Wildfire and Management of Forests and Native Fishes: Conflict or Opportunity for Convergent Solutions?

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Wildfire is a critical land management issue in the western United States. Efforts to mitigate the effects of altered fire regimes have led to debate over ecological restoration versus species conservation framed at the conjuncture of terrestrial and aquatic ecosystems and their respective management regimes. Fire-related management activities may disrupt watershed processes and degrade habitats of sensitive fishes. However, the restoration of forest structure, process, and functionality, including more natural fire regimes, might also benefit longer-term habitat complexity and the persistence of species and populations that are now only remnants of once-larger and more diverse habitat networks. Common language, clear communication of goals and objectives, and spatially explicit analyses of objectives will help identify conflicts and convergences of opportunities to enable more collaborative management. We explore this integration in the context of native fisheries and wildfire, but expect the approach to be relevant in other settings as well.

Keywords: wildfire, native fishes, fuels management, restoration ecology, conservation biology

Following extended debate, the "great fires" of 1910 galvanized public and governmental will in favor of aggressive fire suppression (Pyne 2001) that, with other land uses, has fundamentally altered many forests, watersheds, and related ecological processes (Rieman et al. 2003, Hessburg et al. 2005). Changing patterns of wildfire, linked to fire suppression and climate change, have reinvigorated political and scientific debate over fire and fuels management (e.g., Dellasala et al. 2004, Noss et al. 2006a, Rhodes and Baker 2008). The discussion has important social and economic implications and has been contentious at times (Dellasala et al. 2004). We believe the debate also reflects a basic tension in applied ecology that contrasts restoration management, which is focused on the re-creation of more natural forests and sustainable ecosystem services, and conservation management, which is centered on conservation of remnant species and native biological diversity (see also Young 2000, Noss et al. 2006b).

These challenges are apparent in aquatic and terrestrial management on federal lands in the West (Rieman et al. 2000, 2003, Bisson et al. 2003). An increase in the frequency and extent of high-severity fires has catalyzed major initiatives to mitigate the effects of severe fires (US Government 2003, Agee and Skinner 2005) and restore more natural fire regimes. There is a sense of urgency as fire suppression costs alone have totaled more than $1 billion in recent years (USDA 2006). At the same time, degradation of aquatic ecosystems and a growing list of declining species have leant urgency to conservation efforts, many directed at native fishes (Rieman et al. 2003) and often focused on protection of remnant populations and habitats (Ruckleshaus et al. 2002).

The resolution of interdependent terrestrial and aquatic management issues is not simple. Spatial convergence between terrestrial and aquatic issues is not coincidental; both sets of issues are tied to past land uses, which disrupted terrestrial and aquatic ecosystems simultaneously (Rieman et al. 2000). Depending upon the context, large wildfires may cause watershed disruption and threaten aquatic populations that exist in remnant or compromised habitats (Brown et al. 2001). In this light, mitigation of fire severity or its subsequent hydrologic effects could benefit population or even species persistence. Alternatively, even severe wildfire can be viewed as a natural process that can contribute nutrients, wood, and coarse substrates and thus help maintain or re-create productive habitats

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(Reeves et al. 1995, Bisson et al. 2003), whereas management of fuels can be a disruptive process that further degrades habitats (Rhodes and Baker 2008).

We believe the challenge is not to define fire and related management as good or bad, but to find common ground between diverse and sometimes apparently conflicting objectives. Forests and streams are tightly linked through the transfer of materials and energy that influence habitat structure (large wood and sediment), food webs and trophic dynamics (nutrients and organic carbon supply), water quality and temperature (riparian shade), and other ecological processes and functions. Conditions in forest and riparian communities can strongly influence conditions in the streams and communities they encompass (Naiman and Turner 2000). As a result, terrestrial and aquatic managers may often share the common objectives of conserving or restoring resilient ecosystems and their linkages. Ultimately, a more integrated perspective that considers the entire suite of ecosystem services and resource values is desirable (Day et al. 2009), but the forest and aquatic interface is a good place to start—it has been particularly troublesome and we have direct experience with the relevant issues.

