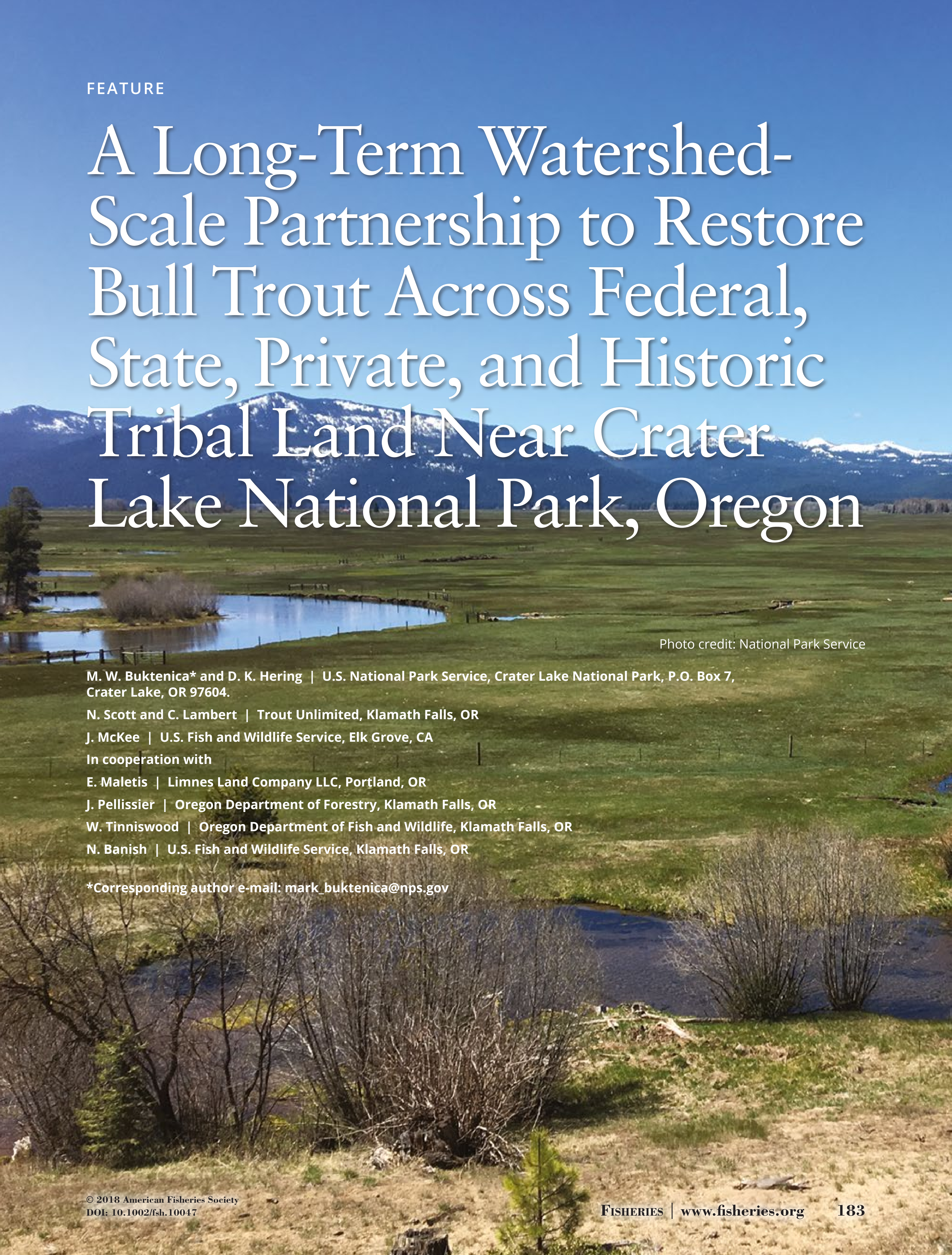

FEATURE

A Long-Term Watershed-Scale Partnership to Restore Bull Trout Across Federal, State, Private, and Historic Tribal Land Near Crater Lake National Park, Oregon

Photo credit: National Park Service

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We review a 28-year project to restore a Bull Trout *Salvelinus confluentus* population in a small Oregon watershed. Restoration evolved from eradication and exclusion of nonnative fishes within the boundaries of a national park to stream reconstruction and reconnection of a historical stream network across state and private property. Management of the project evolved from unilateral actions by a single federal agency to collaborative actions by multiple federal and state agencies, nongovernmental organizations, and private land owners. The project removed nonnative fish from 24 km of one stream by electrofishing and application of chemical piscicide. As a result, Bull Trout abundance and distribution increased from approximately 150 fish occupying 2 km of stream to over 2,000 fish occupying 19 km. Stream restoration included construction of 4 km of stream channel, planting riparian vegetation, fencing to exclude cattle, transfer of water rights to instream use, and facilities to manage fish passage and water withdrawals for irrigation.

Conservation of threatened and endangered species is complex and typically requires addressing multiple threats that operate over a range of spatial scales, largely because the range of a species typically spans publicly and privately owned lands that are managed for competing policy and economic objectives. Sociopolitical complexities of implementing species conservation on a landscape scale can be as vexing as ecological factors limiting recovery, which may be one reason that despite significant public investment in planning and restoration, few species have recovered sufficiently to be removed from the federal endangered species list (Gerber 2016). Conservation of freshwater aquatic species and their habitats is particularly challenging because of water extraction activities and water quality degradation associated with land development (Martinuzzi et al. 2014).

Here, we present a 28-year case history of actions taken to restore a Bull Trout *Salvelinus confluentus* population in a small watershed in southern Oregon that includes federal, state, and private land ownership on historic tribal lands that are managed for preservation, recreation, and the production of timber and cattle. Restoration efforts began as unilateral actions by the National Park Service (NPS) to eradicate and exclude nonnative trout, but over time, these efforts evolved into collaborative actions by federal and state agencies, nongovernment organizations (NGOs), and private land owners to restore stream habitat and water quality and to improve the efficiency of water delivery for irrigation on private ranchland. The history of the project demonstrates the challenges and successes of conserving a threatened population within an expanding management and policy framework (see project video: https://www.youtube.com/watch?v=HCELMTzTicQ&feature=youtu.be&t=13).

