Cattle grazing and fish recovery on US federal lands: can social–ecological systems science help?

Susan Charnley[1]*, Hannah Gosnell[2], Kendra L Wendel[1], Mary M Rowland[3], and Michael J Wisdom[3]

In the western US, grazing management on federal lands containing habitat for fish species listed under the US Endangered Species Act (ESA) has sparked social conflict and litigation for decades. To date, the problem has been addressed through a top-down environmental governance system, but rangeland managers and grazing permittees now believe there is a need for more innovative management strategies. This article explores how social–ecological systems (SES) science can address rangeland management challenges associated with the survival and recovery of ESA-listed fish species on federal lands where cattle grazing is a dominant type of land use. We focus on the Blue Mountains of eastern Oregon, where the Mountain Social Ecological Observatory Network's Blue Mountains Working Group is collaborating with diverse stakeholders to develop and test a novel grazing system designed to reduce the impact of cattle on riparian areas using an SES science approach. Although not a complete solution, SES science holds promise for improving rangeland management.

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This article explores how social–ecological systems (SES) science can help improve grazing management and promote the survival and recovery of threatened and endangered fish in stream systems on federal lands in the western US. Specifically, we describe how SES science is being used to better understand the problem, solicit stakeholder insights into potential solutions, and develop and test management innovations that aim to improve compatibility of cattle grazing and recovery of Endangered Species Act (ESA)-listed fish on federally managed rangelands in the Blue Mountains ecoregion of eastern Oregon (Figure 1). Since the 1990s, when several salmonids (*Oncorhynchus* spp and bull trout, *Salvelinus confluentus*) inhabiting streams in the Blue Mountains were first listed under the ESA, the question of how to manage livestock grazing in the region's national forests while simultaneously protecting and restoring habitat for listed fish to promote their recovery (as required by law) has engendered a considerable degree of social divisiveness and litigation.

In a nutshell:

- In Oregon's Blue Mountains, several fish species listed under the US Endangered Species Act (ESA) and cattle that graze on federal lands benefit from healthy riparian resources, making conservation and restoration of riparian ecosystems essential both for promoting fish recovery and sustaining ranching operations
- The rangeland social–ecological system (SES) dynamics that threaten both fish and ranchers in the Blue Mountains are multiscalar and complex
- Grazing on federal lands is a focal point in fish recovery efforts; research by the Blue Mountains Working Group works to identify, develop, and test innovative range management practices to reduce grazing impacts in riparian areas on national forest grazing allotments containing critical fish habitat
- To address resource management challenges, SES science calls for a research environment conducive to experimentation, flexibility in regulatory standards for protecting ESA-listed species, long-term collaboration between researchers, resource managers, and other stakeholders, and financial support from a diverse range of funding sources

The impacts of grazing in riparian areas have been a focal point of the controversy, and of efforts to resolve it. Salmonids require healthy freshwater stream systems, with clear, cold water for spawning and rearing of juvenile fish, and a dynamic and connected mosaic of habitat components that include coarse sediments and woody debris (Torgersen *et al*. 1999; Bisson *et al*. 2009). Riparian areas support healthy fish habitat by providing food and nutrients to aquatic systems, as well as shade (which helps to maintain optimal water temperatures), preventing erosion and sedimentation, and contributing to in-stream habitat diversity (Beschta 1997; Roni *et al*. 2002; Kauffman *et al*. 2004). Cattle that graze on Blue Mountains national forest lands typically use accessible riparian areas for water, thermoregulation, and nutritious forage, the last of which becomes especially important as summer progresses and upland forage senesces (Parsons *et al*. 2003; McInnis and McIver 2009). However, unmanaged grazing can have deleterious effects on riparian and

[1]*US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR* *(scharnley@fs.fed.us); [2]*Oregon State University, College of Earth, Ocean, and Atmospheric Sciences, Corvallis, OR;* [3]*US Department of Agriculture, Forest Service, Pacific Northwest Research Station, La Grande, OR*


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Figure 1. *The Blue Mountains of northeastern Oregon.*

aquatic ecosystems. Thus, conservation and restoration of riparian areas benefit both cattle and fish (Figure 2).

Social scientists and ecologists who are members of the Mountain Social Ecological Observatory Network's Blue Mountains Working Group (including the authors; http://webpages.uidaho.edu/mtnseon/BlueMountains.html) have been conducting research in collaboration with local stakeholders to develop an understanding of SES dynamics influencing the sustainable coexistence of fish and livestock on federal lands in the region, and have developed management experiments to find solutions (some of which are described below). The Blue Mountains serve as a microcosm for ongoing debates in the western US about how to promote the survival and recovery of ESA-listed species while at the same time maintaining working rangelands and ranching communities in the context of climate and land-use changes.

Rangelands and SES science

Historically, rangelands research has largely been within the purview of biophysical scientists, who focused primarily on characterizing rangelands and how they function, determining their carrying capacity for livestock, and developing grazing systems for the prevention of, and recovery from, overgrazing (Sayre *et al.* 2012; Sayre 2017). Not until the 1990s did research on the human dimensions of rangeland management gain prominence (Brunson 2012), and SES approaches to studying rangelands have only recently begun to emerge. Such approaches focus on the interactions and feedbacks between the social and ecological components of ecosystems at multiple spatial and temporal scales in order to identify the drivers of change and their effects on social and ecological processes (Bestelmeyer and Briske 2012; Brunson 2012; Reid *et al.* 2014; Hruska *et al.* 2017). In addition, SES approaches can help to identify the cross-scale social and ecological dynamics operating at national, regional, and local levels that in turn influence natural-resource dynamics and management (Brunson 2012; Smedstad and Gosnell 2013). They also recognize the important roles of disturbance and unpredictability in influencing rangeland ecosystems, assessing ways to promote adaptation to social and ecological change to increase system resilience (Sayre *et al.* 2013; Reid *et al.* 2014; Hruska *et al.* 2017).

