Postfire Logging in Riparian Areas

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Abstract: *We reviewed the behavior of wildfire in riparian zones, primarily in the western United States, and the potential ecological consequences of postfire logging. Fire behavior in riparian zones is complex, but many aquatic and riparian organisms exhibit a suite of adaptations that allow relatively rapid recovery after fire. Unless constrained by other factors, fish tend to rebound relatively quickly, usually within a decade after a wildfire. Additionally, fire and subsequent erosion events contribute wood and coarse sediment that can create and maintain productive aquatic habitats over time. The potential effects of postfire logging in riparian areas depend on the landscape context and disturbance history of a site; however, available evidence suggests two key management implications: (1) fire in riparian areas creates conditions that may not require intervention to sustain the long-term productivity of the aquatic network and (2) protection of burned riparian areas gives priority to what is left rather than what is removed. Research is needed to determine how postfire logging in riparian areas has affected the spread of invasive species and the vulnerability of upland forests to insect and disease outbreaks and how postfire logging will affect the frequency and behavior of future fires. The effectiveness of using postfire logging to restore desired riparian structure and function is therefore unproven, but such projects are gaining interest with the departure of forest conditions from those that existed prior to timber harvest, fire suppression, and climate change. In the absence of reliable information about the potential consequence of postfire timber harvest, we conclude that providing postfire riparian zones with the same environmental protections they received before they burned is justified ecologically. Without a commitment to monitor management experiments, the effects of postfire riparian logging will remain unknown and highly contentious.*

Keywords: fire behavior, riparian habitat restoration, riparian management, timber harvest, wildfire

Cosecha de Madera Post Fuego en Áreas Ribereñas

Resumen: *Revisamos el comportamiento del fuego no controlado en zonas ribereñas, principalmente en el oeste de Estados Unidos, y las consecuencias ecológicas potenciales de la cosecha de madera post fuego. El comportamiento del fuego en zonas ribereñas es complejo, pero muchos organismos acuáticos y ribereños tienen un conjunto de adaptaciones que permiten una recuperación relativamente rápida después del fuego. A menos que otros factores los constriñan, los peces tienden a rebotar rápido relativamente, generalmente antes de una década después de un fuego no controlado. Adicionalmente, el fuego y los eventos de erosión subsecuentes aportan madera y sedimentos gruesos que pueden crear y mantener hábitats acuáticos. Los efectos potenciales de la cosecha de madera post fuego en áreas ribereñas dependen del contexto del paisaje y de la historia de perturbaciones de un sitio; sin embargo, la evidencia disponible sugiere dos implicaciones claves para la gestión: (1) el fuego en áreas ribereñas crea condiciones que no requieren de intervención para sostener la productividad de la red acuática a largo plazo y (2) la protección de áreas ribereñas quemadas da prioridad a lo que queda en lugar de lo que es removido. Se requiere investigación para determinar el efecto de la cosecha de madera post fuego sobre la dispersión de especies invasoras y la vulnerabilidad de bosques*

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al surgimiento de enfermedades e insectos y la forma en que la cosecha de madera post fuego afectará la frecuencia y comportamiento de incendios futuros. Por lo tanto, la efectividad de la utilización de cosecha de madera post fuego para restaurar la estructura y función ribereña no está probada, pero tales proyectos están ganando interés con la pérdida de condiciones forestales que existían antes de la cosecha de madera, la supresión de fuego y del cambio climático. En ausencia de información confiable sobre la consecuencia potencial de la cosecha de madera post fuego, concluimos que se justifica ecológicamente proporcionar la misma protección ambiental a las zonas ribereñas que recibían antes de ser quemadas. Sin el compromiso de monitorear experimentos de gestión, los efectos de la cosecha de madera post fuego en zonas ribereñas permanecerán desconocidos y altamente contenciosos.

