FEATURE

# Climate Change Adaptation and Restoration of Western Trout Streams: Opportunities and Strategies

Climate change is contributing to the severity and rate of stream degradation by changing the timing of peak flows, altering flow regimes, creating more frequent and intense disturbances, and increasing stream temperatures. Herein we describe three case studies of trout stream adaptation that address existing and climate-driven causes of degradation through habitat restoration. The case studies vary in geography and complexity, but all include restoration efforts intended to address multiple causes of stream degradation and improve the resilience of these streams to floods, droughts, and wildfires. Four elements of successful climate adaptation projects emerge: (1) habitat assessments that help drive project location and design, (2) projects that directly address climate change impacts and increase habitat resilience, (3) projects that combine to achieve watershed-scale impacts, and (4) projects that include sufficient monitoring to determine their effectiveness. We describe solutions to common challenges in conducting climate change adaptation, including how to balance scientific assessments with opportunities when choosing projects, how smaller projects can be aggregated to achieve watershed-scale benefits, and how citizen science efforts can augment monitoring programs.

## Adaptación al cambio climático y restauración de los ríos occidentales para la trucha: oportunidades y estrategias

El cambio climático está contribuyendo a incrementar la severidad y la tasa de degradación de los ríos a través de la alteración en la estacionalidad del flujo máximo, modificación del régimen de flujos, generación de perturbaciones más frecuentes e intensas e incremento de la temperatura de los ríos. Aquí se describen tres casos de estudio de la adaptación de ríos en donde habita la trucha, en los que se abordan las causas de la degradación que son provocadas por el cambio climático, mediante la restauración del hábitat. Los casos de estudio varían en cuanto a ubicación geográfica y complejidad, pero en todos se contemplan esfuerzos de restauración enfocados a abordar múltiples causas de degradación de ríos y mejoramiento de la resiliencia de éstos ante inundaciones, sequías e incendios naturales. Se consideraron cuatro elementos para lograr una adaptación exitosa al cambio climático: 1) evaluaciones del hábitat que ayuden a diseñar y establecer dónde llevar a cabo los proyectos; 2) proyectos que aborden directamente los impactos del cambio climático y el incremento en la resiliencia del hábitat; 3) proyectos que, al combinarse, logren resultados a nivel de cuenca hidrológica; y 4) proyectos que incluyan un monitoreo suficiente como para que se pueda determinar su efectividad. También se describen soluciones a los clásicos retos que implica la adaptación al cambio climático, incluyendo cómo encontrar un balance entre evaluaciones científicas y elección de proyectos, cómo se pueden integrar varios proyectos pequeños para conseguir beneficios a escala de cuenca y cómo se puede incrementar el monitoreo mediante esfuerzos ciudadanos.

**Jack E. Williams**
Trout Unlimited, 4393 Pioneer Road, Medford, OR 97501. E-mail: jwilliams@tu.org

**Helen M. Neville and Amy L. Haak**
Trout Unlimited, Boise, ID

**Warren T. Colyer**
Trout Unlimited, Missoula, MT

**Seth J. Wenger**
University of Georgia, Athens

**Stan Bradshaw**
Trout Unlimited, Helena, MT



## INTRODUCTION

Climate change is rapidly becoming one of the most challenging issues for management of trout, salmon, and other coldwater fisheries. Climate-induced changes in flows and disturbance regimes (Stewart et al. 2005; Haak et al. 2010) will confound stream restoration efforts as rising temperatures and other stressors reduce suitable coldwater fish habitat (Kaushal et al. 2010). Despite the added complexity and uncertainty, stream managers have begun to integrate climate change adaptation into restoration and monitoring efforts.

Over the past decade, researchers have recommended adaptation strategies that promote resistance and resilience to reduce the impacts of climate change (Lawler 2009). "Resistance" is the ability of a system to remain unchanged in the face of external forces. "Resilience" is the ability of a system to recover from disturbance. The most common types of adaptation strategies suggested for dealing with climate change include the expansion

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of reserve systems (Halpin 1997), increasing landscape connectivity and corridors among occupied habitat patches (Hulme 2005; Beechie et al. 2012), restoring degraded habitats (Harris et al. 2006), and removing other threats and stressors such as invasive species (Noss 2001), yet there are few specific examples of how these strategies can be applied in the context of climate adaptation in stream systems.

In this article, we briefly review likely impacts of climate change on trout and their habitats and describe how these impacts were addressed in three stream restoration case studies. One common theme is that the long legacy of human-induced habitat degradation and fragmentation that has led to current levels of decline for native trout species now provides many opportunities for restoration that could help address threats of climate change. These studies demonstrate different approaches to stream restoration in terms of assessment, spatial and temporal scales, and tactics and strategies to increase the persistence of trout populations in a warming but uncertain future.

### How Climate Change Affects Trout

Trout are likely to be particularly susceptible to the effects of climate change. Though there is considerable uncertainty as to the rate of change and variability of these impacts over space and time (Wenger et al. 2013), there is general agreement on the types of impacts that are expected. There also is growing evidence that these impacts are already manifesting themselves on the landscape as described below.

#### *Warmer Summer Temperatures*

Trout are coldwater fish and generally cannot tolerate temperatures above 22–28°C, depending on the species (Selong et al. 2001; Dunham et al. 2002). When temperatures are too high, many trout species experience reduced growth, survival and reproductive capacity, and heightened stress that can leave them more vulnerable to disease and displacement by competitor species. As temperatures warm beyond the preferred range for a trout species, suitable habitat shrinks and becomes increasingly fragmented, reducing population sizes and connectivity (Rieman et al. 2007; Wenger et al. 2011b).

#### *Earlier Peak Flows, Lower Summer Flows, and More Droughts*

In recent decades, stream flow in the western United States has been characterized by earlier timing of spring runoff (Stewart et al. 2005) and declining summer flows (Luce and Holden 2009; Cayan et al. 2010; Fu et al. 2010). Earlier spring runoff and earlier peak flows serve as important behavioral cues for many aquatic species and thus change the phenology of aquatic insect emergence and fish migrations (Harper and Peckarsky 2006; Kovach et al. 2013). Declining flows typically lead to higher water temperatures and overall degradation of habitat condition, size, and connectivity.

