A social–ecological perspective for riverscape management in the Columbia River Basin

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Riverscapes are complex, landscape-scale mosaics of connected river and stream habitats embedded in diverse ecological and socioeconomic settings. Social–ecological interactions among stakeholders often complicate natural-resource conservation and management of riverscapes. The management challenges posed by the conservation and restoration of wild salmonid populations in the Columbia River Basin (CRB) of western North America are one such example. Because of their ecological, cultural, and socioeconomic importance, salmonids present a complex management landscape due to interacting environmental factors (eg climate change, invasive species) as well as socioeconomic and political factors (eg dams, hatcheries, land-use change, transboundary agreements). Many of the problems in the CRB can be linked to social–ecological interactions occurring within integrated ecological, human–social, and regional–climatic spheres. Future management and conservation of salmonid populations therefore depends on how well the issues are understood and whether they can be resolved through effective communication and collaboration among ecologists, social scientists, stakeholders, and policy makers.

In a nutshell:
- Riverine landscapes (riverscapes) are interconnected freshwater habitats that are commonly associated with diverse ecological, socioeconomic, and cultural systems
- Conservation of these systems requires consideration of interacting and often competing ecological and social factors and values
- Empirical findings from ecological and social disciplines highlight the critical need for ecologists to communicate and interact more effectively with social scientists, managers, and stakeholders to find sustainable approaches and solutions to natural-resource management
- Here, we demonstrate the importance of social–ecological perspectives when communicating conservation values and goals, and the role of independent science in guiding management policy and practice for salmonids in the Columbia River Basin

In the early 1800s, Lewis and Clark described an ecologically diverse and biologically productive riverscape in the Pacific Northwest – the Columbia River Basin (CRB): “The multitude of this fish (salmon), indeed, are almost inconceivable” (Lewis et al. 1814). As Euro-American explorers and settlers began moving westward at the turn of the 19th century, so too did the destruction of these riverscapes. The construction of 56 major hydroelectric dams on numerous mainstem rivers within the CRB since the 1930s has fragmented this riverscape and severed connections between critical habitats of migratory salmonids (salmon, trout, and char). Extensive urbanization along rivers and floodplains, along with the widespread release of hatchery-raised fish, have also contributed to the decline and extirpation of several salmon and steelhead (Oncorhynchus mykiss) stocks, resulting in the listing of several species and distinct populations under the US Endangered Species Act (ESA). Other human activities, such as overfishing, pollution, agriculture, grazing of rangelands, logging, railroads, skiing and draining of river floodplains, beaver (Castor canadensis) eradication, mining, and the introduction of non-native species, have also had detrimental impacts on the CRB (Lichatowich 2001; Rieman et al. 2015).

At present, the CRB is one of the most heavily managed river basins in the world. Bernhardt et al. (2005) estimated that, since 1990, more than $1 billion has been spent annually on river restoration throughout the US with many projects focusing on degraded riverscapes in the Pacific Northwest, including the CRB. For example, the Northwest Power and Conservation Council’s fish and wildlife program cost $782 million in 2014 and $757 million in 2015, which included funds for the protection of migrating fish through investments in improving fish passage and hatchery production, and general acquisition
and restoration of habitat; similar amounts have been
dedicated annually to native fish restoration over the
three decades since the Northwest Power Planning Act
was approved by Congress (NPCC 2014, 2015).