Conceptual frameworks to guide the integration of management objectives have been explored in the literature. Seymour and Hunter (1999), Dellasala and colleagues (2004), Everett and colleagues (1994), Maron and Cockfield (2008), and others have suggested a spatially explicit mix of land classification and prioritization for conservation, restoration, or disturbance-based objectives. Cissell and colleagues (1999) developed a plan for a small landscape that integrated the management of forests and fisheries based on the recorded natural disturbance regime. Rieman and colleagues (2000) jointly considered historical changes to forest structure, fire regime, fish communities, and watershed conditions to illustrate distinctive themes for integrated restoration and maintenance across the interior Columbia River basin. Noss and colleagues (2006b) argued that solutions to conflicting management objectives could be found by considering landscapes at broader spatial scales. Zoning to guide multiple-use management and wildfire use has become more common in federal land management, but effective integration of aquatic and terrestrial management objectives with respect to fire still is not widely realized.

We suggest three steps to more successfully integrate the management of forests, fires, watersheds, and native fishes into regional and project-scale planning: (1) communication among disciplinary scientists, managers, and stakeholders, with a clear definition of management goals; (2) translation of goals to objectives within the contexts and constraints of the systems in question; and (3) spatially explicit integration of terrestrial and aquatic objectives to identify opportunities for convergent solutions. The full cycle of management might also include implementation, monitoring, evaluation, and adjustment, but we limit our scope to the initial planning phase and consider the three steps in turn.

Communication of goals

Public-sector land management goals outline management direction, which is a function of societal values associated with natural resources and landscape conditions (e.g., Roni et al. 2008). Conflicts arise when differences in values lead to differences in goals, when there are disagreements over the actions needed to achieve goals, or when there are discrepancies in the perception of risks associated with those actions. These conflicts are not new. Early in the 20th century, Gifford Pinchot and John Muir argued over the wise use of natural resources to serve utilitarian values versus the creation of wilderness reserves for the sake of the intrinsic value of natural systems. A tension between sustainable use, or "resourcism" and "preservationism," has been important since (Callicot 1995).

Economic growth and urban expansion together with the complexity of maintaining functioning political, social, and ecological systems have made sustainable use elusive. The accelerating pace of species declines, local extinctions, and a growing number of populations listed under the Endangered Species Act (ESA) have complicated matters (Callicot 1995, Rieman et al. 2003). For example, agency biologists once trained in habitat and harvest management to sustain fishing and hunting opportunities are now often focused on population viability and emergency conservation of remnant populations and habitats such as those of native fishes in western states (Rieman et al. 2003). At the same time, changing political and natural climates have helped shift emphasis from timber production to the mitigation of severe fire behavior and to the restoration of more natural structure, composition, and functionality in fire-dependent forests (US Government 2003, Reinhardt et al. 2008). In this context, we believe a new tension has emerged across the biological and ecological perspectives guiding land management. On one side we see conservation biology, often focused on stopgap protection of remnant biotic diversity (genes, species, and populations; Young 2000); on the other is restoration ecology, intent on restoring resilient ecosystems and valued ecosystem services (Young 2000, Noss et al. 2006b).

The two perspectives are complementary, not equivalent. Conservation of native species and biotic diversity may depend on functional landscapes (Young 2000), so long-term conservation of native fishes can benefit from, and may even depend on, restoration of forest ecosystems (Bisson et al. 2003, Hessburg and Agee 2003, Rieman et al. 2003). Forest restoration, however, can involve rapid, extensive, or aggressive manipulation of trees and fuels, or other activities that can also compromise water quality and disrupt watershed processes (Rhodes and Baker 2008). Disagreements over acceptable risks associated with restoration and conservation are not easily resolved. Managing sustainable ecosystem goods and services (for humans and ecosystems) requires that you take some and leave some. But how much taking is too much, and where, when, and how might it be taken in such a way that it avoids long-term harm? Some management regulations act to constrain or stop the anticipated negative effects of forest thinning and fuels-reduction projects to sensitive fish habitats. Some have argued that such concern over the short-term risks associated with forest management actions may obscure the long-term risks of large and severe wildfires (Mealey and Thomas 2002). Others have suggested that the watershed disruptions caused by such actions outweigh any potential long-term benefits for aquatic systems (Rhodes and Baker 2008).