Bull Trout in the Klamath and Columbia River basins, Oregon, were listed as threatened under the Endangered Species Act (ESA) in 1998 (USFWS 1998); Bull Trout within the coterminous United States were listed as threatened in 1999 (USFWS 1999). Native to a large portion of the Pacific Northwest, the species historically ranged from southeast Alaska to northern California and Nevada and from the Pacific Ocean to Montana and Alberta, Canada. At the time of their listing, Bull Trout had been extirpated from 60% of their historical range within nine major watersheds in Washington, Oregon, and California (USFWS 2015). The Klamath River basin, where 40% of historical populations have gone extinct (Buchanan et al. 1997), now forms the southwestern extent of the species' range. Principal causes of the rangewide decline of Bull Trout include habitat loss and fragmentation, disruption of migration pathways, and negative interactions with nonnative species.

Crater Lake National Park (CRLA) sits in the northern portion of the Klamath River basin, which covers 40,790 km^2 of southern Oregon and northern California. Historically, CRLA supported populations of Bull Trout in Sun and Annie creeks, which flow southward out of the park and into the

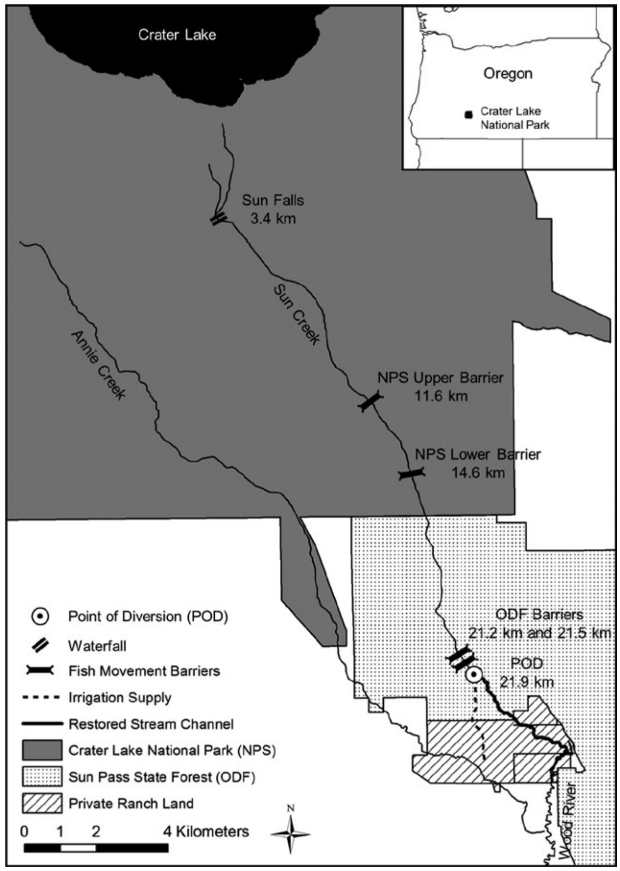

Figure 1. Map of the Sun Creek, Oregon, project area, with distance (km) from the headwaters, management structures, and land ownership boundaries (NPS = National Park Service; ODF = Oregon Department of Forestry).

Wood River (Figure 1; NPS 1924; Wallis 1948). Despite headwater protection in a national park, these streams experienced some of the same factors that contributed to the rangewide declines of Bull Trout, including negative interactions with nonnative species. A survey in 1989 found that as few as 150 adult Bull Trout occupied less than 2 km of Sun Creek (Dambacher et al. 1992), and no Bull Trout have been documented in Annie Creek since 1924 (NPS 1924). Bull Trout in Sun Creek are now CRLA's only remaining native fish (Buktenica et al. 2013).

Nonnative trout were introduced to streams throughout southern Oregon in the early 20th century in an attempt to improve sportfishing. Nonnative Brook Trout *S. fontinalis* were introduced to Sun Creek between 1912 and 1975. Brook Trout threaten Bull Trout populations through competition (Gunckel et al. 2002) and hybridization that produces mostly sterile offspring (Kanda et al. 2002). In addition to the impacts of nonnative competitors, stream fragmentation resulting from management practices has restricted the range of Bull Trout and increased their isolation.

Bull Trout have evolved a diverse suite of life history and migratory behaviors, including potamodromous migrations through river and lake ecosystems and anadromy in coastal basins, to accommodate differences in physical environment, resource availability, and species interactions (Dunham et al. 2008). Historically, Bull Trout in Sun and Annie creeks likely migrated to downstream rivers and lakes, but irrigation dams and diversions constructed in the late 1800s limited this behavior. The isolation, restricted range, and small population size pose long-term risks of extinction from stochastic events, such as wildfire and floods, or the loss of genetic diversity from inbreeding (Allendorf and Luikart 2007).

An additional factor contributing to the decline of Bull Trout has been an overall degradation of fish habitat. Land management in the Sun Creek watershed has generally resulted in less-altered, higher-quality fish habitat in the headwater reaches (Dambacher et al. 1993) and more altered and degraded habitat at lower elevations. The uppermost reaches of Sun Creek have been managed as a protected area since 1886—first within a federal forest reserve and then within CRLA, which was established in 1902 (Figure 1). Downstream of the park, the stream has flowed unmodified through Sun Pass State Forest, where the landscape has been managed by the Oregon Department of Forestry (ODF) for timber harvest, recreation, and wildlife habitat. Logging has occurred within the state forest but has been limited within the stream valley and floodplain. At 22 km from the headwaters, the stream was diverted for flood irrigation beginning in the late 1800s (Figure 1), and the forest was logged at varied intensities. The stream then entered private ranchland that was cleared of timber and understory vegetation, ditched, drained, and irrigated for livestock pasture. Return drains from the irrigation system entered both the Wood River and Annie Creek (at ~26 km from the headwaters).

