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Forest Ecology and Management 178 (2003) 197–211
Forest Ecology and Management
www.elsevier.com/locate/foreco

Status of native fishes in the western United States and issues for fire and fuels management

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Abstract

Conservation of native fishes and changing patterns in wildfire and fuels are defining challenges for managers of forested landscapes in the western United States. Many species and populations of native fishes have declined in recorded history and some now occur as isolated remnants of what once were larger more complex systems. Land management activities have been viewed as one cause of this problem. Fires also can have substantial effects on streams and riparian systems and may threaten the persistence of some populations of fish, particularly those that are small and isolated. Despite that, major new efforts to actively manage fires and fuels in forests throughout the region may be perceived as a threat rather than a benefit to conservation of native fishes and their habitats. The management of terrestrial and aquatic resources has often been contentious, divided among a variety of agencies with different goals and mandates. Management of forests, for example, has generally been viewed as an impact on aquatic systems. Implementation of the management-regulatory process has reinforced a uniform approach to mitigate the threats to aquatic species and habitats that may be influenced by management activities. The problems and opportunities, however, are not the same across the landscapes of interest. Attempts to streamline the regulatory process often search for generalized solutions that may oversimplify the complexity of natural systems. Significant questions regarding the influence of fire on aquatic ecosystems, changing fire regimes, and the effects of fire-related management remain unresolved and contribute to the uncertainty. We argue that management of forests and fishes can be viewed as part of the same problem, that of conservation and restoration of the natural processes that create diverse and productive ecosystems. We suggest that progress toward more integrated management of forests and native fishes will require at least three steps: (1) better integration and development of a common conceptual foundation and ecological goals; (2) attention to landscape and ecological context; and (3) recognition of uncertainty.
Published by Elsevier Science B.V.

Keywords: Wildfire; Fire and fuels management; Native fish; Conservation; Restoration

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0378-1127/03/$ – see front matter. Published by Elsevier Science B.V.
doi:10.1016/S0378-1127(03)00062-8

1. Introduction

Managers of public lands in the western United States face a difficult challenge in restoration and protection of native fishes and their habitats, while simultaneously attempting to develop and implement an effective landscape strategy for management of wildland fire. Native fishes now represent some of the most imperiled biological taxa in North America (Ricciardi and Rasmussen, 1999). In the western US, a growing number of fishes are listed or petitioned for listing under the Endangered Species Act (ESA), or are considered sensitive or of special concern by the agencies responsible for their management. Local and regional extinctions of native fish have occurred over the past century (Frissell, 1993; Lee et al., 1997), and many populations are restricted to small and often isolated remnants of a much larger and more continuous historical range (Moyle and Williams, 1990; Minckley and Deacon, 1991; Young, 1995; Lee et al., 1997). Remnant population networks and many of the remaining strongholds for native species are often found on public lands that now are key to the conservation of these species (Lee et al., 1997). In response, federal agencies have undertaken major assessments of aquatic ecosystems, habitats, species, and the processes that influence them (e.g. FEMAT, 1993; Quigley and Arbelbide, 1997), and proposed major initiatives to recognize, restore, and conserve sensitive populations and critical habitats (USDA, 1995; USDA/USDI, 1995, 2000; NMFS, 2000; NWPPC, 2000).

The rising concern for aquatic systems parallels an emerging dialogue on the management of forests. Decades of fire suppression, grazing, and selective silvicultural and timber-harvest practices have led to changes in the structure and composition of some forest types in the western US (Franklin, 1993; Veblen et al., 1994; Hessburg et al., 1999; Hessburg and Agee, this issue). Change is most apparent in the drier mid- and low-elevation forests where fires once burned more frequently (e.g. 10–100 years), but generally were not stand replacing (Covington et al., 1997; Everett et al., 2000; Hessburg and Agee, this issue). Such change is not apparent in other forest types or in all mid- and low-elevation forests (Romme and Knight, 1981; Veblen et al., 1994, 2000; Arno, 2000). Even so, Hessburg and Agee (this issue) and others (Hann et al., 1998; USDA, 2000) argue that the changes that have occurred may produce an unprecedented continuity of fuels and could lead to larger and more destructive fires than observed in the recent past.

