Postfire Management on Forested Public Lands of the Western United States

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Abstract: *Forest ecosystems in the western United States evolved over many millennia in response to disturbances such as wildfires. Land use and management practices have altered these ecosystems, however, including fire regimes in some areas. Forest ecosystems are especially vulnerable to postfire management practices because such practices may influence forest dynamics and aquatic systems for decades to centuries. Thus, there is an increasing need to evaluate the effect of postfire treatments from the perspective of ecosystem recovery. We examined, via the published literature and our collective experience, the ecological effects of some common postfire treatments. Based on this examination, promising postfire restoration measures include retention of large trees, rehabilitation of firelines and roads, and, in some cases, planting of native species. The following practices are generally inconsistent with efforts to restore ecosystem functions after fire: seeding exotic species, livestock grazing, placement of physical structures in and near stream channels, ground-based postfire logging, removal of large trees, and road construction. Practices that adversely affect soil integrity, persistence or recovery of native species, riparian functions, or water quality generally impede ecological recovery after fire. Although research provides a basis for evaluating the efficacy of postfire treatments, there is a continuing need to increase our understanding of the effects of such treatments within the context of societal and ecological goals for forested public lands of the western United States.*

Key Words: ecological principles, postfire treatments, restoration, salvage logging, wildland fire

Gestión Post-Incendio en Terrenos Boscosos Públicos en el Oeste de E. U. A.

Resumen: *Los ecosistemas boscosos en el oeste de Estados Unidas evolucionaron a lo largo de muchos milenios en respuesta a perturbaciones tales como incendios naturales. Sin embargo, las prácticas de uso y gestión del suelo han alterado estos ecosistemas, incluyendo los regímenes de fuego en algunas áreas. Los ecosistemas boscosos son especialmente vulnerables a las prácticas de gestión post-incendio porque tales prácticas pueden influir en la dinámica del bosque y en los sistemas acuáticos de décadas hasta siglos. Por tanto, hay una mayor necesidad de evaluar el efecto de tratamientos post-incendio desde la perspectiva de la recuperación*

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del ecosistema. Examinamos, vía la literatura publicada y nuestra experiencia colectiva, los efectos ecológicos de algunos tratamientos post-incendio comunes. Con base en esa examinación, las medidas de restauración post-incendio prometedoras incluyen la retención de árboles grandes, la rehabilitación de guardarrayas y caminos y, en algunos casos, la siembra de especies nativas. Las siguientes generalmente son inconsistentes con los esfuerzos para restaurar funciones del ecosistema después del incendio: siembra de especies exóticas, pastoreo, colocación de estructuras físicas en y cerca del canal de arroyos, tala post-incendio, remoción de árboles grandes y construcción de caminos. Las prácticas que adversamente afectan la integridad del suelo, la persistencia o recuperación de especies nativas, las funciones riparias o la calidad del agua generalmente impiden la recuperación ecológica después del incendio. Aunque la investigación proporciona una base para evaluar la eficacia de los tratamientos post-incendio, existe la necesidad de incrementar nuestro entendimiento de los efectos de dichos tratamientos en el contexto de metas sociales y ecológicas para los terrenos boscosos públicos del oeste de Estados Unidos.

Palabras Clave: incendio en terreno silvestre, principios ecológicos, restauración, tala de salvamento, tratamientos post-incendio

Introduction

Wildland fires are disturbances that occur with long recurrence intervals and generally high severity in some forest types and with shorter intervals and lower severity in others (Pyne 1984; Walstad et al. 1990; Agee 1993). For millennia, wildland fires have arguably been the most important disturbance process throughout many western forests (Hessburg & Agee 2003). Seedling germination and establishment, growth patterns, plant community composition and structure, rates of mortality, soil productivity, and other properties and processes of western forest ecosystems are often strongly influenced and shaped by fire disturbance regimes. Even so, perhaps the most controversial aspect of western land management at present is the ecology of fire and fire management.

Land and fire management practices across the western United States have profoundly affected forest, grassland, and aquatic ecosystems by fragmenting ecosystems, simplifying or destroying habitats, and modifying disturbance regimes (McIntosh et al. 1994; Keane et al. 2002; Hessburg & Agee 2003). Cumulatively, these practices have altered ecosystems to the point where local and regional extirpation of sensitive species is increasingly common (Rieman et al. 1997; Thurow et al. 1997). Consequently, the integrity of many terrestrial and aquatic systems has been severely degraded at every level of biological organization, among populations, communities, assemblages, and species (Nehlsen et al. 1991; Frissell 1993; Rieman et al. 2003).

