have had partial barriers of dense forests or that may have had fences broken during harvest.

One of the most important factors involved in maintaining sustainable biomass harvests is social. If not applied at an appropriate scale, biomass utilization can create a boom and bust economic cycle (Shulke, undated). In an examination of biomass generation plants in New Mexico Shulke noted that 600 tons per day of wood was able to produce only 5 MW of power. Logging to support these plants required removal of up to 90% of trees from tens of thousands of acres in stands that did not need this much tree removal. However, once this biomass industry was established, it became the driver for ever-increasing amounts of material at lower prices. Rural Voices (2005) recommends small scale biomass plants (1-10 MW) are the only scale appropriate for rural economies.

Mitigation measures

Mitigation measures to consider for direct impacts to soils:

- Develop an action plan that includes a well-planned access and yarding system with established maximum levels of soil disturbance no greater than 20%. The plan should include descriptions of locations of yarding corridors, skid trails, landing locations, culvert locations, cut and fill road banks, and planned pivot trees for yarding. Mitigation measures should be included in an action plan checklist.
- Perform an evaluation of soil types present on the site. Additional protections for sensitive soils such as ash-cap soils and sandy glacial till or pre-existing at-risk conditions should be described in the action plan along with mitigation measures.
- Develop a monitoring system that stores permanent records on initial and changed site conditions and includes at least one visit per year to the site and at least two years after completion of the project.
- Design the timing of road construction and use activities to occur during dry weather.
- Design the timing of yarding activities to occur during winter when the depth of frozen ground is greater than 4 inches or capable of supporting the size of logs to be yarded without ground shear.
- Reduce the extent of roading through the use of small equipment or articulated grapplers or high-line cables.
- Reduce the weight of machinery through the use of rubber-tracked vehicles instead of wheeled vehicles.
- Limit logging to areas within one-quarter mile of a road and less than 35% slopes.
- Identify and protect large logs and snags from incidental damage.
- Target small diameter stems for removal that will have less felling impact.
- Avoid disturbances to soils and where unavoidable, localize disturbances to known, designated sites.
- Avoid dragging slash and logs across intact forest.

Mitigation measures to consider for indirect impacts to soils:

- All mitigation measures for direct impacts to soil structure also apply to indirect effects on soil structure.
- Modify the harvest methodologies depending on slope and aspect.
- Provide for a reasonable amount of undisturbed forest patches within and adjacent to cutting areas sufficient to allow survival and recolonization by slow moving animals.
- Identify sites where noxious weeds exist prior to harvest and remove these before activities begin.
- Quarantine or steam-clean forestry vehicles that may be contaminated with noxious weed seeds.
- Use native seeds and plantings to restore sites after treatments.
- Avoid the use of pasture grasses for reseeding sites as they can attract browsers that can damage the regenerating forest.
- Inspect the site after harvest for new noxious weed invaders and prevent them from becoming established.
- Provide for adequate CWD retention depending on the fire regime.
- Provide for variable CWD retention to provide a variety of habitats.
- Provide a greater degree of live tree retention along riparian areas (buffers) sufficient to meet long-term needs for wildlife habitat, CWD retention and snag recruitment.

Mitigation measures to consider for long-term site productivity and nutrient cycling:

- Use long rotations.
- Leave as much coarse wood, bark and leaves on site as possible.
- Avoid creating large openings (clearcutting).
- Avoid excessive compaction or destruction of duff and litter to preserve habitat for microarthropods.
- Avoid root scarification of plants that are to be retained.
- Avoid compaction in the first place rather than trying to mitigate it with subsoiling.
- Consider the use of fertilizer where plantations have poor soils. Fertilizer can be derived from burning residue ashes.
- Maintain continuous cover of perennial species throughout a site as habitat for soil microflora.
- Plant native species to restore ground cover, shade and habitat following treatments.
- Avoid pesticides that could harm soil microflora and alter species composition.
- Conduct biomass harvest at a scale and rate that is sustainable for the local human and forest community.