It also has been suggested that such fires are catastrophic from both socio-economic and ecological perspectives (see http://www.whitehouse.gov/infocus/healthyforests/sect5.html). Recent large fires in the western US have seemingly underscored these predictions and galvanized a political and agency will to respond. The National Fire Plan (NFP) (Laverty and Williams, 2000; USDA, 2000), other local or regional initiatives, and funds allocated by Congress have focused resources to reduce and manage fuels and large fires, rehabilitate burned areas, and restore fire to a more natural role. One objective of the NFP is the maintenance of clean water and biological diversity in fire-prone ecosystems. An important assumption is that mitigation of changing fire patterns will directly benefit watersheds and habitats for sensitive species. As we discuss later this assumption may hold in some contexts, but not others. Clearly, past management activities contributed to the disruption and degradation of watersheds and habitats for fishes (Lee et al., 1997). Aggressive fuels treatments that mimic past land management activities (e.g. timber-harvest) could simply exacerbate the problem.

In this paper, we argue for finding common ground in the management of native fishes and forests. Ecosystem management concepts underscore interconnections among systems and reinforce the notion that maintenance of diverse and resilient ecosystems should be the primary constraint on management of all resources (Attiwill, 1994; ESA, 1995; Haynes et al., 1996). Given that forest structure and composition, and the natural processes that influence them, also influence the creation and maintenance of productive aquatic habitats and populations (Naiman et al., 1992; Reeves et al., 1995; Franklin et al., 2001; Helfield and Naiman, 2001), management for wildland fire objectives cannot be isolated from the management of native fishes, or vice versa. Broader recognition of the common issues and linkages between forests, fires, and the management of terrestrial and aquatic ecosystems could provide a foundation for progress.

Other papers in this issue provide a context for the changing patterns and management of fire and fuels (Hessburg and Agee, this issue; Whitlock et al., this issue) and the role of fire-related disturbance in structuring stream channels and habitats (Benda et al., this issue; Meyer and Pierce, this issue; Miller et al., this issue). Dunham et al. (this issue) consider the biological response of fish and fish populations to disturbance that may result from fire. In this paper, we outline the issues confronting managers of aquatic systems and fishes in particular as they begin to explore these ideas. We focus on fishes and aquatic ecosystems associated with the forested landscapes managed primarily by the US Forest Service and agencies in the US Department of Interior. These are systems most likely to be affected by changes in fire and fuels management. We begin by outlining the nature of the fish communities in the west, their status, and the juxtaposition of degraded aquatic systems with a terrestrial system equally out of balance. We then consider regulatory issues that arise as managers struggle to conserve native fishes, restore fish habitats, and implement new management related to fire, and we outline alternative views about the effects of fire on fishes and aquatic ecosystems. Finally, we conclude by examining three challenges that we believe must be addressed to move forward with a more integrated and effective management of terrestrial and aquatic ecosystems influenced by fire.

2. Native fishes and fire in the west

2.1. Status of native fishes

The western US contains a diverse array of aquatic habitats, ranging from large coastal rivers of the temperate rainforests in the Pacific Northwest, to the isolated, and sometimes ephemeral, streams of the arid interior basins, to the high-elevation streams and lakes in the mountains. Historically, fishes occurred throughout these habitats with the exception of inaccessible high-elevation lakes that were not colonized following the most recent glaciation (Smith, 1981; Bahls, 1992; Hauer et al., 1997). Despite the dramatic physical diversity and the relatively large area of habitats in some basins, the streams and rivers of this region support relatively few fish taxa when compared to aquatic systems of the eastern US. For example, the Mississippi River basin supports between 230 and 300 species of fishes (Cross et al., 1986; Sheldon, 1988), but there are fewer than 70 native species found within the major western river basins such as the Columbia, Rio Grande, Colorado, and the Sacramento-San Joaquin (Sheldon, 1988; Moyle and Williams, 1990; Lee et al., 1997).

Typical of systems elsewhere, much of the diversity within these western river basins is found in the large, low-elevation rivers and estuaries. In contrast, much simpler communities are found in the tributaries at higher elevations. This has been attributed to more dynamic, extreme, and less productive environments that support a limited set of species, or have had limited time for speciation and colonization (Smith, 1981; Sheldon, 1988; Lee et al., 1997; Reeves et al., 1998). Salmon and trout *Oncorhynchus* spp., whitefish *Prosopium* spp., sculpins *Cottus* spp., suckers *Catostomus* spp., and minnows (Cyprinidae) are, or once were, the dominant native forms. In the Pacific Northwest, lampreys (Petromyzontidae), and chars (*Salvelinus* spp.) were also important.