#### *More Intense Wildfires and Other Disturbances*

The warming trend in the United States has been accompanied by more frequent and larger wildfires in the West (Westerling et al. 2006) and increasing storm events in the East (Spierre and Wake 2010). These events can kill fish directly, but they also make hillsides more susceptible to landslides and debris flows that can block channels, fill in spawning areas, and impede fish movement (Brown et al. 2001). The combination of increasing disturbance intensity and fragmentation of stream habitats results in more severe degradation of fish populations than would occur under more natural conditions (Rieman and Clayton 1997).

#### *More High Flows in Winter (for Snow-Dominated Areas)*

In mountainous regions in the West, precipitation occurs mainly in the form of winter snow. Stream flows in these locations tend to be steady and moderate over winter, which provide safe conditions for the incubation of the eggs of fall-spawning trout species such as Bull Trout *Salvelinus confluentus*. However, as climate warms, rainstorms in a snowy landscape can melt snow and lead to increasing winter floods (Graybeal and Leathers 2006; Haak et al. 2010), which may be particularly detrimental to fall-spawning of Bull Trout and Brook Trout *S. fontinalis*. Winter floods can scour stream beds and drastically increase erosion.

#### *Increased Cumulative Stressors, Nonnatives, and Disease*

The effects of climate change are likely to increase the cumulative impacts of a variety of stressors on stream systems. High water temperatures also may render trout more susceptible to invasive species and diseases, including whirling disease (Rahel and Olden 2008). Recent studies examined the combined effects of increasing temperatures, declining summer flows, increasing winter high flows, and invasion by competing trout species in the Interior West. The authors found that warming temperatures negatively affect both native and nonnative species, but increasing winter high flows primarily harmed fall-spawning trout species (Wenger et al. 2011a, 2011b). Cutthroat Trout *Oncorhynchus clarkii* were negatively affected by competition with introduced trout species, but Bull Trout were not. However, the combined effects of temperature and flow changes were predicted to lead to large declines of Bull Trout (Wenger et al. 2011a), which is among the most threatened trout species in the lower 48 states. Lawrence et al. (2014) showed

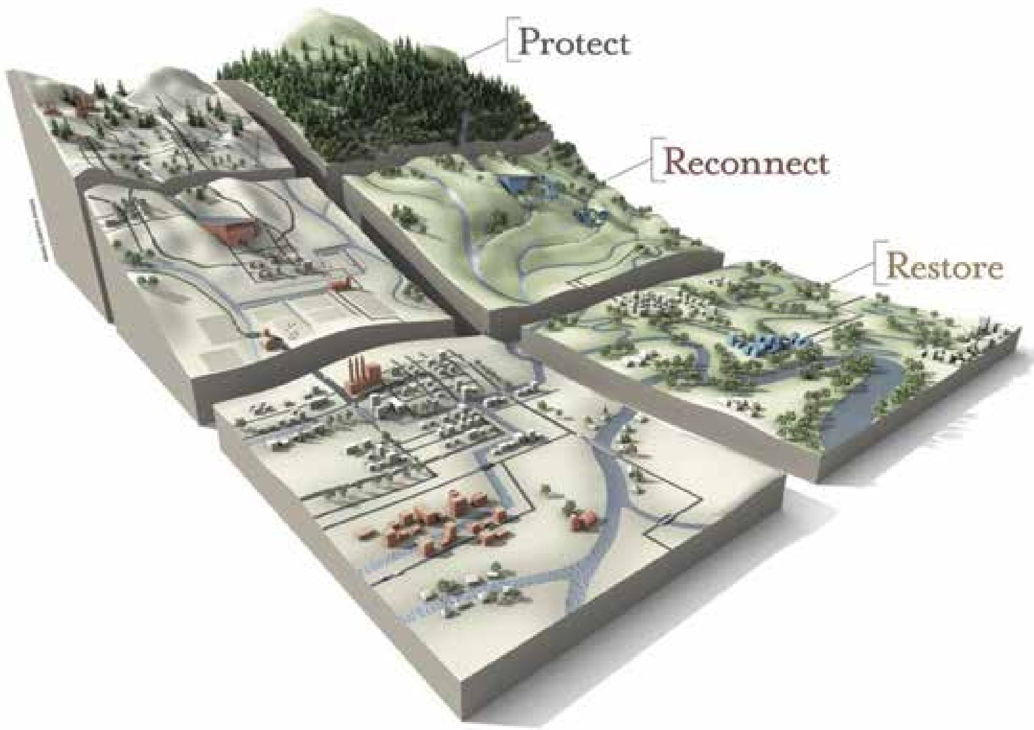


Figure 1. Graphic depicts watershed-scale adaptation strategy consisting of protecting headwater sources of cold water, reconnecting the fragmented stream network, and restoring the mainstem and valley bottom habitats. Illustration courtesy of Bryan Christie Design and Trout Unlimited.

how degraded riparian habitat combines with climate change to facilitate an upstream invasion of salmonid habitat by Smallmouth Bass *Micropterus dolomieu*.

## METHODS

The general approach advocated by Trout Unlimited (TU) to trout conservation consists of watershed-scale efforts to protect remaining high-quality habitats, reconnect mainstem habitats to tributaries through removal of passage barriers and improvements to instream flows, and restoration of degraded riparian, wet meadow, and mainstem channels (Figure 1). Here we describe three restoration case studies from the western United States that incorporate a wide range of likely climate change effects and a mix of the above corresponding adaptation strategies (Table 1). By describing actual case studies, we can compare on-the-ground realities among existing projects and better understand questions of spatial scale. All of the case studies are multiyear projects involving first- to third-order stream systems. The projects were initiated and carried out by a variety of agencies, nongovernmental organizations, and private landowners and corporations. Goals of the individual projects vary, but all focus primarily on the restoration of degraded native trout populations and their habitats.

