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The Influence of Forest Health and Protection Treatments on Erosion and Stream Sedimentation in Forested Watersheds of Eastern Oregon and Washington

Abstract

A variety of Forest Health and Protection treatments have been proposed to reduce long-term risks to forests from wildfire, insects, and disease. This review examines the potential effects of these treatments on sediment production in watersheds, channel forming processes, riparian vegetation, and risks posed to riparian zones. Wildfires can affect upland erosion; however, erosion from prescribed fires burning the same area should be much smaller. Dense riparian vegetation might help regulate the amount of sediment that reaches streams, but this effect would be strongly dependent on the geomorphic setting. Forest pathogens are not expected to cause accelerated erosion and stream sedimentation directly, but indirect effects might be substantial if they lead to increased wildfire. The largest risk of accelerated erosion is expected from ground-disturbing activities during fuels reduction treatments, such as construction of roads and firebreaks or salvage logging or thinning. Intense grazing has changed composition and cover of riparian vegetation, leading to bank erosion, and in many places, widening or incision of stream channels. Improved grazing prescriptions can result in major changes to riparian vegetation, but response of channel morphology will most likely be slow. Most of the studies reviewed were conducted at the site or small-watershed scale. Consequently, conclusions at these scales are generally well supported by the available literature. The cumulative effects of forest health and protection treatments imposed across a large region are difficult to assess, however. Given the current state of knowledge, dramatically changing forest land-use practices across eastern Oregon and Washington–including the widespread use of prescribed fires, salvage logging, and mechanical fuel treatments–is a long-term, landscape-scale experiment, the cumulative effects of which are unknown.

Introduction

The composition and structure of many interior-continental forests of western North America has changed dramatically since Euro-American settlement. These changes, combined with wide-spread tree mortality from recent insect outbreaks and extensive areas burned by recent, stand-replacing wildfires, are perceived as risks to long-term forest health (Gast et al. 1991, Mutch et al. 1993, Hessburg and Smith 1999, Hessburg et al. 2000). The changes in forest composition and the catastrophic mortality of forests in the interior West have been the focus of bio-regional assessments (Everett et al. 1994, Hessburg et al. 1994, Quigley and Arbelbide 1997), and forest health problems have been targeted by management strategies aimed at reducing long-term risks to forests from wildfire, insects, and disease (USDA and USDI 2000).

This paper examines the potential effects of forest health and protection treatments[1] on physical processes that control sediment production in watersheds; the influence of riparian vegetation on stream sedimentation; the effect on, and risks posed to, riparian vegetation by proposed forest health and protection treatments; and how these treatments will influence channel forming processes. This paper focuses on sediment because it has long been recognized as an important determinant of water quality and stream-habitat quality for salmonids and also because riparian zones are widely believed to buffer streams–intercept sediment transported in surface runoff, thereby limiting sediment loading of streams. This paper reviews the published literature and synthesizes the results as they pertain to forested watersheds of eastern Oregon and Washington. Because of the sparseness of published literature describing erosion processes and the role of riparian vegetation in regulating stream sedimentation in the interior Columbia Basin (Table 1), it was necessary to broaden this literature review to include studies from other regions. The paper first provides a brief review of erosion, transport, and deposition processes resulting from mass-movement, surface runoff, channel incision, and bank erosion; then examines the influence of forest-health related disturbances–including fire, insects, disease, and grazing–on these erosional processes; and finally, examines the likely effects of proposed forest health and protection treatments–namely prescribed

TABLE 1. Summary of literature richness for effect of riparian zones on stream sedimentation in eastern Oregon and Washington and effect on stream habitat quality in response to forest disturbance.

	General	Organism	Stand	Subwatershed	Watershed	Landscape
Basic Information	2	2	2	1	1	1
Treatment Options	1	1	1	1	1	1
Effects on FH&P of:	1	1	1	1	1	1
Decision making tools	1	1	1	1	1	1

1 = Almost nothing
2 = Some coverage
3 = Moderate coverage
4 = Considerable coverage
5 = Extensive coverage

fire, mechanical fuel treatment, salvage logging, and changes in grazing prescriptions.