Mitigation measures to consider for soil impacts from burning and fire suppression:

- Plan for the likelihood that fire prone ecosystems will eventually burn by reintroducing controlled fire to reduce fuel loads.
- Plan the timing of controlled fires to optimize safe burning windows and reduce smoke impacts.
- Reconfigure fuels at the base of legacy trees snags and logs to avoid loss of desirable trees and snags. Reconfiguration could involve a combination of pruning, raking and

piling slash away from fine fuels, and digging firelines around important legacy trees, snags and logs.

- Avoid making large slash piles too close to sensitive areas or desirable stands of trees, snags or logs.
- Avoid placing burn piles close too close to riparian areas, where control will be difficult.
- Provide for adequate numbers of burn crew personnel to accomplish objectives within narrow climate windows.
- Avoid conducting controlled burns in areas where creeping duff fires will be problematic to control, e.g., riparian areas and deciduous stands with deep duff without firelines.
- Avoid excessive soil and root heating during post-harvest site burning.

Mitigation measures to consider for impacts on forest structure.

- Prepare a long term stewardship plan that includes a model of stand trajectory and a desired future condition to guide projects. Include a likely discussion of historic fire regime and current fuel loads.
- Design a reforestation plan that is practical and likely to succeed without subsidies.
- Design a site plan that takes climate change into consideration.
- Plan for expected changes in the site microclimate that could impede attainment of the desired future condition. Is the site on a south slope where the ground will become too dry for seedling establishment?
- Involve -ologists in the planning and listen to their advice.
- Carefully weigh the value of single-entry versus multiple entry harvests before harvest begins.
- Use a worst case analysis to determine what-ifs.
- Monitor stand condition as necessary to insure the stand is on the right track.
- Learn to recognize the signs of common forest pathogens and take measures to prevent excessive losses. If a tree is declining due to fungi or beetles, it is probably not a good choice for a leave tree.
- Preferentially remove small trees while leaving legacy trees or large dominant trees that are likely to persist and regenerate in a stand.
- Cut small trees first before cutting larger trees. This may involve more than one stand entry.
- Where the goal includes improving forest health, favor retention and recruitment of early seral species such as ponderosa pine over shade-tolerant species.
- Maintain historic levels of understory species depending on the site ecology. Where sites were historically dominated by grasslands or deciduous forests such as aspen, those species should be restored to those sites.
- Leave all large snags (>12 inches dbh) within OSHA guidelines.
- Leave patches of wildlife habitat unaltered where identified for retention by a biologist.
- Maintain a diverse understory species mix.
- Avoid damage to the stems and roots of perennials that could result in the introduction of root diseases.

- Avoid damage to the stems of leave tree through the use of designated pivot trees, and cut-to-length and forwarder systems.
- Plan projects to be within the historic range of variation of forest structure and composition.

Mitigation measures to consider for impacts on biodiversity and landscape-scale ecosystem processes:

- Design plans on landscape scales
- Map impacts over small and large spatial extents
- Plan stand trajectories to achieve a balance of stand conditions over long times.
- Plan projects with a knowledge of the historic range of species present on a stand.
- Plan for climate change. For Washington state, it is likely that summers will be longer and drier, snowmelt will occur earlier and swifter, and soils will be drier overall.

Mitigation measures that should be used to protect stands from invasive species:

- Perform noxious weed surveys prior to harvest activities and mark all noxious weed locations that may be impacted by harvest.
- Include a long term plan for prevention of noxious weeds and undesirable natives.
- Use landscape-level ecosystem management to control species invasions.
- Take advantage of community interest in weed control.
- Coordinate invasive species control measures with adjacent neighbors.
- Monitor for the presence of noxious weeds on a regular basis
- Prioritize control treatments that prioritize new invaders first.
- Prioritize prevention as a first resort for invasive species control.
- Use herbicides only as a last resort.
- Collect and introduce available biological controls on infested sites if harvest will not involve immediate weed removal.
- Design weed management plans that achieve control of invasive species, when the costs of eradication are beyond reach.
- Reduce fuels in stages before returning fire to the ecosystem to allow revegetate soil sufficient to exclude establishment of invasive species.