Results of each case study are presented below. Each case study includes background information that provides context to the restoration effort, a description of habitat assessment data (if any) that supported the project, a description of the adaptation work, and a description of effectiveness as determined by moni-

Table 1. Comparisons of climate effects, corresponding adaptation strategies and restoration actions, and case studies where these strategies and actions have been implemented.

| Climate effects | Adaptation strategies | Restoration actions | Case studies |
|---|---|---|---|
| Warmer summer temperatures | Increase stream shading and increase cool water habitat | Restore riparian areas; increase meanders, deep pool, and undercut bank habitats | Maggie Creek, NV; Crow Creek, ID; Wasson Creek, MT |
| Earlier peak flows, decreasing summer flows, and more drought | Keep flows in headwaters longer; recharge aquifers; increase refuge habitats | Restore headwater meadows and wetlands; increase channel meanders; restore instream flows; increase number and size of deep pools | Maggie Creek, NV; Wasson Creek, MT |
| More wildfires | Create large wet zones along stream that are resistant to burning | Increase width and lushness of riparian areas; slow flows and remeander to increase shallow groundwater in meadows; introduce beavers | Maggie Creek, NV |
| More floods and higher flows in winter | Increase natural capacity of streamside habitats to absorb and dissipate flow energy | Reconnect and restore floodplains; expand and revegetate riparian areas; improve culvert designs and capacity | Maggie Creek, NV; Wasson Creek, MT; Crow Creek, ID |
| Increased cumulative stress to stream systems | Reduce other sources of stress to minimize cumulative impact of increased climate stressors | Reduce or otherwise improve livestock use; reduce roads and/or improve their maintenance; reduce pollution sources | Maggie Creek, NV; Crow Creek, ID; Wasson Creek, MT |

toring. The assessment data allowed us to examine the relative importance of strategy versus opportunity in project development. The adaptation work facilitated an understanding of spatial scales in project development and how reach-scale projects compare to those at watershed-scale. Monitoring data provided clues as to the success of projects relative to addressing resistance and resiliency to climate change as well as other stressors and provided insights into temporal scales and understanding long-term project success.

Like many degraded streams across the country, the streams described herein have been altered through a long history of intense and long-term livestock use, land use change, off-road vehicles, diversion of flows, and/or stream channelization. Restoration actions focus on the removal of existing stressors through restoring streams to their historical channels, fencing and revegetation of riparian areas, introducing beavers, reconnecting stream fragments, and restoring instream flows. Restoration actions are designed to reduce the cumulative stress on stream systems, increase habitat complexity, increase the number and size of deep pools, reduce channel width–to-depth ratio, and increase shading, all of which generally increase resistance and resiliency to impacts of climate change (Williams et al. 2007; Rieman and Isaak 2010).

## CASE STUDIES

### Maggie Creek, Nevada

#### *Project Context*

Maggie Creek in northeastern Nevada was assumed historically to support an interconnected "metapopulation" of Lahontan Cutthroat Trout (LCT) *O. c. henshawi,* where fish accessed tributary and mainstem habitats needed for growth, gene exchange, spawning migrations, and refuge from stressful conditions (Neville et al. 2006). But decades of intensive livestock grazing, water diversions, and road construction degraded streams and fragmented populations into a few small remnants, making remaining fish particularly vulnerable to increasing stream temperature, drought, and wildfires.

#### *Habitat Assessment*

Previous work demonstrated that LCT in isolated habitats were less likely to persist (Dunham et al. 1997) and that larger habitat patches had a greater probability of occupancy than smaller patches (Dunham et al. 2002). Furthermore, research in a neighboring large, interconnected system (Neville et al. 2006) demonstrated the importance of a migratory life history and metapopulation dynamics in interconnected habitats and the contrasting negative effects of isolation in fragmented streams. Restoring larger interconnected habitats was therefore a high priority for LCT recovery, and reconnecting the three Maggie tributaries would restore one of the largest habitat patches—and assumedly functional metapopulations—in the entire range. A small number of land managers in the watershed (a few large ranches and the Elko District of the Bureau of Land Management [BLM]) helped to facilitate this large-scale work.

#### *Climate Adaptation*

Restoration actions included the removal of existing stressors, in this case, livestock overgrazing; degradation of stream, riparian, and wet meadow habitats; and isolation of tributaries from the mainstem Maggie Creek. In 1993, as mitigation for Newmont Mining Corporation's expanding operations in the basin, Newmont, the BLM, and local landowners and partners initiated the Maggie Creek Watershed Restoration Project to enhance 132 km of stream, 800 ha of riparian habitat, and 16,200 ha of upland watershed in the basin. Although the project included a number of components, including riparian plantings and fencing, a conservation easement, and water developments, the most important change was application of prescriptive livestock grazing practices to limit hot season grazing. Prior to 1993, cattle were present on most riparian areas throughout the growing season. Revised grazing prescriptions ranged from total exclusion to rotational grazing patterns incorporating changes in season and duration of use. Further upstream, along Beaver Creek, the BLM, Nevada Mining Association, and Twenty-Five Ranch constructed a riparian pasture encompassing almost 5,300 ha of public and private lands on more than 48 km of stream habitat. Grazing was changed from season-long use throughout the growing season every year to hot season (July and August) grazing occurring no more than once in four years, and the pasture was either rested or grazed during the spring in other years. Though not official partners, the native beavers that moved back into Maggie Creek following habitat improvements have provided further restoration services.

Finally, three tributaries contained road culverts at their confluence with Maggie Creek. The culverts at two of the primary tributaries, Little Jack and Coyote creeks, were thought to be partial barriers, whereas the structure at the largest tributary, Beaver Creek, was assumed to prevent all LCT movement. In 2005, the culverts were replaced and an irrigation diversion in the mainstem creek was modified with fish-friendly structures designed to allow fish passage (Figure 2), effectively reconnecting the three tributaries to the mainstem river corridor. To safeguard the entire system from nonnative fish invasion, a large instream barrier was installed in 2012 below the reconnected part of the watershed near the Humboldt River.