Palabras Clave: comportamiento del fuego, cosecha de madera, fuego no controlado, gestión ribereña, restauración de hábitat ribereño

Introduction

Riparian zones are important interfaces between terrestrial and aquatic ecosystems, areas where materials are transferred back and forth between land and water and where terrestrial plant and animal communities strongly influence the physical features and biological productivity of rivers and lakes (Fig. 1). Riparian management is often controversial because natural resource objectives for land and water may be at odds (e.g., trees for commodity production vs. trees for aquatic and riparian habitat) (Naiman et al. 2005). Regulatory guidelines for riparian zones usually represent compromises between the demands of forest managers and fish and wildlife managers (Masonis & Bodi 1998), but the tension between interests continues to spark scientific and political discussion. Equally controversial has been the debate between a perceived need to actively manage dysfunctional riparian areas to restore desired conditions and alternative strategies that emphasize passive riparian recovery.

Perhaps nowhere have these controversies been more apparent than in the issue of postwildfire logging on public lands in western North America. The widely read “Beschta Report” (Beschta et al. 1995) and subsequent review (Beschta et al. 2004) emphasize the importance of considering natural recovery processes in postfire planning. The Beschta Report has been cited in many legal challenges to agency plans for salvage logging. Although many of the management recommendations in the report pertain to uplands, the authors specifically argue against postfire salvage logging in riparian zones by any means. In the decade since the Beschta Report, some have argued that salvage logging can and should occur in riparian areas, and both the federal 1995 Salvage Rider Bill and Healthy Forest Restoration Act of 2003 allow for active management of these sensitive areas after fires.

Despite the strong rhetoric that has accompanied debates over salvage logging in riparian zones, the efficacy of postfire salvage and restoration activities is poorly known. Aside from documenting immediate changes after salvage and salvage-related activities (e.g., road construction), few, if any, projects contain provisions for monitoring the ecological effects of a riparian salvage action. As a result, managers continue to face uncertainty about whether their projects are having the desired effect. Habitat protection and water-quality regulations constrain the types and extent of activities that can occur within riparian areas, and the presence of fish populations listed under the U.S. Endangered Species Act (ESA) or given other legal status because of low or declining numbers may further restrict options for riparian management activities in the western United States (Rieman et al. 2000). Options for managers to respond to the effects of disturbances such as wildfire in riparian areas are therefore limited.

Salvage logging following wildfire is viewed as a way of recovering economic value, leveraging funds for restoration work, or directly ameliorating adverse fire effects (McIver & Starr 2001). Results of studies on the effects of postfire salvage logging on terrestrial organisms have been mixed; some organisms show no response, some increase (e.g., Blake 1982; Haim & Izhaki 1994), and others decline (Saab & Dudley 1998). We reviewed the available scientific literature on the effects of wildfire on riparian and aquatic ecosystems. Based on the review and our collective experience, we identify potential ecological effects of salvage logging in riparian areas in western North America.

Fire Effects on Riparian Zones and Aquatic Ecosystems

Boundaries of riparian ecosystems vary longitudinally and laterally throughout the channel network according to position in the watershed and a variety of biophysical factors (Naiman et al. 1998). The ecological influence of riparian zones is often disproportionately larger than their spatial extent, particularly in drier climates. Ecological functions (Fig. 1) associated with riparian systems along perennial streams include wood recruitment, moderation of shade for light and water temperature, litter input (which serves as the major component of the trophic base of stream ecosystems), and enhanced bank structure and stability.

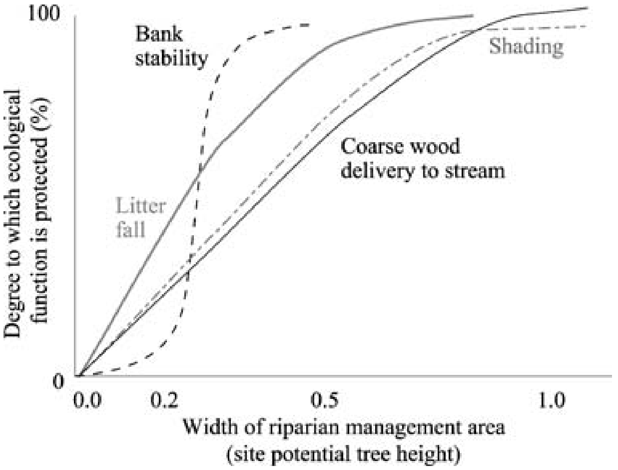

Figure 1. The degree to which key ecological functions of trees in riparian areas are protected as a function of the width of the riparian management area. Site potential tree height is the average maximum height of a 200-year-old tree of the dominant species in a given location (modified from FEMAT 1993).