Although species diversity is low in western river basins, intraspecific diversity is often high. For example, the salmonids can display remarkable variation in life histories and ecotypes (Willson, 1997). This is particularly evident in the coastal rivers (Reimers, 1973), and the larger interconnected streams, rivers, and lakes of the interior west where a variety of migratory life histories may occur (Varley and Gresswell, 1988; Northcote, 1997). Intraspecific diversity probably arises through phenotypic plasticity and genetically based local adaptation to the broad spatial and temporal variation in stream environments (Gresswell et al., 1994; Reeves et al., 1998; Dunham et al., this issue). Furthermore, that diversity may influence the resilience, productivity, and persistence of populations faced with disturbance and environmental change (Healey, 1991; Rieman and Clayton, 1997; Rieman and Dunham, 2000; Dunham et al., this issue).

In much of the western US native fishes have faired poorly in the last 100–150 years. Over half of the native taxa in the region are listed or being considered for listing under the ESA, or are deemed sensitive by the US Forest Service on the lands they manage. In the Pacific Northwest, bull trout *Salvelinus confluentus*, occur at levels similar to historical populations in less than 5% of their potential range (Rieman et al., 1997). Many populations of anadromous salmonids, once a defining feature for many of the aquatic communities in the region, are threatened with extinction (Nehlsen et al., 1991; Thurow et al., 1997). In California, Moyle and Williams (1990) reported that 44% of the native species in the Klamath province were declining or existed in limited distributions. Of the 40 fishes native to the Sierra Nevada, only 18 (45%) are reported to have stable or expanding populations (Moyle et al., 1996). In the interior west, three subspecies of the once-common and widely diverse cutthroat trout *O. clarki* spp., are extinct, four are federally listed, and six have been petitioned for listing (Behnke, 1992; USFWS, 1995, 1998). All of the extant cutthroat trout taxa are considered sensitive by state and federal resource agencies. In most instances the status of non-trout species is unknown (but see Kaya, 1992 concerning Arctic grayling *Thymallus arcticus* in Montana). In the southwest, where the native fish fauna is dominated by cyprinids and catostomids (Minckley, 1973), more than 80% of native fish species are federally listed as threatened or endangered. All of the identified native species in the Colorado River basin in California are now extinct or listed (Moyle and Williams, 1990). The Apache trout *O. apache* and Gila trout *O. gilae* now occur in less than 5% of their historical range (Rinne, 1985).

The decline of fishes and their habitats can be traced to a variety of factors that are common in the region. These include dams and water diversions for irrigation and municipal use; sediment, heavy metal pollution and stream destruction associated with mining; land management activities including grazing, road construction, and timber-harvest; loss of riparian vegetation through land conversion; sport and commercial fishing; and the introduction of non-native fishes (Gresswell, 1988; Moyle and Williams, 1990; Moyle et al., 1996; Hall et al., 1997; Lee et al., 1997; Rahel, 2000; Trombulka and Frissell, 2000; Post et al., 2002; Young et al., 2002; Rinne, in press). The pattern of degradation in aquatic habitats and communities closely parallels human settlement and land use. The most altered systems are commonly at mid- and low-elevations where agriculture and urbanization predominate. The most pronounced impacts at higher elevations are in watersheds that have been intensively logged or grazed, and streams that have been influenced by dams, diversions, or mining. Road density, a primary index of human development, is one of the strongest negative correlates of the status of native fishes throughout the Columbia River basin (Lee et al., 1997). Roads may contribute sediment and other potential pollutants, create barriers to movement, and provide access for the introduction of non-native species and diseases and fishing. Both empirical and anecdotal evidence suggest that remoteness is positively correlated with the condition of aquatic habitats and species (e.g. Lee et al., 1997).

Efforts to conserve aquatic biological diversity and the remnant populations of sensitive, threatened and endangered fishes have been implemented throughout the region. These include the development of management plans and conservation agreements with more restrictive standards for land disturbing activities and water quality, active restoration and rehabilitation of habitats, and the artificial propagation and reintroduction of native species. Despite widespread efforts, progress has been limited and some species, subspecies, or populations continue to decline (Minckley and Deacon, 1991; Nehlsen et al., 1991; Young and Harig, 2001).