#### *Monitoring and Effectiveness*

The BLM—in cooperation with Newmont Mining Corporation and other partners —has employed a variety of monitoring protocols, including stream surveys, proper functioning condition assessments, remote sensing, and photography to track changes in stream and riparian habitat conditions throughout the basin over time. Parts of the system were so severely trampled by cattle that they lacked clear stream channels and were completely bare, but now stream channels are narrower and deeper and show improvements in meandering, pool development, and riparian vegetation (Figure 3).

Additional analysis of aerial photography over time has allowed a birds-eye view of habitat improvements, showing the replacement of upland vegetation with riparian vegetation at broad landscape scales (Figure 4). As habitat improved, the number of beaver increased dramatically, and their success as ecosystem engineers is evident: wetlands created by beavers recolonizing Maggie Creek now provide high-quality habitat for fish and many species of wildlife, including waterfowl and other birds, muskrats, mule deer, mink, and raccoons. Water storage and sediment capture also have improved. Groundwater has increased in elevation by 0.6 m below the restoration area, and the input of suspended sediments during floods has decreased, demonstrating the filtering effect of the restored vegetation.

Trout Unlimited initiated monitoring in 2001 to determine fish responses to the newly established connectivity provided by culvert replacements. Knowing that the culverts were to be removed in 2005, we established 44 monitoring sites in 2001 across the streams and began counting the numbers and sizes of fish at each site. As expected, after the partial barriers in Little

Figure 2. Culverts in Beaver Creek that prevented fish passage (top) were replaced with a fish-friendly structure in 2005 (bottom). Photos courtesy of Elko District BLM.

Jack and Coyote creeks were replaced, the numbers of fish continue to fluctuate almost as before, with possibly a slight bump in numbers. The newly connected Beaver Creek, however, has shown a marked response: not only are there more fish collected in surveys (with fairly stable averages of 25 fish captured at our sites before remediation and 215 after), but there is increasing evidence of successful spawning as indicated by the numbers of young-of-year fish. Larger, migratory-sized fish are also more common. Prior to culvert replacement, nearly all fish collected were less than 100 mm total length, but after fish passage was restored, LCT in the 200–300 mm total length class were collected. These improvements held true even in 2012, one of the worst drought years recorded. All of this suggests both that populations within each stream are benefiting from the restoration work and the system as a whole is now functioning more like it did historically: it now supports large migratory individuals with


Figure 3. BLM monitoring photos of the mainstem Maggie Creek in 1980 (top) and 2011 show obvious improvements in stream ponding, bank stability, and vegetation—in part thanks to an influx of beavers. Photos courtesy of Elko District BLM.

the ability to move among different habitat types in tributaries and the mainstem river to escape areas of habitat disturbance or degradation to find suitable conditions.

### Crow Creek, Idaho

*Project Context*

The Salt River drainage in Wyoming and Idaho is a major tributary to the iconic South Fork of the Snake River and supports populations of native Yellowstone Cutthroat Trout (YCT) *O. c. bouvieri* as well as nonnative Brown Trout *Salmo trutta*, Brook Trout, and Rainbow Trout *O. mykiss*. Crow Creek is a tributary to the Salt River that provides important spawning habitat for migratory YCT from the mainstem as well as being home to resident populations. Like many western streams, Crow Creek has a legacy of habitat and water quality degradation stemming from human activities that include agriculture, mining, and roads—all of which have increased sediment loads that bury spawning gravels and smother trout eggs. As a result, Crow Creek currently has been identified by the state as being impaired in water quality pursuant to Section 303(d) of the Clean Water Act.