Although river restoration has received a great deal of
attention and funding, research has suggested that habi-
tat quantity and the quality of headwaters has not been a
limiting factor for salmon productivity and population
recovery. This is especially true where the shifting habitat
mosaic – the ever-changing patchwork of different envi-
ronmental conditions in naturally functioning river
floodplains that drive salmon productivity and species
biodiversity (Stanford et al. 2005b; Hauer et al. 2016) – of
riverscapes is intact (Bernhardt et al. 2005; Stanford et al.
2005b). Rather, ongoing issues, such as mainstem pas-
sage, hatchery introgression, and overfishing, are compro-
mising natural stocking of the habitats that do remain
functional (Lichatowich 2001; Lichatowich and Williams
2009). The enormous economic and ecological costs of
current management practices in the CRB lead to several
fundamental questions: are these practices realistically
sustainable into the future? If evidence of successful resto-
ration outcomes is lacking or if substantial evidence
exists that some of these practices threaten the persist-
ence of naturally functioning riverscapes (Raymond
1988; Levin et al. 2001; Bernhardt et al. 2005), why
should such adverse practices be continued? Is the con-
ceptual foundation for current restoration actions flawed,
in that it focuses on broad-scale applications, such as
salmon hatcheries and mixed stock fisheries, instead of
place-based actions that are responsive to the natural
attributes of locally adapted populations and communi-
ties (Lichatowich et al. 2017)?

Open communication is central to answering these
questions, but communication among ecologists, decision
makers, and the general public can be challenging because
the CRB is embedded in multiple levels of social, cultural,
and economic organization. This complexity cannot be
navigated by unidimensional or linear thinking, nor does
there exist a straightforward course of action (Brondizio
et al. 2009; Halliday and Glaser 2011). Maintaining eco-
system structure and function in the CRB is dependent on
sound ecological reasoning that is sometimes ignored in
the socioeconomic realm, where important ecological
conditions in naturally functioning riverscapes is intact (Bernhardt et al. 2005; Stanford et al. 2005b). Rather, ongoing issues, such as mainstem passage, hatchery introgression, and overfishing, are compromising natural stocking of the habitats that do remain functional (Lichatowich 2001; Lichatowich and Williams 2009). The enormous economic and ecological costs of current management practices in the CRB lead to several fundamental questions: are these practices realistically sustainable into the future? If evidence of successful restoration outcomes is lacking or if substantial evidence exists that some of these practices threaten the persistence of naturally functioning riverscapes (Raymond 1988; Levin et al. 2001; Bernhardt et al. 2005), why should such adverse practices be continued? Is the conceptual foundation for current restoration actions flawed, in that it focuses on broad-scale applications, such as salmon hatcheries and mixed stock fisheries, instead of place-based actions that are responsive to the natural attributes of locally adapted populations and communities (Lichatowich et al. 2017)?

Open communication is central to answering these questions, but communication among ecologists, decision makers, and the general public can be challenging because the CRB is embedded in multiple levels of social, cultural, and economic organization. This complexity cannot be navigated by unidimensional or linear thinking, nor does there exist a straightforward course of action (Brondizio et al. 2009; Halliday and Glaser 2011). Maintaining ecosystem structure and function in the CRB is dependent on sound ecological reasoning that is sometimes ignored in the socioeconomic realm, where important ecological findings can be compartmentalized and rejected as too idealistic or infeasible in practice. On the other hand, more ecocentric and biocentric ecosystem-focused management and language can be seen to diminish or even provoke those with conflicting sociocultural and economic values (Yaffee 1999; De Lucia 2015).

Here, we illustrate the need for understanding complex problems in the CRB from a social–ecological perspective. For each problem, we describe the social, economic, and ecological challenges faced by decision makers, and include, where relevant, examples of management deci-
sions that were based on ecological research, and put into practice despite political and public opposition. We also discuss the role of new ecological techniques and approaches that might improve our understanding of the ecological ramifications of each problem, and show how adaptive management can provide valuable insights that will help to develop a better balance between ecological and socioeconomic concerns.

### A social–ecological perspective in the CRB

Conflicts between the public, politicians, and ecologists can often be attributed to the complexity of the problems they are attempting to solve, in that they have no immediate or straightforward solution (Rittel and Webber 1973; Brown et al. 2010). Ecologists are used to solving problems that are based on hypothesis-driven questions and issues that are binary in nature (prove or disprove). However, the environmental issues associated with CRB riverscapes are deeply intertwined with political and public discord, the loss of jobs, and potentially severe economic or ecological consequences that are often disproportionately distributed across social groups. In short, the CRB is anything but a straightforward problem, and there is a lot at stake for diverse groups of stakeholders.