For restoration to succeed it may be necessary to address more than the local conditions of habitats and individual populations. The geometry and interconnection of habitats may be particularly important to the dynamics, productivity and persistence of many populations (Rieman and Dunham, 2000; Dunham et al., this issue). Declines in anadromous salmonids associated with dams and other changes in the Pacific Northwest have reduced the influx of nutrients to streams (Gresh et al., 2001), which may further constrain the survival and resilience of remnant populations (Zabel and Williams, 2002) and have cascading effects on whole communities and ecosystems (Willson and Halupka, 1995; Gresh et al., 2001; Helfield and Naiman, 2001). In the interior west, and southwest in particular, trout populations now are characterized by (1) the almost-complete absence of large-bodied fish associated with migratory life histories (i.e. those that move between larger streams suitable for sustained growth and higher, colder spawning and rearing habitats in the tributaries) and (2) physical or biological isolation in small, high-elevation, unproductive waters. The loss of productivity and diversity linked to migratory life histories and the fragmentation and isolation of populations increases the threat of extinction (Rinne, 1982; Rieman and Dunham, 2000; Kruse et al., 2001; Dunham et al., this issue). Regardless of the quality of local habitats, populations that are small and isolated are vulnerable.

2.2. Challenges and opportunities for improvement

Conservation and restoration of native fishes will be a challenge. It is not hopeless; most native species and taxa persist, albeit in fewer and smaller populations. The status of populations and habitats, however, varies substantially across the region; those differences dictate both the issues and opportunities for conservation management. In parts of the interior Columbia River basin and coastal systems of the Pacific Northwest, for example, large interconnected networks of stream habitats remain. Some species (e.g. bull trout), although depressed, still occur across the majority of their historical range (Rieman et al., 1997). Populations of bull trout, cutthroat trout, steelhead, *O. mykiss*, and salmon in some basins still migrate to and through large rivers, lakes, and the ocean. In other basins reconnection of larger networks of habitat is still possible (Lee et al., 1997). Many of these populations will persist and could even flourish if the constraints on important habitat forming and biological processes are addressed (e.g. Beechie and Bolton, 1999; Roni et al., 2002).

By contrast, in some watersheds in the Pacific Northwest and throughout much of the interior west and southwest, habitat loss and fragmentation is pronounced and some watersheds and aquatic communities may be irreversibly altered. Reconnecting large networks of habitat and restoring the natural processes maintaining these systems is unlikely at present. Thus, conservation management may require more intensive and direct intervention and manipulation of habitats, populations, and communities (Young and Harig, 2001; Harig and Fausch, 2002).

The expected trend for the west is one of increasing human density, extractive demands, and desire for access to wildlands (McCool and Haynes, 1996; McGinnis and Christensen, 1996; Hansen et al., 2002). If the historical correlation between population expansion and environmental degradation continues, the condition of aquatic ecosystems and native fish populations will probably continue to decline (Rieman et al., 1997). Nevertheless, a commitment to conservation of remnant strongholds and the restoration and reconnection of more diverse and productive habitats where possible, could slow and sometimes reverse that trend where important elements of native fish communities still remain.

The opportunities to conserve and restore native fish populations are often found in the forested landscapes of the region where fire-related management is now an issue. Despite the role of past land management in the decline of fishes and their habitats, federally managed lands generally support the better (and some times the only) habitats and opportunities for conservation. More than 66% of the remaining spawning and rearing habitats for species like bull trout, stream-type chinook salmon *O. tshawytscha*, and westslope cutthroat trout in the interior Columbia River basin are found on federal lands, principally those managed by the US Forest Service (Lee et al., 1997; Rieman et al., 2001). Over 90% of the remaining genetically pure Yellowstone cutthroat trout occur within the boundaries of Yellowstone National Park (Gresswell, 1995), and virtually all of the known remaining populations of Colorado River cutthroat trout (Young et al., 1996), Gila trout and Apache trout (Rinne, 1985) occur on federally managed lands. Clearly, the issues for fire-related management overlap those for conservation of native fishes.

2.3. The effects of fire

Because wildland fire and fire-related management affect watersheds important for native fishes, such management is a central concern to the biologists and managers charged with the conservation of these species. Empirical studies of fire effects on native fishes are only beginning. Lacking those, inferences come primarily from theory, models, and empirical studies of the physical processes linked to fire and the more general observations and theory of biological population responses to disturbance.