There also can be differences regarding the targets of restoration and conservation. Concepts of ecological diversity have included native species, phenotypes, and genotypes, as well as the environments that support them (Callicot 1995). Concepts of ecological or forest health include natural ecological process, structure, function, and resilience, but do not necessarily imply maintenance of native diversity or unique evolutionary legacies (Jones 2003, Meyer 2006, Palmer 2009). Some argue, for example, that restoration of ecological process is ascendant to conservation of native diversity (Young 2000) and that management action will most likely conserve few endangered species and populations, but that it still can restore or maintain important ecological processes and services (e.g., Meyer 2006).

We do not argue whether conservation biology or restoration ecology should be dominant in the fire-aquatic discussion—both are important in the context for management: interrelated, complementary, but not the same. Rather we argue that clarification and improved integration of objectives should follow from elucidation of the basic goals and societal values that define them.

Values and definitions

Conservation and applied ecological literature are replete with characterizations of values and goals for management. We suggest these can be represented by three general types: evolutionary, ecological, and economic (see also Beechie et al. 2008, Fausch et al. 2009). In our view, evolutionary goals are those associated with conservation of biological diversity that is the evolutionary legacy of the biophysical system of interest. Evolutionary goals are embodied in application of the ESA through the designation of evolutionarily significant units (Waples 1995). Distinct species and population-level genetic and phenotypic divergence, richness and representation of distinctive elements and environments, unique assemblages, and rarity, for example, are all concepts associated with the evolutionary values considered in conservation management of native fishes in the Pacific Northwest (Waples 1995, Allendorf et al. 1997).

Ecological goals may reflect important ecological patterns, processes, functions, or services that are generally perceived at population, community, landscape, and ecosystem scales. Ecosystem services are the tangible benefits derived from ecosystems. Society values clean water, clean air, and the natural flows of energy, organisms, and other resources associated with fully functioning landscapes and watersheds. Humans may particularly value systems that function without extensive management intervention, so ecological goals might include realization of systems that are productive, self-organizing, and resilient to natural disturbance. Subsequent objectives might focus on the restoration or maintenance of natural patterns, functions, and the processes that support them (Ruckelshaus et al. 2002, Palmer 2009). Ecological goals will often include biotic diversity as a foundation for adaptation and resilience in changing environments (Ruckelshaus et al. 2002, Day et al. 2009). Hilborn and colleagues (2003) provided a classic example of salmon populations' resilience to climate change, the result of diversity in life histories expressed across a lake system. Conservation of diversity, however, is not necessarily the same as conservation of an evolutionary legacy. Biotic diversity is a foundation for future evolution, but natural selection and adaptation do not require the native elements of diversity to work (e.g., Kinnison et al. 2002). We might prefer that diversity be represented by native elements, but this is not always central to the realization of some ecological goals (Callicot 1995, Young 2000, Jones 2003, Meyer 2006, Fausch et al. 2009).

Economic goals are commonly associated with commodities and services that have markets or benefits considered in traditional economic terms. Economic values are obvious for services such as harvestable timber or commercial fisheries, but additional benefits come from sport fishing, low unemployment, recreation and tourism, and human infrastructure that might be vulnerable to wildfire. Economic goals can be closely aligned with ecological goals and ecosystem services, but management objectives emerging from economic goals often seek to maximize efficiency in the production of a more narrow selection of services through efforts such as plantation forestry or single-species fisheries.