Two important insights from SES science are relevant for rangeland management: (1) flexibility of rangeland management institutions – rather than uniform and rigid laws and policies – promotes adaptive management and fosters resilience (ie the capacity of an SES to experience shocks and disturbance but retain essentially the same functions, structure, feedbacks, and identity; Walker *et al.* 2006) to prevent rangeland SES from crossing thresholds and entering into undesirable states; (2) because rangeland management problems are complex, participatory approaches that facilitate the sharing of knowledge and co-development of management solutions among scientists, managers, and other stakeholders have the greatest potential for supporting sustainability and resilience in rangeland SES, using research as a guide (Bestelmeyer and Briske 2012; Brunson 2012; Sayre *et al.* 2012; Reid *et al.* 2014). Although SES science holds promise for improving rangeland management, there are few examples in the published literature illustrating how it has been successfully applied in this context (but see Duvall *et al.* [2017] and case studies in Hruska *et al.* [2017]).

Meetings and interviews

To better understand rangeland SES dynamics and the potential for implementing innovative approaches to address management challenges in the Blue Mountains, we hosted or participated in numerous formal and informal stakeholder meetings between 2012 and 2017. Beginning in July 2015, we also conducted semi-structured interviews with (1) a stratified random sample of ranchers who hold grazing permits ("permittees") in three Blue Mountains national forests; (2) a sample of US Forest Service (USFS) managers at the forest and district levels from the three national forests; and (3) a sample of other stakeholders (eg environmental group personnel, university extension agents, community-based organization representatives, employees from other land management agencies). We stratified the sample of ranchers into four classes, based on number of animal unit months (AUMs; one AUM equals the amount of forage a mature cow and calf consume in a 30-day period, or roughly 354 kg of dry weight; USFS 2014) grazed on USFS allotments using a protocol developed by Greer (1995). Ten permittees were randomly chosen from each class (with the exception of the largest class [> 5000 AUMs], for which all permittees were included due to the small number of ranchers who met this criterion). We also sought representation from across the districts within each national forest. Forest Service interviewees primarily consisted of range-program staff but also included hydrologists and fisheries and wildlife biologists. The interview included topics pertaining to endangered fish species, riparian management, and changes that could promote more sustainable grazing on national forest lands, as well as associated barriers and ways they could be overcome. Interviews were recorded and transcribed; research is ongoing, but as of December 2017 we had completed 63 interviews with ranchers, 26 with agency staff, and seven with other key personnel.

Ranching in the Blue Mountains

The Blue Mountains ecoregion forms a rural, relatively remote landscape where many residents pursue natural resource-based livelihoods associated with forestry, farming, and ranching (USFS 2014). Relatively dry, warm summers and cold, moist winters create a mix of open forests, extensive shrublands, and grasslands (Johnson *et al.* 1994) that historically provided some of the best livestock grazing in the western US (Langston 1995), and that continue to support grazing today. Ranching plays an important role in the regional economy; in 2012, the eight Blue Mountains counties accounted for about 41% of Oregon's beef cattle inventory, and 18% of the statewide sheep and lamb inventory (USDA NASS 2012).

In the Blue Mountains, interactions between cattle and ESA-listed fish species occur across land ownerships. Over half of the land in the region is managed by the federal government, including three national forests (Umatilla, Wallowa-Whitman, and Malheur; Figure 3), where grazing allotments encompass ~70% of the overall area (USFS 2014). As elsewhere in the western US, many ranchers in the region depend on USFS lands for high-elevation summer range, where forage is often highly nutritious (Huntsinger *et al.* 2010). Summer grazing on federal lands also enables ranchers to grow hay on their private lands to feed livestock during the winter or to sell for supplemental income. In the 2015 season, 222 ranchers had permits to graze livestock on 241 grazing allotments in these three national forests from roughly June to October, moving animals seasonally between USFS grazing allotments and their private lands, or to other public or leased lands. In 2015, sheep accounted for ~7% of authorized grazing in the three national forests; however, their impact on riparian areas is small as compared to cattle so we focus on cattle here.

Endangered fish in the Blue Mountains

Stream systems in the Blue Mountains are part of the Columbia River Basin. Historically, these systems supported abundant populations of cold-water fish, including bull trout, steelhead trout (*Oncorhynchus mykiss*), and Chinook (*Oncorhynchus tshawytscha*), coho (*Oncorhynchus kisutch*), and sockeye (*Oncorhynchus nerka*) salmon. Populations of these species have declined dramatically