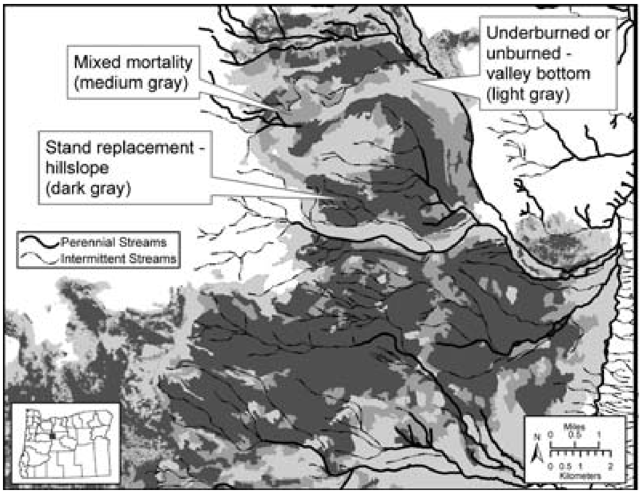

Figure 2. Fire mortality map of the 2003 B&B fire in Deschutes National Forest, Oregon. Riparian zones adjacent to perennial streams, particularly in unconstrained valleys, tended to suffer lower tree mortality than severely burned uplands.

Riparian areas are also important habitats for numerous wildlife species (Kelsey & West 1998).

Until recently, riparian management focused on perennial or fish-bearing streams; now there is growing recognition that important riparian functions extend to intermittent streams and streams that do not contain fish (Naiman & Latterell 2005). These streams may comprise 70% or more of the stream network and provide a suite of ecological functions to fish-bearing streams that include sources of large wood (Benda et al. 2002, 2003*a*; Reeves et al. 2003), coarse sediment (Benda & Dunne 1987), cool water, nutrients (Wipfli & Gregovich 2002), and invertebrates (Wipfli & Gregovich 2002), as well as habitat for many headwater amphibians (Meyer & Wallace 2001). Ecological connections between the fish-bearing and nonfish-bearing streams are maintained by stochastic events (Gomi et al. 2002), such as landslides, hillslope failures, and floods that may occur following a wildfire (Benda et al. 2003).

Numerous researchers have examined the behavior and effect of fire on upland ecosystems in western North America, but there are few studies of fire in riparian areas. These few studies focused on riparian zones along perennial streams (e.g., Olson 2000; Everett et al. 2003), and their results varied with geographic location. In general, the frequency and intensity of fires in riparian areas (following the definitions of Agee [1993]) are less than in adjacent upslope areas (Fig. 2). Differences between fire effects on riparian and upland areas tend to be reduced in regions with more frequent, less severe fires compared with locations where the fire-return interval is longer and fires more severe. The behavior of fire in riparian areas along intermittent and ephemeral headwater streams has not been studied, perhaps because inclusion of these areas as part of the riparian network is only beginning to be recognized. In the absence of direct study, we assume the effects of fire on the riparian zones of ephemeral and intermittent streams are similar to the effects on upland plant communities, but additional research is needed.