Evolutionary, ecological, and economic goals are not readily separable or necessarily complete. Broader intrinsic values of intergenerational equity, interspecific fairness, and spiritual or aesthetic qualities can transcend simple classification. Likewise, long-term conservation of native species diversity may depend on the restoration of ecological process, as well as the economic reality of conservation shaped by other costs and benefits. Healthy ecosystems provide economically valuable services. Clearly, goals may overlap, but it is important to note that goals may not be compatible with one another, particularly in light of the management objectives that lead to actions on the ground. For example, genetically introgressed populations of native cutthroat trout and nonnative rainbow trout occur widely throughout river systems of the interior West (Allendorf et al. 2001), whereas genetically pure populations are commonly restricted to remnant headwater habitats, often above migration barriers (Fausch et al. 2009). Arguably, the former retain the ecological process of migration and support valuable sport fisheries because migration also produces large-bodied adults (i.e., ecological and economic goals; Fausch et al. 2009). However, when the native genome is compromised by introgression, these populations may retain little value as an evolutionary legacy (Allendorf et al. 2001). Should managers attempt to maintain or restore access for migratory fish that could soon be hybridized with nonnative invaders, or should they control invasions with barriers or other efforts to isolate remnants of native genetic diversity (e.g., Fausch et al. 2009)? Should they favor ecological goals with populations that might be more resilient to a large fire and more likely to persist and evolve with changing landscapes (e.g., Jones 2003)? Or should they favor evolutionary goals with populations that might also require extraordinary conservation measures in the face of threatening disturbances and environmental change (e.g., Brooks 2006)?

There is a similar struggle of values, goals, and management objectives associated with fire-prone forests. For example, natural fire regimes can be important to some ecological processes (e.g., downed woody debris that creates complex structures in stream and forest-floor habitats). But wildfire can also result in a substantial loss of marketable timber. Should managers seek to restore structure and composition of forests that support more natural fire regimes including severe stand-replacing events, or should they seek to preempt severe wildfires through thinning or timber harvests that also may provide an economic return? The point is not that any set of goals is right or wrong, but that different goals lead to competing or conflicting objectives that must be resolved across managed landscapes. Explicit definition of goals is an important first step in communication within and among management disciplines.

Translation to objectives: Context matters

Management goals translate to objectives and actions on the ground. We suggest terrestrial and aquatic objectives aim to maintain, restore, or control ecological process, structure, and function. Maintenance might involve largely passive actions such as wildland fire use, or constraint of extractive uses as in wilderness and roadless areas, riparian or species reserves, and on sensitive hillslopes (e.g., Cissel et al. 1999). These objectives might also mean more actively incorporating the intentionally ignited fires. Maintenance objectives will favor conserving ecological processes and minimizing the disruption of systems that are considered diverse, resilient, and within the bounds of their natural potential. Presumably, maintenance objectives will involve the least intensive actions both logistically and financially, with a primary focus of facilitating the self-organization of natural systems.

Restoration objectives may favor reestablishing conditions, patterns, structures, and processes that support ecological function and resilience, diversity, productivity, self-sufficiency, and evolutionary potential (e.g., Palmer 2009). Removing fish passage barriers to restore connectivity and fish movements (Dunham et al. 2003) or restructuring forests and fuel beds to support more natural fire behavior (Allen et al. 2002, Agee and Skinner 2005) are common examples. Restoration can involve intensive and expensive manipulation of landscapes, streams, or populations, but interventions are generally intended to be temporally finite, creating systems that require only maintenance in the long run.

Control will include the most active and aggressive management actions. Efforts to exercise control in natural systems might include reduction or elimination of the effects of undesirable (but otherwise natural) disturbances (e.g., fire suppression, construction of dams and levees for flooding); support of simplified but economically productive conditions (e.g., forest plantations or hatchery sustained fisheries); or circumvention of unsustainable conditions (e.g., hatchery augmentation of declining fish populations). Control-related objectives will generally attempt to create conditions or outcomes that require continued investment of energy and other management resources. Control-related objectives may be the most expensive, uncertain, and open-ended management approaches. However, control also might include stopgap efforts to protect vulnerable resources until more sustainable restoration can be accomplished for the longer term (Rieman et al. 2000).

The translation of goals to objectives (figure 1) will depend on technical and financial limitations (What is our capacity to act?), as well as constraints imposed by systems themselves (Where and when can we act?). For example, if an important fish population exists in a large, well-connected habitat network, control of severe fires may be unnecessary from an aquatic perspective (Dunham et al. 2003), whereas maintenance of the conditions contributing to the population's resilience would be important. Alternatively, if a population exists in a small, remnant, or isolated stream network, restoration through removal of barriers could become important (Fausch et al. 2009). In some cases, restoration may not be feasible for reasons of cost or logistics or because of conflicts, such as the potential invasion of nonnative species. In these cases, objectives may again favor control of natural processes to protect or support the population as long as possible.

