Aquatic Ecology


NPS/JEFF ARNOLD

Goose Lake and Goose Neck Lake (shown here) were surveyed for fishes, macroinvertebrates, and amphibians in 2007 to determine their potential for supporting pure-strain westslope cutthroat trout.

Long-term Water Quality Monitoring

Monitoring water quality continues to be a high priority for Yellowstone, with standardized data available for 17 sites going back to May 2002. The monitoring is conducted in cooperation with the Vital Signs Monitoring Program of the Greater Yellowstone Network, which includes Yellowstone National Park, Grand Teton National Park (including John D. Rockefeller Memorial Parkway), and Bighorn Canyon National Recreation Area. In Yellowstone, 12 sites are on major rivers and 7 are on Yellowstone Lake, including two sites added to the program in 2003 (Figure 1). Because stream discharge strongly influences limnological processes, most of the stream sites are located near U.S. Geological Survey discharge gaging stations so that flow-weighted measurements can be calculated for chemical parameters.


NPS/JEFF ARNOLD

A pair of blotched tiger salamanders at a wetland near the Gibbon River.

The purpose of the long-term water quality program is to acquire baseline information for Yellowstone's surface waters that can be used to evaluate overall ecosystem health, ascertain impacts of potential stressors (e.g., road construction activities or accidental sewage spills), identify any changes that may be associated with water quality degradation, and guide resource management decisions related to water quality. In 2007, data was collected monthly at each monitoring site on core water quality parameters, including water temperature, dissolved oxygen, pH, specific conductance, and turbidity. Water samples were brought back to the laboratory for total suspended solids (TSS) analysis. In addition, 10 of the sites were sampled for various chemical parameters, including anions (sulfate, chloride, bicarbonate and carbonate), cations (calcium, magnesium, sodium, and potassium), and nutrients (total phosphorus, orthophosphate, nitrate, nitrite, and ammonia). Dissolved and total metals (arsenic, copper, iron, and selenium) in water and sediment are measured twice annually during high and low flow periods on the upper Soda Butte Creek at the park boundary near Silver Gate, Montana.

Core Water Quality Parameters

The 2007 statistics for core water quality parameters indicate spatial trends very similar to those observed from 2002 to 2006. In general, physical and chemical characteristics of water quality are related to seasonal changes, elevation, precipitation events, and presence or absence of thermal features. Water temperature and dissolved oxygen (DO) are closely tied because colder water holds more oxygen. With the exception of the Gardner River, overall water temperatures were generally lowest and DO concentrations highest on sites within the Yellowstone River drainage, which has minimal geothermal activity compared to the Madison River drainage (Figure 28a and b). Surface water temperatures ranged between –0.2 and 25.5°C in 2007. The lowest and highest mean annual temperatures were both recorded within the Yellowstone River drainage on upper Soda Butte Creek (4.7°C; range -0.1–13.8°C) and the Gardner River (16.0°C; range 10.6–24.1°C) respectively (Figure 28a). Meanwhile, average DO concentrations remained relatively consistent among sample sites (mean for all sites ranged from 8.5 to 10.8 mg/L).

The acidity of surface water in Yellowstone, measured in pH, commonly ranges from 2.0 to 9.0 standard units (SU), with most waters having a pH near neutral (6.5–7.5) to slightly basic (7.5–8.5). The pH is influenced by water source, local geology, atmospheric deposition, geothermal contributions, and biological factors. Within-site variation of pH was quite low in

ANGELLA SMITH, BOZEMAN, MT

A bull snake Pituophis catenifer sayi *captures a cutthroat trout hybrid from the Gardner River near the Boiling River visitor area.*

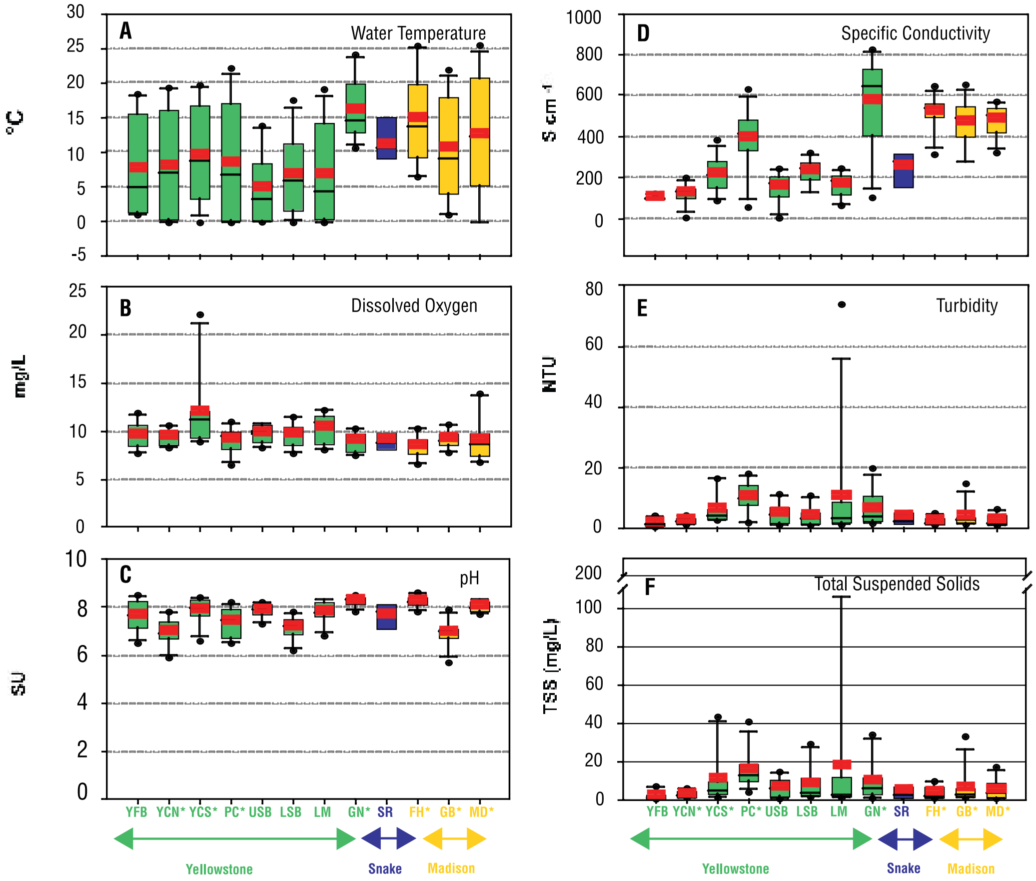

Figure 28. Box and whisker plot illustrating annual variation for selected parameters at each water quality location. Lower and upper portions of boxes represent the 25th and 75th percentile respectively: lower and upper black horizontal bars represent 10th and 90th percentile respectively. Outlying values are represented by black dots; means are indicated by solid red lines. Green, blue, and orange represent the Yellowstone, Snake, and Madison river basins, respectively (YFB = Yellowstone River at Fishing Bridge, YCN = Yellowstone River at Canyon, YCS = Yellowstone River at Corwin Springs, PC = Pelican Creek, USB = upper Soda Butte Creek, LSB = lower Soda Butte Creek, LM = Lamar River, GN = Gardner River, SR = Snake River, FH = Firehole River, GB = Gibbon River, and MD = Madison River). (*) = indicates sites with geothermal contributions. Snake River is not sampled during winter months.


NPS/JEFF ARNOLD

Soda Butte Creek (left) carrying sediment after a thunder shower is much more turbid than the clearer Lamar River (right) at its confluence.

2007; most differences occurred spatially across the park and among sites (Figure 28c). The Madison River, for example, receives water from the Firehole and Gibbon rivers, both of which are influenced by geothermal activity. But while the mean pH at the Firehole River was 8.21 SU (range 7.8–8.6), the Gibbon River, into which flows very acidic geothermal water, had lower pH values (mean of 6.9 SU, range 5.7–7.9). Specific conductance, turbidity, and total suspended solids (TSS) are directly related to stream flow. Specific conductance is a measure of a solution's resistance to conducting electricity. The ability of water to conduct electrical current increases with an increase in ion content (i.e., anions and cations); hence, the purer the water, the lower the specific conductance (Wetzel 2001). Specific conductance at all sites was lower during the high flow periods of May and June, and higher during the low flow periods of late summer and winter. Specific conductance was higher at stream sites that received geothermal inputs, including Pelican Creek and the Gardner River within the Yellowstone River basin and the Firehole, Gibbon, and Madison rivers within the Madison River basin (Figure 28d). Yellowstone Lake operates as a buffer to the upper Yellowstone River system, resulting in low annual variation in specific conductance, turbidity, and TSS. The Yellowstone River at Fishing Bridge (at the lake outlet) had the lowest mean specific conductance, 100 µSiemens (µS cm-1) with a range of 95–123 µS cm-1. Conversely, the Gardner River station exhibited the highest mean specific conductance, 573 µScm-1 with a range of 103–827 µScm-1. Both turbidity, which is measured in nephelometric turbidity units (NTU), and TSS concentrations, which are measured in mg/L, are measures of water clarity. For both parameters water clarity remains very good throughout the year, with more turbid conditions being observed during snowmelt and after rainfall events, which is typical of mountain streams with minimal sediment contributions (Figure 28e and f).