For more than a century, wildland fires have been perceived as the major "threat" to the health of forest ecosystems, and management programs have too often ignored the interaction of human activities and altered fire regimes as a force for change in regional landscapes. For example, human perturbations often produce conditions outside the evolutionary and ecological tolerance limits of native species. In our quest as a society to control some types of forest disturbances, such as wildland fire, insects, and diseases, we have often failed to recognize the vital role these forces play in sustaining ecosystem integrity and biodiversity. In other instances, we have created additional anthropogenic disturbances (e.g., increased sediment production and altered water quality) without adequately recognizing the significance of those activities to landscapes and aquatic systems. Thus, a continuing emphasis on fire suppression and postfire salvage logging on public lands addresses symptoms rather than causes and does not acknowledge the natural dynamics and restoration needs of forest ecosystems.

We reviewed postfire management practices within the context of ecological restoration. Based on this review, we propose guidelines for postfire management aimed at maintaining or restoring the integrity of forested landscapes and their dependent freshwater systems. Only by maintaining crucial ecological processes can we expect to sustain renewable resource systems. Two general themes emerge throughout this paper: (1) native species are adapted to natural patterns and processes of disturbance that produce and maintain diverse ecosystems, and (2) reducing the negative effects of past management practices and avoiding additional impacts of future practices will promote regional recovery of biodiversity. We suggest that understanding these themes is necessary for maintaining viable populations of native species, protecting critical ecosystem functions and services, and meeting stated objectives in laws governing federal land management in the United States (e.g., the Wilderness Act, the Clean Water Act, the Threatened and Endangered Species Act, the National Forest Management Act).

Wildland Fire and Postfire Management in a Landscape Context

Scientific assessments of the current condition of forested systems in the western United States consistently yield the same broad conclusions: a century or more of road building, logging, grazing, mining, fire suppression, and water withdrawals, in conjunction with the loss of key species and the introduction of exotic species, have degraded watersheds, modified streamflows and water quality, altered ecosystem processes, and decreased biological diversity (e.g., Chamberlin et al. 1991; Furniss et al. 1991; Fleischner 1994; Terborgh et al. 1999; U.S. Department of Agriculture Forest Service 2000). Such conclusions have been documented for a variety of areas and over a wide range of scales (Leopold 1937; Henjum et al. 1994; McIntosh et al. 1994; CWWR 1996; Espinosa et al. 1997; Kessler et al. 2001). Past and present actions limit the capacity for ecosystem recovery and reduce the range and abundance of many native species (Williams & Miller 1990; Nehlsen et al. 1991; Quigley & Arbelbide 1997). Thus, forests of the western United States can be viewed as a sea of compromised or degraded ecosystems surrounding a few relatively intact "islands" (Frissell 1993). These intact areas typically retain the full complement of regionally appropriate species and the processes that sustain those species (all the "parts and processes" of healthy regional landscapes; Karr 2000).

Although postfire landscapes are often portrayed as "disasters" in human terms, from an ecological perspective they are the result of vital disturbance processes in forests. The biota of these landscapes is adapted to, and often dependent upon, the occurrence of fires having highly variable frequency (return interval), season of occurrence, size, severity, and ecological effect. Evidence of early fire is present in fossil charcoal deposits of 350–300 million years ago (Komarek 1973); some 100–165 million years later, wildfires were common (Cope & Chaloner 1985). Over time, plants (and other biota) evolved morphological, physiological, and/or reproductive characteristics—long-lived seeds stored in soil, serotinous cones, thick bark—that facilitate and may even be required for species persistence. Furthermore, species that become established early in the postfire environment influence forest dynamics for decades to centuries, through, for example, symbiotic nitrogen fixation, mycorrhizal hosts, pollination and seed dispersal, wildlife habitat, and soil protection (Kauffman 1990; Gresswell 1999).

Restoration Considerations in a Postfire Landscape

Following a wildland fire, a common assumption is that immediate actions are needed to rehabilitate or restore the "fire-damaged" landscape. Yet abundant scientific evidence suggests that commonly applied postfire treatments may compound ecological stresses. For example, soil exposure and the compaction effects of ground-based yarding equipment may substantially increase erosion following postfire salvage logging. Additionally, the removal of standing and downed large wood may eliminate important structural components for the recovery of terrestrial and aquatic systems (Swanson 1981; Trotter 1990; May & Gresswell 2003).

Perhaps the most critical step in undertaking ecological restoration in the postfire environment is to forgo those activities and land uses that either cause additional damage or prevent reestablishment of native species, ecosystem processes, or plant succession (Ebersole et al. 1996; Kauffman et al. 1997). The avoidance of degradation is far easier and more effective than trying to rehabilitate degraded lands (Hicks et al. 1991; Frissell 1993; Rhodes et al. 1994). Reducing significant human impacts to forest ecosystems often enhances system recovery and taps the natural capacities of species to reproduce and survive within the context of natural disturbance regimes, including wildland fires (Frissell et al. 1997). Thus, a crucial priority of postfire management is enhancing the capacity of burned areas to recover naturally.