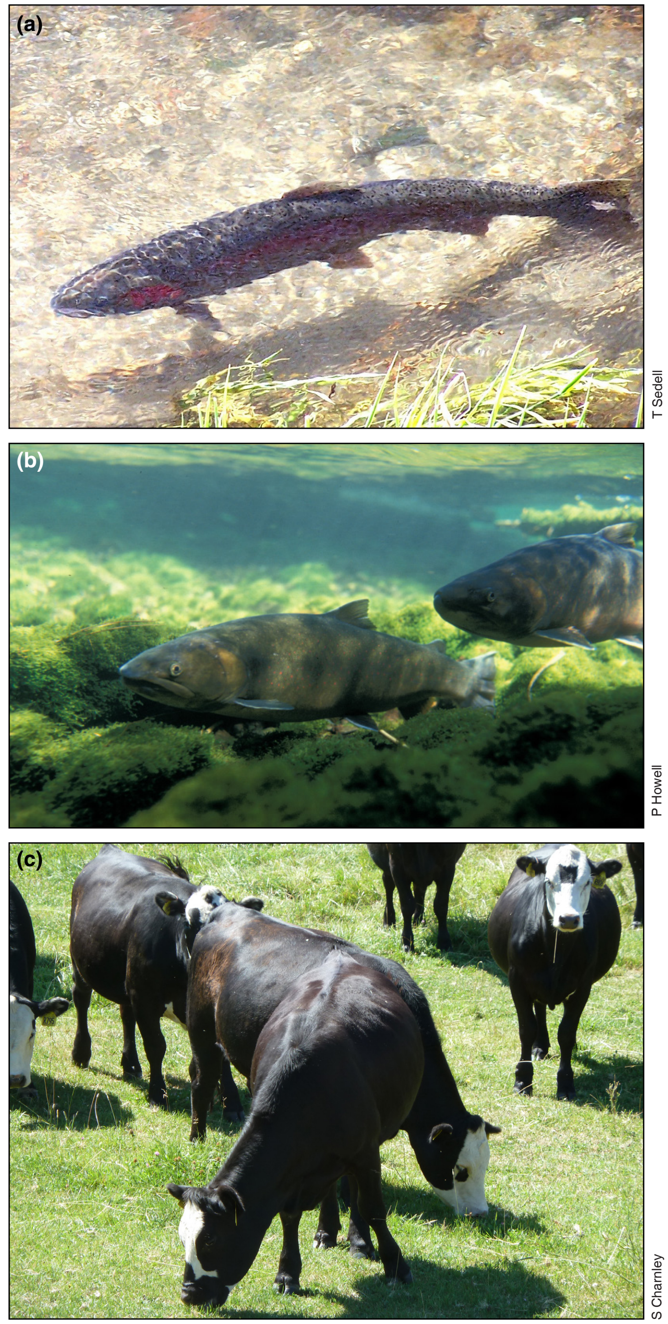

Figure 2. *Spawning fish, such as (a) steelhead and (b) bull trout, and (c) cattle all benefit from healthy riparian systems.*

in the Pacific Northwest, including the Blue Mountains ecoregion, and their ranges have contracted over the past century or so (Rieman *et al.* 1997; Gustafson *et al.* 2007; ICTRT 2010). Currently, six regional subgroups ("evolutionary significant units") of salmonids listed under the ESA are found in Blue Mountains national forests (Table 1).

Many factors operating at different spatiotemporal scales have contributed to the declines in salmonid populations, including altered ocean conditions related to climate change, dam construction for hydroelectric power, agriculture, water removal from stream systems,

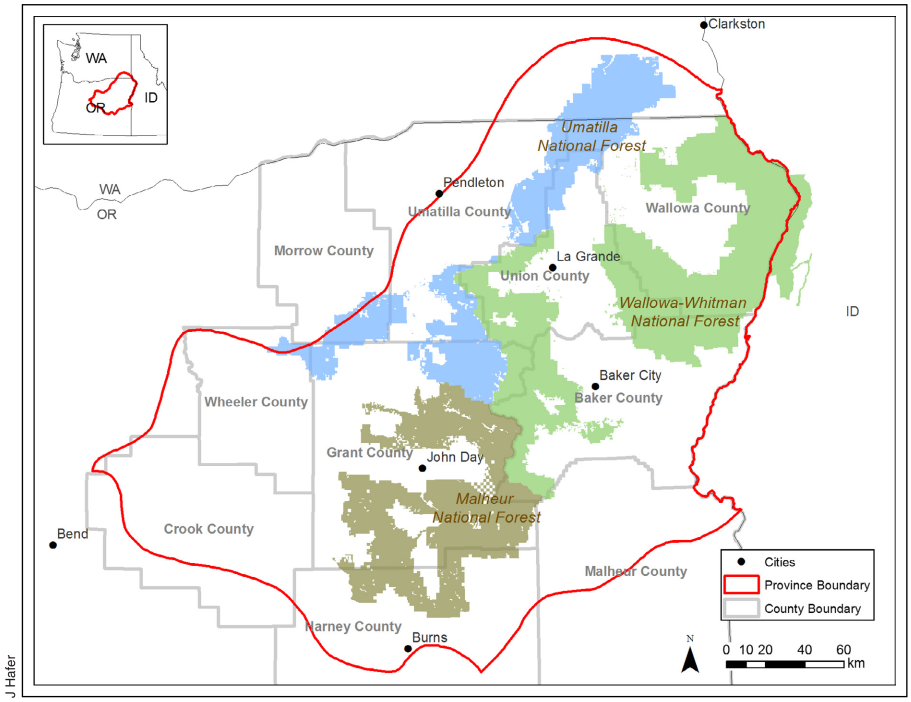

Figure 3. *Map of the Blue Mountains Province (red outline) in northeastern Oregon, which includes the Umatilla, Malheur, and Wallowa-Whitman national forests.*

livestock grazing, logging, urbanization, the widespread release of hatchery-raised fish, overfishing, and introduction of aquatic invasive species (Nehlsen *et al.* 1991; Wissmar *et al.* 1994; Hand *et al.* 2018). The relative contribution of these factors to fish population declines is uncertain. A recent review of published literature about threats to riparian systems in the western US reported that although livestock grazing has been considered the dominant threat since the 1980s, that threat is being superseded by larger concerns about dams, invasive species, and climate change (Poff *et al.* 2011). Specific impacts of cattle grazing on riparian ecosystems and fish populations depend on site characteristics and grazing strategies. Direct effects can include trampling of spawning beds, destabilizing stream banks and altering channel morphology, compacting upland soils (leading to increased runoff and biota), removing or heavily defoliating key riparian plant species, and degrading water quality (Platts 1981; Kauffman and Krueger 1984; Fleischner 1994; Belsky *et al.* 1999).