NPS/JEFF ARNOLD

MSU water quality technician Ty Harrison collecting data from the Lamar River as a part of the NPS Vital Signs Water Quality Monitoring Program.

Chemical Constituents of Surface Waters

As part of the long-term water quality monitoring program, we began collecting water samples for chemical analysis at 10 stream sites within the Yellowstone and Madison river drainages in May 2006, and completed the first calendar year of this data collection in 2007. The added parameters include select anions, cations, and nutrients (Appendix v). Aquatic plants use these dissolved chemicals to varying degrees for basic cellular structure, metabolism, growth, and development. In Yellowstone, dissolved concentrations of ions and nutrients are most closely related to natural factors such as geology, discharge, geothermal input, grazing, and uptake by aquatic plants, but there are also anthropogenic sources such as sewage spills, runoff from paved road surfaces, and acid mine drainage. Generally, dissolved ion concentrations in Yellowstone waters are relatively low, with higher concentrations observed during low flow conditions and lower concentrations during high flow conditions.

Relative concentrations of major anions and cations were calculated for each site and a unique pattern of relative dissolved ion concentrations were observed between the Yellowstone and Madison River drainages (Figure 29). For the most part, relative concentrations of bicarbonate (HCO$_3^{2-}$) ions were dominant at all water quality stations. However, concentrations of other major ions seemed to vary among watersheds. The Lamar River drainage, within the Yellowstone River basin, had higher concentrations of calcium (Ca^{2+}) ions than the Yellowstone River mainstem, which had higher concentrations of sulfate (SO$_4^{2-}$) ions. In addition to bicarbonate ions, both sodium (Na$^+$) and chloride (Cl$^-$) were present in approximately equal proportions within the Madison River basin (Figure 29). Both phosphorus and nitrogen concentrations remained very low for all sites sampled. Mean total phosphorus concentrations were highest on the Firehole River (0.23 mg/L, with a range between 0.18 and 0.30 mg/L). Orthophosphate, nitrate, nitrite, and ammonia were very low; most concentrations were below the analytical detection limits.

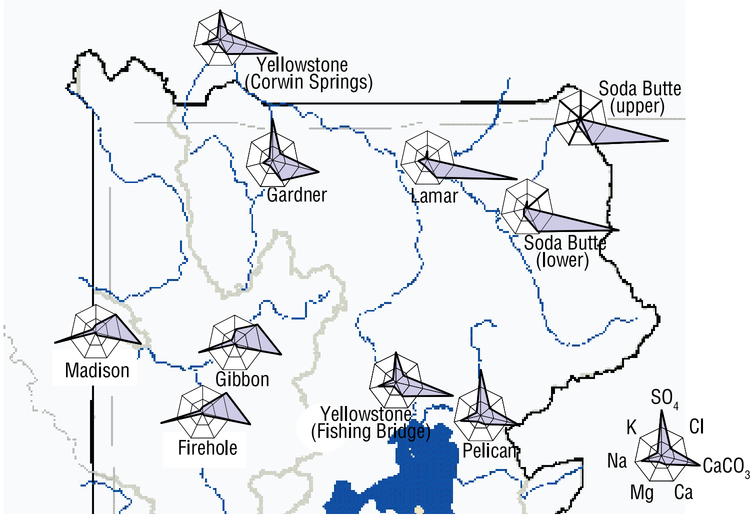

Figure 29. Average annual percent ion concentration of seven measured ions from water quality sites on rivers and streams in Yellowstone National Park. The concentric heptagons represent the 10th and 20th percentiles respectively from the center with remaining percentiles not shown. (SO4 = sulfate, Cl = chloride, CaCO3 = bicarbonate, Ca = calcium, Mg = magnesium, Na = sodium, K = potassium).

Regulatory Monitoring on Soda Butte Creek

In conjunction with routine water quality monitoring, we sampled dissolved and total metals in water and sediments on Soda Butte Creek near the park's northeast boundary. The state of Montana has listed Soda Butte Creek upstream of the Northeast Entrance as "water quality impaired" because of elevated metal concentrations from the McClaren mine tailings that are located near Cooke City and within the Soda Butte Creek floodplain. On June 14 and September 20 (during periods of high and low stream flow, respectively), we collected water and sediment in both the morning and evening to capture diurnal variations in arsenic, copper, iron, and selenium. Total and dissolved arsenic, copper, and selenium were below analytical detection limits in all water samples. Levels of dissolved and total iron concentration in water did not exceed the state of Montana's aquatic-life standards for any sample event. Dissolved iron


NPS/JEFF ARNOLD

Student Conservation Association (SCA) intern and international VIP Eefje Smit collecting water quality data from Soda Butte Creek.

was below detection limits, while total iron had recorded values of 0.393 and 0.535 mg/L in June and 0.536 and 0.55 mg/L in September. Total hardness was near 41 mg/L in June and near 91 mg/L in September.

In the sediment samples, arsenic and selenium were below detection limits on both sample days. Concentrations for both copper and iron tended to be lower in June than in September: copper (12.25 and 24.55 mg/kg respectively) and iron (17,050 and 25,600 mg/kg respectively). Concentrations of arsenic and copper in sediments were well below the probable effect concentrations listed by Ingersoll and MacDonald (2002), at 33 mg/kg and 149 mg/kg respectively. There are no recognized standards for iron and selenium in sediments.

Whirling disease, caused by the exotic parasite *Myxobolus cerebralis*, is responsible for severe declines in wild trout populations in the Intermountain West…

Yellowstone Lake Limnology

Yellowstone Lake is the largest high alpine lake in the contiguous United States and the most prominent body of water in Yellowstone National Park. Understanding Yellowstone Lake limnology is an important element in comprehending the ecology of lake trout and aids park fisheries biologists with the lake trout suppression program. Water temperature, dissolved oxygen, specific conductance, and turbidity measurements were sampled monthly from May through October 2007 at seven sites located throughout the Yellowstone Lake basin (Figure 1). In addition, with weather permitting, temperature profile data was collected from the West Thumb and South Arm area of Yellowstone Lake. Water samples were collected at each location for analysis of total suspended solids (TSS) and volatile suspended solids.

Avian Piscivores as Whirling Disease Vectors

Whirling disease, caused by the exotic parasite *Myxobolus cerebralis* (Myxozoa: Myxosporea), is responsible for severe declines in wild trout populations in the Intermountain West, including a decline in native cutthroat trout in Yellowstone National Park (Koel et al. 2005). Movement of infected hatchery fish has been blamed for the spread of *M. cerebralis* in Colorado and its introduction in Wyoming (Bartholomew and Reno 2002). The vector for dissemination to many waters of the Intermountain West, including the relatively pristine and highly protected waters of Yellowstone, is unclear. Obvious possible vectors include the movement of myxospores by anglers and their gear (Gates 2007) or by fish-eating wildlife, especially those capable of traveling long distances in a short time, such as birds.


PHOTOS BY USDA/APHIS

A great blue heron is fed a rainbow trout in the USDA/APHIS aviary at Fort Collins, CO (top); a double-crested cormorant enjoys his tank while waiting for feeding time at the aviary.

Although the specific mechanism resulting in transmission was unclear, in an early study by Taylor and Lott (1978), trout were infected with *M. cerebralis* in ponds exposed to waterbirds. El-Matbouli and Hoffman (1991) demonstrated that myxospores can pass through the gastrointestinal tracts of northern pike (*Esox lucius*) and mallard (*Anas platyrhynchus*) without loss of infectivity. However, it remained unknown if myxospores remain viable after passage through wildlife species that specifically prey on trout, especially avian piscivores and other animals that can range widely among drainages. Research initiated by Barrows et al. (1999) documented the evacuation rates of trout by white pelicans (*Pelicanus erythrorhynchos*) and bald eagles but did not examine the myxospore transfer through these birds or subsequent viability.