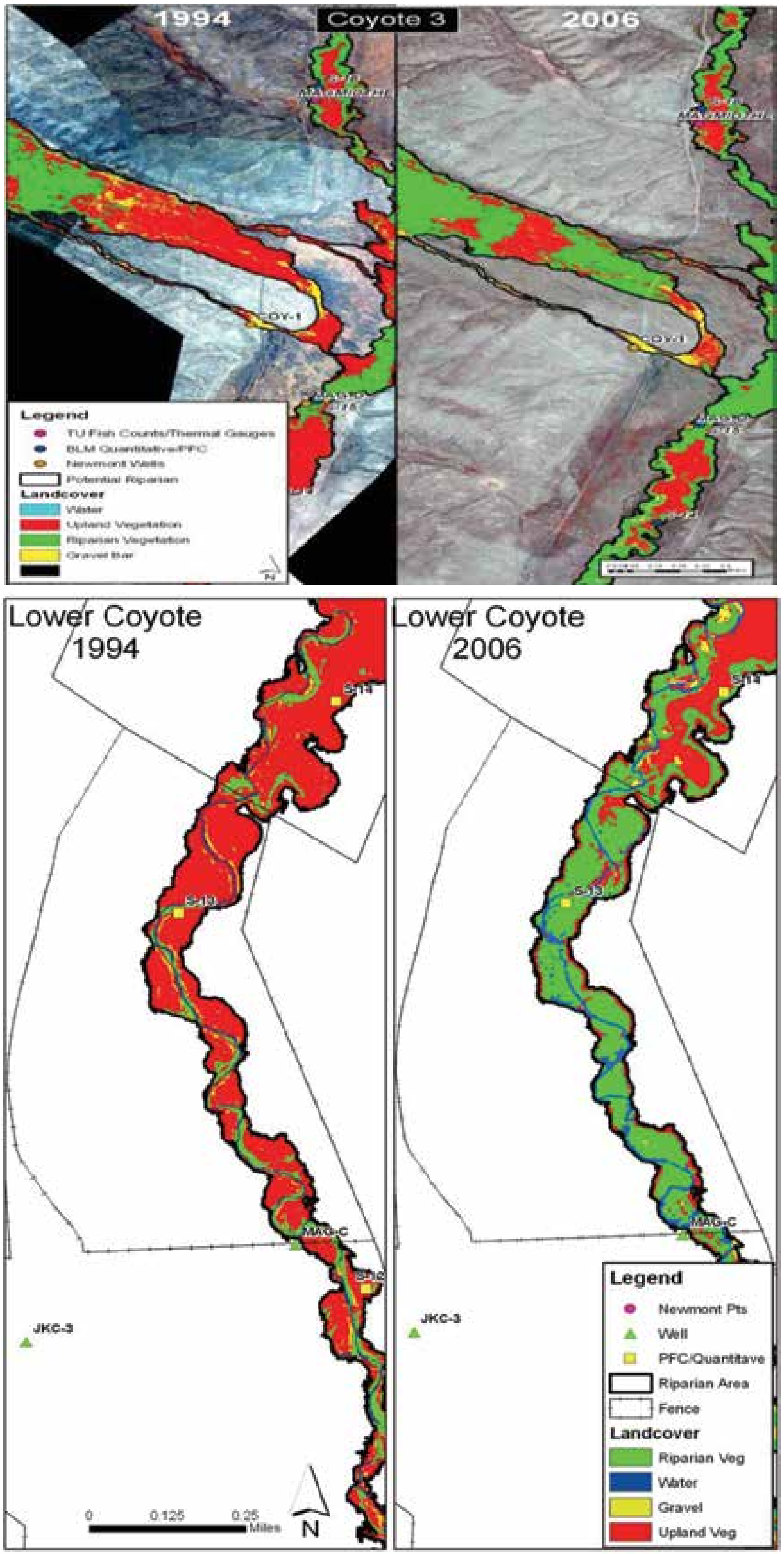


Figure 4. Remote sensing analyses completed by Open Range Consulting show increases in the amount of riparian vegetation (green) and reductions in upland vegetation (red) along Coyote Creek, a tributary of Maggie Creek. Figure from Simonds et al. (2009).

Figure 5. Photo of Crow Creek, Idaho, project immediately after we began to divert streamflow from the straightened channel (adjacent to road) into the reconstructed channel (top).



One especially significant source of sediment on Crow Creek was a channelized section of stream located in the Caribou-Targhee National Forest. Sometime around the mid-1900s, a local rancher used a bulldozer to straighten the channel and move it to one side of the valley in order to increase the land available for hay cultivation. The resulting lack of meanders and pools not only reduced cover and habitat for fish but also significantly increased erosion.

### Habitat Assessment

Crow Creek and the Salt River support resident and migratory life histories of genetically pure YCT, which makes their protection and restoration a high priority within TU's climate adaptation strategies (Haak and Williams 2012). The Salt River drainage supports genetically unaltered metapopulations of both the large- and fine-spotted forms of YCT. From the Forest Service's perspective, Crow Creek was a high priority in their five-year watershed action plan because of its importance for water quality, fisheries, and aquatic stream stability as well as the presence of willing partners and available funding (Louis Wasniewski, Caribou-Targhee NF, personal communication).

### Climate Adaptation

In 2009, TU and the U.S. Forest Service initiated a project to reconstruct the historic Crow Creek channel and restore the natural hydrologic processes that had been interrupted when the channel was straightened. The goal of the project was to restore channel function, increase available instream habitat, and improve water quality to buffer Salt River YCT populations from catastrophic environmental events like floods, fires, and droughts that are predicted to increase in the region (Haak et al. 2010). Intact stream channels and vegetated floodplains mitigate the effects of those events by attenuating flood flows, storing and slowly releasing ground water back to streams during low flows, and providing lush riparian vegetation that resists fire and filters sediment and ash during run-off events.

The Crow Creek restoration project was implemented in three phases. First, a combination of aerial imagery and topographic survey data from the project reach and an upstream reference reach (e.g., stream reach that had not been modified and represented a "natural" condition) was used to design a new channel with a meander pattern representative of historical conditions (Figure 5). Where the original channel was still evident, it was used; where it was not, a new channel was designed consistent with historical meander patterns. During the second phase of the project, a new channel was excavated and the resulting fill stockpiled at regular intervals along the old, straightened channel. At this point, a new channel was connected to the existing channel at the upstream and downstream ends, and a water control device was installed at the upstream end of the straightened channel. In phase three, flow was gradually diverted into the new channel over the course of a few months in 2011–2012, rather than flooding it immediately, thereby allowing vegetation to become established and begin to stabilize the new channel (Figure 6). To that end, sod mats were installed on raw, excavated stream banks, and willow clumps were transplanted from adjacent reaches. Stockpiles of excavated fill material were then used to fill in the old channel.

### Monitoring and Effectiveness

Trout Unlimited and project partners continue to monitor the YCT population responses to the newly restored channel and expect that fish numbers will increase in the project reach within a few years. The physical habitat benefits, in contrast, have been immediate (Table 2). The project reduced the stream gradient by nearly 50% and more than doubled the sinuosity to match reference conditions. The result is slower stream velocities and less streambank erosion, as well as a gradual elevation of the groundwater table, which will promote wetland and riparian vegetation and augment late season stream flows with cool water. Remeandering stream channels can decrease stream temperatures by increasing pool development and increasing the length of hyporheic flows, which cools water during the summer (Arrigoni et al. 2008). Available stream habitat was significantly increased by nearly doubling the length of stream through the project reach—from 1,007 to 1,973 m—and increasing pools and associated tail outs (preferred spawning habitat for YCT) by nearly a factor of 10. The resulting combination of increased and improved habitat, restored stream and riparian function, and improved water quality will increase resiliency to environmental disturbances in both Crow Creek hydrologic systems and the native YCT populations that depend on them.