While "active restoration" may be required in some postfire situations (Kauffman et al. 1997), such activities should be carefully considered and aimed at complementing natural recovery processes. Beneficial active restoration activities might include reducing sediment production from firelines and roads, replacing faulty drainage structures, and planting native species depleted by fire or previous management activities. A logical, and necessary, first step in assessing postfire management needs includes reducing or eliminating factors that degrade forest ecosystems and prevent recovery. This strategy can sometimes be difficult to implement because it often requires changing land uses in a watershed.

Another flaw in management approaches today is the tendency to use the current, altered status of many watersheds in the western United States as a baseline for assessing restoration strategies in landscapes following wildfire. This ignores the chronic or continuing effects of past management activities and may relegate aquatic systems to a permanently degraded condition.

Promoting Natural Recovery Processes

Fire and other natural disturbances in landscapes where natural biological integrity is relatively intact are not detrimental to the maintenance of diverse and productive aquatic ecosystems (Minshall et al. 1997; Gresswell 1999; Minshall et al. 2001). For example, riparian vegetation is typically quite resilient to fire and rapidly recovers following fire. In landscapes altered by decades of resource extraction or fire suppression, however, the consequences of fire for forest ecosystems may be severe. Furthermore, recovery of stream ecosystems from the effects of fire may be slower, more sporadic, and potentially incomplete in landscapes where natural processes and ecosystem structures have been degraded or impaired. Under these conditions, prefire restoration of ecosystem integrity (i.e., at the watershed scale and larger) is likely to be more effective than fire prevention or postfire attempts at protection and rehabilitation of the stream channel (Gresswell 1999).

Postfire treatments such as seeding of exotic species, livestock grazing, or salvage logging can alter succession and delay restoration by removing elements of recovery or by accentuating damage to soil and water resources. Instead, management priorities should aim at the prevention or minimization of activities that increase stress upon surviving native biota, disrupt the establishment of early seral native species, or alter microclimates. Postfire treatments should be implemented only when they are needed to facilitate ecosystem recovery and do not interfere with natural succession or to reduce human disruptions of natural ecosystem processes. For example, natural recovery could be augmented by rehabilitation of areas disturbed by fire-suppression activities or other management practices (e.g., dozed firelines, roads). In other instances, planting of conifers may be needed where seed sources of native species have been lost by fire.

Protecting Soils

Fire intensities and patterns of fuel consumption vary across landscapes with weather, topography, and differences in fuel loads and condition; all these factors also influence the effect of fire on soils. With a moderate- to high-severity fire, litter and duff are consumed, and the soil surface experiences high temperatures. Over a 25-year period (1973–1998), burned-area reports for western forests indicate that moderate- and high-severity categories account for about one-half of the total burned area (Robichaud et al. 2000). Burned area varies substantially from decade to decade (Fig. 1).

To protect aquatic ecosystems in areas with moderate- to high-severity burns, postfire management should not increase soil erosion or reduce soil productivity. For example, use of ground-based logging equipment will cause additional site disturbance and soil compaction. Decreased infiltration, increased overland flow, and accelerated sedimentation following ground-based logging not only degrade forest soils (Kattleman 1996; McIver & Starr 2000, 2001) but can also affect aquatic systems, including reduced survival of salmonids and other aquatic species (Young et al. 1991; Rhodes et al. 1994; Quigley & Arbelbide 1997). Furthermore, onsite impacts to early successional native plant species during postfire logging, where such species are nitrogen fixers, can significantly affect a major pathway of nutrient replenishment in the postfire environment.

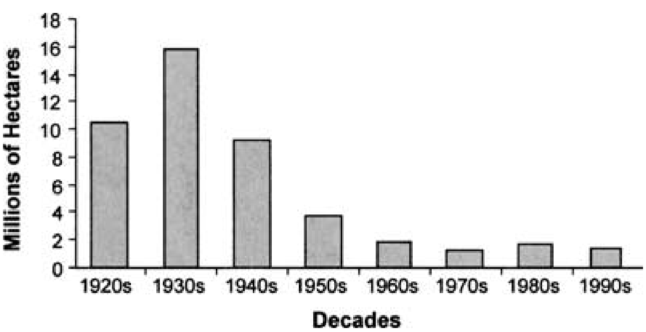

Figure 1. Area burned annually, by decade (1920–2000), for U.S. federal agencies (1994–2001) (U.S. Department of Agriculture Forest Service Annual Fire Statistics).

After fire, some soils may exhibit a water-repellant (hydrophobic) condition that reduces the infiltration of water (DeBano et al. 1998). Although these changes can significantly alter the hydrologic properties of forest soils, the magnitude of change varies with soil texture and organic-matter content, vegetation, and fire behavior. Water-repellant soils mainly develop on sites that experience moderate- or high-severity burns with coarse-textured soils and certain vegetation, such as waxy-leaved shrublands and woodlands (Wells et al. 1979; Debano et al. 1998).