Fires can strongly influence water chemistry, water quantity, and channel stream structure through changes in transpiration, infiltration, ground water recharge, erosion and mass wasting, riparian shading, and the recruitment and delivery of coarse debris (e.g. Benda et al., this issue; Meyer and Pierce, this issue; Minshall, this issue; Spencer et al., this issue; Wondzell and King, this issue). Fires can have important direct and immediate effects on native fishes or their habitats (Rieman and Clayton, 1997; Dunham et al., this issue; Minshall, this issue; Spencer et al., this issue), but the ultimate effects of fire on aquatic organisms and fishes in particular may be apparent only some time after the fire has occurred (Reeves et al., 1995; and see Dunham et al., this issue, for an overview). Those effects will depend on a variety of conditions including: (1) the nature of the fire (patchiness, intensity) and subsequent precipitation; (2) the prior conditions of the watershed and riparian communities; (3) the potential for demographic support or recolonization of fish communities as influenced by proximity and location of refugia; (4) the expression of complex life history patterns and overlapping generations (Warren and Liss, 1980; Rieman and Clayton, 1997; Dunham et al., this issue); and (5) the nature of fire suppression and post-fire management (Gresswell, 1999; McIver and Starr, 2000). Given the many factors involved, accurately predicting the effects of fire at any particular site is not possible. Existing experience and theory, however, provide some perspective on the relative magnitude of the threats that exist.

Over millennial time scales, large disturbances and climatic variation undoubtedly had a profound influence on the distribution and dynamics of fish populations and their habitats (e.g. McPhail and Lindsey, 1986; Taylor et al., 2001). Local extinctions were common and global extinctions occurred as well (Smith, 1981). The native species and distinct forms of those species that persist today evolved in the context of changing environments influenced by floods, glaciers, fires, and other large disturbances. For some, the current constraints imposed by human development may not even exceed the natural constraints of the extreme events in the past. The current problem is that fish populations are faced with the combined effects of natural disturbance and human disruption of aquatic ecosystems. Historically, most fish existed for extended periods as part of a larger interconnected network of streams and populations and some exhibited a variety of life histories. This spatial- and life-history diversity likely was the result of, and an evolutionary hedge against, environmental variability (Healey, 1991; Gresswell et al., 1994; Thorpe, 1994a,b; Rieman and Clayton, 1997; Dunham et al., this issue) resulting from natural events including disturbances like fire. In second- or third-order streams, fire effects should be most noticeable in individual stream segments (sensu Frissell et al., 1986) or smaller units of stream network organization (Gresswell, 1999; Dunham et al., this issue). Given that most existing native fishes have persisted in North America for hundreds of thousands to millions of years (Stearley and Smith, 1993), they undoubtedly evolved strategies to survive large disturbances that occurred at the spatial extent and frequency of even the most extreme wildland fires. In watersheds with adequate connectivity and sufficient diversity in habitats, many populations persisted and perhaps even flourished. There is a growing body of evidence that suggests that many species that evolved with large disturbances, such as fire may even benefit through the ultimate creation of more complex habitats (Reeves et al., 1995; Benda et al., this issue).

Where populations can still express the full range of life histories and remain connected to a range of habitats, even large fires may pose little threat (Dunham et al., this issue). Indeed, fire could even be critical to the long-term maintenance of important habitats. In contrast, where populations have been constrained by habitat loss, fragmentation, and the expansion of exotic species, the probability for local extinctions linked to any disturbance has probably increased. If changes in fire patterns lead to larger, more severe disturbances than characteristic of at least the more recent evolutionary past for these species, the risks are compounded (i.e. fragmentation interacting with larger disturbances) (Dunham et al., this issue). Where these conditions coincide the mitigation of extreme fires and their effects might benefit native fishes (Brown et al., 2001).

3. Issues for management and integration

The challenges of conserving native fishes and simultaneously managing fire and fuels are defined by context and by perceptions about the role of fire in the systems of interest. As we have discussed above, context varies with species and the characteristics of populations, watersheds, and landscapes. Perceptions are inconsistent as well. Biologists, ecologists, and managers in the agencies charged with conservation and land management often have very different experiences and perspectives. They are also constrained by a regulatory process that is not easily reconciled with the emerging concepts of diverse and dynamic ecosystems.

The institutional framework for regulation of fire and aquatic related management is established by the National Environmental Policy Act (NEPA), the ESA, the Clean Water Act, and planning rules specific to each land management agency. The NEPA and planning guidance within the US Forest Service require disclosure of environmental and ecological effects and the development of reasonable alternatives. The ESA requires the development of a biological assessment (BA) about the effects of management activities on listed fishes and consultation with the regulatory agencies. Management activities that may affect a listed species require consultation with the National Marine Fisheries Service (NMFS) or the US Fish and Wildlife Service (USFWS). There also may be a requirement for coordination with the Environmental Protection Agency or state water quality management authority. This framework requires the collaboration of scientists and managers from different disciplines within an agency and among agencies with different goals. A common perception of the role of fire, and fire-related management in aquatic ecosystems should encourage consensus regarding the management that should proceed. That foundation has proven elusive for at least three reasons.