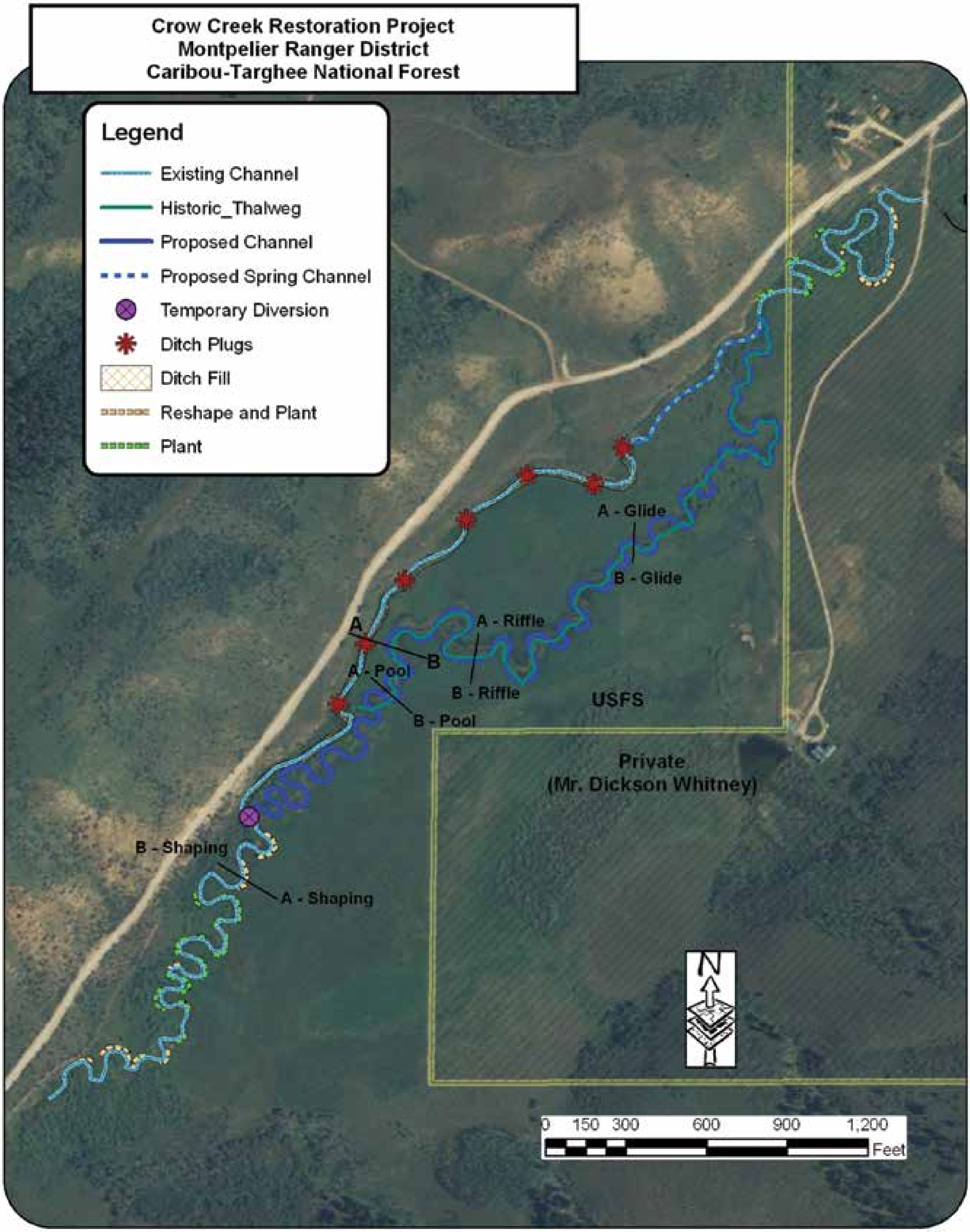


Figure 6. Diagram of Crow Creek, Idaho, showing project design. Graphic courtesy of Louis Wasniewski and U.S. Forest Service.

**Table 2. Comparison of Crow Creek, Idaho: project reach characteristics before and after restoration.**

| | Stream gradient (%) | Sinuosity | Stream length (m) | # Pools |
|---|---|---|---|---|
| **Before** | 0.7 | 1.1 | 1,007 | 9 |
| **After** | 0.4 | 2.4 | 1,973 | 86 |

### Wasson Creek, Montana

*Project Context*

Wasson Creek is a small second-order tributary of the Nevada Creek drainage of the Blackfoot River in Montana. Nevada Creek has been identified as a major source of nutrient, sediment, and increases in temperature to the middle reach of the Blackfoot River as a result of past ranching and other human uses. In 2003, the Montana Department of Fish, Wildlife & Parks (MDFWP) documented a genetically pure population of Westslope Cutthroat Trout (WCT) *O. c. lewisi* in the upper reaches of Wasson Creek, which provided further stimulus to undertake restoration actions.

Wasson Creek suffered from a litany of impairments, including fish barriers, diversion of water for irrigation, entrainment of fish into ditches, channel straightening, livestock damage to banks, and water quality impairments from agricultural runoff. As a result, lower reaches of the creek heated to near-lethal temperatures for trout in the summer (Figure 7), and low flows often precluded any fish migration. The genetically pure WCT population was effectively isolated from the watershed below the irrigation diversions.

*Habitat Assessment*

Staff from MDFWP have been conducting fisheries inventories and establishing stream restoration priorities in the Blackfoot River Basin since 1989. Their most recent stream and native fish assessment for the Blackfoot ranked Wasson Creek as a "high priority" for restoration based on the potential for improvements to flows and water quality (Pierce et al. 2005). The small but persisting genetically pure population of WCT also indicated good potential for restoration. These factors, plus the presence of interested landowners, made the project a high priority for TU and other partners.

*Climate Adaptation*

In 2004, TU, the MDFWP, local ranchers, and a host of other partners embarked on a restoration project with the goal to restore hydrologic connectivity and resilience to Wasson Creek. A variety of restoration actions were undertaken, including livestock exclusions with other long-term improvements to grazing management, channel reconstruction and reconnection of the creek to its floodplain, screening of two critical ditches, and restoration of minimum flows in the lower creek in late summer.

In 2005, TU and the ranchers entered into a series of one-year agreements to keep a minimum of 0.5 cfs in the stream while the parties worked for state approval of a long-term instream flow lease. At the same time, the ranch fenced off the creek from livestock, and TU initiated channel restoration efforts. Even before all parts of the restoration were complete, small numbers of trout started to appear below the diversions just through the maintenance of 0.5 cfs. Completion of a 10-year lease for 0.75 cfs was reached in 2007 along with the installation of fish screens on the two ditches.