An overarching mandate of the NPS is to preserve natural resources unimpaired for future generations (NPS Organic Act of 1916). Therefore, the discovery in 1989 that the Bull Trout population was alarmingly low in abundance and restricted in distribution prompted CRLA to assemble an advisory panel, complete a management plan, and initiate conservation actions (Buktenica et al. 2000). The advisory panel met in 1991 and 1997 prior to the ESA listing of this Bull Trout population in 1998 (USFWS 1998). Panel membership changed as program priorities changed and included aquatic professionals with expertise in restoration, conservation genetics, invertebrate ecology, hydrology, fish barrier design, fish taxonomy, and the use of electrofishing and piscicides (Table 1). Personnel from the NPS Pacific West Regional Office and from Oregon Department of Fish and Wildlife (ODFW) local and regional offices were also in attendance. Guiding recovery were four conservation goals: (1) stabilize the Bull Trout population so that it was no longer declining; (2) remove and exclude nonnative fish; (3) increase Bull Trout distribution and abundance throughout Sun Creek; and ultimately, (4) reconnect the population to the downstream watershed to re-establish migration pathways and reduce isolation.

The NPS has long recognized that ecological processes operate across park boundaries and that collaboration with outside entities is necessary to fulfill its mission of conserving wildlife unimpaired for future generations (Leopold et al. 1963; NPS 1993, 2012). Throughout much of its history, however, the NPS has "…pursued their mission solely within the borders of their units and paid little attention to what happened outside their boundaries—the borders of which commonly cut across watershed, animal migration, and other ecologically based lines…" (NPS 1993). This phenomenon has not been unique to the NPS, as federal resource agencies in the early 20th century largely operated in isolation (Lachapelle et al. 2003). However, growing knowledge of regional and global-scale environmental issues (e.g., pesticide use, atmospheric pollution, and climate change) and the development of ecosystem-based management approaches have led to changes in policy and law that provide authority and incentives for collaborative work in resource management across traditional boundaries. In 2008, Congress specifically authorized the NPS to enter into cooperative agreements with state, local, or tribal governments; other federal agencies; public entities; educational institutions; private nonprofit organizations; or private land owners for purposes of protecting natural resources and ecological processes outside of National Park System units (Consolidated Natural Resources Act of 2008). The Sun Creek project demonstrates this cultural and policy-based shift toward collaboration among land management agencies and exemplifies how multiple cooperating organizations can share strengths to achieve success in conservation biology.

At the start of restoration efforts in 1992, the Sun Creek Bull Trout population was perceived to be on the brink of extirpation, and there was considerable uncertainty among the advisory panel of specialists that the small and precarious Bull Trout population could be stabilized. Furthermore, given the lack of supporting NPS legal authority and policy, which would develop independently throughout the course of the project, re-establishing connectivity between Sun Creek and historical habitat in the Wood River was a distant pipedream.

Table 1. Members of the Crater Lake National Park Bull Trout advisory panel.

Panel member	Affiliation
Phil Pister (chair)	Desert Fishes Council
Fred Allendorf	University of Montana
Norm Anderson	Oregon State University
Tom Felando	U.S. Forest Service, Deschutes National Forest
Doug Markle	Oregon State University
Steve Moore	National Park Service, Great Smoky Mountains National Park
Bruce Rosenlund	U.S. Fish and Wildlife Service, Lakewood, Colorado

CONSERVATION GOALS 1 AND 2: STABILIZE BULL TROUT AND REMOVE AND EXCLUDE NONNATIVE FISH

The first steps in the recovery of Bull Trout in Sun Creek were to stop the decline of the existing population and remove and exclude nonnative Brook Trout. Prior to eradicating Brook Trout, a pair of migration barriers were built in CRLA to prohibit the reinvasion of nonnative fish from downstream reaches (Figure 1; NPS barriers). Redundant structures were built to limit the risk of reinvasion if one structure failed over time. The NPS barriers consisted of log weirs keyed into the streambanks that created 2-m vertical steps in the streambed (Buktenica 1997). After the construction of migration barriers, Brook Trout were removed using a combination of two methods: electrofishing and treatment with the piscicide antimycin-A (hereafter, antimycin).

Nonnative fish removal began in 1992. A detailed description of the methods is provided by Buktenica et al. (2013), but in brief, electrofishing was used to remove Brook Trout annually but was performed sparingly to reduce impacts to Bull Trout. Piscicide was initially applied to limited reaches outside the main distribution of Bull Trout. Antimycin was applied at 8–10 µg/L for 6–8 h following the methods described by Moore et al. (2008). Consultation with the U.S. Fish and Wildlife Service (USFWS; Klamath Falls, Oregon) was initiated in 1998 to meet regulatory requirements associated with the ESA listing of Bull Trout. Bull Trout response was slow but positive, and by 2000, the population had increased to approximately 500 adult fish (Figure 2). With the perception that Bull Trout faced less-imminent peril, piscicide was then applied to 15 km of stream from Sun Falls to a detoxification station located 2 km downstream of the NPS boundary. Bull Trout were salvaged from the stream prior to the 2000 treatment and were held in upstream reaches and a streamside raceway (Buktenica et al. 2013). A 3-km section between NPS barriers was re-treated in 2004 and 2005 after some Brook Trout were discovered to have survived the 2000 treatment. From this experience, we found that two piscicide treatments in consecutive years were more successful than single or double treatments in a given year. During all piscicide treatments, antimycin was detoxified below the target reaches by the addition of potassium permanganate (Moore et al. 2008). Effectiveness of the chemical and detoxification was monitored by using caged sentinel fish held in the treatment areas.