First, there are often fundamental differences in management and scientific perspectives. Terrestrial and forest ecologists and managers have generally accepted the notion that ecosystems are dynamic and that disturbances such as fire structure forest ecosystems (e.g. Hessburg and Agee, this issue). Manipulating forest patterns and composition to be more consistent with anticipated natural fire regimes has become an important element of proposed forest ecosystem management. Active manipulation of vegetation and fuels might also benefit the conservation of vertebrate species that evolved with the structure and composition of forest habitats dependent on natural fire regimes (Franklin, 1993, 1998; Carey and Curtis, 1996; Carey, 1998; McKelvey et al., 2000; but see the cautions in Tiedemann et al., 2000 and Franklin et al., 2001).

Aquatic scientists also have argued that aquatic ecosystems are inherently dynamic and strongly linked to terrestrial ecosystems and landscapes (e.g. Nankervis and Young, 1994; Reeves et al., 1995; Benda et al., 1998; Naiman et al., 2000). Conservation and restoration of the physical processes that represent these linkages are emphasized in much of the recent literature (e.g. Frissell et al., 1997; Kauffman et al., 1997; Beechie and Bolton, 1999; Roni et al., 2002) and guidance for interagency consultation (NMFS, 1999). Conceptually, management efforts to restore the structure and composition of forests could be consistent with this view, but that integration remains problematic. Some aquatic scientists have argued that vegetation management can and should be made more consistent with natural disturbances (e.g. Reeves et al., 1995; Bisson et al., 1997; Naiman et al., 2000), opening the door to more experimentation with active forest and watershed manipulations. Others have remained skeptical (Frissell and Bayles, 1996; Franklin et al., 2001) and reinforce the notion that we have already lost too much to risk any further experimentation in the last vestiges of aquatic biological diversity. The failures of optimal and sustainable harvest strategies (Ludwig et al., 1993; Post et al., 2002) and technologically based solutions such as hatcheries (Hilborn, 1992; Meffe, 1992; Bottom, 1997) and habitat manipulation (Beschta et al., 1995; Ebersole et al., 1997; Frissell et al., 1997) have led to a skepticism in our ability to intelligently manipulate, sustain, or even predict the productivity of natural or managed systems (Ludwig et al., 1993; Holling and Meffe, 1995; Ludwig, 1999). Arguably, restoration of natural processes and forest management, intended to be more consistent with natural disturbances including fire, are not necessarily the same thing.

Second, complex procedural requirements do not necessarily facilitate effective integration; they may in fact lead to further simplification of inherently complex ecological systems. Proposals resulting from the NFP must meet the statutory requirements of the agency and all Federal laws. Under NEPA, a project with significant environmental effects (e.g. to sensitive fishes) might require an environmental impact statement (EIS) that requires significant time and money to produce. The BA required by the ESA is produced only after a preferred alternative has become solidified during the NEPA process.

Planning fire management projects and the associated regulatory procedures have highlighted the evolving and often conflicting views within and among agencies. In our experience, two distinct goals often emerge from the process, one focused on managing fire and fuels, and the other focused on mitigating the short-term effects of that management on sensitive fishes and their habitats. Formal consultation between management and regulatory agencies often occurs after a major investment in project planning and development. Managers have complained that the regulatory process is overly complicated, difficult to predict, costly, and seemingly endless (e.g. US Forest Service Chief's Testimony, House Subcommittee on Forests and Forest Health, Committee on Resources, US House of Representatives, 12 April 2001). That frustration has stimulated a search for ways to standardize and simplify the process.

One result has been a system of criteria outlining acceptable management activities and a series of indicators to characterize acceptable habitat conditions. Examples in the US Forest Service include standardized riparian management objectives. The FWS and NMFS have used similar standards for management activities and a ''matrix'' of pathways and indicators to evaluate effects of federal land management actions on some listed fishes (NMFS, 1996). Implementation of the Clean Water Act has lead to a similar concept of water quality standards focused on a threshold level of allowable degradation (Poole et al., 2001).