Local topography, microclimatic conditions (which are influenced largely by the proximity to water and the size of the stream), presence of saturated soils, and watershed orientation all influence fire characteristics (Brosofske et al. 1997). Moister, cooler microclimates can lower the intensity, severity, and frequency of fires in riparian areas. Wind speed is often lower than in surrounding uplands, which favors less severe fires, decreased flame lengths, and lower fireline intensity (Dwire & Kauffman 2003). Fire intensity may be exacerbated under extreme weather conditions where steep terrain, narrow canyons, and fuel-rich riparian corridors act as "chimneys" that promote severe fire behavior (Kauffman 2001). Although direct evidence is sparse and accounts are primarily anecdotal, under extreme conditions hot convective smoke columns stimulated by orographic features such as steep, narrow canyons may occasionally collapse, smothering a large area with volatile gases that can combust or cause widespread tree mortality without burning. In contrast, unconstrained stream reaches (i.e., reaches with low gradients and wide valley floors [Gregory et al. 1989]) may act as firebreaks, reducing fire intensity and slowing the rate of spread (Dwire & Kauffman 2003). Occasionally, however, riparian zones in unconstrained stream reaches can burn with high intensity, particularly where drought conditions have resulted in lower water tables and an abundance of highly combustible invasive plants (Bess et al. 2002).

Riparian plants exhibit a suite of adaptations that allow relatively rapid recovery after fire. Adaptations include epicormic and basal sprouting, windborne and water-dispersed seeds, refractory seeds buried in the soils, and on-plant seed storage. Trees such as ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and coastal redwood (*Sequoia sempervirens* Lamb. ex D. Don) have thick bark that protects the cambium from heat damage during low and moderate-severity fires (Miller 2000). Increases in soil moisture, higher riparian water tables, and elevated summer flows due to reduced evapotranspiration after fires also accelerate recovery in riparian areas, particularly among phreatophytic species of grasses, forbs, and hardwoods. Nevertheless, the resiliency of riparian vegetation may be compromised by previous management activities (Beschta et al. 2004).

Fire can profoundly influence aquatic ecosystems (Gresswell 1999). Immediate effects of severe fires that burn through riparian areas and across small streams include high mortality or emigration of fishes and other organisms caused by direct heating and changes in water chemistry (Minshall et al. 1997; Rieman & Clayton 1997; Spencer et al. 2003). In-channel wood often declines immediately after intense fires (Berg et al. 2002). Consequences of the loss of vegetation and reduced infiltration capacity of soils include increased surface erosion, changes in the timing and amount of runoff, elevated stream temperatures, and changes in the morphology of stream channels (Wondzell & King 2003). The nature of these changes depends on the extent, continuity, and severity of the fire and on lithology, landform, and local climate (Swanson et al. 1988; Luce 2005). A severe fire burning through dense fuels can produce extensive areas of hydrophobic soils (DeBano et al. 1998), although this condition is often transitory. A large rainstorm following closely after a severe fire in steep, highly dissected terrain can result in massive erosion, debris torrents, and hyperconcentrated flows that reconfigure mountain streams and deposit large volumes of sediment in lower gradient reaches. This natural process has strongly influenced the development of watershed topography throughout western North America.

Even in cases where the physical effects of fire are pronounced, whether fire constitutes an ecological catastrophe should be treated as a matter of context and scale. For example, most fish populations rebounded relatively quickly after fires near Boise, Idaho, in part through recolonization from nearby unburned reaches of stream (Rieman & Clayton 1997). Approximately 10 years after the fires, there was little evidence that fish communities in streams in burned watersheds were fundamentally different from similar-sized unburned streams (B. Rieman, unpublished data). Fires may result in increased aquatic productivity by stimulating primary and secondary production (Minshall 2003; Spencer et al. 2003), which may ameliorate otherwise stressful conditions for fish (e.g., high temperatures).

Over time scales of tens to hundreds of years, large disturbances have been common in landscapes of western North America. Aquatic organisms have evolved adaptive mechanisms such as reproductive dispersal and variation in life-history patterns that allow them to "spread the risk" of exposure to severe environmental disturbances and recover quickly after them (Dunham et al. 2003). Although it is easy to interpret a severe burn in a riparian area as a catastrophe, results of most studies show that short-term effects of fire on aquatic communities are transitory, unless those systems are already seriously impaired by habitat loss, fragmentation, or other effects. Fire and subsequent erosion contribute wood and coarse sediment that create and maintain productive aquatic habitats (Reeves et al. 1995; Benda et al. 2003). Debris-flow deposits at tributary junctions produce heterogeneity in channel structure and increased habitat complexity (Benda et al. 2003). Natural disturbances interacting with complex terrain produce a changing mosaic of habitat conditions in both terrestrial and aquatic systems (Miller et al. 2003). Disturbance-mediated variation in space and time is important to maintaining biological diversity and, ultimately, the resilience and productivity of many aquatic populations and communities (Poff & Ward 1990).