Governing cattle–fish interactions in Blue Mountains national forests

To date, management to promote compatibility of cattle grazing and listed fish recovery has been addressed through a multilayered, top-down environmental governance system involving USFS grazing management policies, National Environmental Policy Act (NEPA) requirements, and regulations stemming from Section 7 of the ESA administered by the US Fish & Wildlife Service (FWS) (terrestrial and freshwater species) and the National Marine Fisheries Service (NMFS) (marine and anadromous species). Section 7 of the ESA requires that federal agencies uphold their role in contributing to the survival and recovery of protected species occurring on federal lands. When a fish species or population is listed under the ESA, FWS or NMFS designates critical habitat and associated guidelines for recovery (Benson 2012). If a federal agency proposes an action that could jeopardize the species or adversely modify its critical habitat, such as permitting livestock grazing on federal land, the agency must consult with FWS and/or NMFS. Formal consultation results in a Biological Opinion (BiOp) determining whether the action is likely to cause jeopardy and/or adverse habitat modification, and sometimes recommending "reasonable and prudent alternatives" (Benson 2012). The BiOps released for the Blue Mountains national forests provide an interagency framework for protecting, conserving, and

Table 1. Fish listed under the ESA in the Blue Mountains national forests

Species/ regional subgroup	*Scientific name*	*Forest(s) documented*	*Federally threatened or endangered (year listed)*
Steelhead trout, Middle Columbia River	*Oncorhynchus mykiss*	Malheur, Wallowa-Whitman	Threatened (1999)
Bull trout, Columbia River Basin	*Salvelinus confluentus*	Malheur, Umatilla, Wallowa-Whitman	Threatened (1998)
Steelhead trout, Snake River Basin	*O mykiss*	Umatilla, Wallowa-Whitman	Threatened (1998)
Spring Chinook salmon, Snake River Basin	*Oncorhynchus tshawytscha*	Umatilla, Wallowa-Whitman	Threatened (1992)
Fall Chinook salmon, Snake River Basin	*O tshawytscha*	Umatilla, Wallowa-Whitman	Threatened (1992)
Sockeye salmon, Snake River Basin	*Oncorhynchus nerka*	Wallowa-Whitman	Endangered (1992)

Sources: USFS (2014); USFWS (nd).

managing aquatic and riparian habitat critical for ESA-listed fish (Meredith *et al.* 2012; USFS 2014).

Over half of the USFS grazing allotments in the Blue Mountains national forests contain critical habitat for at least one of the six extant groups of ESA-listed fish. To minimize impacts on listed fish and critical habitat where present on grazing allotments, the BiOps contain standards that address degree of streambank alteration, stubble height (the post-grazing height of herbaceous plants along the "greenline" [streambank edge] of the stream), and woody browse removal. Exceeding the standards may cause a permittee to face a reduction in the number of permitted livestock that graze the allotment or a reduction in the grazing season, and can trigger a re-initiation of the consultation process, potentially leading to stricter standards. Responsibilities and management requirements associated with ESA consultation strain agency range program resources, where capacity is already limited.

Under the current regulatory process for USFS grazing, eligible ranchers usually hold term grazing permits that identify the allotment, period of use, and allowable number and type of livestock to be grazed (USFS 2005a,b). Allotment management plans typically accompany the permit and provide direction for grazing management, consistent with the national forest's land management plan. Allotment management plans are usually developed following a NEPA decision that is based on an analysis of the environmental impacts of livestock grazing on the allotment. Each year, range managers and permittees develop operating instructions for the allotment that stipulate pasture rotations and schedules, and the annual number of livestock authorized to graze. Permits expire every 10 years and, ideally, allotment management plans are updated every 10 years, which requires NEPA analysis (although there have been exceptions owing to a backlog of allotment analyses).

Since the fish listings in the 1990s and the passage of the Rescissions Act of 1995 (which established a schedule for NEPA analysis on national forest grazing allotments), litigation has occurred over the impacts of livestock grazing on listed fish, lengthy delays in the allotment NEPA process, and other grazing-related concerns. For example, a 2003 lawsuit brought by three environmental groups (Oregon Natural Desert Association vs Tidwell *et al.*) alleged that livestock grazing in the Malheur National Forest harmed critical fish habitat and resulted in endangered steelhead take in violation of the ESA. The 2010 ruling in this case led to an injunction that temporarily halted grazing on seven allotments in the Malheur National Forest. Another lawsuit, brought in 2011 (Hells Canyon Preservation Council vs Connaughton *et al.*), challenged the renewal of grazing permits on 24 allotments in the Wallowa-Whitman and Umatilla national forests. The suit alleged that through its application of categorical exclusions (which allow federal agencies to exclude certain actions from the NEPA requirement to undertake an environmental assessment or environmental impact statement), the USFS failed to adequately assess the individual and cumulative impacts of grazing on over 250,000 acres of land. In 2013, a judge ruled in favor of the plaintiffs and ordered the USFS to either conduct adequate NEPA analysis for 20 of these grazing allotments or provide a more complete explanation for their categorical exclusion determinations.

Several permittees we interviewed stated that such lawsuits increase their financial burdens (through legal fees, lost forage, and so on) because uncertainty about future forage availability reduces the number of acres available for grazing, at least temporarily, and creates a climate of mistrust and contentiousness around federal lands grazing. According to one permittee who had spent a considerable amount of money defending himself in two court cases, prevailing in both, "It can become…a war of attrition. They don't even have to be right. You can only defend yourself so long before finally you wear down". In addition, grazing standards established by the BiOps are the source of much concern among permittees whose allotments contain listed fish. The standards are often perceived as being overly restrictive and costly, do not account for the effects of cattle versus wild ungulates (such as elk, *Cervus canadensis*), and knowledge gaps exist regarding how well compliance affects a variety of stream and riparian metrics considered important for fish recovery. For their part, environmentalists want to ensure that the agency is fulfilling its legal obligation to protect endangered species on federal lands. As one interviewee from an environmental group stated, "I think public land grazing is always gonna be part of the West. It's always gonna be part of the Wallowa-Whitman, but it's just, how do we continue that use and make modifications to it to also protect these resources? When you drive along the forest in the summertime, the cows are always in the creek…that's having a direct impact on our fisheries." Unfortunately, threat of litigation by environmental organizations can influence the risk tolerance of USFS rangeland managers and limit possibilities for innovation.