Scientists have increasingly come to realize that complicated issues cannot be addressed by a single disciplinary approach but instead require integrative, interdisciplinary consideration and collaboration (Warren 1979; Binder et al. 2013). In broadest terms, a social–ecological perspective is required to fully understand key processes and linkages between people and nature (Folke et al. 2000). In the CRB, there is a need for recovery strategies that prioritize the allocation of funding and enactment of regulations to protect riverscapes of high social value and high ecological vulnerability (Palmer 2012). Such a perspective can aid understanding of the multifaceted and multidimensional interface among ecologists, stakeholders, and the general public by clarifying the seeming disconnects between ecological health and social demands (Anderies and Janssen 2013). Although the phrase “social–ecological systems framework” is often attributed to the “SES Club” of researchers focused on institutional and governance organization related to resources (McGinnis and Ostrom 2014), here we refer to social–ecological systems and thinking in a broad, integrative sense (Redman et al. 2004).

To better understand the complicated issues in the CRB, we envision a nested conceptual structure linking major operating and interacting elements into three major spheres: the ecological setting, the human–social setting, and the regional–climatic setting (Figure 1). In basic terms, the ecological setting provides ecosystem services (eg clean water, fish and wildlife, commercial and recreational opportunities) to humans (Figure 1). The ecological setting is nested within the human–social setting, which also includes multiple interacting and often opposing forces, such as the laws and policies that govern resource management, local-to-global economic concerns (eg to economize the ecological setting or to...
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Complex problems in the CRB: the dynamics of social–ecological interactions

Hydrological dams

Large dams are increasingly viewed as problematic due to environmental, social, and economic concerns (McCully 2001; Scudder 2006). Some dams in the CRB have a history of local interests and needs overriding regional and system-wide sustainability of natural resources. Although dams have created economic boons in some regions, and are critical for providing power generation, flood-risk management, and water for irrigation over much of the Pacific Northwest, these dams have negatively affected wild fish populations in the CRB for over a century, and contributed substantially to the severe declines in anadromous fish populations that occurred during the latter part of the 20th century (Williams et al. 1989; Stanford et al. 2005a). Declines in wild salmon and steelhead runs, as well as increased smolt and adult migration mortality, have been attributed to habitat alteration (Raymond 1988; Kareiva et al. 2000) and warming water temperatures (Stanford et al. 2005a) associated with dams along the Columbia and Snake rivers. In addition to ecological knowledge, future sustainable management of wild anadromous fish populations will therefore require integrating economic, fiscal, engineering, and social–political analytic expertise into management strategies. One management and policy change proposed in recent years is the removal of dams that are no longer of critical importance throughout the CRB. However, this has proven to be very difficult to implement, due to strong political resistance and a poor understanding of the ecological and social pros and cons of dam removal, including the relatively high economic costs of refurbishing physically obsolete dams that are not removed. For example, the largest dam removal project in history (the Elwha Dam in Washington State, in 2011–2012; Panel 1), was only initiated following 20 years of rancorous debate, and shifts in both political regimes and perspectives (Nijhuis 2014).

Another social–ecological issue complicating river and fisheries management is the transference of dam ownership from private to tribal interests, which may alter priorities and outcomes regarding water releases. Salmon and steelhead recovery programs have called for late

Figure 1. Interconnected social–ecological relationships of riverscapes (dotted line) in relation to regional conditions. Riverscapes are nested within three major and increasingly broad settings, consisting of the ecological, the human–social, and the regional–climatic. Interactions are multidirectional between the human–social setting and the ecological setting, whereas the regional–climatic setting operates largely independent of the human–social and ecological settings.
summer flow augmentation intended to assist with the outmigration of smolts; however, summer flow augmentation produces higher flows during the summer months, which greatly reduces the quantity and availability of critical habitats for resident (freshwater) salmonids, including threatened bull trout (Salvelinus confluentus), in the headwaters of the CRB (Muhlfeld et al. 2012). A social–ecological perspective is essential in balancing the ecological and socioeconomic trade-offs of flow augmentation for anadromous and resident fish recovery with power and flood control management.