CONSERVATION GOAL 3: EXPANDING BULL TROUT DISTRIBUTION

As the Bull Trout population continued to increase within the park, work began to expand the distribution outside of park boundaries. In 2006, a partnership with ODF funded the development of a conceptual framework that evaluated alternatives for stream restoration on state and private property and initiated conversations with new partners. The conceptual framework evaluated (1) barrier and migrant fish trap design for the low-gradient valley floor found within the state forest, (2) reconstructing a stream channel to the Wood River, (3) screening previously unscreened irrigation diversions, and (4) improving the efficiency of water delivery for irrigation (Inter-Fluve 2008). Cost estimates for stream restoration developed in the conceptual framework were prohibitively high, however; as a result, channel restoration was put on hold while efforts focused on construction of additional barriers (Figure 1; ODF barriers) and eradication of Brook Trout above those barriers.

By 2009, efforts to increase Bull Trout within CRLA were successful, and the population estimate was approximately 1,600 individuals occupying 11.2 km of stream between Sun Falls and the lower NPS barrier (Figure 2). Project work progressed downstream in a manner similar to that within the park. Migration barriers were constructed in 2010 to prevent reinvasion of nonnative fish, followed by piscicide treatments between NPS and ODF barriers in 2012 and 2013. Because of low streambed gradient and unconstrained channel morphology, the ODF barriers could only create an approximate 1-m step in elevation or jump height. To compensate for this, a metal grate and boulder apron were installed immediately downstream of each weir to prevent formation of a "jump pool." Earthen levees were constructed on the floodplain to prevent Sun Creek from altering course around the barriers

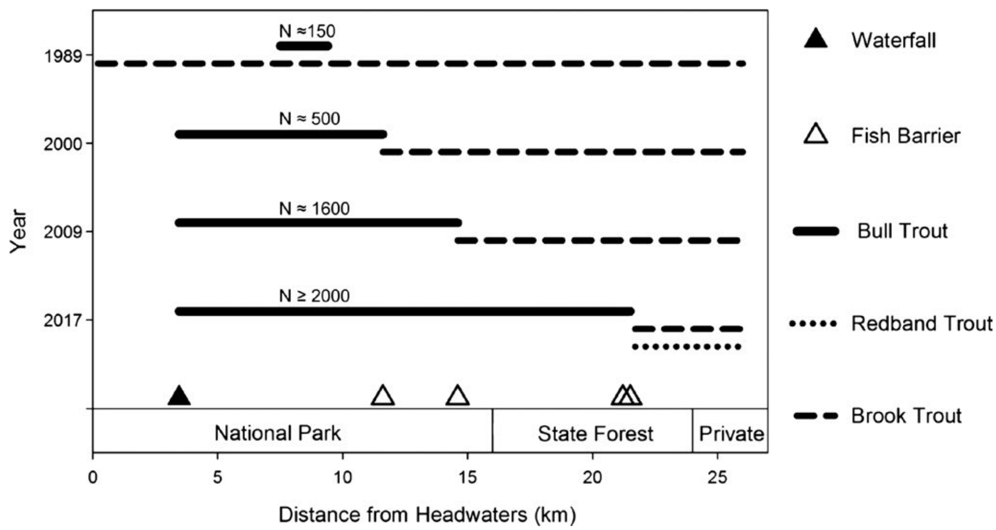

Figure 2. Trout distribution and abundance of Bull Trout in Sun Creek, Oregon, 1989–2017. Methods for each year listed on the *y*-axis (1989, 2000, 2009, and 2017) are as follows. In 1989, direct observation by a snorkel diver was conducted in a stratified systematic sample of habitat units (Dambacher et al. 1993). In 2000, 560 total Bull Trout were returned to the stream after a piscicide treatment: 480 of these were returned the same year from the upstream reaches and streamside raceway, and an additional 80 were collected as fry before the treatment, were returned the following year when they were large enough to reliably identify to species (Buktenica et al. 2013). In 2009, a mark–resight estimate was obtained; the Bull Trout were first marked with a fin clip, and then both marked and unmarked fish were observed by a snorkel diver (Buktenica et al. 2013). In 2017, estimates for areas upstream of National Park Service (NPS) barriers were obtained from snorkel diver counts, and estimates for areas below NPS barriers were obtained by single-pass electrofishing without block nets. The absence of Brook Trout was also supported by environmental DNA collected throughout Sun Creek in 2015, 2016, and 2017.

during high flows. In addition to preventing reinvasion, the barrier farthest downstream was equipped with a fish trap to allow native fish migrating upstream to be captured and transported around the barriers.

Exclusion and removal of nonnative trout from this section allowed Bull Trout to recolonize an additional 7.3 km of stream between the lower NPS and ODF barriers; approximately 200 Bull Trout colonized the renovated reach from upper Sun Creek in the first year, and only Bull Trout were observed during 4 years of intensive electrofishing afterwards. Several Bull Trout were captured downstream of ODF barriers in the stream and irrigation channels and were relocated upstream before piscicide treatments, which elevated the importance of screening the irrigation supply and providing downstream fish passage.

CONSERVATION GOAL 4: RECONNECT SUN CREEK TO THE DOWNSTREAM WATERSHED

After nonnative trout were excluded from the national park and much of the state forest and Bull Trout had increased in abundance and distribution, we focused project work on reconnecting the population to the downstream watershed. Even though this part of the project involved only 16% of the stream length, the project objectives, leadership, and management considerations grew exponentially. Additional partnerships developed when USFWS hired a stream hydrologist (2011), ranch ownership changed (2013), a relationship with Trout Unlimited (TU) was strengthened, and additional state agencies (Oregon Water Resources Department [OWRD] and Oregon Watershed Enhancement Board), federal agencies (U.S. Forest Service [USFS] Fremont–Winema National Forest and Natural Resources Conservation Service), and NGOs (National Fish and Wildlife Foundation and Western Trout Initiative) joined the project. These partnerships energized and increased the momentum of the project. For example, additional in-house expertise with the USFWS reduced project costs considerably through scaled-down design and engineering solutions. The new land owner included enhancing fish and wildlife habitat in ranch management goals, was interested in a broader range of irrigation strategies, and recognized added value to ranch land from stream restoration and infrastructure improvements. Trout Unlimited provided restoration expertise; conducted water right transfers; managed grant proposals, awards, and contracts for project work; and served as a central point of contact for contractors, agency personnel, and private land owners.