Water-repellant soils occur naturally in the absence of fire (Kattleman 1996), and fire does not always cause hydrophobic conditions. Although comprehensive studies on water repellency following fire are uncommon, generally water-repellant conditions are spatially variable and diminish as vegetation and soils recover (Robichaud et al. 2000; Huffman et al. 2001; Letey 2001). If organic matter on the soil surface remains intact following a burn, the occurrence of hydrophobic soils and associated effects on erosion and runoff are greatly reduced.

Some researchers (McIver & Starr 2000) suggest that benefits can be derived from the mechanical disturbance of hydrophobic soils by postfire logging, whereby disruption of hydrophobic soil surfaces increases infiltration and reduces overland flow, peakflow, and sediment production to streams. For several reasons, such an approach would have far more persistent negative effects on soils, watersheds, and aquatic resources than would allowing soils to recover naturally. For example, soil disturbance during ground-based logging that is severe enough to "mix" or break through soil layers would also cause significant compaction, contributing to accelerated surface erosion and long-term reductions in soil productivity. Although cable-logging systems typically cause less compaction than ground-based systems, dragging logs across burned terrain without full suspension can still damage soils. Because salvage logging often occurs a year or more after a fire, and because water-repellant conditions usually last only a few years, at most, water-repellant soils may no longer exist by the time logging occurs, if they ever did. Finally, water-repellent soils can occur in the absence of fire, so the intensity and location of hydrophobic soils is generally not determined in postfire assessments (Robichaud et al. 2000).

Evidence continues to mount of a direct relationship between mechanical disturbance to the postfire environment and accelerated erosion (Kattleman 1996; McIver & Starr 2000, 2001). Soil compaction can persist for 50–80 years in many forest soils (Quigley & Arbelbide 1997) and even longer in areas with high clay content, which is substantially longer than the negative influence on soils that may be associated with fire (U.S. Department of Agriculture Forest Service & BLM 1997).

Because soils and soil productivity are irreplaceable in human time scales, postfire management practices that compact soils, reduce soil productivity, or accelerate erosion should not be undertaken or allowed to continue. The recovery of organic matter in soils, which is essential to the recovery of soil productivity in areas with moderate- to high-severity burns, can be accomplished efficiently and inexpensively by leaving burned areas undisturbed (Kattleman 1996; Quigley & Arbelbide 1997). Although postfire treatments are often undertaken in an attempt to reduce soil erosion and impacts to water quality, prefire management practices—prescribed fire, obliteration of problem roads, removal of exotic species, reduced grazing pressure—may have an even larger payoff at both local and landscape scales.

Changing Postfire Practices

Dramatic changes are needed in forest management practices and policies that relate to land use and fire management in the western United States. Management with short- and long-term ecological goals should reduce human impacts to ecosystems and allow natural disturbance regimes to retain or reestablish some of their historical influence in maintaining the diversity and productivity of regional landscapes. Instead of focusing on the immediate effects of a given fire, land managers might more fruitfully direct their attention to historical and on-going land uses and policies, including the loss of natural disturbance regimes (i.e., fire exclusion).

Rehabilitating Sites Disturbed by Fire Suppression

The postfire environment is a reflection of not only the conditions that influence the spread and intensity of fire but also the magnitude of suppression efforts. For some fires, hundreds of kilometers of firelines may be constructed. Whether built by hand or machinery, these firelines involve soil disturbance and the removal of vegetation and litter. This can increase surface runoff, erosion, and sediment delivery to streams and facilitate the invasion of noxious weeds (Kattleman 1996). Firelines constructed by bulldozers are of greatest concern because of their width (up to 15 m) and the severity of soil disturbance and compaction. Firelines in riparian areas contribute to aquatic degradation by reducing recruitment of large wood, bank stability, and stream shading, and they increase sediment delivery to streams. Although handlines are typically narrower and involve less severe impacts than bulldozer lines, negative effects can be substantial, especially in areas that are highly susceptible to erosion.

Fireline locations cause additional ecological concerns. Although this issue has received increased attention in recent years, firelines continue to be constructed in riparian areas and down the fall line of steep slopes when deemed necessary by fire managers. Unfortunately, little can be done to remedy adverse effects if firelines are constructed in areas prone to erosion. Although less significant than firelines at the watershed scale, fire camps can sometimes result in local soil damage. Furthermore, water-drafting sites can damage soils near streams and disrupt channel banks.

As Kattleman (1996) has suggested, the principal objectives of postfire rehabilitation efforts should be to avoid additional damage, repair potential problems from fire-suppression activities (e.g., firelines and fire camps), and enhance the reestablishment of native vegetation to provide soil cover and organic matter. Consequently, highly disturbed sites should be rehabilitated (e.g., through water bars and seeding with native species) immediately following fires. It should be recognized, however, that such treatments may not eliminate persistent effects from areas that are prone to erosion or that have been severely affected.