*Monitoring and Effectiveness*

The summer of 2007 was one of the hottest on record in the Blackfoot, and the temperature response to increased flows was immediate. Temperatures at the mouth of Wasson Creek, which rose as high as 27°C in 2003, peaked at just over 18°C in 2007 (Figure 7). Cutthroat Trout populations below the diversions went from zero in 2003 to an average of 30.4 fish/100 m in 2007–2012. Downstream areas that were inhabited by small numbers of Brown Trout but no Cutthroat Trout prior to the project in 2000 showed upwards of 81 Cutthroat Trout/100 m by 2010. In 2012, the MDFWP radio-tagged 14 mature migratory Cutthroat Trout in Nevada Creek and tracked their movements over the course of the spring and summer. Of the 14, 10 migrated up Wasson Creek past the irrigation diversions and spawned.

## DISCUSSION

As the impacts of climate change on stream flows, stream temperatures, and disturbance regimes become more pronounced, it becomes important to examine the efficacy of stream and riparian restoration within the context of a rapidly changing environment. Herein we report on three case studies of trout stream restoration for insights into the following elements of climate change adaptation: (1) how projects are chosen and specifically what role habitat assessments are likely to play in these decisions, (2) how restoration efforts address climate change impacts, (3) how local projects can achieve results at watershed scales, and (4) how projects are monitored and evaluated.

Restoration projects that ultimately improve climate resistance and resiliency for trout may be initiated for a variety of reasons, and thus initial habitat assessments may vary in both focus and scale. In the above examples, assessments and project selection were carried out with a variety of goals, ranging from a local opportunity that fit an ecologically-based, range-wide need for species recovery (Maggie Creek: the need to restore and reconnect a large metapopulation of LCT) to a desire to maximize multiple resource benefits (Crow Creek: the U.S. Forest Service's desire to improve water quality, bolster the status of multiple fishes, and increase habitat stability) to a focus on a specific habitat attribute such as water quality (Wasson Creek).

Recognizing that species declines result not just in fewer populations but potential losses in important characteristics of a species' evolutionary and ecological history, TU has recently developed a broad-scale conservation assessment approach to help maximize restoration and retention of these diverse attributes. Our portfolio approach helps compare existing levels of genetic, life history, and geographic diversity to historical levels range-wide in order to determine gaps in each species or subspecies' portfolio that may leave them at particular risk, with climate change as an explicit risk factor to consider (Haak and Williams 2012, 2013). Where desirable, this type of broad spatial analysis can be used as a range-wide prioritization tool by highlighting projects that would improve specific components of the portfolio—while evaluating areas of the range least at risk of climate change or where the best improvements in habitat or population status could be made.

Ideally, this type of large-scale assessment would be a first step in prioritization, following which factors such as landowners, partners, and available funding can then be overlain to determine final project location. Typically, the process of project selection combines part scientific strategy and part opportunity; it is important that habitat assessments and a strong fundamental knowledge of the species' ecology drive project selection, but

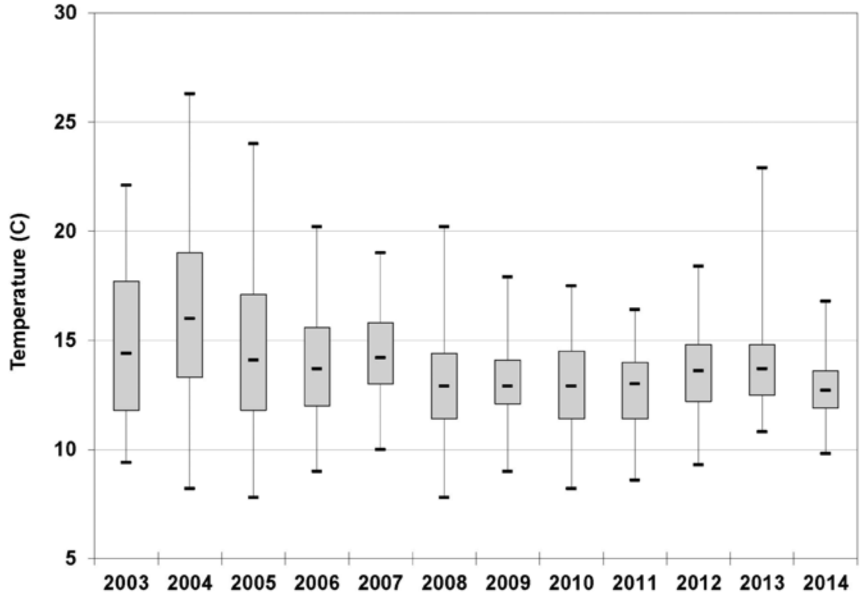

Figure 7. July water temperatures for Wasson Creek, Montana, just upstream of Nevada Spring Creek, 2003–2014.



the presence of willing landowners, partners, and funding is an integral part of project reality. The three case studies described herein all have elements of science-driven assessments but also landowner, partner, and funding opportunities. For some species and geographies, there are many projects that will rank as high priority, but in other regions, choices are more limited. Wasson Creek, for example, was one of 34 streams designated as high restoration priority in the Blackfoot River drainage (Pierce et al. 2005). But in more arid regions, such as northern Nevada's Great Basin, there are few places where a metapopulation of LCT could be restored. It was fortunate in the case of Maggie Creek that there were opportunities for collaboration among BLM, landowners, and partners in this particular basin and that the drainage contained just a few ranches in addition to BLM lands, which facilitated work across the entire watershed.