Mitigation measures to consider for fire reduction and fire suppression:

- Restore controlled fire in fire-prone ecosystems.
- Include a plan for safe access into and out of stands in case of wildlfire.
- Design stands so that some trees will survive even if a wildfire does occur.
- Thin smaller diameter trees as a higher priority over larger diameter trees.
- Use lower branch pruning and thinning from below as a first priority to reduce ladder fuels and separate crowns from surface fuels.
- Leave old trees for seed stock.

- Consider thinning stands in stages to avoid creating temporary fuel hazards from released herbaceous growth and slash accumulation.
- Provide for shaded fuel breaks where fuel reduction is difficult to accomplish.
- Design burn plans that can be ready to implement depending on funding contingencies.
- Take advantage of local weather stations to improve local forecasting for burning within the suitable burn window.

Mitigation measures used to reduce impacts to hydrologic aquatic and riparian systems::

- Use partial cutting and thinning to retain as much canopy as possible from leave trees.
- Use pruning and thinning from below instead of whole tree felling when it is desirable to retain as cover from the remaining trees.
- Use directional felling on the slope contour and prune branches and seal log bases to provide check dams for surface runoff.
- Avoid incidental destruction of live understory species.
- Build roads and culverts to RMAP or BMP standards. This includes making roads slope outward where culverts are lacking, and building check dams on slopes that will be closed to traffic after project completion.
- Protect water quality with streamside barriers made of straw (avoid hay that may contain noxious weeds).
- Use native seeds and plantings to revegetate sites as soon as possible after treatments.

Mitigation measures for wildlilfe protection:

- Provide for biologists to conduct valid surveys on sites.
- Analyze effects to wildlife on a watershed scale.
- Perform pre-field reviews of the PHS database.
- Assess habitat capability for species of concern.
- Retain some existing canopy cover for species that dwell in trees or require shade.
- Retain snags for wildlife habitat.
- Retain CWD sufficient to provide suitable wildlife habitat.
- Maintain the structure of organic soil layers.
- Avoid soil disturbances that will result in uncontrollable germination of a new cohort of young trees, except in stands with a high-severity disturbance regime.
- Provide for a diversity of habitats within a site to allow for escapement of a prey base and to provide for a biologically diverse species mix.
- Prevent or control invasive species with the potential to harm important and desirable native wildlife species.

Mitigation measures for livestock grazing in thinned stands

- Site-specific grazing plans should be in place on livestock allotments that will also have logging activities on them.
- If logging will occur on rangelands, consider fencing cattle off from riparian areas or defer grazing until the site has had several years to revegetate.
- To reduce negative impacts of grazing, determine the critical period(s) for riparian sites,

and limit grazing during the critical period(s) to no more often than once every 3 or 4 years.
- Where sites are already badly degraded from livestock, they should be given extended periods of rest or deferment from grazing.
- Salt licks and water developments should be located at least 12 to 20 feet from surface waters to protect water quality.
- The utilization of forage should be limited to less than 65% overall and ground cover basal area should be maintained at 50% or more. End-of-season stubble heights should be at least 2 inches for Kentucky bluegrass, 3 to 4 inches for sedges, and short grasses and at least 4 to 6 inches for larger bunchgrasses.

Mitigation measures for cumulative effects:
- Determine the season of logging and be sure that recreational and residential traffic will have alternate travel provisions.
- Mitigate road dust by keeping roads watered down.
- Sign all logging roads and be sure operators are certified and obey speed limits.
- Keep equipment in good order to prevent air pollution and fluid leaking.
- Maintain a Hazardous Materials facility on site.
- Coordinate logging plans with cattle grazing allotments.
- Design a long-term biomass recovery plan that fits within the scale of the human community it will be located in.

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