Background Erosion and Sediment Transport Processes

In regions of steep, unstable topography, erosion is dominated by mass-movement processes such as landslides, debris flows, and earth flows (Swanson et al. 1982). Steep hillslope hollows at the heads of ephemeral channels are common initiation points for landslides. Once initiated, landslides can stall in ephemeral channels, especially where logs transported in small landslides lodge against dense stands of large trees. Alternatively, landslides can be mobilized into debris flows that entrain logs, trees, and sediment from riparian zones and transport it down the stream network (Nakamura et al. 2000). Debris flows typically stop where channel gradients flatten or when they encounter sharp turns in channels, especially at tributary junctions (Nakamura et al. 2000). Riparian forests are unlikely to stop debris flows once they have gained momentum (Beschta 1990), but roots of trees may help stabilize the soil, tending to prevent landslides. Several studies have shown that removal of upland forests by clear-cut logging (Swanson and Dyrness 1975, Nakamura et al. 2000) or stand-replacing forest fires (Swanson 1981, Beschta 1990, Meyer and Wells 1997) can significantly increase landslide rates. However, increased landslide rates following loss of forest cover tend to occur in relatively landslide-prone landscapes, and not in areas with more landslide-resistant geology (Swanson and Dyrness 1975).

Surface runoff almost never occurs in mesic forests (e.g., the moist forest and cold forest potential vegetation groups of Hann et al. 1997) because precipitation rates almost never exceed infiltration rates (Helvey 1980, Wilson 1999). Infiltration rates in mesic forests are high because litter and organic layers tend to be well developed, protecting the underlying soil from raindrop impact, and because underlying mineral soils are well structured. Surface runoff and attendant erosion does occur in forests, but tends to be restricted to dry forest types (e.g., the dry forest potential vegetation group described by Hann et al. 1997 for eastern Oregon and Washington), but even in dry forests, surface runoff is relatively rare. For example, the only surface runoff observed in ponderosa pine forest in the Entiat Experimental Forest, where annual precipitation averages 58 cm/yr, came from exposed bedrock (Helvey 1980). In other dry forest types, rainfall intensities of 30 to 45 mm/hr are needed to generate surface runoff from undisturbed soils and have expected return periods of 2-5 yr, but storms with these intensities tend to be of short duration (Wilson 1999).

If surface runoff were to occur, riparian vegetation could be an important factor regulating the amount of sediment transported in surface runoff that reaches streams (Kauffman and Krueger 1984). Dense vegetation slows surface runoff, allowing deposition of fine sediment before it reaches streams. However, in steep "V"-shaped valleys, riparian vegetation is less likely to be effective in buffering streams. Conversely, where valley floors are wide, sediment may be trapped effectively, even without significant interaction with riparian vegetation. Of course, rainfall from intense storms (e.g., thunderstorms) can generate extreme surface runoff capable of moving large quantities of sediment, leading to sedimentation of streams and valley floors. The contribution of such intense storms to long-term sediment budgets has not been assessed because these storms are rare and typically cover a small area.

Soil creep and dry ravel are important erosion processes wherever topography is steep, in both dry- and wet-forest types (Helvey 1980, Swanson et al. 1982, Beschta 1990). Where valley floors are narrow, or where stream channels are located at the base of steep slopes, dense riparian vegetation may effectively trap dry ravel preventing it from reaching stream channels. Soil creep, however, tends to continuously feed bank erosion in these geomorphic settings. In contrast, where streams are isolated from steep slopes by wide valley floors, little sediment from either dry ravel or soil creep will reach the stream, regardless of the status of riparian vegetation.

Most research and published literature has focused on hillslope erosion processes at the site and small-watershed scale (Grant and Wolff 1991, Ketcheson and Megahan 1996, Lewis 1998). This research documents that many historical land-use practices have led to accelerated erosion rates throughout much of western North America. However, few studies have attempted to quantify the amount of sediment eroded from hillslopes that is actually delivered to stream channels. Simply assuming that all sediment eroded is rapidly delivered to stream channels may overestimate stream sedimentation (Gill 1994, Trimble and Crosson 2000) because much of the sediment eroded from hillslopes is either redistributed downslope (Ketcheson and Megahan 1996, Davenport et al. 1998, Reid et al. 1999, Trimble and Crosson 2000) or stored on alluvial fans and floodplains (Costa 1975, Trimble 1983, de Ploey and Yair 1985, Nakamura et al. 1995). Because stored sediment may remain on valley floors for 10s to 100s of years (Bunte and MacDonald 1995, Nakamura et al. 1995, Nagle and Ritchie 1999), continued erosion of stored sediment may maintain elevated sediment loads in streams long after restoration activities have reduced accelerated rates of erosion on upland sites (Trimble 1983, Trimble and Crosson 2000). Nagle and Ritchie (1999) showed that surface erosion appears to contribute little to current stream-sediment loads in three streams in eastern Oregon, irrespective of dominant land use within each of the three watersheds. Rather, sediment loading in streams dominated by agriculture or grazing of domestic livestock was primarily from bank erosion. The sediment load of the stream draining a watershed dominated by forest land use was low. Nagle and Ritchie (1999) suggested that channel meandering and stream avulsions occurring during high discharge rework sediment stored on valley floors, entraining it into stream channels where it may be transported downstream.