Beginning in 2005, park staff partnered with Montana State University's Department of Ecology and the USDA Animal and Plant Health Inspection Service's National Wildlife Research Center (NWRC) to determine the potential of highly mobile avian piscivores, including American white pelicans, great blue herons (*Ardea herodius*), great egrets (*Ardea alba*), and double-crested cormorants (*Phalacrocorax auritus*) as dispersal vectors for *M. cerebralis*. Our specific objectives were to determine if *M. cerebralis* can be detected after it has passed through these bird species' gastrointestinal tracts and, if so, whether it remains viable.

In May 2005, rainbow trout (six weeks post hatch) were infected by *M. cerebralis* by exposure to triactinomyxons (TAMs) at the Montana Water Center's Wild Trout Laboratory in Bozeman. In winter/spring 2006, biologists at the NWRC Mississippi Field Station (Mississippi State University) captured six each of American white pelicans, double-crested cormorants, great blue herons, and great egrets and transported them to an aviary at Fort Collins, Colorado, for disease challenges. Three birds of each species were simultaneously fed 10 infected trout; the other three were given certified disease-free placebos. Fecal material was collected prior to the experimental feeding and each day for 10 days afterward. A one-gram fecal sub-sample from each bird was sent to Pisces Molecular, Colorado, for genetic analysis to detect *M. cerebralis* DNA. Another 1-gram sub-sample was used to test for infectivity in *Tubifex tubifex* in the ecology laboratory at Montana State University.

Through analysis of fecal samples spiked with known concentrations of myxospores, we determined that the lowest detectable limit of our PCR method was 250 myxospores per gram of fecal material. We found *M. cerebralis* DNA in the feces of all 12 birds that had been fed infected fish, but only the great blue herons' feces induced TAM production by *T. tubifex* held in laboratory cultures. Thus, our study confirms the ability of herons to vector *M. cerebralis* among aquatic habitats in the Greater Yellowstone Ecosystem and elsewhere. Our more equivocal results for the other three bird species may have been caused by an unknown aspect of our experimental protocol or real differences in the effects of these bird species' gastrointestinal tracts on myxospores. Replication of this work may improve our understanding of the ability (or lack thereof) of pelicans, cormorants, and egrets to vector *M. cerebralis*.


USDA/APHIS

A great blue heron ready to select one of the rainbow trout placed in the pool at the USDA/APHIS aviary.

...our study confirms the ability of herons to vector *M. cerebralis* among aquatic habitats in the Greater Yellowstone Ecosystem.


NPS/TODD KOEL

Research conducted by NPS, MSU, and USDA/APHIS documented the ability of avian piscivores to move whirling disease within Yellowstone. Here, great blue herons and American white pelicans search for trout along the margin of the Yellowstone River near Alum Creek, a whirling disease infected stream.

Angling in the Park

Drought Fishing Restriction Strategy

Yellowstone adopted a Drought Fishing Restriction Strategy in 2007 that outlined criteria and options for restrictions on fishing in an effort to preserve native and wild trout.

Geothermal features naturally affect the temperature regimes of several popular Yellowstone fishing waters, such as the Firehole, Gibbon, and Madison rivers. Although the trout in these streams are considered "coldwater" species, they have behaviorally adapted to deal with these conditions. In recent years, however, regional weather patterns have resulted in extremely low flows and high stream temperatures in the park. These changes have heightened effects on fish living in geothermally-influenced streams and threaten to stress native and wild trout in many other park waters where they are not accustomed to such conditions. During three of the past six years (2002, 2003, and 2007, see below), low flows and high water temperatures have necessitated placing additional restrictions on angling to protect trout populations from stress. Given predictions of a warming climate, drought conditions in Yellowstone may persist long term, and actions to protect trout may become routine.

Yellowstone streams vary in temperature but are always coldest at dawn and warmest at dusk. The relatively high elevation and cool nighttime air temperatures cause stream temperatures to drop overnight, especially in smaller streams. It is not uncommon for the temperature of a park stream to range 25°F or more during a 24-hour period. However, the larger rivers are much slower to cool down, and fishes in these waters get little relief from extended heat during the summer season. There is also much less variation between daytime and nighttime temperatures in smaller streams that are influenced by geothermal features.

Temperature limits vary among trout species, with rainbow and brown trout tolerating somewhat higher temperatures than do cutthroat trout. The cumulative impact of sustained high stream temperatures is that cold-water adapted trout become extremely stressed. In general, trout mortality is high in waters >68°F (20°C) and complete in waters >73°F (22.7°C). Above this temperature, trout almost certainly will die, especially if exposed for extended periods. Angling of heat-stressed trout, which often congregate in deep pools seeking shade and cooler water, significantly adds to their stress. Trout that would be capable of revival and release following a fight when caught in cold water are more likely to die when caught in warm water. Because of this, Yellowstone adopted a Drought Fishing Restriction Strategy in 2007 that outlined criteria and options for restrictions on fishing in an effort to preserve native and wild trout. When stream flows decline below long-term averages, and/or stream temperatures approach 73°F (22.7°C) for three consecutive days, the park may impose either of the following restrictions:


NPS/BRIAN ERTEL

High temperatures resulted in a trout die-off on the Firehole River in 2007.

A) Time-of-Day Restriction: Fishing begins at 5 AM and ends at 2:00 PM each day. No fishing allowed after 2:00 PM.

B) Full Closure: All fishing on the designated waters will be prohibited. This restriction is appropriate for waters with extremely low flows that threaten the fishery resources (e.g., excessive angling pressure concerns). Full closures may be implemented in priority waters that meet the thresholds and in which Time-of-Day Restrictions are inadequate, and in other waters if conditions warrant.

The decision regarding which restriction to apply will depend on the threat to the fisheries as well as the existing and projected fishing pressure.

Extreme Heat Forces Angling Restrictions

By the third week in June 2007, temperatures on the Gibbon and Firehole rivers were already exceeding 22.7°C each day. By the first week of July, daily temperatures were exceeding 77°F (25°C) and 82°F (28°C) in the Gibbon and Firehole rivers, respectively (YVO, 2007). On July 6, the same day the park issued a Fishing Advisory, we learned of a significant trout die-off on the Firehole River. We found hundreds of dead fish along the river all the way from Midway Geyser Basin downstream to Firehole Cascades. Dead trout were also found in Nez Perce Creek from the road bridge downstream to its confluence with

NPS/BILL VOIGT

Anglers on Grayling Creek participate in the Yellowstone Fly Fishing Volunteer program.

the Firehole River. All of the fish were 2–14" brown or rainbow trout in varying stages of decay. It was felt that the fish kills within these geothermally-influenced streams were anomalies, and were very surprised when three days later the Fisheries Program ecologists conducting water quality monitoring found evidence of a large fish die-off on Pelican Creek near the road viaduct and upstream in the location of the historical fish weir. The dead fish along the stream margin and bottom included longnose dace, longnose suckers, and redside shiners. Fish that were still alive were lethargic and unresponsive. None of the fish found were cutthroat trout.

The July 6 Fishing Advisory asked anglers for voluntary cooperation in refraining from fishing between noon and 6 PM on several priority waters. However, because heat and dry conditions continued, mandatory restrictions announced on July 21 limited fishing on these waters to 5:00 AM to 2:00 PM. By late July the flows within the park, particularly those across the Yellowstone River drainage, had declined to a mere fraction of their normal levels. The low flows occurred from Soda Butte Creek downstream through the Lamar River and mainstem Yellowstone River at the park's north boundary (Figure 1). These conditions were also seen far upstream on Slough Creek at the park boundary and Silvertip Ranch area. Although stream flows remained low through August, cooling nighttime temperatures brought much needed relief to streams. On August 22, with daily peak temperatures rapidly declining and remaining well below 73°F (22.7°C), the fishing restrictions were lifted.

Trends from Volunteer Angler Report Cards

Angling remains a popular pastime for those visiting, living near, and working in Yellowstone National Park. Of the record 3,151,342 visitors to the park in 2007, 47,069 obtained the special use fishing permit required for fishing in park waters and a volunteer angler response (VAR) card. These cards, which have been handed out since 1973, provide anglers an opportunity to share their fishing success and opinions about the park's fishing opportunities with park managers. The response rate of almost 3,000 angler outings is a decrease from recent years. Exit gate surveys, in which some visitors are interviewed as they leave the park, also provide information about how many visitors fished. This year's gate surveys revealed that nearly 2.4% of the visitors who purchased a permit did not fish, while 0.5% of visitors fished without a permit; this resulted in an estimated 46,318 anglers fishing during the 2007 season.