Banning Introduction of Exotic Species

The rationale for seeding burned areas with non-native grasses includes reducing onsite erosion, decreasing sediment runoff into streams, reducing noxious weed invasions, and increasing the availability of forage for grazing animals (Barro & Conard 1987, Sexton 1998, Robichaud et al. 2000). Although the efficacy of seeding for accomplishing these objectives has not been well evaluated, results of studies show that seeding grasses in burned ecosystems can lead to long-term changes in ecosystem composition and structure (Nadkarni & Odion 1986; Barro & Conard 1987). Comparing seeded burned areas to those that were not burned or seeded, Sexton (1998) found no differences in total herbaceous cover but did quantify a significantly greater cover of exotic grasses and a lower cover of native flora in seeded areas. Furthermore, rates of growth and survival of shrubs and conifer seedlings were reduced in areas seeded following fire (Amaranthus et al. 1993; Sexton 1998). Establishing a dense cover of seeded grasses, which decreases survival of woody plant seedlings, may cause long-term diminution of many important functional roles of species that shape ecosystem structure and productivity, roles including nitrogen accumulation, alternative hosts to mycorrhizal fungi, wildlife habitat, and erosion control.

Established exotic grasses can increase the flammability of burned sites; thus, reburns through these sites can have severe ecological consequences (Zedler et al. 1983). Furthermore, a dense stand of exotic grasses will increase the likelihood of a reburn because (1) there is a continuous fuel bed with a high surface-to-volume ratio that is conducive to rapid rates of fire spread, (2) annual foliage dies and moisture content is low by late summer, and (3) fine fuels such as dried grasses and grass litter are more susceptible to ignition (Barro & Conard 1987).

Grass seeding has a low probability of reducing postfire erosion in the first season of erosion because any benefits of grass cover occur after the initial damaging runoff events (Barro & Conard 1987; Amaranthus 1989). In reviews of grass seeding and postfire erosion, Barro and Conard (1987), Kattleman (1996), and Raubichaud et al. (2000) could not find a significant relationship between establishment of grass cover and reduction in erosion in the years following wildland fire. Furthermore, they note the potential for grass seeding to exacerbate long-term erosion rates. Even so, seeding remains a widely used postfire rehabilitation activity, considered a panacea by many.

From an ecological perspective, seeding or planting should be avoided unless the prefire landscape has been severely degraded or dominated by alien or nonindigenous species. When species introductions are initiated, only species and seed sources native to the site should be utilized.

Curtailing Livestock Grazing

Livestock grazing, as practiced throughout much of the western United States, significantly damages soils, elevates erosion, thwarts vegetative recovery, contributes to invasions of exotic species, and degrades stream and riparian conditions (Platts 1991; Fleischner 1994; Belsky et al. 1999). Consequently, this land use has been a major contributor to declines in native salmonids across western states (Rhodes et al. 1994; CWWR 1996; NRC 1996, 2002). Furthermore, postfire livestock grazing is widely recognized as an inhibitor of soil recovery and plant succession following fire, delaying the recovery of burned areas. Thus, livestock grazing should not occur in burned areas, particularly riparian areas, until vegetation recovery has occurred.

Avoiding Use of Structures in and Near Stream Channels

The installation of structures such as sediment traps, wood additions, bank stabilizations, weirs, check dams, and gabions in and along streams often occurs in conjunction with postfire recovery activities. The cost of these structures, combined with their limited functional utility and short lifetimes, limits their value, especially in streams with elevated sediment and flow (Frissell & Nawa 1992). Instream structures often interfere with important interactions among sediment flux, channel form, and erosion (Frissell & Nawa 1992; Thompson 2002), thus negatively affecting the maintenance and diversity of aquatic habitats (Schmetterling et al. 2001). Managers should not assume that these structures mitigate the negative effects of other postfire management practices (e.g., road construction, postfire logging) that might accelerate sediment delivery to streams.

Restricting Postfire Logging

In the past, logging of fire-affected forest stands often occurred with little consideration of potential ecological consequences. However, postfire salvage logging inherently involves the removal of large trees that play important roles in numerous biological and physical processes and provide habitat for a variety of species (Thomas 1970; Harmon et al. 1986; Perry et al. 1989; Rose et al. 2001). In Oregon and Washington, for example, at least 96 wildlife species are associated with snags in forests. Most use snags >36 cm diameter at breast height (dbh); about one-third use snags >74 cm dbh. Hollow trees >51 cm dbh are often the most valuable for animal shelter, roosting, and hunting (Rose et al. 2001). Salvage logging may be especially detrimental in those watersheds where only a few large trees or snags remain following fire.