Terrestrial objectives may be constrained in similar ways. For example, it may make little sense to attempt restoration of natural flood or fire regimes in urbanized landscapes where ecological objectives are inconsistent with human infrastructure already in place. The decision to maintain or

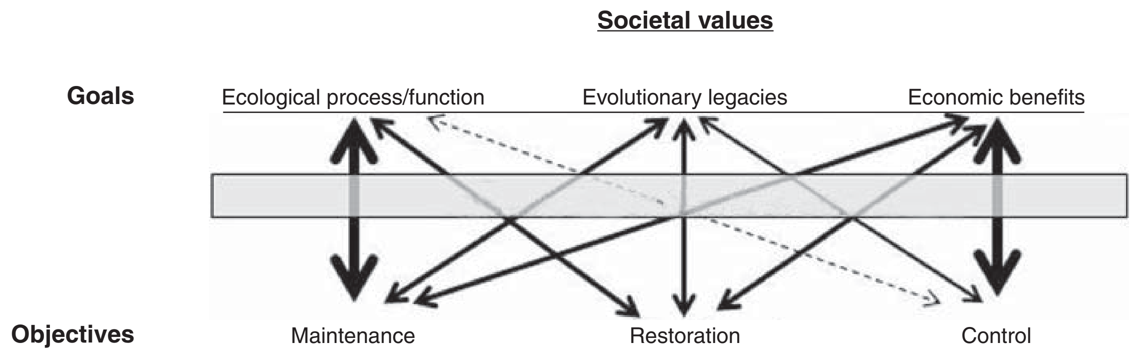


Figure 1. Management goals reflect societal values, but translate into objectives for work on the ground in the context of biological and physical conditions and available management resources. The arrows are bidirectional to imply that accomplishment of objectives will produce benefits associated with each goal. The thickness of the arrows reflects that some goals may lead managers to favor some objectives over others. For example, goals associated with ecological process and function may favor opportunities for maintenance over restoration because they may be less costly and because restoration will rarely re-create the full natural potential of ecological processes, structures, and functions. It is more effective to maintain than to restore. Similarly, control objectives are likely to support ecological goals only when they are viewed as an interim measure to longer-term restoration because control is fundamentally at odds with the full expression of natural process.

restore forest structure or composition through thinning, prescribed burning, or wildland fire use may be a result of available financial support (e.g. available biomass, merchantable timber, or subsidy). Control of fire through suppression or fuels reduction may be dictated by the location of human settlements and infrastructure (Dellasala et al. 2004).

Integration

A common framework and terminology for goals and objectives can be the foundation for effective communication and integration in terrestrial and aquatic management. Ecosystems are neither terrestrial nor aquatic in functionality alone; by virtue of their linkages, they are both. Integration, however, remains a challenge. Scientists and managers have struggled to articulate inclusive management programs that recognize the multidimensional nature of all the conditions, goods, and services valued by society. Taken site by site or project by project, conflict between objectives could emerge through internal inconsistencies in relevant temporal and spatial scales. Differences in the dominant ecological patterns or processes constraining (top-down) differing objectives or providing the fundamental elements (bottom-up) to each objective (Wu and Loucks 1995) could also pose problems.