Parkwide angler use (total number of days anglers spent fishing) was 389,360 days in 2007, which was 36% more than in 2006. Based on the 2007 VAR data, we estimate that anglers landed 998,318 fish and creeled 51,752, releasing more than 95% of the fish they caught. Anglers fished for an average of 2.79 hours a day during a typical outing and on an average of 1.71 days during the season. Although visitors who fished only one day comprised 63% of fishermen, 82% of all anglers caught fish. Anglers reported being satisfied with their overall fishing experience (76%), with the number of fish caught (64%), and with the size of fish

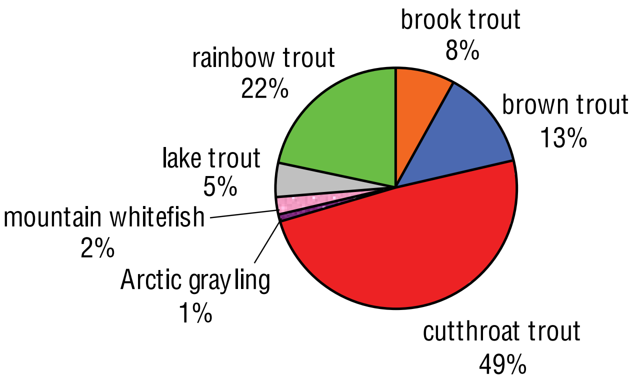

Figure 30. Percentage of each species in parkwide, angler-reported catch during the 2007 fishing season.

Native cutthroat trout remained the most sought after and caught fish species again in 2007, comprising 50% of all fish caught.

(66%), representing little change from previous years.

The 2007 VAR cards reported the lengths of 20,988 fish. The overall mean length of fish caught in the park was 11.4 inches, with 38% of them longer than 12 inches and 26% longer than 14 inches. Average fish lengths increased in 2007 for all but cutthroat and rainbow trout. Lake trout had the greatest average length (17.5", a 0.5" increase from 2006), followed by whitefish (12.1", a 0.7" increase), cutthroat (12.0", a 0.3" decrease), brown trout (11.3", a 0.5" increase), rainbow trout (10.1", no change), grayling (9.9", a 1.6" increase) and brook trout (7.5", a 0.5" increase).

Native cutthroat trout remained the most sought after and caught fish species again in 2007, comprising 50% of all fish caught (Figure 30). Rainbow trout were the second most caught fish, comprising 21% of angler catch, followed by brown trout (13%), brook trout (8%), lake trout (5%), mountain whitefish (2%) and grayling (1%). Native fish species (cutthroat, whitefish, and grayling) comprised 53% of all reported fish caught.

An estimated 7,764 anglers, or about one out of every seven anglers in the park, fished Yellowstone Lake, making it again the most popular place to fish. Anglers caught an estimated 84,411 cutthroat trout in the lake in 2007, an increase from 2005 and 2006. The reported number of cutthroat trout caught per hour also increased, from 0.41 in 2006 to 0.57 in 2007. However, the average reported size of cutthroat trout decreased slightly from 454 mm (17.9") in 2006 to 444 mm (17.5") in 2007 (Figure 31). Extremely large cutthroat trout continue to be caught each year on Yellowstone Lake; in 2007 the relative abundance of fish >20 inches long (27% of the total catch) was nearly equal that of fish 18–20 inches long (28% of the total catch). Unlike the size distribution of cutthroat trout caught during the fall netting assessment, cutthroat trout 18–20 inches long have comprised the majority of the angler catch since 2003 (Figure 32). The cutthroat trout most often caught by anglers measured 14–16 inches in 2000, 16–18 inches in 2001, and 18–20 inches during 2003–2007. Similar sizes of lake trout have been reported by anglers on Yellowstone Lake. In 2007, the majority of lake trout caught were in the 16–20 inch (40–50 cm) size classes (Figure 32). The lake trout suppression program (discussed above) has been effective at ensuring that most lake trout do not live to larger sizes. A fishing guide at the Bridge Bay marina on Yellowstone Lake speculated that the recent increases in lake trout catches could be due to local anglers targeting them and having better knowledge of angling tactics designed to catch lake trout, such as downriggers and weighted fishing line. Anglers in Yellowstone Lake reported good catches of lake trout in 40 to 70 feet of water, especially in the West Thumb, Breeze Channel and areas near Frank Island.

Mercury in Lake Trout and Rainbow Trout

Although Yellowstone's waters are among the most pristine in the world, mercury (Hg) is present from both natural and unnatural sources. Natural sources include the park's iconic geothermal features (Hall et al. 2006; King et al. 2006), which are typically associated with streams and lakes. However, atmospheric deposition of inorganic Hg is an additional source of contamination (Krabbenhoft et al. 1999; Krabbenhoft et al. 2002) from sources that can be great distances away (Sorensen et al. 1994; Glass and Sorensen 1999). Methylmercury (MeHg) is the most common form of organic Hg (Hg bound to carbon) and the form that most easily accumulates in organisms (USGS 2008). Inorganic Hg deposited from the atmosphere in rain or snow is transformed into MeHg within aquatic systems by sulfur-reducing bacteria found in the anoxic (low oxygen) environment of bottom sediments. Within these environments, MeHg can persist for long periods, allowing bottom-dwelling organisms to accumulate them and pass them up the food chain to fish. Since concentrations of MeHg increase at each level in the food chain, concentrations in top predators may be a million or more times that found in the water where they live (EPA 2007).

Methylmercury is a neurotoxin, meaning that it has the potential to harm the nervous system, especially that of an unborn baby or young child. In fact, MeHg is considered the most toxic and widespread contaminant effecting aquatic systems in the United States (Krabbenhoft 1999). Over 80% of all fish consumption advisories nationwide are due, at least in part, to Hg, and 49 states have issued fish consumption advisories due to elevated MeHg levels (EPA 2007).

Since the presence of lake trout in Yellowstone Lake was confirmed in 1994, the park has required that all lake trout caught there be harvested or otherwise killed. In addition, the 2006 changes to the park's angling regulations included a liberalization of harvest limits for non-native trout (Koel et al. 2006*b*). Encouraging the harvest of introduced fish has compelled us to find out more about the possible health risks associated with their consumption. During 2007 we collected 24 lake trout from Yellowstone Lake and 27 rainbow trout from the Lamar, Gardiner, and Gibbon rivers and had them analyzed for total mercury by the Environmental Research Laboratory at the University of Minnesota–Duluth. Two samples were also analyzed for MeHg, which confirmed that most of the mercury was in the MeHg form (>90%).

The lab results indicated that consumption advisories are appropriate for Yellowstone. Because MeHg levels vary across water bodies and increase dramatically in a fish as it grows, consumption advisories are typically specific for a given species and water body. Mercury concentrations in the lake trout from Yellowstone Lake ranged from 38 to 90 ng/g (wet weight) in fish <50 cm long, to 527–599 ng/g for fish >80 cm (Figure 33). However, no statistically significant difference was found between the mercury concentrations in lake trout from the West Thumb and those from the main basin of Yellowstone Lake. Consumption guidelines based on thresholds developed by the U.S. Environmental Protection Agency are given as the recommended safe number of meals per month for fish of the indicated size (EPA

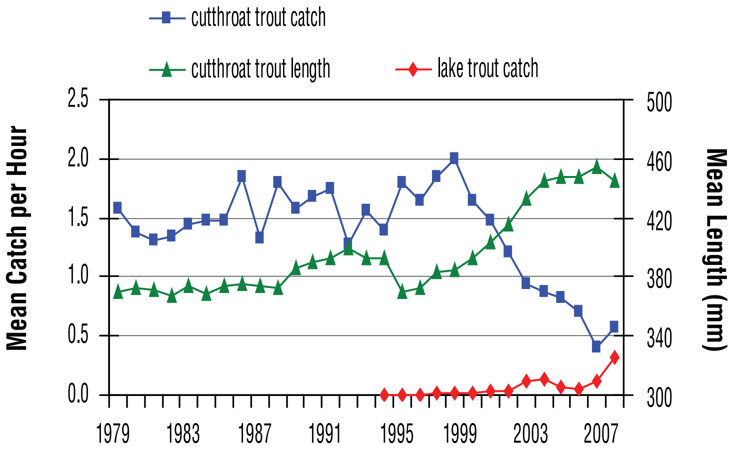

Figure 31. Angler-reported catch rates of Yellowstone cutthroat trout and lake trout and the mean length of angler-reported cutthroat trout caught on Yellowstone Lake in 2007.