Driven by new partnerships, the first step in reconstructing the stream channel was designing the channel location, form, and capacity for water and sediment transport to be consistent with the geomorphic context of the watershed. Sun Creek was formed in a glacial valley filled by volcanic debris and airborne ejecta during the eruption of Mt. Mazama approximately 7,700 years ago (Bacon et al. 2002). In upper reaches, the stream channel cuts through deep volcanic deposits and occupies a narrow valley between higher terraces. Valley width gradually broadens downstream, and at approximately 21.5 km from the headwaters (Figure 1), it undergoes a major transition as the upper glacial valley opens into a prehistoric lake bed. Here, the channel transitions to an environment typical of a depositional fan with a slightly convex valley cross-section. Relict stream channels and a land survey by the General Land Office (GLO) in 1872 indicated that Sun Creek occupied many channels across the depositional fan over time and terminated in a marsh-like environment that connected to the Wood River.

The final layout of the reconstructed stream channel was selected based on topography and the ability to utilize historical channels, capture groundwater, and provide long-term stability for land management needs (Figure 3). Historical alignments were determined using several tools, including hand-drawn maps and field notes from the 1872 GLO survey, aerial photographs, vegetation mapping, geodetic field surveys conducted by project partners, and Light Detection and Ranging (LiDAR) data. Aerial photographs and vegetation mapping identified a large swath of older riparian wood species, including black cottonwood *Populus trichocarpa*, alder *Alnus* spp., willows *Salix* spp., and quaking aspen *Populus tremuloides*, which delineated a historical floodplain and flow path through the upper part of the project area. The 1872 survey and aerial photographs indicated that Sun Creek had been ditched, straightened, and relocated to the highest elevation on the alluvial fan, presumably to flood irrigate lower-elevation pasture. Prior to modifications for irrigation, Sun Creek would have responded dynamically to major floods, seeking new down-gradient alignments when the capacity of the pre-existing channel was reduced through sedimentation. To achieve long-term stability and capture groundwater inputs, the reconstructed channel was aligned within topographically low areas. Where topographically low areas could not be used, new dikes or floodplain benches set back from channel margins were incorporated. Stream crossings and off-channel stock watering wells were also included to meet the operational needs of the ranch.

Reference reaches in an unmodified area of Sun Creek upstream of the irrigation diversion were characterized to guide design aspects of the new channel, including channel geometry, pool–riffle spacing, meandering, and bed material. For the restored channel downstream of the state forest, the design relied on reference reaches in areas of similar gradient on nearby Annie Creek and remnant channel geometry. Stream discharge measurements taken in irrigation ditches downstream of the irrigation diversion indicated that 10–25% of surface flow was lost to evaporation and seepage between the point of diversion and the ODF–ranch boundary. For this reason, and to allow fluvial geomorphic and hydrologic processes to better create flow paths, the channel was generally undersized relative to upstream reference reaches. If the channel was designed to accommodate discharge above the losing reach, then the channel might be oversized and cause fish passage problems during low-flow periods. In addition to design aspects, reducing water withdrawal from Sun Creek was also necessary to ensure year-round hydrologic connectivity between the upper reaches of Sun Creek and its confluence with the Wood River.

Sun Creek water rights were adjudicated by the State of Oregon to allow diversion of up to 0.58 cubic meters per second (cms; 20.5 cubic feet per second [cfs]) to irrigate over 1,000 acres of pasture, resulting in frequent dewatering of the creek. To address this, TU facilitated the acquisition and transfer of water rights (0.085–0.113 cms [3–4 cfs]), permanently dedicated to instream use, to the State of Oregon. The 108 ha (267 acres) of pasture associated with the transferred water rights were subsequently converted to dryland grazing (Figure 3). Irrigation channels received all of the flow year-round for the past one and a half centuries, whereas the reconstructed stream channel now receives all of the annual hydrograph (0.283–1.416 cms [10–50 cfs]) outside the irrigation