Along these lines, our work in Maggie Creek has emphasized the importance of increasing efforts to work with private landowners. Partly because the private landowner realm can be contentious and partly because of the difficult logistics in coordinating many different landowners, much of the restoration work for LCT to date has been on public lands—management teams have effectively tackled the "low-hanging fruit" first. But for LCT and many other native trout, much of the historical range falls on private lands, including the habitat along larger streams that is critical for restoring migratory life histories. So our greatest gains in the future are likely to come from working effectively with the private sector. Accordingly, we have initiated a suite of strategies, including funding a biologist with the state fish and wildlife agency to implement safe harbor agreements with landowners. These agreements protect landowners from legal aspects of having a listed species, such as LCT, on their properties and are thus an essential step in being able to carry out restoration activities on private properties. We are also working with our partner ranches to outreach to their peers, rancher-to-rancher, about the benefits of "conservation ranching" to improve habitat and species status.

For restoration work to have long-term benefits to native coldwater fishes, projects must directly address climate change impacts. Often, the most obvious need is to mitigate warming stream temperatures through riparian restoration and creation of coldwater refuge habitats within stream channels (Seavy et al. 2009). However, riparian restoration work can vary in effectiveness according to channel width (Cristea and Burges 2009) and riparian area species composition (Price 2013). Riparian restoration in multiple headwater streams may be necessary to realize benefits in downstream reaches. For salmon restoration in the western United States, Beechie et al. (2012) argued the importance of large-scale projects that jointly restore floodplain connectivity, instream flows, and re-aggrade incised channels (rather than more localized instream work in isolation) in order to ameliorate climate change effects.

In Maggie Creek, the beavers that recolonized helped re-aggrade channels and restore floodplain connectivity. Beaver dams slow stream flows, help offset drought conditions (Hood and Bayley 2008), and aid in restoration of incised channels (Pollock et al. 2014). Based on our experience in the Great Basin, the increased extent of wet meadow and riparian habitats created by beaver provide a wet refuge area resistant to wildfires. Beavers were an important component to the Maggie Creek project, and their positive impacts resulted in changed attitudes among local ranchers, who might have readily shot any beavers seen 15 or more years ago.

Climate change is having a dynamic influence on stream systems, but our understanding of how environmental change will play out on the landscape is imprecise. Given this uncertainty, projects that restore proper function and diversity across larger scales are more likely to be successful than projects that are driven solely by local site conditions. Based on case studies of climate change impacts on Rocky Mountain trout populations, Isaak et al. (2012) described the value of large, interconnected populations as a hedge against climate change uncertainty and how these populations are less likely to be eliminated by large-scale disturbances that are becoming increasingly common in western landscapes. It is relatively easy for stream restoration efforts to address problems at the stream reach scale but much more difficult to remediate them at the scale of larger rivers or watersheds, yet these larger basins are precisely the scale where we need to see improvements if trout and salmon are to persist.

One way for the restoration practitioner to address this issue of scale is to integrate reach-scale flow restoration and hydrologic reconnection efforts across multiple headwater streams to result in watershed-scale improvements in climate change impacts. Another approach is to implement reach-scale restoration projects that result in larger-scale benefits. Projects such as Wasson Creek are a good model and can have watershed-scale benefits for native trout if such projects can be replicated across multiple headwater streams or if restored reaches create refugia and limiting habitat types (e.g., spawning areas) that can be accessed by individuals from throughout the watershed. Efforts that treat isolated stream reaches that do not address watershed-scale limiting factors are more likely to fail in the long term (Williams et al. 1997; Bernhardt and Palmer 2011).

Restoration projects need clear and quantified goals and monitoring programs designed to detect changes in desired conditions to determine their success. Monitoring for effectiveness of projects designed to reduce climate change effects is sorely needed as managers struggle to fully understand climate change impacts over longer time scales. Unfortunately, funding for monitoring programs often is a lower priority especially long after project completion. Practitioners should ensure that funding for monitoring is an integral component of overall project funding. For example, the monitoring conducted at Maggie Creek since 2001 has provided essential confirmation to agency, funding, and landowner partners of restoration benefits, thus garnering support for continued work and monitoring. Given the complex and synergistic relationships among livestock grazing, drought, LCT movement, cheatgrass *Bromus tectorum* invasion, and wildfire in the watershed, continuing such monitoring in the long term will be particularly valuable for evaluating future benefits in light of climate change.

Whereas in Maggie Creek nonnative species were not an issue (but were a threat that was address by the permanent barrier), determining long-term project effectiveness for both Wasson and Crow creeks is complicated by the presence of native and nonnative trout in the drainages. Habitat restoration projects that improve channel conditions and stream temperature but do not convey a distinct advantage for the native over nonnative trout may be problematic. To date, the Wasson Creek project appears to provide a distinct advantage to native Cutthroat Trout because access to historical spawning areas of the Cutthroat Trout is now available. Projects such as Crow Creek that restore instream channels clearly improve local conditions and remove cumulative stress to the stream, but the relative benefits to native versus nonnative trout are less certain. For this reason, it is especially important to monitor the effectiveness of these projects to determine whether supplemental work or some form of nonnative control efforts is warranted.

Angler-based citizen science efforts can help augment monitoring capabilities. Many local TU chapters are already engaged in stream monitoring programs, and others are being encouraged to participate through development of stream monitoring manuals designed for anglers. The U.S. Environmental Protection Agency's (2014) best practices manual for monitoring stream temperatures and flows is an excellent reference for citizen science monitoring programs. Recent technological innovations that provide new tools (such as smartphone applications for naturalists, websites such as the U.S. Environmental Protection Agency's How's My Waterway) or reduce the costs of monitoring equipment (such as temperature data loggers) also facilitate an expansion of angler-based and other citizen science stream monitoring efforts.

The case studies examined herein demonstrate some of the complexities of restoration actions that are intended to restore degraded habitats and address impacts of a changing climate. We recommend restoration projects that incorporate science-driven habitats and species-level assessments, address local climate drivers but work at larger scales and across varying land ownerships, and have long-term monitoring components. The ability to work across entire watersheds, including streams, riparian areas, floodplains, and uplands, may be necessary to result in desired changes, especially in larger drainages and mainstem rivers. Similarly, the ability to implement and monitor projects over multiple years or even decades may be required to determine success in landscapes characterized by increasingly rapid change and future uncertainty.

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