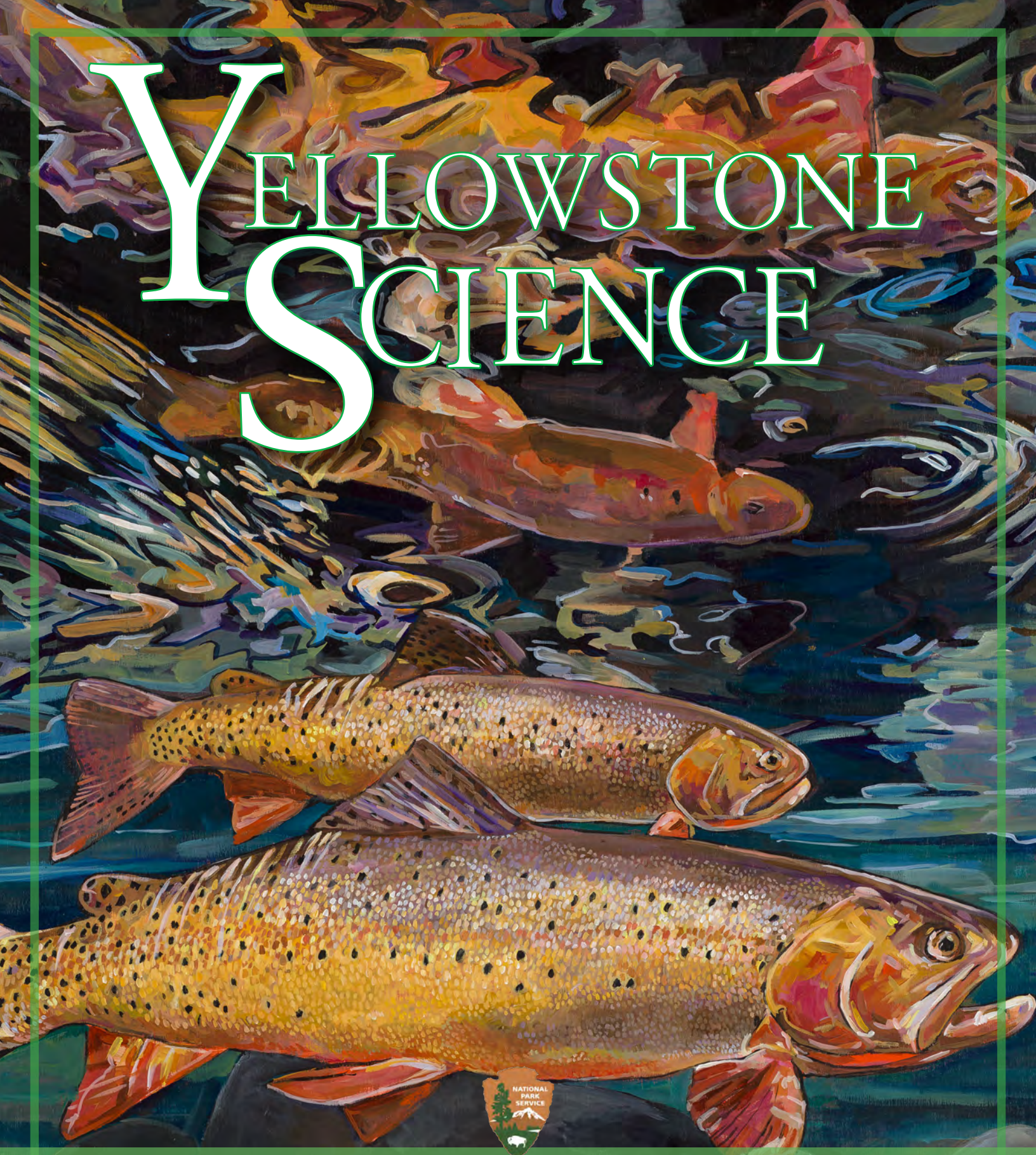
Yellowstone Science



Native Fish Conservation

Native Trout on the Rise

The waters of Yellowstone National Park are among the most pristine on Earth. Here at the headwaters of the Missouri and Snake rivers, the park's incredibly productive streams and lakes support an abundance of fish. Following the last glacial period 8,000-10,000 years ago, 12 species/subspecies of fish recolonized the park. These fish, including the iconic cutthroat trout, adapted and evolved to become specialists in the Yellowstone environment, underpinning a natural food web that includes magnificent animals: ospreys, bald eagles, river otters, black bears, and grizzly bears all feed upon cutthroat trout.

When the park was established in 1872, early naturalists noted that about half of the waters were fishless, mostly because of waterfalls which precluded upstream movement of recolonizing fishes. Later, during a period of increasing popularity of the Yellowstone sport fishery, the newly established U.S. Fish Commission began to extensively stock the park's waters with non-natives, including brown, brook, rainbow, and lake trout. Done more than a century ago as an attempt to increase angling opportunities, these actions had unintended consequences. Non-native fish caused serious negative impacts on native fish populations in some watersheds, and altered the parks natural ecology, particularly at Yellowstone Lake. It took a great deal of effort over many decades to alter our native fisheries. It will take a great deal more work to restore them.

As Aldo Leopold once said, "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise."

Today, we have a strong scientific understanding of the impacts of non-native fish, and we have tools available to mitigate for them. Guided by scientific reviews, public input, and following an adaptive management approach, we are working together with our partners to reduce long-term extinction risk of fluvial arctic grayling, westslope cutthroat trout, and Yellowstone cutthroat trout. Our shared goal is as bold as it is difficult: restore the ecological role of Yellowstone's native fish species.

In this edition of *Yellowstone Science*, we describe the significant progress that has already been made, along with the challenges that lie ahead as we continue our efforts to conserve native fish. As most of what occurs with fish lies under the surface of the water and largely out of sight, we hope that these articles will be revealing, enlightening, and increase understanding of the management approaches taken as we promote the restoration and preservation of native fish.

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FEATURES

DEPARTMENTS

An Approach to Conservation of Native Fish in Yellowstone

Todd M. Koel, P.J. White, Michael E. Ruhl, Jeffery L. Arnold, Patricia E. Bigelow, Colleen R. Detjens, Philip D. Doepke, & Brian D. Ertel

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In the late 1800s, the waters of Yellowstone National Park (YNP) supported an abundance of fish. Twelve species (or subspecies) of native fish, including Arctic grayling, mountain whitefish, and cutthroat trout, dispersed to this region about 8,000-10,000 years ago following glacier melt. These native fish species provided food for both wildlife and human inhabitants. At the time YNP was established in 1872, park inhabitants and visitors initially harvested fish for sustenance and survival in this wild, remote place. Soon after, popular publications describing the quality and abundance of fishing in Yellowstone began to appear. While most hunting was curtailed by early park management, harvest of fish was allowed. During those early years, sport fishing became an accepted use of resources; and the phenomenal sport fishing experience that the park provided rose in notoriety. Yellowstone's recognition as an angling mecca was born.

Lying on a high plateau and spanning the continental divide, the headwaters of three major rivers are found in YNP: the Missouri, Snake, and Yellowstone (figure 1). The park is home to 150 lakes and 4,265 km (2,650 mi.) of flowing waters, but historically fish were not able to access all of them. The original distributions of native

fish species were constrained by natural waterfalls and watershed divides, which caused a natural variation of species distributed across the landscape and vast areas of fishless water. When American naturalist David Starr Jordan conducted the first survey of fish in YNP in 1889, he found that about 40% of the park was fishless, including the upper reaches of the Bechler, Firehole, Gibbon, and Gardner rivers (Jordan 1891). Also fishless were Lewis and Shoshone lakes, most of the small lakes, and numerous tributaries isolated by waterfalls.

The huge diversity of aquatic habitats—from large rivers to tiny tributaries, immense lakes to small ponds, fish-bearing and fishless, geothermally influenced and not—supports an array of native aquatic animals. In addition to fish, the park's waters are home to amphibians, aquatic invertebrates, fish-eating birds, waterfowl, and mammals.

Origin of the Non-native Fish Threat

Soon after the park was established, its aquatic species composition changed. This change was driven by the desire to establish recreation and sustenance fisheries in more park waters, and an emerging fish culture technology that enabled the long-distance transport of exotic sport fish. Park managers started planting native cutthroat trout in fishless waters in 1881 and were introducing non-native species into the park by 1889 (Varley and Schullery 1998). A majority of the non-native

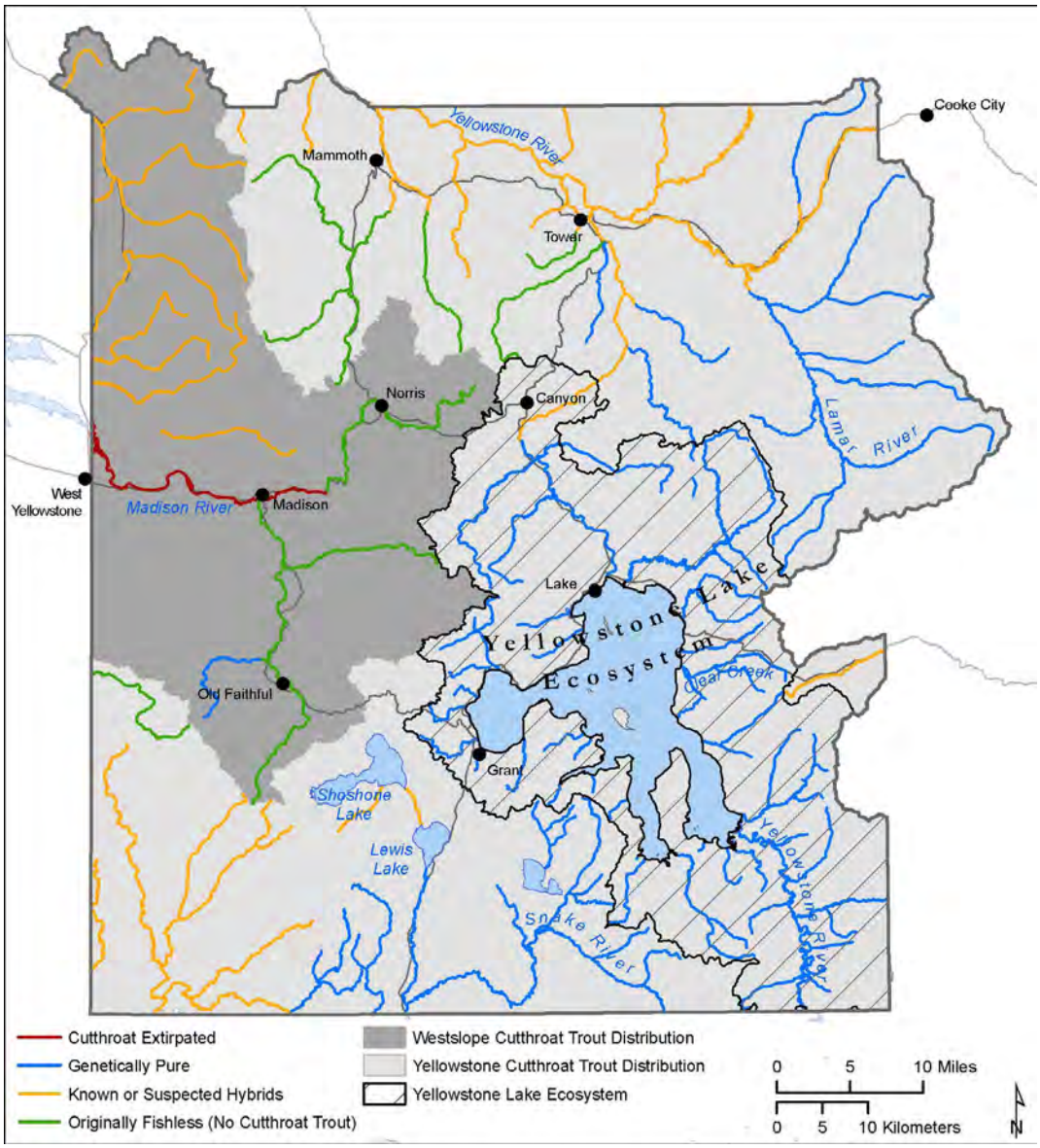

Figure 1. Map of Yellowstone watershed showing the historic ranges and genetic status of westslope cutthroat trout and Yellowstone cutthroat trout within Yellowstone National Park.

Rangers planting fish, 1922; photograph by Linkey (Courtesy of National Park Service, Yellowstone National Park, YELL 34635).

fish introductions were trout species (lake trout, brook trout, brown trout, and rainbow trout), but several other species were also introduced. By the 1930s, managers realized that non-native fish introductions caused a loss of native fish; as a result, the National Park Service (NPS) created a formal stocking policy to discontinue these efforts (Madsen 1937).

Even though the stocking of non-natives stopped, stocking of Yellowstone cutthroat trout from Yellowstone Lake continued both within and outside the species' native range. More than 818 million cutthroat trout eggs were shipped by rail to locations across North America. They were also stocked extensively across the park, including waters that already supported native cutthroat trout with unique genetics (e.g., Slough, Soda Butte, Grayling, and Specimen creeks).

Overall, from the early 1880s to the mid-1950s, more than 300 million fish were stocked throughout Yellowstone. As a result, non-native species became firmly established in most lakes and in larger rivers and streams; exceptions were Yellowstone Lake, the upper Yellowstone River, the upper Lamar River, the upper Snake River, and tributaries to these watersheds. Constrained by waterfalls, watershed divides, or other landscape features, the native fish within these stocked waters were forced to live together with the non-natives, be displaced to downstream habitats, or die.

Non-native lake trout, brook trout, and brown trout consume native fish and compete for resources, thereby reducing native abundance and, as occurred in the Madison, lower Gibbon, and lower Firehole rivers, completely eliminating natives (Arctic grayling and westslope cutthroat trout) from large pristine habitats in the park. Native fish losses also occur through interbreeding. Because Yellowstone cutthroat trout, westslope cutthroat trout, and rainbow trout are closely related, they can hybridize when living in the same areas. Hybrid individuals can also be capable of reproduction, further exacerbating the problem. In only a few generations, hybrids proliferated in many rivers and streams. Large areas of the park where significant hybridization has occurred include the Bechler, Gallatin, lower Lamar, and lower Yellowstone rivers, and their tributaries.

To address these threats, fisheries biologists increased monitoring and research on the status of Yellowstone fishes, which eventually led to the development of a Native Fish Conservation Plan in 2010 (Koel et al. 2010). This plan outlined a strategy for restoring the ecological role of native fishes, while continuing to provide sustainable angling and fish viewing experiences. The plan included actions to isolate, suppress, or remove non-native fish from certain areas of the park, and then restore native fish in these areas.

More than a quarter million native fish have been stocked in restored watersheds in recent years, most as embryos within incubators placed in streams.

Ecologists and a majority of the angling community and the general public strongly supported the plan. However, some anglers and wilderness advocates were uncomfortable with portions of the plan that proposed the enhancement or installation of barriers to prevent further invasion into areas with native fishes; the removal of non-native fishes from several watersheds using fish toxins such as rotenone; and the intense netting of non-native lake trout from Yellowstone Lake, including the frequent use of motorized boats in wilderness areas. Currently, more than 300,000 non-native lake trout are captured in nets and killed each year in an attempt to increase the survival and recruitment of native cutthroat trout in Yellowstone Lake. Also, hundreds to thousands of other non-native fish are electrocuted or removed with rotenone in rivers and streams each year to facilitate the restoration and recovery of native fishes such as Arctic grayling and cutthroat trout.

Native fish cannot fulfill their ecological role in YNP if their populations are extirpated or remain decimated, hybridized, and isolated. However, there is great potential to reconstruct native aquatic communities in some headwaters areas to conditions more closely resembling their historic state (Franke 1997). Thus, managers decided to take bold actions to restore native fish communities in some lakes and watersheds where it was feasible and success was reasonably likely. These large-scale restoration activities necessitate encroaching on wildlife and wilderness principles in the short term to restore a more natural system in the long term (White 2016). Indeed, some complex projects may require intensive intervention and persistent maintenance actions for many decades. In the long term, however, these actions will contribute to the National Park Service (NPS) mission of preserving native species and the ecological processes that sustain them for the benefit and enjoyment of people.

Understanding the Conservation Need

Prior to the recent implementation of large-scale restoration efforts, native river-dwelling Arctic grayling were completely absent from park waters. Westslope cutthroat trout, within its native range, remained in only a single, tiny stream known as Last Chance Creek. Yellowstone cutthroat trout faced serious threats in the waters where they persisted.

Non-native fish distribution and their influence on native fish are not static. While they have not been intentionally stocked since the 1930s, non-native fish continue to advance, hybridize, or displace native fish that previously persisted for thousands of years. Hybridization of cutthroat trout resulting from rainbow trout range expansion continues to be the greatest threat to the park's remaining native fish populations in waters

NPS fisheries staff hiking into the remote Grayling Creek backcountry to conduct a survery for fish, amphibians, and macroinvertebrates.

outside the Yellowstone River headwaters, Yellowstone Lake, and the Snake River headwaters (figure 1). As an example, an important cutthroat trout stronghold in Slough Creek in the Lamar River watershed has been invaded by rainbow and hybrid trout in just the last 15 years; hybridization of the native cutthroat trout in this creek continues.

Not all of the movement by non-native fish in Yellowstone that has occurred recently is natural. Non-native lake trout, intentionally introduced by managers in 1890 to Lewis and Shoshone lakes, and unintentionally introduced (possibly illegally) to Yellowstone Lake in the mid-1980s, first appeared in angler catches in 1994 (Kaeding et al. 1996). The lake trout population expanded and over the following decade caused a rapid decline in the Yellowstone cutthroat trout population in Yellowstone Lake. Concurrent with cutthroat trout loss were declines in several important avian and terrestrial species near the lake and its tributaries that depended upon the cutthroat trout as a food source (see "Non-native Lake Trout Induce Cascading Changes in the Yellowstone Lake Ecosystem," this issue). Thus, the introduction and subsequent expansion of lake trout significantly altered the natural function of the lake and the larger ecosystem (Tronstad et al. 2010). Only through direct management intervention will cutthroat trout recover, with the function of the ecosystem restored.

Conservation Approach

As continued losses of native fish and altered ecology were realized over the past two decades, Yellowstone's approach to native fish conservation has greatly evolved. Management now focuses on the implementation of large-scale, innovative actions to preserve and restore native fish faced with non-native threats. The success of these activities requires a broad approach; includes a wide range of partners and stakeholders; and utilizes independent scientific oversight, assessment, and project adjustments to ensure conservation goals are being met. Key aspects of the approach to native fish conservation in Yellowstone include the following:

Vision—Every activity to conserve native fish is driven by a vision to achieve a desired condition. These clearly articulated desired conditions are typically, but not exclusively, based upon conditions that existed in the past, before alteration by European American colonists and settlers. Some desired conditions do not represent a historic or natural condition, but they are the best we can achieve given existing constraints. For example, building barriers and restoring genetically-pure populations of westslope cutthroat trout and Arctic grayling to headwater refuges are primary desired conditions given the looming threats of non-native fish and climate change to these native species across their historical ranges. Because lake trout cannot be completely eradicated, re-

storing cutthroat trout to an abundance and population structure that existed when lake trout abundance was low (in the early 1990s), and allowing cutthroat trout to regain their ecological importance within the food web are primary desired conditions for Yellowstone Lake.

Partnership—Each aspect of native fish conservation is influenced and benefits from networking, interacting, and partnering with other agencies, conservation organizations, and interested stakeholders with similar visions and goals. Examples of strong partnerships which have resulted in significant advancements in native fish conservation activities in Yellowstone include the Montana Arctic Grayling Recovery Program, the Sun Ranch Westslope Cutthroat Trout Hatchery Program, the Rangewide Yellowstone Cutthroat Trout Conservation Team, and the Yellowstone Lake Workgroup. Formal partnerships have enabled the transfer of information and sharing of successes and failures; increased understanding and use of emerging technologies; leveraged resources, including staff time and equipment in the field; and forged development and implementation of diverse fundraising strategies. The transfer of information and communication has also occurred during public meetings held in park gateway communities each spring, which increases the public's awareness about program activities.

Planning—The 2010 Native Fish Conservation Plan includes an adaptive management framework to guide efforts to recover native fish and restore natural ecosystem functions. Adaptive management allows for continuous learning and adjustment of actions to ensure desired outcomes are achieved. The overall goals of the 20-year plan are to: 1) reduce the long-term extinction risk for native fish, 2) restore and maintain the important ecological role of native fish, and 3) ensure sustainable native fish angling and viewing opportunities. Annually, fish conservation needs are prioritized and planning for individual projects occurs prior to the forthcoming summer. Planning involves fisheries staff, as well as staff from other workgroups within the park that provide support for fisheries operations. Projects occurring in watersheds that cross park boundaries involve staff from all affected agencies with jurisdiction.

Fundraising—Having a vision with clearly articulated desired conditions and a detailed plan for achieving them has provided a strong basis for fundraising. The budget for the native fish program in Yellowstone is highly diverse and is used to implement a wide range of conservation actions each year. The program is primarily supported by the NPS, other federal agencies, private donations to the Yellowstone Park Foundation (now Yellowstone Forever), and competitive grant awards. Formal partnerships enhance fundraising potential even further. For example, significant funding to support a large, multi-year research initiative on Yellowstone Lake has been acquired by the Yellowstone Lake Workgroup. This funding supports critical research aimed at understanding lake trout movements and spawning locations. Without partner support and fundraising, important studies like this could not take place.

Actions—The activities necessary to preserve and restore native fish varies by species and drainages across the park. Because genetically pure westslope cutthroat trout and Arctic grayling are mostly gone from park waters, activities within the Gallatin and Madison river drainages include creating barriers and isolating headwater refuges; removing non-native and hybrid fish using piscicides (fish toxins); and reintroducing native species as eggs, juveniles, and/or adults from genetically-unaltered or other pure sources from within and outside YNP. Yellowstone cutthroat trout still persist, and all life history forms (large-river migratory, stream-resident, lake-dwelling) are represented in several river systems across the park. However, because they occur in populations mixed with non-natives or hybrids, the actions taken to conserve Yellowstone cutthroat trout focus on selective removal of rainbow trout and hybrids via electrofishing and angling from these waters. On Yellowstone Lake, substantial conservation actions are being taken to restore cutthroat trout. During a six-month field season (May-October), several crews operating large boats set and retrieve miles of net to catch and kill non-native lake trout. In addition, biologists are developing new, alternative methods to suppress lake trout. These actions include electroshocking, suction-dredging, placement of lake trout carcasses, and/or use of rotenone to kill embryos on spawning areas.

Assessment—Long-term monitoring and statistical population modeling are conducted to determine if conservation actions are positively influencing native fish as desired. Independent review of native fish conservation actions and data assessment are provided by technical specialists from state and federal agencies and universities. For the lake trout suppression program specifically, there is a standing panel of scientists that meets annually to provide a critical review (Gresswell et al. 2015). Questions to be addressed through research are also identified. These research needs are met through col-

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laborations with several university and federal (e.g., U.S. Geological Survey) scientists and graduate assistants.

Following an adaptive management approach, feedback obtained during reviews and assessments are used to adjust conservation actions to progress towards desired conditions. This approach is used because of the varied environments and stressors impacting native fish across the park, and the fact that some uncertainty exists in the possible response by native fish following management actions. For example, although initial science indicates lake trout expansion in Yellowstone Lake could be curtailed, it is not known precisely how many years high levels of suppression need to be maintained or if the effort could eventually be reduced without resulting in a lake trout resurgence. Similarly, the rate of native cutthroat trout recovery after the population is released from overriding lake trout impacts is also uncertain. Because of these and other uncertainties, performance metrics are closely monitored to track system responses to lake trout suppression; and the results are used to make adaptations and adjust management actions each year.

Moving Forward with Measurable Objectives

Several recent, significant advancements have been made towards achieving desired conditions for native fish in Yellowstone. However, actions need to be sustained and continued if goals of the Native Fish Conservation Plan are to be met. These efforts would include innovative actions to remove threats and stressors (e.g., non-native fish such as lake trout), thereby creating refuges for native fish as climate change alters aquatic habitats across their respective historic ranges in the future.

Measurable objectives are the guiding benchmarks to determine if the purpose and need for an action are being met. At present, the technology does not exist to fully eradicate lake trout from Yellowstone Lake or to completely remove all non-native fish from large, complex river systems. Given these constraints, the measurable objectives for the Yellowstone Lake ecosystem are to:

1. increase large-scale suppression of lake trout so more than half are removed annually, driving the population into decline;

2. maintain surface water access for spawning cutthroat trout in spawning tributaries; and

3. recover cutthroat trout to abundances observed during the early stages of lake trout invasion.

Once the lake trout population has been reduced and spawning tributary connections have been maintained, it is anticipated that an additional 10 years (20 years following plan implementation) may be required for cutthroat trout recovery.

The cumulative result of multiple projects would be used to meet the following measureable objectives for streams, rivers, and other lakes:

4. preserve and/or restore Yellowstone cutthroat trout to maintain their current spatial extent in streams (3,300 km [2050 mi.]);

5. restore westslope cutthroat trout until they occupy at least 200 km (124 mi.); and

6. restore fluvial (i.e., stream-dwelling) Arctic grayling until they occupy at least 200 km (124 mi.).

We intend to work within a few project areas each year, with the cumulative results of multiple projects meeting Objectives 4-6 within 20 years.

A healthy ecosystem requires sustainable communities of both terrestrial and aquatic organisms. Park managers have documented the repercussions of historical, non-native fish introductions, including the resulting loss of native fish populations and cascading effects on the environment. In addition, over the past two decades, it has become apparent that these changes were not static. In fact, real-time, present-day losses were occurring to premier, native cutthroat trout populations and fisheries recognized by anglers world-wide. The technology to preserve and restore native fish has greatly advanced in recent years, and YNP is among those actively developing and using these new methods. Park managers, guided by a large body of science and with support by a multitude of external partners, have implemented an aggressive native fish conservation program, which will ensure the persistence of native fish and the ecosystems they support far into the foreseeable future.

Literature Cited

Franke, M. A. 1997. A grand experiment. The tide turns in the 1950s: Part II. Yellowstone Science 5:8-13.

Gresswell, R.E., C.S. Guy, M.J. Hansen, M.L. Jones, J.E. Marsden, P.J. Martinez, and J.M. Syslo. 2015. Lake trout suppression in Yellowstone Lake: science review panel. Interim Scientific Assessment, 2014 Performance Year Final Report. YCR-2015-04. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, USA.

Jordan, D.S. 1891. A reconnaissance of streams and lakes in Yellowstone National Park, Wyoming in the interest of the U.S. Fish Commission. Bulletin of the U.S. Fish Commission 9:41-63.

Kaeding, L.R., G.D. Boltz, and D.G. Carty. 1996. Lake trout discovered in Yellowstone Lake threaten native cutthroat trout. Fisheries 21:16–20.

Koel, T.M., P.E. Bigelow, P.D. Doepke, B.D. Ertel, and D.L. Mahony. 2005. Non-native lake trout result in Yellowstone cutthroat trout decline and impacts to bears and anglers. Fisheries 30:10-19.

Koel, T.M., J.L. Arnold, P.E. Bigelow, and M.E. Ruhl. 2010. Native fish conservation plan. Environmental assessment, December 16, 2010. National Park Service, U.S. Department of the Interior, Yellowstone National Park, Wyoming, USA. http://parkplanning.nps.gov/document. cfm?parkID=111&projectID=30504&documentID=37967.

Madsen, D.H. 1937. Protection of native fishes in the National Parks. Transactions of the American Fisheries Society 66:395-397.

Syslo, J.M. 2015. Dynamics of Yellowstone cutthroat trout and lake trout in the Yellowstone Lake ecosystem: a case study for the ecology and management of non-native fishes. Dissertation. Montana State University, Bozeman, Montana, USA.

Tronstad, L.M., R.O. Hall, Jr., T.M. Koel, and K.G. Gerow. 2010. Introduced lake trout produced a four-level trophic cascade in Yellowstone Lake. Transactions of the American Fisheries Society 139:1536-1550.

Varley, J.D., and P. Schullery. 1998. Yellowstone fishes: ecology, history, and angling in the park. Stackpole Books, Mechanicsburg, Pennsylvania, USA.

White, P. J., with R. A. Garrott, editor. 2016. Can't chew the leather anymore: musings on wildlife conservation in Yellowstone by a broken-down biologist. Yellowstone Association, Gardiner, Montana, USA.

Todd Koel (pictured on page 2) has served as leader of the Native Fish Conservation Program at Yellowstone National Park since 2001. Koel holds affiliate and graduate faculty status at Montana State University and University of Wyoming. A native of northern Minnesota, Koel received his Ph.D. in Zoology from North Dakota State University in 1997. After teaching at colleges in Minnesota and North Dakota, he served as Riverine Fish Ecologist and Interim Field Station Director for the Illinois Natural History Survey at Havana. He later worked for the Minnesota Department of Natural Resources on a resource monitoring program for the Upper Mississippi River System. When not working on the conservation of cutthroat trout, Koel spends most of his time with his four young boys and two horses roaming the backcountry of the Greater Yellowstone Ecosystem.

NPS PHOTO - J. ARNOLD

Status & Conservation of Yellowstone Cutthroat Trout in the Greater Yellowstone Area

Robert Al-Chokhachy, Bradley B. Shepard, Jason C. Burckhardt, Scott Opitz, Dan Garren, Todd M. Koel, & M. Lee Nelson

Yellowstone cutthroat trout are native to the Greater Yellowstone Ecosystem (GYE) and surrounding drainages, including the Yellowstone River, Snake River, and Two Ocean Pass that facilitate connectivity between these drainages (Behnke and Tomelleri 2002; figure 1). Despite some differences in physical appearance between fine-spotted cutthroat trout, typically found in the Snake River, and "large-spot," found across much of the range, there has been no evidence of genetic distinction between these two groups of Yellowstone cutthroat trout (Novak et al. 2004).

Yellowstone cutthroat trout live in a variety of habitats, including small headwater streams, large rivers (e.g., Yellowstone and South Fork of the Snake rivers), and lakes, each demonstrating multiple life-history forms (Gresswell 2011). These trout are a key component of native communities as a food resource for several species (see "Birds and Mammals that Consume Yellowstone Cutthroat Trout," this issue). Indeed, changes in Yellowstone cutthroat trout abundance can have cascading effects on ecosystems (see "Non-native Lake Trout Induce Cascading Changes in the Yellowstone Lake Ecosystem," this issue). Yellowstone cutthroat trout also embody an important cultural and economic role through angling for many communities in the area (Gresswell and Liss 1995).

There have been significant declines in Yellowstone cutthroat trout distribution (figure 1) and abundance, with only 43% of their historic range currently occupied (Endicott et al. 2016). Losses of Yellowstone cutthroat trout have largely been attributed to habitat destruction and fragmentation, non-native species, and overharvest (Gresswell 2011). Only 23% of the current distribution of Yellowstone cutthroat trout is genetically unaltered (i.e., pure), with losses of genetic integrity largely due to hybridization with non-native rainbow trout (Campbell et al. 2002). However, recent assessments indicate the distribution of Yellowstone cutthroat trout has remained relatively stable over the past decade (Endicott et al. 2016). Coordinated efforts of fisheries managers through the Multistate Interagency Yellowstone Cutthroat Trout Conservation Work Group (May et al. 2007) are likely responsible for stemming declines in distribution observed during earlier decades.

Threats and Conservation Actions to Combat Threats

The severity of threats to populations of Yellowstone cutthroat trout have changed recently, and these changes are likely to continue into the future. Overharvest has been greatly reduced through angling regulations and changes in angler behavior (Cooke and Schramm 2007). As a result, current threats are primarily related to non-native species, habitat limitations, and climate change.

Non-native species—These are one of the greatest threats across the current range of Yellowstone cutthroat trout (Gresswell 2011). Species including rainbow trout, brook trout, and brown trout were extensively introduced as sport fish. While populations of some non-native species are socioeconomically important resources to many communities, they can threaten Yellowstone cutthroat trout populations through predation, competition, and hybridization (Campbell et al. 2002, Peterson et al. 2004, Seiler and Keeley 2007). Recent studies indicate the distribution and abundance of non-native species are increasing through time (Meyer et al. 2014). Streams accessible to these non-native species, even in some of the most pristine locations

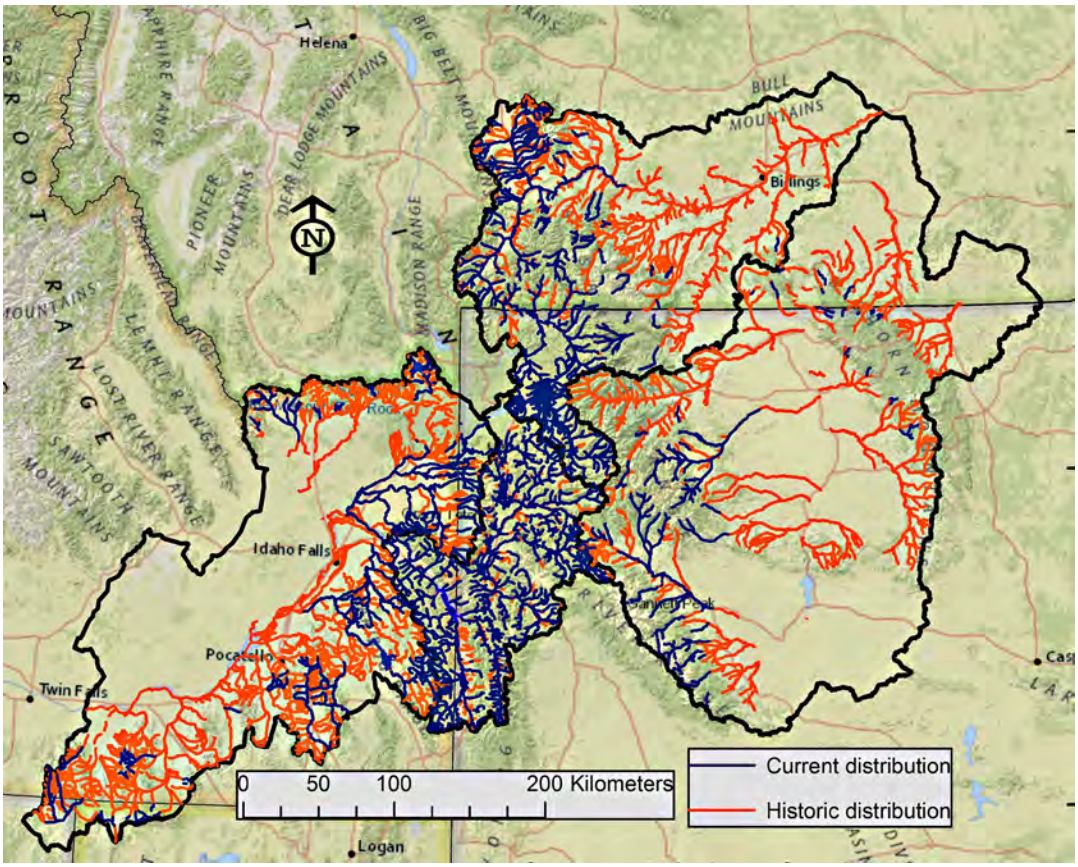

Figure 1. The historic and current distribution of Yellowstone cutthroat trout within the Greater Yellowstone Area in Montana, Wyoming, Idaho, Utah, and Nevada.

like the Lamar River in Yellowstone National Park, are being invaded by non-native species such as rainbow trout. Changes in non-native fish distributions and the effects of these non-native species on Yellowstone cutthroat trout will likely be exacerbated by climate change (Al-Chokhachy et al. 2013).

Fisheries managers have implemented a variety of conservation tools across the range of Yellowstone cutthroat trout to combat non-native species and enhance the persistence of existing populations. Tools include using fish toxins (piscicides) and mechanical methods (e.g., electrofishing) to remove non-native species in streams, erecting barriers to prevent invasions by non-natives, creating angler incentives to harvest non-natives, altering releases at hydropower dams to limit non-native spawning recruitment, and implementing intensive netting programs to reduce populations of lake trout. For example, Idaho Fish and Game recently implemented an incentive program to encourage anglers to harvest non-native rainbow trout in order to reduce their abundance in the South Fork of the Snake River. Similarly, Yellowstone National Park recently altered angling regulations to align with native fish conservation goals. Other approaches, such as the use of barriers that isolate populations from non-natives but also fragment cutthroat populations, represent a necessary paradigm in fisheries (Peterson et al. 2008). Often such programs are socially challenging and costly, yet may be necessary due to recent invasions by non-native species and their effects on Yellowstone cutthroat trout (Kruse et al. 2000).

Habitat—Degradation and fragmentation of habitat continue to be factors limiting Yellowstone cutthroat trout populations in some areas. Degradation has occurred to varying extents from land use, habitat alteration, and water diversions. Over the past 20 years, a substantial amount of habitat has been restored by state and federal agencies and non-governmental organizations (e.g., Friends of the Teton River, Henry's Fork Foundation, Trout Unlimited; Williams et al. 2015). Projects that improve fish passage, limit entrainment into irrigation systems, prevent invasion of non-native species, and restore stream channels and riparian habitat have been implemented across the range of Yellow-

stone cutthroat trout (figure 2). Despite such efforts, there continue to be abundant opportunities for additional restoration projects in areas currently occupied by Yellowstone cutthroat trout and in historically occupied areas where reintroductions may be feasible.

Climate change—Recent and future changes in climatic conditions have and are expected to substantially alter aquatic communities in the GYE and surrounding areas (Shepard et al. 2016). Cutthroat trout have relatively narrow thermal tolerances (Bear et al. 2007), and migration timing and life-history expressions are strongly tied to thermal and hydrologic regimes (DeRito et al. 2010). Warming summer temperatures coupled with changes in the magnitude and timing of precipitation and snowmelt runoff are likely to create more stressful summer conditions for Yellowstone cutthroat trout in some areas (Uthe et al., in review). As stream temperatures warm, the amount of thermally suitable habitat for Yellowstone cutthroat trout may be reduced considerably in some populations (Al-Chokhachy et al. 2013, Isaak et al. 2015). Lake-dwelling populations will also be affected by climate change because they rely on adequate connectivity to tributary streams (Kaeding 2010). In addition to the direct effects of changing thermal regimes, Yellowstone cutthroat trout are likely to become increasingly exposed to diseases in streams where temperatures warm dramatically (Koel et al. 2006) and suffer increased mortality from catch-and-release angling

Figure 2. An example of restoration activity conducted by Friends of the Teton River (Driggs, Idaho) to improve nearly 2 km (1.2 mi.) of habitat for Yellowstone cutthroat trout in Teton Creek, Idaho (PHOTOS - M. LIEN, FRIENDS OF THE TETON RIVER).

(Cooke and Schramm 2007). Most fish managers in the region restrict opportunities for angling when water temperatures reach critical levels, and these restrictions will likely become more frequent as the climate warms. Such restrictions may affect visitation to the Yellowstone area because angling is often an important component of tourism.

Future Conservation of Yellowstone Cutthroat Trout

Significant efforts are being made to maintain and enhance the existing distribution of Yellowstone cutthroat trout and stem the tide of historic losses. Fortunately, large networks of Yellowstone cutthroat trout populations still exist, particularly within the Yellowstone, the Upper Snake, and Lower Snake rivers (Endicott et al. 2016). The vast expanses of public land at relatively high elevations, including Yellowstone and Grand Teton national parks, can and will likely continue to support cold water habitats that make up the core areas of the Yellowstone cutthroat trout. Populations outside these large lake and river networks vary in size. While populations occupying larger, connected stream networks are likely more resilient (Morita et al. 2009), small populations of Yellowstone cutthroat trout also can have high resiliency (e.g., Peterson et al. 2014). Furthermore, geographically distinct populations (e.g., Camas Creek drainage, lower Bighorn drainage, and the Snake River near the Idaho/Utah border; Haak et al. 2010) are likely to represent areas of key genetic diversity that facilitate the long-term persistence of the species.

The extent and severity of current (e.g., non-natives) and future (e.g., climate change) threats to Yellowstone cutthroat trout populations suggest it will become increasingly important to address these concerns and secure populations. The relatively broad distribution of Yellowstone cutthroat trout suggests the importance in developing effective and coordinated conservation strategies (Williams et al. 2015), particularly as resource constraints often predicate the need to prioritize conservation actions (Lynch and Taylor 2010). With respect to climate change, this may involve identifying habitats that are most resilient to climatic shifts, both within the current distribution and where Yellowstone cutthroat trout were historically located to target population reintroductions. For example, populations with considerable groundwater inputs or those with access to deep, thermally stratified lakes (e.g., Yellowstone and Jackson lakes) are likely to be particularly resilient to climatic shifts.

Continued threats by non-native species will require expanding the tools to cost-effectively reduce or eliminate their threat to important Yellowstone cutthroat trout populations. We need to increase public support for dealing with these threats through improved communication with the public of how non-native species and illegal introductions threaten populations of Yellowstone cutthroat trout. Concomitantly, it will be important to consider novel approaches to control non-native populations, particularly given the high costs and efforts often needed to successfully reduce and/or remove non-native species.

Merging information regarding climatic resilience with existing non-native threats to populations can provide an overall framework for considering the urgency of conservation and management actions. For example, restoring habitat or removing a non-native species in an area with high climatic resilience may be given a higher priority for funding conservation actions than other areas that may be more sensitive to future climatic changes (Lynch and Taylor 2010). Decisions to implement particular conservation actions might be made through a hierarchical framework that considers potential conservation opportunities at range-wide, regional, and local scales, in terms of financial support and the ecological importance of specific populations. Within this framework, coordinating efforts across public and private entities to conserve and restore Yellowstone cutthroat trout populations will become increasingly important in the future, as both our human footprint and conservation needs grow.

Literature Cited

Al-Chokhachy, R., J. Alder, S. Hostetler, R. Gresswell, and B. Shepard. 2013. Thermal controls of Yellowstone cutthroat trout and invasive fishes under climate change. Global Change Biology 19: 3069-3081.