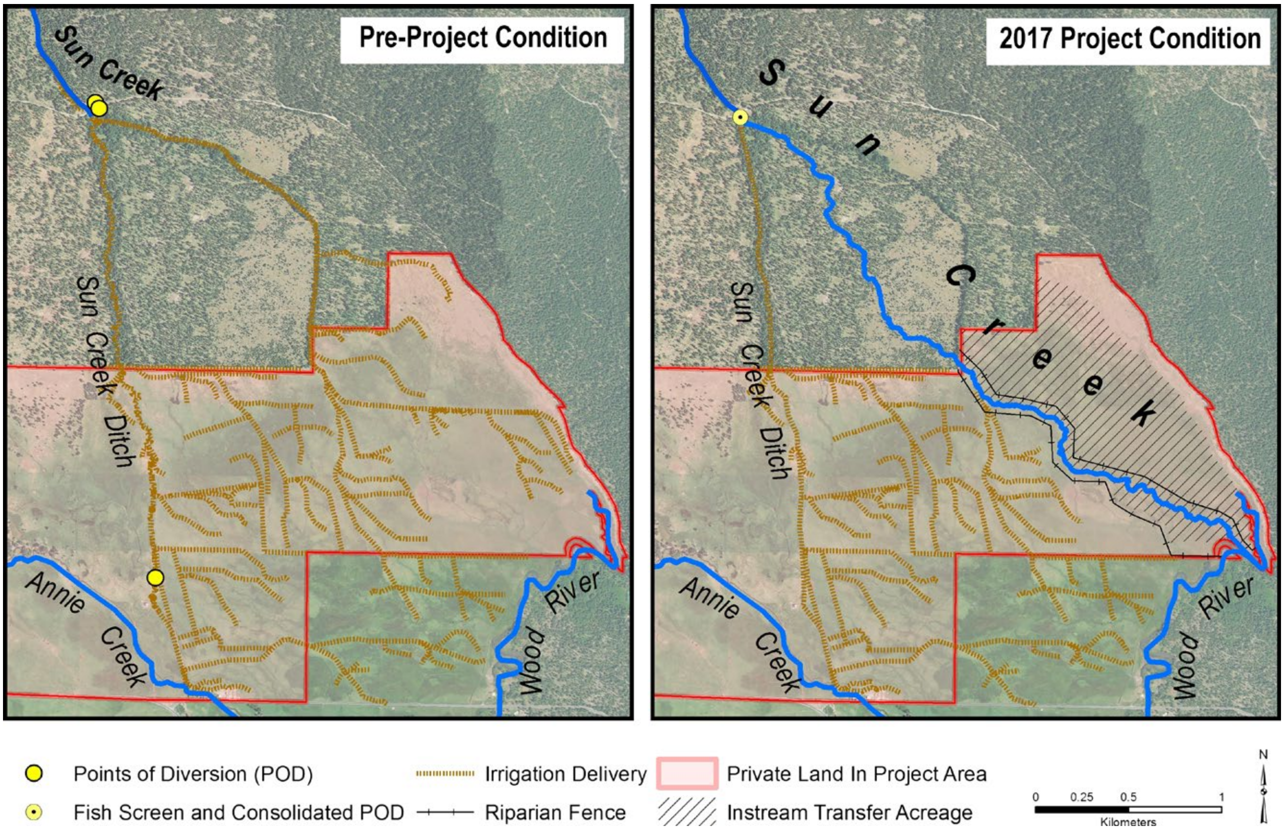

Figure 3. Pre-project and 2017 project conditions, including land ownership boundaries, management structures, and stream and irrigation networks, in Sun Creek, Oregon.

period; it receives the hydrograph minus the water right during the irrigation period (Figure 4); and is assured year-round minimum flows from the instream transfer. Additional efforts were made to improve irrigation efficiency and conserve instream flows, including conveyance piping to replace existing open ditches that lose water through seepage and evaporation (pipe installation is scheduled in 2018).

Efforts to restore and protect instream flows were possible because the State of Oregon enjoys some of the most progressive and actively utilized water right laws (Szeptycki et al. 2015). Oregon passed the Instream Water Right Act in 1987, which provides that instream water rights dedicated to ecological use hold equal regulatory standing with other appropriations of water. Even at present, only a limited number of western states have similar statutory authorities that provide for both the efficient and effective transfer and protection of instream water, and the specific provisions are highly variable. For example, more than 2,000 instream water dedications have been completed in Oregon and slightly over 1,000 have been completed in Washington, while the other western states average well below 50 individual transactions. Oregon law facilitated the instream transfer of water rights and further protects that water instream in perpetuity for the people of Oregon. In the case of Sun Creek, water rights that were transferred instream carried a designated beneficial use for conservation, maintenance, and enhancement of aquatic life, wildlife, fish and wildlife habitat, and other ecological values. These water rights hold priority dates of 1895 because in Oregon, water rights transferred to instream flow are able to maintain their date of appropriation, allowing for full allocation of water to this instream purpose before junior out-of-stream water appropriations are fulfilled.

With increased surface flow secured for the new channel, additional design aspects were developed to protect fish and improve habitat quality. Safeguards were designed to prevent fish entrainment into the irrigation system. Multiple points of water withdrawal were consolidated to a single point of diversion (Figure 3) and screened with a Farmers Screen (FCA Solutions, Hood River, Oregon), which uses slope and bypass flow to self-clean and requires no electricity or moving parts (Mesa et al. 2010). Irrigation water then continues past the screening facility into the main irrigation conveyance, while bypass water and screened fish are returned to Sun Creek by way of a bypass return channel.

Design aspects to improve fish habitat included improvements to both instream and riparian habitats. Two improvements of high priority were providing shade to the restored channel and excluding cattle from the riparian area. The width of the planted (14 m) and fenced (54 m) corridor, centered on the stream, was negotiated with the land owner to allow enough area for periodic, low-intensity grazing. Native riparian vegetation (Table 2) was planted during late fall of 2016 along 2.8 km of the constructed channel, including all of the pasture reach and the downstream portion of the ODF reach with the least forest canopy cover due to past timber harvest (relative canopy development is visible in Figure 3). All of the trees and 10% of the shrubs were caged to prevent damage from browsing by domestic and wild ungulates.

Over time, riparian plantings will provide important wood inputs to the stream for fish and aquatic biota; however, it

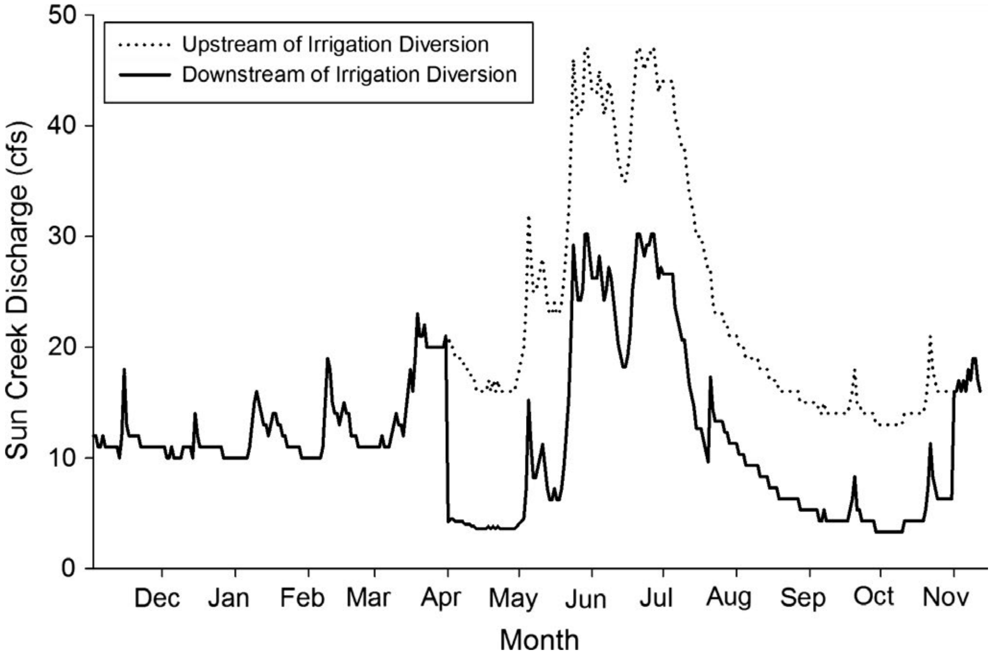

Figure 4. Total discharge (cubic feet per second [cfs]; 1 cfs = 0.028 cubic meters per second) of Sun Creek measured above the point of irrigation diversion (dotted line) and hypothetical surface flow remaining in the reconstructed stream channel after water withdrawal for irrigation (solid line), November 2016–November 2017.