**Hatchery augmentation and supplementation**

Hatcheries were initially prescribed as a solution to the loss of spawning and rearing habitat caused by the installation of hydroelectric dams in the CRB. Currently, more than 200 hatcheries are used to supplement the natural reproduction of anadromous fish lost due to the construction and operation of dams. Collectively, these hatcheries cost over $50 million per year to operate, and produce 130–150 million juvenile salmon and steelhead annually (Naiman et al. 2012; Rieman et al. 2015). These fish are released into the CRB with the intention that they will find their way to the ocean to mature and then return as adult fish to their hatchery of origin. Although most hatchery programs are designed to produce fish for harvest, captive breeding programs have been widely used for conservation of critically endangered species and restoration of declining natural populations (Frankham 2008). However, hatchery-raised fish commonly interbreed with natural fish populations and their offspring may have reduced fitness in comparison with wild fish, owing to unintentional artificial selection and relaxation of natural selection in the hatchery environment (Fleming et al. 2000; Araki et al. 2007). Recent studies suggest that supplemental gene flow between wild and hatchery populations might help to reduce genetic divergence over the short term compared to segregated hatchery management (Hess et al. 2012; Waters et al. 2015), but the release of large numbers of hatchery fish also has inherent ecological consequences (eg competition, predation, displacement, behavioral alterations) for wild fish that may not be fully addressed by genetic mitigation measures (Levin et al. 2001; Chilcote et al. 2011).

Ecological research helped fisheries management come to a highly criticized and controversial management decision in Montana in 1974, in which Montana Fish and Game resolved to end trout stocking in streams and rivers that already supported populations of wild trout (Anonymous 2004). Vincent (1987) found that cessation of stocking hatchery-raised trout in the Madison River dramatically increased trout abundance (>10 inches, by 213%) and size (by eight- to 10-fold) within 4 years post stocking. In contrast, the introduction of hatchery fish into O’Dell Creek, a previously unstocked stream, resulted in wild trout numbers and biomass declining by almost 50% (Vincent 1987). Although at the time this change in management strategy was highly controversial, and was opposed by anglers, fishing-related businesses, and even some members of Montana Fish and Game itself (Anonymous 2004), Montana’s streams and rivers have now been largely free of hatchery stocking for more than 40 years, and support valuable and internationally prized wild trout fisheries.

Montana’s stocking program during the 1970s represents a small fraction of contemporary hatchery operations, which introduce hundreds of millions of fish into the CRB system annually (Paquet et al. 2011; Naiman et al. 2012). Proposed changes in hatchery management and hatchery closures are often subjected to strong cultural and ideological resistance, driven largely by uncertainty about whether natural production would be sufficient to compensate for reductions in hatchery production. Recreational and commercial fishing generate millions of dollars (eg ~$35 million annually in Oregon and Washington combined) in revenue and create thousands of jobs throughout the CRB (NMFS 2014). Recreational fishing is also an important part of the American West’s natural heritage, as well as Native American culture and subsistence (Naish et al. 2007; Lang 2014). Currently, an estimated 80% or more of salmon and steelhead harvested through commercial and
recreational fishing are raised in hatcheries, and large fractions of both state and tribal management budgets are supported by fishing license fees (Naish et al. 2007; Paquet et al. 2011). The complex issues surrounding hatcheries require a social–ecological perspective in order to gain a better understanding of the greatly differing values and potential conflicts that often arise between users (eg commercial fishers, tribal fishers, recreational fishers, conservation groups) and managers (state, tribal, and federal agencies). Communication grounded in such a perspective could help guide policy and management to determine where reformulation of hatchery policies and practices could prove most beneficial and transformative.

Climate change

The ecological and evolutionary characteristics of steelhead and salmon are strongly influenced by climatic conditions through population-specific adaptations to elevated water temperatures and streamflow regimes (Jonsson and Jonsson 2009). Ongoing and future changes in climate, in the form of increased water temperatures and intensification of drought conditions (Figure 2; Panel 2) are expected to further impact wild fish populations as streamflow and temperature regimes continue to shift in the coming decades (Beechie et al. 2013; Wade et al. 2016). In comparison to other river basins in the Pacific Rim, the CRB ranks among those considered most vulnerable to climate change (Figure 3; Whited et al. 2012).