Riparian vegetation is an important factor determining rates of bank erosion. Roots of riparian vegetation can stabilize stream banks and slow bank erosion (Smith 1976, Kauffman and Krueger 1984, Platts et al. 1985, Clifton 1989, Gregory et al.1991), although it may be ineffective in stabilizing banks along some deep channels or along larger rivers (Nanson and Hicken 1986). Riparian vegetation can also slow flowing water that has overtopped channel banks, creating environments where fine sediment can be deposited, leading to floodplain accretion (Platts et al. 1985, Clifton 1989, Gregory et al. 1991) and may reduce sediment load of flood water. Consequently, protection and maintenance of riparian vegetation may be an important way to maintain or reduce stream sediment loads.

Effects of Disturbance

Fire

The effect of fire on erosion depends on the size of the area burned, the intensity of the fire, and in some cases, on the frequency of fires (Swanson 1981, Gresswell 1999, Wilson 1999). Under current fire management practices, most naturally ignited fires are quite small (Pyne 1984, Turner et al. 1994) even when allowed to burn without interference (Romme and Despain 1989). Because the typical fire is small, it is unlikely to have severe effects in most watersheds. In contrast, fires ranging in size from the site/stand (1,000 ac; 400 ha) to the subwatershed (8,000-20,000 ac; 3,200-8,000 ha), or larger, may have a large effect on stream sediment budgets (Swanson 1981). While such fires are relatively uncommon, land management practices over the last century, such as selective harvesting, fire suppression, fire exclusion via domestic livestock grazing, and road construction converted open-forest stands into denser stands dominated by shade tolerant mid- and late-seral species (Mutch et al. 1993, Belsky and Blumenthal 1997, Hann et al. 1997, Tiedemann et al. 2000). In present-day forests, severe fires probably affect larger areas; increased landscape contagion combined with high fuel loading, high crown bulk density, and fuel ladders all contribute to higher rates of fuel consumption and energy release for given burn conditions. Thus, there is increasing concern that many Interior Columbia Basin forests may be increasingly vulnerable to large, stand-replacing fires (Agee 1993, Mutch et al. 1993, Hessburg et al. 1994, Hann et al. 1997). However, both long fire-free intervals and extensive stand-replacing fires also occurred prior to Euro-American settlement (Romme and Despain 1989, Meyer et al. 1995, Brown et al. 1999)

Surface runoff is the factor that generates most concern when considering potentially accelerated erosion following fires. However, greatly accelerated surface erosion can occur after fires, even in the absence of rainfall and surface runoff (Beschta 1990). Dry-ravel erosion can increase to rates that greatly exceed background following the loss of physical structures on steep slopes (e.g., large logs laying across slopes) and release large quantities of stored sediment (Bennett 1982, Beschta 1990). Although much of the eroded sediment will be redeposited further downslope, dry ravel will, over time, transport substantial amounts of sediment from hillslopes to valley floors (Swanson et al. 1982).

Post-fire rainstorms have the potential to severely erode burned hillslopes, but this depends on fire intensity, storm intensity, time since fire and the availability of erodible sediment. Fire intensity is the primary factor determining the degree to which soil properties are changed by fire (Beschta 1990). Intense fires burn surface litter layers and combust soil organic horizons, which, combined with the loss of the forest canopy, exposes the surface soil to raindrop impact that can disperse soil aggregates, allowing fine sediment to clog soil pores and reduce infiltration (Beschta 1990). Similarly, combustion of organic matter in the mineral soil can lead to the loss of soil structure, reducing both porosity and infiltration rates (DeBano et al. 1998). Finally, heating can convert soil organic matter into hydrophobic compounds that also limit infiltration (DeBano et al. 1998).