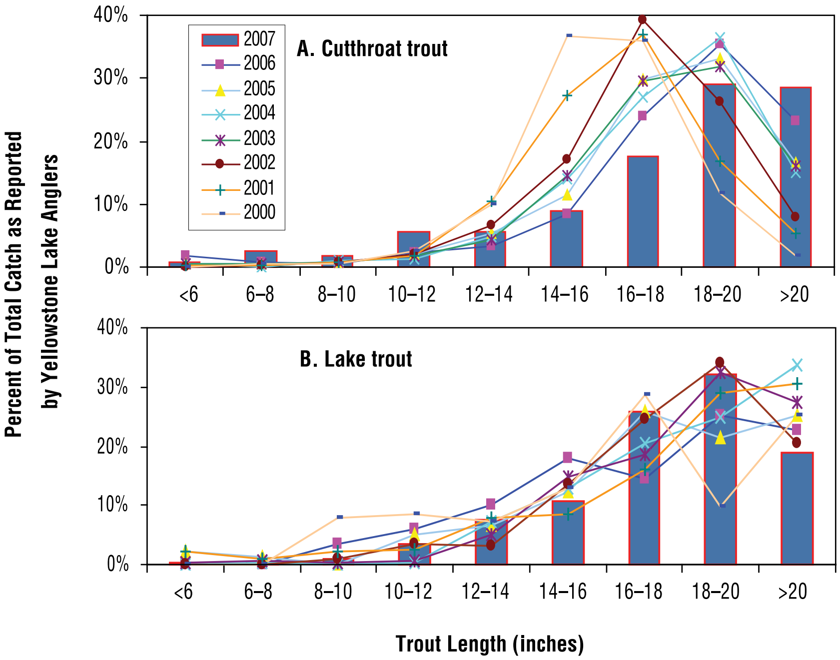

Figure 32. Percentage of angler-reported catch among length classes for (A) Yellowstone cutthroat trout and (B) lake trout from Yellowstone Lake, 2000–2007.

2007). Safe consumption of the lake trout most commonly caught on Yellowstone Lake, which are 40–50 cm long, allows for up to 12 meals per month (Figure 33). However, fewer meals are recommended for larger lake trout, and those that are very large (>470 mm) should not be consumed more than once per month.

The rainbow trout analyzed contained lower concentrations of mercury than the large lake trout. However, the levels varied from one river to another, with the Lamar River trout having the lowest mercury levels (36 ng/g), and those from the Gibbon River the highest (185 ng/g), perhaps due to the abundant geothermal influences found there (Figure 34). Safe consumption of these rainbow trout allows for up to 12 meals per month (Figure 34) in these rivers, but large fish (30–40 cm) should be eaten no more than three times per month. Although no large fish were caught from the Gibbon River for us to analyze, model predictions indicate that any rainbow trout exceeding approximately 20 cm should be consumed no more than twice each month.

The mercury concentration for a standard sized fish (60 cm) from Yellowstone Lake (183 ng/g) was lower than that from other large lakes at similar latitude (J. Sorensen, University of Minnesota, personal communication, 2007; Figure 35). Lake Superior had the highest mean mercury concentration (285 ng/g), whereas Lac La Croix, a large northern Minnesota lake, and a group of eight lakes located in northern Alberta and Saskatchewan (Evans et al. 2005); had moderate levels. This evidence suggests that Yellowstone fishes are safer to consume than those found in many other large northern lakes.

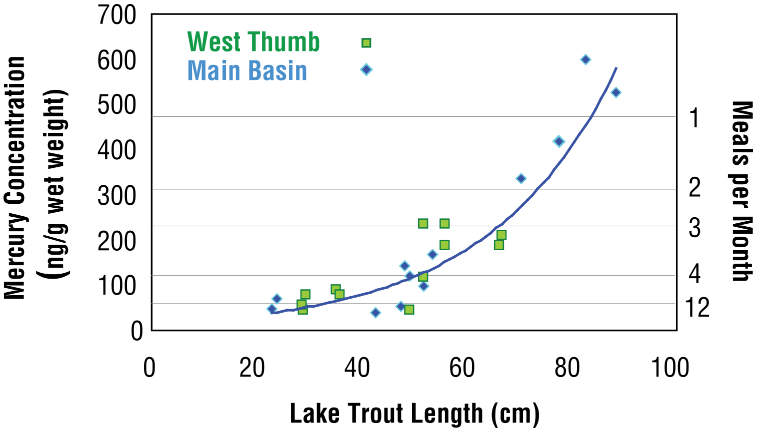

Figure 33. Mercury concentration of 24 lake trout of various lengths collected from the West Thumb and main basin of Yellowstone Lake in 2007. Recommended number of meals per month as provided by the U.S. Environmental Protection Agency are given on the alternate y-axis (EPA 2007).

The significant differences in mercury concentrations found in fish from the three rivers included in this survey clearly indicate that they are being affected by environmental variables such as geothermal features or total annual precipitation. More detailed sampling on the Gibbon and Gardner rivers could reveal which river reaches are the highest in mercury and what factors are responsible. Unfortunately, only smaller fish were sampled from the Gibbon River and an extensive extrapolation of those data was required to estimate consumption guidelines for the bigger fish. We need to analyze more fish of larger sizes to complete that data set and to analyze lake trout from other lakes to create consumption guidelines specific to those waters.

Aquatic Nuisance Species Prevention

Yellowstone's world-class fisheries are threatened by introductions of exotic and non-native aquatic nuisance species (ANS) that displace native species, such as cutthroat trout and many native macroinvertebrates upon which Yellowstone fishes depend for growth and survival. ANS also have the potential to impact important trout consumers such as eagles, ospreys, and grizzly bears, causing a disruption of the Greater Yellowstone Ecosystem.

The New Zealand mud snail (*Potamopyrgus antipodarum*; Richards 2002; Hall et al. 2003; Kerans et al. 2005) and the parasite that causes whirling disease (*M. cerebralis*) in trout (Koel et al. 2006*a*) are already present in park waters. The park again placed high priority on ANS prevention in 2007. Staff were assigned to contact boaters and anglers in both Yellowstone and Grand Teton national parks to increase awareness of the issue (Fey et al. 2007). Contacts with boaters, anglers, the general public, NPS staff, and concessions staff more than tripled, increasing from 828 in 2006 to 3,541 in 2007.

Due to the looming threat of additional ANS introductions, of particular interest is the origin of equipment arriving here, especially boats which may be carrying water in bilges or livewells. Regarding this, Fey et al. (2007) states:

> *"Though over half of the boats entering Yellowstone National Park (1,748 of 2,641)… came from the surrounding states of Montana, Idaho, and Wyoming; many came to the greater Yellowstone area from waters in 42 of our 50 States. Some (of the visitors) were from as far away as Australia, Canada, Mexico and Germany. The greater Yellowstone area is in effect an international destination for recreational boaters and anglers; and along with them is the potential for spreading invasive ANS."*

Given that hundreds of ANS exist in the United States and more are introduced each year (<http://nas.er.usgs.gov>), the threat to park waters will persist into the foreseeable future.

For fisheries, it is the spread of Viral Hemorrhagic Septicemia (VHS) that is especially worrisome. Historically considered the most serious of viral diseases for freshwater salmonids reared in Europe, it has evolved into a problem for marine finfish and most recently has become a fast-spreading disease in wild, freshwater fish across the Great Lakes, where it has caused a significant number of large-scale fish mortalities (GLC 2007; USGS 2008). This contagious virus is active in cold water (<15°C) and causes severe internal and external hemorrhaging of the fish. Once introduced into a wild fishery, it is essentially impossible to eliminate or control. As VHS is spread largely by the movement of fish, eggs, urine, feces, and sexual fluids within water, methods to prevent its introduction to Yellowstone are similar to those of other ANS.

Although our efforts to prevent additional ANS invasion are far above those of just a few years ago, a new paradigm is required in Yellowstone regarding the way people and equipment are allowed to move among water bodies. Unless risk of introduction is reduced to zero, ANS will eventually populate all accessible, suitable habitats across the park. In that case, they will be here to stay, and will impact biodiversity and ecosystem processes beyond that which park managers can repair. The Fisheries Program will continue to work closely with park Resource Protection Specialists and others across the ecosystem to guide research, provide scientific information, actively pursue funding, and support other means for the prevention of ANS introductions.