Large wood has multiple roles in the ecological recovery of disturbed aquatic ecosystems. Salvage logging conducted in or near riparian zones or streams diminishes the source of large wood important for stream structure and function (Maser et al. 1988; McMahon & deCalesta 1990; Hauer et al. 1999). Postfire wood inputs are important in creating physical habitat, recycling nutrients, and providing structural components during stream and riparian recovery (Minshall et al. 1989; Lawrence & Minshall 1994; Benda et al. 2003). Damaging effects from postfire logging in riparian areas can persist for many decades because of the loss of dead trees that would normally become incorporated into stream channels and forest floors over several decades or more (Lyon 1984; May & Gresswell 2003). Similarly, logging large trees from upslope areas that are prone to landslides would also reduce, over time, the recruitment of large wood to riparian and aquatic ecosystems.

Based on the need to preserve important ecological functions associated with trees and large wood following fire, Beschta et al. (1995) recommend that salvage logging should leave at least 50% of standing dead trees in each diameter class. They also indicate that proportional retention is needed because of the important graded inputs that a mix of large wood contributes to streams over the extended postfire recovery period (Lyon 1984; Minshall et al. 1989). Furthermore, R.L.B. et al. (unpublished report) recommend no harvest of live trees within burn perimeters or of dead trees >51 cm dbh or older than 150 years. Henjum et al. (1994) similarly recommended retention of trees >51 cm dbh or >150 years old and cessation of logging in late-successional forests. These recommendations emphasize the importance of retaining the oldest and largest trees, both live and dead, in postfire environments.

Postfire salvage logging has sometimes been justified on the assumption that >50% crown scorch results in tree mortality. However, trees within low- and mid-elevation forests of the western United States possess a suite of adaptations that facilitate fire survival (Kauffman 1990). Stephens and Finney (2000) found that the probability of conifer mortality is low when the percentage of the crown scorch was <60%. For trees ≥50 cm dbh, they determined that the probability of mortality of ponderosa pine, incense cedar, and white fir was <40% when crown scorch was as high as 80%. The multiple ecological roles of large trees and their high probability of survival supports the need to retain them in burned areas.

Postfire salvage logging, based primarily on economic values, typically removes only the largest trees and, by reducing total fuel loads, can supposedly reduce the severity of a subsequent fire. The principal fuels that carry wildland fire are not large trees, however, but finer fuels such as grasses, shrubs, and tree foliage. With regard to future fires, perhaps a more important concern of postfire logging is its influence on fuel composition, particle-size distribution, and site microclimate (i.e., creating warmer, drier, and windier conditions; Sexton 1998). The harvest of green trees increases fine fuels (activity fuels) even though the mass of large wood has decreased (Brown 1980). If similar shifts in fuel composition (and loads) occur on salvage logged sites, they could increase the potential future fire intensity and rate of spread of these sites over the short term. Few, if any, studies have quantified the effects of salvage logging on fuel loads (McIver & Starr 2000).

Postfire salvage logging also affects plant species composition and forest succession through changes in microclimate and mechanical damage to regenerating plants and soils. Even where salvage logging occurred in winter over approximately 60 cm of snow, logged areas had significantly lower understory biomass, species richness, species diversity, growth, and survival of both tree and shrub species (Stuart et al. 1993; Sexton 1998). Such logging can also have detrimental effects on the microhabitats of organisms associated with recovery (e.g., soil microbes) (Borchers & Perry 1990) and early successional vegetation.

Both ground-based yarding systems (tractors and skidders) and, to a lesser degree, cable systems can cause significant soil disturbance and compaction. Such practices should be prohibited in burned areas whenever they are likely to accelerate onsite erosion. Logging may be suitable where accelerated soil erosion and increased soil compaction are unlikely to occur and where there will be no impairment of hydrologic and soil biological integrity. Helicopter logging and cable yarding systems (particularly those providing partial or full suspension) that use existing roads and landings also may be appropriate in some areas because they produce smaller impacts on surface runoff and sediment production. Salvage logging generally should be prohibited on sensitive sites, however, including riparian areas, moderately or severely burned areas, fragile soils, steep slopes, roadless areas, watersheds where sedimentation is already a problem, where significant impacts to early successional vegetation may occur, and sites where accelerated surface erosion or accelerated mass soil erosion are likely to occur.

Prohibiting New Road Construction

In the western United States, roads represent a persistent cause of watershed degradation (U.S. Department of Agriculture Forest Service 1993, 2000; Henjum et al. 1994) and a major cause of the reduced abundance and range of native salmonids (Quigley & Arbelbide 1997; Kessler et al. 2001). Accelerated short- and long-term sediment production from roads is of particular concern in most watersheds because it exacerbates the effects of severe fires on soils, aquatic habitats, and water quality (CWWR 1996; U.S. Department of Agriculture Forest Service 2000).