Despite some success in improving the status of ESA-listed species (Schwartz 2008), a number of scholars argue that the ESA makes it difficult to manage for resilience, as it focuses on individual species rather than the complex SES dynamics that underlie species decline (Benson 2012). It also limits the range of feasible management actions that can be taken to address problems, thereby inhibiting experimentation, innovation, and more bottom-up approaches to environmental governance (Garmestani and Benson 2013; Garmestani *et al.* 2013; Gunderson 2013). Furthermore, key drivers of decline in complex systems often cannot be addressed through regulations (Boyd *et al.* 2014). The Blue Mountains case exemplifies these challenges.

Ways forward

Managers and permittees have employed several strategies to comply with grazing standards and minimize negative grazing impacts on listed fish. These strategies are designed

Table 2. Conventional strategies for reducing grazing impacts and facilitating recovery of ESA-listed fish within Blue Mountains national forests

Strategy	*Advantages*	*Disadvantages*
Permanently fence stream corridors containing critical fish habitat	• Keeps livestock out of riparian areas if fences are well maintained • Decreases stakeholder conflict • Streamlines regulatory consultation and NEPA processes • Helps reveal negative riparian impacts caused by wild ungulates vs livestock • May reduce management burden on permittees and managers • Grant funding available to help pay costs	• Loss of access to riparian pastures and the nutritious forage they contain • Limits water sources for livestock • Creates resource shortages for livestock in canyon allotments • Impedes efficient livestock movement across streams • Costly to build and maintain • Requires regular monitoring and maintenance • If fences are breached, livestock may trespass and damage riparian resources, with penalties for permittees
Increase controls on timing and use of riparian pastures throughout grazing season	• Keeps livestock out of riparian pastures during critical fish spawning and rearing periods • Prevents damage to riparian ecosystem during vulnerable periods, such as drought	• Loss of temporal flexibility in using and managing riparian pastures • Date restrictions may make pasture rotations and resting difficult, increasing impacts on vegetation • Reduced access by livestock to forage in riparian pastures
Develop water sources in uplands to keep livestock away from riparian areas	• Provides alternate water sources away from streams and increases potential use of upland pasture resources	• NEPA analysis, when required, may be time consuming • Funding for developments often lacking • Requires regular monitoring and maintenance to ensure water is consistently available • Emphasizes grazing in upland pastures that may have limited forage quantity and quality, with potential overuse • Potential impacts to cultural resources, often located near springs
Shorten season of use on allotments	• Reduces grazing impacts on water sources and vegetation, and presumably listed fish, especially in drought years	• Requires reduction in livestock numbers; ranchers must find alternative grazing on private lands or provide supplemental forage
Provide nutritional supplements in uplands (eg salt, mineral blocks) to draw livestock away from streams	• Provides nutritional supplementation and favored food source • Increases use of uplands relative to riparian zones	• Cost and labor to place supplemental materials • Potential for negative impacts on upland vegetation around sites
Temporarily fence redds during spawning season	• Reduces livestock trampling on redds and increases future recruitment of fish	• Not always effective • Costly, time consuming, and unpredictable year to year

Source: interview data.

to restrict use of riparian pastures and streams, and to increase use of water and forage in uplands by cattle. Each strategy has both benefits and drawbacks, which were described by our interviewees (Table 2). Although the strategies seem to be working well in some places – especially the Umatilla National Forest – elsewhere interviewees reported problems associated with the drawbacks listed in Table 2. Thus, as one USFS range manager stated, "…there's an absolute need to figure out how to do things differently", while another noted that, "With our management, it's not real flexible. It's one-size-fits-all. With changing environmental conditions from year to year, it would be nice to have more flexibility, not less." Numerous agency personnel we interviewed believed that "building flexibility into the operation" was the best way to increase system resilience, indicating the need for innovative management approaches.

Several ranchers and range managers we interviewed described range management strategies that have been tried in other places and suggested for or attempted in the Blue Mountains to address drawbacks associated with conventional approaches to reducing grazing impacts on fish (Table 3). However, implementation of many of these

Table 3. Management innovations for promoting coexistence between fish and livestock within Blue Mountains national forests, and potential barriers