Incorporating Disturbance Considerations into Riparian Management

To estimate the potential effect of salvage logging in riparian areas, it is necessary to consider stream networks and processes that structure aquatic ecosystems. Watershed processes have been hypothesized as continuously variable and spatially predictable, with the implication that biophysical changes along an upstream–downstream gradient could be easily modeled (Vannote et al. 1980). Recent evidence suggests that changes in the characteristics of streams in space and time are punctuated by occasional disturbances (Montgomery 1999; Rice et al. 2001), leading to a drainage network in disturbance-prone areas that appears more patch-like than continuously variable (Weins 2002). Viewing stream systems as patchy networks rather than as linear systems provides a more accurate portrayal of the processes that link riparian and aquatic ecosystems in western North America (Fausch et al. 2002; Benda et al. 2004). The potential effects of salvage logging in riparian areas are therefore dependent on the landscape context and disturbance history of a site. Periodic disturbances are necessary to maintain a full range of ecosystem conditions through time (Lugo et al. 1999). The mosaic of riparian habitats created by fires, floods, forest diseases, and other disturbances provides opportunities for different communities of plants and animals as well as for expression of a variety of life histories and phenotypes. Attempts to manage disturbance-prone ecosystems as steady states have generally been unsuccessful, resulting in unintended consequences when new disturbances alter successional trajectories and favored life cycles (Holling 1973).

An appreciation of the role of natural disturbances in structuring aquatic and riparian ecosystems is emerging within the management community. Understanding natural cycles of disturbance and recovery is necessary for developing locally appropriate management policies for postfire activities, whether emergency habitat rehabilitation or timber salvage. We suggest that current ecological insights have two implications for salvage logging: (1) fire in riparian areas creates a set of conditions that may not need to be "fixed" in order to sustain the long-term productivity of aquatic ecosystems in a watershed and (2) ecological protection of burned riparian areas should consider foremost what is left rather than what is removed.

Riparian Resilience

Riparian ecosystems are likely to be resilient after disturbance when environmental changes fall within the natural range of conditions that were expressed before the disturbance event and where biophysical processes reestablish the full range of functions and structures that existed through time. Reduced resilience constrains the diversity of conditions that can be exhibited over time, the present range of conditions in a particular ecological state, or both (Frissell et al. 1997). Biological consequences of reduced resilience may include extirpation of some species and increases in other species favored by available conditions, including invasive species (Harrison & Quinn 1989; Reeves et al. 1993). The cumulative impact of wildfire and subsequent salvage logging may affect some species but not others (Lindenmayer et al. 2004).

Ecosystem resilience is strongly influenced by the "legacy" that remains following a disturbance (Franklin et al. 2000; Lindenmayer & Franklin 2002). In forested riparian areas, the primary physical legacies are dead trees (downed and standing), live trees, and coarse sediment of varying characteristics. Biological legacies include surviving plants, animals, and propagules of the previous forest (Lindenmayer & Franklin 2002). These legacies set the stage for riparian recovery after fire by providing habitat for opportunistic species that colonize disturbed areas and by providing a template for the reassembly of a new riparian community. Wildfires typically leave large amounts of downed and standing trees that provide seed sources and substrate for future riparian forests, habitat for a variety of organisms (e.g., amphibians and cavity-nesting birds), and a source of large wood for streams. Wood is delivered to streams episodically, along with sediment, through landslides and streambank erosion (Benda et al. 1998; Benda & Sias 2003), providing structural elements that promote pool formation, sediment terraces, and a diversity of aquatic habitats. Removal of large wood from riparian areas and adjacent unstable hillslopes limits the future recruitment of this material to stream channels.