There is great concern over the risk of accelerated erosion following wildfire, but actual erosion is highly dependent upon both rainfall intensity and infiltration rate. In many mesic-forest types, little sheet, rill, or gully erosion may occur, even following intense wildfires. For example, in western Oregon and Washington, intense rainfall tends to be rare. Further, soils tend to be well structured, and hydrophobic layers tend to be spatially discontinuous and relatively short lasting (Beschta 1990) so that surface runoff is rare and causes little surface erosion (Swanson et al. 1982). In contrast, increased surface erosion following severe wildfire is well documented in areas that receive intense rainfall from thunderstorms, especially where infiltration rates decrease (Helvey 1980, Beschta 1990, Scott and Van Wyk 1990, Scott 1993, Rinne 1996, Robichaud and Brown 1999, Wilson 1999). For example, in dry-forest types of central Idaho, the coarse, unconsolidated soils are easily eroded once surface litter is removed. There, prescribed burning following helicopter logging greatly accelerated erosion. Further, because recovery of overstory vegetation on dry, south-facing slopes was slow, high erosion rates persisted for at least 10 years following burning. In contrast, vegetation regrowth on nearby north-facing slopes was rapid and erosion returned to background rates within 3 years (Megahan et al. 1995).

The amount of sediment eroded after fires is also dependent upon the resistance of sediment particles to detachment, and the amount of sediment available to be eroded. Fires, especially those of low to moderate severity, typically cause minimal surface disturbance so that relatively little sediment is available to be eroded. In contrast, accelerated erosion is often observed where the soil surface is heavily disturbed–for example from tree fall, fire-fighting activities, pre-fire land use, or post-fire salvage logging (Swanston 1971, Beschta 1990, Marston and Haire 1990, Gresswell 1999, Wilson 1999, McIver and Starr 2000), both because more sediment is exposed to erosional processes and because sediment from disturbed soil is usually more easily detached.

Extreme climatic events soon after severe fires can lead to unusually severe erosion. For example, an intense thunderstorm 1 year after a stand-replacing wildfire led to the deposition of as much as 1 meter of sediment on the valley floor of N.

Cable Creek in the Blue Mountains, Oregon (William Russell, Oregon State University, personal communication). In another case, Helvey (1980) documented major landslides and debris flows 2 years after a severe stand-replacing fire on the Entiat Experimental Forest in central Washington. The landslides were triggered when unusually deep snow packs combined with rapid warming pushed stream discharge to three times the maximum observed during the previous 10-year calibration period. It is unknown if these landslides would have occurred without the preceding fire, but increased rates of landslides and debris flows have been observed following timber harvest in western Washington and Oregon (Swanson and Dyrness 1975, Nakamura et al. 2000). Although landslides and debris flows have also been documented in mountainous landscapes of the interior Columbia Basin, they are mostly case studies of isolated events. The overall effects of fire regimes on geomorphic processes and long-term stream sediment budgets are poorly documented in most landscapes (Swanson 1981, Meyer et al. 1995).

Magnitudes of peak flows from small (50 to 500 ha) watersheds (Helvey 1980, Scott and van Wyk 1990, Scott 1993) may increase following fires, and peak flows that equal or exceed the bankfull depth are dominant channel-forming processes. Thus, if fires increase the frequency of peak flows, increased rates of bank erosion, channel meandering, or channel incision might be expected (Lewis 1998). Similarly, if fires burn the riparian zone, death of bank-side vegetation should eventually lead to decreased bank stability as roots decompose, increasing susceptibility to bank erosion (Helvey 1980, Beschta 1990, Lewis 1998). However, bank erosion may be limited by the rapid recovery of understory vegetation, especially grasses and sedges growing along streams where moisture is readily available during the growing season. Similarly, riparian hardwoods adapted to frequent disturbance resprout from roots and rapidly recolonize disturbed areas. Thus, the speed of riparian recovery will be critical in determining the risk of accelerated bank erosion following fire.