Bear, E.A., T.E. McMahon, and A.V. Zale. 2007. Comparative thermal requirements of westslope cutthroat trout and rainbow trout: implications for species interactions and development of thermal protection standards. Transactions of the American Fisheries Society 136:1113-1121.

Behnke, R.J., and J.R. Tomelleri. 2002. Trout and salmon of North America. Free Press, New York, New York, USA.

Campbell, M.R., J. Dillon, and M.S. Powell. 2002. Hybridization and introgression in a managed, native population of Yellowstone cutthroat trout: genetic detection and management implications. Transactions of the American Fisheries Society 131:364-375.

Cooke, S.J., and H.L. Schramm. 2007. Catch-and-release science and its application to conservation and management of recreational fisheries. Fisheries Management and Ecology 14:73-79.

DeRito, J.N., A.V. Zale, and B.B. Shepard. 2010. Temporal reproductive separation of fluvial Yellowstone cutthroat trout from rainbow trout and hybrids in the Yellowstone River. North American Journal of Fisheries Management 30:866-886.

Endicott, C., L. Nelson, S. Opitz, A. Peterson, J. Burckhardt, S. Yekel, D. Garren, T.M. Koel, and B.B. Shepard. 2016. Range-wide status assessment for Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*): 2012. Yellowstone Cutthroat Trout Interagency Coordination Group, Helena, Montana, USA.

Gresswell, R.E. 2011. Biology, status, and management of the Yellowstone cutthroat trout. North American Journal of Fisheries Management 31:782-812.

Gresswell, R.E., and W.J. Liss. 1995. Values associated with management of Yellowstone cutthroat trout in Yellowstone National Park. Conservation Biology 9:159-165.

Haak, A.L., J.E. Williams, H.M. Neville, D.C. Dauwalter, and W.T. Colyer. 2010. Conserving peripheral trout populations: the values and risks of life on the edge. Fisheries 35:530-549.

Isaak, D.J., M.K. Young, D.E. Nagel, D.L. Horan, and M.C. Groce. 2015. The cold-water climate shield: delineating refugia for preserving salmonid fishes through the 21st century. Global Change Biology 21:2540-2553.

Kaeding, L.R. 2010. Relative contributions of climate variation, lake trout predation, and other factors to the decline of Yellowstone cutthroat trout during the recent three decades. Dissertation. Montana State University, Bozeman, Montana, USA.

Koel, T.M., D.L. Mahony, K.L. Kinnan, C. Rasmussen, C.J. Hudson, S. Murcia, and B.L. Kerans. 2006. *Myxobolus cerebralis* in native cutthroat trout of the Yellowstone Lake ecosystem. Journal of Aquatic Animal Health 18:157-175.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 2000. Status of Yellowstone cutthroat trout in Wyoming waters. North American Journal of Fisheries Management 20:693-705.

Lynch, A.J., and W.W. Taylor. 2010. Evaluating a science-based decision support tool used to prioritize brook charr conservation project proposals in the eastern United States. Hydrobiologia 650:233-241.

May, B.E., S.E. Albeke, and T. Horton. 2007. Range-wide status of Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*): 2006. Yellowstone Cutthroat Trout Interagency Coordination Group, Bozeman, Montana, USA.

Meyer, K.A., E.I. Larson, C.L. Sullivan, and B. High. 2014. Trends in the distribution and abundance of Yellowstone cutthroat trout and nonnative trout in Idaho. Journal of Fish and Wildlife Management 5:227-242.

Morita, K., S.H. Morita, and S. Yamamoto. 2009. Effects of habitat fragmentation by damming on salmonid fishes: lessons from white-spotted charr in Japan. Ecological Research 24:711-722.

Novak, M.A., J.L. Kershner, and K.E. Mock. 2004. Molecular genetic investigation of Yellowstone cutthroat trout and finespotted Snake River cutthroat trout. A report in partial fulfillment of Agreement # 165/04, Wyoming Game and Fish Commission. Utah State University, Logan, Utah, USA.

Peterson, D.P., K.D. Fausch, and G.C. White. 2004. Population ecology of an invasion: effects of brook trout on native cutthroat trout. Ecological Applications 14:754-772.

Peterson, D.P., B.E. Rieman, J.B. Dunham, K.D. Fausch, and M.K. Young. 2008. Analysis of trade-offs between threats of invasion by nonnative brook trout (*Salvelinus fontinalis*) and intentional isolation for native westslope cutthroat trout (*Oncorhynchus clarkii lewisi*). Canadian Journal of Fisheries and Aquatic Sciences 65:557-573.

Peterson, D.P., B.E. Rieman, D.L. Horan, and M.K. Young. 2014. Patch size but not short-term isolation influences occurrence of westslope cutthroat trout above human-made barriers. Ecology of Freshwater Fish 23:556-571.

Seiler, S.M., and E.R. Keeley. 2007. A comparison of aggressive and foraging behaviour between juvenile cutthroat trout, rainbow trout and F1 hybrids. Animal Behaviour 74:1805-1812.

Shepard, B.B., R. Al-Chokhachy, T.M. Koel, M.A. Kulp, and N. Hitt. 2016. Likely responses of native and invasive fish to climate change in the Rocky and Appalachian mountains. Pages 232-256 in A.J. Hansen, D.M. Theobald, W.B. Monahan, and S.T. Olliff, editors. Climate change in wildlands: pioneering approaches to science and management. Island Press, Washington, D.C., USA.

Uthe, P., R. Al-Chokhachy, B.B. Shepard, A.V. Zale, and J.L. Kershner. In review. Effects of climate-driven stream factors on summer growth patterns of Yellowstone cutthroat trout. Journal of Fish Biology.

Williams, J.E., H.M. Neville, A.L. Haak, W.T. Colyer, S.J. Wenger, and S. Bradshaw. 2015. Climate change adaptation and restoration of western trout streams: opportunities and strategies. Fisheries 40:304-317.

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Westslope Cutthroat Trout and Fluvial Arctic Grayling Restoration

Jeff L. Arnold, Colleen R. Detjens, Brian D. Ertel, Michael E. Ruhl, & Todd M. Koel

The Madison and Gallatin rivers, two major headwaters of the Missouri River, originate in Yellowstone National Park (YNP) along the western boundary (figure 1). Combined, these two rivers provide 1,031 km (640 mi.) of stream habitat for both westslope cutthroat trout and Arctic grayling in YNP. Indigenous westslope cutthroat trout currently occupy 2 km (1.2 mi.) of stream within their historic range in the park, while resident grayling were extirpated from the park by 1935 (Vincent 1962). Within the Madison River drainage, westslope cutthroat trout and grayling occupied the Madison River and lower portions of the Gibbon River (up to Gibbon Falls) and the Firehole River (up to Firehole Cascades; figure 1). The Gallatin River begins on the northwest side of YNP and flows for approximately 27 km (17 mi.). Westslope cutthroat trout were historically found throughout the Gallatin River and its tributaries, while grayling were confined to the main stem (figure 1).

Status of Westslope Cutthroat Trout

In Montana, genetically pure westslope cutthroat trout occupy less than 3% of their historic range and are confined to isolated headwater streams. Extensive stocking and subsequent establishment of populations of non-native competing species, including brook and brown trout, and interbreeding with rainbow trout led to a serious reduction in the park's resident westslope cutthroat trout, and their near extinction from most park streams by the 1930s (Varley and Schullery 1998).

In 2005 park fisheries biologists discovered two previously unknown populations of westslope cutthroat trout. That June, a population was discovered in an unnamed tributary of Grayling Creek (Madison River drainage), which was later given the name Last Chance Creek (figure 1). Testing confirmed these fish were 100% genetically pure westslope cutthroat trout. Since their discovery, gametes (reproductive cells) from this population have been used to restore trout populations into other areas of the upper Madison and Gallatin river drainages. Then, in August 2005, a second population was discovered in Geode Creek, a tributary of Yellowstone River located in northern Yellowstone. These fish are not native to this drainage and were most likely stocked in the 1920s. The discovery of this genetically pure population in a location with quick and easy access was exciting because it has enabled biologists to collect and move large numbers of fish or gametes for re-establishing westslope cutthroat trout to restored habitats elsewhere.

Status of Fluvial Arctic Grayling

Grayling are comprised of two distinct strains depending on life history: fluvial (stream dwelling) and adfluvial (living in lakes and spawning in streams). Historically, fluvial grayling were indigenous to the park in the headwaters of the Madison and Gallatin rivers. Grayling within the upper Gallatin River drainage disappeared around 1900, while grayling in the upper Madison River drainage disappeared by 1935 (Vincent 1962). Although grayling had disappeared in the Madison River, anglers continued to report catching them in the Gibbon River (figure 1). Intensive sampling in 2005-2006 found grayling in low numbers (Steed et al. 2011). Genetic analyses provided conclusive evidence that the grayling observed were fish which had strayed downstream from Grebe and Wolf lakes. These grayling descended from an adfluvial population introduced in the early 1900s and are not native to YNP. An additional introduced population also exists in nearby Cascade Lake in the Yellowstone River drainage (Kaya 2000).

Approach to Native Fish Restoration in Streams and Lakes

To successfully restore native westslope cutthroat trout and fluvial grayling, high priority watersheds were iden-

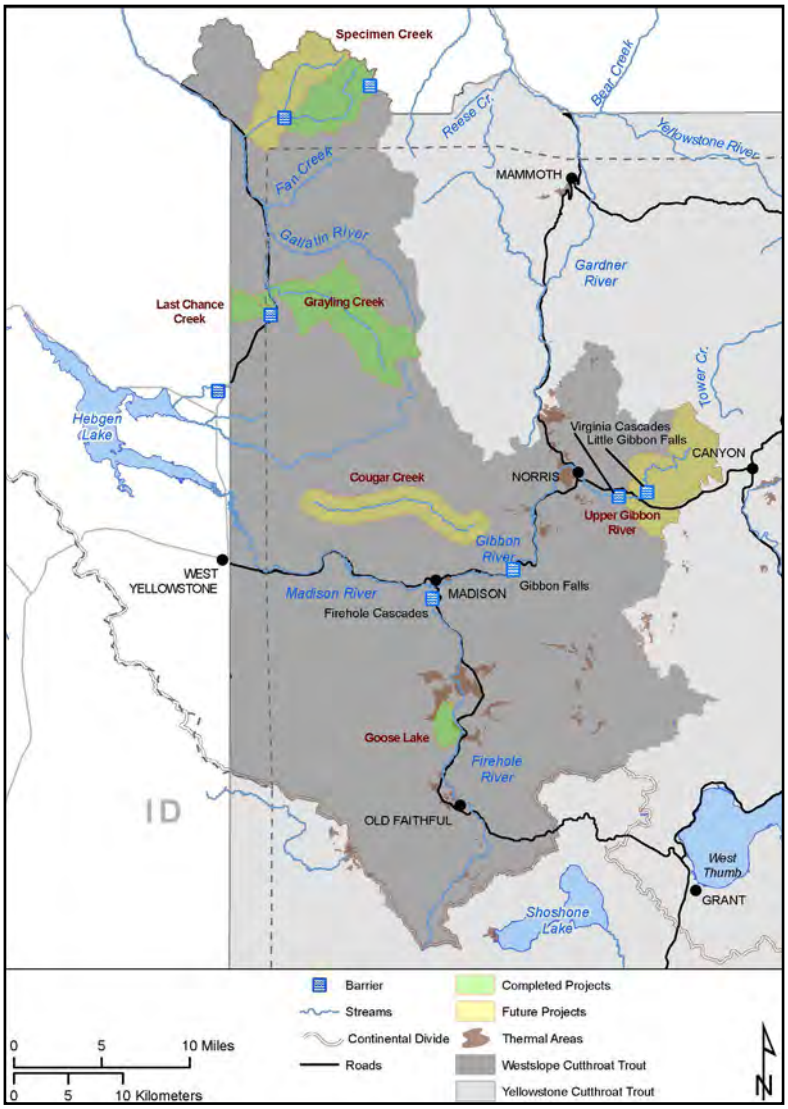

Figure 1. Madison and Gallatin river watersheds in Yellowstone National Park. Completed (green) and future (yellow) project areas for westslope cutthroat trout and fluvial Arctic grayling.

tified; restoration areas were protected via a waterfall or other in-stream barrier; non-native and/or hybridized fish were removed from the area above the barrier using an approved fish toxin (rotenone); and native fish were reintroduced from genetically-unaltered sources.

Prioritizing Watersheds—Watersheds must be large enough to support a fish population and resilient enough to withstand natural disturbances such as fires, droughts, and/or floods. Because the largest threat to native fish is invasion by non-natives, we also initially looked for the presence of barriers that would serve to isolate the restoration area and create a headwater refuge for native species. Information used in this prioritization process included fish species composition, genetic integrity, presence of barriers, road and trail access, and watershed complexity. This information was used to create a prioritization matrix designed to rank each stream based on its potential for successful restoration. The absence of brook trout was a major deciding factor in choosing which streams in the Gallatin and Madison river drainages would be initially restored, as brook trout can be incredibly challenging to extirpate from complex stream systems. Grayling Creek and the upper Gallatin River and all of its tributaries (e.g., Fan and Specimen creeks) do not contain brook trout and, therefore, were considered locations with a high probability of restoration success.

Isolating the Project Area—For native fish restoration, the best option for long-term persistence of species is to create isolated headwater refuges. Some stream systems in Yellowstone have natural waterfalls that can be altered, if necessary, to ensure upstream passage by fish

To chemically remove fish, drip stations are used to dispense rotenone along measured intervals within the project stream.

is prevented and a headwater native refuge is secured. Stream systems not having waterfalls naturally allow unimpeded access from fish downstream. In these systems, if a suitable location exists, an artificial barrier can be created to isolate the drainage. Artificial barriers are created with logs, rocks, and mortar, and are designed to completely preclude all upstream fish movement while ensuring structural integrity and function across a wide range of water flows. Structures of this type are commonly at least 1.8 m (6 ft.) in height, with a vertical or near vertical drop onto a concrete splash pad preventing a plunge pool from forming at the base of the barrier. Ideal locations for fish barriers are in high-gradient stream reaches with steep banks and exposed bedrock. Fish barriers would be built in the most downstream location suitable for construction, to provide the largest possible area upstream for native fish restoration.

Pre-Project Assessments—Once a watershed has been selected for a fish restoration project, biologists map the watershed; conduct surveys to document fish, amphibian, and aquatic invertebrate populations; and determine the upper extent of water in each tributary. Knowing fish and amphibian distributions are important because it helps biologists make better informed decisions during the planning phases of the project. For example, if some waters in the extreme upper extent of the watershed are isolated above falls or steep cascades and do not have fish, then those waters do not need to be chemically treated. To achieve a complete removal of non-native fish, all connected surface waters having the potential to support fish must be treated with rotenone.

Non-native Fish Removal—Fish toxins (piscicides) are commonly used to control or eradicate non-native and undesirable fish species in both standing and flowing water. Rotenone, the only piscicide currently available, is toxic to gill breathing organisms, affects fish at the cellular level, and is relatively nontoxic to humans or wildlife. All piscicide applications follow applicable permitting requirements and guidelines set forth by regulatory authorities.

Before applying rotenone to remove fish, we conduct biological assessments on the water to be treated. Bioassays are done on-site to evaluate how environmental factors such as water temperature, sunlight, and pH influence the effects of rotenone on fish. Bioassays ensure the lowest concentration of rotenone is used to achieve a complete fish kill, while minimizing impacts to other aquatic organisms.

Rotenone is applied using drip stations during stream treatments and a boat bailer pump system during lake treatments. Backpack sprayers with hand-held wands are used to apply highly diluted rotenone in stagnant water areas along streams and shorelines of lakes. Drip stations consist of a five-gallon container that dispenses a dilute concentration of rotenone to flowing waters at a constant rate. Placement of drip stations along a stream is determined by conducting travel time studies using nontoxic dye. Because rotenone breaks down and loses its toxicity quickly in flowing water, multiple drip stations are needed to maintain concentrations lethal to target fish. The amount of rotenone used in each drip station is calculated from stream flow measurements taken prior to treatment and from results of bioassays.

For lake applications, we use inflatable rafts with an 80-gallon collapsible tank. The tank is filled with concentrated rotenone which is pumped directly into the motor wash during application. The amount of rotenone applied to a lake is determined by estimating the

NPS Fisheries Biologist Jeff Arnold and Fisheries Intern Emily Mathieson place fertilized westslope cutthroat trout eggs into remote site incubators (RSIs) in upper Grayling Creek.

total water volume in the lake. Lake water volume, along with results from our bioassays, is used to determine how much rotenone is needed to achieve a complete fish kill.

At the downstream reach of the project area, a neutralization station is set up to detoxify rotenone. The neutralization station consists of a volumetric feeder that applies potassium permanganate at a predetermined rate. Potassium permanganate neutralizes rotenone, eliminating its toxic effects. Potassium permanganate is applied until the last of the rotenone has theoretically flowed pass the neutralization station, as calculated from our travel time study, and stopped after sentinel fish placed above the station remain alive for an additional four hours.

To ensure all fish are removed, treatments are typically conducted at least twice within the same year or over successive years. Monitoring by electrofishing is conducted following rotenone treatments to ensure all fish have been removed and the restoration area is ready for reintroduction of native fish.

Reintroduction of Native Fish—Two methods are used for introducing native fish. One method is the introduction of gametes using remote site incubators (RSIs). After fertilization, embryos are reared in hatchery settings to enhance survival during early growth and development. The developed embryos are then transported to the field and placed in RSIs positioned in streams and tributaries. Over a 2-3 week period, the embryos hatch and swim out of the incubator into the stream system.

A second method for introducing native fish is to stock them as fry (young fish capable of self-feeding), juveniles, and/or adults directly into project waters. These fish are acquired from existing wild populations or from a hatchery facility.

Both methods have distinct advantages and limitations. The use of RSIs allows fish to hatch in the stream and imprint to its waters, which theoretically results in these fish later returning to spawn as adults. In addition, RSIs make it possible to stock large numbers of genetically diverse fish with relatively little transportation effort. The main limitations of RSIs are their susceptibility to failure from clogging, or disturbance by wildlife or people during the period the embryos are completing final development and hatching.

Stocking live fish is accomplished by transporting them from a hatchery or wild population into the project area using tanks on trucks or suspended below a helicopter. This method requires little or no post-stocking maintenance, can quickly restore recreational fishing, and is not susceptible to disturbance from wildlife or humans. However, stocking live fish is costly in remote locations because of the need for a helicopter to move fish with large amounts of water. Additionally, because fish were not born within or imprinted to project area waters, it is suspected they experience lower survival and reproductive success than their natal counterparts.

Once native fish have been reintroduced into an area, we continue monitoring the population to confirm it has become successfully established. To evaluate fish populations, we conduct electrofishing surveys in streams, and use seines, gillnets, and snorkel surveys to evaluate lake populations. Collecting different age classes of fish helps determine the health of the population and validate natural reproduction, which indicates the population can likely sustain itself.

Westslope Cutthroat Trout and Arctic Grayling Successes To-Date

East Fork Specimen Creek

Specimen Creek is a tributary of the Gallatin River located on the northwest corner of YNP. East Fork Specimen Creek is a large watershed that originates in the Gallatin Mountain Range beginning at High Lake at 2,682 m (8,800 ft.) elevation (figure 1). High Lake encompasses 2.9 ha (7.1 ac) and was historically fishless due to a natural waterfall just downstream from the lake outlet. In 1937, however, the National Park Service (NPS) stocked the lake with Yellowstone cutthroat trout, which are not native to the upper Missouri River drainage. Over time, these fish migrated downstream, while rainbow trout from the Gallatin River moved upstream into the watershed. Due to interbreeding among species, the genetic integrity of native westslope cutthroat trout was severely compromised with a hybridized population less than 80% pure. Because these westslope cutthroat trout were not considered a "conservation population" (which requires more than 90% genetic purity), the fish were prime candidates for removal and replacement with genetically pure westslope cutthroat trout.

Because High Lake was isolated by a waterfall, we were able to work on the lake independently of the waters downstream. During August 2006, rotenone was applied to High Lake and its associated waters. Two 14-foot rafts with outboard motors were used to apply the bulk of rotenone, while backpack sprayers and drip stations were used to treat shallow water and inlet streams. Following the first treatment, daily visual surveys of the lake and inlet streams did not detect any live fish; however, to ensure a complete removal of fish, a second treatment was conducted two weeks later.

In July 2007, we surveyed High Lake for any remaining fish. No fish were collected or observed during these efforts, confirming the absence of fish and eliminating the need for an additional piscicide application. As a result, during 2007-2009 westslope cutthroat trout were introduced into High Lake. A total of 5,345 fertilized eggs and 2,963 fish from Geode Creek were moved to High Lake. In 2010, fry were observed within High Lake inlet tributaries, indicating successful reproduction. In 2016 we sampled High Lake by placing a gillnet in the lake for one night. This net yielded 14 fish ranging in size from 174-440 mm (6.8-17.3 in.) This range of sizes again demonstrates successful reproduction and a healthy fish population.

In 2008, a log barrier was completed on lower East Fork Specimen Creek, allowing the restoration project to extend from High Lake downstream near the confluence with North Fork Specimen Creek. During chemical treatment of East Fork Specimen Creek, we divided the drainage into two manageable reaches by placing a portable barrier approximately halfway down the watershed. The upper and lower reaches were each treated twice within a 2-week period down to the barrier. Rotenone was applied using drip stations and backpack sprayers. A third treatment of East Fork Specimen Creek was conducted in 2009. No fish were found during this

An existing waterfall was modified on lower Grayling Creek watershed to provide a complete barrier to upstream fish movement. The large yellow structure temporarily diverted the stream and was removed after construction was completed.

treatment, and subsequent monitoring provided evidence all fish were successfully removed from the system.

Following two years of treatments and monitoring, the creek was considered free of non-native fish; restocking efforts took place from 2010-2013. During this time, approximately 10,300 eyed-eggs, which are embryos, were placed in RSIs throughout East Fork Specimen Creek.

In 2015 and 2016, we conducted several surveys throughout East Fork Specimen Creek. These surveys indicated a natural reproducing population of westslope cutthroat trout with all fish appearing healthy. The long-term goal for this watershed is to integrate East Fork Specimen Creek into a larger westslope cutthroat trout restoration project that includes the North Fork to improve the resilience of this isolated population to natural threats.

Goose Lake Chain-of-Lakes

Goose Lake and two other small, historically fishless lakes lie within the Firehole River drainage, but are not connected to the river by surface waters (figure 1.) Their proximity to a service road makes the lakes easily accessible most of the year. Yellow perch, stocked in the lake early in the 20th century, were eradicated from the lake in 1938. The lake was then stocked with non-native rainbow trout which established a self-sustaining population.

In September 2011, the Goose Lake chain-of-lakes were treated with rotenone to remove rainbow trout. In 2012, fisheries staff completed surveys within the three lake system. These surveys did not yield any sign of fish, a good indication that complete removal of rainbow trout was achieved. For three consecutive years (2013-2015), more than 10,300 westslope cutthroat trout fry were stocked into Goose Lake. In 2016 we placed a gillnet in Goose Lake to asses the fish population. This overnight net yielded 12 fish ranging in size from 170-200mm (6.7-7.8 in.). We will continue to monitor the success of these stocking efforts over the coming years; plans are to one day use this pure westslope population as a brood source, providing offspring for restoration projects elsewhere within the upper Missouri River system.

Grayling Creek

Grayling Creek, a tributary of the Madison River, was historically home to westslope cutthroat trout and fluvial grayling (figure 1.) Two waterfalls existed on the lower portions of Grayling Creek, but were not complete barriers because fish could move past them during certain times of year. By the 1950s, grayling had disappeared entirely from the watershed due to non-native fish introduction and completion of Hebgen Dam (Kaya 2000), which submersed the stream's lower reaches where grayling were most abundant. Westslope cutthroat trout fared little better, with most of the population being eliminated or hybridized with rainbow trout by the early 2000s.

In 2007, federal and state fisheries biologists assessed Grayling Creek for a potential westslope cutthroat trout and fluvial grayling restoration project. The plan included modification of the existing waterfall near Highway 191 to create a complete barrier to upstream fish movement. In 2012, the NPS partnered with technical blasters from Gallatin National Forest, a private contractor, and a Montana Conservation Corps crew to create the barrier. The completed modification elevated the barrier to a height of more than 1.8 m (6 ft.) and filled deep pools in order to create a large concrete "splash pad" at the barrier base, making it a complete barrier to upstream fish movement.

The upper Grayling Creek watershed is located in a remote section of the park with limited road and trail access. Access to the upper portions of the watershed involves hiking off trail, through downed timber and thick vegetation. The Grayling Creek restoration area includes 95 km (59 mi.) of connected stream habitat. Actions to remove fish from upper Grayling Creek took place in August 2013 and 2014 with assistance from the USDA Forest Service; U.S. Fish and Wildlife Service; Montana Fish, Wildlife & Parks; and Turner Enterprises, Inc. Because of the remote nature of the watershed, most equipment and supplies had to be flown in via helicopter. More than two dozen fish biologists and technicians worked for several weeks to remove non-native and hybrid trout from the restoration area using rotenone. Electrofishing surveys conducted after the rotenone treatments in 2014 did not yield any fish, indicating fish removal was a success.

In 2015, we began introducing westslope cutthroat trout and fluvial grayling into the Grayling Creek project area. In April 2015, approximately 680 westslope cutthroat trout of varying sizes from Geode Creek were captured and moved to the lower portions of Grayling Creek above the barrier. In May 2015, more than 100,000 fluvial grayling eggs were placed in RSIs throughout the South Fork Grayling Creek watershed. In addition 4,800 westslope cutthroat trout eggs were placed in RSIs along the lower portion of Grayling Creek while 5,000 westslope cutthroat trout eggs were placed in the North Fork of Grayling Creek.

Restoration of westslope cutthroat trout and fluvial grayling continued in 2016. During May, 263 westslope cutthroat trout were captured and moved from Geode Creek to lower portions of Grayling Creek, and 50,000 fluvial grayling eggs were placed in RSIs throughout the South Fork Graying Creek. During June, approximately 27,800 westslope cutthroat trout were placed throughout the Grayling Creek drainage above the barrier. Restoration efforts are scheduled to continue in 2017-2018.

Potential Future Westslope Cutthroat Trout and Arctic Grayling Restoration Projects

Upper Gibbon River

The upper Gibbon River (above Virginia Cascades) and connecting lakes in YNP will be used as a refuge for native fish threatened with a warming climate. The refuge would include 16 km (10 mi.) of stream, three fish bearing lakes totaling 92 ha (228 surface ac), and extensive tributary networks, representing the largest and most logistically feasible location for westslope cutthroat trout and fluvial grayling restoration in the species' historic range (figure 1). High-elevation aquatic systems, such as the upper Gibbon River, may be the only chance to protect sensitive, cold water species such as westslope cutthroat trout and fluvial grayling against climate change. The project will begin with the removal of fish from Ice Lake. The project will continue with the complete removal of fish from the Gibbon River above Virginia Cascades upstream to Grebe Lake. Westslope cutthroat trout and fluvial grayling will be introduced immediately afterwards. This project is expected to take three years to complete.

Cougar Creek

Cougar Creek is a small stream that, prior to reaching the Madison River, flows underground (figure 1). Cougar Creek is an ideal candidate for westslope cutthroat trout restoration because it is physically isolated from downstream reaches of the drainage (Kaya 2000). In the early 1990s, this stream was documented as having pure westslope cutthroat trout and mottled sculpin, two species native to the drainage. However, genetic testing of the westslope cutthroat trout in 2011 indicated these fish were highly hybridized with rainbow trout. Future plans for the Cougar Creek drainage are to chemically remove the hybridized trout and reintroduce pure westslope cutthroat trout and mottled sculpin.

North Fork Specimen Creek

Fisheries staff in YNP plan to continue native fisheries restoration work in Specimen Creek. In 2013, plans were developed to construct a concrete barrier on the lower portion of the creek near Highway 191. This barrier would isolate the entire drainage and prevent non-na-

tive fish from moving upstream into Specimen Creek from the Gallatin River. The barrier would allow for native fish restoration of the entire watershed including the North Fork Specimen Creek, and would allow for the East Fork Specimen Creek to be reconnected to the rest of the drainage.

Conclusions

Creating secure habitats for the conservation of native inland fish has become a common fisheries management practice in recent years. Most commonly, the goals of these efforts are to restore and preserve native fish biodiversity through the exclusion and removal of non-native fish and the reintroduction of genetically unaltered native species. The need for projects of this nature is largely driven by competition, predation, and/or hybridization by non-native fish; however, other factors including habitat alteration, disease, and climate change may also contribute to the need for action. A common project model that has evolved and become widely used follows three basic steps: 1) ensure isolation of the project area, 2) completely remove all non-native species, and 3) re-introduce genetically unaltered native species. The body of scientific information that has accrued around this model, conventional wisdom, and on-the-ground experience is used to carry out the project.

In the park's early history, non-native trout were readily stocked into park waters to provide additional fishing opportunities for visitors. Over the last century, these non-native trout have eroded native trout populations to a small fraction of their historic range. Once occupying hundreds of stream kilometers, indigenous westslope cutthroat trout now occupy only 2 km (1.2 mi.) of streams in the Grayling Creek drainage, while fluvial grayling disappeared entirely from the park by 1934. As park biologists, we have worked diligently to restore these native fish back into their historic ranges using approaches described above. Over the past decade, genetically pure westslope cutthroat trout have been reintroduced into the headwaters of Specimen and Grayling creeks, with a local brood source being developed in the Goose Lake complex. Our restoration efforts have added 74 km (46 mi.) of stream that are now occupied by native westslope cutthroat trout and/or fluvial grayling. The grayling introduced to upper Grayling Creek in 2015 were the first fluvial grayling to swim in park waters in more than 80 years. Future projects for westslope cutthroat trout and fluvial grayling include native fish restoration in North Fork Specimen and Cougar creeks as well as the upper Gibbon River. Once these projects are completed, an additional 61 km (38 mi.) of stream will be restored to native fish. As the NPS enters its next century, we continue to work to preserve and protect native fishes of Yellowstone for future generations.

Literature Cited

Kaya, C.M. 2000. Arctic grayling in Yellowstone: status, management, and recent restoration efforts. Yellowstone Science 8:12-17.

Steed, A.C., A.V. Zale, T.M. Koel, and S.T. Kalinowski. 2011. Population viability of Arctic grayling in the Gibbon River, Yellowstone National Park. North American Journal of Fisheries Management 30:1582-1590.

Varley, J.D., and P. Schullery. 1998. Yellowstone fishes: ecology, history, and angling in the park. Stackpole Books, Mechanicsburg, Pennsylvania, USA.

Vincent, R.E. 1962. Biogeographical and ecological factors contributing to the decline of Arctic grayling, *Thymallus arcticus* (Pallas), in Michigan and Montana. Dissertation. University of Michigan, Ann Arbor, Michigan, USA.

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Environmental DNA: A New Approach to Monitoring Fish in Yellowstone National Park

Colleen R. Detjens & Kellie J. Carim

Environmental DNA (eDNA) is genetic material obtained from an environmental sample such as soil, sediment, water, or ice without directly handling the organism from which it originated (Thomsen and Willerslev 2015). This DNA is shed from the organism into the environment in a variety of forms, including skin cells, mucus, feces, or tissue. Biologists are able to collect this DNA and analyze it to determine the presence of specific species. In fact, this technique is so sensitive that even a single copy of DNA from an animal may be detected in an environmental sample.

In recent years, eDNA-based sampling methods have become an increasingly common tool for wildlife managers. Within Yellowstone National Park (YNP), fisheries biologists have begun using eDNA from water samples to understand the distribution of various fish species. In collaboration with researchers at the National Genomics Center for Wildlife and Fish Conservation, located at the Forest Service Rocky Mountain Research Station in Missoula, Montana, we hope to contribute to the growing body of knowledge on the effectiveness and limitations of eDNA sampling as a monitoring tool.

Applications and Analysis

There are many potential benefits to collecting eDNA samples in conjunction with native fish restoration projects in YNP. Because eDNA sampling does not require fish be observed, biologists can survey waters without having to electrofish, handle, or stress fragile populations. The sensitivity of this tool may also allow biologists to detect invasive species while numbers are still low, which could prove invaluable to containing the spread of an invasion (Goldberg et al. 2013). The use of eDNA may also be helpful in determining the effectiveness of rotenone treatments to remove non-native fish from watersheds where native fish are being restored. Finally, biologists can use the amount of DNA in a sample to understand the relative abundance of a species at the landscape level (Takahara et al. 2012, Pilliod et al. 2013). In essence, eDNA samples provide a powerful snapshot in time for biologists to catalog information not on just one species, but potentially an entire biological community.

Following water sample collection, eDNA samples are taken to a laboratory and analyzed using a meticulously designed test that can detect any DNA from the fish species of interest, as well as DNA from other non-target species. Therefore, samples can be reanalyzed multiple times to detect DNA from any additional species that may have been present at the time of sample collection but not part of the original research study. The samples can be preserved in a freezer and analyzed months or even years later for fish or wildlife species that may not have been the initial target of investigation.

Because of YNP's immense size and rugged landscape, access to study sites is often gained on foot. Hiking in and out of remote locations and sampling via electrofishing or netting take a lot of time, effort, and personnel; this is when the eDNA method becomes a valuable tool. Due to its high sensitivity and the efficiency of its use, eDNA sampling may be the most effective way to determine whether or not a species is present in remote areas.

Limitations

Despite the many benefits of using eDNA-based monitoring methods, there are still some limitations that can affect the accuracy of detecting a species. DNA that is free-floating in the environment will eventually degrade; factors such as temperature and exposure to ultraviolet light will speed the degradation process (Strickler et al. 2015). As a result, the further you are from a fish in the stream, the less likely you are to collect its DNA in a sample. Additionally, the rate at which fish shed DNA may not always be consistent and could be affected by conditions such as diet, temperature, and

spawning activities (Klymus et al. 2015). Consequently, the ability of eDNA sampling to replace traditional methods of estimating species presence or abundance is not completely understood and, therefore, warrants further study.

Because eDNA-based methods can detect a single copy of DNA, preventing cross-contamination of samples must be carefully considered. Samples must be handled with caution to avoid contamination during both field collection and laboratory processing. For example, biologists must take care to avoid the transfer of DNA from their waders, which are exposed to DNA when working in bodies of water. Also, it is possible to detect fish DNA in a water sample after movement through, or defecation by, fish predators (Merkes et al. 2014). However, many of these limitations can be accounted for by carefully choosing sample locations, avoiding contamination during the sampling process, and implementing rigorous lab protocols. Researchers at the National Genomics Center for Wildlife and Fish Conservation have been at the forefront of the efforts to understand these limitations and help wildlife managers, like those in Yellowstone, collect samples with the highest possible quality.

eDNA in Yellowstone National Park

Within YNP, eDNA sampling was used to estimate the geographic extent of non-native brook trout within Soda Butte Creek, which helped direct eradication efforts and allowed biologists to confidently exclude portions of the drainage where the use of rotenone was not needed. Environmental DNA sampling has also been used in follow-up sampling to verify the success of rotenone treatments, including the treatment of Elk Creek to remove non-native brook trout (see "Preservation of Native Cutthroat Trout in Northern Yellowstone," this issue). The use of eDNA may also prove to be a valuable tool for assessing the recovery of Yellowstone cutthroat trout in Yellowstone Lake and may be able to confirm the presence of spawning fish in tributaries where other visual survey methods in recent years have not detected them. Cutthroat trout eDNA in Yellowstone Lake spawning streams may also be useful for estimating the relative abundance of spawning fish throughout the spawning period. In addition, environmental samples aimed at detecting terrestrial organisms, such as bears and river otters, could provide additional insight on the use of cutthroat trout as a prey source for these animals, especially in the remote tributaries of Yellowstone Lake. All of this information will be extremely valuable to managers as native cutthroat trout continue to recover within the Yellowstone Lake ecosystem.

Literature Cited

Goldberg, C.S., A. Sepulveda, A. Ray, J. Baumgardt, and L.P. Waits. 2013. Environmental DNA as a new method for early detection of New Zealand mudsnails *(Potamopyrgus antipodarum*). Freshwater Science 32:792-800.

Klymus, K.E., C.A. Richter, D.C. Chapman, and C. Paukert. 2015. Quantification of eDNA shedding rates from invasive bighead carp *Hypophthalmichthys nobilis* and silver carp *Hypophthalmichthys molitrix*. Biological Conservation 183:77-84.

Merkes, C.M., S.G. McCalla, N.R. Jensen, M.P. Gaikowski, and J.J. Amberg. 2014. Persistence of DNA in carcasses, slime and avian feces may affect interpretation of environmental DNA data. PLoS One 9:e113346.

Pilliod, D.S., C.S. Goldberg, R.S. Arkle, L.P. Waits, and J. Richardson. 2013. Estimating occupancy and abundance of stream amphibians using environmental DNA from filtered water samples. Canadian Journal of Fisheries and Aquatic Sciences 70:1123-1130.

Strickler, K.M., A.K. Fremier, and C.S. Goldberg. 2015. Quantifying effects of UV-B, temperature, and pH on eDNA degradation in aquatic microcosms. Biological Conservation 183:85-92.

Takahara, T., T. Minamoto, H. Yamanaka, H. Doi, and Z. Kawabata. 2012. Estimation of fish biomass using environmental DNA. PLoS One 7:e35868.

Thomsen, P.F., and E. Willerslev. 2015. Environmental DNA - an emerging tool in conservation for monitoring past and present biodiversity. Biological Conservation 183:4-18.

Colleen Detjens is a native fish conservation biologist for the Yellowstone Native Fish Conservation Program. Her work focuses on both the streams and lakes within Yellowstone National Park and includes a wide variety of projects. A Chicago native, Colleen came to Yellowstone in 2011 and hasn't looked back since! Colleen works in cooperation with Montana State University's Institute on Ecosystems.

Effects of Rotenone on Amphibians and Macroinvertebrates in Yellowstone

Donald R. Skaar, Jeffrey L. Arnold, Todd M. Koel, Michael E. Ruhl, Joseph A. Skorupski, & Hilary B. Treanor

Piscicides are fish toxins approved by the Environmental Protection Agency and used by managers to eradicate non-native fishes. With the exception of sea lamprey control in the Great Lakes, all fish removal projects in the United States utilize piscicide formulations containing either rotenone or antimycin as the active ingredient. Both of these natural compounds have been used extensively in fisheries management since the 1930s to control invasive species, recover native species, or restore sport fish (e.g., removing suckers to make habitat available for a sport fish). Over the past decade, biologists in Yellowstone National Park (YNP) have used rotenone in High Lake and East Fork Specimen Creek (2006-2009), Goose Lake (2011), Elk Creek (2012-2014), Grayling Creek (2013-2014), and Soda Butte Creek (2015-2016) to remove non-native fish species.

Piscicides are effective at removing fish from habitats where nets, electrofishing, angling, traps, or other mechanical methods are impractical or ineffective. However, piscicides are also non-specific, meaning they can impact all gill-breathing organisms, including larval amphibians and macroinvertebrates. Therefore, when using this powerful tool, natural resource managers need to consider these potential impacts and seek ways to lessen them.

What is Rotenone, and How Does it Work?

Rotenone occurs in the roots, stems, and leaves of tropical plants in the pea family (Fabaceae), including the jewel vine (*Derris involuta*), lancepod or cube plant (*Lonchocarpus utilis*), and *Tephrosia* genus found in southeast Asia, South America, and east Africa, respectively. Rotenone and other related compounds are produced by these plants for a variety of functions, including defense against the growth of microorganisms (Dixon and Passinetti 2010). Indigenous peoples discovered that the roots of these plants are toxic to fish and developed a variety of ways to apply these roots to water to kill fish for consumption (Cannon et al. 2004).

Rotenone's toxicity results from the inhibition of a biochemical reaction called oxidative phosphorylation, which occurs in the energy-producing mitochondria within the cells of animals. The resulting loss of usable energy for cellular function results in death. To reach most tissues in an animal, rotenone must first be absorbed into the bloodstream. Ingestion of rotenone has a relatively minor effect on land animals because the enzymes and acids of the digestive system break it down, thus limiting absorption through the lining of the intestinal tract. On the other hand, the absorption of rotenone in water across the gill membrane by fish or other aquatic organisms (amphibians, immature insects) is a direct route into the blood.

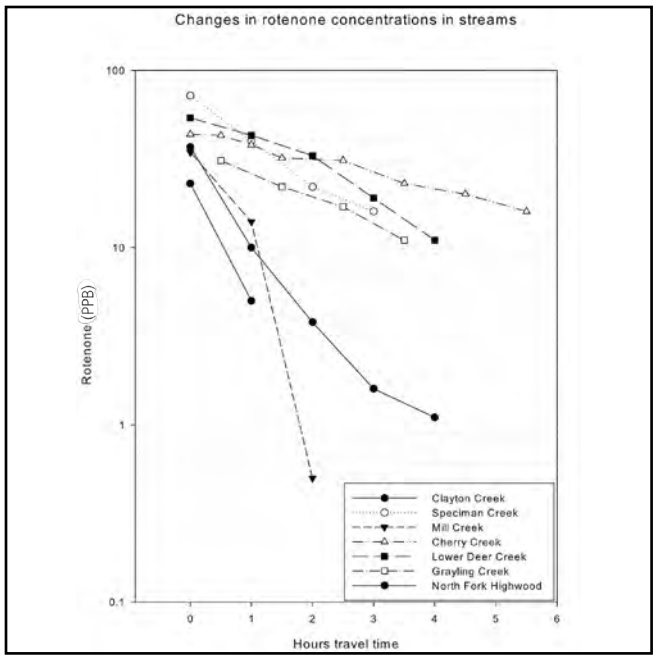

Figure 1. Concentration of rotenone (parts-per-billion, or PPB) in water downstream of drip stations in several Montana streams. Rotenone was applied, marked with an inert fluorescent dye, and then followed as it traveled downstream, with water samples taken to determine concentration at timed intervals within 1-6 hours. The y-axis is a log-normal scale.