The more management activities depart from the disturbance regime under which a riparian area developed, the less likely the riparian zone will be able to return to premanagement conditions (Lindenmayer & Franklin 2002). The challenge for managers is to implement fire-related actions that complement natural recovery processes in terms of physical and biological legacies and the frequency and severity of natural disturbance events, to the extent possible. An equally important challenge is to establish long-term monitoring programs so that the efficacy of postfire projects, such as salvage logging and the U.S. Forest Service's Burned Area Emergency Rehabilitation (BAER) program, can be evaluated. Currently, data on the effects of salvage logging on aquatic and riparian ecosystems are lacking primarily because long-term monitoring programs are absent.

Potential Postfire Impacts

Effects of salvage logging in riparian zones will be expressed primarily through the number and size of trees that are left and the extent of direct and indirect impacts of the salvage operations on plants and animals that persist after the fire. Available scientific evidence suggests that the more trees retained and the more the impacts to survivors are minimized, the more resilient the riparian ecosystem will be (Bisson et al. 2003). Fish populations may rebound from fire impacts relatively quickly (Rieman & Clayton 1997; Dunham et al. 2003). This is likely related to the development of favorable habitat conditions resulting, at least partially, from the recruitment of large wood to streams. Wood that enters channels following fires in riparian areas will, in many cases, be the main source of wood for the stream (Fig. 3) until trees in the postfire stand reach a sufficient size to be effective in creating habitat, which may take decades to centuries (Beechie 2000). Brown et al. (2003) suggest that there could be an excess of coarse wood following severe fire in unnatural forest stands (i.e., increased density of small trees through fire suppression), but we are not aware of similar evidence in riparian forests. In fact, reducing the amount of wood that can be delivered to channels by postfire logging may exacerbate the negative effects of fires and delay the improvement of fish habitats that already may be deficient in wood because of past management practices.

Amphibian populations may be negatively affected by the removal of trees from burned riparian zones, particularly in dry forests. Downed wood, particularly with large-diameter boles, provides high-moisture microhabitats and

Figure 3. Recruitment of large wood to stream channel in Payette National Forest, Idaho, following wildfire (photo by Payette National Forest staff member).

reproductive sites for many riparian-associated amphibians (Pilliod et al. 2003). Loss of these microhabitats may further exacerbate the effects of the fire and impede the potential recovery of amphibian populations.

Removal of large wood also influences short- and long-term erosional processes. Over time, headwater depressions and channels fill with material from the surrounding hillslopes, including large wood that falls into these channels forming obstructions behind which sediments accumulate (Benda & Cundy 1987; May & Gresswell 2003). These areas are evacuated when a debris flow delivers the material to larger channels downstream. The cycle of filling and emptying creates pulses of coarse sediment and wood that move down the channel network (Benda et al. 1998), replenishing structural habitat elements that maintain the long-term productivity of stream ecosystems (Reeves et al. 1995). Salvaging trees that have accumulated in headwater depressions and small ephemeral channels thus removes an important source of wood for larger streams and reduces the sediment storage capacity of small catchments. This may result in chronic routing of sediment out of headwater streams, leading to downstream channels that are sediment rich and have lost habitat complexity (Beschta et al. 2004). The presence of large wood eroded from headwater catchments also influences the runout length of debris flows (Lancaster et al. 2003). Debris flows without wood often move faster and travel longer distances than those with wood and are less likely to stop high in the stream network.

Downed wood in burned riparian zones traps fine sediment before it erodes to channels and intrudes into stream substrates (Wondzell & King 2003). The presence of downed wood may be particularly important in areas where chronic overland erosion occurs. Soil disturbance and compaction caused by ground-based harvesting and yarding (movement of cut timber) may exacerbate the effects of the fire on surface erosion and riparian-associated plants and animals. These impacts can potentially be reduced by using helicopter logging or full-suspension cable yarding (Beschta et al. 2004).