New conservation approaches like riverscape genetics (eg the study of neutral patterns of genetic differentiation to describe the interaction between environment and evolutionary processes such as gene flow) can reveal how population genetic diversity of aquatic species is related to and potentially influenced by such environmental factors as stream flow and temperature (Hand et al. 2016; Scribner et al. 2016). The results of recent riverscape genetic studies have important management implications, including the finding that genetic diversity and connectivity of fish populations in the CRB are more highly correlated with and likely dependent on climatic variables (Matala et al. 2014; Hecht et al. 2015; Kovach et al. 2015; Hand et al. 2016). Climate change also has implications for the spread of human-mediated hybridization between native and non-native salmonids; for instance, smaller and earlier spring streamflows and warmer stream temperatures are hastening the spread of invasive non-native rainbow trout and native westslope cutthroat trout (Oncorhynchus clarkii lewisi) hybrids in the upper CRB (Muhlfeld et al. 2014).

Incorporating landscape genetic data into management strategies is challenging, as this requires effective

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**Figure 3.** (a) Overall ranking of North Pacific Rim watersheds based on their physical freshwater habitat complexity and relative human impact. The Riverscape Analysis Project geodatabase rankings (rap.ntsg.umt.edu) indicate that the CRB scores on the low end of relative riverine quality habitat. Continental US watersheds are ranked lower due to relatively less available floodplain habitat and greater human impact. (b) Example regional ranking of Columbia Basin salmon vulnerability based on physical habitat metrics and potential habitat vulnerability to projected climate change; northern subwatersheds are relatively more resilient to climate change due to greater habitat abundance and cooler predicted stream temperatures, although dams currently restrict fish access to many headwater streams. (Figure and caption reprinted from Whited et al. [2012] by permission of the American Fisheries Society, www.fisheries.org.)
Panel 1. Dam removal outside of the CRB: the Elwha Dam

Although outside of the CRB, the recent removal of two dams on the lower Elwha River in Washington State illustrates the dual legacies of dam building and reliance on hatchery production that have created obstacles to wild fish recovery (Figure 4). The Elwha River catchment encompasses ~500 km², of which approximately 430 km² is within Olympic National Park, and most of which is designated as wilderness area under the Wilderness Act. The Elwha Dam was originally built in 1914, followed by a second dam (Glines Canyon Dam) in 1929, to power a local pulp and paper mill. The dam lacked any fish passage structures, thus blocking anadromous fish access to 110 km of high-quality spawning and rearing habitat upstream of the dam, and confining the remnant populations to the lower reaches of the river. The dam was built in violation of existing state law requiring full fish passage (Brown 1995). After dam construction was underway, the Washington State legislature passed the “Hatchery Lieu Law”, which stated that if fish passage was not or could not be provided, lost salmon production had to be replaced by hatchery supplementation (Brown 1995).

Prior to dam construction, nearly 400,000 salmon and steelhead returned annually to the Elwha. The ensuing 100 years of hatchery production, primarily of Chinook salmon (Oncorhynchus tshawytscha), failed to restore returning salmon abundance to that of the pre-dam period. In 1992, Congress passed the Elwha River Ecosystem and Fisheries Restoration Act (the “Elwha Act”) authorizing the acquisition and removal of the two dams. Funding for the dam removal was finally secured in 2010, with Elwha Dam deconstruction beginning in September of 2011; removal of both dams was completed by September 2014.