The physical and chemical properties of rotenone combine with environmental conditions to determine its fate and toxicity in the environment. It is a large compound quickly broken down in the environment by sunlight and other factors. The degradation time in lakes ranges from one day in warm water to several weeks in cold water. Rotenone is also somewhat hydrophobic, meaning once applied in the environment, it will readily bind to sediments or organic matter in the water. These factors result in a relatively quick dissipation and degradation of rotenone from the environment, which poses a challenge for biologists attempting to kill fish before rotenone concentrations decrease to nontoxic levels. This challenge is greatest in rapidly moving waters where rotenone, once applied, will either degrade or bind to streambed sediments within 1-5 hours of travel time, thus requiring reapplication to maintain toxic concentrations (figure 1).

Impacts of Rotenone on Organisms Other than Fish

The use of rotenone to kill fish can affect non-target organisms. In YNP, this includes most gill-breathing, immature forms of aquatic macroinvertebrates, specifically the insect taxa Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies; Magnum and Madrigal 1999, Hamilton et al. 2009). Factors such as age and size contribute to sensitivity, as younger insects have thinner cuticles and smaller animals have higher surface area to volume ratios, both leading to greater absorption of rotenone. Life history characteristics are also a factor, since animals living on the water-sediment interface of lakes or streams are more likely to be exposed to rotenone than those living in the spaces between gravel/cobble or burrowed into mud (Minckley and Mihilack 1981, Whelan 2002). Additionally, insects with high oxygen requirements will typically succumb more quickly to rotenone because it inhibits the oxygen-mediated production of energy molecules in the body (Engstrom-Heg et al. 1978). Finally, aquatic invertebrates with tracheal gills for respiration generally are more sensitive to rotenone than those that acquire oxygen through the skin, air, or respiratory pigments (Vinson et al. 2010).

Immature gill-breathing forms of amphibians may also be inadvertently impacted by rotenone treatments. In YNP, this potentially includes the boreal toad (*Anaxyrus boreas*), a species of concern in YNP and the Rocky Mountain West, blotched tiger salamander (*Ambystoma tigrinum melanostictum*), boreal chorus frog (*Pseudacris maculata*), and Columbia spotted frog (*Rana luteiventris*). Rotenone generally has a greater impact on larval forms of both frogs and salamanders than on adult forms (Farringer 1972, Burress 1982, Fontenot et al. 1994, Grisak et al. 2007). However, during the larval stage, frogs undergo lung development as they approach metamorphosis and rely very little on gill respiration; whereas, toads remain gill-breathers during the entire larval period (McDiarmid and Altig 1999). Frog tadpoles, therefore, may be less susceptible to the negative effects of rotenone as they grow older.

Research Conducted During East Fork Specimen Creek Rotenone Treatments

Rotenone treatments were used in the East Fork of Specimen Creek (EFSC) drainage during 2006-2009 to remove non-native trout. The first treatment occurred in 2006 at the upper end of the drainage, which included High Lake and its outlet stream, ending at a waterfall barrier (Koel et al. 2008). This was followed by treatment of Specimen Creek in 2008 and 2009 from the waterfall to a man-made barrier near the confluence with the North Fork Specimen Creek (figure 2), approximately 27 km (16.6 mi.) downstream. In all treatments,

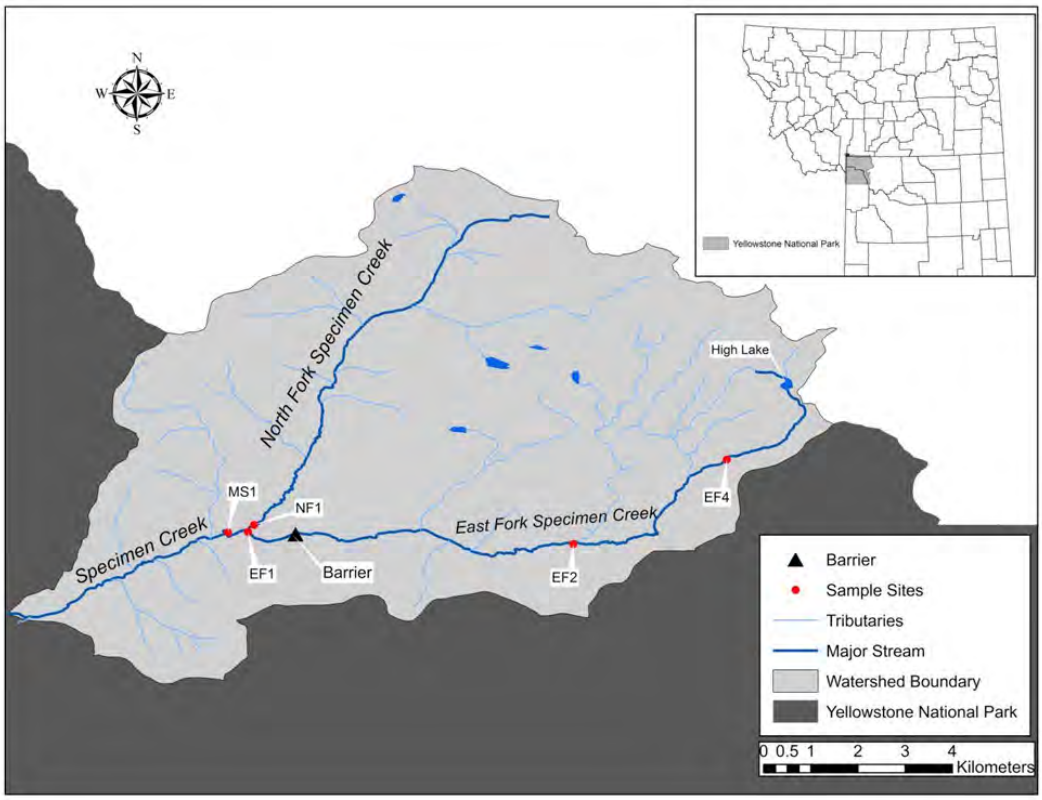

Figure 2. The Specimen Creek drainage in Yellowstone National Park, with sites sampled for macroinvertebrates (red dots) before, during, and after treatment with rotenone, 2006-2009. This figure was adapted from Skorupski (2011) and Billman et al. (2012).

a liquid formulation of rotenone called CFT-Legumine (5% active rotenone) was applied at a concentration of 1 part per million (ppm). For the stream treatments, the primary means of applying rotenone was through the use of "drip stations" consisting of a 5-gallon container filled with a CFT-Legumine/water mixture, metered out at a constant rate to maintain a 1 ppm concentration in the stream. Because the rotenone degraded and bound with streambed materials after it was applied, there was a decrease in the concentration of rotenone in the water with increasing distance from each drip station. Therefore, it was necessary to utilize additional drip stations spaced evenly throughout the treated section. On Specimen Creek, each drip station applied rotenone for 8 hours; stations were spaced at a distance equivalent to 2-3 hours travel time in the stream water.

The CFT-Legumine rotenone formulation used at High Lake and the EFSC was a relatively new product whose impacts to non-target organisms had not been previously evaluated in the field. In spite of this information gap, this formulation was chosen over traditional products because it contained oil-based solvents, which contain fewer and less persistent contaminants, and reduced odor, rather than petroleum-based solvents. Biologists used this opportunity to investigate how CFT-Legumine impacts benthic macroinvertebrates (EFSC) and amphibians (High Lake and outlet EFSC) in an effort to identify ways to mitigate effects during future treatments.

Benthic Macroinvertebrates – Scientists measured changes in the abundance and richness (number of taxa) of macroinvertebrates at a total of five sites: two sites on the EFSC downstream of rotenone drip stations, two sites below the detoxification station where potassium permanganate was applied to deactivate rotenone (see "Westslope Cutthroat Trout and Fluvial Arctic Grayling Restoration," this issue), and one reference (non-treated) site (Skorupski 2011; figure 3). Sampling occurred at each site before the rotenone treatments, immediately after treatments, and one year after treatments. A total of 57 insect taxa were found at the five sampling sites, dominated by the true flies (family Chironomidae), mayflies, stoneflies, and caddisflies. The CFT-Legumine treatment slightly reduced the abundance and richness of

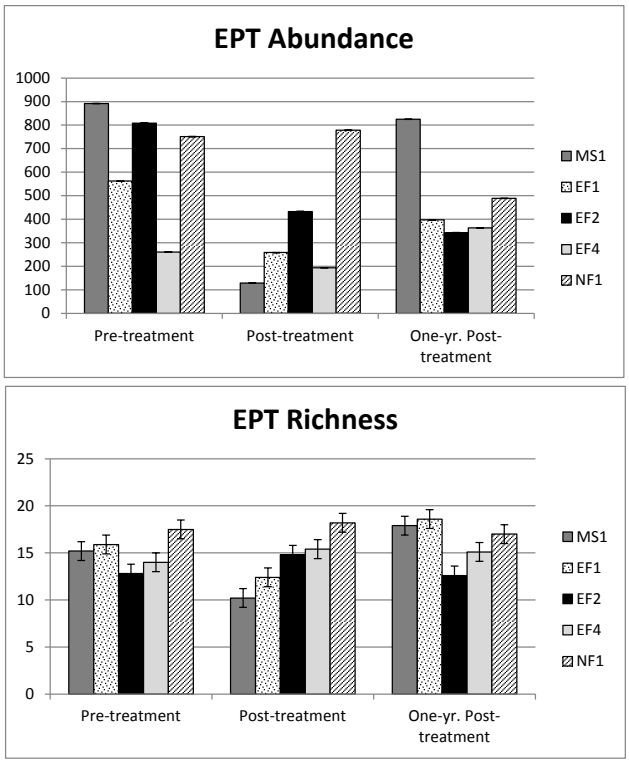

Figure 3. Mean abundance and richness (number of taxa) of mayflies, stoneflies, and caddisflies (EPT) combined at four treated sites on East Fork Specimen Creek (MS1, EF1, EF2, EF4) and one control (untreated) site on North Fork Specimen Creek (NF1). Sites MS1 and EF1 were below the potassium permanganate detoxification station. Sites EF2 and EF4 were only treated with rotenone. Sites were sampled prior to rotenone treatment in 2009 (pre-treatment), immediately following rotenone treatment in 2009 (post-treatment), and one year following rotenone treatment in 2010 (one-year post-treatment). Error bars are standard deviations (adapted from Skorupski 2011).

mayflies, stoneflies, and caddisflies immediately following the treatment, but did not impact overall insect richness. Macroinvertebrates sampled within the detoxification area experienced similar, but greater, effects from the potassium permanganate than individuals within the treatment area that were exposed to rotenone. However, the abundance and richness of mayflies, stoneflies, and caddisflies returned to pre-treatment levels at most sites within a year (figure 3).

Five taxa found during pre-treatment sampling were not detected after the rotenone treatments. There were also six taxa not detected before treatment that were collected after treatment. None of these taxa are endangered or listed as sensitive by the Montana Natural Heritage Program (2010). Skorupski (2011) indicated these "missing" taxa were probably an artifact of low abundance because most were not consistently detected during all the years (2004-2010) of previous sampling in the drainage. Also, the amount of streambed sampled during treatments was small (less than one square meter at each site), which could contribute to rare taxa going undetected.

The phenomenon of missing taxa is not uncommon in macroinvertebrate sampling. A study was conducted on the Logan River in Utah in which the river was sampled for macroinvertebrates once a month for 10 years. The monthly samples routinely counted an average of 28 different genera. However, the cumulative number of taxa continued to rise over the 10-year period to 84 genera, demonstrating the difficulty in developing a complete inventory of all taxa in a waterbody (Vinson et al. 2010). Overall, the best way to characterize impacts of rotenone to macroinvertebrate communities is to use metrics such as total abundance, total taxa, or community indices.

Critics of piscicide treatments have used missing taxa as an argument against the use of these chemicals, claiming it shows they will extirpate sensitive taxa from treatment areas. Treatments of the Green River in Wyoming and the Strawberry River in Utah are often cited because some taxa disappeared after rotenone was applied (Binns 1967, Magnum and Madrigal 1999). However, those treatments were conducted using much higher concentrations and older, petroleum-based formulations of rotenone for longer periods of time than used currently in YNP.

Skorupski (2011) also evaluated downstream drift by benthic macroinvertebrates during rotenone treatments. Drift is a behavior used by benthic macroinvertebrates to disperse to new areas in search of food or habitat, as well as a response to stressors such as fire, floods, and, in this case, rotenone (Waters 1972). On EFSC, taxa differed in their drift response to rotenone. Stoneflies were the first to drift, showing a marked increase in drift after only 30-60 minutes of exposure. This was followed by other non-insect species, the true flies, and then mayflies, which showed peak drift at 180-210 minutes after exposure. The slowest taxa to respond were caddisflies and beetles, with low drift rates that were still increasing after 330-360 minutes. Although these results suggest some macroinvertebrates can avoid rotenone by drifting downstream and out of the treatment area, a better understanding of the ultimate fate of drifting insects would be useful for interpreting the significance of

Boreal toad eggs. NPS PHOTO - J. FLEMING

species not detected during sampling before and after rotenone treatments.

Amphibian Tadpoles – Another study examined the effects of rotenone on the distribution and abundance of Columbia spotted frog tadpoles in High Lake and nearby wetlands before (2006) and after (2007-2009) the rotenone treatment (Billman et al. 2012; figure 4). Scientists measured impacts of the rotenone treatment on different life stages, as well as the impacts of Yellowstone cutthroat trout and westslope cutthroat trout in High Lake on the frogs (Billman et al. 2011, 2012). The Gosner (1960) staging system for amphibian development was used to assign a number to the stages of larval development through complete metamorphosis, with stage 1 being the fertilized egg and stage 46 being the full adult form. Frog tadpoles begin to develop lungs and rely less on gills for respiration during the late stages (40-45).

Prior to the rotenone treatment, tadpoles (stages 40-43) and adult spotted frogs were placed in mesh sentinel cages at different locations in the treatment area and in

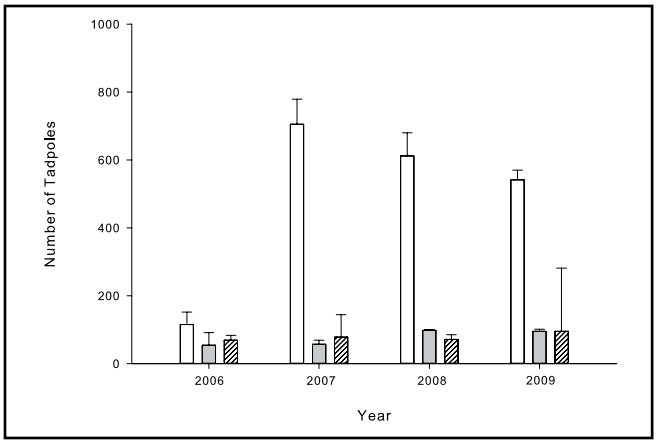

Figure 4. Estimated number of tadpoles (with 95% confidence intervals) at High Lake (open bars), the north wetland (shaded bars), and the south wetland (striped bars), 2006-2009. Sampling in 2006 occurred prior to treatment with rotenone when high densities of Yellowstone cutthroat trout remained in the lake. Sampling in 2007 occurred after the rotenone treatment of High Lake and during a period when native westslope cutthroat trout were being reintroduced as embryos to inlet streams, and as juveniles and adults to the lake (Koel et al. 2008). The north and south wetlands were isolated from High Lake and not treated with rotenone (adapted from Billman et al. 2012).

two of the nearby wetlands not being treated with rotenone (figure 4). While the caged animals in the nearby wetlands survived, all tadpoles in the cages held in High Lake died as a result of the treatment. All adult spotted frogs held in High Lake survived. No live tadpoles were found elsewhere in the lake after the treatment, but non-gill-breathing juveniles and adults were found at multiple locations (Billman et al. 2012).

Immediately prior to the rotenone treatment in 2006, tadpole abundance in High Lake was similar to that found in the much smaller nearby wetlands (figure 4). Over the next three years, tadpole abundance in the wetlands was essentially unchanged. In 2007, the first year following treatment, tadpole abundance in High Lake increased about sixfold, but then declined slightly in each of 2008 and 2009. The marked increase in tadpoles following the rotenone treatment was likely a result of the absence of trout in High Lake, as the rotenone treatment removed over 800 trout from the lake, some as large as 400 mm (in length (Koel et al. 2007). These fish likely preyed on the tadpoles and suppressed their numbers. The estimate of the tadpole population in 2007 was made before more than 8,300 westslope cutthroat trout were reintroduced into the lake and inlet streams between 2007 and 2009 (Koel et al. 2011). Therefore,

the slight downward trend in tadpole abundance from 2007 to 2009 likely reflects the impact of reintroduced trout on the tadpoles. Observations of tadpole behavior support this hypothesis. In 2006 when fish were present, tadpoles were only found in the sedge-protected portions of the outlet channel to the lake, while adults were found throughout the lake. When fish were absent in 2007, tadpoles were found throughout the outlet and in margins around the main portion of the lake. By 2009, tadpoles were again restricted to sedge-protected portions of the outlet margins (Billman et al. 2012).

Laboratory experiments were also conducted in 2008 and 2009 to determine the toxicity of rotenone to different life stages of Columbia spotted frog and boreal toad tadpoles (Billman et al. 2011). After a 96-hour exposure to CFT-Legumine at levels ranging from 0.1-1.0 ppm, older Columbia spotted frog tadpoles (stages 40-45) were found to be less susceptible to rotenone than younger tadpoles (stages 21-25 or 30-35). The youngest Columbia spotted frog tadpoles had 100% mortality at concentrations of 0.5 and 1.0 ppm, but only 1% mortality at 0.1 ppm. Medium-aged tadpoles (stages 30-35) had between 73-100% mortality at 1.0 ppm, but only 2% at lower concentrations. At 1 ppm, the oldest Columbia spotted frog tadpoles experienced 57% mortality in 2008 but only 6% mortality in 2009. Conversely, boreal toad tadpoles experienced high mortality at 1 ppm across age groups (83%-99%; Billman et al. 2011).

The reduced mortality of older tadpoles was likely due to their increased reliance on lungs for respiration rather than on gills. Gill surfaces are the quickest route for an organism to absorb rotenone, so it is not surprising that the laboratory studies found gill-breathers are more sensitive than lung-breathers. These findings are also consistent with observations of frogs in High Lake following the treatment in 2006, where non gill-breathing juveniles were found alive, while no gill-breathing larvae survived the treatment.

Summary

This work provides strong evidence that rotenone treatments have not significantly impacted benthic macroinvertebrates or amphibians in YNP in the long-term. Rotenone degraded quickly within streams, and many macroinvertebrates escaped the treatment area via downstream drift. Sampling of macroinvertebrates within stream substrates indicated a slight reduction in the abundance of mayflies, stoneflies, and caddisflies immediately following rotenone treatments. However, abundance increased to pre-treatment levels within one year. This variation was most pronounced at sites located immediately downstream of detoxification stations, suggesting that the potassium permanganate, a strong oxidizing agent also used to purify city drinking water, may have a slightly greater effect on macroinvertebrates than the CFT-Legumine rotenone formulation itself.

Both Skorupski (2011) and Billman et al. (2011) recommended using a minimum dosage of rotenone to reduce potential impacts on non-target organisms. All High Lake and EFSC treatments were conducted using a CFT-Legumine concentration of 1.0 ppm, and the drip stations on the creek applied rotenone for 8 hours. Skorupski (2011) noted that if the duration of stream treatments could be reduced from 8 to 4 hours, then the amount of macroinvertebrate drift would be reduced by roughly 50%, which would probably be less harmful to the macroinvertebrates. Billman et al. (2011) suggested treating at a lower dose, if possible, based on laboratory experiments which revealed that the percentage of early and middle stage tadpoles that died after 96 hours of exposure to 0.5 ppm was less than half the percentage that died when exposed to 1.0 ppm. These recommendations are consistent with the CFT-Legumine label guidance to treat at a concentration of 0.5-1.0 ppm for "normal" types of use, for a duration of 4-8 hours in streams. Following the EFSC treatment, YNP biologists have generally treated streams for 4 hours. Bioassays are also conducted prior to any treatment (see "Westslope Cutthroat Trout and Fluvial Arctic Grayling Restoration," this issue) to determine the minimum dose necessary to effectively kill fish (Finlayson et al. 2010).

Studies on EFSC also provided guidance on how to appropriately time, or sequence, treatments to reduce impacts to non-target species. Skorupski (2011) suggested partitioning the drainage into multiple treatments zones with intermediate barriers, and leaving time between treatments to allow for dispersal and recolonization of invertebrates from untreated areas. He also recommended not treating headwater areas that are fishless, which would then leave a source for recolonization of downstream treated reaches. Billman et al. (2011, 2012) noted impacts to amphibians could be reduced if treatments were timed to occur when tadpoles were no longer present or were in their older life stages. All treatments in YNP have and will continue to be conducted during late summer or fall to avoid impacts on amphibians.

Literature Cited

Billman, H.G, S. St-Hilaire, C.G. Kruse, T.S. Peterson, and C.R. Peterson. 2011. Effects of rotenone on Columbia spotted frog and boreal toad tadpoles. Transactions of American Fisheries Society 140:919-927.

Billman, H.G, C.G. Kruse, S. St-Hilaire, T.M. Koel, J.L. Arnold, and C.R Peterson. 2012. Effects of rotenone on Columbia spotted frog *Rana luteiventris* during field application in lentic habitats in southwestern Montana. North American Journal of Fisheries Management 32:781-789.

Binns, N.A. 1967. Effects of rotenone treatment on the fauna of the Green River, Wyoming. Wyoming Game and Fish Commission. Cheyenne, Wyoming, USA.

Burress, R.M. 1982. Effects of synergized rotenone on nontarget organisms in ponds. Investigations in Fish Control 91. U.S. Fish and Wildlife Service, Washington, D.C., USA.

Cannon, J.G., R.A. Burton, S.G. Wood, and N.L. Owen. 2004. Naturally occurring fish poisons from plants. Journal of Chemical Education 81:1457-1461.

Dixon, R.A., and G.M. Pasinetti. 2010. Flavonoids and isoflavonoids: from plant biology to agriculture and neuroscience. Plant Physiology 154:453-457.

Engstrom-Heg, R., R. Colesante, and E. Silco. 1978. Rotenone tolerances of stream bottom insects. New York Fish and Game Journal 25: 31-41.

Farringer, J.E. 1972. The determination of the aquatic toxicity of rotenone and Bayer 73 to selected aquatic organisms. Thesis. University of Wisconsin-Lacrosse, Lacrosse, Wisconsin, USA.

Finlayson, B., R. Schnick, D. Skaar, J. Anderson, L. Demong, D. Duffield, W. Horton, and J. Steinkjer. 2010. Planning and operating procedures for the use of rotenone in fish management – rotenone SOP manual. American Fisheries Society, Bethesda, Maryland, USA.

Fontenot, L.W., G.P. Noblet, and S.G. Platt. 1994. Rotenone hazards to amphibians and reptiles. Herpetological Review 25:150-156.

Gosner, K.L. 1960. A simplified table for staging anuran embryos and larvae with notes on identification. Herpetologica 16:183-190.

Grisak, G.G., D.R. Skaar, G.L. Michael, M.E. Schnee and B.L. Marotz. 2007. Toxicity of Fintrol (antimycin) and Prenfish (rotenone) to three amphibian species. Intermountain Journal of Sciences 13:1-8.

Hamilton, B.T., S.E. Moore, T.B. Williams, N. Darby, and M.R. Vinson. 2009. Comparative effects of rotenone and antimycin on benthic macroinvertebrate diversity in two streams in Great Basin National Park. North American Journal of Fisheries Management 29:1620-1635.

Koel, T.M., J.L. Arnold, P.E. Bigelow, P.D. Doepke, B.D. Ertel, and M.E. Ruhl. 2007. Yellowstone Fisheries & Aquatic Sciences: annual report, 2006. YCR-2007-04. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, USA.

Koel, T.M., J.L. Arnold, P.E. Bigelow, P.D. Doepke, B.D. Ertel, and M.E. Ruhl. 2008. Yellowstone Fisheries & Aquatic Sciences: annual report, 2007. YCR-2008-02. National Park Service, Yellowstone National Park, Wyoming, USA.

Koel, T.M., J.L. Arnold, P.E. Bigelow, P.D. Doepke, B.D. Ertel, and M.E. Ruhl. 2011. Yellowstone Fisheries & Aquatic Sciences: annual report, 2009–2010. YCR-2011-11. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, USA.

Montana Natural Heritage Program. 2010. Animal species of concern database. http://mtnhp.org/docs/2010_Animal_SOC.pdf

McDiarmid, R.W., and R. Altig. 1999. Tadpoles: the biology of anuran larvae. University of Chicago Press, Chicago, Illinois, USA.

Magnum, F.A., and J.L. Madrigal. 1999. Rotenone effects on aquatic macroinvertebrates of the Strawberry River, Utah: a five year summary. Journal of Freshwater Ecology 14:125-135.

Minkley, W.L., and P. Mihalick. 1981. Effects of chemical treatment for fish eradication on stream-dwelling invertebrates. Journal of the Arizona-Nevada Academy of Sciences 16:79-82.

Skorupski, J.A. 2011. Effects of CFT-Legumine rotenone on macroinvertebrates in four drainages in Montana and New Mexico. Thesis. University of North Texas, Denton, Texas, USA.

Vinson, M.R., E.C. Dinger, and D.K. Vinson. 2010. Piscicides and invertebrates: after 70 years, does anyone really know? Fisheries 35:61-71.

Waters, T.F. 1972. The drift of stream insects. Annual Review of Entomology 17:253-272.

Whelan, J. 2002. Aquatic macroinvertebrate monitoring results of the 1995 and 1996 rotenone treatments of Manning Creek, Utah. Publication No. 02-02. Utah Department of Natural Resources, Salt Lake City, Utah, USA.

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Preservation of Native Cutthroat Trout in Northern Yellowstone

Brian D. Ertel, Kurt C. Heim, Jeffrey L. Arnold, Colleen R. Detjens, & Todd M. Koel

The northern portion of Yellowstone National Park (YNP) is a valuable stronghold for native fish; it presents many opportunities to protect and restore them where they have been impacted by human activities. More than 3,700 km (2,299 mi.) of streams drain into the Yellowstone River and flow north into Montana (figure 1). The Lamar River drainage alone contains over 1,792 km (1,113 mi.) of streams and accounts for almost 20% of the stream distance in YNP (Jones et al. 1986). Large portions of the rivers in northern Yellowstone are interconnected with no barriers to upstream fish movement, providing extensive habitat for migratory fish. The barriers (mostly waterfalls) that do exist are typically found in headwater streams, but a few are present in lower drainages (e.g., Knowles Falls, Ice Box Falls; figure 1). This watershed was likely colonized by fish about 10,000 years ago, as glaciers receded and fish populated mainstem river systems (Campbell et al. 2011). Barriers located higher in the drainage fostered the creation of genetically isolated headwater populations or naturally fishless areas.

The variety of habitats, large expanses of connected waters, and isolated headwater reaches resulted in the formation of various life history types within the wa-

tershed through local adaptations to diverse habitats (Gresswell et al. 1994, Fausch and Young 1995, Woolnough et al. 2009). Fluvial (living and spawning within a single stream or river), fluvial-adfluvial (living in a stream and moving into a tributary to spawn), and lacustrine-adfluvial (living in a lake and spawning in a tributary stream) life history types have all been identified in northern Yellowstone. Movements of fish can range from just a few hundred meters over a lifetime for fluvial headwater fish to over 50 km (31 mi.) annually for fluvial-adfluvial and lacustrine-adfluvial fish (Fausch et al. 2002, Ertel 2011). Life history diversity within an ecosystem helps to protect a population from being lost in a single extreme natural event. However, there are still serious threats to the persistence of native fish species in northern Yellowstone, the most evident being the presence of non-native fish.

Historically, northern Yellowstone was home to native cutthroat trout, mountain whitefish, longnose dace, mottled sculpin, longnose sucker, and mountain sucker. The stocking of non-native fish began in YNP in the early 1880s to enhance sport and sustenance fishing for visitors. Many early stockings were aimed at establishing fish populations in fishless waters, and over 27 million fish were stocked in northern Yellowstone alone. Cutthroat trout accounted for about 89% of fish stocked in this region. Although most of these fish were Yellowstone cutthroat trout, in a few cases westslope cutthroat trout were stocked because a distinction was not made between the subspecies at the time. Non-native fish, including brook trout (4.4%), Arctic grayling (2.9%), rainbow trout (2.3%), and brown trout (1.9%) were also stocked in streams in northern Yellowstone.

Habitat remains pristine within YNP, but non-native fish species now reside with varying frequency in northern Yellowstone and pose a serious threat to the persistence of native fish. Brown, brook, and rainbow trout all compete with cutthroat trout for food and habitat. Rainbow trout also pose the additional threat of crossbreeding with cutthroat trout. Because of the lack of barriers in the lower reaches of the drainage, non-native fish have been dispersing upstream. In other areas, non-native fish have replaced, threaten to replace, or hybridize with cutthroat trout. Fortunately, brown trout are found only in the Yellowstone River and several of its tributaries below Knowles Falls (figure 1). Brook trout were located in the Yellowstone River and its tributaries below the Lower Falls (at Canyon) and in Soda Butte Creek upstream of Ice Box Falls. Rainbow trout

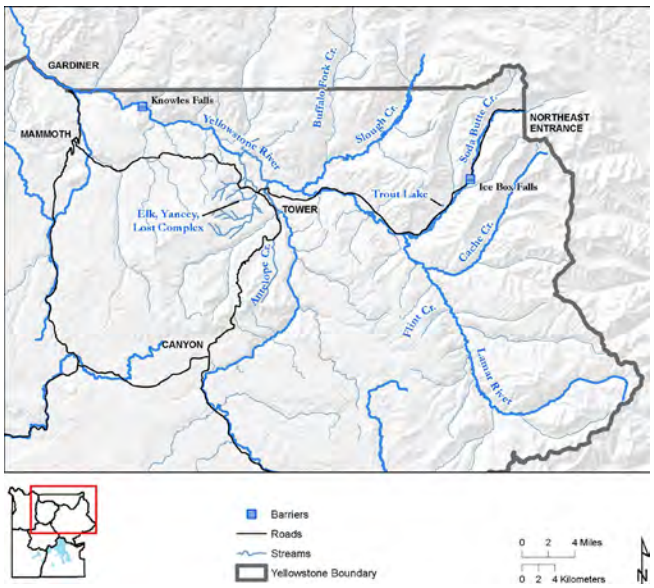

Figure 1. Waters in the northern portion of Yellowstone National Park. Knowles and Ice Box falls are known barriers to upstream fish migration.

are found in most waters in northern Yellowstone, with the exception of the upper reaches of Slough Creek and the Lamar River upstream of the Flint Creek confluence (figure 1). The upstream dispersal of rainbow trout and progression of hybridization with cutthroat trout continues today (figure 2). Because non-native species continue to pose the most significant threat to native fish in northern Yellowstone, the National Park Service (NPS) is taking direct actions to protect and restore native fish populations.

To restore Yellowstone cutthroat trout in northern Yellowstone, a multifaceted approach has been implemented to address immediate threats and develop long-term solutions. A combination of angling, electrofishing, headwater isolation, and piscicide treatments are used to reduce or eliminate non-native fish from targeted areas. Following reduction or removal of unwanted species, stocking using live fish transfer, eyed-eggs (embryos) using remote site incubators, or a combination of the two is used to boost or restore cutthroat trout. Liberalization of creel limits and mandatory kill regulations for anglers and electrofishing by biologists are effective tools for the selective removal of detrimental species. However, in some instances these tools have not been enough to completely eliminate the non-native invaders; as a result, barriers and chemical treatments are used. In some locations, natural barriers already exist, such as the cascade on Elk Creek. In other places, modifications to natural structures, such as Ice Box Falls on

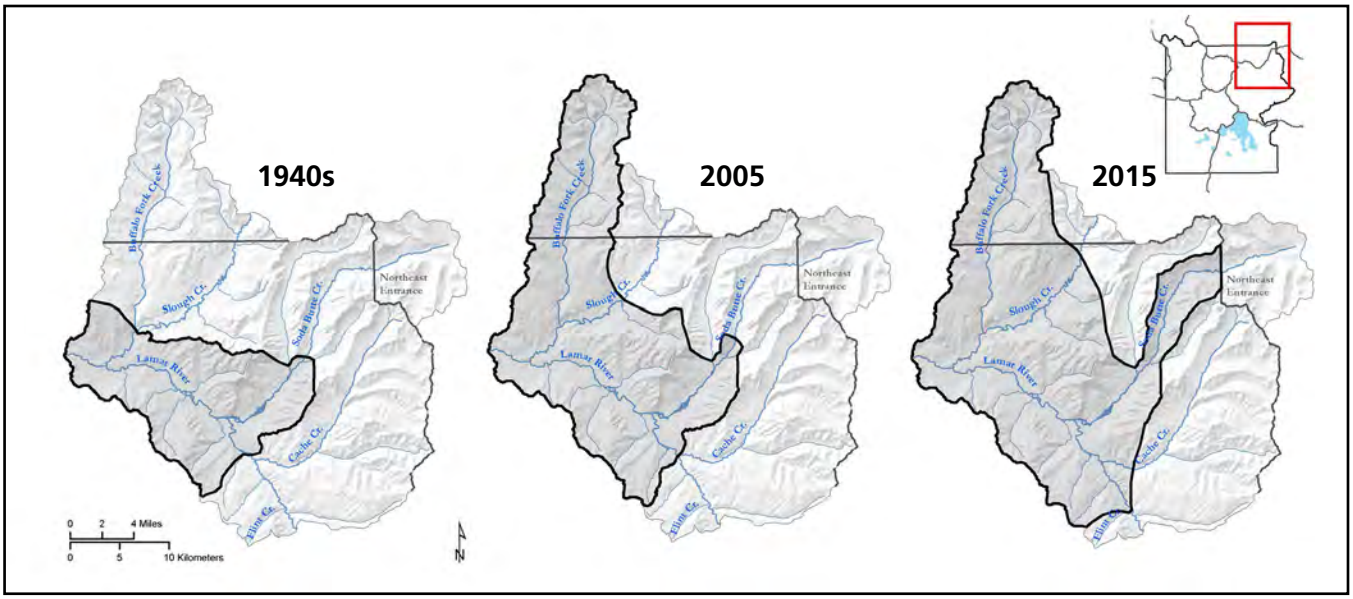

Figure 2. Progression of non-native rainbow trout genetics through time. Work is being conducted throughout northern Yellowstone to slow or stop the spread of genetic introgression. Current projects are being conducted on the Lamar River, Soda Butte Creek, Slough Creek, Buffalo Fork Creek, and Tower Creek.

Soda Butte Creek, are necessary to form complete barriers to upstream migration. In a few places, such as the Slough Creek Canyon, barriers must be completely fabricated. Once native trout are protected from invasion, selective removal continues or, if necessary, chemical treatment is used to eliminate non-native species.

Restoration and Preservation Projects

Lamar River—Because no barriers to upstream fish migration exist in the mainstem Lamar River, descendants of rainbow trout stocked in the 1930s have spread to many locations across the watershed and hybridized with cutthroat trout. Not all has been lost, however. Genetic analysis of tissue samples collected in recent years indicate cutthroat trout in the headwater reaches of the Lamar River and Slough Creek remain genetically unaltered.

Because identification of low levels of hybridization is difficult to detect in the field, molecular genetic techniques have been employed to test for hybridization. Analysis of tissue samples collected in the Lamar River upstream of Soda Butte Creek in 2013 identified slightly hybridized fish as far upstream as the cascades by Flint Creek (figure 2). Samples at the Soda Butte Creek confluence had a rainbow trout hybridization of 2.40%; at Flint Creek, hybridization dropped to just 0.01%. Samples collected upstream of Flint Creek were genetically pure Yellowstone cutthroat trout, indicating rainbow trout have not yet invaded the upper portions of the Lamar River. However, the lack of a natural barrier in the Lamar River is a serious concern.

To protect the remaining Yellowstone cutthroat trout, the NPS has implemented a selective removal approach. A mandatory kill fishing regulation on all rainbow trout caught upstream of the Lamar River bridge was instituted in 2014 and has served to actively engage the public in conservation efforts. In addition, selective removal by electrofishing has been conducted annually through the Lamar Valley since 2013. During electrofishing events, all rainbow trout and obvious hybrid trout are removed; and native fish are returned. To-date, just 21 rainbow trout and hybrids have been removed from the system upstream of the Lamar River Canyon.

Downstream of the Lamar River Canyon, hybridized fish and rainbow trout are encountered more frequently. In 2015, in collaboration with Montana State University, 136 fish were sampled in this section of the Lamar River. Based on field identification, 48% were Yellowstone cutthroat trout, 19% were rainbow trout, and 31% were hybrids. The majority of these fish were tagged with radio transmitters or passive integrated transponder (PIT) tags as part of an ongoing research project to identify trout spawning locations. Selective removal of the non-native fish occurs annually in this river reach by electrofishing and an unlimited harvest angling regulation.

NPS crews use a boat-mounted electrofisher to selectively remove non-native rainbow and hybrid trout from the Lamar River watershed.

Slough Creek—In Slough Creek, rainbow-cutthroat trout hybrids have been found with increasing frequency over the past decade (figure 2). Rainbow trout and hybrids have been found in the lower reaches of Slough Creek, below Slough Creek Campground, since the 1930s, but were not officially recorded in the upper meadows until 2003. The unnamed falls and cascade located in the canyon below the first meadow were thought to be a barrier to upstream fish passage. Unfortunately, during certain flow conditions, trout are able to navigate around the margins of the falls and move into upper Slough Creek. Currently, methods used to suppress non-native trout are similar to those used in the Lamar River. However, there are differences between these systems. Slough Creek is smaller, a seasonal barrier exists, and a site has been identified to construct a complete barrier to upstream fish movement. With a barrier in place and rainbow trout no longer allowed passage into the system, existing rainbow and hybrid trout can be effectively managed with angling and electrofishing removal.

Angling and electrofishing removal efforts appear to have decreased the percentage of rainbow and hybrid trout in Slough Creek. In 2012, the percentage of rainbow and hybrid trout captured in the first and third meadows was 14% and 4%, respectively. In 2015, those percentages decreased to just 0% and 1.6%, respectively. The percentage of rainbow and hybrid trout in the second meadow, which was not electrofished prior to 2015 because of logistical constraints, was the highest of the three meadows at 6.9%, down from 8% in 2015. These results demonstrate electrofishing and angling have been an effective combination in decreasing the percentage of rainbow and hybrid trout in this drainage.

Soda Butte Creek—Brook trout became established in Soda Butte Creek outside of the park boundary in the 1980s and, over time, spread downstream into park waters. Initially, brook trout were isolated in headwater reaches by a chemical barrier created from the McClaren Mine tailings located along the river upstream of Cooke City, Montana. When the tailings were removed, brook trout passed downstream and began to negatively impact the cutthroat trout. It is well known brook trout will negatively impact native trout (Peterson et al. 2004, Shepard 2004). Thus the progression of brook trout caused great concern and compromised the security of the cutthroat trout throughout the entire Lamar River system. Mitigation of brook trout by annual interagency electrofishing surveys began in the 1990s, shortly after they were discovered downstream of Cooke City. To-date, no brook trout have been found in Soda Butte Creek downstream of Ice Box Falls.

A mandatory kill angling regulation for brook and rainbow trout and annual electrofishing removals have been used to control the number of non-native fish in Soda Butte Creek. Since the early 1990s, a cooperative work group consisting of the NPS; Montana Fish, Wildlife & Parks; Forest Service; and Wyoming Game and Fish have conducted electrofishing removals annually. In addition, rotenone treatment of Lulu Creek, a headwater tributary of Soda Butte Creek, was conducted in 2004 to eliminate the primary spawning population of brook trout in the system (Montana Fish, Wildlife & Parks 2004). Brook trout in Lulu Creek were eliminated by the treatment; however, subsequent surveys indicated brook trout had already spread downstream in the mainstem of Soda Butte Creek and other tributaries.

For nearly two decades, the interagency efforts were enough to prevent the brook trout from expanding in abundance but not in range. An average of 133 (range 48-230) brook trout were removed annually from 2006-2014. Over time, brook trout spread downstream and became a threat to the Lamar River. In addition, rainbow trout hybridization continued to be identified in cutthroat trout upstream of Ice Box Falls. It was determined that to entirely eliminate the threat of non-native fish, the falls would need modification to be a complete barrier to upstream passage and a rotenone treatment of the entire system upstream of the falls would be necessary (Montana Fish, Wildlife & Parks 2015).

Ice Box Falls was modified to ensure it would be a complete barrier to upstream fish movement in 2013. Before rotenone treatment, approximately 3,000 cutthroat trout were collected upstream of Ice Box Falls and held in waters to avoid chemical exposure during treatment of Soda Butte Creek and its tributaries. Nearly 450 brook trout were removed during the treatment in 2015. This represents a minimum number of fish killed, as there were some observed dead in pools too deep to retrieve and many likely went undetected. The 450 brook trout killed were more than three times the catch by annual week-long electrofishing removals. To ensure that all brook trout have been removed from Soda Butte Creek, a second rotenone treatment was conducted in 2016. Approximately 1,500 Yellowstone cutthroat trout were salvaged prior to treatment. Just two brook trout were removed during this salvage and treatment. Additionally, electrofishing surveys and water sampling for environmental-DNA (see "Environmental DNA," this issue) will be conducted for several years to ensure all non-native brook and rainbow trout have been removed from the system.

Elk Creek Complex—A natural cascade barrier is located in Elk Creek just upstream from its confluence with the Yellowstone River (figure 1). Because the cascade prevented fish from naturally populating the system, the Elk, Lost, and Yancey creeks complex of streams (Elk Creek Complex) was naturally fishless when first stocked with cutthroat trout in the early 1920s (Varley 1980). In 1942, the streams were stocked with brook trout, eventually resulting in the complete loss of cutthroat trout. Because of the close proximity of this stream system to the Lamar River/Yellowstone River confluence (figure 1), it was determined that brook trout should be removed. Because of the lack of any native fish in the system, the presence of a complex habitat, and the existing cascade barrier, it was decided a rotenone treatment was the best way to completely remove brook trout.