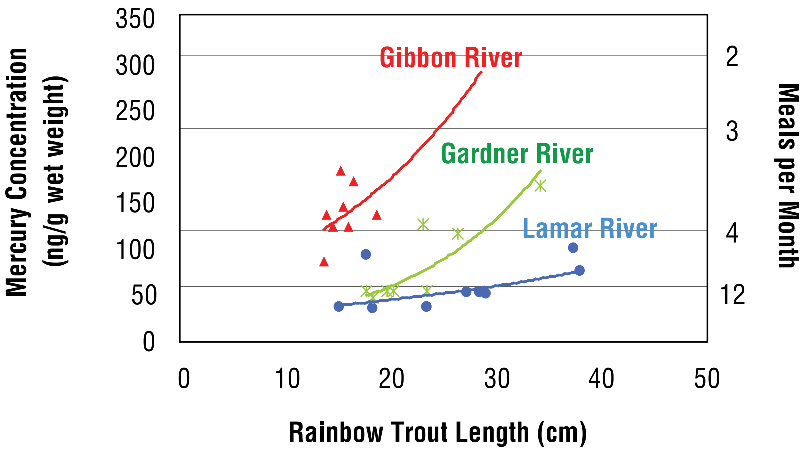

Figure 34. Mercury concentration of 27 rainbow trout of various lengths collected from the Gardner, Gibbon, and Lamar rivers in 2007. Recommended number of meals per month as provided by the U.S. Environmental Protection Agency are given on the alternate y-axis (EPA 2007).

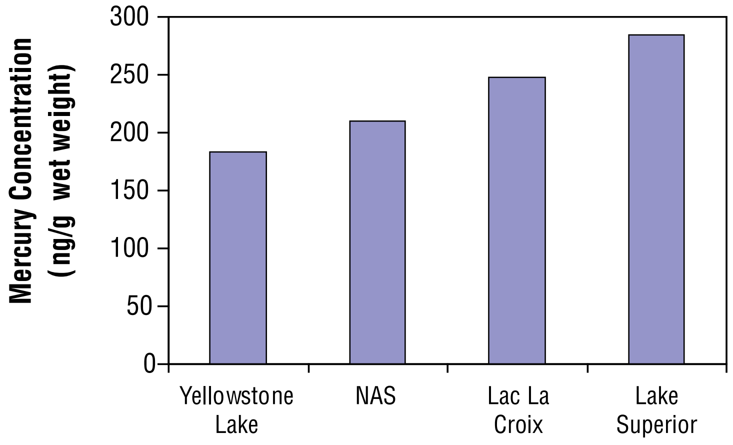

Figure 35. Comparison of mercury concentrations in 60-cm lake trout from Yellowstone Lake in 2007; eight lakes located in northern Alberta & Saskatchewan (Evans et al. 2005); and Lac La Croix (northern Minnesota) and Lake Superior (John Sorenson, University of Minnesota, unpublished data).

Public Involvement

Sixth Year of Fly Fishing Volunteers

Led by volunteer coordinators Timothy Bywater and Bill Voigt, field work for the 2007 season began in early June with the fly fishing volunteers focusing on distribution of pure and hybridized cutthroat trout in Slough Creek and documenting the effectiveness of a waterfall on Grayling Creek as a barrier to upstream passage by trout. In addition, to determine the effectiveness of a natural cascade on Elk Creek as a barrier to upstream fish movement, brook trout were captured upstream of the cascades, marked by clipping a fin, and then moved downstream to a location below the cascades near the Yellowstone River. Effectiveness of the barrier was then assessed by angling for brook trout upstream and examining for clipped fins. Elk Creek above the cascades provides excellent habitat for removal of the non-native brook trout and reintroduction of Yellowstone cutthroat trout.

This year, the volunteer fly fishing program also focused on several small lakes. Samples were taken to understand the degree of hybridization of cutthroat trout at Trout Lake and to determine species presence in Goose Lake and its potential for westslope cutthroat trout stocking. The program also developed a list of lakes in the park that would be good candidates for native cutthroat trout stocking.

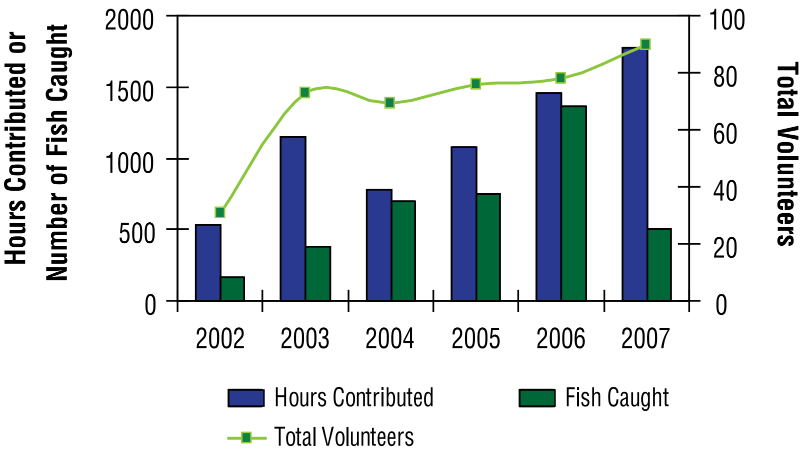

Figure 36. Total number of fly fishing volunteers, and the hours contributed and number of fish caught by them from streams and lakes within Yellowstone National Park, 2002–2007.


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NPS/BILL VOIGT

Artificial beaver dams set up for research on willows were examined for their potential to restrict passage of trout by fly fishing volunteers (top); fly fishing volunteers sample the Gibbon River (bottom).

During the 2007 field season, 90 volunteers participated in the program, contributing 1,776 hours to the park's fisheries—the most volunteer involvement we have experienced since this program began in 2002 (Figure 36). Information collected from a total of 3,853 fish caught by the Fly Fishing Volunteer Project has been used by the Fisheries Program to guide research and management within the park. This project is funded by the Yellowstone Park Foundation and is expected to continue at least through 2009.

Long-term Volunteer Assistance

The Fisheries Program recruits volunteers through the Student Conservation Association (SCA) and other sources (see Appendix iii). These volunteers stay in park housing at Lake or Mammoth for 12 or more weeks and work a full-time schedule similar to paid National Park Service staff. Typically, two groups of SCA volunteers participate: the first from mid-May through early August, and the second from early August through late October. Our goal is to have the volunteers gain experience with as many Fisheries Program activities as possible. Given that 10,000s of hours of assistance have been provided by volunteers over the years, there is

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NPS/BILL VOIGT

A focus on Artic grayling by the fly fishing volunteer program has resulted in greater understanding of the biology of this native species (top). Fly fishing volunteers led by coordinator Bill Voigt on a trip to acquire genetic samples from cutthroat trout in the upper Slough Creek watershed (bottom).

no question that all aspects of our program have greatly benefited from both long- and short-term volunteer support.

Educational Programs

Fisheries Program staff continued to provide a variety of short-term educational programs for visiting schools and other interested groups, with an emphasis on native fish conservation. The staff also provided American Red Cross first aid certification, CPR, electrofishing certification, and the DOI Motorboat Operator Certification Course for National Park Service employees and other agencies.

Collaborative Research

The Fisheries Program, through the Yellowstone Center for Resources, provides both direct and indirect support for collaborative research with scientists at other institutions, primarily universities. These studies address some of the most pressing issues faced by NPS biologists and other regional managers of aquatic systems.

Projects by Graduate Students

Graduate student: Julie Alexander (Doctor of Philosophy candidate).
Committee co-chairs: Drs. Billie Kerans and Todd Koel, Department of Ecology, Montana State University.
Title: Detecting *Myxobolus cerebralis* infection in *Tubifex tubifex* of Pelican Creek.
Status: Field studies completed, lab work, analyses, and writing on-going.

Graduate student: Patricia Bigelow (Doctor of Philosophy candidate).
Committee chair: Dr. Wayne Hubert, U.S. Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming.
Title: Predicting lake trout spawning areas in Yellowstone Lake.
Status: Field studies completed, analyses, and writing on-going.

Graduate student: Hilary Billman (Master of Science candidate).
Committee chair: Dr. Charles Peterson, Department of Biological Sciences, Idaho State University.
Title: Effects of fish restoration on amphibian populations in Yellowstone National Park and southwestern Montana. Status: Field studies initiated.