Entire sub-watersheds and watersheds are seldom burned because most fires are small. However, large fires, when they occur, can have severe effects. For example, Meyer et al. (1995) showed that major episodes of Holocene-aged sedimentation in Yellowstone National Park resulted from fires. Fire effects at this scale are rare, so predicting their effect within eastern Oregon and Washington is infeasible. Perhaps more important are the ways in which the effects of smaller fires propagate through larger watersheds and the cumulative effects of many such smaller fires. In general, a single, site-scale event is thought to have little effect on the larger watershed because the effects are attenuated as they move downslope and downstream. For example, much of the sediment eroded from burned areas may be stored in tributary valleys and the sediment that does reach the mainstem will be a relatively small proportion of the mainstem sediment load. Nevertheless, headwater streams are important sources of sediment for mainstem channels, and the morphology of mainstem channels is often sensitive to sediment inputs (Montgomery and Buffington 1997, Montgomery 1999). Thus, over the long term, sediment from tributary streams is important in maintaining channel morphologic features (Salo and Cundy 1987, Meehan 1991, Benda et al. 1998) and therefore, may also be important for maintaining stream habitat (Reeves et al. 1995). Dry ravel, soil creep, and surface erosion from adjacent hillslopes fill small channels with sediment that is entrained by floods or debris flows and transported down the stream network (Meyer and Wells 1997; William Russell, Oregon State University, personal communication). These episodic events, often categorized as catastrophic disturbances at the site/stand scale, may dominate long-term, large-scale budgets of bedload transport in many streams. The effect of post-fire episodic events on long-term large-scale sediment budgets has received comparatively little attention.

The cumulative erosion and sedimentation effects of many small fires have seldom been studied or documented. However, there are parallels between the expected cumulative effect of fires and the effect of clear-cut harvesting (Tiedemann et al. 2000). In general, watershed-scale studies of forest management have been difficult to interpret. Difficulties occur because of the high degree of natural variability in watershed processes, relatively slow response times of geomorphic processes observed in stream channels (Bunte and MacDonald 1995, 1999), the site-scale effects of other management practices, such as water withdrawals for irrigation, and the effects of historical land management practices, such as the removal of large wood (Beschta 1990).

Insects and Disease

The direct effects of forest pathogens on stream sediment budgets have not been studied. Large-scale insect outbreaks have superficial resemblance to fire because they cause mortality of overstory forest trees over a substantial proportion of the landscape. However, the effects of wide-scale forest mortality resulting from insect outbreaks should be quite different from those caused by fire. For example, fires alter soil properties because they remove forest floor litter and may also consume much of the organic matter in upper soil horizons. In contrast, the effects of tree mortality caused by insect outbreaks will be more subtle. Initially, litter inputs to the forest floor would increase. At the same time, changes in soil moisture resulting from decreased transpiration and changes in soil temperature will alter decomposition rates of litter and soil organic matter. Although these changes would be expected to occur over several years following insect outbreaks, they are unlikely to increase erosion and sedimentation.

Indirect effects of wide-scale insect outbreaks may be substantial. For example, where large-scale outbreaks of pathogenic insects increase fuel loading, forests may become more susceptible to large-scale stand-replacing fires (Agee 1993, Hessburg et al. 1994, Hann et al. 1997). Large wood also controls sediment storage in many small mountain streams (Nakamura and Swanson 1993). Tree mortality in riparian areas would increase inputs of large logs to streams in the years following an insect outbreak. Over the long term, however, the inputs of large logs should decline while riparian trees regrow, especially if regrowth is further delayed by fires occurring in the decades after an insect outbreak. The cumulative effect of these changes could be substantial because insect outbreaks are synchronous across large portions of the landscape.

Grazing

Unlike fire and insect outbreaks, which are infrequent or episodic events with dramatically visible changes in vegetation, the effects of grazing of domestic livestock are more subtle. Most of eastern Oregon and Washington has been grazed by domestic livestock for more than a century. The cumulative effects of grazing by domestic livestock can change vegetation composition, and reduce both the biomass of standing vegetation and soil organic matter (Elmore and Beschta 1987, Elmore 1992, Johnson 1992, Belsky and Blumenthal 1997). When grazing is intense, loss of soil cover and soil organic matter leads to reduced infiltration rates and increased surface runoff and erosion from upland parts of watersheds (Gifford and Hawkins 1978, Johnson 1992, Davenport et al. 1998, Belsky et al. 1999, Reid et al. 1999). In contrast, differences in runoff or erosion between lightly grazed areas and ungrazed areas may be small or difficult to detect (Gifford and Hawkins 1978, Belsky et al. 1999). Thus, the hydrologic effects of grazing share many attributes with those observed after fires–namely a potential increase in surface runoff and erosion. And similar to studies of accelerated erosion following fire, few studies have attempted to determine how much of the sediment eroded from grazed hill slopes is transported to streams. Undoubtedly, the overall influence of riparian vegetation in buffering streams from sedimentation caused by grazing of domestic livestock would be similar to that described above for surface runoff and attendant erosion, with one important exception. Whereas upland forest disturbances may leave riparian vegetation intact, riparian vegetation is often heavily grazed by domestic livestock.