Accelerated surface erosion from roads is typically greatest within the first years following construction, although in most situations sediment production remains elevated over the life of a road (Furniss et al. 1991; Ketcheson & Megahan 1996). Thus, even "temporary" roads can have enduring effects on aquatic systems. Similarly, major reconstruction of unused roads can increase erosion for several years and potentially reverse reductions in sediment yields that occurred with disuse (Potyondy et al. 1991). Where roads are unpaved or insufficiently surfaced with erosion-resistant aggregate, sediment production typically increases with increased vehicular usage (Reid & Dunne 1984).

Elevated sedimentation can adversely affect aquatic biota (Young et al. 1991) and inhibit pool development (Quigley & Arbelbide 1997; Buffington et al. 2002). In depositional environments, elevated sedimentation can widen channels (Dose & Roper 1994). Either of these situations—shallower or wider channels—can contribute to increased water-temperature maxima (Bartholow 2000).

It is perhaps widely accepted that "best management practices" (BMPs) can reduce damage to aquatic environments from roads. Time trends in aquatic habitat indicators indicate, however, that BMPs fail to protect salmonid habitats from cumulative degradation by roads and logging (Espinosa et al. 1997). Ziemer and Lisle (1993) note a lack of reliable data showing that BMPs are cumulatively effective in protecting aquatic resources from damage. Although the location, design, construction, and maintenance of roads may have improved over the years, many tens of thousands of kilometers of roads remain on public

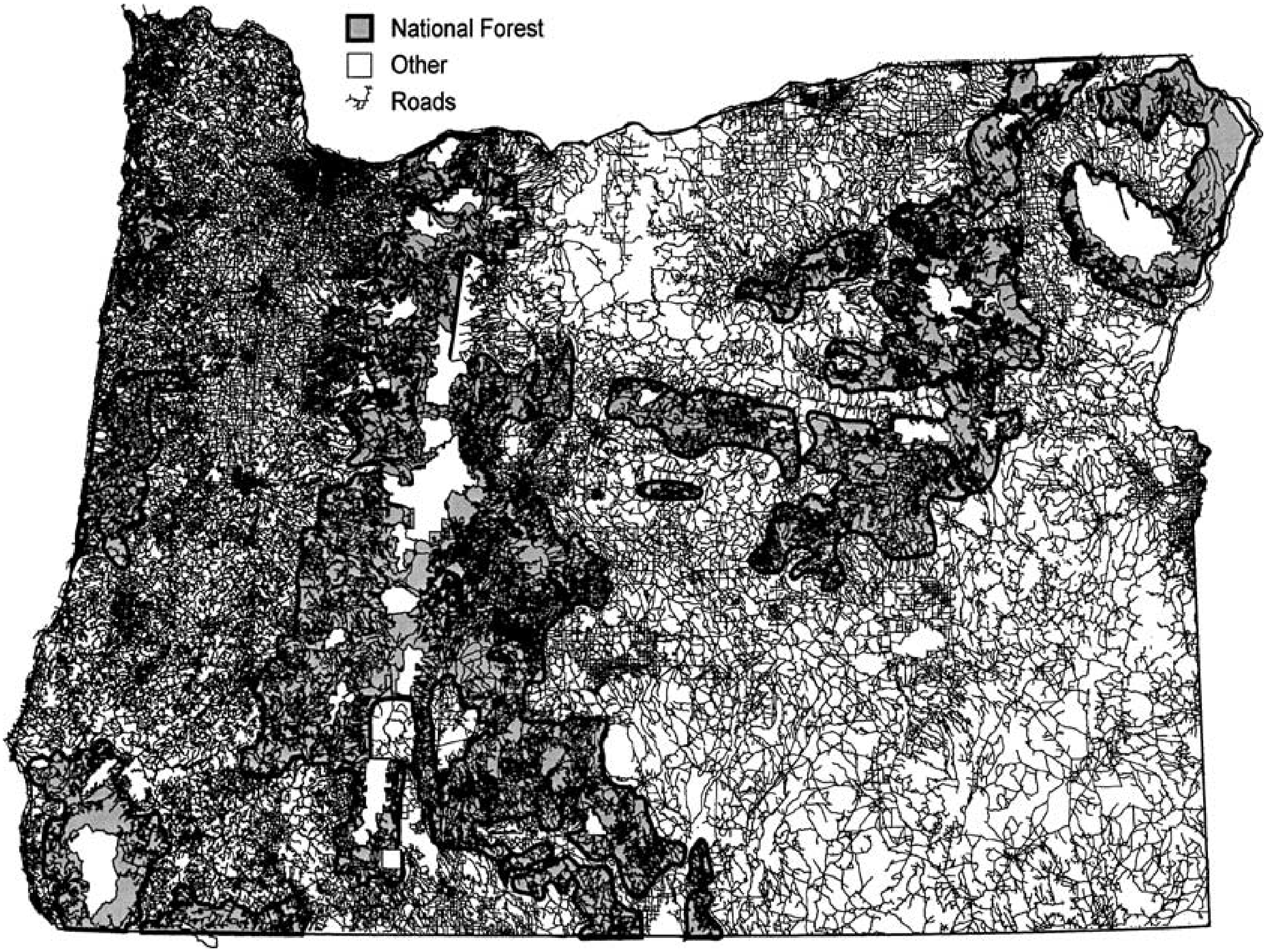

Figure 2. Road densities on public lands managed by the U.S. Department of Agriculture Forest Service and other lands in Oregon (source: Oregon Natural Resources Council, Portland).