As suggested earlier, spatially explicit consideration of management objectives may reveal possible solutions. On the basis of the dominant issues associated with terrestrial and aquatic objectives, we argue that opportunities for convergence can be more common where objectives coincide; conflict, or in some cases nonissues, may be more likely where they do not (table 1). By integrating objectives managers may begin to identify projects and landscapes where integrated management can move forward, as well as projects where progress may require more focused or higher-resolution analyses. The following are some examples:

- In landscapes or watersheds where the existing conditions are essentially wild and mostly unaffected by human management or settlement, terrestrial and aquatic management objectives may give high priority to maintenance of natural patterns, processes (upper left cell, table 1), and their linkages (Rieman et al. 2000). Wildfires would most likely not be viewed as a threat to relatively large, well-connected, and diverse aquatic communities and fish populations (e.g., Dunham et al. 2003). Intentional wildland fire use or prescribed burning to maintain mosaics of disturbance-driven forest structural conditions could contribute to maintenance of aquatic biological diversity, productivity, and resilience (Reeves et al. 1995, Bisson et al. 2003). Under these circumstances, terrestrial and aquatic managers could support each other in promotion of wildland or prescribed fire use and the maintenance of other important conditions driving these landscapes. Moreover, because such wild systems may be poorly represented across broad regions,

Table 1. A matrix of terrestrial and aquatic management objectives.

Terrestrial	Aquatic		
	Maintain	Restore	Control
Maintain	Converge	No issue	No issue
Restore	Conflict	Converge or conflict	Conflict
Control	Conflict	Conflict	Converge or conflict

collaboration in their identification and management may be a key to success.

- In many landscapes, forests and streams have been dramatically altered by ecologically disruptive road systems, repeated timber harvests, grazing, and other human interventions (Rieman et al. 2000, Luce and Wemple 2001), and both terrestrial and aquatic managers may be eager to restore more functional conditions (center cell, table 1). Aquatic managers may wish to avoid any activity that would continue the disruption of watershed or stream conditions (Rhodes and Baker 2008), anticipating conflict in any further terrestrial work. But in some cases, additional ground disturbance linked to forest thinning and fuels management could be minor relative to past effects of fragmentation or watershed disruption. It could be opportune to use existing road networks to support forest restoration in one area, while restoring hydrologic and biological connectivity through road obliteration and barrier removal in another (Rieman et al. 2000, Brown et al. 2004). If efforts to restore one system could simultaneously encourage interest or leverage capacity to restore the other (e.g., by sharing limited planning or capital resources), benefits could be greater than those realized working alone.
- Many headwater streams are prone to large floods or debris flows triggered by wildfire and storms that follow. Large habitat networks can often absorb and benefit ecologically from such events (Reeves et al. 1995), but small, isolated systems will be more vulnerable (Dunham et al. 2003, Rieman et al. 2003). Aquatic management objectives may tend toward control in the latter case (e.g., Brown et al. 2001). When these conditions overlap with an interest in controlling fire for other reasons (e.g., near urban areas; lower left cell, table 1), aggressive fuels management or fire suppression to mitigate the extent of severe fire effects (Reinhardt et al. 2008) could reflect a convergence in management objectives.

In these examples, we suggest that spatial and temporal convergence in management objectives can present opportunities for collaboration (table 1). Conflict appears more likely when management objectives for different resources diverge; for example, where forest managers are eager to restore forest structure, composition, and fuel conditions and aquatic managers are concerned with controlling any further activity on the ground (middle cell, right column, table 1). Opportunity might still be found, however, through even higher-resolution analyses. For example, within the range of critical habitat for sensitive species, not all stream segments and contributing hillslopes will be hydrologically connected or sensitive to activities like road maintenance and forest thinning (Luce and Wemple 2001, Benda et al. 2007). A compromise may be to reduce continuous fuels with patchy treatments rather than to treat it all (Hessburg and Agee 2003, Finney et al. 2007, Lehmkuhl et al. 2007). Because changes in fuels and forest structure have been most widespread in the lower- and mid-elevation forests (Hessburg and Agee 2003, Hessburg et al. 2005), the opportunity may be widespread for treatment in terrestrial and aquatic systems without direct conflict. Low-elevation-facing drainages that contribute to larger mainstem rivers or the lower and unconfined reaches of tributary streams are less likely to be closely linked to critical spawning and rearing habitats for sensitive headwater and cold-water fish species. In such cases, it may be opportune to break up the continuity of fuels away from the critical habitats, simultaneously reducing the potential for severe disturbances throughout both systems (Rieman et al. 2000). Opportunities like these could be recognized through the simultaneous evaluation of forest vegetation, sensitive hillslopes and aquatic habitats, and the geomorphic and hydrologic processes that link them (e.g., Istanbulluoglu et al. 2004, Benda et al. 2007). Such opportunities should exist in many landscapes, but more refined analyses may be required to recognize them.