The removal of the two dams has provided a unique opportunity to evaluate the prevailing management hypothesis that the principal factor causing the decline and continued depression of salmon populations in the Pacific Northwest is impaired freshwater habitat conditions. Woody debris and riparian vegetation are rapidly re-establishing upstream of the dam removals, along with rapid recolonization by anadromous fish (McMillan et al. 2015). However, a new hatchery facility and expanded hatchery production of Chinook, coho (Oncorhynchus kisutch), chum (Oncorhynchus keta), and pink (Oncorhynchus gorbuscha) salmon, as well as steelhead (>7,000,000 juveniles annually), has also been initiated; legitimate concern exists as to whether hatchery production will accelerate or slow recovery through reduced reproductive success resulting from interbreeding, ecological competition, and increased predation (Naish et al. 2007; Berntson et al. 2011; Chilcote et al. 2011; Christie et al. 2014). Moreover, construction and operation of salmon and steelhead hatcheries as a presumed prescription for restoration has resulted in a reduction in the amount of funding available for monitoring the process of natural recovery of Elwha salmon and steelhead, and has led to multiple lawsuits aimed at halting or reducing ongoing and planned hatchery production. The role of salmonid hatcheries in habitat restoration projects like the Elwha and throughout the CRB remains a substantial and expensive science–management dispute that requires a social–ecological perspective (Figure 1) for resolution.

Aquatic invasive species

Aquatic invasive species are among the biggest threats to the aquatic biodiversity of and ecosystem services provided by the CRB, as these species can disrupt human and ecological systems through numerous ecological and evolutionary pathways. Consideration of social–ecological interactions is important when addressing this ongoing and impending problem for multiple reasons. For example, unintentional (eg transport via recreational vehicles) or intentional (eg via “bucket biologists”) introductions of invasive species have enormous economic and ecological consequences. Species such as quagga (Dreissena rostriformis bugensis) and zebra (Dreissena polymorpha) mussels have the potential to cause substantial ecological and economic damage over the long term; cost estimates for the state of Idaho alone amounted to ~$95 million if these species were to become established in the state (WPR-ANS 2010). Invasive species may also have irreversible and far-reaching ecological effects on entire natural communities, food-web dynamics (Ellis et al. 2011), and intra- and interspecific species interactions, including predation, competition, hybridization, and disease transmission (Rahel 2000; Muhlfeld et al. 2009).
Application of environmental DNA (eDNA) analyses has great potential to aid in the early detection of aquatic invasive species, including quagga and zebra mussels (Bohmann et al. 2014). In some cases, early detection could lead to successful control or eradication of recently established populations prior to their expansion into new environments. Recent advances in eDNA techniques may also enable future monitoring of species abundance at a lower cost and with less intrusive sampling than current methods (eg Lacoursière-Roussel et al. 2016).

Citizen-science initiatives are a potential means for the public to take part in monitoring of aquatic invasive species (Cohn 2008; Biggs et al. 2014). Citizen science offers a platform for informing the general public and managers of important ecological processes and the potential consequences of aquatic invasive species introductions. Technology plays an ever-increasing role in conservation, as the ability to record and share high-resolution images, times, dates, and GPS-located coordinates allows smartphone users to essentially act as several hundreds or thousands of additional field observers (Pimm et al. 2015). Through concentrated efforts by state fish and game agencies, and federal agencies (eg National Aeronautics and Space Administration, US Geological Survey, US Forest Service, etc), citizen scientists could aid in the day-to-day observations of native (eg TroutBlitz; www.tu.org/tu-projects/trout-unlimited-troutblitz) and non-native species, and to record the introduction and spread of aquatic invasive species, among other as yet unforeseen uses of advancing technologies.

**Transboundary issues in the headwaters**

The headwaters of the CRB span the US–Canada border, posing additional challenges for stakeholder negotiations and transboundary agreements. River floodplains in the CRB headwaters are among the most biodiverse landscapes on the planet, but are also among the most endangered due to accelerating climate warming and the legacy effects of mining, urbanization, dams, logging, and agriculture (Tockner and Stanford 2002; Hauer et al. 2016). Mining activities in these relatively intact landscapes offer a high potential economic payoff at the ecological expense of far-reaching and long-lasting impacts to downstream aquatic and terrestrial ecosystems. As our understanding of these impacts on shared natural resources increases, the impetus for preserving these wild areas of high importance has also grown. For example, ecological research played a central role in providing the necessary information for the development of natural-resource policy protecting the international Flathead River from mining (Hauer and Muhlfeld 2010; Hauer and Sexton 2010). The Flathead, which originates in the Canadian province of British Columbia and flows into Montana via Glacier National Park, a World Heritage Site and Biosphere Reserve, is considered one of the wildest rivers in the US.