and private lands that were constructed with relatively little concern for their environmental consequences (Fig. 2). Until problem "legacy roads" are improved (e.g., surfaced, stabilized, obliterated), they will continue to degrade water quality and aquatic systems for many years. Furthermore, the assumption that road obliteration or BMPs will offset the negative impacts of new road and landing construction and use is unsound because road construction has immediate negative impacts and the benefits of obliteration accrue slowly.

Finally, road and landing construction is expensive and can siphon limited funds away from effective restoration measures, such as obliteration and maintenance. The backlog in maintenance of U.S Forest Service roads has been estimated to be several billion dollars (U.S. Department of Agriculture Forest Service 2000), and road construction inevitably adds to this seemingly insurmountable backlog. For these reasons, the construction and reconstruction of roads and landings is not consistent with postfire ecosystem restoration.

Research Needs: Social, Ecological, and Economic Issues

In recent years, fire suppression costs for U.S. federal agencies have averaged in excess of $500 million annually. Given expenditures of this magnitude and the desire by land-management agencies to capture economic benefits from burned areas via salvage logging, the need increases for research to answer a wide range of questions to guide postfire management decisions. Of particular importance is a need to address the consequences—social, ecological, and economic—of various postfire treatments. For example, few studies have rigorously addressed the short- and long-term ecological effects of systematically dispensing nonindigenous species across burned landscapes. Similarly, there is limited scientific literature quantifying changes in sediment yield following postfire salvage logging. A wide range of postfire treatments is often implemented following fire to reduce erosion and runoff, but their effectiveness remains largely unknown

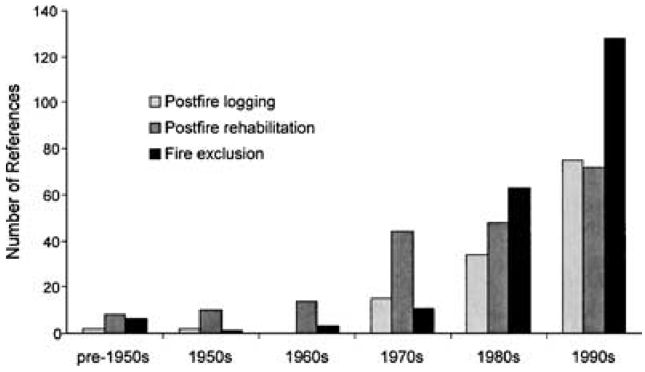

Figure 3. Frequency distribution of publication dates for fire-related publications, by decade, from three literature reviews: postfire logging (McIver & Star 2000), postfire rehabilitation (Robichaud et al. 2000), and fire exclusion (Keane et al. 2002).

(Robichaud et al. 2000), and rigorous research is scarce. Similarly, relatively few large areas have been allowed to recover without major intervention after fire, limiting the availability of "control" areas in ecological research. This is a particularly acute need in low-elevation ponderosa pine forests. Although research productivity on diverse fire and postfire issues (Fig. 3) has increased in recent years, the complexity and controversy surrounding many of these issues indicates the need for carefully focused research programs. We strongly encourage public land-management agencies to significantly invest in interdisciplinary research that directly addresses important issues and concerns associated with wildland fire, postfire salvage logging, and other postfire treatments. Until additional research provides different information, an ecologically based approach to postfire restoration is in order.

Conclusions

Based on our review of the research and from the perspective of ecosystem restoration, several promising approaches to postfire management exist, including full protection of soils, road and fireline restoration, retention of large trees, and nurture of natural recovery processes. Some of these approaches are likely to be even more effective if undertaken proactively before a fire. Conversely, available information indicates that the following postfire activities are not likely to be consistent with ecosystem restoration: seeding non-native species, livestock grazing, installation of instream structures, ground-based logging and soil disruption, removal of large trees, road and landing construction, and logging of ecologically sensitive areas including roadless areas, riparian areas, and areas with moderate to severe burns. Postfire land-use decisions obviously occur in a very challenging environment for the general public and for managers of the nation's public lands. Although we understand the need and desire for society to obtain products of economic value from forested landscapes, the current body of research indicates that the loss of ecosystem services that can result from postfire treatments is significant.

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