The conditions in terrestrial and aquatic systems will vary with all possible combinations of landform, climate, geology, and history of natural and management-related disturbance (e.g., Hargrove and Hoffman 2005). If these primary controls were largely random and independent, we might anticipate limitless combinations leading to conflict, with little convergence in management objectives. Landscape controls and the histories of terrestrial and aquatic management are not independent, however, and opportunities for convergence in management could be common (Rieman et al. 2000, Brown et al. 2004).

Exploring opportunities

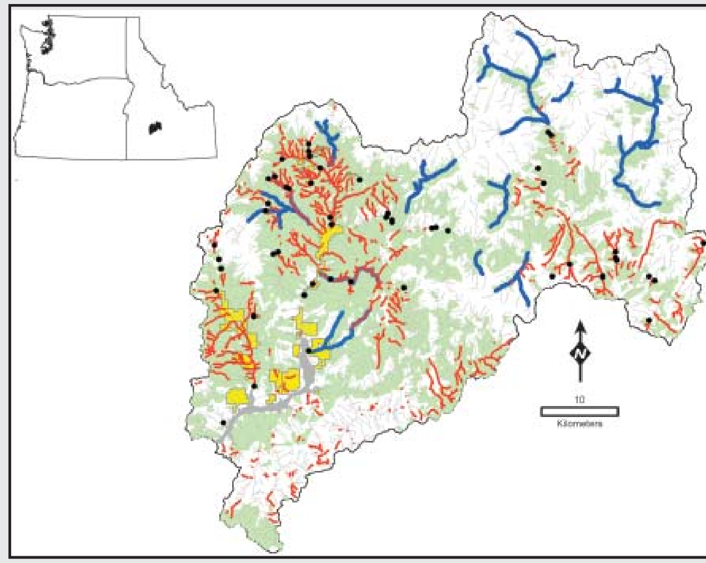
The results of recent efforts to consider fire-related management issues in the South Fork Boise River basin (Luce et al. 2009) indicate that convergence in management objectives could exist over large portions of that basin (box 1). Existing conditions across this landscape will influence where maintenance, restoration, and control will emerge as objectives of forest and aquatic management, and could define spatial domains where opportunities for common solutions also exist. Conflict most likely cannot be eliminated, but if attention is first focused to reveal domains where convergence and conflict are anticipated, collaborative management, planning, and further analyses could become more tractable. By identifying areas where terrestrial and aquatic management can support each other, the domain of areas needing more complex analyses or solutions may be much reduced. More expensive and detailed analysis can be focused where it is needed, reducing costs and facilitating progress unhampered by remaining conflicts or wickedly complex problems.

Summary and conclusions

In this article, we explored a conceptual framework to identify convergence of management solutions for forests, aquatic habitats, and aquatic species such as native fishes influenced by wildfire. We suggest that by considering management goals and contexts, aquatic and terrestrial objectives can be generalized into one of three categories:

Box 1. Mapping conditions that may define goals and objectives in aquatic and terrestrial management to explore the distribution of potential opportunity and conflict.

The South Fork Boise River (SFBR), located in southwestern Idaho, encompasses a variety of forest types, a patchwork of critical habitats for native salmonid fishes, and a range of landscape conditions from nearly pristine to highly altered (see the figure). To explore the potential for convergence in management objectives, Luce and colleagues (2009) considered landscape patterns in five elements: forest type; occupied and potential spawning and rearing habitats for important populations of native trout; stream habitats disrupted by road-related sediment; road-related barriers to fish migration; and boundaries of the wildland-urban interface (WUI), where the protection of human property will often take precedent over ecological concerns. Dry forests in the SFBR are generally mixed conifer, and past effects of fire suppression and exclusion are most apparent there—there was nearly no fire in the basin through most of the 20th century. Goals are likely to reflect both economic values linked to protection of human infrastructure and ecological values that favor functional forests wherever possible. Forest restoration and control are likely to be common objectives in dry forest due to an expanded threat of severe wildfires. Maintenance will probably be more important where dry forest is limited.