The Flathead has been under threat from proposals for coal strip-mining and coal-bed methane development projects in the Canadian headwaters since the 1970s. A comparison of data collected from mined and undisturbed sites showed that mine-affected waters were significantly more polluted and lower in biodiversity (Hauer and Muhlfeld 2010; Hauer and Sexton 2010). In 2010, British Columbia and Montana signed an accord to prohibit coal mining, coal-bed methane extraction, and oil and gas exploration and development in the transboundary Flathead River, with the only stipulation being $10 million in compensation to the mining companies to offset exploration costs. The Nature Conservancy in the US and Canada led efforts to raise the funds needed to save nearly 400,000 acres of wildlands and help protect the pristine water quality of the Flathead. The termination of mining activities in the Flathead headwaters is one example of a successful international collaborative effort among scientists, politicians, nonprofit groups, and the natural-resource extraction industry to protect a remarkable, shared ecosystem.

- Potential future directions in riverscape management

**Policy reform and open communication**

Ecological research is not always integrated into policy dealing with complex problems and competing agendas (Likens 2010). Scientists can assist in the process by assuming a more creative and formative role, in which they are actively engaged in helping to inform social decisions about ongoing and future natural-resource management issues (Palmer 2012). More sustainable outcomes might be achieved through truly collaborative efforts, which are more effective in establishing balances among the shared and conflicting interests of diverse stakeholders based on ecological, social, and economic considerations. Science can help inform ultimate outcomes, particularly when communicated clearly using a stepwise, incremental sequence of decisions and actions to achieve deliberate policy and environmental change. Open public forums involving both stakeholders and ecologists can facilitate multidirectional, mixed knowledge communication and shared learning to systematically improve management practices (Pahl-Wostl 2007). The integration of local and professional knowledge with scientific knowledge is an important way not only to understand complex systems, but also to identify possible pathways for sustainable change.

There is a need for policy reform, starting with clear and attainable conservation goals, along with conservation practices that produce quantifiable results (eg pursuant to laws like the ESA) that can be evaluated objectively through independent science. A potentially powerful approach to better inform policy and resource management in the CRB would be to pursue a process in
Panel 2. Climate change in the Lapwai Creek watershed

The effects of global climate change on mountainous headwater rivers of the inland Northwest are likely to have unpredictable consequences for native salmonids. In the Idaho headwaters of the CRB, rapid alteration to riverscapes that serve as habitat and migratory corridors for steelhead will have multifaceted impacts on their migratory behavior, with important consequences for steelhead population abundance and management.

The Lapwai Creek watershed provides critical habitat for a distinct subpopulation of steelhead that contributes a unique element of life-history diversity in the Snake River, and represents a watershed with a diverse set of socioecological drivers (Figure 5). The Lapwai watershed is located almost entirely within the Nez Perce reservation, in a region that depends on irrigation water in the dry and warm summer months, during which fish are often subjected to stream temperatures approaching their maximum thermal tolerance (Myrvold and Kennedy 2015b).

Since 1906, a system of irrigation canals and reservoirs within the Lapwai Creek watershed have stored and delivered a significant amount of streamflow out of the basin to the city of Lewiston, Idaho, first for agricultural demands but more recently to support growing domestic consumption by an expanding urban center. Prior to the ESA listing of Snake River steelhead populations, the system was likely dewatered during the dry parts of most years, making it inhospitable for juvenile salmon and steelhead. However, protection status, the increased ability of the Nez Perce tribe to bring legal action, and a heightening awareness of the unique life history types present in the basin, have resulted in the establishment of minimum flows for steelhead.