Many studies show livestock tend to concentrate in riparian areas, especially during the summer, leading to increased utilization and trampling of riparian vegetation (Kauffman et al. 1983a, 1983b; Kauffman and Krueger 1984; Platts and Raleigh 1984; Elmore 1992; Johnson 1992). Also, grazing systems designed to limit use of upland forage often result in over-use of riparian forage, especially woody plants such as willows (Elmore 1992, Belsky et al. 1999). The long-term effects of persistent, and often intense, grazing of riparian areas has reduced the amount of willow (*Salix* spp.), grass, and sedge on stream banks (Elmore 1992). Exposed stream banks are especially prone to erosion during major floods (Platts et al. 1985, Elmore and Beschta 1987), which may result in substantial widening of stream channels, channel incision, or both (Kauffman and Krueger 1984). These long-term changes in channel morphology, especially channel incision, have important feedbacks on the hydrology of riparian zones. The height of the water table beneath the riparian zone is sensitive to the height of water in the stream, so channel incision can lower the water table for long distances across valley floors (Wondzell and Swanson 1999). In wet meadows, where longitudinal channel gradients are very low and valley floors are flat, small changes in channel incision can change interactions between the streams and riparian vegetation eventually converting wet, riparian meadows to drier, upland vegetation types (Elmore and Beschta 1987, Elmore 1992, Belsky et al. 1999) with much reduced vegetative cover on stream banks and valley floors. The grazing effects described above cannot be applied directly to all streams in eastern Oregon and Washington because not all channel types are equally susceptible to grazing-induced changes. The linkages among riparian vegetation, geomorphic processes, and hydrologic disturbance regimes need to be better understood to guide effective assessment of current condition and restoration potential.

Forest Health and Protection Treatments

Prescribed Fire and Mechanical Fuel Treatment

Prescribed fires are widely proposed as a treatment to reduce fuel loading and restore forest health (restore forests to pre-settlement conditions) (Brown and Arno 1991, Gast et al. 1991, Everett et al. 1994, Mutch et al. 1993). However, most fire studies have focused on either wildfire or slash burning following forest harvest (Beschta 1990). Relatively few studies have examined the effect of prescribed fire on watershed processes. Under-burning should remove fine fuel such as herbaceous vegetation and forest litter, and may create hydrophobic soils. However, hydrophobicity usually persists for only a few years. Most prescribed fires will be set when fuels are moist and climatic conditions are unlikely to support intense fires. Prescribed fires should have relatively little effect on soil organic matter and soil structure deeper in the soil profile because low fire temperatures and short-duration fires should not raise mineral soil temperatures significantly (DeBano et al. 1998). Litterfall from the retained forest canopy should rapidly renew the forest floor litter layer, protecting the soil from raindrop impact. Thus, low-intensity, prescribed fires typically have minimal effect on soil properties controlling infiltration (DeBano et al. 1998) so that the risk of increased surface erosion is relatively minor. Dry ravel from steep hillslopes could increase if prescribed fires consume logs and other organic matter that retain sediment on hillslopes (Bennett 1982, Beschta 1990) but this will depend on fuel conditions and the time elapsed since the last fire.

Management activities associated with prescribed fires that disturb the soil surface may have substantial effects on erosion and stream sedimentation. For example, dry ravel should be expected following mechanical fuel treatments if those treatments remove logs that are storing sediment on hillslopes. Additionally, soil disturbance (Beschta 1990, Gill 1994, Wilson 1999) resulting from mechanical fuel treatments prior to burning, building or re-opening roads for access to sites to be burned (Ketcheson and Megahan 1996, Trombulak and Frissell 1999, Jones et al. 2000), or construction of fuel breaks may increase erosion much more than would prescribed fire alone. Overall, the effects of prescribed fires on riparian and aquatic systems should be much less than those expected from large, stand-replacing fires, and the greatest risks are posed by ground-disturbing activities, rather than resulting directly from prescribed burns. However, the cumulative effect of dramatically increasing the number, frequency, and area of prescribed fires is unknown (Rieman and Clayton 1997, Tiedemann et al. 2000).