Innovation	*Potential advantages*	*Potential barriers*
Redraw allotment boundaries where needed to make more ecological sense	• Better aligns allotment boundaries with temporal and spatial availability of resources • Enables allotment designs that build in rest and deferred rotation systems, decreasing potential for negative impacts	• Some permittees may benefit, others may not • Requires new administrative process and NEPA analysis, which are expensive and time consuming • May require additional fencing, which is expensive
Ask permittees on adjacent allotments to share them where ecologically and economically appropriate	• Improves utilization and distribution to better match seasonal resources with livestock demands under varying climatic conditions • Provides greater flexibility for livestock movements across the landscape to access water and forage in an ecologically appropriate manner	• May favor some permittees more than others • Permittees may not be interested in working together • Adjacent allotments may not have additional forage capacity
Adopt shorter duration, higher intensity grazing by increasing the number of pastures and movement between them	• Installing temporary electric or permanent fencing to increase the number of pastures in an allotment may improve range conditions by concentrating grazing impacts for a short period, thus allowing longer recovery periods • Provides more flexibility for deferred and rest rotation systems	• Ecological benefits of short duration, high intensity grazing debated in the scientific literature and not accepted by all stakeholders • More labor intensive and costly • Would require NEPA, consultation, and permit modifications for maintenance responsibility
Encourage increased use of range riders, possibly with initial financial assistance	• Riders actively herd livestock, largely controlling their use of riparian areas without the need for fencing • Helps control upland pasture use, herding livestock to places where forage is optimal, and better distributes their impacts across the landscape • Riders may deter predators	• Cost to hire and ability to find capable range riders
Incentivize responsible grazing practices and reward range management that demonstrates long-term trends toward range improvement	• Gives permittees more flexibility and potential financial benefits when needed (eg drought years), or in general, with less restrictive standards or by increasing AUMs • Encourages more ecologically sustainable range management	• Regulatory ability to provide rewards through more flexible grazing, increased AUMs, or less restrictive standards
Improve upland water availability using innovations such as use of solar pumps to pump water away from springs and streams to tanks, building larger or more tanks, and streamlining NEPA approval process using programmatic NEPA for aquatic restoration projects	• Can reduce riparian impacts if strategically placed and numerous enough • Increases potential use of upland pasture resources	• Funding for water developments • Ability to streamline NEPA
Allow more flexible on and off dates on allotments, and movement dates between pastures, that are adapted to forage dynamics and fish needs, using a decision tree that allows permittees to manage as they deem best	• Varying timing and length of use of allotments and pastures enables more adaptive management in response to variable ecological conditions and forage dynamics, and is responsive to fish needs (ie variations in spawning timing and number of redds in streams) • Allows permittees flexibility to manage as they see fit in response to changing rangeland conditions • Rewards good management with continued management flexibility • Punishes bad management with top-down prescriptions or AUM reductions	• May require changes to allotment management plans, invoking NEPA • Requires monitoring to assess when and where to move • Requires high level of trust

Source: interview data.

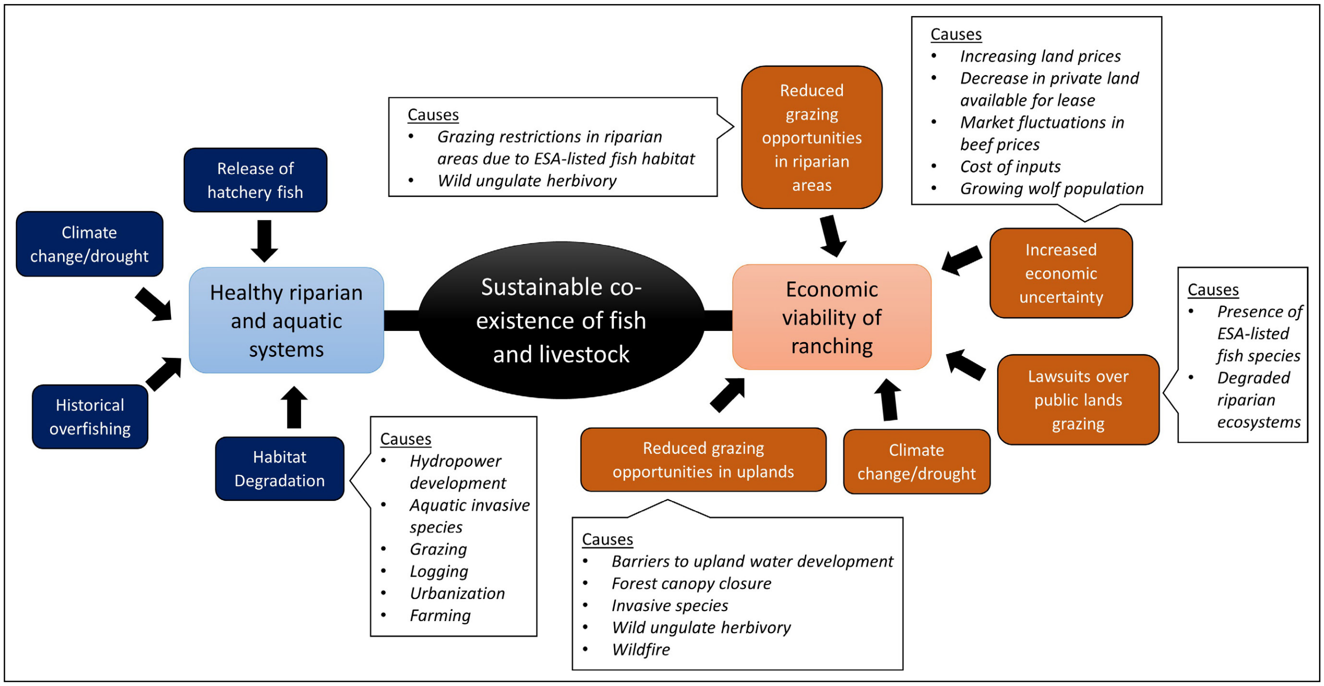

Figure 4. *System dynamics that threaten sustainable coexistence of fish and livestock in the Blue Mountains.*

approaches has been limited because they require ranchers, agency managers, or regulatory agencies to adapt conventional practices and management regulations in ways that foster experimentation, innovation, and flexibility without the threat of litigation. Experimentation involving flexibility is risky when the species in question is arguably on the brink of extinction. The suggested approaches also depend on ranchers' willingness and ability to try novel practices. In addition, there needs to be trust between ranchers, resource managers, regulatory agencies, and stakeholders, and ranchers need tools that can help them succeed, such as easily implemented monitoring systems and necessary infrastructure.