Intensive monitoring of steelhead populations across the basin since 2008 has revealed a complex spatial pattern of density dependence, growth, survival, and migratory behavior in this heterogeneous riverscape (Hartson and Kennedy 2015; Myrvold and Kennedy 2015b,c). Overall, steelhead juvenile density appears to be strongly impacted by hydrologic withdrawal, but lower water levels seen in many years in these areas have also led to increased growth and survival of juvenile steelhead that are released from density pressures (Hartson and Kennedy 2015). Apparent increases in individual performance at impacted sites is also likely a function of an unforeseen cooling effect that the irrigation system has on stream temperatures (Myrvold and Kennedy 2015a,b) – a process that was critically important in several unusually warm years between 2008 and 2015 (Hartson and Kennedy 2015) but which may come at a cost at the population level. Although individual growth rates have responded positively to cooler waters, the net result has been a decrease in steelhead life-history diversity. In a warm system with vulnerabilities to climate change, one effect of a century-old hydrologic alteration was the artificial selection for residency in a historically migrant steelhead population.

Reduction in life-history diversity associated with environmental change could have negative consequences for future salmonid populations, as life-history diversity can buffer populations from evolving environmental and ecological conditions and increase viability (Greene et al. 2010; Schindler et al. 2010; Moore et al. 2014). In addition to being a contentious sociocultural issue, the Lapwai Creek system requires an integrative riverscape approach (Figure 1) to understand how system alterations have transformed not only the habitat but also the fitness landscape for a threatened organism that has evolved with multiple and complex life-histories. Moreover, proposed solutions for the local population issue may worsen the situation for steelhead at the larger scale and transfer the ecological risks to other parts of the basin.

which management stakeholders collaborate with scientists to identify and prioritize questions that are relevant to sustainable conservation management (eg the human–social sphere depicted in Figure 1; Palmer 2012). Establishing an environment of shared understanding and goal-setting in riverscape management increases the likelihood that the results of ecological research are mindful of socioeconomic needs, and the potential for such research to have a positive impact on management and governance (Daniels and Walker 2012). General scientific inquiry that is outside of the immediate interests of management stakeholders will always play a critical role beyond the specific focus of mission-oriented research (our major focus here), by bringing new methods, information, and perspectives to refresh our understanding of ecosystems and their organization.

New technologies

New approaches that arise as a result of technological advances (eg crowdsourcing, citizen science) offer improved monitoring and observation of wild populations in conservation science (Pimm et al. 2015). Although integration of genomic data into conservation practices must be further advanced (Shafer et al. 2015), there are a growing number of promising examples of
the role genomics will play in the future of conservation management (Garner et al. 2016). In addition, the growing availability of environmental data from ground-based and remotely sensed data products (e.g. https://earthdata.nasa.gov), including ever-expanding climate-related and land-use time-series datasets, offers unprecedented opportunities to identify, monitor, and predict species abundance in response to environmental changes (e.g. lifemapper.org). With the advent of web-based analytic and decision tools (e.g. see www.congressgenetics.eu [Hoban et al. 2013]; rap.ntsg.umt.edu [Whited et al. 2012]), we have only seen a fraction of the potential for fundamental changes in the accessibility, flow, and presentation of scientific information to managers, decision makers, and the public.

Conclusions

Social–ecological thinking is important for understanding politically sensitive, volatile, or gridlocked situations in which social, cultural, and economic demands and norms may be at odds with ecological understanding and management of threatened species and ecosystems. One of the greatest needs in decision management is to better clarify the ways in which different factions and interests can contribute to the framing and analysis of a resource problem. Complex problems are transdisciplinary in nature and require effective communication among stakeholders and scientists (Hadorn et al. 2008); this need for better communication has become clear because of convoluted processes such as the one that leads to the removal of unproductive dams. New technologies in the realms of information sharing (e.g. crowdsourcing) and data collection (e.g. citizen scientists) offer opportunities for increasing the integration and dissemination of ecological research into and throughout the human–social sphere. However, much work remains to be done to restore and manage the natural resources of the CRB, and this will require new and creative forms of cooperation among ecologists, social scientists, and stakeholders to sustain and rebuild human and natural ecosystems into the future.

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References


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