Insects and Disease

The greatest risks posed by Forest Health and Protection treatments to control insects and disease, or from treatments (salvage logging) of stands killed by insect outbreaks, will be from ground-disturbing activities. Again, building or re-opening roads for access to salvage sites would be expected to have large effects on stream sediment budgets (Ketcheson and Megahan 1996, Trombulak and Frissell 1999, Jones et al. 2000). Salvage operations typically use tractor logging, and erosion and sedimentation rates should be similar to those documented for harvest treatments under similar conditions. The effects of ground-disturbing activities can be minimized by maintaining buffers along stream channels; however, wind throw along buffered streams can lead to increased bank erosion and increase stream sedimentation (Lewis 1998), although the effects might be balanced by the contribution of large wood in forming stream habitat and sediment storage structures. Finally, where salvage plans call for piling and burning of non-merchantable materials, they are likely to have large and long-lasting effects on soil properties owing to high soil temperatures and long-duration heating that can sterilize the soil, and change infiltration rates (Beschta 1990, DeBano et al. 1998).

Grazing

Grazing prescriptions must be designed for ecologic and geomorphologic conditions of specific stream and riparian systems (Elmore 1992). Possible changes in grazing prescriptions for domestic livestock include reducing the intensity and duration of grazing, changing the season of use, improving the distribution of livestock within pastures, periodic rest from grazing, and in some cases, complete exclusion of domestic livestock. However, flexibility in designing grazing prescriptions for higher elevation pastures will be limited by severe climatic conditions. Further, because most studies examining effects of grazing on riparian vegetation, channel morphology, and fish compared grazed areas to non-grazed exclosures and tended not to report grazing intensity or forage utilization in grazed areas, there is relatively less information available to guide development of grazing prescriptions that are consistent with restoration goals (Clary and Webster 1989, Platts and Raleigh 1984, Rinne 1999).

A study of a grazing exclosure in Wickiup Creek in eastern Oregon (Clifton 1989; Nagle and Clifton, unpublished data[2]) showed rapid increase in vegetation cover in riparian areas followed by substantial changes in channel morphology with complete exclusion of livestock. Similar geomorphic responses were observed in a study of mountain meadow systems in central Idaho (Clary 1999). In both of these studies, substantial changes also occurred in grazed reaches outside exclosures. These study areas appear to be more lightly grazed today than in the past and suggest that complete removal of domestic livestock is not always necessary to gain improvements in stream condition.

Studies that focus on changes in channel morphology, especially reduced width:depth ratios and number of pools, have shown mixed results (McDowell and Magilligan 1997). Several studies failed to show significant changes in channel morphology despite many years of livestock exclusion (Medina and Martin 1988, Kondolf 1993). However, these studies were conducted in relatively small riparian grazing exclosures, whereas stream channel morphology is sensitive to processes within the entire watershed that regulate delivery of water, sediment, and wood to stream channels, as well as the recent history of large floods, and the availability of key structural elements such as large logs or large boulders that interact with sediment transport and deposition to change channel structure.

Risks and Forest Health and Protection Treatments

Proposed forest health and protection treatments may accelerate upland erosion and increase sedimentation of streams. Treatments designed to minimize short-term risks may conflict with activities that will minimize long-term risks. This conflict is well illustrated by management prescriptions for riparian forests. Passive restoration, in which detrimental land management activities are reduced, or eliminated, is a reasonable response to many stream management problems because the effects of specific land management practices are well understood in many areas (Meehan 1991, Kauffman et al. 1997, Rieman and Clayton 1997, Howell 2001). Forest health and protection prescriptions, however, call for active management to speed restoration—specifically, using silvicultural treatments to modify stand composition, structure, and stocking (including salvage logging, mechanical fuel treatment, and prescribed fire) and thereby control insect and disease outbreaks as well as reduce fuel loading. These treatments may help reduce the long-term risk of stand-replacing fires. Active restoration will use best management practices. Certain treatments, such as salvage logging and mechanical fuel treatments, will require the use of roads (existing roads, reopening roads, or construction of new roads) and use of heavy equipment off roads (such as tractor skidding) that may lead to sedimentation of streams with possible negative impacts on stream habitat for salmonids. Because of this, management prescriptions call for leaving substantial buffers of undisturbed forest adjacent to both perennial and ephemeral stream channels (USDA and USDI 2000). However, some riparian forests pose special problems. For example, in many dry forest types on volcanic lithology, the deepest and most productive soils are in riparian areas. Increased moisture availability in these areas has led to establishment of shade-tolerant, late-successional species. Many of these riparian forests now have high fuel loadings and are dominated by dense stands of trees that are prone to insect attack. Over the long term, passively managed riparian forests may have increased risk of insect and disease outbreaks, and certainly, intense wildfires would remove riparian buffers. Frequent stand-replacing disturbances could limit the size of riparian trees from which large wood is recruited to streams and therefore have long-term effects on channel morphology. Thus, strategies that preserve buffers of undisturbed forest to protect streams from land management practices and avoid short-term risks of active management present unknown long-term risks.