Removing surviving riparian trees (Fig. 4) and the boles of dead trees decreases shade and thus can result in increases in postfire stream temperatures. Additionally, activities associated with tree removal (e.g., felling, skidding, and road building) retard the recovery of shading vegetation. Although water temperatures increase following wildfires (Helvey 1972; Minshall et al. 1997), predicting the biological consequences of such changes is difficult (Beschta et al. 1987). Where temperatures are already marginally suitable for aquatic organisms, further increases could lead to local extirpations. In areas where low water temperatures limit primary production, some warming that remains within ranges favorable to organisms of interest may increase productivity (Minshall et al. 1989).

Even slight increases in stream temperature that are well within the thermal tolerance of many species can have important ecological consequences. For example, increased water temperature led to an elevated abundance of aquatic invertebrates that resulted in higher growth rates of coho salmon (*Oncorhynchus kisutch*) following limited riparian timber harvest in Carnation Creek, British Columbia. Overall, however, survival and production of young salmon ultimately declined because increased growth led to earlier seaward migrations that were no longer matched to productivity cycles in the ocean (Holtby 1988). Franco and Budy (2004) found that cutthroat trout (*O. clarki*) in streams where the average summer temperature is 12° C have a greater incidence of whirling disease than trout in streams where the average

Figure 4. Large live trees serving as an important ecological "bridge" that maintains stream habitat as the new postfire forest develops (photo by P.A. Bisson).

summer temperature is below 9.5° C. Isaak and Hubert (2004) found that trout abundance varies nonlinearly with summer stream temperature, with highest abundance at intermediate temperatures and reduced abundance associated with both warm and cold conditions. Salvage logging in riparian areas potentially exacerbates thermal maxima by reducing shade and lowers thermal minima by increasing long-wave radiation loss at night (Beschta et al. 1987). Unfortunately, we are aware of no investigations that specifically address the effect of postfire salvage logging on stream temperature in western North America, although virtually all watershed studies involving logging in riparian zones have documented water temperature increases after harvest.

Roads, including temporary roads, built to facilitate salvage logging can result in increased erosion (Furniss et al. 1991), affecting aquatic organisms and their habitats (Trombulak & Frissell 2000; Buffington et al. 2002). Roads can impinge directly on a stream, constraining the channel and reducing floodplain connections or crossing the stream (Fig. 5) and creating an additional source of erosion and a potential barrier to movement of aquatic organisms. Barriers that restrict or eliminate dispersal and full expression of life histories may preempt recolonization of vacant habitats or restrict demographic support of populations depressed by immediate and subsequent effects of fires (Rieman & Clayton 1997; Dunham et al. 2003).

Figure 5. A new road (center) built for salvage logging and fuels management that is restricting dispersal of aquatic organisms and thus directly influencing the resilience of aquatic communities (photo by D. Powell).

Need for Riparian Management Experiments

Apparently, no studies have specifically tested the proposed benefits of postfire salvage logging as a measure of riparian restoration. Additionally, we are unaware of research directed at determining whether salvage logging in riparian areas reduces the spread of invasive species, lowers the vulnerability of upland forests to insect and disease outbreaks, or lessens the frequency or severity of future fires. In the absence of such studies, we conclude that there is little ecological justification not to provide postfire riparian zones with the same environmental protections they received before fire. Nevertheless, we acknowledge that the current lack of data limits our ability to identify areas where active postfire riparian management, including salvage operations, can confer long-term benefits to aquatic resources and riparian-associated wildlife. Western landscapes, including many places considered relatively pristine, bear the long-term legacies of previous land uses (Foster et al. 2003), and these legacies continue to shape recovery trajectories in burned riparian ecosystems. As a matter of policy, treating active versus passive postfire riparian management as a blanket either-or choice constrains the ability of managers to apply appropriate restoration strategies to different field situations. Without controlled experimentation, however, the ecological benefit of salvage logging in riparian areas will remain highly contentious.