Selective removal of non-native and hybrid fish by electofishing and angling has reduced their abundance in northern Yellowstone.

The Elk Creek Complex was treated with rotenone annually from 2012 to 2014. Electrofishing surveys conducted following each treatment revealed low numbers of brook trout remained in the system until spring 2015. Electrofishing surveys conducted in 2015 did not detect any brook trout, and water samples collected in spring and autumn contained no fish DNA. Because of its close proximity, similarity of habitat, and ease of access from the road, Antelope Creek (figure 1) was selected to be the source of fish for stocking the Elk Creek Complex. Reintroduction of genetically pure Yellowstone cutthroat trout began in October 2015, with the transfer of approximately 450 fish of varied age classes. Additional stocking of cutthroat trout and eyed-eggs (embryos) using remote site incubators will take place in future years. Cutthroat trout monitoring will occur to track recovery.

Future Yellowstone Cutthroat Trout Conservation

Protection of genetically unaltered cutthroat trout will continue to be a top priority in Yellowstone. As the global climate shifts, high-elevation headwater stream reaches may become critically important cold water refugia for salmonids, including Yellowstone cutthroat trout (Isaak et al. 2015). Furthermore, the spread of hybridization may be exacerbated as flow and temperature conditions become more favorable for rainbow trout (Muhlfeld et al. 2014). Currently, brook trout and rainbow trout pose the most immediate threat to cutthroat trout in northern Yellowstone, and they must be suppressed to ensure the long-term persistence of the Yellowstone cutthroat trout subspecies in this region.

Projects to eliminate or control brook trout and rainbow trout are in varying stages of development and implementation in northern Yellowstone. Stream project priorities are determined using criteria in the Native Fish Conservation Plan (Koel et al. 2010). This plan calls for non-native fish to be removed or reduced in streams when they directly or indirectly impact native fish species and where control is possible. Streams where suppression or complete removal of non-native fish may occur in northern Yellowstone include, but are not limited to, the Lamar River, Slough Creek, Soda Butte Creek, Buffalo Fork, Blacktail Deer Creek, and Tower Creek.

Prior to any management actions taking place, preliminary research on a stream or stream network must be completed to identify the biological implications of management actions. Within the Lamar River watershed, a research project was initiated in 2015 to better understand the distribution, dynamics, and source of rainbow trout introgression. Genetic sampling is being used to map the current distribution of rainbow trout introgression. From this information, sources of rainbow trout and locations of genetically unaltered Yellowstone cutthroat trout will be identified. Radio telemetry and PIT tags are also being used to help identify differences in the behavior and movements of cutthroat, rainbow, and hybrid trout. The information collected in this study will help identify when and where hybridization is occurring, and will determine locations and time periods when rainbow trout and hybrids may be more susceptible to electrofishing, angling, and other suppression efforts. Collectively, the results of the study will help guide management actions in the Lamar River watershed in the most effective manner, based on the unique biology and dynamics in the system.

Buffalo Fork Creek, a tributary of Slough Creek (figures 1 and 2), is a large, remote watershed that was stocked with rainbow trout in the 1930s. Today, Buffalo Fork Creek is suspected of being a significant contributor of rainbow trout to lower Slough Creek and the Lamar River.

Similarly, Tower Creek, a tributary of the Yellowstone River, was historically stocked with brook, rainbow, and cutthroat trout. Now, brook and rainbow trout are considered a serious threat to the native cutthroat trout of the Yellowstone and Lamar river systems. Preliminary investigations are being conducted on Tower Creek and Buffalo Fork Creek to determine the feasibility of removing brook, rainbow, and hybrid trout from the systems. In the coming years, all waters in each watershed will be mapped, including mainstem creeks, tributaries, springs, seeps, lakes, ponds, and wet meadows. Potential barriers to fish migration will be identified. The upper extent of fish distribution and densities of fish will be determined by electrofishing surveys conducted throughout the watersheds. From this information, the feasibility of mechanical or chemical removals of non-native fish will be determined. While this work is occurring, potential source populations of native cutthroat trout for reintroductions will be identified and tested for genetic purity and lack of disease.

The northern portion of YNP offers a unique opportunity to preserve and restore native fish populations. As native fish populations in other areas become more fragmented by human activity, inundated by non-native species, and genetically compromised, pristine headwa-

ters and protected areas such as those found in Yellowstone will become increasingly important for the long-term persistence of native species. Unless management actions are taken, non-native fish will continue to exert pressure on native fish populations through competition, predation, and hybridization. By following the adaptive management protocols set forth in the Native Fish Conservation Plan, carefully researching each potential project, and carrying out projects when native fish are being impacted, we can preserve and expand on their current range. Through sound science and targeted actions, we can ensure the long-term persistence of our native fish species for generations to come.

Literature Cited

Campbell, M.R., C.C. Kozfkay, K.A. Meyer, M.S. Powell, and R.N. Williams. 2011. Historical influences of volcanism and glaciation in shaping mitochondrial DNA variation and distribution in Yellowstone cutthroat trout across its native range. Transactions of the American Fisheries Society 140:91-107.

Ertel, B.D. 2011. Distribution, movements, and life-history characteristics of Yellowstone cutthroat trout, *Oncorhynchys clarkii bouvieri*, in the upper Yellowstone River drainage. Thesis. Montana State University, Bozeman, Montana, USA.

Fausch K.D., and M.K. Young. 1995. Evolutionarily significant units and movement of resident stream fishes: a cautionary tale. American Fisheries Society Symposium 17:360-370.

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. Bioscience 52:483-498.

Gresswell, R.E., W.J. Liss, and G.L. Larson. 1994. Life-history organization of Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) in Yellowstone Lake. Canadian Journal of Fisheries and Aquatic Science 51:298-309.

High, B., D. Garren, G. Schoby, and J. Buelow. 2015. Fishery management investigations: Upper Snake River Region, 2013. Fishery management annual report IDFG 15-108. Idaho Fish and Game, Boise, Idaho, USA.

Isaak, D.J., M.K. Young, D.E. Nagel, D.L. Horan, and M.C. Groce. 2015. The cold-water climate shield: delineating refugia for preserving salmonid fishes through the 21st century. Global Change Biology 21:2540-2553.

Jones, R.D., D.G. Carty, R.E. Gresswell, C.J. Hudson, L.D. Lentsch, and D.L. Mahony. 1986. Fishery and aquatic management program technical report for calendar year 1985. U.S. Fish and Wildlife Service, Yellowstone National Park, Wyoming, USA.

Koel, T.M., J.L. Arnold, P.E. Bigelow, and M.E. Rhul. 2010. Native fish conservation plan. Environmental assessment, December 16, 2010. National Park Service, U.S. Department of the Interior, Yellowstone National Park, Wyoming, USA.

Montana Fish, Wildlife & Parks. 2004. Yellowstone cutthroat trout recovery project in Soda Butte Creek. Environmental assessment. Region 5, Billings, Montana, USA.

Montana Fish, Wildlife & Parks. 2015. Soda Butte Creek Yellowstone cutthroat trout conservation project. Environmental assessment. Region 5, Billings, Montana, USA.

Peterson, D.P., K.D. Fausch, and G.C. White. 2004. Population ecology of an invasion: effects of brook trout on native cutthroat trout. Ecological Applications 14:754-772.

Shepard, B.B. 2004. Factors that may be influencing nonnative brook trout invasion and their displacement of native west-slope cutthroat trout in three adjacent southwestern Montana streams. North American Journal of Fisheries Management 24:1088-1100.

Varley, J.D. 1980. A history of fish stocking activities in Yellowstone National Park between 1881 and 1980. Information paper 35. Department of the Interior, National Park Service, Yellowstone National Park, Wyoming, USA.

Woolnough, D.A., J.A. Downing, and T.J. Newton. 2009. Fish movement and habitat use depends on water body size and shape. Ecology of Freshwater Fish 18:83-91.

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Non-native Lake Trout Induce Cascading Changes in the Yellowstone Lake Ecosystem

Todd M. Koel, Jeffery L. Arnold, Lisa A. Baril, Kerry A. Gunther, Douglas W. Smith, John M. Syslo, & Lusha M. Tronstad

The mountainous region within and bordering southeastern Yellowstone National Park (YNP) is among the most remote in the contiguous United States. Lying completely within wilderness, the watershed of the upper Yellowstone River is pristine. Snowmelt waters feed numerous tributaries to the Yellowstone River, which ultimately winds northward to Yellowstone Lake. The Yellowstone River contributes one-third of the flow to Yellowstone Lake within a watershed that encompasses >2,600 square kilometers (>1,004 square miles) upstream of the Great Falls at Canyon. A majority of Yellowstone Lake shoreline is undeveloped, and the lake is covered with ice for approximately five months (January-May) each year. The lake is large (35,391 hectares [87,453 acres]), deep (43 meters [141 feet] average depth; Kaplinski 1991), and mesotrophic, which means it has a moderate amount of nutrients and is productive with clear, cold, oxygen-saturated water. Active geothermal features influence water temperature and chemistry in localized areas.

Following glacial recession from the region about 8,000-10,000 years ago, plant and animal species recolonized the Yellowstone Lake basin. On Two Ocean Pass, waters flowing to the Pacific and Atlantic oceans coalesce in a single stream that then splits, sending water in two different directions. Apparently, cutthroat trout

Yellowstone Lake, located at the heart of the Greater Yellowstone Ecosystem, is the largest lake above 7,000 ft. (2100 m) elevation in North America. NPS PHOTO - N. HERBERT

originating in the Snake River drainage to the south were able to naturally cross the Continental Divide in this area, and colonize Yellowstone Lake, and the river downstream (Behnke and Tomelleri 2002). Aside from the longnose dace, cutthroat trout were the only fish species evolving over several thousand years in Yellowstone Lake free of exposure to predatory fish. Park managers later stocked non-native fish species into Yellowstone Lake, including the redside shiner, lake chub, and longnose sucker. These species remain today as viable, reproducing populations.

Native Food Web of Yellowstone Lake

Cutthroat trout evolved as an important component of a food web within Yellowstone Lake, with several resident and migratory animal species relying on them as a source of energy during critical periods of the year (figure 1). Cutthroat trout of all ages are generally found in shallow waters of the lake (less than 20 meters [66 feet] below the surface) where, during open-water seasons, they are accessible by predatory raptors and colonial water birds. Each spring, when snowmelt run-off begins to decline, spawning cutthroat trout move extensively within the lake and river system, ascending 60 or more tributary streams to Yellowstone Lake, including the expansive upper Yellowstone River system. During spawning migrations, these large-bodied, mature, and energy-rich cutthroat trout become highly vulnerable to predation in shallow streams and are consumed by grizzly and black bears, river otters, white pelicans, and other species. Overall, 4 mammal and 16 bird species feed on cutthroat trout in Yellowstone Lake and its tributaries (see "Birds and Mammals that Consume Yellowstone Cutthroat Trout," this issue).

Within Yellowstone Lake, cutthroat trout feed on macroinvertebrates (e.g., amphipods, insect larvae) and zooplankton (e.g., copepods, cladocerans; Tronstad et al. 2010). The zooplankton feed on phytoplankton, which are the free-floating, photosynthesizing algae within the lake. The larger zooplankton species are highly efficient feeders on phytoplankton, and cutthroat trout are able to filter them from the water. When cutthroat trout are abundant, densities of larger zooplankton are reduced, allowing for a relative increase in the smaller-sized species, which are incapable of feeding on the larger size range of algal particles within the phytoplankton. This increased density of phytoplankton reduces lake water clarity.

Transport of Nutrients by Cutthroat Trout

Cutthroat trout accumulate substantial nutrients and energy in their bodies as they grow within Yellowstone Lake. During their spawning migrations, cutthroat trout physically transport these lake-derived nutrients long distances into the lake's tributaries (Tronstad et al. 2015). Cutthroat trout enter tributaries from May to early July and spend 1-3 weeks in the streams before returning to the lake. During spawning migrations, cutthroat trout transport nutrients and energy in their carcasses (if preyed upon), deposit gametes when they spawn, and excrete ammonium and other nutrients via normal body metabolism. Nutrients and energy transported by migratory, adult cutthroat trout enhance conditions for the growth of developing fry or juvenile fish. During the period cutthroat trout are abundant within spawning tributaries, they excrete ammonium orders of magnitude higher than the background levels of ammonium naturally exported by the watershed. These nutrients, delivered by spawning cutthroat trout, enhance primary productivity by plants and algae through photosynthesis, and secondary productivity of aquatic macroinvertebrates such as mayflies, caddisflies, and midges.

Introduction of Predatory Lake Trout

Nearly half of the waters in YNP were fishless when the park was established in 1872 because waterfalls prevented recolonization following deglaciation (Everman 1892). Early managers began seeking ways to populate these waters. In 1890, some of the first fish brought to Yellowstone were lake trout from Lake Michigan, which were stocked in Lewis and Shoshone lakes in the upper Snake River drainage (Varley 1980). Over time, the lake trout dispersed downstream, invading Heart and Jackson lakes and establishing sizable populations. Lake trout were present in Yellowstone for more than a century before they were found in Yellowstone Lake, where one was caught by an angler in 1994 (Kaeding et al. 1996). By analyzing the microchemistry of bone from several larger lake trout from Yellowstone Lake, scientists determined they had come from Lewis Lake, perhaps introduced illegally by someone (Munro et al. 2005).

The detection of lake trout in Yellowstone Lake prompted the National Park Service (NPS) to initiate gillnetting. Gillnetting effort and the biomass of lake trout removed increased annually, but was not sufficient to suppress the population (Koel et al. 2005). Estimated

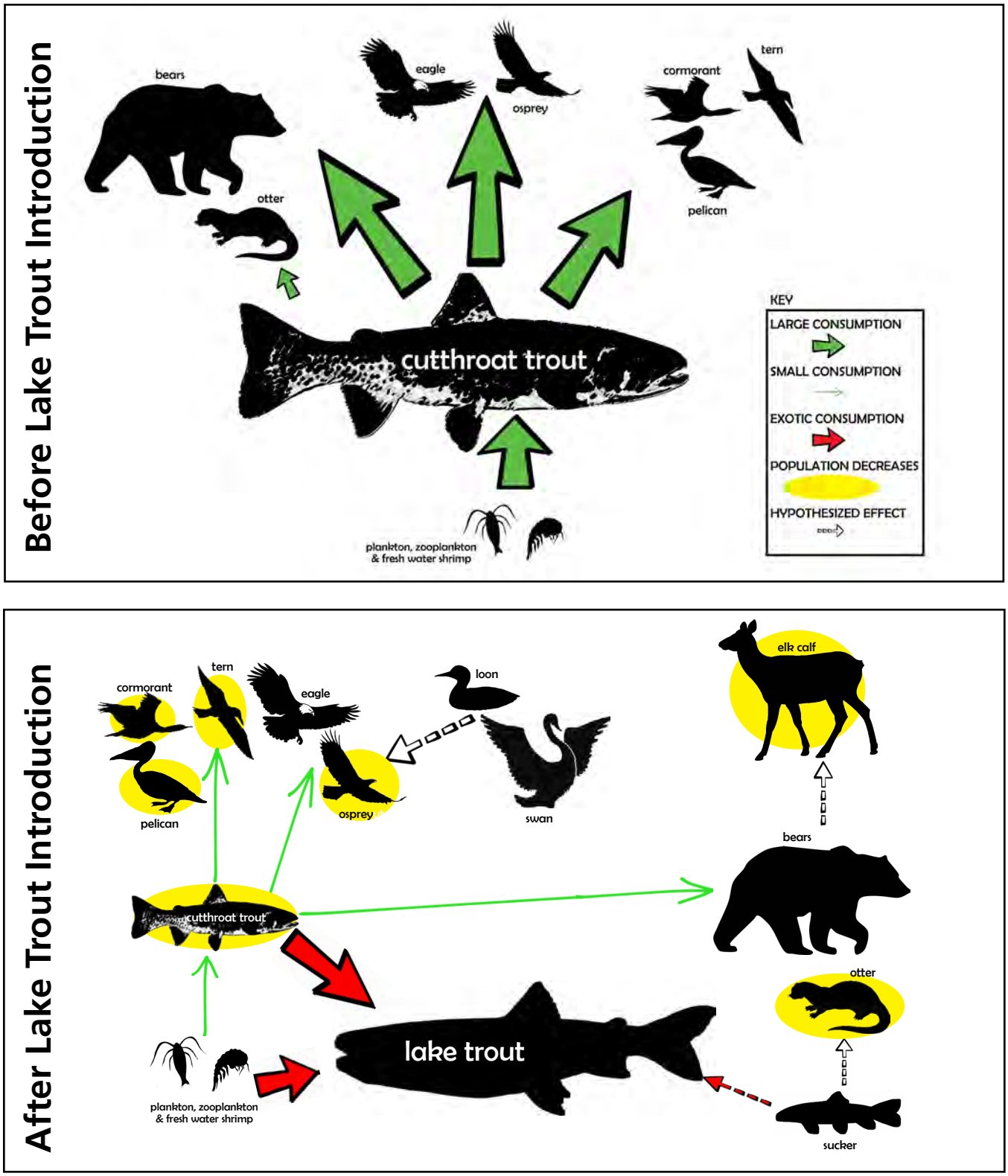


Figure 1. Trophic cascade in the food web of the Yellowstone Lake ecosystem, emphasizing those components known (solid arrows) or hypothesized (dashed arrows) to be affected by the introduction of non-native lake trout. Thick arrows indicate consumption of that food item is high by predator or herbivore; thin arrows indicate consumption is low, before and after expansion of lake trout. Consumption of phytoplankton, zooplankton, amphipods, cutthroat trout, longnose suckers, elk calves, common loon, trumpeter swan, American white pelican, double-crested cormorant, and Caspian tern is shown. Yellow shading indicates a decline in population. Red arrows indicate consumption by an exotic species, in this case, lake trout.

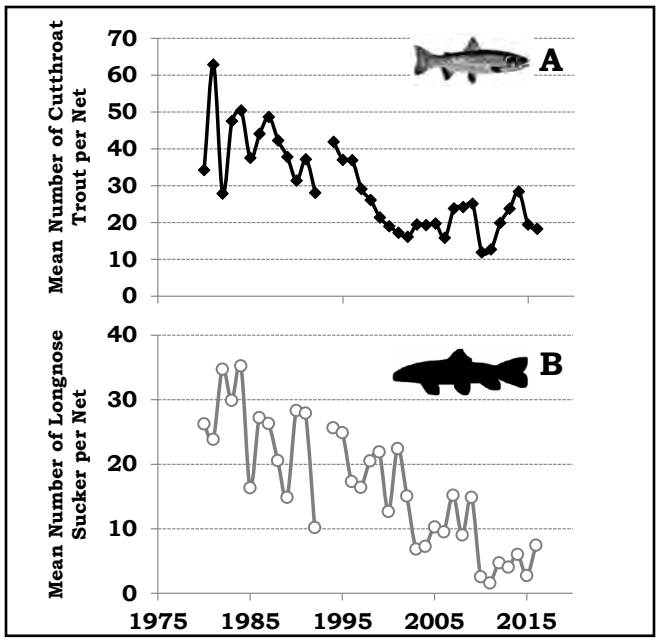


Figure 2. Long-term decline in the average number of cutthroat trout (A) and longnose sucker (B) caught per net during annual fish population assessment netting on Yellowstone Lake, 1980–2016. The within-lake assessment netting is an index of abundance of fish age 2 and older (approximately 100 mm [3.9 in.] and larger).

abundance of age-2 and older lake trout increased from 125,000 fish in 1998 (Ruzycki et al. 2003) to 790,000 fish in 2012, despite the removal of over 800,000 fish during this period (Syslo et al. 2011, Syslo 2015). The NPS suppression netting effort was then greatly increased, resulting in more than 1.5 million lake trout removed from 2012 to 2016. Lake trout abundance remained >700,000 fish in 2015.

Impacts of Lake Trout on Cutthroat Trout and Longnose Suckers

During the early stages of lake trout expansion, lake trout consumption of cutthroat trout was high. The estimated 125,000 lake trout present in 1998 likely consumed 3-4 million cutthroat trout that year (Ruzycki et al. 2003, Syslo et al. 2016). Subsequent lake trout population growth and expansion resulted in a precipitous, lake-wide decline in cutthroat trout (Koel et al. 2005; figure 2). In 1987, about the time lake trout were introduced, nearly 50 cutthroat trout were caught per unit of netting effort during annual monitoring on Yellowstone Lake (figure 2). Cutthroat trout of all lengths were well represented in the population, including a high proportion of juvenile fish. The catch of cutthroat trout declined to just 13 per effort unit in 2010. The size structure of the cutthroat trout population also changed, and the proportion of juvenile fish in the population was very low.

Concurrent with the decline in cutthroat trout was a steady, long-term decline in the introduced longnose sucker population within Yellowstone Lake (figure 2). Unclear, however, is the mechanism causing this decline. Longnose suckers occur, primarily, throughout the shallow-water, littoral zones of the lake, and spawn along the lake shore and in tributaries during the spring. Although analysis of diets conducted during the summer did not suggest significant predation upon suckers by lake trout in Yellowstone Lake (Ruzycki et al. 2003, Syslo et al. 2016), in Lake Tahoe suckers were the major food item of large lake trout sampled throughout the year (Franz and Cordone 1970). It is possible consumption of suckers by lake trout is higher during winter when water temperatures are extremely cold, allowing lake trout to exploit shallow water habitats where the suckers reside.

Cascading Impacts on Plankton, Macroinvertebrates, and Nitrogen Cycling

The introduction of lake trout added a fourth predatory trophic level and resulted in cascading interactions within the food web of Yellowstone Lake (Carpenter et al. 1985, Spencer et al. 1991, Ellis et al. 2010). Before the decline, cutthroat trout consumed mostly larger-bodied cladocerans (Syslo et al. 2016); and as a result, smaller-bodied copepods were more prevalent within the lake (Tronstad et al. 2010; figure 1). Cladocerans represented 80% of the cutthroat trout diet in 1989, but only 11% in 2011 (Syslo et al. 2016). After the population declined, the remaining cutthroat trout consumed mostly amphipods, which represented 8% of the cutthroat trout diet in 1989, increasing to 79% in 2011 (Wilmot et al. 2016). The result was a concurrent shift within the lake's zooplankton community from dominance by (smaller-bodied) copepods before lake trout introduction to dominance by (larger-bodied) cladocerans after lake trout introduction. Total zooplankton biomass and average length of zooplankton individuals increased after the invasion of lake trout (Tronstad et al. 2010).

These changes to the zooplankton community, in turn, affected the phytoplankton community. Chlorophyll a, a concentration which is an indicator of phytoplanton biomass, was twice as high in 1972 (Knight 1975) prior to lake trout introduction than it was in 2004 and 2005 (Tronstad et al. 2010). Also, the number of phytoplankton in a given volume of water was three times higher in

1972 and 1996, and 6.5 times higher in 1997, compared with 2004. Thus, lake trout introduction, cutthroat trout decline, and a shift in the zooplankton community to larger-bodied cladocerans caused a reduction in phytoplankton abundance. This lowered abundance resulted in an increase in overall water clarity throughout this period. Secchi depths, an indicator of water clarity, averaged 1.6 m (5.2 ft.) deeper in 2006 than in 1976, prior to lake trout introduction (Tronstad et al. 2010).

There were strong interactions among trophic levels within Yellowstone Lake as the effects of lake trout predation were transmitted down the food web. These impacts also extended into connected tributary streams. The lake trout-induced decline in cutthroat trout resulted in fewer spawning fish returning to tributary streams and, as a result, a significant reduction in the transport of nutrients (e.g., ammonium) from Yellowstone Lake into the tributaries (Tronstad et al. 2015). In fact, lake trout had a larger effect on nitrogen cycling within adjacent tributaries than within the lake itself because the spawning behavior of cutthroat trout concentrated them in tributaries, thus increasing the effect (Tronstad et al. 2015). This reduction in nutrients and energy flow to tributaries may have contributed to a decline in the overall productivity of those waters.

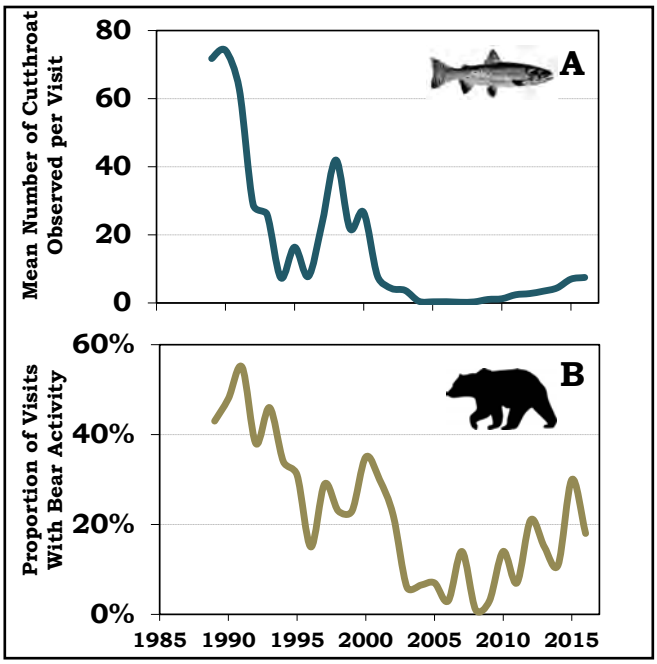


Figure 3. Mean number of spawning adult cutthroat trout observed (A) and proportion of visits where activity by black and grizzly bears was found (B) during weekly spawning visual surveys of 9-11 tributaries located along the western side of Yellowstone Lake between Lake and Grant, 1989-2016.

Cascading Impacts on Bears and Otters

The introduction and expansion of lake trout caused significant, cascading effects that extended to land-dwelling animals, such as grizzly and black bears because spawning cutthroat trout are an important, high energy food for them within the Yellowstone Lake basin (Mattson and Reinhart 1995, Gunther et al. 2014; figure 1). The densities of cutthroat trout were high in the tributaries during spring, making them attractive to fishing by bears (Reinhart and Mattson 1990). During 1985-1987, bear activity occurred on 93% of the lake's spawning tributaries, with evidence of fish consumption on 61% of the tributaries (Reinhart and Mattson 1990). Evidence of bear activity on spawning streams was noted 50 times on 11 frontcountry streams in 1991 when spawning cutthroat trout were abundant (Reinhart 1990, Koel et al. 2005; figure 3). However, concurrent with the cutthroat trout decline through the 1990s, evidence of bear activity also declined. No bear activity was found on any of these spawning streams in 2008, 2009, or 2011 (figure 3).

In the late-1990s and after cutthroat trout had declined considerably, an estimated 14-21% of grizzly bears in the Greater Yellowstone Ecosystem (GYE) were feeding on spawning cutthroat trout in Yellowstone Lake tributaries (Haroldson et al. 2005). When compared to estimates obtained in 1997-2000, the number of grizzly bears visiting spawning streams a decade later (2007-2009) decreased by 63%, and the number of black bears decreased 64-84% (Teisberg et al. 2013). Fortin et al. (2013) estimated the biomass of cutthroat trout consumed by grizzly and black bears declined 70% and 90%, respectively, in the years between 1997-2000 and 2007-2009. The low densities of the remaining trout were no longer efficiently fed upon by grizzly or black bears.

Overall, the estimated number of spawning cutthroat trout consumed by grizzly bears annually declined from 20,910 in the late 1980s (Stapp and Hayward 2002) to 2,266 in the late 1990s (Felicetti et al. 2004) to only 302 in the late 2000s (Fortin et al. 2013). However, grizzly and black bears are opportunistic feeders with a flexible diet (Gunther et al. 2014); consequently, they made use of other foods available in the Yellowstone Lake area when cutthroat trout abundance was low (Fortin et al. 2013). Recently, evidence suggests bears are beginning to return to spawning streams to prey upon cutthroat

trout. Visual surveys from 2012 to 2016 documented a slight increase in spawning cutthroat trout and bears returning to feed upon them. Evidence of bears was found during 30% of visits to the frontcountry tributaries surveyed in 2015 (figure 3).

River otters are another common semi-aquatic predator that is heavily dependent upon cutthroat trout. Although otters move freely and frequently throughout Yellowstone Lake and connected streams (Crait et al. 2015), they are relatively restricted in their abilities to travel long distances over land and across drainage divides. Thus, they are thought to be vulnerable to impacts of the cutthroat trout decline. Otters followed the movements of spawning cutthroat trout and were active on spawning streams during 2002-2003. Cutthroat trout occurred in 72% of otter scat collected at 87 otter latrine sites during this period (Crait and Ben-David 2006). The otters transported lake-derived nutrients to terrestrial latrine sites, and the nutrients influenced the prevalence and growth of plants in localized areas around Yellowstone Lake (Crait and Ben-David 2007).

Temporal changes in otter latrine activity occurred in response to declines in spawning cutthroat trout. By 2006-2008, otter activity at latrine sites decreased; and the prevalence of cutthroat trout in otter scat declined to 53% (Crait et al. 2015). Otters supplemented their diet with alternative prey, including non-native longnose suckers and amphibians, which are not likely comparable replacement foods. Estimates of otter abundance do not exist prior to the 2000s and before cutthroat trout began to decline; however, the estimate of 1 otter per 13.4 kilometers of shoreline along Yellowstone Lake in 2008 (Crait et al. 2015) will be used as a baseline to document changes following the recovery of cutthroat trout.

Cascading Impacts on Eagles, Ospreys, and Colonial Shorebirds

Yellowstone Lake supports an abundant diversity of bird life (Smith et al. 2015), including numerous fish-eating birds such as bald eagles and ospreys (McEneaney 2002). During the 1960s and 1970s, a period when pesticides impacted bald eagles, there were typically 4-6 eagle nests on Yellowstone Lake (McEneaney 2002). The number of nests increased to 16 from 1987 to 2003, but then declined to 12 nests by 2007 (figure 4). There was a steady, long-term decline in eagle nest productivity over two decades (1987-2007), concurrent with the lake-wide decline in cutthroat trout. In the 1980s, 60%-80%

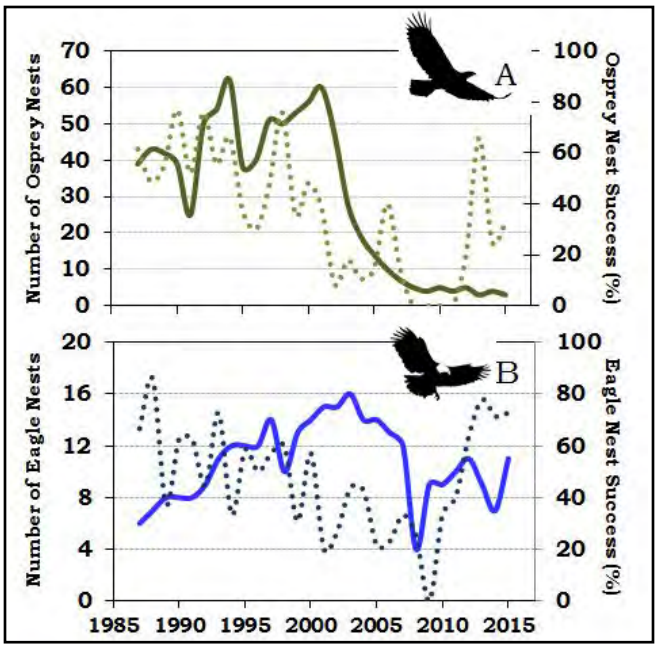


Figure 4. Number of nests (solid line) and nest success (dashed) during May-August for ospreys (A) and during April-June for bald eagles (B) within approximately 1 km (.6 mi.) of the Yellowstone Lake shoreline, connected tributaries, and forested islands, 1987-2015.

of eagle nests on Yellowstone Lake successfully fledged young (figure 4); however, nest success declined to zero in 2009 when cutthroat trout abundance was low. Bald eagles are opportunistic feeders, and they increased consumption of alternative prey and scavenged carcasses for food. As a result, the number of bald eagle nests increased and nesting success increased to 64%-76% during 2013-2015 (Smith et al. 2015; figure 4).

Yellowstone Lake once had the highest densities of nesting ospreys in YNP, but the number of osprey nests and nest productivity has dramatically changed. The number of nests declined from 60 in 2001 to 3-5 during 2008-2015 (figure 4), likely due to the decline in small cutthroat trout less than 280 mm (11 in.) in length, the preferred-size prey of ospreys (McEneaney 2002, Baril et al. 2013). Nesting success prior to 1994 was typically 49%-77%, but it declined to zero during 2008-2011 when no young ospreys were fledged from Yellowstone Lake nests (Baril et al. 2013). Only 1-2 nests have successfully fledged young in recent years (figure 4). Although a few osprey nests remain on Yellowstone Lake, these ospreys are not observed foraging for cutthroat trout. In 2010, despite more than 60 hours of active nest monitoring, no ospreys were observed foraging or attempting to forage at Yellowstone Lake (Soyland 2010). Ospreys are obligate fish eaters that do not switch to other alternative food sources in the absence of fish. The ospreys

have been leaving the Yellowstone Lake area to forage in nearby waters where prey fish are more abundant, likely at Heart, Lewis, and Shoshone lakes (Soyland 2010).

The number of pelicans, cormorants, gulls, and terns fledged from the Molly Islands' colonies has been highly variable, but has declined overall since the 1990s (McEneaney 2002, Smith et al. 2015). Although the loss of cutthroat trout is thought to be a factor impacting the colonial birds, nesting success of these species is also strongly influenced by environmental factors, including air temperature, duration of ice cover, and lake surface levels (Diem and Pugesek 1994). During years with high lake water levels, for example, nests of colonial birds on the Molly Islands have flooded resulting in complete, or near complete, reproductive failures (Diem and Pugesek 1994, McEneaney 2002). In 2014, a year with a relatively early ice melt and lower than average lake surface levels, 307 pelican nests were observed on the Molly Islands, producing 276 young (Smith et al. 2015). A total of 56 nesting cormorants were also observed, which fledged an estimated 25 young. In the same year, none of the observed 18 gull nests produced any young.

Long-term declining trends in colonial birds suggest a factor other than weather and lake levels is impacting them on Yellowstone Lake. For example, although as many as 28 tern nesting pairs produced 28 young on the Molly Islands in 1990, only 3 nesting pairs produced 3 young in 2001 (McEneaney 2002); and no terns have nested on the Molly Islands since 2005 (Smith et al. 2015).

Hypothesized Links to Elk, Loons, & Swans

The lake trout-induced decline in cutthroat trout directly affected and displaced several avian and terrestrial consumers, but indirect effects on alternative prey are less understood. Following the cutthroat trout decline within spawning tributaries, grizzly and black bears fed less upon them and shifted their diet to other foods in the lake area, including elk calves (Fortin et al. 2013; figure 1). Each spring, thousands of elk that winter on lands at lower elevations in the GYE migrate to the interior of YNP. Elk calves born in the Yellowstone Lake area are vulnerable to predation, especially during the first few weeks after birth. From 2007 to 2009, elk accounted for 84% of all ungulates consumed by bears (Fortin et al. 2013), suggesting lake trout had an indirect impact on migratory elk (Middleton et al. 2013). Even though there is strong evidence bears were consuming fewer cutthroat trout, it is unknown whether individual bears increased predation on elk calves specifically due to the cutthroat trout decline.

As cutthroat trout declined and gradually became less available, bald eagles increasingly consumed alternative foods, including scavenging of elk, bison, and other carcasses when available. Bald eagles have also been observed more frequently in recent years preying on sensitive waterfowl, including common loons and trumpeter swans (Smith et al. 2015). The south arms of Yellowstone Lake and nearby Riddle Lake are among the highest quality and highest producing loon nesting habitats in Wyoming. However, common loon nesting pairs have declined by 50% since 1990 in YNP (Evers et al. 2013). Trumpeter swans are also a sensitive species that has experienced a decline. In recent years, only two breeding pairs and 6-10 non-breeding swans spend the summer in the park. Reasons for the declines in common loons and trumpeter swans are unclear, but may include the reduced availability of cutthroat trout as a food source for loons and increased predation on loon chicks and trumpeter swan cygnets due to consumption by bald eagles in the Yellowstone Lake area.

Yellowstone Lake Restoration Potential

Yellowstone Lake and connecting streams and rivers lie within the heart of YNP and, as such, are among the most pristine waters remaining on Earth. The watershed of Yellowstone Lake remains largely unaltered by humans; as a result, the entire assemblage of native plant and animal species remains. Contributing to the decline of cutthroat trout in the late 1990s and 2000s was the introduction of the exotic parasite *Myxobolus cerebralis*, which caused whirling disease in cutthroat trout in localized areas of the ecosystem, including Pelican Creek and the Yellowstone River downstream of Yellowstone Lake through Hayden Valley (Koel et al. 2006, Alexander et al. 2011, Murcia et al. 2014). Drought, which occurred over several years in the early 2000s, resulted in low lake levels and the loss of surface water connections with many tributary streams, potentially limiting the ability of cutthroat trout fry emigration to Yellowstone Lake prior to winter (Koel et al. 2005). Although *M. cerebralis* has been present for nearly two decades and fish-eating birds have the ability to move the parasite throughout the ecosystem (Koel et al. 2010), whirling disease has not spread or widely influenced recruitment of cutthroat trout across Yellowstone Lake (Koel et al. 2015).

The primary deleterious factor influencing the ecology of Yellowstone Lake is the presence of lake trout. There are no other well-established, introduced species or altered watersheds. Thus, it is reasonable to assume that if lake trout are suppressed and predation pressure on cutthroat trout is reduced, thereby allowing the cutthroat population to rebound, the trophic cascade we have described in this article can be largely reversed. Already, cutthroat trout have shown signs of recovery. Concurrent with a massive surge in lake trout suppression during 2012-2016, the cutthroat trout population has increased in abundance and is once again comprised of a large proportion of juvenile fish (Koel et al. 2015). Spawning adult cutthroat trout are slowly returning to several of the smaller tributaries, and bear use of these streams has increased as a result. The status of the plankton communities will be reassessed in 2017, as they would be additional, leading indicators of ecosystem change. Although lake trout abundance throughout Yellowstone Lake remains high, it's apparent that suppression is having a positive effect. The potential for restoration of Yellowstone Lake is extremely high if lake trout suppression is maintained.

Conclusion

Because of the migratory behavior of cutthroat trout, impacts of lake trout on the ecology of the Yellowstone Lake ecosystem extend far beyond the shoreline and smaller tributaries and into the extremely remote, largely unmonitored reaches of the upper Yellowstone River drainage in the Bridger-Teton Wilderness of Wyoming (Ertel 2011). Anecdotal evidence from anglers and outfitters in this region suggest large-scale declines in spawning cutthroat trout occurred during the 1990s and 2000s. However, due to remoteness and inaccessibility during much of the spring and summer spawning period, no quantitative information exists on impacts to cutthroat trout consumer species throughout this region. Because cutthroat trout are the only fish in this large drainage and most of the adults return to Yellowstone Lake immediately after spawning (Ertel 2011), it is likely that bears, otters, eagles, ospreys, and other species have been widely displaced throughout the upper Yellowstone River drainage.

Herein we have documented impacts to multiple aquatic and terrestrial trophic levels across a large, complex ecosystem, free from any confounding effects of land use or other anthropogenic disturbance. Because there are no other large interconnecting lakes within this ecosystem, the lake trout have and will remain confined to Yellowstone Lake, where suppression activities are focused. However, because technologies do not exist to completely extirpate lake trout, cutthroat trout may not be able to fully recover within Yellowstone Lake and tributary spawning streams. We predict the operations to suppress lake trout will reduce their abundance, thereby allowing cutthroat trout recovery to a level where they regain their ecological importance, and again underpin and support the natural processes and biodiversity for which Yellowstone National Park is widely recognized.

Literature Cited

Alexander, J.D., B.L. Kerans, T.M. Koel, and C. Rasmussen. 2011. Context-specific parasitism in *Tubifex tubifex* in geothermally influenced stream reaches in Yellowstone National Park. Journal of the North American Benthological Society 30:853-867.

Baril, L.M., D.W. Smith, T. Drummer, and T.M. Koel. 2013. Implications of cutthroat trout declines for breeding ospreys and bald eagles at Yellowstone Lake. Journal of Raptor Research 47:234-245.

Behnke, R.J., and J.R. Tomelleri. 2002. Trout and salmon of North America. Free Press, New York, New York, USA.

Carpenter, S.R., J.F. Kitchell, and J.R. Hodgson. 1985. Cascading trophic interactions and lake productivity. Bioscience 35:634-639.

Crait, J.R., and M. Ben-David. 2006. River otters in Yellowstone Lake depend on a declining cutthroat trout population. Journal of Mammalogy 87:485-494.

Crait, J.R., and M. Ben-David. 2007. Effects of river otter activity on terrestrial plants in trophically altered Yellowstone Lake. Ecology 88:1040-1052.

Crait, J.R., E.V. Regehr, and M. Ben-David. 2015. Indirect effects of bioinvasions in Yellowstone Lake: response of river otters to declines in native cutthroat trout. Biological Conservation 191:596-605.

Diem, K.L., and B.H. Pugesek. 1994. American white pelicans at the Molly Islands, in Yellowstone National Park: twenty-two years of boom and bust breeding, 1966-1987. Colonial Waterbirds 17:130-145.

Ellis, B.K., J.A. Stanford, D. Goodman, C.P. Stafford, D.L. Gustafson, D.A. Beauchamp, D.W. Chess, J.A. Craft, M.A. Deleray, and B.S. Hansen. 2010. Long-term effects of a trophic cascade in a large lake ecosystem. Proceedings of the National Academy of Sciences 108:1070-1075.

Ertel, B.D. 2011. Distribution, movements, and life-history characteristics of Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri* in the upper Yellowstone River drainage. Thesis. Montana State University, Bozeman, Montana, USA.

Everman, B.W. 1892. Report on the establishment of fish culture stations in the Rocky Mountain region and Gulf States. U.S. Government Printing Office, Washington, D.C., USA.

Evers, D.C., V. Spagnuolo, and K. Taylor. 2013. Restore the call: Wyoming status report for the common loon. Science Communications Series BRI 2013-21. Biodiversity Research Institute, Gorham, Maine, USA.