Employing SES science to promote cattle–fish compatibility

The debate over cattle–fish interactions takes place within the larger context of SES dynamics that influence fish populations and ranching in the Blue Mountains and contribute to overall system vulnerability. Blue Mountains Working Group members have been investigating these dynamics, which we illustrate in Figure 4. Although grazing is only one of many stressors on healthy riparian and aquatic systems that threaten listed fish populations, it has associated legal requirements (eg Section 7 of the ESA) and grazing on federal lands is a key point in fish recovery efforts. Other factors (eg climate change, hydroelectric dams) are harder to address or are being addressed beyond the Blue Mountains. Similarly, the economic viability of ranching is influenced by multiple factors at different spatiotemporal scales; grazing conditions on federal lands, in conjunction with other social, economic, and environmental stressors, put ranchers at financial risk. Permittees vary with regard to the size of their operations, management objectives, production systems, incomes, and so on (Gentner and Tanaka 2002); some can adapt to these stressors, whereas others may be forced to sell their ranches or otherwise abandon ranching, leading to a potential cascade of effects associated with changes in ranch ownership that have major implications – both positive and negative – for fisheries and other conservation concerns (Gosnell and Travis 2005; Gosnell *et al.* 2006, 2007).

SES are large and complex, making analyses of all of their components difficult and often impractical (Hruska *et al.* 2017). Recognizing that cattle–fish interactions take place within the context of larger SES dynamics, Blue Mountains Working Group members are collaborating with other scientists, managers, permittees, and stakeholders to develop and test innovative grazing practices that incorporate some of the elements described in Table 3 in an effort to promote sustainable grazing on federal lands that is compatible with fish recovery. This research is taking place at the USFS's Starkey Experimental Forest and Range (EFR) in the Wallowa-Whitman National Forest, as part of the Meadow Creek Riparian Restoration Project.

The Meadow Creek project is a long-term, multidisciplinary endeavor within the Starkey EFR, aimed at investigating responses of threatened steelhead trout and Chinook salmon populations in the Snake River to traditional methods of riparian restoration (Averett *et al.* 2017). The new research, which uses an innovative grazing system to test the impacts of wild ungulates versus livestock on riparian ecosystem function and restoration outcomes, represents an expansion of the project. For more than two decades prior to this experiment, several kilometers of the Meadow Creek riparian corridor had been withdrawn from livestock grazing due to past overgrazing by cattle and concomitant concerns about salmonid habitat. Thus, the reintroduction of livestock into the system represents a high-profile investigation of the compatibility (or lack thereof) between ESA-listed fish and grazing. Extensive discussions with ranchers, resource managers, and other stakeholders helped frame the research ideas and approaches, and have helped build the trust, social license, and agreed-upon risk management that make the experiment possible.

Re-designing grazing practices to be more compatible with salmonid restoration requires grazing prescriptions not typically applied under conventional grazing management. The new cattle grazing system, which was introduced in Meadow Creek in summer 2017, includes extensive development of strategically placed upland water sources and nutritional supplements to attract and keep cattle away from riparian areas and increase accessible forage; intensive range riding to herd cattle into upland areas; new fencing to create smaller grazing pastures, with more frequent pasture moves and higher intensity, shorter duration grazing; and frequent and intensive real-time monitoring of riparian and upland vegetation to guide within-pasture moves and pasture rotations. It also includes grazing exclosures to parse out effects of grazing by wild versus domestic ungulates, since elk and mule deer (*Odocoileus hemionus*) also forage in riparian areas and affect plant structure and composition. Social science will be incorporated into the research project in two ways. First, an economist will evaluate how alternative cattle grazing systems that hold promise for reducing impacts on riparian areas affect livestock condition and productivity (eg weight gain and economic return to permittees). Second, social scientists will conduct qualitative research about the willingness and capacity of Blue Mountains national forest permittees and federal managers to adopt alternative grazing systems that are compatible with fish, including those tested at the Starkey EFR. Thus, SES subsystem dynamics of concern include the impacts of wild ungulate versus livestock grazing in riparian areas on riparian ecosystem function and restoration outcomes (including steelhead and Chinook salmon population monitoring); impacts of wild ungulate herbivory on forage availability for livestock, and vice versa; and the effects of increased upland grazing on vegetation, livestock condition, and economic viability for grazing permittees (Figure 4).

To date, the new grazing research at the Starkey EFR has successfully transcended some of the barriers to management innovation described in Table 3. One such barrier involves sufficient funding for range riding to move livestock out of riparian areas, and extensive fencing and upland water development. These interventions were largely funded by local, state, and federal partners charged with riparian restoration and fish recovery, particularly the Bonneville Power Administration, which is legally required to fund mitigation of the effects of Columbia River dams on ESA-listed fish. A second example is an unusual degree of regulatory flexibility in grazing management relating to the stubble height standard, a key monitoring metric relied on by NMFS and USFWS to inform grazing management decisions. Monitoring of stubble heights of herbaceous plant species along the riparian greenline is the most common and sometimes only indicator used to inform grazing management decisions; when stubble height falls below a threshold value, cattle are generally removed from the pasture. Although stubble height can be a good indicator of some elements of riparian health, such as bank stability or short-term recovery of grasses from grazing, major knowledge gaps exist regarding how the metric relates to other key riparian components, such as woody species utilization and fish habitat, and it has also been criticized for its "one-size-fits-all" approach. In a newly released BiOp (NOAA NMFS 2017), NMFS proposed a more conservative (ie taller) stubble height threshold for Meadow Creek and other riparian pastures supporting ESA-listed salmonids in the Blue Mountains than had previously been in place. The new standards could lead to reductions in the duration and number of cattle grazing at the Starkey EFR and on Blue Mountains grazing allotments containing critical fish habitat, raising concerns among some stakeholders, including many permittees.