The justification used most often for postfire logging has been to recoup the economic value of fire-killed trees or to lessen the threat of further disturbances to human infrastructure and safety. Salvage plans often contain provisions to minimize ecological risks, and postfire logging can target certain ecological benefits (McIver & Starr 2001). Managers typically attempt to determine whether social and economic benefits outweigh the ecological risks associated with logging and, if they do, plan salvage operations that address specific environmental concerns. Where ecological risks are clearly limited (e.g., where the area in question already bears a legacy of heavy environmental damage) or where human values are clearly dominant (e.g., at the wildland–urban interface), this analysis may favor postfire logging. Where ecological risks of timber salvage are high, the trade-offs become much more problematic. Use of modern logging systems may minimize the effects of ground-disturbing activities, and new analytical methods can be used to evaluate short-term risks of salvage-related erosion (e.g., Elliot & Miller 2002). Nevertheless, long-term implications of postfire logging for riparian forest development, large wood recruitment, and stream food webs have not been investigated adequately. Controlled field experiments and development of more realistic models incorporating nutrient, sediment, and wood dynamics (e.g., Benda & Sias 2003) are needed to clarify these issues.

The use of postfire salvage logging to restore desired ecological structure and function is unproven, but the prospect of doing so is gaining interest with the departure of forest conditions from those that existed prior to timber harvest, fire suppression, and climate change (Hessburg & Agee 2003). In essence, the concern is that climate change and past management have led to such dramatic changes in forest structure and composition that fuel loads and fire behavior are well outside the range of natural variability (Brown et al. 2003). Postfire logging has been suggested as a possible tool to improve ecological conditions through (1) reduction of the potential for catastrophic "reburn" (Brown et al. 2003); (2) break-up of hydrophobic soils and reduction of potential surface erosion by adding slash (Poff 1996); and (3) reestablishment of vegetative assemblages to further the development of structurally complex forest communities (Sessions et al. 2004).

Some type of postfire logging might directly mitigate the potential for subsequent disturbance that could damage aquatic communities, at least in the short term. We previously described the role and potential benefits of disturbance in aquatic ecosystems, but situations may exist where a major disturbance subsequent to a large fire could be catastrophic for endangered species. This is most likely to be an issue where such species have declined or become isolated because of past habitat loss and fragmentation (Bisson et al. 2003). Unfortunately, reburn probability and reburn fire behavior are understood mostly in theory (e.g., Brown et al. 2003); there is little empirical evidence that would be useful for evaluating risks. We face similar limitations in understanding the distribution and temporal dynamics of hydrophobic soils, especially in riparian areas. For these reasons, field trials to test postfire logging as a tool to mitigate reburn potential and reduce hydrophobic soils should avoid areas with sensitive aquatic species until their efficacy has been demonstrated in watersheds where risks to native species are less critical.

With regard to reestablishing desired vegetative conditions, many riparian areas and their associated ecological processes are currently degraded or compromised by past and recent management activities (Hicks et al. 1991). Some suggest that thinning could be used to enhance the long-term recruitment of large wood to streams (Rainville et al. 1985), a key ecological process, because it would increase the growth of remaining trees and hasten the recruitment of larger trees to streams. Although these ideas are intriguing, evidence is largely confined to models of upland forest stands (e.g., Sessions et al. 2004), and we await silvicultural trials in postfire riparian areas.

In each of these cases, managers may have concerns and rationales that argue for the benefits of logging after wildland fires. Still, empirical evidence of the efficacy of postfire treatments in these complex ecosystems is largely lacking, and predicting the long-term response of such projects is almost impossible at present. Arguments against postfire riparian logging seem equally valid without more research. Perceived risks and benefits of postfire actions in riparian zones will usually guide the resolution of debates until controlled field studies are undertaken across a variety of fire-prone areas. Changing climate, the potential for more frequent severe fires in the future (McKenzie et al. 2004), and a growing concern over protecting sensitive species (Rieman et al. 2003) suggest this is an issue that will not soon disappear. Thoughtful experimentation in the context of adaptive management provides a mechanism to inform the debate (Bisson et al. 2003). Long-term studies that explore the use of postfire logging in riparian areas for either socioeconomic or ecological reasons will be possible in a wide range of environments in coming years. If those involved in the discussion over postfire riparian logging fail to take advantage of that opportunity, the debates will hinge on beliefs instead of data.

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