The South Fork of the Boise River basin in south-central Idaho encompasses a diverse landscape and a wide range of conditions in terrestrial and aquatic ecosystems that are not independent of each other. In this figure, light green areas represent dry, mixed-conifer forests that most likely diverged from historic conditions through past management; stream segments highlighted in blue represent current critical habitats for sensitive fishes; stream segments in red represent habitats degraded by high sediment levels from high road densities in their watersheds; black dots represent barriers to fish migration associated with road crossings; and yellow areas encompass the wildland-urban interface, where human property is concentrated in proximity to fire-prone forest. A spatially explicit representation of forest and aquatic conditions like this one might be used to begin to explore potential conflicts and opportunities for convergence in forest and aquatic management issues.

Stream segments that support remnant populations of native trout are considered critical habitat for conservation of native populations and gene pools. Introgressive hybridization with nonnative trout is not an important threat; therefore, goals are defined primarily by evolutionary legacies and ecological functions. Aquatic management objectives range from control of any disturbance in small or highly fragmented habitat networks to restoration of more and larger networks in areas that are now degraded to maintenance of existing conditions, depending on the current conditions of the local populations, habitats, and surrounding watersheds. Road-related sediments and barriers are both important constraints on fish habitat and native fish populations and they are an excellent proxy for prior disruption of the aquatic system.

By superimposing these five elements (see the figure), we can begin to consider interrelations and potential for conflict or convergence in forest and aquatic management. Two striking patterns emerge: (1) dry and presumably highly altered forest conditions strongly coincide with high road density and road-related stream disruption, and (2) both of these conditions are particularly concentrated adjacent to or within the WUI. Mid-low elevation forests tend to be the most accessible (lower gradient, adjacent to towns, rivers, and transportation routes), and among the first to be developed. Prior work has shown strong spatial association in the degree of ecological departure of terrestrial and aquatic systems throughout the interior Columbia River basin (Rieman et al. 2000). The result is that intensive human activity has tended to disrupt forest and aquatic systems simultaneously (see also Brown et al. 2004). The implication to us is that management objectives could converge over large areas of the SFBR.

For areas adjacent to and within the WUI, managers will focus largely on fire control and aggressive restoration of surface fire regimes to protect human lives and property. In trout habitats, they will favor either control or restoration strategies because remaining critical populations tend to be small, highly fragmented, and vulnerable. Similarly, there are broad areas in the northeast corner of the basin where both forest and aquatic systems are in good condition. We anticipate that management will tend to converge across landscapes here as well, focusing on maintenance of ecological process. This could be a primary area for wildland fire use. Conditions are more mixed and patchy throughout the remainder of the basin. Opportunities for convergence in restoration could be common, but these are areas where objectives also may conflict, and higher-resolution analysis may be needed to define conflicts and opportunities.

- Maintenance of ecological processes, where management objectives are to facilitate or conserve function in systems that are already considered healthy and sustainable;
- Restoration, where management is focused on having systems emulate or move toward more natural conditions; and
- Control, where management is focused on intensive manipulation to maintain systems in a particular state that could not be sustained if direct intervention were stopped.

We believe that potential opportunities and conflicts in management can be illuminated by spatially explicit intersection of the objectives defined by terrestrial and aquatic conditions and the context of the landscapes that encompass them. New analytical tools and the capacity of geographic information system–based analyses that consider the biophysical processes linking terrestrial and aquatic systems should make it possible to explore the possibilities in a spatially extensive and explicit way. In our experience, management of forest and aquatic systems is often focused independently, constraining potential benefits that might be derived from broader context and collaboration. We hypothesize that there will be a substantial area of opportunity for more convergent solutions to management of terrestrial and aquatic ecosystems and that opportunity will vary along gradients of climate, geomorphology, and past human disruption. Because the health and function of forests are strongly linked to the health and function of streams and sensitive aquatic populations and communities such as native fish species, finding opportunities for common solutions in management is important.

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