Felicetti, L.A., C.C. Schwartz, R.O. Rye, K.A. Gunther, J.G. Crock, M.A. Haroldson, L. Waits, and C.T. Robbins. 2004. Use of naturally occurring mercury to determine the importance of cutthroat trout to Yellowstone grizzly bears. Canadian Journal of Zoology 82:493-501.

Fortin, J.K., C.C. Schwartz, K.A. Gunther, J.E. Teisberg, M.A. Haroldson, M.A. Evans, and C.T. Robbins. 2013. Dietary adjustability of grizzly bears and American black bears in Yellowstone National Park. Journal of Wildlife Management 77:270-281.

Frantz, T.C., and A.J. Cordone. 1970. Food of lake trout in Lake Tahoe. California Fish and Game 56:21-35.

Gunther, K.A., R.R. Shoemaker, K.L. Frey, M.A. Haroldson, S.L. Cain, F.T. van Manen, and J.K. Fortin. 2014. Dietary breadth of grizzly bears in the Greater Yellowstone Ecosystem. Ursus 25:60-72.

Haroldson, M.A., K.A. Gunther, D.P. Reinhart, S.R. Prodruzny, C. Cegelski, L. Waits, T. Wyman, and J. Smith. 2005. Changing numbers of spawning cutthroat trout in tributary streams of Yellowstone Lake and estimates of grizzly bears visiting streams from DNA. Ursus 16:167-180.

Kaeding, L.R., G.D. Boltz, and D.G. Carty. 1996. Lake trout discovery in Yellowstone Lake threaten native cutthroat trout. Fisheries 21:16-20.

Kaplinski, M. A. 1991. Geomorphology and geology of Yellowstone Lake, Yellowstone National Park, Wyoming. Thesis. Northern Arizona University, Flagstaff, Arizona, USA.

Knight, J.C. 1975. The limnology of the West Thumb of Yellowstone Lake, Yellowstone National Park, Wyoming. Thesis. Montana State University, Bozeman, Montana, USA.

Koel, T.M., P. Bigelow, P.D. Doepke, B.D. Ertel, and D.L. Mahony. 2005. Nonnative lake trout result in Yellowstone cutthroat trout decline and impacts to bears and anglers. Fisheries 30:10-19.

Koel, T.M., D.L. Mahony, K.L. Kinnan, C. Rasmussen, C.J. Hudson, S. Murcia, and B.L. Kerans. 2006. *Myxobolus cerebralis* in native cutthroat trout of the Yellowstone Lake ecosystem. Journal of Aquatic Animal Health 18:157-175.

Koel, T.M., B.L. Kerans, S.C. Barras, K.C. Hanson, and J.S. Wood. 2010. Avian piscivores as vectors for *Myxobolus cerebralis* in the Greater Yellowstone Ecosystem. Transactions of the American Fisheries Society 139:976-988.

Koel, T.M., J.L. Arnold, P.E. Bigelow, C.R. Detjens, P.D. Doepke, B.D. Ertel, and M.E. Ruhl. 2015. Native fish conservation program, Yellowstone Fisheries & Aquatic Sciences 2012-2014, Yellowstone National Park. YCR-2015-01. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, USA.

Mattson, D.J., and D.P. Reinhart. 1995. Influences of cutthroat trout (*Oncorhynchus clarki*) on behavior and reproduction of Yellowstone grizzly bears (*Ursus arctos*), 1975-1989. Canadian Journal of Zoology 73:2072-2079.

McEneaney, T. 2002. Piscivorous birds of Yellowstone Lake: their history, ecology, and status. Pages 121-134 in R.J. Anderson and D. Harmon, editors. Yellowstone Lake: hotbed of chaos or reservoir of resilience? Proceedings of the 6th Biennial Scientific Conference on the Greater Yellowstone Ecosystem. Yellowstone Center for Resources, Yellowstone National Park, Wyoming, USA.

Middleton, A.D., T.A. Morrison, J.K. Fortin, C.T. Robbins, K.M. Proffitt, P.J. White, D.E. McWhirter, T.M. Koel, D.G. Brimeyer, W.S. Fairbanks, and M.J. Kauffman. 2013. Grizzly bear predation links the loss of native trout to the demography of migratory elk in Yellowstone. Proceedings of the Royal Society B 280:1-8.

Munro, A.R., T.E. McMahon, and J.R. Ruzycki. 2005. Natural chemical markers identify source and date of introduction of an exotic species: lake trout (*Salvelinus namaycush*) in Yellowstone Lake. Canadian Journal of Fisheries and Aquatic Sciences 62:79-87.

Murcia, S., B.L. Kerans, T.M. Koel, and E. MacConnell. 2014. *Myxobolus cerebralis* (Hofer) infection risk in native cutthroat trout *Oncorhynchus clarkii* (Richardson) and its relationships to tributary environments in the Yellowstone Lake basin. Journal of Fish Diseases 38:637-652.

Reinhart, D.P. 1990. Grizzly bear use of cutthroat trout spawning streams in tributaries of Yellowstone Lake. Thesis. Montana State University, Bozeman, Montana, USA.

Reinhart, D.P., and D.J. Mattson. 1990. Bear use of cutthroat trout spawning streams in Yellowstone National Park. Pages 343-350 in L.M. Darling and W.R. Archibald, editors. Bears—their biology and management: Proceedings of the Eighth International Conference on Bear Research and Management. International Association for Bear Research and Management, Madison, Wisconsin, USA.

Ruzycki, J.R., D.A. Beauchamp, and D.L. Yule. 2003. Effects of introduced lake trout on native cutthroat trout in Yellowstone Lake. Ecological Applications 13:23-37.

Smith, D.W., L. Baril, L. Strait, D. Haines, B. Cassidy, and K. Duffy. 2015. Yellowstone bird program 2014 annual report. YCR-2015-03. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, USA.

Soyland, A. 2010. Effects of the introduced lake trout (*Salvelinus namaycush*) on the osprey (*Pandion haliaetus*) population in Yellowstone National Park. Thesis. Institute of Nature Management, Norwegian University of Life Science, Sørhellinga, Norway.

Spencer, C.N., B.R. McClelland, and J.A. Stanford. 1991. Shrimp stocking, salmon collapse, and eagle displacement. Bioscience 41:14-21.

Stapp, P., and G.D. Hayward. 2002. Effects of an introduced piscivore on native trout: insights from a demographic model. Biological Invasions 4:299-316.

Syslo, J.M., C.S. Guy, P.E. Bigelow, P.D. Doepke, B.D. Ertel, and T.M. Koel. 2011. Response of non-native lake trout (*Salvelinus namaycush*) to 15 years of harvest in Yellowstone Lake, Yellowstone National Park. Canadian Journal of Fisheries and Aquatic Sciences 68:2132-2145.

Syslo, J.M. 2015. Dynamics of Yellowstone cutthroat trout and lake trout in the Yellowstone Lake ecosystem: a case study for the ecology and management of non-native fishes. Dissertation. Department of Ecology, Montana State University, Bozeman, Montana, USA.

Syslo, J.M., C.S. Guy, and T.M. Koel. 2016. Feeding ecology of native and nonnative salmonids during the expansion of a nonnative apex predator in Yellowstone Lake, Yellowstone National Park. Transactions of the American Fisheries Society 145:476-492.

Teisberg, J.E., M.A. Haroldson, C.C. Schwartz, K.A. Gunther, J.K. Fortin, and C.T. Robbins. 2013. Contrasting past and current number of bears visiting Yellowstone cutthroat trout streams. Journal of Wildlife Management 78:369-378.

Tronstad, L.M., R.O. Hall, T.M. Koel, and K.G. Gerow. 2010. Introduced lake trout produced a four-level trophic cascade in Yellowstone Lake. Transactions of the American Fisheries Society 139:1536-1550.

Tronstad, L.M., R.O. Hall, and T.M. Koel. 2015. Introduced lake trout alter nitrogen cycling beyond Yellowstone Lake. Ecosphere 6:1-24.

Varley, J.D. 1980. A history of fish stocking activities in Yellowstone National Park between 1881 and 1980. Information paper 35. U.S. Department of the Interior, National Park Service, Yellowstone National Park, Wyoming, USA.

Wilmot, O., L. Tronstad, R.O. Hall, T. Koel, and J. Arnold. 2016. Lake trout-induced spatial variation in the benthic invertebrates of Yellowstone Lake. Park Science 32:25-35.

Todd Koel (see page 11)

Yellowstone Lake Working Group Established to Enhance Native Fish Conservation

Dave Sweet, Wyoming Trout Unlimited

Native coldwater species, such as Yellowstone cutthroat trout, westslope cutthroat trout, fluvial Arctic grayling, and mountain whitefish, are especially important to the natural ecology and human enjoyment of the Greater Yellowstone Ecosystem (GYE). In the early 2000s, these native coldwater species faced multiple threats; the most significant were from introduced non-native aquatic species, including lake trout, brook trout, rainbow trout, and the exotic parasite that causes whirling disease. Of particular concern was the rapid decline of Yellowstone cutthroat trout in Yellowstone Lake and the upper Yellowstone River system due to introduced lake trout. Yellowstone National Park (YNP) managers recognized these threats and implemented a plan of action to address them as described in the Native Fish Conservation Plan (Koel et al. 2010). A missing link, however, was a process to better incorporate anglers, conservation groups, and the general public with on-the-ground actions to conserve native fish as described in the plan.

In late 2011 and early 2012, a consortium of conservation groups met with YNP officials with the intent of becoming a partner in addressing the threats to the Yellowstone Lake fishery and the lake ecosystem. From that meeting and subsequent discussions, a Memorandum of Understanding (MOU) was developed that formalized a cooperative relationship among participants to ensure the GYE is protected, maintained, and managed to achieve established goals. The groups which were signatures to the MOU are Trout Unlimited National, Wyoming Council, Montana Council, and Idaho Council; National Parks Conservation Association; Greater Yellowstone Coalition; Yellowstone Park Foundation; and Yellowstone National Park.

Some of the goals of the MOU and its partners include:

- Maintain a cooperative relationship focusing on conservation in the GYE and ensuring communication is timely and regular.
- Secure and improve populations of native fish through implementation of the Native Fish Conservation Plan and ensure objectives of the plan are achieved.
- Ensure fundraising to implement the Native Fish Conservation Plan is sufficient, coordinated, and not in competition with collaborators. Seek funding for research and innovative measures to improve management and conservation.
- Maintain the primary priority for the MOU as the declining Yellowstone cutthroat trout in Yellowstone Lake and those efforts are informed through periodic consultation with an independent scientific panel.
- Use the best available science to guide management decisions.
- Ensure the public and policymakers are informed about fisheries management and native fish restoration.
- Ensure the recreational and economic value of YNP and the GYE fisheries are preserved.
- Seek additional cooperators and supporters to enhance the goals of native fish conservation.

Since the establishment of the MOU, the partners have taken on the title of "Yellowstone Lake Working Group" and have accomplished a great deal. The group typically meets twice a year to review past results and plan for the following year's activities. The Yellowstone Lake Working Group acts as a sounding board to review lake trout suppression activities, population monitoring activities and trends, telemetry research results, new suppression technologies, and other fisheries-related science. They also initiate positive public outreach and education, and have authored publications directed at the general public and potential funders, including a publication with answers to frequently asked questions about the science supporting management of Yellowstone Lake (Trout

Unlimited 2014). The group responds to public concerns about fish conservation actions when applicable.

The Yellowstone Lake Working Group is actively involved in fundraising and has raised over one million dollars to directly support Yellowstone cutthroat trout restoration in Yellowstone Lake. The majority of the funds are spent on telemetry studies on the seasonal movement patterns of lake trout and the location of lake trout spawning areas; on studies assessing the reproductive potential, cycles, and timing of lake trout spawning; and on studies which identify and optimize alternative suppression technologies aimed at lake trout ova and fry. The Yellowstone Lake Working Group contracts with U.S. Geological Survey scientists and fisheries professionals at multiple universities to complete the research. In addition, partners of the Yellowstone Lake Working Group provide volunteer labor to support the work on Yellowstone Lake.

Over the past five years, the Yellowstone Lake Working Group has proven to be an incredibly valuable partnership. Working together, the team has made significant advancements towards restoration and the long-term preservation of native cutthroat trout and the natural ecology of Yellowstone Lake.

Literature Cited

Koel, T.M., J.L. Arnold, P.E. Bigelow, and M.E. Ruhl. 2010. Native fish conservation plan. Environmental assessment, December 16, 2010. National Park Service, U.S. Department of the Interior, Yellowstone National Park, Wyoming, USA.

Trout Unlimited. 2014. Science supporting management of Yellowstone Lake fisheries: responses to frequently asked questions. Trout Unlimited, Lander, Wyoming, USA. http://wyomingtu.org/wp-content/uploads/2014/03/Science-Supporting-Management-of-Yellowstone-Lake-Fisheries.pdf

Dave Sweet is a trained chemist who happens to love fly fishing and our native trout species. Here in the west that means cutthroat trout. In particular, he has been working on the restoration of Yellowstone cutthroat trout in Yellowstone Lake for the past 8 years. These fish and the ecosystem that they support have been devastated by invasive lake trout, their numbers reduced to 5-10% of historic levels. Dave is an avid member of Trout Unlimited, serving currently as Wyoming Trout Unlimited Treasurer and Yellowstone Lake Special Project Manager. The work on Yellowstone Lake has earned Dave TU's Distinguished Service Award, Field and Stream magazine's 2013 Hero of Conservation Award, and induction into Wyoming's Outdoor Hall of Fame in 2014. He lives in Cody, Wyoming, with his wife Cathy and has two daughters, Cindy and Diana and one grandson, Spencer. He is currently retired.

Strong partnerships among agencies, universities, non-governmental organizations, private sector businesses, and the public have resulted in the completion of several large-scale restoration projects. Crews from the National Park Service; Montana Fish, Wildlife, & Parks; U.S. Fish and Wildlife Service; Turner Enterprises; and the Custer-Gallatin National Forest are shown here in a backcountry camp at Grayling Creek in Yellowstone National Park.

Suppressing Non-native Lake Trout to Restore Native Cutthroat Trout in Yellowstone Lake

Patricia E. Bigelow, Philip D. Doepke, Brian D. Ertel, Christopher S. Guy, John M. Syslo, & Todd M. Koel

Lake trout are extremely efficient predators, even when their preferred prey are scarce. These lake trout were caught in Yellowstone Lake during 2007 when cutthroat trout numbers were low. The 21 lake trout caught in this overnight set had remains of at least 47 cutthroat trout in their stomachs. NPS PHOTO - S. SIGLER

The suppression of lake trout via netting has been ongoing in Yellowstone Lake since 1994 when this non-native species was first discovered. Twenty-two years later, we continue to catch large numbers of lake trout. So, why should lake trout suppression be maintained, what's the science behind it, and what's the prognosis for the future? This article provides information about why lake trout are detrimental in Yellow-

stone Lake, reviews past suppression efforts, describes where the program is now, and reflects on the future of lake trout suppression and Yellowstone cutthroat trout recovery.

Background

Yellowstone Lake is home to the largest population of Yellowstone cutthroat trout in existence. This population plays a critical role in the ecosystem, transporting nutrients from lake waters to tributary streams during spawning and to the terrestrial (land) system when the fish are eaten by birds and mammals (see "Birds and Mammals that Consume Yellowstone Cutthroat Trout," this issue; Crait and Ben-David 2006). Also, cutthroat trout have a predominant influence on the structure of the lake community, including zooplankton and phytoplankton (see "Non-native Lake Trout Induce Cascading Changes in the Yellowstone Lake Ecosystem," this issue; Tronstad et al. 2010). They have provided a world-renown angling opportunity for more than a century, drawing anglers from around the globe and contributing $36 million annually to local economies (Varley and Schullery 1995).

Lake trout, however, are voracious, efficient predators that frequently live 20-25 years and are able to reach large sizes—the Wyoming state record for a lake trout is approximately 23 kg (50 lb.; Martinez et al. 2009). Their large size enables them to produce thousands of eggs annually, which leads to rapid population growth and an expanding distribution. Lake trout can consume cutthroat trout up to one-third their own size. Although lake trout need energy-rich prey such as cutthroat trout to continue to grow, they can persist for years with minimal food resources due to their cold-blooded nature. For example, in a reservoir in Colorado, tagged lake trout persisted for over 10 years after the loss of kokanee salmon, their preferred prey, though most of these fish had not grown since release (Martinez et al. 2009).

These traits make it possible for lake trout to have drastic impacts on ecosystems outside their native range. Given their long lives, ability to eat large prey, efficient predatory skills, and ability to persist on a variety of foods, lake trout not only deplete native species, but also persist at levels that keep native populations suppressed. Thus, when a 43 cm (17 in.) lake trout was caught in Yellowstone Lake in 1994, fishery professionals and park managers realized they had a serious problem. Non-native lake trout could decimate the native cutthroat trout population and then, due to their cold-blooded nature, persist at high numbers on other foods preventing their preferred prey (cutthroat trout) from recovering. Lake trout readily consume foods cutthroat trout historically subsisted on in Yellowstone Lake. In addition to killing cutthroat trout, lake trout could reduce the cutthroat trout's food base, thereby making cutthroat trout recovery impossible until the lake trout population is suppressed.

Initial Efforts to Suppress Lake Trout

After confirming lake trout were successfully reproducing in Yellowstone Lake (Varley and Schullery 1995, Kaeding et al. 1996), the National Park Service (NPS) convened a panel of expert scientists to determine the likely extent of the problem, recommend actions, and identify research needs. The panel concluded the suppression of lake trout was necessary to protect and restore native cutthroat trout, but would require a long-term, possibly perpetual, commitment. The panel also indicated direct removal efforts, such as gillnetting or trap netting, would likely be most effective (McIntyre 1995). As a result, research on lake trout movements, spawning, diet, and abundance was initiated (Ruzycki et al. 2003). Early removal efforts were expanded in 2001 using a Great Lakes-style gillnetting boat, miles of gillnets, and personnel specifically hired to gillnet lake trout through summer (June through mid-October). These efforts increased the amount of gillnet fishing for lake trout more than 10-fold. In response, the number of lake trout removed from the population doubled, and incidental catch of native cutthroat trout was greatly reduced by fishing deeper waters not typically used by cutthroat trout (Bigelow et al. 2003).

Over time, fishery biologists learned more about the best ways to detect and target lake trout. In spite of this, increased gillnetting effort continued to result in increased catch, suggesting the lake trout population was continuing to grow (figure 1). Thus, Yellowstone National Park (YNP) managers decided an in-depth review and reevaluation of the direction of the program was needed. In 2008, 15 experts were convened to evaluate the suppression program and recommend future actions. Although the lake trout population had continued to expand (Syslo et al. 2011), the panel concluded netting remained the most viable option for suppressing the population. Yet, they also indicated a considerable increase in suppression effort would be needed over many years to collapse the lake trout population (Gresswell 2009). In addition to maintaining the

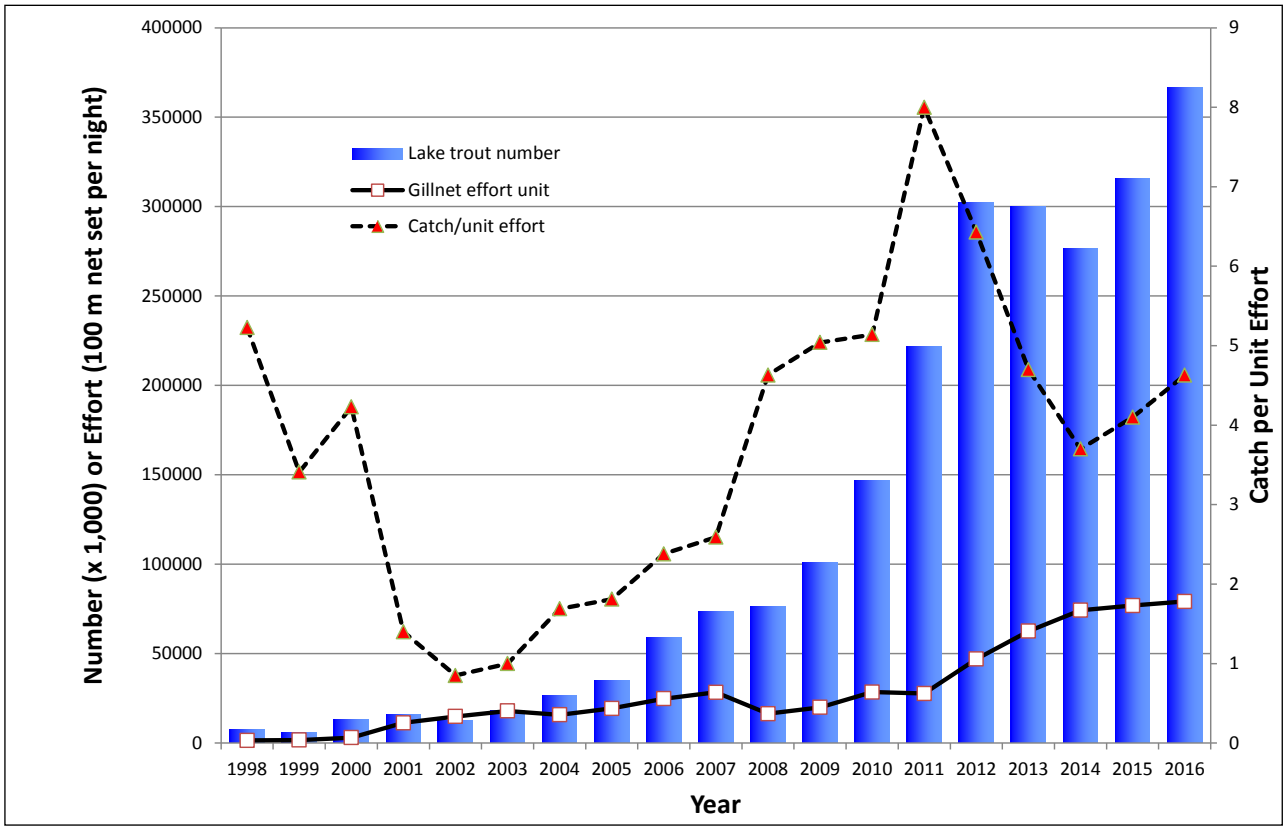


Figure 1. Numbers of non-native lake trout removed from Yellowstone Lake,1998-2016, along with gillnetting effort and catch per unit of effort. To-date, more than 2.3 million lake trout have been removed to restore the native cutthroat trout of Yellowstone Lake.

number of NPS staff dedicated to the program, the panel recommended contracting commercial fishermen to substantially increase effort and efficiency (Gresswell 2009). If commercial fishing could collapse lake trout populations in many of the Great Lakes, it could work in Yellowstone Lake.

Filling the Data Gaps

Following this intensive review, YNP expanded monitoring, launched a pilot program to determine if commercial fisherman could increase catch of lake trout, and initiated more in-depth research to estimate lake trout abundance and predict the level of suppression needed to collapse the population. A goal was set to reduce the abundance of lake trout to mid-1990s levels, when it's likely relatively few lake trout impacted the native cutthroat trout population (Koel et al. 2010). However, a major uncertainty was the amount of netting pressure needed to induce such a substantial decrease in lake trout abundance. Population modeling and analyses of lake trout removals were used to address this question and to assess the suppression program's success. Three important metrics were assessed for lake trout: total annual mortality in the population, abundance, and population growth rate.

A catch-at-age analysis based on the age structure of the total catch of lake trout removed by the suppression program, and the effort used to do so each year, was conducted to estimate lake trout mortality and abundance. Randomly selected sites dispersed throughout the lake were sampled via gillnetting to obtain an independent estimate of mortality conducted separately from suppression netting efforts (see "Cutthroat Trout Response to Suppression of Lake Trout," this issue). In addition, a model based on mortality and several other population descriptors (e.g., length at age, survival and fecundity of females at each age, probability of maturity, survival of young until large enough to be captured in the nets) was developed to estimate the change in population growth rate associated with changes in total netting effort (Syslo et al. 2011). This model also estimates the amount of netting effort needed to achieve a population decrease. In combination, the analyses and modeling results provide rigorous estimates of how successful the program has been at decreasing lake trout in Yellowstone Lake.

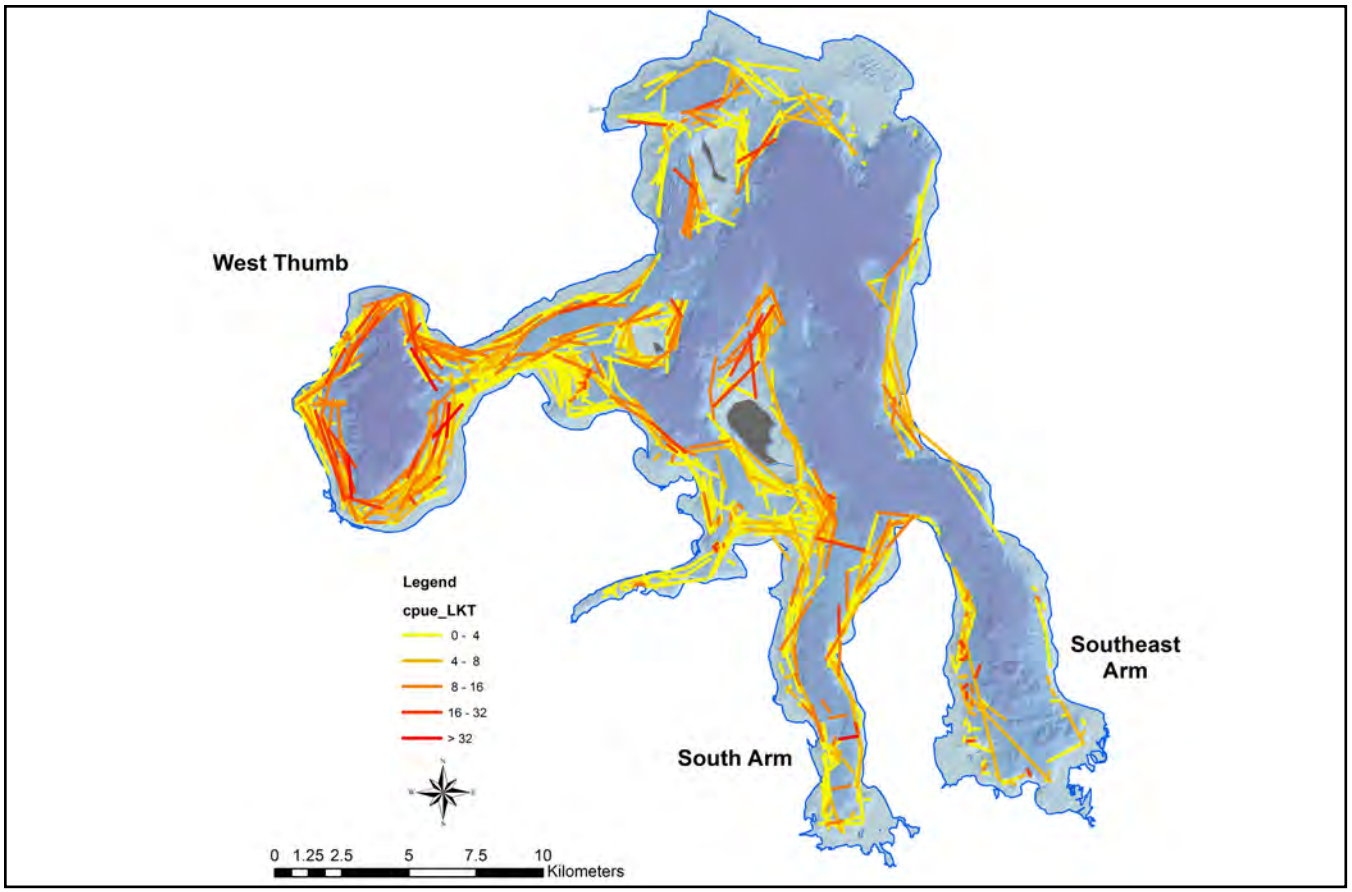


Figure 2. Increased gillnet suppression has allowed better coverage throughout Yellowstone Lake, as well as increases in "hot spot" areas, such as South Arm and West Thumb. Each line approximates one gillnet set; the darker the color, the more lake trout caught per night fished. The abbreviation cpue_LKT indicates catch-per-unit-effort for lake trout.

The *Patriot* is a large, tug-style fishing boat designed to handle large numbers of gillnets per day.

Increased Efforts to Suppress Lake Trout

Multiple scientific reviews stressed that substantial suppression of lake trout was necessary for the cutthroat trout population to recover. In 2012, removal efforts were increased dramatically in order to drive the lake trout population growth rate from one that had been increasing for over a decade to one that is decreasing (Syslo et al. 2011, Gresswell et al. 2012). Hickey Brothers Research, LLC, a company with roots in commercial fishing on Lake Michigan, was tasked with the bulk of the suppression work, operating three full-time boats designed specifically for gillnetting. Crews work six days per week from late May into early October, with each crew setting and retrieving 60 nets per day. Letting each net soak, or catch fish, for 3-4 nights allows each crew to handle 180 nets twice a week.

Thus, the amount of gillnet in the water on a typical mid-season day increased from almost 23 km (14 mi.) in 2007 to just over 61 km (38 mi.) in 2015. Total gillnetting effort increased from an average of 20,500 units (100 m of net set over one night constitutes one unit of

effort) from 2001 to 2011 to an average of 65,200 units from 2012 to 2015. In 2016, gillnet suppression effort increased to 79,000 units; netting was expanded into the South and Southeast arms of the lake, areas that previously received relatively little effort (figure 2). Plans are to continue netting effort during 2017 and beyond. The latest population modeling suggests at least 55,000 units of netting effort is needed each year to suppress the lake trout population; we intend to expend approximately 80,000 units.

In 2013, we conducted a mark-recapture study to validate population estimates and obtain an independent estimate of the annual exploitation rate (the percentage of the population, or given age/size class, removed) in a given year. A large number of lake trout (2,400) were captured, marked with numbered tags (monofilament inserted between the bones of the dorsal fin with a T-bar similar to clothing tags), and released. Tagged fish later caught in suppression nets or via angling were documented and used to estimate the number of lake trout present in the lake; the derived estimate was 367,650 fish greater than 210 mm (8.3 in.) long. The mark-recapture study also enabled an estimate of the probability of capture for four size classes. In 2013, 69% of tagged fish were recaptured by netting or anglers. Estimated exploitation rates were 72% for lake trout 210-451 mm (8.3-17.8 in.) in length, 56% for fish 451-541 mm (17.8-21.3 in.) long, 48% for fish 541-610 mm (21.3-24.0 in.) long, and 45% for fish more than 610 mm (more than 24.0 in.) long (Gresswell et al. 2015). These results supported previous estimates and highlight the difficultly in catching older, larger lake trout which eat the most cutthroat trout. Older, larger lake trout also have the highest reproductive success.

Lake Trout Response to Increased Suppression Efforts

In 2016, we experienced our highest lake trout suppression effort, along with the highest number of lake trout removed, to-date (figure 1). Catch per unit effort remained relatively low, indicating crews had to work harder and smarter to catch the same number of fish. Increases in catch and catch per unit effort can reflect increased efficiency, increased abundance, or both. Improvements in fishing gear, increased knowledge of how lake trout use the ecosystem, and experienced personnel can lead to increases in catch and catch per effort despite a decreasing population. Hence, independently monitoring the effectiveness and results of suppression activities, as well as updating population models, is an important aspect of the program.

Models have shown the lake trout population continued to expand through at least 2011, but increased netting since then has begun to reduce lake trout numbers and biomass (total weight) in Yellowstone Lake. Abundance estimates for lake trout age 2 and older indicate a cessation of population growth and a decrease in fish older than 2 years (figure 3). As this continues, the reproductive and expansion potential of the population will be reduced, greatly aiding overall suppression. Also, total annual mortality rates have been steadily increasing over the last several years and have exceeded 50% in two of the last three years, which should decrease the population size. In addition, the total biomass of lake trout removed has been well above what is considered a sustainable harvest (0.5kg per ha) for the last several years.

Future Outlook

The magnitude of the lake trout problem in Yellowstone Lake remains enormous. Lake trout have had several decades to expand throughout the lake and pioneer several spawning areas. Yellowstone Lake provides near-perfect spawning and rearing habitat for lake trout with few natural predators present. Lake trout are long-lived, and one individual female can produce thousands of eggs each year. The survival of young lake trout in the lake is estimated to be 2.5 times higher than in its native range (Syslo 2015). Even without cutthroat trout, other foods in Yellowstone Lake would support a large lake trout population. Reducing the lake trout population to a level that will have only minor impacts to the cutthroat trout population is predicted to take until at least 2025, provided we maintain current high levels of suppression effort. Given the high reproductive potential of this lake trout population, we will regress immediately and likely dramatically if we reduce the amount of suppression effort applied without adequate alternative techniques (see "Lake Trout Suppression Alternatives to Gillnetting," this issue).

Compared to other lakes invaded by lake trout in the West, Yellowstone Lake has a relatively simple fish assemblage. Only two species, cutthroat trout and lake trout, occupy the vast majority of the habitat; however, they segregate into different depths or water temperatures of the lake most of the time. Thus, the solution is deceptively simple: decimate the lake trout population while not adversely impacting Yellowstone cutthroat

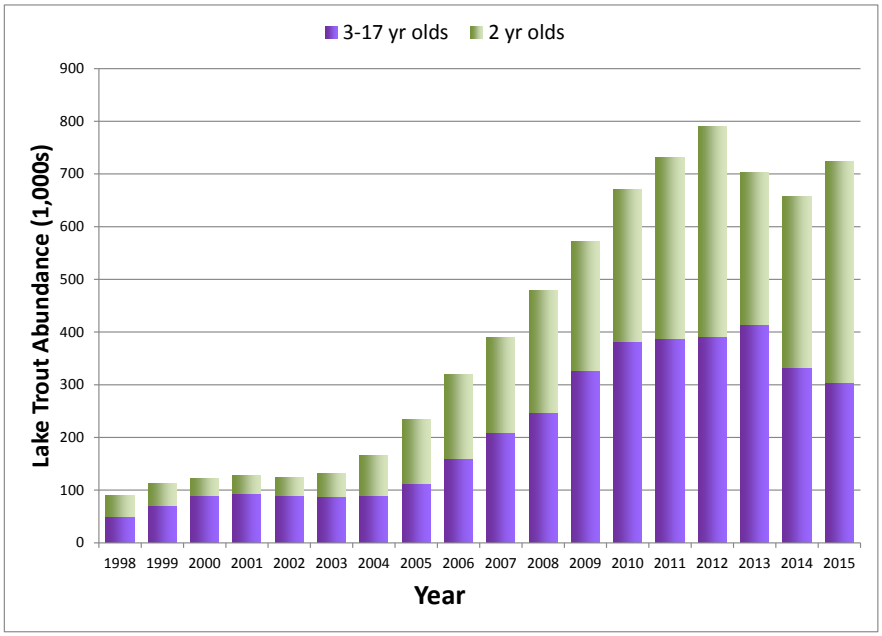


Figure 3. Abundance estimates for 2-year-old and 3-7-year-old lake trout in Yellowstone Lake, 1998-2016.

trout. Reviews of the program over multiple years by multiple fishery scientists, along with in-depth population modeling, continue to emphasize this resource issue can be solved given sufficient suppression effort. In fact, recent monitoring suggests both the abundance of older lake trout and the biomass of lake trout removed has been decreasing since 2012. With planned increases in suppression netting for 2017 coupled with emerging technology for killing lake trout eggs and embryos, a population crash is expected to happen sooner than population models suggest. However, until new methods can be verified, netting suppression of lake trout in Yellowstone Lake must continue and is widely supported by anglers, fishery experts, and park managers. Thus, suppression efforts will continue in an attempt to restore a robust native Yellowstone cutthroat trout population in Yellowstone Lake.

Literature Cited

Bigelow, P.E., T.M. Koel, D. Mahony, B. Ertel, B. Rowdon, and S.T. Olliff. 2003. Protection of native Yellowstone cutthroat trout in Yellowstone Lake, Wyoming. Technical Report NPS/NFWRD/NRTR-2003/314. Yellowstone National Park, Wyoming, USA.

Crait, J.R., and M. Ben-David. 2006. River otters in Yellowstone Lake depend on a declining cutthroat trout population. Journal of Mammalogy 87:485-494.

Gresswell, R.E. 2009. Scientific review panel evaluation of the National Park Service lake trout suppression program in Yellowstone Lake, August 25-29. Final report. YCR-2009-05. U.S. Geological Survey, Northern Rocky Mountain Science Center, Bozeman, Montana, USA.

Gresswell, R.E., P. Budy, C.S. Guy, M.J. Hansen, M.L. Jones, P.J. Martinez, C. Suski, and J.E. Williams. 2012. Confronting a lake trout invasion of Yellowstone Lake: an interim scientific assessment, June 14-16, 2011. A report to the superintendent of Yellowstone National Park. YCR-2012-04. U.S. Geological Survey, Northern Rocky Mountain Science Center, Bozeman, Montana, USA.

Gresswell, R.E., C.S. Guy, M.J. Hansen, M.L. Jones, J.E. Marsden, P.J. Martinez, and J.M. Syslo. 2015. Lake trout suppression in Yellowstone Lake: science review panel. Interim scientific assessment, 2014 performance year. A report to the superintendent. YCR-2015-04. National Park Service, Yellowstone National Park, Wyoming, USA.

Kaeding, L.R, G.D. Boltz, and D.G. Carty. 1996. Lake trout discovered in Yellowstone Lake threaten native cutthroat trout. Fisheries 21:16-20.

Koel, T.M., J.A. Arnold, P.E. Bigelow, and M.E. Ruhl. 2010. Native lake trout conservation plan. Environmental assessment, December 16, 2010. National Park Service, Yellowstone National Park, Wyoming, USA.

Martinez, P.J, P.E. Bigelow, M.A. Deleray, W.A. Fredenberg, B.S. Hansen, N.J. Horner, S.K. Lehr, R.W. Schneidervin, S.A. Tolentino, and A.E. Viola. 2009. Western lake trout woes. Fisheries 34:424-442.

McIntyre, J.D. 1995. Review and assessment of possibilities for protecting the cutthroat trout of Yellowstone Lake from introduced lake trout. Pages 28-36 *in* J.D. Varley and P. Schullery, editors. The Yellowstone Lake crisis: confronting a lake trout invasion. A report to the director of the National Park Service. Yellowstone National Park, Mammoth, Wyoming, USA.

Ruzycki, J.R., D.A. Beauchamp, and D.L. Yule. 2003. Effects of introduced lake trout on native cutthroat trout in Yellowstone Lake. Ecological Applications 13:23-37.

Syslo, J.M., C.S. Guy, P.E. Bigelow, P.D. Doepke, B.D. Ertel, and T.M. Koel. 2011. Response of non-native lake trout (*Salvelinus namaycush*) to 15 years of harvest in Yellowstone Lake, Yellowstone National Park. Canadian Journal of Fisheries and Aquatic Science 68:2132-2145.

Syslo, J.M. 2015. Dynamics of Yellowstone cutthroat trout and lake trout in the Yellowstone Lake ecosystem: a case study for the ecology and management of non-native fishes. Dissertation. Montana State University, Bozeman, Montana, USA.

Tronstad, L.M, R.O. Hall, Jr., T.M. Koel, and K.G. Gerow. 2010. Introduced lake trout produced a four-level trophic cascade in Yellowstone Lake. Transactions of the American Fisheries Society 139:1536-1550.

Varley, J.D., and P. Schullery. 1995. Socioeconomic values associated with the Yellowstone Lake cutthroat trout. Pages 22-27 *in* J.D. Varley and P. Schullery, editors. The Yellowstone Lake crisis: confronting a lake trout invasion. A report to the director of the National Park Service. Yellowstone National Park, Wyoming, USA.

Patricia Bigelow has worked in fisheries for over 34 years, 20 of those in Yellowstone National Park. She currently focuses on suppression of the non-native lake trout in Yellowstone Lake in defense of the Yellowstone cutthroat trout. She obtained her PhD from University of Wyoming, modeling potential lake trout spawning habitat in the lake.

NPS PHOTO - N. HERBERT

Fish Population Responses to the Suppression of Non-native Lake Trout

Jeffrey L. Arnold, Phil D. Doepke, Brian D. Ertel, & Todd M. Koel

Unprecedented actions are being taken on Yellowstone Lake to suppress lake trout, recover native cutthroat trout, and restore the natural character of the ecosystem. To understand the outcomes of these actions, long-term monitoring of the fish populations is conducted to inform an adaptive management strategy. Multiple lines of evidence are used to assess status and trends. For example, progress towards cutthroat trout recovery on Yellowstone Lake is measured annually by means of lake-wide assessments using gillnets, visual counts of spawning fish in tributary streams, and angler catch success. Each of these assessments is made annually to evaluate progress towards desired conditions for cutthroat trout. In this article, we describe the status and trends of native cutthroat trout and non-native lake trout following two decades of suppression on Yellowstone Lake.

Lake-Wide Cutthroat Trout Population Assessment

Within Yellowstone Lake, cutthroat trout population abundance and length structure are assessed by standardized gillnetting (Koel et al. 2005, Syslo et al. 2014). During the August distribution netting program, 24 sites are sampled within four regions of Yellowstone Lake, including the West Thumb, the main basin surrounding Dot and Frank islands, the northern shore and Stevenson Island, and the east shore and two southern arms (figure 1). At each sampling site, nets are set in shallow water near shore, at mid-depth (8-20 m [26-66 ft.]), and at more than 40 m (131 ft.) deep.