Graduate student: Brian Ertel (Master of Science candidate).
Committee chair: Dr. Thomas McMahon, Department of Ecology, Montana State University.
Title: Distribution, movements, and life history of Yellowstone cutthroat trout in the upper Yellowstone River basin.
Status: Field studies completed, lab work, analyses, and writing on-going.

Graduate student: Lynn Kaeding (Doctor of Philosophy candidate).
Committee chair: Dr. Daniel Goodman, Department of Ecology, Montana State University.
Title: Comprehensive analysis of historic and contemporary data for the cutthroat trout population of Yellowstone Lake.
Status: Analyses and writing on-going.

Information collected from a total of 3,853 fish caught by the Fly Fishing Volunteer Project has been used by the Fisheries Program to guide research and management within the park.

Graduate student: Silvia Murcia (Doctor of Philosophy candidate).
Committee co-chairs: Drs. Billie Kerans and Todd Koel, Department of Ecology, Montana State University.
Title: Relating *Myxobolus cerebralis* infection in native Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) with environmental gradients at three spawning tributaries to Yellowstone Lake.
Status: Field studies and lab work completed, analyses and writing on-going.

Graduate student: Amber Steed (Master of Science candidate).
Committee co-chairs: Drs. Al Zale, U.S. Geological Survey Cooperative Fisheries Research Unit, and Todd Koel, Department of Ecology, Montana State University.
Title: Spatial dynamics of Arctic grayling in the Gibbon River.
Status: Project completed in August 2007.

Graduate student: John Syslo (Master of Science candidate).
Committee chair: Dr. Christopher Guy, U.S. Geological Survey Cooperative Fisheries Research Unit, Department of Ecology, Montana State University.
Title: Lake trout suppression program data analysis, modeling, and guidance to improve efficiency.
Status: Field studies initiated.

Graduate student: Lusha Tronstad (Doctor of Philosophy candidate).
Committee chair: Dr. Robert Hall, Department of Zoology and Physiology, University of Wyoming.
Title: The ecosystem consequences of invasive lake trout in Yellowstone Lake and tributary streams.
Status: Field studies, lab work, and analyses are completed and writing is on-going.


NPS/BILL VOIGT

Rainbow trout collected by the fly fishing volunteers in 2007.

Interagency Workgroups

Yellowstone National Park actively participates in the Yellowstone Cutthroat Trout Interstate Workgroup, the Montana Cutthroat Trout Steering Committee, and the Fluvial Arctic Grayling Workgroup. Shared goals and objectives among partner agencies and non-governmental organizations are defined in a memorandum of agreement for the rangewide conservation and management of Yellowstone cutthroat trout, a memorandum of understanding (MOU) and conservation agreement for westslope cutthroat trout and Yellowstone cutthroat trout in Montana (http://fwp.mt.gov/wildthings/concern/yellowstone.html), and an MOU concerning the recovery of fluvial Arctic grayling (http://fwp.mt.gov/wildthings/concern/grayling.html).

Cutthroat Trout Broodstock Development

In previous years, Wyoming Game and Fish Department has collected a limited number of Yellowstone cutthroat trout gametes from the Yellowstone River at LeHardys Rapids that have been used for enhancement of the native Yellowstone cutthroat trout broodstock (now located at Ten Sleep, Wyoming) and restoration activities in Montana and Wyoming. As an added benefit for Yellowstone fisheries, age-zero Yellowstone cutthroat trout from the broodstock in Wyoming (LeHardys Rapids origin) are often provided for whirling disease exposure studies in the park.

The park has verified two genetically pure westslope cutthroat trout populations. In 2007 gametes from the population located in Last Chance Creek were incorporated into the upper Missouri River westslope cutthroat trout broodstock at the Sun Ranch in the Madison Valley, Montana.

Acknowledgments

Much-appreciated administrative support for the Fisheries Program in 2007 was provided by Barbara Cline, Montana Lindstrom, Melissa McAdam, and Becky Wyman. Trudy Haney of the contracting office also worked especially hard for us with contracting of the Specimen Creek fish barrier and modifications due to the Owl Fire.

Special thanks to the Wyoming Game and Fish Department for help on Yellowstone Lake by providing the assistance of five seasonal technicians and several other senior staff, including Rob Gipson, Bill Wengert, Mark Smith, and Jason Burckhardt, who helped with gillnetting and electrofishing, and Andy Dux who assisted with underwater videography. The U.S. Fish and Wildlife Service, Idaho Fishery Resources Office in Ahsahka once again allowed us to use their electrofishing boat for removal of spawning lake trout. We greatly appreciate their support and assistance.

We received much appreciated support and guidance for our cutthroat trout restoration activities from Lee Nelson, Don Skaar, and Ken Staigmiller, Montana Fish, Wildlife and Parks; and Dale White, Gallatin National Forest. Special thanks to Emily Renns and Austin McCullough of Montana Fish, Wildlife and Parks for helping us determine the suitability of upper Grayling Creek for fluvial Arctic grayling. Julie Alexander of Montana State University and Troy Davis and Dan Quinn of Yellowstone's Wildlife Program provided much appreciated assistance with fish and habitat surveys on the upper Yellowstone River.

Diane Eagleson and John Varley of the Big Sky Institute, Montana State University, have graciously provided much-needed staff support for the Northern Range Restoration Initiative. This support made it possible to move aggressively forward with cutthroat trout restoration in the park.

Cathie Jean and the staff of the Greater Yellowstone Network have been instrumental in the development of and provided funding for the park's water quality monitoring program.

Many other people from within Yellowstone National Park contributed to the success of Fisheries Program activities in 2007; unfortunately, we cannot mention them all here. However, we would like to especially thank Ben Cunningham, Dave Elwood, Tim McGrady, and Wally Wines from Corral Operations; Wendy Hafer from Fire Cache; Phil Anderson, Greg Bickings, Earl McKinney, Bruce Sefton, Art Truman, Mark Vallie, Lynn Webb, and Dave Whaley from Lake Maintenance; Dan Reinhart from Resource Management; Rick Fey, Brad Ross, and Kim West from the South District Rangers; and Bonnie Gafney from the West District Rangers.

NPS/TODD KOEL

Fisheries biologist Pat Bigelow with research advisor Dr. Wayne Hubert, USGS Wyoming Cooperative Fisheries and Wildlife Research Unit, University of Wyoming.

NPS/TODD KOEL

NPS/TODD KOEL

MTFWP fisheries biologist Lee Nelson spawned westslope cutthroat trout at Last Chance Creek in June 2007 (left). Dale White, Gallatin National Forest, measures topography of Specimen Creek near Highway 191 to determine the potential of a fish barrier in this area (right).

Special thanks to our dedicated technicians and volunteers for their contributions to our program. The accomplishments of 2007 would not have occurred without your hard work and tireless efforts!

The Fisheries Program is supported through Yellowstone Center for Resources base funding and a portion of the fees collected from anglers who purchase fishing permits. In 2007, additional funding was received from these sources:

- The Yellowstone Park Foundation, through the Fisheries Fund Initiative and Fly Fishing Volunteer Program
- The Yellowstone Association
- The Whirling Disease Initiative of the National Partnership for the Management of Wild and Native Coldwater Fisheries
- The Inventory and Monitoring Program and Vital Signs Monitoring Program of the National Park Service
- The Recreational Fee Demonstration Program of the Federal Lands Recreation Enhancement Act
- The Greater Yellowstone Coordinating Committee
- The Park Roads and Parkways Program of the Federal Highway Administration

We would like to extend special thanks to the Yellowstone Park Foundation board and staff, and to the many private individuals who have graciously provided support for our critical fisheries projects in the park.

This report is made possible only by the dedicated work of the Resource Information Team, Yellowstone Center for Resources. Special thanks to Tami Blackford, Mary Ann Franke, and Virginia Warner for making this report a reality.


NPS/BRIAN ERTEL

Fisheries horse Ethan takes a break in the backcountry with supervisory fisheries biologist Dr. Todd Koel.


NPS/BRIAN ERTEL


NPS/TODD KOEL

MSU fisheries restoration specialist Mike Ruhl and NPS supervisory fisheries biologist Dr. Todd Koel with fisheries horses Pat, Sammy, and Scotty on the back side of Turret Mountain in the Teton Wilderness, Wyoming (left). Dan Reinhart of Yellowstone's Resource Protection led efforts to identify hazard trees in the burned area of East Fork Specimen Creek (right).