One problem is that these approaches essentially ignore the dynamics of aquatic ecosystems. The emerging science argues that disturbance is natural and potentially important for the long-term maintenance of diverse and productive habitats. It seems unlikely that we can constrain any system to a range of conditions we deem optimal and it is probably ill advised even if we could (Franklin, 1993; Reeves et al., 1995; Bisson et al., 1997; Franklin et al., 2001). The standardized approaches have some benefits for the existing bureaucracy of management and regulation, but risk oversimplifying the problems. The current process seems to ask whether each proposed project meets a checklist of dos and don'ts. It may not ask whether the project makes sense in the larger context of managing whole landscapes for both forests and fish. The current process seems to focus on mitigating the disruption of activities as they are proposed. It may not identify the key processes influencing whole watersheds and constraining populations or the potential of their habitats (e.g. Beechie and Bolton, 1999; Roni et al., 2002).

Third, the scientific uncertainty is substantial. A common challenge for biologists and managers is to consider the tradeoff between treatments that may mitigate the effects of the next fire and the direct effects of the treatments. This is problematic because we generally lack the information necessary to reliably predict the effects of large fires (Wondzell, 2001). Lacking that knowledge, planners must rely on professional judgments based on the scientific literature, personal observation, and logical conclusion. The results are often uncertain and contentious.

Much of the resulting debate centers on the apparent need for active and widespread management to reduce fuel loadings and the potential for stand-replacing fire. Because past management activities often contributed to degradation of aquatic and terrestrial systems, further activities are often perceived more as threats than benefits. From the perspective of fish and aquatic issues, there are arguments for and against active management to mitigate new fires.

For example, large fires can affect watershed processes dramatically. The loss of vegetation and creation of hydrophobic soils can increase the potential for flooding and surface and mass erosion leading to dramatic increases in sedimentation, debris flows, or even complete channel reorganization (Rieman and Clayton, 1997; Meyer et al., 2001). The loss of riparian shading and changes in flow volume may produce more extreme temperatures (McMahon and deCalista, 1990). Large fires threaten a negative influence on the quality of habitats for fishes and other aquatic organisms. Arguably, we should minimize the potential for large fires to minimize those risks.

Alternatively, logging and thinning intended to remove fuels or to replace fire may ultimately remove a legacy of materials that would structure aquatic habitats in the future. Management intended to replace or mimic the effects of fire may look nothing like those fires from a watershed perspective (Reeves et al., 1995). Because management often involves repeated entry and the maintenance of an infrastructure including roads, the negative effects of management can be chronic or persistent compared to the acute and periodic effect of fire (Rieman and Clayton, 1997). Species that evolved in variable environments may be adapted to the periodic or pulsed events, but not the chronic ones (Poff and Ward, 1990).

It might also be argued that the current fuels conditions and a changing climate threaten more intense, severe, and extensive fires than have been typical of the past. Fires burning over larger areas will produce more dramatic and synchronous disturbances. Because many of the remnant populations of fishes are already depressed, small or isolated, they lack the resilience, diversity, or demographic support to rebound from disturbance. Small and isolated populations do face greater risks of extinction (Dunham et al., 1999; Rieman and Dunham, 2000; Dunham et al., this issue) and this may be a particularly important problem for many remnant populations of salmonids in the southwest (Rinne and Neary, 1996; Brown et al., 2001). Large fires whether characteristic or not, are more likely to be biologically catastrophic.

In response, some may suggest that management focused on the threat of a large disturbance could be considered treatment of the symptoms of endangerment without addressing its ultimate causes. The legacy of past management including roads, migration barriers, water diversions, and the introduction of exotic species has simplified and disconnected habitats for fishes (Minckley and Deacon, 1991; Lee et al., 1997; Rinne, in press). Aggressive management of fire and fuels will often require an infrastructure of roads and stream crossings that will likely perpetuate the disruption to streams and the expansion of non-native taxa. Existing demands for, and the diversion of, water are not likely to be reduced without active negotiation and mitigation. In short, if we do not address the fundamental problems constraining native fishes, extinction may be a problem whether fire regimes are changing or not.

The arguments from each of these and other perspectives can be compelling. Many systems and species that forest and fish managers are charged with conserving have been seriously degraded and depressed. Further management seems foolish from one perspective and absolutely critical from another. Undoubtedly there is some truth in these seemingly disparate views. No argument can be generalized to the forests and watersheds of the west, however, because the ecological conditions underlying this debate are not consistent or homogeneous. Context matters. The tradeoffs inherent in any decision ultimately depend on local conditions and interacting effects of landscape, climate, and ecological process. A better understanding of the differences between the effects of large fires and management intended to mitigate those fires is a primary question for future research and management. Without that information these debates are likely to persist.