Over the past five years, the distribution netting program has detected an influx of juvenile cutthroat trout in Yellowstone Lake. In 2010 and 2011, few cutthroat trout were caught; the majority of them were large fish between 470-570 mm (18.5-22.4 in.), suggesting an aging population with low recruitment of young fish (figure 2). However in 2012, concurrent with a substantial increase in lake trout suppression netting, the number of cutthroat trout caught by distribution netting more than doubled and then steadily increased. Catch then declined slightly in 2015 and 2016 (figure 3). The overall increase in catch from 2012 to 2014 was primarily due to an influx of young, juvenile cutthroat trout entering the system, a good indication the population is beginning to recover. This increase was observed lake-wide in each of the four regions sampled (figure 4). Similarly, the slight decrease in cutthroat trout that occurred in 2015 and 2016 was also observed lake-wide. Of the four lake regions sampled, cutthroat trout were most abundant along the east shoreline and within the two southern arms. The lowest numbers of cutthroat trout were caught in the West Thumb area, where lake trout abundance has always been high (figure 4). Factors contributing to the increased number of young fish in the lake likely include the greatly increased effort to suppress lake trout, as well as improved winter snow conditions and stream runoff in recent years. Although the total number of cutthroat trout caught in 2015 and 2016 was not a continuation of the upward trend we had been experiencing, it remains encouraging to see a large number of young cutthroat trout entering the population.

Lake-Wide Lake Trout Population Assessment

The number of lake trout caught during distribution netting remained relatively constant from 2010 to 2016, ranging from 331-575 fish annually, with a mean total length ranging from 309-330 mm (12-13 in.; figure 5). Over the past five years, we have seen a gradual decrease in the number of large lake trout measuring over 470 mm (18.5 in.), with most lake trout caught being 220-420 mm (8.6-16.5 in.) in length and sexually immature (figure 5). Catch per unit effort for lake trout varied each year, but remained relatively consistent with no indication of a change in abundance (figure 3). In general, catches of lake trout were highest in the West Thumb region and along the east shoreline/southern arms por-

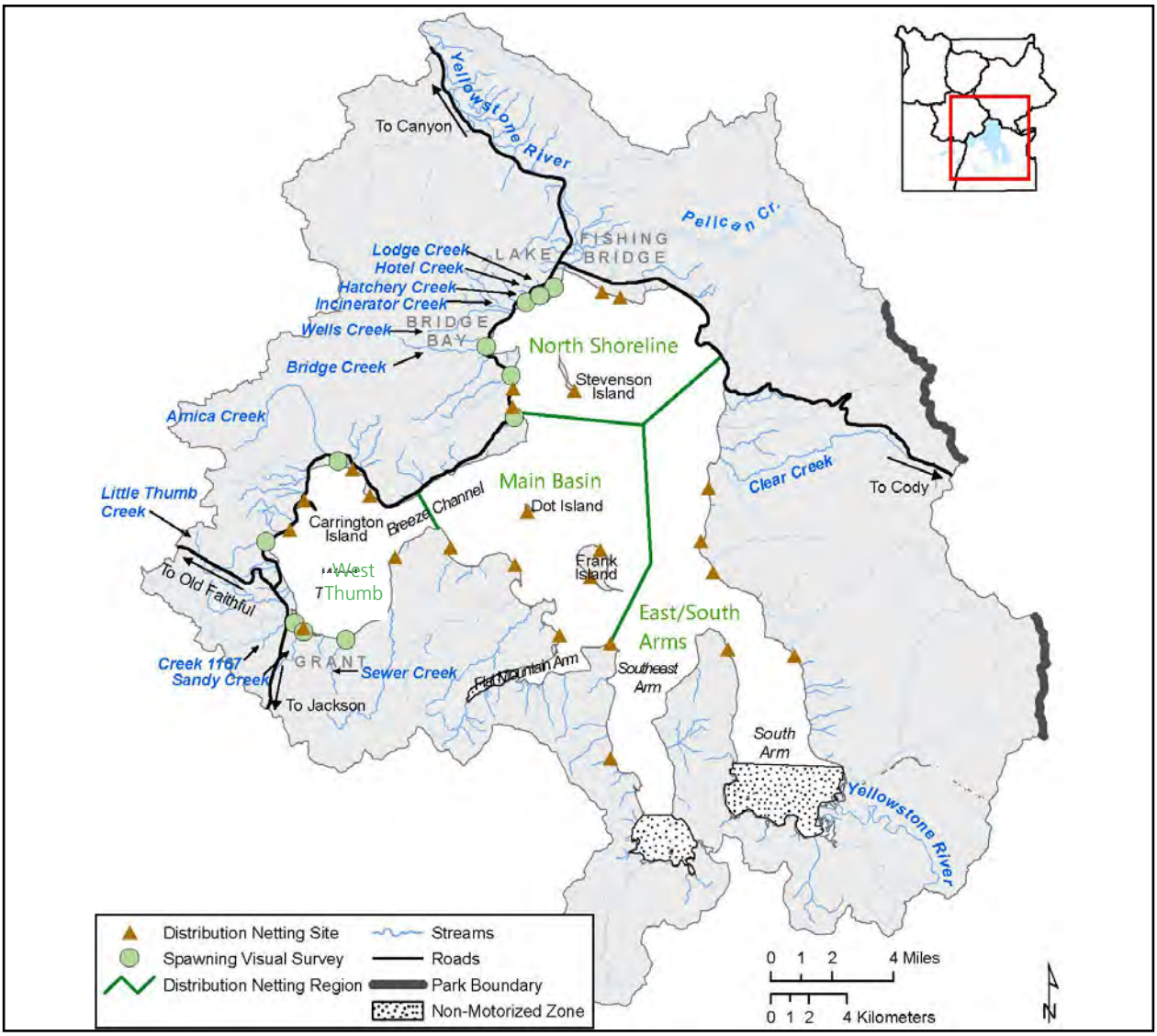


Figure 1. Location of streams visually surveyed for spawning cutthroat trout and distribution netting sample sites within four regions of Yellowstone Lake.

tion of Yellowstone Lake, while the lake region with the lowest catch of lake trout was generally along the north shore (figure 4).

Cutthroat Trout Tributary Spawner Assessment

Visual surveys for cutthroat trout have been conducted annually since 1989 on 9-11 tributaries located along the western side of Yellowstone Lake between Lake and Grant (Reinhart 1990; figure 1). Spawning reaches were initially delineated on each tributary, and the standardized reaches are walked in an upstream direction once each week from May through July. These surveys indicated a significant decrease in spawning-age cutthroat trout in Yellowstone Lake over the past two decades (figure 6). In the late 1980s, more than 70 cutthroat trout were typically observed during a single visit to one of the streams, compared to only 1 or 2 cutthroat trout in recent years (figure 6b). One exception is Little Thumb Creek, a tributary in the West Thumb near Grant, where more than 50 cutthroat trout were seen during a single visit in 2013, and more than 100 were seen during visits in 2014 and 2015. In 2016, the number of fish observed in Little Thumb Creek increased to 295 fish, which is appoximately 80% of the total fish counted. Although the increased number of fish observed in this stream is encouraging, counts remain far below the desired conditions of at least 40-60 spawning cutthroat trout observed per visit on average at all of the visually-assessed spawning tributaries.

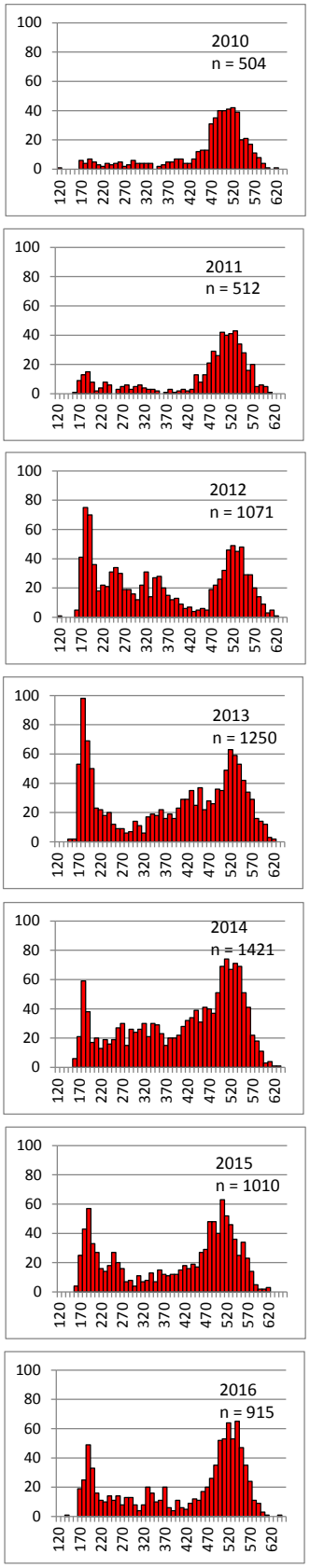


Figure 2. Length-frequency of cutthroat trout collected during distribution netting on Yellowstone Lake with total number of trout (n), 2010-2016.

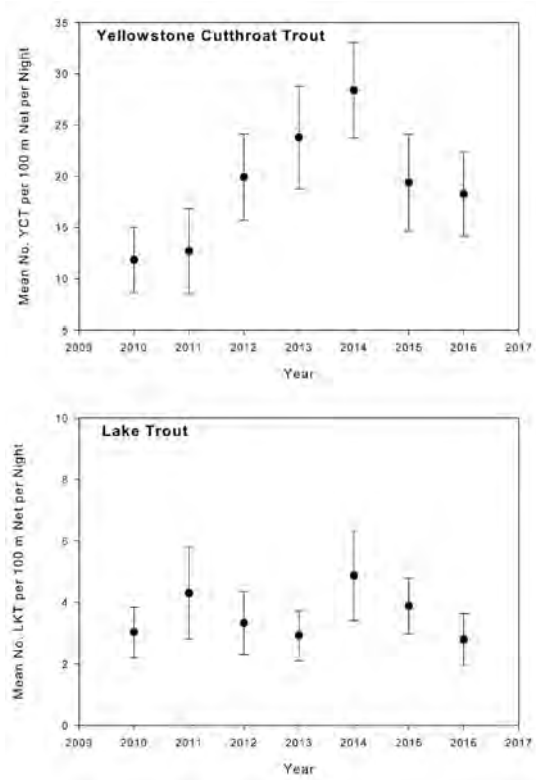


Figure 3. Mean number of cutthroat trout (above) and lake trout (below) caught per 100 meters net per night during distribution netting on Yellowstone Lake, 2010-2016. Bars delineate 95% confidence intervals. The lowest mean catch of cutthroat trout was 11.8 in 2010. The mean number of cutthroat trout steadily increased to 28.4 in 2014, then declined to 18.3 in 2016. The mean lake trout caught per net varied from 2.8 in 2016 to 4.9 in 2014, but was not significantly different among years.

Cutthroat Trout and Lake Trout Caught by Anglers

Since 1979, angler effort and success have been assessed via a report card distributed to all anglers when purchasing a special use permit for fishing (Jones et al. 1980). Information on the waters fished, time spent fishing, and species and sizes of fish caught by anglers is obtained on these cards. Annually, approximately 4,000 anglers (5% of all anglers) have voluntarily completed and returned cards to the park's fisheries program. The angler report card data estimated more than 8,000 anglers (21% of all park anglers) fished Yellowstone Lake with a catch rate of 0.8 cutthroat trout per hour during the 2015 fishing season. This is below the desired goals of 1.5 (secondary) and 2.0 (primary) cutthroat trout per hour for Yellowstone Lake, and a reduction from the 2014 catch rate of 1.2 cutthroat trout per hour. In 2016 the catch rate increased to 0.9 cutthroat trout per hour. This is the third highest catch rate over the last 11 years.

Average length of cutthroat trout caught by anglers was 462 mm (18 in.) in 2016, which is similar to other recent years.

An estimated 12,000 lake trout were caught by anglers in Yellowstone Lake in 2016 at a rate of 0.2 fish per hour. Many of these lake trout were large, with anglers reporting 42% were more than 462 mm (18 in). Because of the mandatory kill regulation for lake trout caught by anglers, angling accounted for an estimated 3% of the total lake trout removed from Yellowstone Lake by all methods (angling and suppression netting) in 2016.

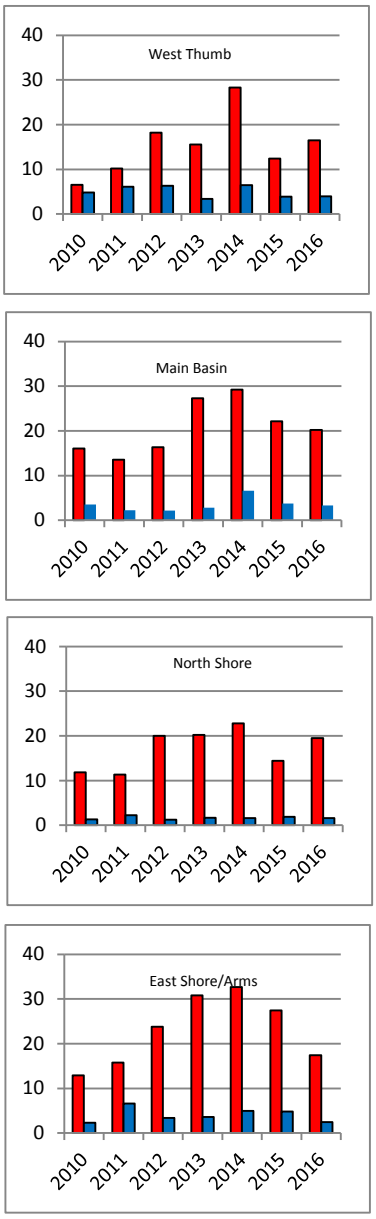


Figure 4. Mean catch of native cutthroat trout (red) and non-native lake trout (blue) during distribution netting within four Yellowstone Lake regions, 2010-2016.

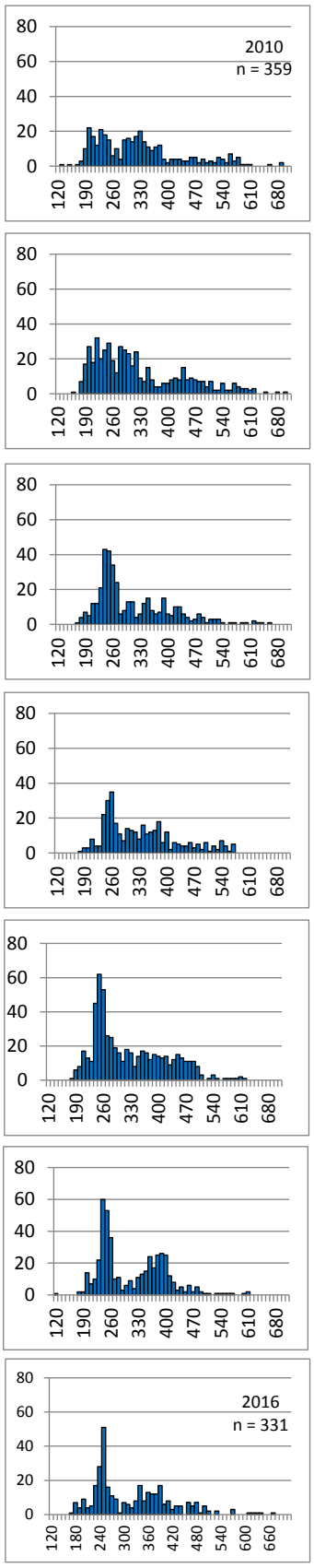


Figure 5. Length-frequency of lake trout collected during distribution netting on Yellowstone Lake with total number of trout (n), 2010-2016.

Conclusion

The cutthroat trout population in Yellowstone Lake has experienced declines due to the introduction of lake trout, drought years that may have negatively affected successful spawning, and whirling disease that is prevalent in some tributary streams. Monitoring to assess the effectiveness of large-scale suppression of lake trout indicates improvement in the cutthroat trout population, but there remains much work to be done. The desired condition for cutthroat trout as monitored by our distribution netting program is an average catch of 26 (secondary goal) to 40 (primary goal) fish per 100 meters of net set over one night. Although recent years have detected an increasing trend in cutthroat numbers, the secondary goal has been met only once (in 2014; figure 6a). Information from our spawning stream visual surveys indicates spawning cutthroat trout numbers have remained very low over the past decade. Although there has been a slight increase in the overall number of fish observed in these streams, we are still below the desired conditions of 40 (secondary goal) to 60 (primary goal) cutthroat trout observed per stream visit across all 11 tributaries (figure 6b). Similarly, catches of cutthroat trout reported by anglers have increased, but are still below the desired conditions of 1.5 (secondary goal) and 2.0 (primary goal) cutthroat trout per hour (figure 6c).

All three lines of evidence suggest cutthroat trout abundance, although improving, remains well below recovery goals (figure 6). Lake trout abundance, on the other hand, has essentially remained unchanged over the past six years (figure 3). Although statistical population modeling suggests the lake trout population may be beginning to decrease, there is uncertainty associated with the models; it is anticipated that 10 or more additional years of suppression at the current levels of effort will be required to crash the population (Syslo 2015). Long-term monitoring will continue in an effort to document the resulting changes to the Yellowstone Lake fish populations and inform the program's adaptive management strategy.

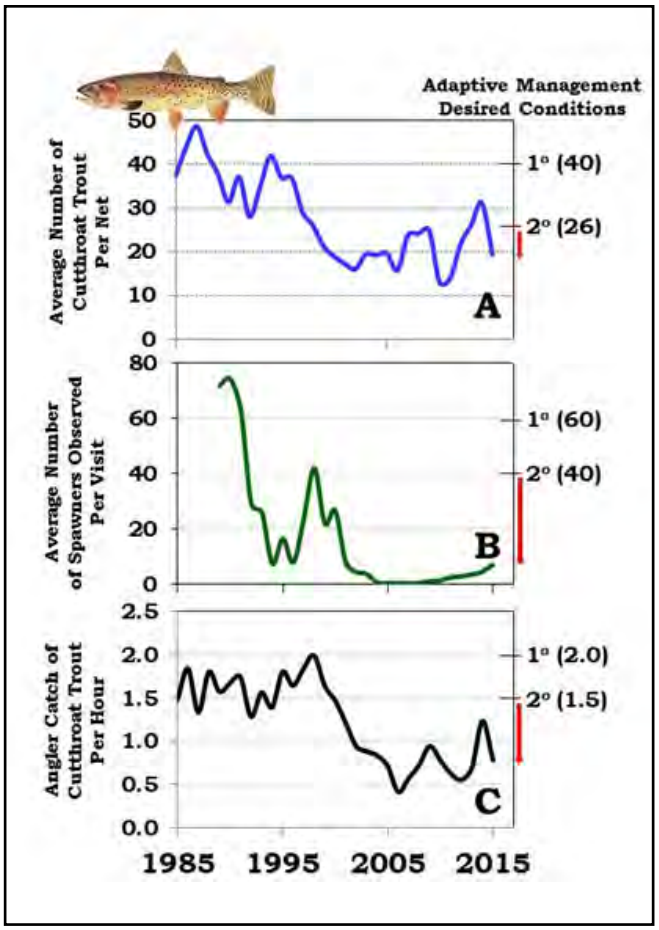


Figure 6. Metrics monitored to assess the effects of conservation actions on Yellowstone Lake include the average number of cutthroat trout caught per net during within-lake netting assessments (A), observed during visual surveys of spawning streams (B), and caught per hour by lake anglers (C), 1985-2016. Primary and secondary desired conditions are from the Native Fish Conservation Plan (Koel et al. 2010).

Literature Cited

Jones, R.D., R.E. Gresswell, D.E. Jennings, S.M. Rubrecht, and J.D. Varley. 1980. Fishery and aquatic management program in Yellowstone National Park. Technical Report 1979. U.S. Fish and Wildlife Service, Yellowstone National Park, Wyoming, USA.

Koel, T.M., P. Bigelow, P.D. Doepke, B.D. Ertel, and D.L. Mahony. 2005. Nonnative lake trout result in Yellowstone cutthroat trout decline and impacts to bears and anglers. Fisheries 30:10-19.

Koel, T.M., J.L. Arnold, P.E. Bigelow, and M.E. Ruhl. 2010. Native fish conservation plan. Environmental assessment, December 16, 2010. National Park Service, U.S. Department of the Interior, Yellowstone National Park, Wyoming, USA.

Reinhart, D.P. 1990. Grizzly bear habitat use on cutthroat trout spawning streams in tributaries of Yellowstone Lake. Thesis. Montana State University, Bozeman, Montana, USA.

Syslo, J.M., C.S. Guy, J.L. Arnold, T.M. Koel, and B.D. Ertel. 2014. Standard operating procedures for distribution netting in Yellowstone Lake. U.S. Geological Survey, Montana Cooperative Fishery Research Unit, Department of Ecology, Montana State University, Bozeman, Montana, USA.

Syslo, J.M. 2015. Dynamics of Yellowstone cutthroat trout and lake trout in the Yellowstone Lake ecosystem: a case study for the ecology and management of non-native fishes. Dissertation. Department of Ecology, Montana State University, Bozeman, Montana, USA.

Jeff Arnold (see page 25)

WOMEN IN SCIENCE

2016 Fisheries Staff. TOP: Pat Bigelow (see page 44), Sarah Rubenstein, Sarah Koeber, Colleen Detjens (see page 21), Taylor Preul, BOTTOM: Kim Barrett, Lauren McGarvey, Michelle Briggs, Andriana Puchany, and Jordan Critcher.

Yellowstone National Park presents a unique opportunity for young professionals pursuing a career in fisheries management and research. Every year seasonal fisheries technicians, Student Conservation Association (SCA) interns, and volunteers from all over the world are hired to join the fisheries team. Many who start as technicians or interns here go on to pursue graduate education and careers in the fisheries profession. This year, women represent 38% of the fisheries staff, a higher level than the fisheries profession in general. A study conducted by Oregon State University researchers and the U.S. Forest Service (Arismendi and Penaluna, 2016) found that just 26% of federal fisheries biologists (GS 11-15) are women. The study revealed that numbers for minorities are even lower. These disparities in race and gender in professions such as fisheries biology are important to highlight and discuss as we look toward diversifying the workforce in all branches of science.

Bibliography

Arismendi, I., and B.E. Penaluna. 2016. Examining Diversity Inequalities in Fisheries Science: A Call to Action. BioScience 66(7): 584-591.

Sarah Rubenstein has been pursuing a career in fisheries since graduating from Cornell University in 2015 with a degree in environmental sciences. A rewarding and enjoyable summer of working with Yellowstone cutthroat trout has confirmed that she is in the right field, and she plans to further her education and opportunities with graduate school in the coming years.

Andriana Puchany grew up fishing with her father in rural North Dakota. She obtained her BS in fisheries management and came to Yellowstone in 2014 as an SCA intern. Her future plans are to become a biologist in a fisheries-related field.

Taylor Preul worked as an SCA intern for the lake trout removal program in Yellowstone this summer. She is currently finishing a degree in Ecology from Northern Michigan University and researching fish ecophysiology in the Northern Michigan University fish lab. She has previous fisheries experience in Michigan and Wisconsin.

Michelle Briggs worked as an SCA intern and a fisheries technician for Montana State University in Yellowstone this summer. She has a degree in biology from the University of Southern California and has done seasonal fisheries work in Washington and Alaska.

Lauren McGarvey started working in fisheries as a summer intern with Trout Unlimited in Pennsylvania. Lauren then came to Yellowstone as a SCA native trout restoration intern. She worked several seasons as a fisheries technician with the National Park Service and will soon be attending Montana State University for her MS in Fish and Wildlife Management.

Sarah Koeber received her BS with a major in Natural Resource Management from Grand Valley State University in 2016. Sarah started working with Yellowstone fisheries as an SCA intern in the summer of 2015. She has now returned as a National Park Service technician working in the lake trout suppression program.

Kim Barrett completed her first season as a fisheries technician at Yellowstone this summer. She has degrees in Natural Resources Management and Environmental Studies with concentrations in fisheries and community engagement. She has worked on several fisheries projects with organizations such as the Forest Service, Fish and Wildlife Service, and Trout Unlimited in Alaska and Vermont. She plans to do community-based fisheries management with under-served communities.

Jordan Critcher is originally from North Carolina, where she obtained her BS in Marine Biology. This past season she worked for Hickey Brothers Research assisting with lake trout suppression. She currently resides in Idaho where she works with freshwater species and volunteers with the community to help better the environment.

Identifying Movement Patterns and Spawning Areas of Lake Trout in Yellowstone Lake

Robert E. Gresswell, Nicholas A. Heredia, Jason G. Romine, Lee F. G. Gutowsky, Philipp T. Sandstrom, Michael J. Parsley, Patricia E. Bigelow, Cory D. Suski, & Brian D. Ertel

The National Park Service has been attempting to suppress non-native lake trout in Yellowstone Lake since 1995, primarily using gillnets (Koel et al. 2005). By October 2016, approximately 2.3 million lake trout had been removed. Increased gillnetting effort accelerated the number of lake trout removed per summer, from approximately 70,000 in 2007 to approximately 366,000 in 2016. The efficiency of these netting efforts was enhanced by better understanding lake trout movement patterns and seasonal changes in those patterns.

There is growing concern it will not be possible to maintain the current levels of netting effort indefinitely. As a result, more effective and cost-efficient means of suppressing this introduced invader will be needed, even as lake trout numbers continue to decline. Alternative suppression technologies focused on the developing embryos and larvae of lake trout may have potential for supplementing a continued, but diminished gillnetting program (see "Lake Trout Suppression Alternatives to Gillnetting," this issue). All strategies to increase the efficacy of removing adult lake trout and destroying their embryos and larvae require knowledge of lake trout movement patterns, and accurate locations of spawning and embryo incubation areas.

Although two spawning areas were identified in the West Thumb of Yellowstone Lake (Ruzycki 2004), new spawning areas have been pioneered since that time (see "Lake Trout Suppression Alternatives to Gillnetting," this issue). Computer models suggest about 4% of the lake has sufficient habitat for supporting lake trout reproduction (Bigelow 2009). High gillnet catches in areas where lake trout congregate during the fall suggest additional spawning sites, but many of them have yet to be verified by locating lake trout embryos on the sites.

To this end, we initiated a collaborative project in 2011 to identify lake-wide movement patterns and spawning areas of invasive lake trout in Yellowstone Lake. Federal and academic scientists, with additional funding support from the Yellowstone Lake Working Group (see "Yellowstone Lake Working Group," this issue), implanted acoustic transmitters in lake trout and established a network of stationary telemetry receivers in Yellowstone Lake. Specific research goals included: 1) locating spawning sites, 2) determining periods of greatest movement during the netting season (ice-off through mid-October), 3) locating areas where lake trout concentrate during the netting season (time within season and day versus night), and 4) determining specific travel corridors during the netting season.

Transmitters (or tags) are surgically implanted into the body cavity of the lake trout by experienced biologists. Because we were most interested in locating spawning areas, and to ensure the behavior of the individual was unaffected by tag size, we only tagged lake trout longer than 460 mm (18 in.). All transmitters are coded to emit a unique identification signal; some also have depth and temperature sensors.

Stationary receivers with an average detection radius of about 500 m (1,640 ft.) are attached to an anchored rope, with a float located at the surface visible to boaters. The number of receivers (48-65) and the position of the receivers in the lake have fluctuated annually as short-term research goals change. Field work generally begins soon after ice-off (late May-early June) with the retrieval of receivers deployed overwinter. After winter

data retrieval, receivers are redeployed in a general positioning array that remains in the lake until the beginning of the spawning season in late August. Data collected during this period are focused on lake trout distribution and non-spawning movement patterns.

As the spawning season begins, the general positioning array is replaced by 1-3 fine-scale positioning arrays of 11-64 receivers each to identify specific spawning sites within the more general suspected spawning areas (figure 1). Receivers within these arrays are positioned in a grid about one km (0.6 mi.) apart. Because numerous receivers can detect an individual lake trout, it is possible to obtain two-dimensional locations for all individuals with coded transmitters and three-dimensional locations for those with depth and temperature sensors. These arrays generally operate until mid-October, when final data retrieval occurs and some receivers are retrieved. Buoys for the remaining 17-55 receivers are suspended 1.5-3 m (6-9 ft.) below the water surface to avoid encasement in the ice, where they remain submerged overwinter.

Although results are still preliminary, some patterns are emerging. For example, despite relocations lake-wide, few lake trout have been detected in the northern part of the lake or along the east shore. Throughout the year, the greatest number of relocations has occurred between Frank Island and the southeast shoreline between the South Arm and Breeze Channel. Activity in West Thumb has been greatest near Breeze Channel and the Solution Creek outlet, numbers increasing substantially during spawning (late August-early October) near Carrington Island, a verified spawning area.

Seasonal patterns of lake trout relocations vary. Movement is generally low during the winter period (November 1-April 30) when water temperatures are low (less than 4˚C or 39˚F) and the lake is covered by ice. Most lake trout are detected deeper in the water column where temperature is higher (about 4˚C or 39˚F) than near the surface (0-1˚C or 32-34˚F).

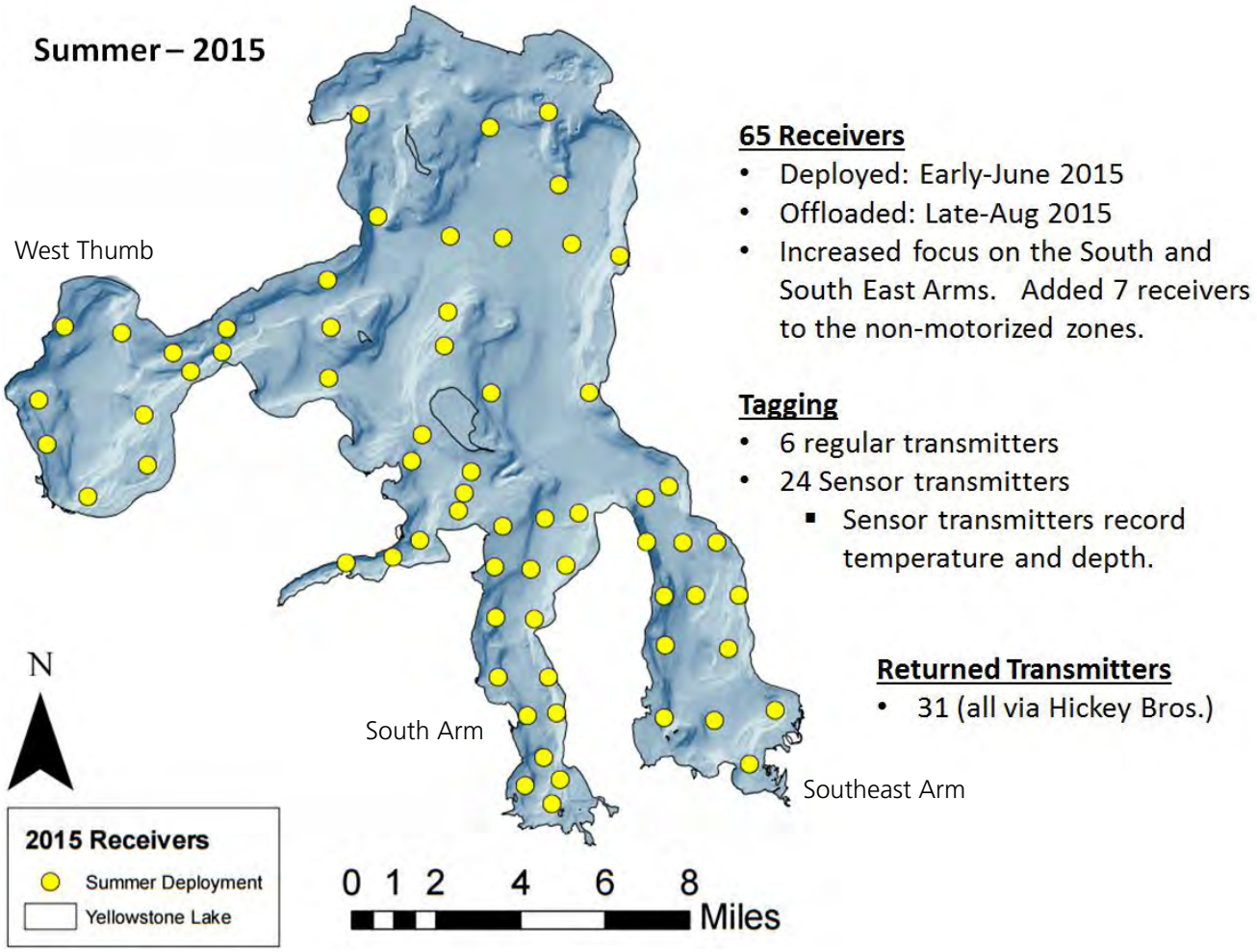


Figure 1. Locations of acoustic receivers to detect lake trout in Yellowstone Lake, June–late August 2015.

As air temperatures increase in the spring and the ice on the lake melts, lake trout become more active. Activity remains high from ice-off until the lake begins to stratify in late June-early July; during that time individuals are often found in shallower portions of the water column.

As surface water temperatures increase in July, lake trout move to deeper, colder portions of the lake; individuals are most commonly detected at water depths where temperatures are between 7.8 and 10°C (46°F and 50°F). Although lake trout still may be active, the number of receivers that detect the same individual declines, so the distances between relocations diminishes. During this period, individual lake trout make brief forays from deeper water into very shallow water, presumably to feed on native Yellowstone cutthroat trout that tend to remain in shallower water.

As day length shortens toward the middle of August, lake trout again become more active and movements become localized. We assume this is pre-spawning behavior because the number of individuals in the vicinity of known and presumed spawning areas increases. Lake trout frequent shallow water (less than 5 m or 15 ft.) at this time and are often found near the surface. This activity increases through the middle of September as water temperatures decline, though the timing of movements around suspected spawning sites can vary locally. Many lake trout move away from spawning areas by mid-October. As water temperature continues to decline, lake trout begin to move toward wintering areas, the largest of which appears to be south of Frank Island.

To identify specific spawning sites within more general spawning areas, we use statistical models to analyze individual lake trout tracks within the fine-scale receiver arrays. For example, preliminary results suggest spawning in the immediate vicinity of Carrington Island, an area where reproduction has been confirmed repeatedly. Deeper water to the southeast of the island was also identified as a probable spawning area; however, the substrate in this area consists of small gravel with no interstitial spaces and, therefore, is not ideal for spawning. Possibly lake trout are using this as a staging area prior to moving into shallower water to spawn. Analysis of data from the Snipe-Plover fine-scale array suggested several "hotspots" or sites where there was a higher density of predicted spawning behavior (figure 2); many of these coincide with verified spawning locations within the array.

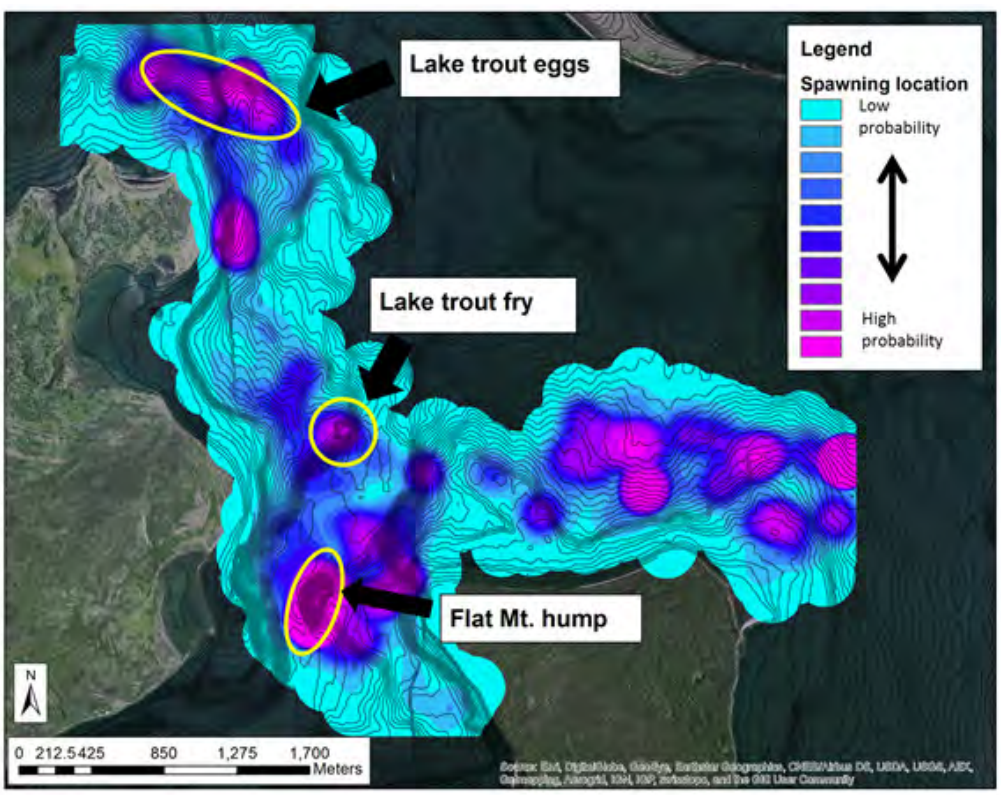


Figure 2. Predicted areas of spawning behavior based on 3-D positioning of lake trout with the Snipe-Plover underwater acoustic array, 2013-2014. Eggs and fry have been found at the identified areas. The model indicated spawning may be occurring in the southeastern end of the area; however, the substrate in this area is sandy and not ideal.

A project website (http://www.nrmsc.usgs.gov/yellowstone_lake/telemetry) hosted by U.S. Geological Survey, Northern Rocky Mountain Science Center was developed to serve as a platform for sharing findings. Currently, relocation information of individual lake trout is available for 2011-2012. The website also has descriptions and photos of receiver deployments, transmitter implantation, egg basket deployments, and a Frequently Asked Questions feature concerning the lake trout suppression program at Yellowstone Lake. Acknowledgement of the numerous individuals and funding supporting this research are included on the website.

Literature Cited

Bigelow, P.E. 2009. Predicting areas of lake trout spawning habitat within Yellowstone Lake. Dissertation. University of Wyoming, Laramie, Wyoming, USA.

Koel, T.M., P.E. Bigelow, P.D. Doepke, B.D. Ertel, and D.L. Mahony. 2005. Nonnative lake trout result in Yellowstone cutthroat trout decline and impacts to bears and anglers. Fisheries 30:10-19.

Ruzycki, J.R. 2004. Impact of lake trout introductions on cutthroat trout of selected western lakes of the continental United States. Dissertation. Utah State University, Logan, Utah, USA.

Robert E. Gresswell is an emeritus research biologist with the U.S. Geological Survey's Northern Rocky Mountain Science Center and affiliate assistant professor in the Department of Ecology at Montana State University. His current research is focused on the effects of fire, timber harvest, invasive species, and climate change on persistence of native trout. Bob has been involved with the lake trout issue in Yellowstone Lake since these invaders were first discovered in 1994 and has acted as chair of the lake trout suppression independent scientific review panel since 2008.

NPS PHOTO - N. HERBERT

Lake Trout Supression Alternatives to Gillnetting

Philip D. Doepke, Todd M. Koel, Christopher S. Guy, Alex S. Poole, Nathan A. Thomas, & Alexander V. Zale

We are researching lake trout suppression tactics that involve reducing the survival of embryonic lake trout in Yellowstone Lake. Invasive lake trout spawn over rocky substrates during September and October in Yellowstone Lake. Their spawning style is such that they broadcast eggs into the water column, which then settle to the bottom and often fall between rocks. Within minutes of fertilization, the eggs expand slightly, often causing them to wedge in place between the rocks. Being wedged between rocks protects the eggs from strong currents, making it difficult for predators to eat the eggs. However, being wedged in place may also help the lake trout removal effort; because if we know where the lake trout deposit their eggs, it will be easier for us to remove or treat them in a way that will prevent their survival.

In 2004, a design engineering class at Montana State University investigated some options for killing lake trout eggs, including egg suctioning, resonance, egg/fry traps, fish toxicants, ultrasonics, microwaves, and polymers (Bernhart et al. 2005). Shortly after, investigators at the U.S. Geologic Survey (USGS), Northern Rocky Mountain Science Center, also began work on suppression methods that target early life history stages of lake trout, including electricity, carbon dioxide, ultraviolet light, egg suctioning, and acoustic energy.

The USGS investigators' objectives were to critically assess the ecological effectiveness, cost effectiveness, and safety of alternative methods to destroy lake trout embryos in natural settings, and develop a practical methodology and associated equipment for field use (Gross 2010). Initial studies held some promise, but little field work was conducted in Yellowstone; and equipment for field use was not developed. Following these early exploratory efforts, attempts were made to create equipment that would be mobile and could cause the demise of lake trout embryos on their spawning reefs.

Present research efforts by Yellowstone National Park biologists and collaborating scientists at the USGS Montana Cooperative Fishery Research Unit and Montana State University are to locate all lake trout spawning habitats and evaluate the effectiveness of electricity, suction-dredging, tarping, chemical, and lake trout carcass suppression techniques at killing lake trout embryos on spawning sites.

Electroshocking Grids

Mobile electrical shocking devices have proven to be a promising tool for alternative suppression on spawning sites. Previous research demonstrated fish embryos are vulnerable to electric field intensities commonly generated by electrofishing equipment (Bohl et al. 2010). These devices were designed with the simple purpose of delivering a localized electrical shock that would destroy lake trout eggs (Brown 2014). The device that holds the most promise is a mobile 3 x 7 m (23 x 9.8 ft.) grid. The grid is positioned over spawning substrate on the bottom of the lake. Electricity is discharged into the lake substrate between several cables within the frame. Once the area within the grid has been shocked, the grid is lifted and moved to the next site; the process is continued until all the lake trout spawning grounds have been systematically electro-shocked. Water is typically an excellent conductor; therefore, electricity that escapes the grid is quickly reduced to a non-lethal level, preventing the demise of anything outside the grid.