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Appendices

Appendix i. Fish Species List

Native (N) and introduced (non-native or exotic, I) fish species and subspecies known to exist in Yellowstone National Park waters including the upper Missouri (Missouri, Madison, and Gallatin rivers), Snake River (Snake), and Yellowstone River (Yell R.) drainages.

Family	Common Name	Scientific Name	Status	Missouri	Snake	Yell R.
Salmonidae	Yellowstone cutthroat trout	*Oncorhynchus clarki bouvieri*	Native	I	N	N
	westslope cutthroat trout	*Oncorhynchus clarki lewisi*	Native	N		
	finespotted Snake River cutthroat trout	*Oncorhynchus clarki behnkei**	Native		N	
	rainbow trout	*Oncorhynchus mykiss*	Non-native	I	I	I
	mountain whitefish	*Prosopium williamsoni*	Native	N	N	N
	brown trout	*Salmo trutta*	Exotic	I	I	I
	eastern brook trout	*Salvelinus fontinalis*	Non-native	I	I	I
	lake trout	*Salvelinus namaycush*	Non-native		I	I
	Arctic grayling	*Thymallus arcticus montanus*	Native	N		I
Catostomidae	Utah sucker	*Catostomus ardens*	Native		N	
	longnose sucker	*Catostomus catostomus*	Native			N
	mountain sucker	*Catostomus platyrhynchus*	Native	N	N	N
Cyprinidae	lake chub	*Couesius plumbeus*	Non-native			I
	Utah chub	*Gila atraria*	Native	I	N	
	longnose dace	*Rhinichthys cataractae*	Native	N	N	N
	speckled dace	*Rhinichthys osculus*	Native		N	
	redside shiner	*Richardsonius balteatus*	Native		N	I
Cottidae	mottled sculpin	*Cottus bairdi*	Native	N	N	N

* Scientific name suggested by Behnke (2002), *Trout and Salmon of North America* (New York: The Free Press), and not currently recognized by the American Fisheries Society.

NPS/JEFF ARNOLD

Student Conservation Association (SCA) intern Lindsey Belt and MSU water quality technician Ty Harrison in the lab at Lake.

Appendix ii. The Waters of Yellowstone (adapted from Varley and Schullery, 1998)

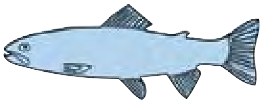
Size of the park	898,318 hectares
Water surface area	45,810 hectares (5% of park)
Number of lakes	150
Lake surface area total	43,706 hectares
Number of fishable lakes	45
Yellowstone Lake surface area	36,017 hectares
Number of streams	>500
Stream length total	4,265 kilometers
Stream surface area total	2,023 hectares
Number of fishable streams	>200

NPS

The Yellowstone Fisheries and Aquatic Sciences Program staff in July 2007. Seated (left to right): Pat Bigelow, Becky Adams, Hallie Ladd, Jeff Arnold, Lindsey Belt, Audrey Squires, Stacey Sigler, Brad Olszewski. Standing (left to right): Nicole Legere, Phil Doepke, George Monroe, Chelsey Young, Bill Voigt, John Syslo, Patrick Smith, Cody Burnett, Brian Ertel, Robert McKinney, Ty Harrison, Mike Ruhl, Derek Rupert, Todd Koel.

Appendix iii. Long-term Volunteers, 2007

Name
Belt, Lyndsay
Burnett, Cody
Giorgi, Connor
Ladd, Hallie
McKinney, Robert
Metler, Brad
Millar, Allison
Monroe, George
Smit, Eefje
Smith, Patrick
Voigt, JoAnn



Appendix iv. Seasonal Staff, 2007

Name
Adams, Rebecca
Billman, Hilary
Bywater, Timothy
Harrison, Ty
Helmy, Olga
Legere, Nicole
Olszewski, Brad
Rupert, Derek
Romankiewicz, Christopher
Squires, Audrey
Sigler, Stacey
Voigt, Bill
Young, Chelsey

NPS/JEFF ARNOLD

Fisheries volunteer Eefje Smit, summer 2007.

Appendix v. Chemical Characteristics of Yellowstone National Park Surface Waters and Sediment in 2007.*

		Anions			Cations				Nutrients				
									Phosphorus		Nitrogen		
Stream/River	**Statistic**	**SO_4**	**Cl**	**Alkalinity**	**Ca**	**Mg**	**Na**	**K**	**Total**	**Ortho_P**	**Nitrate**	**Nitrite**	**Ammonia**
Yellowstone River Fishing Bridge	Mean	16.6	6.7	38.0	6.8	3.5	12.9	2.6	-	-	-	-	-
	Minimum	7.6	4.3	31.0	4.8	2.2	8.6	1.6	-	-	-	-	-
	Maximum	102.0	26.7	95.0	20.6	14.3	48.0	11.9	0.09	0.5	0.2	-	0.9
	Std. dev.	27.0	6.3	18.0	4.4	3.4	11.1	2.9	-	-	-	-	-
	N. obs.	12	12	12	12	12	12	12	12	12	12	12	12
Yellowstone River Corwin Springs	Mean	30.0	10.6	61.2	15.7	4.9	19.1	4.1	0.07	-	-	-	-
	Minimum	6.5	2.0	34.0	7.6	2.4	5.3	1.3	0.03	-	-	-	-
	Maximum	46.4	16.6	76.0	22.7	7.1	29.2	6.5	0.10	0.2	0.3	-	0.2
	Std. dev.	13.7	4.9	13.8	5.0	1.5	7.9	1.7	0.02	-	-	-	-
	N. obs.	12	12	12	12	12	12	12	12	12	12	12	12
Pelican Creek	Mean	75.3	19.4	67.4	15.4	10.3	35.6	9.1	0.10	-	-	-	0.4
	Minimum	7.7	1.0	17.0	3.7	2.1	3.7	1.6	-	-	-	-	-
	Maximum	119.0	30.3	94.0	23.0	15.9	53.9	14.0	0.15	0.3	0.3	-	0.9
	Std. dev.	38.6	10.1	27.5	6.1	4.5	17.4	4.3	0.03	-	-	-	0.3
	N. obs.	12	12	12	12	12	12	12	12	12	12	12	12
Soda Butte Creek at park boundary	Mean	8.1	-	84.3	23.9	5.5	4.2	0.4	0.05	-	-	-	-
	Minimum	5.1	-	44.0	11.4	2.5	3.1	0.2	-	-	-	-	-
	Maximum	10.9	-	109.0	32.3	7.2	5.3	0.5	0.10	0.4	-	-	-
	Std. dev.	2.0	-	21.3	7.0	1.6	0.6	0.1	0.02	-	-	-	-
	N. obs.	12	12	12	12	12	12	12	11	12	12	12	11
Soda Butte Creek near confluence with Lamar River	Mean	7.2	-	114.8	28.9	9.5	3.9	1.5	0.07	-	-	-	-
	Minimum	3.9	-	64.0	15.2	4.5	2.5	0.7	0.04	-	-	-	-
	Maximum	9.0	-	147.0	36.8	12.7	4.6	2.1	0.17	0.4	-	-	0.1
	Std. dev.	1.7	-	27.6	7.4	2.8	0.6	0.5	0.04	-	-	-	-
	N. obs.	12	12	12	12	12	12	12	10	12	12	12	10
Lamar River	Mean	6.5	-	79.0	18.1	6.1	7.3	1.3	0.08	-	-	-	-
	Minimum	1.5	-	34.0	7.2	2.3	2.5	0.6	-	-	-	-	-
	Maximum	9.8	-	104.0	23.9	8.2	9.9	1.7	0.21	0.2	-	-	-
	Std. dev.	2.6	-	24.6	5.9	2.1	2.5	0.4	0.06	-	-	-	-
	N. obs.	12	12	12	12	12	12	12	11	12	12	12	11
Gardner River	Mean	123.6	31.7	151.8	65.7	18.0	30.3	11.5	0.08	-	-	-	-
	Minimum	32.7	7.4	77.0	27.8	6.5	8.2	3.2	0.05	-	-	-	-
	Maximum	227.0	55.6	216.0	95.3	29.1	53.2	20.5	0.11	0.2	0.2	-	-
	Std. dev.	50.2	12.6	35.5	18.2	5.9	12.0	4.6	0.02	-	-	-	-
	N. obs.	12	12	12	12	12	12	12	11	12	12	12	11

*Table of reporting limits provided in the annual report for 2006 (Koel et al. 2007).