4. Conclusions and challenges for progress

New research will better define the tradeoffs between management for fire and fuels and watersheds and native fishes. The answers, however, will emerge slowly and we will never have the detailed understanding to predict with certainty the effects of our management on aquatic ecosystems. Management must and will move forward in the face of that uncertainty. We suggest that effective integration of terrestrial and aquatic management faces at least three fundamental challenges to progress.

First, we have argued that more integrated fire and aquatic management will require a common understanding or conceptual foundation. We suggest that the emerging ideas of ecosystems as dynamic rather than static is an important element of that foundation. In our view, progress will require an integration of disciplines and a common theme in management goals (e.g. the conservation and restoration of ecological processes and management of human disturbance in any form). The management of fishes and other aquatic organisms on forested lands is largely the responsibility the USFWS, the NMFS, tribes and treaty organizations, and the state fish and game agencies. Management of forests and the watersheds that support important habitats on federal lands is largely the responsibility of the US Forest Service and the Department of Interior. Historically, these have been agencies with divergent mandates and management goals (Poff et al., 1997; Samson and Knopf, 2001). Research, training, and agency structures that support integrated analysis and decision-making would seem useful. One step might be the creation of long-term, inter-agency management studies that could foster communication, and the development of common goals (such as the conservation of linkages between terrestrial and aquatic ecosystems), objectives, and understanding. A second might be to focus the growing number of biologists now intent on implementing regulatory processes, instead on the design, analysis, and implementation of projects necessary to identify and influence the watershed and ecological processes that actually constrain the systems we manage.

Second, we have argued that context matters when we consider the role of fire and fire-related management in aquatic ecosystems. Effective conservation and restoration will require attention to landscape and ecological conditions. The future of the west appears to be one of continuing population growth, increasing demand for natural resources and recreational opportunities, and human development on some forested lands (Hansen et al., 2002). The habitats for many species have been lost and extensive areas of forested landscapes are dramatically altered but the changes have not been and will not be consistent across all watersheds. Biophysical constraints vary as well. Realizing significant ecological benefits will require that managers identify the ecological potential of and the most important constraints on the systems of interest. We emphasize that doing the same thing everywhere for fire management or recovery of native fishes is risky business. Recognition of areas of significant ecological potential and opportunities to restore the processes regulating both terrestrial and aquatic ecosystems could be especially important (Rieman et al., 2000).

Third, we acknowledge that the science is limited. In our view, integrated management will require a larger scale vision and commitment and the recognition of substantial uncertainty. Much of the controversy in forest management is borne from past experience with conflicting management objectives and uncertainty about the behavior of ecological systems. Virtually all natural resource management is experimental (Wilhere, 2002). That we have been wrong in the past is now evidenced by the effects of fire suppression, selective silvicultural practices, and our inability to mitigate effects of land management on fish habitats (e.g. Beschta et al., 1995; Frissell et al., 1997; Lichatowich, 1997). Any vision of management which is based on natural disturbance implies a vision of whole landscapes and planning horizons consistent with the time scales of vegetative succession (e.g. 100–500 years). Natural systems also are changing. The invasion of exotic species, the loss of keystone species like anadromous salmonids, and climate change, mean that we are now attempting to manage communities with which we have no experience. Progress will require a commitment and continuity of management over unprecedented time and space. It will also require bold steps without guaranteed results. It is hard to accept that we really know how to do this and harder yet to assume that we can guarantee the management and political commitment to an experiment that must proceed far beyond the next election, management initiative, budget crisis, or the tenure of a district ranger. Until we have demonstrated an ability to actually implement more natural management in human-dominated systems, and to effectively learn in the process of doing it, skepticism and conflict will remain.

Acknowledgements

D. Horan provided considerable assistance in the preparation of the manuscript. K. Overton, J. Dunham, L. Ulmer, K. Walker, J. Morrison, T. Quigley, C. Luce, C. Frissell, and an anonymous reviewer provided constructive comments that helped improve earlier drafts. The work to produce this manuscript and the workshop where it was originally presented were supported in part by funding from Regions 1 and 4 of the US Department of Agriculture, Forest Service.

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