will take years for vegetation to grow to an adequate size. Therefore, large- and medium-sized wood pieces were also added to the restored channel to approximate reference conditions. As the stream passes through the project area, it moves from a densely forested stream ecosystem to a low-gradient meadow with no woody riparian vegetation. Accordingly, a greater number of wood pieces was placed in the stream on ODF land and the upper portion of the ranch—areas that were historically forested—and less wood was placed near the confluence of the Wood River. Overall, stream habitat will improve as riparian vegetation matures under reduced grazing pressure, thereby stabilizing banks and providing shade and a source of wood for the stream.

With the new stream channel under construction in 2016, ODFW removed nonnative fish from the stream and irrigation channels downstream of ODF barriers prior to the activation of the newly restored connection with the Wood River. The piscicide rotenone was applied to wetted channels following the methods described by Finlayson et al. (2000), and other channels were desiccated. The stream reach downstream of ODF barriers was then seeded with fry of Redband Trout *Oncorhynchus mykiss newberrii*, which is native to the Wood River. The objective of stocking Redband Trout was to inhibit re-invasion of nonnative trout from the Wood River through biotic resistance (Elton 1958), since this reach was unprotected by fish passage barriers.

DISCUSSION

Bull Trout abundance in Sun Creek increased from approximately 150 to over 2,000 individuals, and their distribution increased from less than 2 km to approximately 19 km between 1989 and 2017. Distribution, however, is not uniform, and the bulk of the population remains upstream in the national park (Figure 5). Downstream movement appeared to be led by larger fish (166–282 mm FL), and expansion of distribution occurred only after initial increases in local abundance following Brook Trout removal (Figure 5; Buktenica et al. 2013). Bull Trout dispersal was slow relative to Brook Trout dispersal observed in Sun Creek and Brook Trout invasion rates reported in the literature. For example, within 5 years of the 1992 antimycin treatment in Sun Creek, Brook Trout were well distributed in the area between NPS barriers (Buktenica et al. 2013). Roghair et al. (2002) reported Brook Trout reinvasion within 3 years in a Virginia stream that was defaunated by a debris flow. In Colorado, Brook Trout repeatedly reinvaded a stream segment within 8 months after removal (Peterson and Fausch 2003). Dispersal of Bull Trout in Sun Creek may be limited by restricted movement of individuals or poor spawning success. However, there have been relatively few Bull Trout generations since Brook Trout removal, and we expect Bull Trout to continue to increase in abundance, particularly downstream of NPS barriers as they occupy vacant downstream habitat and reproduce.

Sun Creek was reconnected to the Wood River through 4.3 km of reconstructed stream channel after approximately 150 years of separation. Through this restored connection, Bull Trout have access to historically occupied habitats in the Wood River and nearby tributaries, including Annie Creek. Fish screening will prevent downstream-moving fish from becoming entrained in the irrigation system, and upstream-migrating native fish can be trapped and hauled around migration barriers. The instream transfer of water rights associated with the conversion of pasture to dryland grazing (Figure 3) assures 0.085–0.113 cms (3–4 cfs) of summer-season surface flow regardless of irrigation withdrawal (Figure 4). By carrying full discharge for most of the year, channel restoration also benefits basinwide water conservation efforts in the Klamath River watershed. Bull Trout may co-exist with Brook Trout in the lower watershed if intact habitat allows for production of large, fecund, migratory Bull Trout (Dunham et al. 2008). If

Sun Creek irrigation ditch at the Oregon State Forest–private ranch boundary (treeline).

Reconstructed Sun Creek stream channel below the Oregon State Forest–private ranch boundary (treeline).

Table 2. Riparian revegetation plantings in Sun Creek, Oregon, by taxon.

Common name	Scientific name	Count
White/gray alder	*Alnus incana*	132
Saskatoon serviceberry	*Amelanchier alnifolia*	58
Milkweed, mixed	*Asclepias* spp.	50
Water birch	*Betula occidentalis*	17
Nebraska sedge	*Carex nebrascensis*	460
Winecup clarkia	*Clarkia purpurea*	60
Red twig dogwood	*Cornus sericea*	300
Oceanspray	*Holodiscus discolor*	20
Twinberry honeysuckle	*Lonicera involucrata*	22
Mock orange	*Philadelphus lewisii*	70
Ponderosa pine	*Pinus ponderosa*	44
Quaking aspen	*Populus tremuloides*	131
Black cottonwood	*Populus trichocarpa*	250
Bitter cherry	*Prunus emarginata*	30
Chokecherry	*Prunus virginiana*	175
Antelope bitterbrush	*Purshia tridentata*	165
Golden currant	*Ribes aureum*	210
Woods rose	*Rosa woodsii*	296
Coyote willow	*Salix exigua*	2,886
Geyer willow	*Salix geyeriana*	325
Pacific willow	*Salix lasiandra*	210
Small fruited bulrush	*Scirpus microcarpus*	300
Douglas spirea	*Spiraea douglasii*	123
Common snowberry	*Symphoricarpos alba*	84
Total		6,418