Initial results suggest embryos residing near the surface of the substrate were almost entirely killed (figure 1). However, embryos 20-40 cm (7.9-15.8 in.) in the substrate were more likely to survive the electrical shock. Yellowstone Lake water is very pristine, which reduces its ability to conduct an electrical charge. Because of this, embryos that have settled into the substrate are less vulnerable to electrical shock. Thus, the natural purity

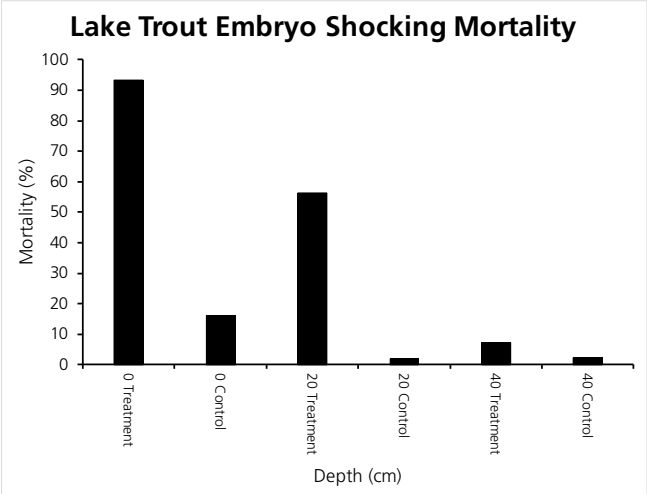


Figure 1. Lake trout embryos experienced a range of mortality after being shocked by the electrical grid (i.e., treatment). The highest mortality rate of 93% occurred in eggs placed on the surface of the substrate. Eggs 20 cm (7.8 in.) into the substrate experienced a mortality rate of 56%, while eggs 40 cm into the substrate experienced only 7% mortality. Control areas were not treated with electricity.

of the water may limit the usefulness of an electrical grid for killing lake trout in Yellowstone Lake. However, this technique holds promise for other waters where lake trout are invasive.

Suction-Dredging

A suction dredge is also being tested on Yellowstone Lake, consisting of a large pump placed on the deck of a boat, with long hoses that scour the substrate below and pick up lake trout eggs. The effluent is sucked up to the boat, where it is run through a series of screens. Everything except lake trout egg-sized particles drops back to the bottom of the lake. Egg-sized particles, including lake trout eggs, are separated in a salt water bath; eggs float in the salt water while rocks and pebbles remain on the bottom, allowing eggs to be easily skimmed from the surface. The suction dredge has proven effective at verifying lake trout spawning areas; we now know of 12 lake trout spawning sites in Yellowstone Lake.

Tarping

Tarping is a technique that restricts the flow of water over lake trout eggs so they do not get enough oxygenated water for respiration. Biologists tarp the substrate where eggs have naturally been deposited, thus preventing oxygenated water from flowing over the eggs and ultimately suffocating the developing embryos. The cover

Three of the suppression strategies for eliminating lake trout embryos we have recently been researching in Yellowstone Lake are (top to bottom) electroshocking, suction dredging, and carcass dumping. Bottom photo - USGS, G. GUY

currently being tested is a plastic tarp, but other materials that would act similarly or better at restricting water flow are being considered. Tarping studies are being conducted at the Carrington Island spawning site.

Chemical Treatment

An embryo toxicology study is attempting to determine the effectiveness and feasibility of various chemical compounds in the suppression of lake trout embryos. An initial pilot study completed in January 2016 assessed the potential of two compounds to cause embryonic mortality: salt (common stock salt, 99% NaCl) and rotenone, an organic fish toxicant commonly used by biologists to remove non-native fish. Long-term exposure (up to 21 days) of freshwater fish embryos to elevated salt concentrations has been shown to reduce hatching success (Koel and Peterka 1995), but what was not known is if short-term exposure (less than 1 day) to salt would affect their survival.

The effectiveness of rotenone for removing juvenile and adult fish is well documented, and the chemical is used for this purpose annually. However, developing embryos are protected by a nearly impermeable outer chorion (shell), and it was not known if rotenone can pass through the chorion or increase mortality of embryos in any way.

The results of the pilot study suggested short-term exposure (4-12 hours) of embryos to salt concentrations up to 5,000 mg per liter does not increase mortality. However, short-term exposure of lake trout embryos to a rotenone concentration of 4 parts-per-million resulted in an average cumulative mortality rate of 98% (figure 2). Thus far, all trials have been conducted in a laboratory environment; we now need to expose eggs in Yellowstone Lake to this low concentration of rotenone and examine its effectiveness. One of the greatest benefits of a chemical treatment would be its ability to reach eggs that are wedged between rocks and too difficult to remove by vacuum (suction-dredge) or have settled too deep into the substrate for an electrical grid to deliver a lethal shock.

Lake Trout Carcasses

Lake trout spawn in late September and early October in Yellowstone Lake. Some lake trout spawning areas are in water more than 20 m (65 ft.) deep, thereby limiting some viable methods (e.g., electroshocking).

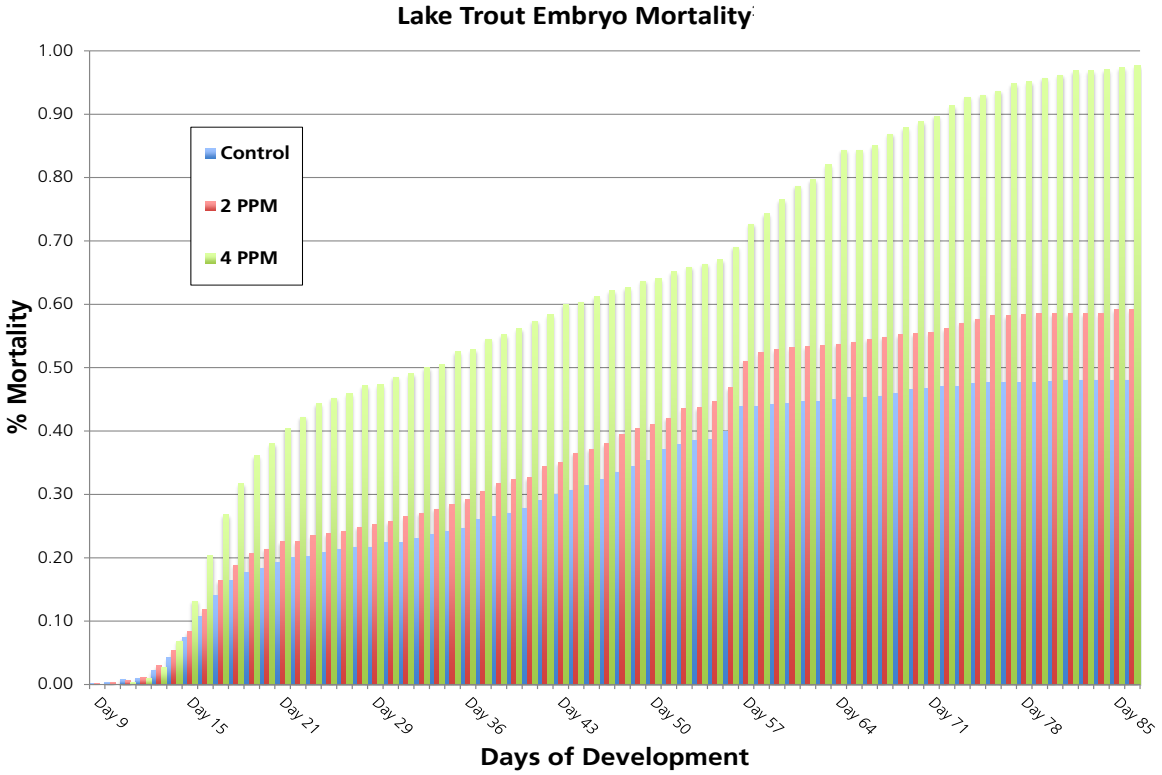


Figure 2. Lake trout embryos were exposed to Rotenone for 12 hours, eights days after fertilization. Eggs experienced 98% mortality after 86 days of development when they were exposed to rotenone at 4 parts per million (PPM).

One alternative suppression method fisheries crews could feasibly apply at all depths is the placement of lake trout carcasses. During September and October of 2016 we dumped several hundred lake trout carcasses on three of the twelve known lake trout spawning grounds in Yellowstone Lake. Prior to dumping the carcasses, we placed trays with several thousand developing lake trout embryos on these spawning grounds to determine if we could cause mortality. After just 16 days there was almost 100% mortality of the lake trout embryos. Carcasses placed at 0-20 cm (0-8 in.) showed an average mortality of 99.4% (86-100%) as compared to the control group mortality of 46.6% (29-75%). These are very promising results. Lake trout embryos would typically take over 90 days to hatch in the water temperatures of Yellowstone Lake. Dumping lake trout carcasses in Yellowstone Lake is something that has been occurring since the removal project started. The gillnetting aspect of the lake trout removal project has been dumping more than 300,000 lake trout carcasses in the deep waters of Yellowstone Lake annually for the last several years. If we just dump a small portion of these on the lake trout spawning grounds we may be able to greatly reduce lake trout recruitment. We will continue to research this technique to determine minimum amount of carcass material necessary to cause mortality and if there are any drawbacks to dumping fish carcasses in relatively shallow water (1-30 meters in depth).

Summary

Additional fisheries research in Yellowstone Lake is complimenting studies on alternative suppression methods, by locating lake trout spawning areas and delineating their outer margins. Finding ways to limit the number of lake trout eggs has great potential because lake trout have specific areas where they spawn. If we find a method that removes or destroys developing eggs, we could remove numerous lake trout from Yellowstone Lake by treating only a small portion of the lake.

The search for suppression alternatives will continue as long as there is a need to remove lake trout. As gillnetting removes more lake trout from Yellowstone Lake, the cutthroat trout population will increase, making bycatch (the accidental catch of cutthroat trout) more of a concern. This bycatch issue emphasizes the need to find alternatives to gillnetting for future fisheries management. It is possible that the use of several methods to attack multiple developmental stages of lake trout will be the best strategy to allow the native cutthroat trout population in Yellowstone Lake to recover.

Literature Cited

Bernhart, B., C. Blackwood, R. Gale, E. Held, D. Shaffer, M. Wells, and D. Weston. 2005. Yellowstone National Park lake trout crisis. ME 404/ChE 411, Senior Design. Montana State University, Bozeman, Montana, USA.

Bohl, R.J., T.B. Henry, and R.J. Strange. 2010. Electroshock-induced mortality in freshwater fish embryos increases with embryo diameter: a model based on results from 10 species. Journal of Fish Biology 76:975-986.

Brown, P.J., C.S. Guy, and M.H. Meeuwig. 2014. Use of electrofishing to induce mortality in lake trout embryos in Yellowstone Lake. Final Report. Montana State University, Bozeman, Montana, USA.

Gross, J., R.E. Gresswell, and M. Webb. 2010. Destruction of lake trout *Salvelinus namaycush* embryos in natural settings to enhance persistence of native trout. U.S. Geological Survey Northern Rocky Mountain Science Center, Bozeman, Montana, USA.

Koel, T.M., and J.J. Peterka. 1995. Survival to hatching of fishes in sulfate-saline waters, Devils Lake, North Dakota. Canadian Journal of Fisheries and Aquatic Sciences 52:464-469.

Phil Doepke is a fisheries biologist working in Yellowstone National Park since 2003. Phil is a Yooper, born and raised in the Upper Peninsula of Michigan. He studied Fisheries and Resource Management practices at Northern Michigan, Michigan State, Michigan Tech, and Utah State universities. Previous employment locations have been the Ottawa National Forest, Bighorn National Forest, U.S. Fish and Wildlife Service in Marquette, MI, and the Great Lakes Indian Fish and Wildlife Commission. Most of his current work deals with the lake trout removal project in Yellowstone Lake.

Protecting the Greater Yellowstone Ecosystem from Aquatic Invasive Species

Clint M. Sestrich, Sue M. Mills, & Leah C. Elwell

Perhaps no greater threat exists to public recreation, infrastructure, and aquatic resources in the Greater Yellowstone Ecosystem (GYE) than that from aquatic invasive species (AIS). AIS are aquatic animals, plants, and pathogens that can negatively impact ecosystems, industry, tourism, and even human health when they become established in waters outside of their historic range. Invasive species owe their success to tolerance for a wide variety of habitat conditions, rapid growth and reproduction, and the ability to compete aggressively for resources. Given these characteristics, as well as a lack of natural predators and diseases in their new environments, AIS can rapidly overpopulate. When this occurs, they may drastically alter habitat, rendering it inhospitable for native aquatic species. The resulting ecological and economic impacts can be devastating.

AIS may be spread unintentionally to new waters by hitchhiking on any type of gear or equipment that comes in contact with AIS-contaminated water or sediment. Of greatest concern are the motorized and non-motorized watercraft transported to the Intermountain West annually from potentially infested waters all across North America (figure 1). Additionally, fishing gear and fire suppression equipment are some of the many vectors that inadvertently spread AIS. Aquatic invaders may also be introduced intentionally through illegal fish introductions and bait bucket releases known as "bucket biology," and releases of household and classroom pets. Once AIS are established, there are few effective or inexpensive control measures—eradication is usually impossible. Therefore, preventing the spread of AIS is essential for conserving our aquatic resources, and the recreating public must assume an active role in these efforts.

Greater Yellowstone Ecosystem at Risk

The GYE is a nationally important hydrologic resource with over 27,000 mi. (43,500 km) of streams and numerous lakes totaling over 278,000 surface ac (112,500 ha). World-famous headwater tributaries, including the Madison, Jefferson, Gallatin, Yellowstone, Bighorn, Wind, and Teton, give rise to the mighty Missouri, Snake, and Green rivers, which ultimately flow into the Gulf of Mexico, Pacific Ocean, and the Gulf of California, respectively. Because AIS can disburse downstream in flowing waters, the GYE is of national strategic importance in the fight against aquatic invaders. For example, AIS introduced into Yellowstone Lake could spread downstream into the Yellowstone River, its connected tributaries, and, ultimately, the Missouri River, threatening ecosystems, industry, and recreation along the way.

The multitude of clear, cold, high elevation lakes and streams in the GYE support unique native aquatic species assemblages. Some endemic species, like the Yellowstone cutthroat trout, occur naturally nowhere else on earth. Historically, these native trout occupied about 61 lakes regionally, with Yellowstone Lake (96,000 surface ac [39,000 ha]) accounting for 78% of the overall area (Endicott et al. 2016). Within their historic range, 80% of all currently occupied streams (8,000 mi./ 13,000 km) occur within the GYE. Keeping AIS from invading these waters is essential for the long-term persistence of native species like cutthroat trout.

Tourism is the main source of economic support for many communities in the Yellowstone area (Marcus et al. 2012). Visitors travel from around the world to experience blue-ribbon trout fishing, diverse wildlife, and pristine waters and shorelines found in wilderness areas. About 40,000 visitors fish in Yellowstone National Park each year. In 2002, these anglers valued fishing in and near the park at $172-$977 a day, which translates into a total value of $67.5-$385 million (Kerkvliet et al. 2002). By physically altering habitat complexity, food webs, and reducing the amount and quality of food

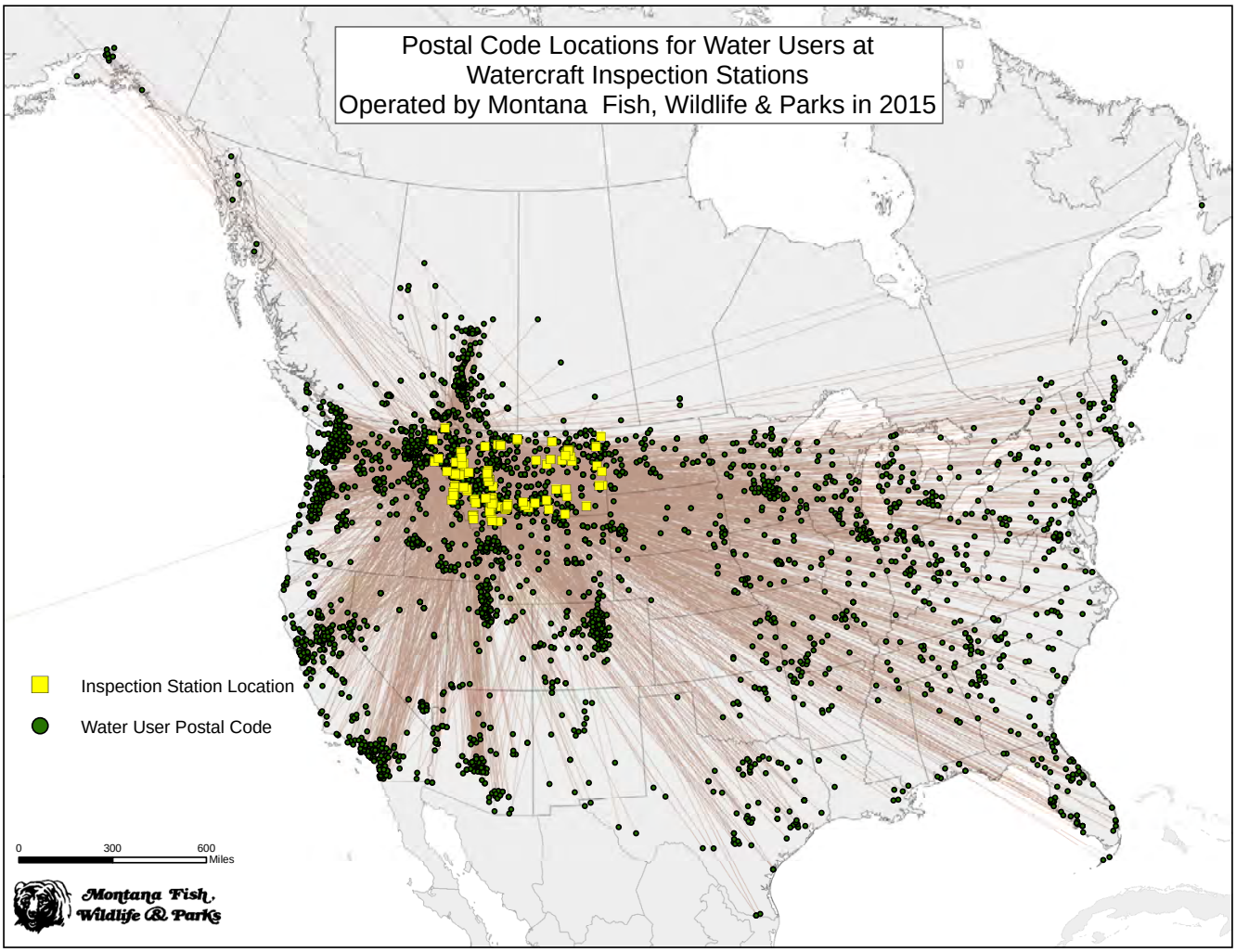


Figure 1. Origins of watercraft surveyed in Montana during 2015 (by zip code; Montana Fish, Wildlife & Parks 2015). Because aquatic invasive species exist in many of these locations, inspections are required to prevent their introduction into Greater Yellowstone Ecosystem waters.

available, an AIS outbreak could have an immense impact on visitor use and enjoyment of waters and local economies.

High Priority AIS Species

Species considered by managers to pose the greatest risk to ecologic, recreational, and economic values in the greater Yellowstone area include zebra and quagga mussels, Asian clams, Asian carp species, Eurasian watermilfoil, hydrilla, flowering rush, whirling disease, and viral hemorrhagic septicemia. Zebra and quagga mussels, collectively called dreissenids, are of particular concern given their ability to attach to watercraft, survive many days out of water, and cause irreparable harm. Once established, these efficient filter feeders can significantly reduce the biomass of phytoplankton, the foundation of aquatic food webs (Nichols and Hopkins 1993, Caraco et al. 1997). Dreissenid mussels have the ability to rapidly colonize hard surfaces (U.S. Geological Survey 2016), thus blocking water supply pipes of power and water treatment plants, irrigation systems, and industrial facilities. In addition, mussels can impact recreation activities and associated economies by covering docks, boats, and beaches (figure 2). The Idaho Aquatic Nuisance Species Task Force (2009) estimated the potential economic impacts to infrastructure and recreation from a dreissenid introduction would be in excess of $94 million. Fortunately, dreissenid mussels are not yet present in the GYE due to proactive watercraft inspection and decontamination programs.

While opinions differ regarding which AIS are a priority, every AIS is capable of spreading and causing irreparable harm. The Greater Yellowstone Coordinating Committee AIS database lists 5 sites in the GYE with

Figure 2. Quagga mussels can completely cover any object below the water's surface including this compact disc. PHOTO © L. ELWELL

American bullfrogs, 46 sites with curly-leaf pondweed, 16 sites with Eurasian watermilfoil, and 37 sites with New Zealand mudsnails. These AIS are continuing to spread; as a result, their full impact on aquatic ecosystems has yet to be realized. Moreover, several pathogens, including chytrid fungus and ranavirus, also threaten native amphibians in the ecosystem. Therefore, it is imperative the public and local, state, and federal agencies be vigilant for any suspicious plant, animal, or pathogen and take a broad, multispecies prevention approach.

Protecting the Greater Yellowstone Ecosystem's Waters

Simply draining, cleaning, and drying all equipment that comes in contact with any waterbody provides a high degree of certainty AIS will not spread. As simple as these three steps seem, their broad cultural acceptance and strict adherence is yet to be realized. Responsibility for leading AIS prevention and management efforts falls to the states of Idaho, Montana, and Wyoming; numerous counties; Yellowstone and Grand Teton national parks; five national forests; three national wildlife refuges; and the Bureau of Land Management. Together, these entities with assistance from nonprofit organizations coordinate, prioritize, fund, and implement projects within the GYE through participation in the Greater Yellowstone Coordinating Committee AIS Cooperative (http://www.fedgycc.org/subcommittees/aquatic-invasive-species-cooperative). Public outreach, watercraft inspections, and early detection survey and monitoring are the cornerstones of cooperators' AIS programs.

Watercraft Inspection Programs

Watercraft inspections are the most widely used tool for preventing the movement of AIS (Elwell 2015). Most western states as well as some national park units, local governmental entities, and others are operating stations where boat owners are required to stop for inspection. Although there are variations in program authorities and implementation, all watercraft inspection programs include a careful examination to determine if a watercraft and trailer are transporting suspected AIS.

The two most common approaches to conducting inspections are at geographic borders (or roadside) and at waterbodies. Border (roadside) inspection stations are typically used to prevent AIS from entering a defined geographic area. These programs use a series of inspection stations placed at entries to an area, and all watercraft are required to stop for an inspection. In addition, these boat inspections provide an opportunity for public outreach about AIS.

Inspections at a waterbody typically address one of two management scenarios: containing existing AIS within a waterbody or preventing AIS from entering a waterbody. Within the western region, a concerted effort has been made to standardize watercraft inspection programs to allow for greater protection of aquatic resources, improve boater-inspection experience, and improve the management of watercraft inspection programs. For watercraft that do not pass inspection, established decontamination procedures are used that include lowering boat motors and pulling drain plugs (to remove all water), using a hot pressure washer to clean all surfaces, followed by a period that ensures the watercraft is allowed to dry.

GYE Inspection Program Results

Presently, there are 12 permanent watercraft inspection stations within the GYE (figure 3). With a few exceptions, these stations are located along roadways and operated seasonally. In addition, there are 37 inspection sites intermittently staffed with roving crews, typically located at high-use boat launch sites. During 2015, 19,821 inspections were conducted among all perma-

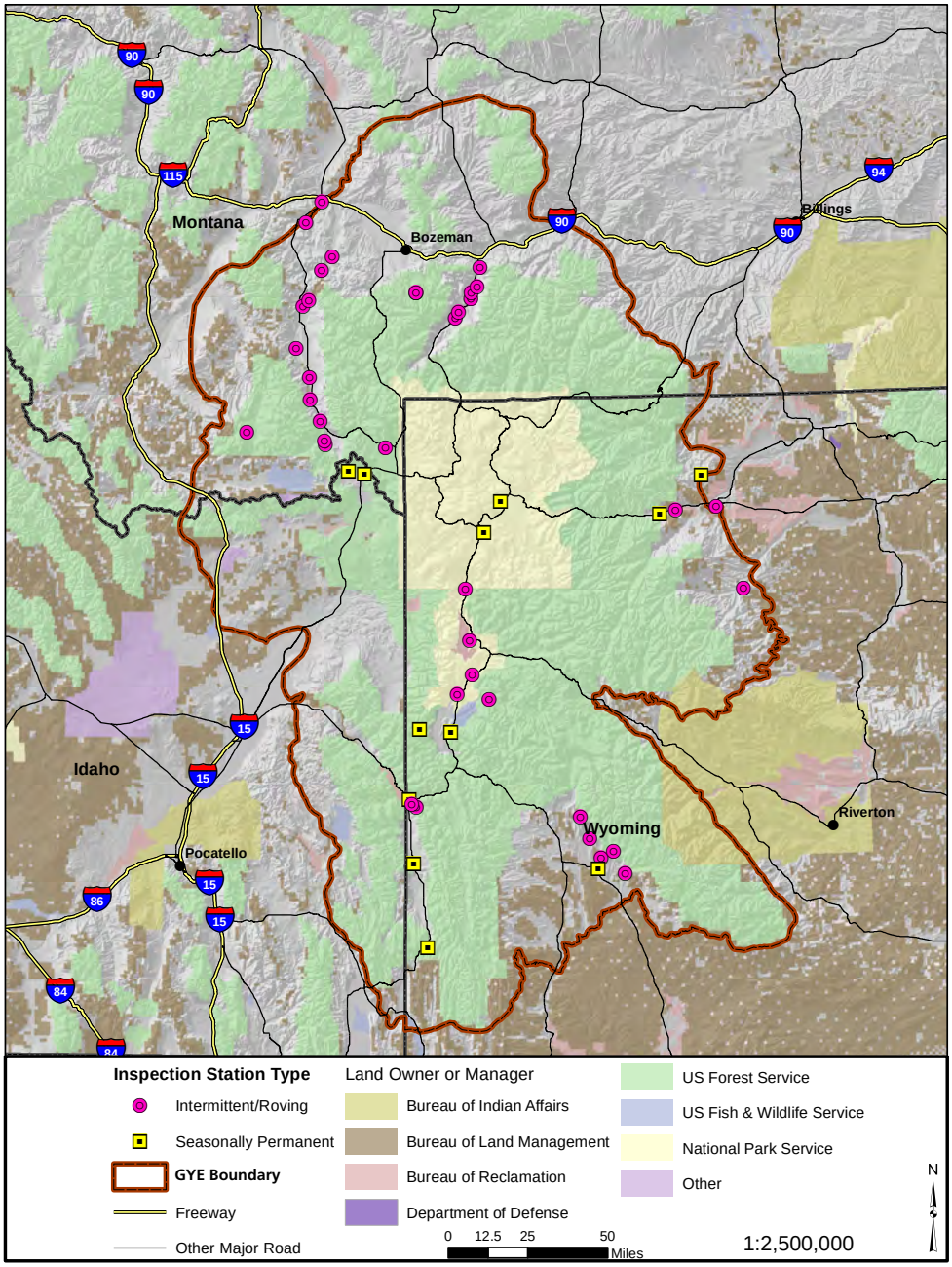


Figure 3. Locations of permanently operated (summer) and intermittently staffed/roving inspection sites for aquatic invasive species in the Greater Yellowstone Ecosystem.

nent and roving check stations. Inspected watercraft originated from all 50 states, southern provinces of Canada, and even Mexico, Costa Rica, and France. Less than 1% of inspected watercraft had standing water or attached vegetation or organisms that required decontamination. The majority (69%) of watercraft in Wyoming that required decontamination had standing water in the motor that could potentially be harboring AIS (Wyoming Game and Fish Department 2015).

Inspectors at the Highway 87 station in Idaho intercepted a mussel-fouled boat in 2015 that required decontamination. The majority of boats coming from mussel-infested waters originated in Lake Powell, located in Arizona and Utah. The effectiveness and efficiency of watercraft inspection stations across the west is rising with increased coordination. As an example, over 60% of mussel-fouled boats intercepted by the state of Idaho in 2015 were due to notification from state and regional partners (Idaho State Department of Agriculture 2015).

Protect Your Waters – Drain, Clean, Dry!

The potential ecological, social, and economic impacts from AIS invasions are devastating and irreversible. Thus, neither the public nor their agency servants can afford to sit back and consider defeat inevitable, especially in the GYE. Everyone needs to acknowledge the potential for water-based activities to spread AIS and accept responsibility for draining, cleaning, and drying waders, nets, motorboats, jet skis, canoes, kayaks, float tubes, and other equipment before moving to new waters. These simple actions will protect our aquatic ecosystems, water-based economies, and activities for ourselves and future generations.

Literature Cited

Caraco, N.F., J.J. Cole, P.A. Raymond, D.L. Strayer, M.L. Pace, S.E.G. Findlay, and D.T. Fischer. 1997. Zebra mussel invasion in a large, turbid river: phytoplankton response to increased grazing. Ecology 78:588-602.

Elwell, L., and R. Wiltshire. 2015. A management assessment of motorized watercraft and aquatic invasive species prevention in the Greater Yellowstone Area. Invasive Species Action Network, Livingston, Montana, USA.

Endicott, C., L. Nelson, S. Opitz, A. Peterson, J. Burckhardt, S. Yekel, D. Garren, T. Koel, and B. Shepard. 2016. Range-wide status of Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*): 2011. Report prepared for the Yellowstone Cutthroat Trout Interagency Coordination Group, Bozeman, Montana, USA.

Idaho Aquatic Nuisance Species Task Force. 2009. Estimated potential economic impact of zebra and quagga mussel introduction into Idaho. Idaho Invasive Species Council, Boise, Idaho, USA.

Idaho State Department of Agriculture. 2015. Idaho aquatic invasive species program summary 2015. Boise, Idaho, USA.

Kerkvliet, J., C. Nowell, and S. Lowe. 2002. The economic value of the Greater Yellowstone's blue-ribbon fishery. North American Journal of Fisheries Management 22:418-424.

Marcus, W.A., J.E. Meacham, and A.W. Rodman. 2012. Atlas of Yellowstone. University of California Press, Berkeley, California, USA.

Montana Departments of Agriculture; Fish, Wildlife & Parks; Natural Resources and Conservation; and Transportation. 2014. Montana aquatic invasive species program 2014 annual report. Helena, Montana, USA.

Nichols, K.H., and G.J. Hopkins. 1993. Recent changes in Lake Erie (north shore) phytoplankton: cumulative impacts of phosphorus loading reductions and the zebra mussel introduction. Journal of Great Lakes Research 19:637-647.

U.S. Geological Survey. 2016. Nonindigenous aquatic species database. Gainesville, Florida, USA.

Wyoming Game and Fish Department. 2015. Wyoming aquatic invasive species 2015 program summary. Laramie, Wyoming, USA.

Clint Sestrich is the Custer Gallatin National Forest Absaroka Beartooth Zone fisheries biologist. His passion and expertise lie in working collaboratively to conserve and restore native Yellowstone cutthroat trout populations, preventing the spread of aquatic invasive species, and providing public education focused on aquatic ecosystem function and management. Clint is currently the chair of the Greater Yellowstone Coordinating Committee AIS Cooperative. He has BS and MS degrees in Fish and Wildlife Management from Montana State University in Bozeman, Montana.

Yellowstone Trout Facts

KINGDOM: Animalia

PHYLUM: Chordata

CLASS: Actinopterygii

ORDER: Salmoniformes

FAMILY: Salmonidae

GENERA: *Oncorhynchus, Salmo, Salvelinus*

SPECIES: *Oncorhynchus clarki, Oncorhynchus mykiss, Salmo trutta, Salvelinus fontinalis, Salvelinus namaycush*

COMMON NAMES: Cutthroat (native), rainbow, brown, brook, lake, char

CUTTHROAT TROUT: Named for the red slash along their jaw

AVERAGE LIFE SPAN : Cutthroat/rainbow/brown/ brook trout: 6-12 years

OLDEST DOCUMENTED FISH IN YNP: Cutthroat trout: 16 years. Lake Trout: 26 years

OLDEST DOCUMENTED LAKE TROUT: 62 years (Canada)

CAUSES OF MORTALITY: predation, disease, environmental factors

SEX RATIO: Typically 1:1 but can vary greatly.

COLORATION: Fish can change colors (darken or lighten) to blend in with the environment. Spawning fish are typically more brightly colored. Cutthroat trout turn deep orange and red on the belly, while brown and brook trout develop colorful spotting patterns along their sides. Males are often more brightly colored than females.

HIGHEST POTENTIAL JUMP: Rainbow trout can jump up to 5 times their body length.

ADULT LENGTH: Cutthroat trout 8-24", brook trout 5-18", lake trout 16-40"

BODY TEMPERATURE: Trout are cold-blooded; their body temperature is the same as the environment. Trout are most successful in water temperatures ranging from 0-20 degrees C. They can survive in warmer temperatures but do not thrive.

RESPIRATION: Trout are gill breathers. Gills are filled with blood vessels which exchange oxygen and carbon dioxide as water passes over them.

VISION: Outstanding. Trout can focus their eyes in two different directions at the same time, and they see in color. Trout cannot blink.

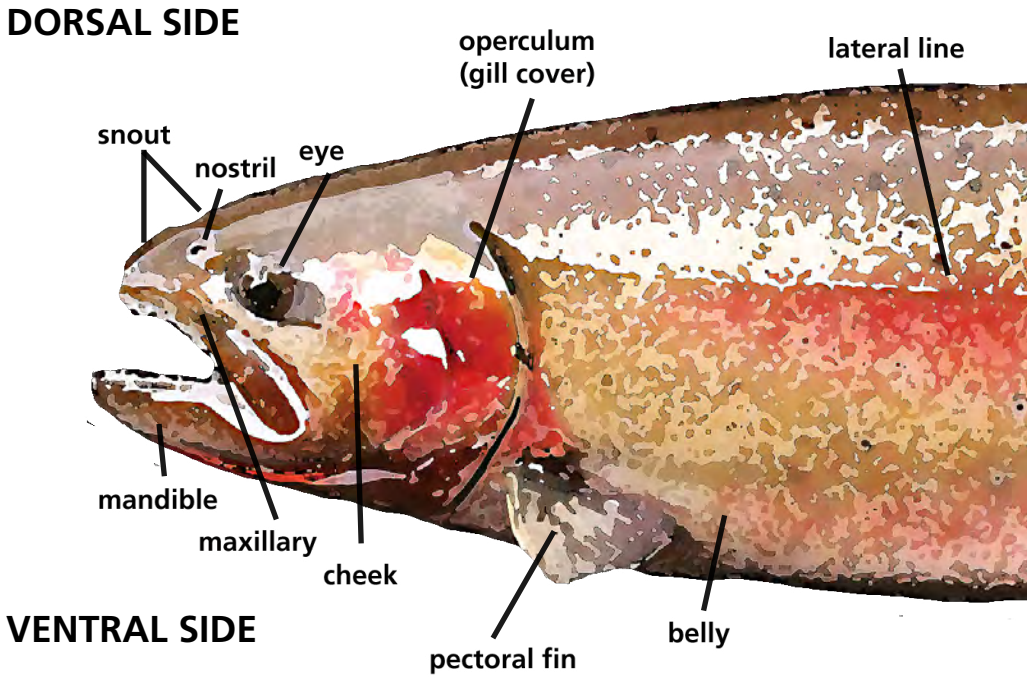
HEARING: Hearing occurs in the inner ear; there is no external or middle ear.

OTOLITHS: Composed of calcium carbonate, these small ear bones are used in sound detection but, similar to human ear bones, also provide balance, movement, and directional indicators. Otoliths can be read like tree rings to determine age.

SCALES: As with otoliths, growth patterns on scales can be used to determine age.

LATERAL LINE: Fish have an extension of their hearing system built into their "lateral line," a series of organs dispersed down the length of their bodies that sense vibrations, allowing them to detect movements in the water near them.

FISH "SLIME": Reduces friction, protects fish from fungus, bacteria, and some parasites,



aids in regulation of internal fluid, salt levels, and gas exchange.

OTHER SENSES: Olfaction (smell) is accomplished by passing water through the nares (nostrils) over nasal sacs. This is important for feeding, spawning, predator avoidance, and natal homing.

AIR BLADDERS: Trout are physostomes, meaning they can rapidly fill or empty their bladder by gulping or expelling air. As a result trout bladders will not burst when ascending through water quickly.

GROWTH: Indeterminate growth capabilities (fish continue to grow throughout their lives).

FEEDING HABITS: Trout spend 80% of the day foraging for food. However, foraging activities are reduced when water temperatures are too warm or too cold.

PRIMARILY FEED ON: Aquatic invertebrates, zooplankton, and, at times, other fish

GENETICS: Some species are genetically similar enough to hybridize (interbreed) with one another, while others do not naturally hybridize.

SPAWNING LOCATIONS: Cutthroat, rainbow, brook, and brown trout spawn in gravel/sand with moderate stream flow; lake trout spawn in lakes in cobble-sized substrate.

SPAWN TIMING: Cutthroat trout and most rainbow trout spawn in spring as water temperatures rise, starting at about 5 degrees Celsius (C). Brown, brook, and lake trout all spawn in the fall as water temperatures drop. Some trout in the Firehole River spawn in winter months, a shift caused by the thermally influenced waters.

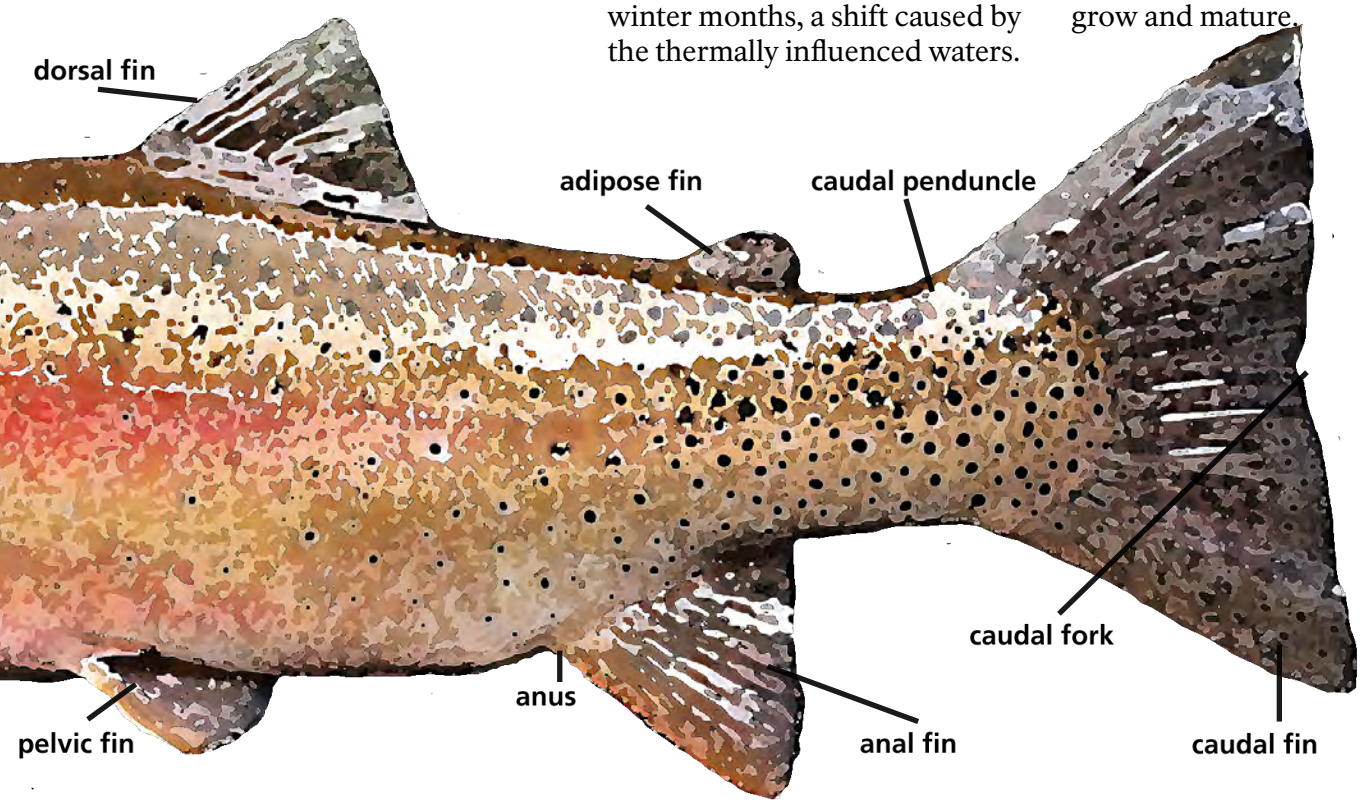
INCUBATION TIME: Varies greatly depending on water temperature. Cutthroat trout average 4-5 weeks at 11 degrees C.

NUMBER OF EGGS PER FEMALE: Can vary greatly, but general rule of thumb is 1,000 eggs per kg of body weight.

FISHABLE WATERS: At one time, 48% of park waters were fishless. There are currently 45 lakes and over 200 streams in the park that are now fishable.

FISHING PERMITS: About 40,000 fishing permits are issued annually in Yellowstone National Park.

LIFE HISTORY: **Resident** fish live their entire life in tributaries. **Fluvial** fish spawn in small tributaries but migrate to larger rivers to grow and mature. **Adfluvial** fish spawn in streams but migrate to lakes to grow and mature.



SHORTS

Fly Fishing Volunteers Support Native Fish Conservation in Yellowstone

Colleen R. Detjens, William Voigt, Joann Voigt, & Todd M. Koel

The Yellowstone Fly Fishing Volunteer Program was conceived in 2002 as a way Yellowstone's biologists could acquire information about fish populations without having to travel to distant locations throughout the park and sample the populations themselves using electrofishing or other sophisticated gear. Yellowstone National Park contains an estimated 4,265 km (2,650 mi.) of streams and more than 150 lakes, many of which support native fish populations that could be monitored; however, emerging resource concerns such as the invasion of non-native lake trout and whirling disease occupy progressively more time and financial resources of the park's fisheries program. As a way to sample fish populations and address fisheries issues park biologists would otherwise not be able to do, the fly fishing volunteers use angling to gather and archive information and biological samples.

Each year, a list of projects is developed by park biologists, so volunteers can focus their efforts. In its early years, the program was led by Timothy Bywater, an avid fly fisher and supporter of Yellowstone's native fish conservation program. William Voigt, also an avid fly fisher, joined the program in 2004 and eventually took over the job of program coordinator. Over the years, hundreds of fly fishers have volunteered with the program. These volunteers are important to the conservation of Yellowstone's native fish in a myriad of ways. They provide data and collect samples in important project areas, as

Flyfishing volunteer anglers (left to right) Ryan Kane, Matt Laliberte, Rob LaRocque, and Bob Liepsner.

well as in areas we may not know much about. They also play an important role in communicating with the public. They interact with tourists and other fly fishers on a regular basis and are able to discuss important topics, such as park fishing regulations, the reasoning behind some of the more controversial restoration projects, and why native fish are an important resource in Yellowstone.