To some extent, trade-offs between short- and long-term risks can be avoided by considering the spatial component of forest health treatments. Upland and riparian forest conditions are good in many of the watersheds that currently support strong populations of threatened and endangered salmonids and have little immediate need for restoration. Conversely, populations of threatened and endangered salmonids are missing in many watersheds with poor habitat, even though these watersheds have the potential to support strong populations. Here, the only risk associated with restoration practices will be the lost opportunity if restoration is not successful. Not all risk can be avoided. Priority restoration watersheds for threatened and endangered salmonids tend to be those with existing populations where potential to support strong populations is judged to be high, but where upland, riparian, and aquatic conditions are poor. These priority restoration watersheds often target geographically isolated remnant populations considered ecologically important. In these cases, trade-offs between active restoration strategies with well known short-term risks and passive management with potential, but poorly known long-term risks need to be considered carefully. Unfortunately, the present state of scientific knowledge is insufficient to inform choices between these tradeoffs.

Summary

Forest health and protection treatments need to be considered individually to assess their potential effects at the site scale. Prescribed fires would likely have a relatively small effect on rates of erosion and stream sedimentation, and any increase would likely be much smaller than from a stand-replacing wildfire burning the same area. Improved grazing prescriptions may lead to major changes in composition and biomass of stream-side vegetation, especially the abundance of woody species such as willow. However, response will be highly dependent on geomorphic conditions. Although some studies have shown that channel morphology can respond quickly to changes in grazing, changes in channel and floodplain morphology will be slow in most areas, and in those areas, restoration is likely to be difficult. The largest risk of accelerated erosion is expected from ground-disturbing activities, such as road use and road reconstruction, construction of fire breaks, or off-road use of heavy machinery. Overall, carefully designed and implemented site-scale treatments are expected to have little effect on erosion and sedimentation at the watershed, or larger scale, because effects are attenuated as they move down the stream network. Most studies of forestland use and stream sedimentation have been conducted at the site or small-watershed scale, so that conclusions at these scales are generally well supported by the available literature.

Large-scale studies and cumulative-effect studies of forest land-use practices are relatively rare, so the cumulative effects of forest health and protection treatments imposed across a large region are difficult to assess. Current knowledge of cumulative effects comes mostly from large, watershed-scale studies of past practices. However, the results of these studies have been difficult to interpret because of the high degree of natural variability, relatively slow response times of geomorphic processes, the site-scale effects of other management practices, and the difficulty of reconstructing historical land management practices. Further, there are no large-scale empirical studies of cumulative effect resulting from current best management practices. Restoration goals often target reference conditions considered to be the condition prior to Euro-American settlement, or attempt to mimic a natural disturbance regime, both of which are reconstructed from a variety of proxy records. Given the current state of knowledge, dramatically changing forest land-use practices across eastern Oregon and Washington–including the widespread use of prescribed fires, salvage logging, mechanical fuel treatments, combined with an extensive network of riparian buffers–is essentially a long-term, landscape-scale experiment, the cumulative effects of which are unknown.

Acknowledgements

I thank Phil Howell, Will Russell, and Greg Nagle for interesting discussions that helped me refine ideas for this paper. I thank Dominique Bachelet and two anonymous reviewers for helpful comments. Support for this work was provided by the Interior Columbia Basin Ecosystem Management Project. Additional support was provided by the US Forest Service's Pacific Northwest Research Station and both the Aquatic and Land Interactions Program and the Managing Disturbance Regimes Program.

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Notes

This special issue of *Northwest Science* is a set of papers reviewing the state of knowledge about disturbance processes in eastern Oregon and Washington, related management practices, and effects on key management issues.

[1] See Starr et al. 2001 for a definition of Forest Health and Protection treatments.

[2] Nagle, G.N., and C. F. Clifton. Channel changes over 13 years on grazed and ungrazed reaches of Wickiup Creek in eastern Oregon.