Through extensive discussion and consultation between Starkey EFR scientists and NMFS, the agency agreed to relax stubble height thresholds for the Meadow Creek research pastures. Grazing is anticipated to result in wide variability in stubble heights along Meadow Creek. Regulatory flexibility will allow ecologists to evaluate this stubble height variability in relation to over 200 metrics of stream and riparian health being monitored for fish recovery. This variability is key to assessing how well stubble height monitoring serves as an indicator of overall stream and riparian health for salmonids in relation to grazing impacts. The knowledge gained will help improve future grazing management direction for recovery of cold-water fish and may have implications for ESA implementation.

Management experiments to test the effectiveness of new grazing practices for the sustainable coexistence of fish and livestock alone will not be sufficient to overcome all of the barriers to implementation described in Table 3. A key question is how results from grazing research like that at Meadow Creek will be adopted by regulators, managers, permittees, and other stakeholders to reduce conflict and promote compatible grazing strategies. There are many possible outcomes, ranging from acceptance of results and scaled-up implementation of more effective solutions for cattle grazing on federal lands, as appropriate; to questioning the scientific credibility of the research results, and continuing debates and litigation regarding solutions. Key conditions for promoting SES science that help build trust in research and monitoring, and support acceptable resolution of the grazing–fish issue include the following.

(1) Research environments conducive to testing innovative management practices not traditionally enabled by the regulatory process for ESA-listed species

The ability of SES science to help resolve the cattle–fish issue relies on a research environment that is conducive to testing and monitoring new grazing approaches. Designated landscapes such as the Starkey EFR, experimental grazing allotments, an experimental USFS ranger district, or private lands are needed for such testing. Regulatory exemptions may also be required to test innovations outside the normative regulatory process without the threat of litigation. Equally important is the willingness and ability of permittees to test and adopt new grazing approaches.

(2) Engagement of all interested stakeholders in the research and monitoring process

The design, implementation, and dissemination of research on controversial topics calls for the involvement of all stakeholders in order to build trust and improve the research and monitoring process. Ranchers, environmentalists, natural resource managers, regulatory agency personnel, extension agents, social and biological scientists, elected officials, and tribal government representatives are among the key partners whose involvement could help in the identification of management problems, development of research questions, design and implementation of management innovations, and monitoring of outcomes. For example, permittees could propose changes in infrastructure (eg fences, off-stream water sources) and in the timing and duration of grazing on their allotments to minimize grazing impacts in riparian areas, while range managers could facilitate the design and development of each permittee's suggestions through a collaborative process with stakeholders in coordination with research scientists. These proposals could serve as working hypotheses, to be tested by researchers. Ideally, stakeholders would remain engaged throughout the processes of data collection and analysis, interpretation of results, and dissemination of findings for management use. Monitoring is a central component of any experimental research endeavor, and monitoring programs developed and implemented in coordination with relevant stakeholders could help address shortfalls in agency staffing for monitoring activities, engage all interested parties in evaluating different experimental management practices, build trust, and encourage use of results for improved management (Fernandez-Gimenez *et al.* 2005, 2008). Although stakeholder collaboration in research and monitoring has many benefits, it is not a panacea. For instance, in some cases, stakeholder collaboration with agencies has been found to decrease trust among group members (Wagner and Fernandez-Gimenez 2009), perhaps because the outcomes of past collaborations were not what participants hoped for or because expectations regarding their role were not made clear at the start of the process.

(3) Financing from a broad spectrum of public and private sources to enable experimentation

The grazing strategy being tested at the Starkey EFR involves more intensive herd management and other practices that can represent a substantial financial investment, and may not be readily accepted by producers as economically feasible. To be successful, stakeholders must assume leadership roles in securing funds and pursuing creative financing options for developing, implementing, and evaluating innovative grazing approaches. For example, over a billion dollars have been spent to date on riparian restoration initiatives in the Columbia River Basin to help listed fish recover (Hand *et al.* 2018). About $1.2 million of Bonneville Power Administration funding has been used to develop and test cattle grazing practices at the Starkey EFR that may be compatible with riparian restoration. Perhaps fish mitigation funds could also be used to help livestock permittees test innovative practices they consider to be economically risky.

■ Conclusions

The ongoing and unresolved controversy over whether livestock grazing on federal lands can be compatible with recovery of ESA-listed fish – and if so, how best to achieve it – represents a daunting challenge. In the Blue Mountains, conventional grazing strategies characterized by top-down, government-led efforts have substantial drawbacks for ranchers, and data are lacking about their benefits for recovery of ESA-listed fish populations. SES science holds promise for collaboratively developing and testing management innovations that reduce the impacts caused by cattle grazing on riparian ecosystems while also offering ranchers more flexibility to meet regulatory standards and successfully manage their livestock. Innovative grazing approaches that are both compliant with management standards for protecting fish and economically viable for ranchers represent one promising outcome of SES science efforts.

However, SES science is not a magic bullet; improving the compatibility of cattle grazing and fish recovery also calls for the development and application of promising innovations, and overcoming barriers such as absence of trust, the use of litigation as a stopgap, and the lack of flexibility to experiment and implement adaptive management under the current regulatory framework. Moreover, the best solutions to the grazing–fish controversy will not alleviate other SES dynamics that make ESA-listed fish and ranching vulnerable in the Blue Mountains; major stressors operating at other spatial and temporal scales will also need to be addressed. Despite such limitations, we believe that SES science can contribute to the sustainable coexistence of fish and livestock on federal lands, and conservation of working rangelands in the Blue Mountains and elsewhere in the western US, by providing insight into the interacting SES dynamics that make these rangeland ecosystems vulnerable, and providing the science needed to identify, test, and implement management solutions.

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