How They Contribute

The volunteer fly fishing program attracts anglers from all across the United States, many of whom choose to come back year after year. Since the start of the program, 914 volunteers have contributed almost 23,000 hours to support native fish conservation in Yellowstone (figure 1). Of the 914 volunteers, 309 have returned for more than one season. These volunteers perform a wide range of duties in assisting the Yellowstone fisheries program, providing everything from logistical support to extensive sample collection. Collectively, program volunteers have sampled 7,000 fish since 2002 via angling. Data collected from each fish is recorded on datasheets and archived in computer databases. Along with fish lengths, weights, condition, and other basic data, volunteers also collect biological samples to be later processed in a laboratory. For example, volunteers have been integral in collecting genetic samples from various locations. Most notably, the samples they collected from the Lamar River and Slough and Soda Butte creeks aided park managers in understanding the extent of cutthroat trout hybridization in these drainages, thus contributing to subsequent management decisions. Other genetic sampling efforts across the park have been used to confirm or dismiss the presence of hybridization in a population, again aiding park biologists in management decisions.

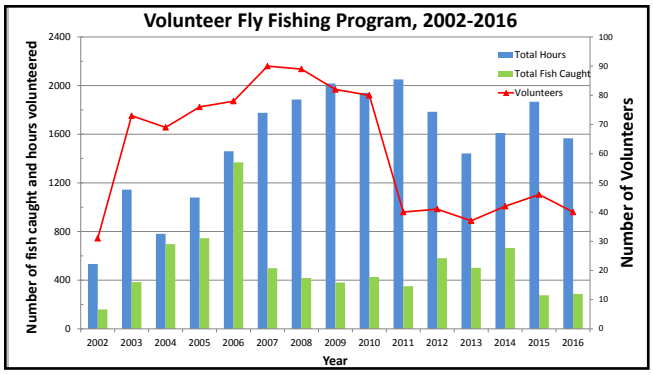


Figure 1. Number of Fly Fishing Volunteers with hours contributed and fish caught in Yellowstone National Park, 2002-2016.

Between 2007 and 2014, volunteers collected 263 genetic samples from the Slough Creek drainage alone.

The volunteer fly fishers also provide invaluable support for fish tagging projects, such as those conducted on the Gibbon and Lamar rivers. These projects provide information on the life history and movement of species, such as Arctic grayling (Gibbon River) and rainbow trout and cutthroat rainbow trout hybrids (Lamar River and Slough and Soda Butte creeks). The collection of fish large enough to tag and for insertion of the tag itself can be an arduous process. During 2015, the volunteer fly fishing program caught and tagged approximately 220 fish in the Lamar River system. With the help of the volunteer program, biologists and collaborating graduate students were able to work more efficiently and effectively, ultimately providing managers with the best data possible.

Since the start of the program, volunteers have also assisted with several other projects, including removal of non-native species, evaluation of fish barrier efficacy and success, a study to determine injury and mortality rates when using barbed versus barbless hooks, surveys to determine species composition, and logistical support for large multi-agency projects.

Their Role with the Public

In addition to providing valuable data, samples, and assistance to the fisheries program, volunteer fly fishers play an important role with the public. The program itself gives dedicated anglers a chance to contribute to fish conservation efforts in a positive way. Through their role as volunteers, they are able to positively interact with the public and demonstrate their passion for native fish and the importance of protecting these species. Volunteer fly fishers promote an understanding of the park's fishing policies and regulations, and generate awareness of the current issues facing Yellowstone's native fish. Passionate and informed supporters such as these are an important contribution to the success of native fish conservation in Yellowstone.

Shared Experiences

Over the years the Yellowstone Fly Fishing Volunteer Program has been in existence, there have been many experiences shared among the coordinators and participating volunteers. Notes are taken by the volunteer coordinator during field outings with volunteers; below are three examples of those notes.

William Voigt joined the volunteer fly fishing program in 2004 and jointly coordinated the program with Timothy Bywater until 2008. Bill Voigt and his wife Joann continued to recruit and lead volunteer anglers each summer from 2008-2016.

Cache Creek

"Today, August 11, 2005, we hiked 3 miles up the Lamar River Trail to collect genetic samples from the Cutthroat Trout in Cache Creek. It started bright and sunny but as the afternoon progressed many thunderstorms passed around us. We fished a half mile of the stream and took fin clips and scale samples from 20 fish. There wasn't any hatch but fish rose to our hopper and caddis patterns. With more storms threatening, we headed back down the trail to the parking lot. It was obvious that it had rained hard along the Soda Butte Creek because the trail and the creek were muddy.

As we loaded our gear into our van, two park ranger cars blocked us in and the rangers demanded to see our licenses and fish. They had a report of six people catching fish and keeping them in yellow buckets up on Cache Creek. After some explanation of the program, one of the rangers remembered fishing with Tim Bywater the previous year.

One of our volunteers was quite a large lad with a voracious appetite and had brought half of a pork roast in his pack for lunch. We teased him that one of the rangers was eyeing him up to decide how to take him down if he was to run. We all chuckled.

The Lamar valley is becoming one of our favorite places in the park. The broad vistas of the valley are quite spectacular! We saw bison, pronghorns, and a coyote as well as a kestrel hunting in the meadows. It was great day!"

High Lake

"High Lake was the first body of water recently reclaimed for West Slope [sic] *Cutthroat Trout. Now, two years later in August 2009, we were going to High Lake for two days of fishing for West Slope* [sic] *Cutthroat Trout. This was our first horse-packing trip in the park and we all were excited. Our volunteers were so eager that they willingly rented their own horses and brought their own supplies and equipment. We were to weigh and measure every fish we caught. We were also to record whether the adipose fin had been clipped. That would indicate that they had been stocked as fingerlings. If the adipose fin was intact, they had hatched from egg boxes put in the spring feeding the lake or from natural reproduction.*

It was a ten mile ride up to the lake on top of the mountain very close to the northwest border of the park. We set up camp and then started fishing. We caught many fish in the 11 to 11 ¾ inch range with their adipose fin clipped; so many so that a competition was occurring to see who would catch the first 12 inch fish. However, several smaller fish were caught with their fins intact. The lake and its fish seemed to be doing well; we caught 67 fish over the course of two days.

The days were pleasant, but the nights were very cold. Hot chocolate was welcome in the morning. And no one caught that 12 inch fish."

Pelican Creek

"Our destination in July 2011, was Pelican Creek. We hiked 1.5 miles up the trail to the creek with 2 volunteers. The creek had been closed for seven years because of the discovery of whirling disease and had just been reopened. We were to sample the Yellowstone Cutthroat trout population to see how their recovery was progressing. During the course of the sunny day, we saw a few elk, a grizzly bear, a small herd of bison, a Trumpeter swan, and a Swainson's hawk. Fishing was slow, but we caught two 19" cutthroat trout obviously up from the lake to spawn. On our way out, one of our volunteers turned to us, and even though he didn't catch any fish, he said, 'Thank you. You took me to a beautiful place I would never have seen on my own.'

Several days later we went back up Pelican Creek with writer Nate Schweber and caught several 5-6 inch healthy-looking Yellowstone Cutthroat trout. Schweber dedicated the final chapter of his book, Fly Fishing Yellowstone National Park, *to the recovery of Pelican Creek."*

Colleen Detjens (see page 27)

Where People Can Catch Trout, & Trout Can Catch People

Nate Schweber

There were more than 4 million visits to Yellowstone National Park in 2016, all drawn by the same want—to better know the wonders of our natural world. And what better place to meet nature's best ambassadors? Yellowstone is well-known for its animals, such as grizzly bears, bison, wolves, elk, and eagles. Yet among these ambassadors, one species stands out as the best: trout. Hear me out, non-anglers. Of all the game animals in Yellowstone, the only ones people are welcome to make a physical connection with are trout (I'm including in my thesis brook trout and lake trout, technically char, and also their cousins, Arctic grayling and mountain whitefish).

Think of the reciprocation in that ceremony. A person wrangles, touches, lifts, and studies a wild animal, from the mercurial colors of its speckled sides to the obsidian triangles in its eyes. If the trout is non-native, under the right circumstances the angler can eat it—a communion with Yellowstone. Native trout, however, always must be let go. Then each release becomes a human lesson in the magnanimity of restraint, a concept with wide-reaching implications for our changing earth.

But for this ceremony to happen, for the lessons to be learned, trout must first be preserved. Native trout are the most imperiled. For their sake, Yellowstone officials have taken some of the bravest and most proactive steps in conservation history.

When Yellowstone cutthroat trout in Yellowstone Lake dropped to dangerously low levels in the mid-20th century, the park set strict angler limits. When these native cutthroats were killed in even more devastating numbers by illegally-introduced lake trout in the early 21st century, officials began using boats to net lake trout. To-date, this ambitious netting campaign has removed more than two million of the non-natives. Slowly, native cutthroats are returning.

On the sunset side of the Continental Divide, Yellowstone biologists led by Todd Koel recently restored populations of another native trout gone for nearly a century—westslope cutthroat. Ambitious hikers can climb to High Lake and find westslope cutthroats cruising teal waters deep in the Gallatin Range. Cyclists can pedal to Goose Lake, a short ride from steaming Midway Geyser Basin, to find westslope cutthroat. Soon, people will be able to once again catch westslope cutthroat and sail-finned Arctic grayling in Grayling Creek. That's welcome news for anglers, for the rare grayling, and for the veracity of maps.

Recently, Yellowstone set rules requiring anglers to automatically kill non-native trout in certain imperiled waters. While controversial, the decision sent a powerful message throughout the National Park Service about the urgency of protecting native trout and, by extension, all animals that coexist with them. By setting this precedent, Yellowstone saved steelhead in Washington's Olympic National Park, bull trout in Montana's Glacier National Park, Bonneville cutthroat trout in Nevada's Great Basin National Park, and brook trout in North Carolina and Tennessee's Great Smoky Mountains National Park.

One million years of mankind's exploratory and intellectual effort led to the creation of Yellowstone National Park—the world's first national park, the best idea from the best country in history. The next million years will be shaped for the better if Yellowstone remains a place where people can catch trout, and trout can catch people.

Nate Schweber is the author of "*Fly Fishing in Yellowstone National Park: An Insider's Guide to the 50 Best Places*." A freelance journalist, his work has appeared in the *New York Times*, Al Jazeera America, and *Montana Quarterly*. Born and raised in Missoula, Montana, he now lives in Brooklyn, New York. Nate spent the summers of 1997 and 2011 working in Yellowstone.

Birds & Mammals that Consume Yellowstone Cutthroat Trout in Yellowstone Lake and Its Tributaries

Daniel J. Bergum, Kerry A. Gunther, & Lisa M. Baril

NPS PHOTO - D. BERGUM

Yellowstone Lake in Yellowstone National Park (YNP) contains the largest inland population of Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) in North America (Behnke and Tomelleri 2002). Historically, these native trout provided food for a variety of wildlife. In 1994, however, park managers discovered non-native lake trout (*Salvelinus namaycush*) had been surreptitiously introduced into the lake. Their numbers increased rapidly and, in turn, their piscivorous (i.e., fish eating) food habits became a significant threat to the Yellowstone cutthroat trout population (Koel et al. 2005). In addition, the non-native parasite (*Myxobolus cerebralis*) that causes whirling disease, a significant cause of juvenile mortality, was discovered in tributaries to Yellowstone Lake during 1998 (Koel et al. 2006). Plus, a recent period of drought reduced the survival and recruitment of juvenile cutthroat trout (Koel et al. 2005). These combined effects caused a 90% decline in the cutthroat trout population in Yellowstone Lake (Koel et al. 2005).

Lake trout are not a suitable ecological substitute for cutthroat trout in the Yellowstone Lake system. Lake trout inhabit deeper waters and, unlike cutthroat trout, do not move into tributary streams to spawn; therefore, lake trout are inaccessible to many avian and terrestrial predators (Koel et al. 2005). Although lake trout do move into shallow waters of the lake to spawn, they often spawn at night which makes them unavailable to shallow water avian predators with diurnal habits. Spawning cutthroat trout migrate throughout the day and night (Gresswell 2011), which makes them vulnerable to nocturnal, crepuscular, and diurnal shallow water predators.

Table 1. Mammals and birds known to consume Yellowstone cutthroat trout in Yellowstone Lake and its tributaries, Yellowstone National Park.

Animal	Genus/Species	Source
Mammals		
American black bear	*Ursus americanus*	Reinhart and Mattson 1990, Haroldson et al. 2005, Fortin et al. 2013
Grizzly bear	*Ursus arctos*	Reinhart and Mattson 1990, Haroldson et al. 2005, Fortin et al. 2013
Mink	*Mustela vison*	P. Bigelow, Yellowstone Fisheries and Aquatics Program, personal communication 2014
River otter	*Lutra canadensis*	Crait and Ben-David 2006
Birds		
American dipper[a]	*Cinclus mexicans*	Varley and Schullery 1983, McEneaney 2002
American white pelican	*Pelecanus erythrorhynchos*	Davenport 1974, McEneaney 2002
Bald eagle	*Haliaeetus leucocephalus*	Davenport 1974, Swenson et al. 1986, McEneaney 2002
Barrow's goldeneye	*Bucephala islandica*	Davenport 1974
Belted kingfisher	*Megaceryle alcyon*	Davenport 1974
Bufflehead	*Bucephala albeola*	Davenport 1974
California gull	*Larus californicus*	Davenport 1974, McEneaney 2002
Caspian tern	*Hydroprogne caspia*	Davenport 1974, McEneaney 2002
Common loon	*Gavia immer*	Davenport 1974, McEneaney 2002
Common merganser	*Mergus merganser*	Davenport 1974
Common raven[b]	*Corvus corax*	Heinrich 1999, McEneaney 2002
Double-crested cormorant	*Phalacrocorax auritus*	McEneaney 2002
Eared grebe	*Podiceps nigricollis*	Davenport 1974
Great blue heron	*Ardea herodias*	Davenport 1974
Great horned owl[c]	*Bubo virginianus*	McEneaney 2002
Osprey	*Pandion haliaetus*	Davenport 1974, Swenson 1978, McEneaney 2002

[a] American dippers forage on Yellowstone cutthroat trout fry and eggs.
[b] Common ravens scavenge Yellowstone cutthroat trout and other fish carcasses, but do not generally forage for fish.
[c] This is based on one observation of a great horned owl catching and consuming a trout in Yellowstone, but is not likely a common occurrence. Fish are not part of its typical diet.

The decline in cutthroat trout could have negative consequences on the reproduction and survival of birds and mammals that consume them in the Yellowstone Lake watershed. We reviewed available literature to determine which predator and scavenger species are known to prey on or scavenge cutthroat trout in Yellowstone Lake or its tributaries and, as a result, might be adversely affected by the decline in cutthroat trout. Our literature review included all 221 bird and 67 mammal species known to inhabit YNP (see www.nps.gov/yell/learn/nature/ to view species checklists for the park).

We identified 20 species, including 16 birds and 4 mammals, which prey on or scavenge cutthroat trout in Yellowstone Lake or its tributaries (table 1). The bird species known to prey on cutthroat trout include osprey, American white pelican, Caspian tern, double-crested cormorant, belted kingfisher, common merganser, eared grebe, great blue heron, California gull, bald eagle, common loon, American dipper, Barrow's goldeneye, bufflehead, common raven, and great horned owl. In addition, four species of mammals—American black bear, grizzly bear, mink, and river otter—have been documented preying on cutthroat trout in Yellowstone Lake or its tributaries. The cutthroat trout decline has likely affected each of these species differently, due to their varied feeding habits and lifestyles.

Although the decline in cutthroat trout in Yellowstone Lake probably has caused some disruption in the food supply for all 20 of these species, the greatest impacts have been incurred by five species: osprey, American white pelican, Caspian tern, double-crested cormorant, and river otter. Nesting success for ospreys, cormorants, American white pelicans, and Caspian terns has decreased over the last 20 years, coinciding with the period of cutthroat trout decline (Smith et al. 2012, 2013, Baril et al. 2013). The only known nesting area for Caspian terns, American white pelicans, and dou-


NPS PHOTO - J. PEACO

ble-crested cormorants in YNP is on the Molly Islands in the Southeast Arm of Yellowstone Lake. The reduced availability of cutthroat trout and lack of an alternative prey source means these species have to travel farther to find food, which in turn likely reduces nesting success and increases the energetic costs of foraging with possible consequences to survival.

The river otter has also incurred significant impacts. Crait and Ben-David (2006) found little evidence otters could switch to feeding on introduced lake trout as an alternative prey to cutthroat trout. Lake trout are abundant and lipid rich, but are generally found in deep water beyond the foraging depth range of otters (Ben-David et al. 2000). Although longnose suckers (*Catostomus catostomus*) are a slow moving species, grow to a large size, and are obligate stream spawners (Brown and Graham 1954), they are less abundant (Stapp and Hayward 2002) and of lower energetic value (Ruzycki et al. 2003) than cutthroat trout. Therefore, longnose suckers are not an equivalent alternative prey for otters (Crait and Ben-David 2006). The decline in the cutthroat trout population in combination with the inaccessibility of lake trout and lower abundance and energetic return of alternative prey is expected to reduce the population density of otters in Yellowstone Lake (Crait and Ben-David 2006).

Grizzly bears, black bears, and bald eagles with home ranges around Yellowstone Lake have exhibited dietary flexibility and switched to other foods, limiting the potential nutritional stress caused by the loss of cutthroat trout as a food item. Bears are opportunistic omnivore generalists that feed on many species of plants, fungi, mammals, insects, birds, and fish. Fortin et al. (2013) found evidence that bears with home ranges adjacent to Yellowstone Lake may now be preying more on elk calves during the time period when they used to fish for cutthroat trout. Bald eagles appear to have compensated for the decrease in cutthroat trout by preying more on waterfowl (Baril et al. 2013). Like bears, the California gull and common raven are also opportunistic omnivore generalists (Davenport 1974, McEneaney 2002) capable of eating many different foods, thereby minimizing the impacts of the cutthroat trout decline.

In the past, cutthroat trout comprised a large portion of the diets of common loons, common mergansers, eared grebes, great blue herons, and belted kingfishers around Yellowstone Lake (Davenport 1974). However, except for the common loon, the reproduction and nesting success of these species has not been monitored. As a result, the impacts of cutthroat trout decline on these species are not known. The number of adult common loons observed in YNP appears stable, although nesting pairs and fledglings have decreased since 1987 (Smith et al. 2012). As of 2014, one-third of the park's 29 loons nested and foraged on Yellowstone Lake. Loons in YNP are of special concern since they represent nearly 64% of all loons in Wyoming and are isolated from other populations by more than 200 miles (Evers et al. 2013).

Cutthroat trout comprise a minor component of the diets of mink (Lariviere 2003, Melquist et al. 1981), American dippers, Barrow's goldeneyes, buffleheads (Davenport 1974), common ravens, and great horned owls (McEneaney 2002). Therefore, the impact of the cutthroat trout decline on the reproduction and survival of these species is likely minimal.

The cutthroat trout is an iconic and important species due to its place in the food web in Yellowstone and the Greater Yellowstone Ecosystem. Park managers are attempting to restore cutthroat trout in Yellowstone Lake and its tributaries through an aggressive lake trout removal program. If this program results in a significant long-term reduction in predatory lake trout, native cutthroat trout may reestablish at higher numbers in Yellowstone Lake and its tributary streams, and once again become an important dietary item for the birds and mammals that feed on this resource in the Yellowstone Lake watershed.

For an expanded version of table 1 which includes all known, suspected, and possible species that consume Yellowstone cutthroat trout, please visit go.nps.gov/who_eats_YCT

Literature Cited

Behnke, R.J., and J.R. Tomelleri. 2002. Trout and salmon of North America. Free Press, New York, New York, USA.

Ben-David, M., T.M. Williams, and O.A. Ormseth. 2000. Effects of oiling on exercise physiology and diving behavior of river otters: a captive study. Canadian Journal of Zoology 78:1380-1390.

Baril, L.M., D.W. Smith, T. Drummer, and T.M. Koel. 2013. Implications of cutthroat trout declines for breeding ospreys and bald eagles at Yellowstone Lake. Journal of Raptor Research 47:234-245.

Brown, C.J.D., and R.J. Graham. 1954. Observations on the longnose sucker in Yellowstone Lake. Transactions of the American Fisheries Society 83:38-46.

Crait, J.R., and M. Ben-David. 2006. River otters in Yellowstone Lake depend on a declining cutthroat trout population. Journal of Mammalogy 87:485-494.

Davenport, M.B. 1974. Piscivorous avifauna on Yellowstone Lake, Yellowstone National Park. U.S. Department of the Interior, National Park Service, Yellowstone National Park, Wyoming, USA.

Evers, D.C., V. Spagnuolo, and K. Taylor. 2013. Restore the call: Wyoming status report for the common loon. Science Communications Series BRI 2013-21. Biodiversity Research Institute, Gorham, Maine, USA.

Fortin, J.K., C.C. Schwartz, K.A. Gunther, J.E. Teisberg, M.A. Haroldson, M.A. Evans, and C.T. Robbins. 2013. Dietary adjustability of grizzly bears and American black bears in Yellowstone National Park. Journal of Wildlife Management 77:270-281.

Gresswell, R.E. 2011. Biology, status, and management of the Yellowstone cutthroat trout. North American Journal of Fisheries Management 31:782-812.

Haroldson, M.A., K.A. Gunther, D.P. Reinhart, S.R. Podruzny, C. Cegelski, L. Waits, T. Wyman, and J. Smith. 2005. Changing numbers of spawning cutthroat trout in tributary streams of Yellowstone Lake and estimates of grizzly bears visiting streams from DNA. Ursus 16:167-180.

Heinrich, B. 1999. Mind of the raven: investigations and adventures with wolf-birds. Harper-Collins Publishers, New York, New York, USA.

Koel, T.M., P.E. Bigelow, P.D. Doepke, B.D. Ertel, and D.L. Mahony. 2005. Nonnative lake trout results in Yellowstone cutthroat trout decline and impacts to bears and anglers. Fisheries 30:10-19.

Koel, T.M., D.L. Mahony, K.L. Kinnan, C. Rasmussen, C. Hudson, S. Murcia, and B.L. Kerans. 2006. *Myxobolus cerebralis* in native cutthroat trout of the Yellowstone Lake ecosystem. Journal of Aquatic Animal Health 18:157-175.

Lariviere, S. 2003. Mink (*Mustela vison*). Pages 662-671 *in* G.A. Feldhamer, B.C. Thompson, and J.A. Chapman, editors. Wild mammals of North America: biology, management, and conservation. Johns Hopkins University Press, Baltimore, Maryland, USA.

McEneaney, T. 2002. Piscivorous birds of Yellowstone Lake: their history, ecology, and status. Pages 121-134 *in* R.J. Anderson and D. Harmon, editors. Yellowstone Lake: hotbed of chaos or reservoir of resilience? Proceedings of the 6th Biennial Scientific Conference on the Greater Yellowstone Ecosystem. National Park Service, Yellowstone National Park, Wyoming, USA.

Melquist, W.E., J.S. Whitman, and M.G. Hornocker. 1981. Resource partitioning and coexistence of sympatric mink and river otter populations. Pages 187-220 *in* J.A. Chapman and D. Pursley, editors. Proceedings of the worldwide furbearer conference. Frostburg, Maryland, USA.

Reinhart, D.P., and D.J. Mattson. 1990. Bear use of cutthroat trout spawning streams in Yellowstone National Park. International Conference on Bear Research and Management 8:343-350.

Ruzycki, J.R., D.A. Beauchamp, and D.L. Yule. 2003. Effects of introduced lake trout on native cutthroat trout in Yellowstone Lake. Ecological Applications 13:23-37.

Smith, D.W., L. Baril, A. Boyd, D. Haines, and L. Strait. 2013. Yellowstone National Park bird monitoring report 2013. YCR-2013-1. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, USA.

Smith, D.W., L. Baril, A. Boyd, D. Haines, and L. Strait. 2012. Yellowstone bird program 2012 annual report. YCR-2012-01. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, USA.

Stapp, P., and G.D. Hayward. 2002. Estimates of predator consumption of Yellowstone cutthroat trout (*Oncorhynchus clarki bouveri*) in Yellowstone Lake. Journal of Freshwater Ecology 17:319-329.

Swenson, J.E., K.L. Alt, and R.L. Eng. 1986. Ecology of bald eagles in the Greater Yellowstone Ecosystem. Wildlife Monographs 95:1-46.

Swenson, J.E. 1978. Prey and foraging behavior of ospreys on Yellowstone Lake, Wyoming. Journal of Wildlife Management 42:87-90.

Varley, J.D., and P. Schullery. 1983. Freshwater wilderness, Yellowstone fishes and their world. The Yellowstone Library and Museum Association, Yellowstone National Park, Wyoming, USA.

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Dan Bergum first visited Yellowstone during the 1988 fires as a boy, leading him to pursue a BS in Ecology at the University of Minnesota at Mankato. He has worked as a biologist for the past 12 years and a Bear Management Technician in Yellowstone National Park for the past five. Dan, his wife Karin, and two sons Colter and Theodore, spend their time outdoors exploring the mountains of Wyoming.


Yellowstone National Park
go.nps.gov/bearspray
A bear doesn't care if you're stocking fish eggs.
Fisheries biologists Colleen Detjens and Nate Thomas pour cutthroat trout fish eggs into an incubator in Specimen Creek.
Carry bear spray.
Know how to use it.
Be alert. Make noise. Hike in groups. Do not run.

A DAY IN THE FIELD

Of Mice and Hantavirus

Sarah Haas

NPS PHOTO - N. HERBERT

Yellowstone's northern range, undoubtedly one of the prime wildlife viewing spots in North America, harbors impressive bison herds, wolf packs, and meandering bears. Visitors are likely to depart from the park's northern lands with at least one, if not more, checks on their wildlife card.

Beneath the awe of the large herds and charismatic megafauna lives a quiet, hidden life. The world of the bottom of the food chain is not as glamorous or appreciated as some of Yellowstone's other attractions, but is no less as important. The small mammal communities of the northern range include species such as the deer mouse, bushy-tailed woodrat, and several kinds of voles and shrews. For every bison or wolf, there are probably thousands of these small animals, running over the landscape and providing a whole slew of ecological services: soil enrichment, predator nutrition, enhancing vegetative diversity, etc.

Some of my days in the field have been devoted to the large, captivating wildlife species that attract millions of visitors each year. In August 2015, I devoted a couple of days to learning about the wildlife that don't receive much press, unless it is bad press. Accompanied by Jessica Richards of the park's Wildlife Health Program, we spent one afternoon setting up live traps around the historic Lamar Buffalo Ranch to gather information on the prevalence of hantavirus in small mammal communities in that part of the park.

Rodents are natural reservoirs of hantaviruses, which can cause hantavirus pulmonary syndrome in humans, a rare but potentially deadly respiratory disease. Deer mice (*Peromyscus maniculatus*) are common in the park

Figure 1. (a) Sherman live traps are set against travel corridors of rodents around the barn at Lamar Buffalo Ranch. Jessica Richards (b) weighs and (c) checks the reproductive status of a deer mouse to assess the health and condition of each individual captured.

and a primary host for transmitting hantavirus, if they are infected. Many rodents, but especially deer mice and woodrats, take advantage of human structures such as barns and old cabins to gain protection from predators and improved shelter opportunities. The Lamar Buffalo Ranch was an ideal location to trap and assess the rodents living in the area.

Using peanut butter and oats, along with some cotton to keep the rodents warm once inside the traps, we laid out a grid of 120 traps surrounding the main barn and corrals. The next morning we carefully gathered up the traps, noting which traps were empty and which held a resident. Over 75% of the traps caught a rodent…sometimes two in one trap! Processing that many individuals was a marathon, and once started we did not stop until all the traps were empty and every capture was released back into the wild.

Jess Richards was the conductor of the processing operation, running the program with the skill and speed that only comes with handling thousands of small mammals. Pat Strong, another volunteer, and I provided back-up logistics: data recording, equipment preparation, trap stacking and rearranging, and finally releasing the rodents in the surrounding sagebrush.

From start to finish, nearly 3 hours passed between the first capture and mouse #92. All were deer mice, with the exception of one montane vole. Each rodent was checked for age, sex, reproductive status, and weight. Ear tags were placed on each individual, unless already present from a previous capture operation; a small blood sample was collected; and the animal was released.

Why the need for all this data? Hantavirus is a zoonotic disease, meaning it can pass from animals to humans. Rodents carry and can transmit the virus without detrimental impacts to themselves. For a human, however, infection can be fatal. The primary way a human can be infected is through inhaling airborne dust particles contaminated with saliva, urine, and/or feces from infected rodents. Early signs of infection include flu-like symptoms (fatigue, fever, aches, abdominal pain, nausea, etc.). The first symptoms usually develop within 5 weeks of exposure, with additional symptoms such as coughing and shortness of breath appearing shortly after.

Hantavirus is an important disease to understand due to the high prevalence of the virus in rodents such as deer mice (approximately 10-15%, with some areas far exceeding that rate), a species that is often found near human habitation. Understanding the relationship between zoonotic diseases and human-wildlife interactions is a key component of the National Park Service Wildlife Health Program. Although hantavirus is a disease to be taken seriously, the answer is not to eliminate all rodents from the planet, but rather to learn to live with them wisely. This can be especially critical in national parks, where the mission is to preserve ecosystems, including components that could cause human harm. Wise cohabitation with rodents leads to putting up a healthy distance between our living spaces and theirs, including keeping households and buildings safe, clean, and well maintained to exclude rodent entry.

There has fortunately never been a documented case of humans contracting hantavirus at Yellowstone; how-

Jessica Richards before processing over 90 rodents at Lamar Buffalo Ranch.

ever, an outbreak in Yosemite National Park in 2012 that resulted in the deaths of three visitors was a reminder of the presence and power of this virus in our environment. Most visitors who come to Yellowstone may never encounter a rodent such as a deer mouse, or even their diurnal and more respected cousins the squirrels, and probably leave the park with no sense of missing out. Perhaps the human-wildlife dangers in Yellowstone most people envision (bear attacks, bison goring, elk charging, etc.) keep the mind focused on the megafauna that dominate the landscape. When visitors return home, they keep the images and memories of their experiences in play, retelling stories of the large herds and sharp-clawed creatures they observed. Meanwhile, the mice that make up the food chain dance around our houses and whisper stories of their own—how they stole our scraps and made cushions out of our leftovers. Learn about these creatures and what they bring to our environment, both desirable and unwanted characteristics alike.

To learn more about the National Park Service Wildlife Health Program visit:

www.nature.nps.gov/biology/wildlifehealth/

Sarah Haas is the Science Program Coordinator at the Yellowstone Center for Resources. Her favorite rodent is the Utah prairie dog, a species she grew to know and admire while working at Bryce Canyon National Park.

Learn How to Protect Yourself

Hantaviruses can cause a rare but deadly respiratory disease in people called hantavirus pulmonary syndrome (HPS). Certain rodent species carry hantaviruses, including white-footed and deer mice. Inhaling viral particles of infected urine, feces, and saliva is the primary mode of contracting HPS. The best way to prevent HPS is to exclude rodents from your home, office, or other structure to avoid contact with rodents and their waste. Proper clean up of rodent droppings or urine, including first spraying the area with a 1:10 bleach solution and letting it soak for at least 10 minutes, is also important to kill hantaviruses and prevent contraction of HPS. To learn more about hantavirus and managing rodents in your living space, visit:

www.cdc.gov/hantavirus

Source: NPS Integrated Pest Management Fact Sheet "Managing Rodents to Prevent Hantavirus Infection"

NEWS & NOTES

Member of University of Montana Faculty Wins Prestigious Award

Dr. Fred Allendorf, professor emeritus at the University of Montana and member of the University's Fish and Wildlife Genomics Group, has won the 2015 Molecular Ecology prize. This international award, bestowed annually by the journal *Molecular Ecology*, recognizes scientists for their significant contributions in this interdisciplinary field of research. Dr. Allendorf is considered one of the world's founders of conservation genetics, and his research has dramatically advanced and directed the conservation approaches of numerous taxa and ecosystems. Conservation genetics continues to be an emerging field that contributes significantly to our understanding of wildlife population health, by increasing our knowledge of genetic diversity, inbreeding, hybridization, and species fitness. Dr. Allendorf has worked shoulder-to-shoulder with other prominent University of Montana researchers (e.g., Gordon Luikart, Stephen Amish, Robb Leary, and Clint Muhlfeld) on conservation genetics research demonstrated to be vital to the Northern Rockies ecosystem. From Glacier to Yellowstone national parks, the University of Montana Fish and Wildlife Genomics Group has shed significant light on population genetics and the recovery of key species, such as westslope cutthroat trout, Yellowstone cutthroat trout, bison, and bighorn sheep. Specifically, their work has helped us better understand the effects of hybridization on native cutthroat trout populations across much of the western United States. Their continued research on the use of different genetics methods to improve and direct applied conservation remains a formidable partner in species management and conservation both regionally and worldwide.

Jennifer Carpenter Named Chief of Yellowstone Center for Resources

Jennifer Carpenter has been selected as the park's new chief of the Yellowstone Center for Resources (YCR), selected in July 2016 after serving as the acting chief for 18 months.

As YCR Chief, Carpenter is responsible for overseeing more than 100 permanent and seasonal employees. YCR was created in 1993 and is responsible for managing all park science and resource management operations—wildlife management, aquatic resources, vegetation, cultural resources, geology and physical resources, social science, environmental compliance, science communications, and research programs. YCR works to promote scientific research within the park and integrate that research into management decisions.

Jennifer has worked in Yellowstone since 2012, where she served as the Branch Chief for Compliance and Science Communications until 2014. Prior to arriving in Yellowstone, Jennifer worked at Grand Teton National Park, Lassen Volcanic National Park, and Bandelier National Monument. Before joining the National Park Service in 2004, Jennifer worked as a biologist for several environmental consulting firms and for the Arizona Game & Fish Department. Jennifer obtained a Bachelor of Arts in Ecology and Evolutionary Biology from the University of Arizona and a Master of Science in Applied Ecology and Environmental Resources from Arizona State University.

Jennifer is a native of Colorado, although she grew up in Arizona. Jennifer lives in Mammoth, Wyoming, with her husband, Dan Kowalski, a park law enforcement ranger, and their three-year-old daughter, Estelle.

13th Biennial Scientific Conference Held in Grand Teton National Park

On October 4-6, 2016, the Biennial Scientific Conference of the Greater Yellowstone Ecosystem (GYE) gathered 345 researchers, land managers, conservations groups, and students at the Jackson Lake Lodge in Grand Teton National Park.

This year's conference focused on deriving management lessons and applications from previous practices, recognizing trends, and anticipating future conservation needs within the GYE.

Over 100 talks and posters were presented on a range of topics, including:

- connecting current protected areas to promote landscape-level protection
- building public-private partnerships critical to work across political and administrative boundaries to achieve conservation goals
- inspiring the next generation of scientists through research and citizen science opportunities
- identifying and preserving culturally relevant sites and stories as a core part of our conservation approach

Distinguished keynote speakers and award winners joined the conference. They included Opening Keynote speaker, David Quammen; Aubrey L. Haines Award winner, Dr. Bill Wyckoff; Starker Leopold Award winner, Dr. Robert Gresswell; and Superintendent's International Lecture, Dr. Gary M. Tabor.

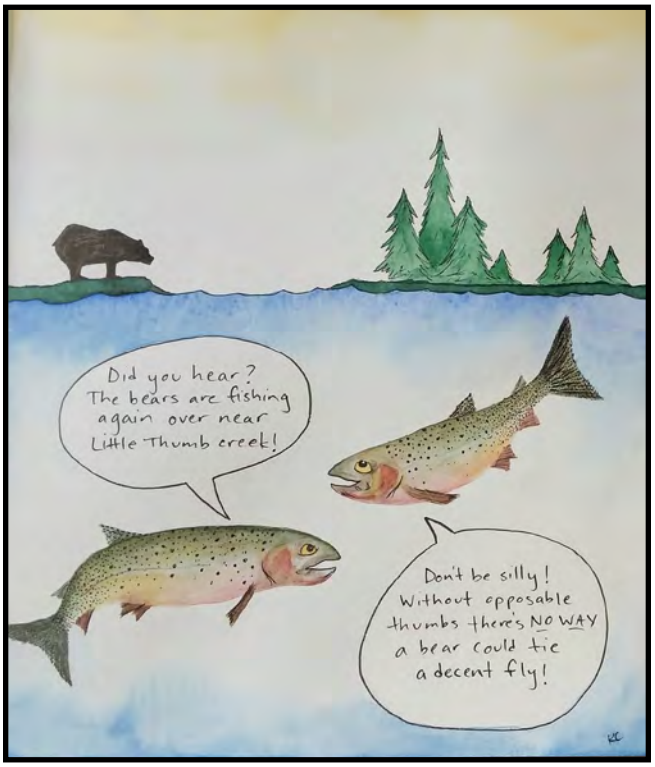
The Conference featured field trips for the first time. Natural History participants learned about resource management issues related to warm spring illegal aquarium dumping, native restoration efforts to revegetate 4,500 acres by Kelly Hayfield, century scale vegetation change fire effects, and pronghorn migration.

Cultural history attendees toured the National Historic Landmark Jackson Lake Lodge, Colter Bay Museum, the historic AMK Ranch, and concluded with a short skills session on creating and fostering a culture of resource stewardship in parks.

Over 50 students, many of whom were granted scholarships, added their perspectives to the future.

"*Attending the conference gave me hope for the future of our planet when I saw so many scientists contributing to our knowledge of ecosystem dynamics, and climate change. It was good to see so many people working together to solve problems and to come up with real life solutions.*" –Danielle Beazer, Great Basin College.

This important event will continue to rotate throughout the GYE for future conferences and continue to bring together those who work to conserve the GYE in the coming century.



@ KIRA CASSIDY

SNEAK PEEK

Coming Up in *Yellowstone Science*

60 Years of Acheology in Yellowstone

Tobin Roop

Archeologists walk in grid formation while doing a boundary survey in the northern part of Yellowstone National Park. PHOTO © D. MACDONALD

Wild, pristine, untrammeled. When thinking about Yellowstone, a vast and amazing back-country, large carnivores, ungulates, iconic geysers, and geothermal features fill the imagination. However, 11,000 years of Yellowstone's human history is for most people a hidden text. As we approach sixty years of archeological research in the park, we know a great deal more about how ancestors of today's Native American tribes lived in Yellowstone. Decades of careful scientific research on thousands of archeological sites, such as Osprey Beach and Fishing Bridge Village, provide a window into what it was like to live in this area before it was "discovered" by Europeans. Obsidian Cliff, a designated National Historic Landmark, was one of the most important stone quarries in North America, its stunning black glass traded over thousands of miles for millennia. On a more somber note, one recently documented site in the park is a high-altitude bivouac where a band of Nez Perce camped in 1877 as they fled the United States Army in one of the last great acts of resistance during the Indian Wars of the west. Yes – that's right: that terrible event is captured in an archeological site dating to five years after the creation of the worlds' first national park. Not long after the park

was established, burgeoning commercial ventures, and administration by the U.S. Army and the National Park Service are represented by archeological sites, including trash dumps, abandoned buildings, and privies.

Philetus Norris, serving from 1877 to 1882 as the park's second superintendent, collected prehistoric artifacts, often documenting and sketching them. He shipped many of those artifacts to the Smithsonian in Washington, D.C., where they remain today. He did this even as the park actively pushed Native Americans out of Yellowstone and discouraged acknowledgment of native occupation. Artifacts were seen as novelties to be collected, and not as resources worth protecting. For many late-19th century Americans, glimpses of Native American tools and campsites were simply reminders of a recently pacified west where the vast majority of Native Americans had been forcefully moved to reservations. Yellowstone was no different.

In 1948, Smithsonian surveyors initiated the long history of formal archeological work in Yellowstone. The contemporary advent of radiocarbon dating allowed researchers to construct fine scaled cultural histories across the continent, including the Northern Rockies. This was followed by the passage of the National Historic Preservation Act in 1966. This seminal legislation required consideration of cultural resources, including archeological resources, into government planning efforts and park management. In Yellowstone, archeological surveys and excavations are undertaken in preparation for park development projects. Over the following decades, a body of thousands of archeological sites has been documented and protected in Yellowstone, though to-date, roughly 86 square miles, or just 2.5% of the park, has been surveyed. Alongside this work are traditional stories and place names from many tribes whose ancestors had for millennia visited and lived in Yellowstone. Collectively, this information helps us more accurately understand the human history of one of the most treasured landscapes in the world and challenge the myth of a "wild" place discovered by Euro-American explorers.

Prehistoric and historic archeological resources in Yellowstone inform and challenge how we think about this ecosystem. Yellowstone, more than any place in the lower 48, has come to symbolize "wildness." Yet, how do we reconcile a narrative that this place is "wild" with the clear implication that wild means without human presence – when the evidence clearly refutes this? What is "wild" about a place that was the center of a continental wide obsidian trade for thousands of years. How has recent research by park staff and university partners helped us better understand the long and complex human history of Yellowstone? How do the stories of native peoples about Yellowstone challenge our assumptions? That is the story for our next issue of *Yellowstone Science*.


PHOTO © D. MACDONALD

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OUR DEDICATED FISHERIES STAFF 2016

Back row (left to right): Sarah Rubenstein, Ben Brogie, Chris Pullano, Brandon Piper, Nichole Diedrich, Paul Van Winkle, Andrew Stimetz, Brian Ertel, Ben Holt, Drew MacDonald. Middle row (left to right): Kurt Heim, Jesse Gordon, Taylor Preul, Lauren McGarvey, Phil Doepke, Pat Bigelow, Michelle Briggs, Colleen Detjens, Jeff Arnold, Andriana Puchany, Todd Koel. Front row (left to right): Kim Barrett, Bryan Giordana, Logan Yurga-Bell.

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