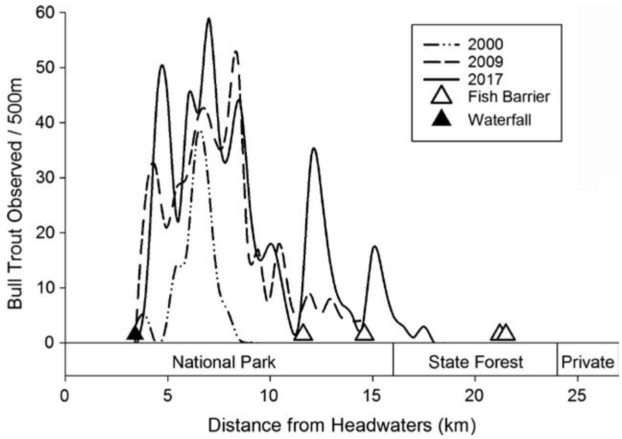

Figure 5. Bull Trout relative abundance in Sun Creek, Oregon, presented in relation to distance from the headwaters.

not, the lowest reach of Sun Creek will still provide a corridor through which migratory Bull Trout can access Brook Trout-free spawning habitat. Other tributary streams in the basin may need to follow the model of nonnative fish removal and exclusion used in Sun Creek.

Beyond its function as a migratory corridor, the reconstructed stream channel may also provide improved rearing habitat for native fish and for other native aquatic and terrestrial biota. In addition to Bull Trout and Redband Trout, other fish native to the Wood River, such as the Speckled Dace *Rhinichthys osculus*, Slender Sculpin *Cottus tenuis*, Pit–Klamath Brook Lamprey *Entosphenus lethophagus*, and ESA-listed Oregon spotted frog *Rana pretiosa*, are expected to colonize restored habitat in lower Sun Creek. Within weeks of reconnecting Sun Creek to the Wood River, several hundred fish had occupied the first several kilometers of the new channel from the Wood River, including sculpin, dace, Redband Trout, Brown Trout *Salmo trutta*, and Brook Trout.

Although stream reconnectivity removed the last major impediment to recovery for this Bull Trout population, recovery is still pending. We expect that management structures, the new stream channel, fencing, and riparian plantings will require maintenance and possible alteration, particularly where the channel is artificially constrained. Monitoring efforts will document changes in fish distribution, abundance, community structure, and behavior as well as channel morphology and habitat condition. These observations will guide adaptive restoration actions as necessary, underscoring the long-term commitment necessary to achieve species recovery.

The collaborative approach used by this project provided efficiencies and opportunities that greatly reduced project costs from initial projected estimates (Inter-Fluve 2008). Nonetheless, this effort and level of expenditure cannot be matched for every population of threatened species and may only be warranted for critical population segments with special status, local management interest, or sufficient conservation value (Clancy et al. 1996). By conserving Bull Trout in Sun Creek, this project addressed the NPS mandate to "preserve unimpaired" wildlife for future generations, while conserving the only native fish remaining in CRLA. Moreover, reconnecting Sun Creek to the Wood River and historically occupied habitat accomplished an important recovery goal for Bull Trout in the Upper Klamath River Recovery Unit identified in the USFWS Recovery Plan for the Coterminous United States (USFWS 2015). Sun Creek, on the southern margin of the Bull Trout's range, is in an area of the Cascades Mountains where models have predicted that stream temperatures will remain suitable for the species under future climate scenarios (Isaak 2016); investing in Bull Trout conservation in these habitats may be the most effective way to prevent further contraction of the species' range. Although initiating a collaborative effort with a commensurate commitment of resources for comprehensive watershed-scale restoration is daunting, such an approach can begin with manageable actions and leadership by a single entity toward stabilization, as was the case in Sun Creek.

Leadership plays a vital role in the success or failure of collaborative resource management (Ansel and Gash 2007). This project operated in an evolving management framework in which no entity had overall project authority. At times, this framework translated to no one having authority and no clear path to project leadership. In our experience, inter-agency working groups find leadership within the group systematically, indirectly, or not at all. Often someone with one or more of the following characteristics will assume the leadership role: innate leadership ability, more time to dedicate to a project, a heightened commitment to or passion for the project, or a senior professional. In our case, project leadership shifted organically as collaborators with relevant expertise took greater or lesser responsibility for different phases of the project. A passionate senior biologist periodically requested updates that returned focus on the project from disparate competing duties and responsibilities. We navigated minor issues, including assertion of traditional agency scope of authority, agency reluctance to operate outside the scope of authority, and individual personalities and leadership styles. Continuity in personnel was invaluable, but equally important was the infusion of new partners with fresh ideas and enthusiasm. Our experience suggests that once the requisite professional skills are assembled on a collaborative team, a measured approach, persistence, passion, and patience are necessary, though less-tangible, qualities required for a project to continue over the time scales necessary to achieve meaningful conservation goals.

Effective conservation necessitates collaboration among multiple land owners, stakeholders, and interest groups. Restoration of Sun Creek was a relatively small example of landscape-scale conservation, involving a handful of land managers and one primary species of conservation concern. The Sun Creek watershed includes four land owners (NPS, ODF, and two private ranches) and multiple organizations with management interest, including USFWS; multiple state agencies, including ODFW, ODF, and OWRD; and the Klamath Tribes. Nongovernment organizations can facilitate work between agencies and may play an increasingly larger role in resource management during times of flat or declining government budgets. Trout Unlimited has a growing interest and role in native trout conservation in the upper Klamath Basin. Thus, this small stream drainage exemplifies the diversity of land management interests that are present in many areas of conservation concern throughout the western United States. The Sun Creek project also illustrates (1) how anthropogenic impacts outside a natural area can penetrate boundaries, and (2) conversely, how the values of a protected area (e.g., a national park) can extend beyond the bounds of the protected area to influence species recovery on a broader spatial scale. Principles of collaboration have become integral to modern resource management and are necessary to meet environmental challenges and pressures facing natural resources and the agencies responsible for managing them. Only through such collaborative efforts can we preserve biological diversity and integrity of ecological systems on meaningful scales that cross management boundaries.

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