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

NATIONAL PARK SERVICE

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Front cover: Public scoping meeting for Native Fish Conservation Plan (*bottom*). Paul Saunders, Tyler Long, and Pat Bigelow check one of the trap nets set in Yellowstone Lake (*left*) and gillnetting contractors Hickey Brothers Fisheries, LLC (*center*) display their catches aboard the *Finn* (*center*). Background shows the scale and markings of lake trout from Yellowstone Lake. NPS photos.

Inside front cover: Yellowstone Lake. NPS photo.

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Introduction

Following the confirmation of the presence of nonnative lake trout (*Salvelinus namaycush*) in Yellowstone Lake during the summer of 1994, the National Park Service (NPS) first sought expert scientific guidance and immediately launched a major suppression program to curtail potential negative consequences to the native Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) and the Yellowstone Lake ecosystem. In August 2008, the NPS again convened a scientific review panel to evaluate the suppression program and provide direction for future suppression and recovery activities. A report of the findings and recommendations of the panel was released in October 2009.

By 2011, the NPS had implemented several of the panel's recommendations and developed a new plan for native fish conservation. Given new information from contracted fishing, lake trout population modeling, three additional years of suppression effort, and proposed actions in a native fish conservation plan, the NPS sought further critical scientific review of the program. This report summarizes recommendations developed during a June 2011 review of the Yellowstone lake trout suppression and cutthroat trout restoration programs.

Panel Objective

The goal of the 2011 review was to seek further guidance and recommendations from an expert panel for future cutthroat trout restoration activities on Yellowstone Lake.

Panel Charge

I. Evaluate the effectiveness of the lake trout suppression program.
II. Review the relevance of 2008 recommendations and assess progress to date.
III. Provide guidance for the future direction of the program.

Overview of 2008 Panel Recommendations

Recommendation 1. Intensify existing lake trout suppression efforts for a minimum of six years.
Recommendation 2. Maintain and enhance Yellowstone cutthroat trout monitoring.
Recommendation 3. Initiate a statistically robust lake trout monitoring program.
Recommendation 4. Develop a lake trout suppression plan that will increase agency administrative commitment to meet benchmarks, the effectiveness of the lake trout removal effort, and the conservation of the Yellowstone Lake ecosystem through the coming decades.

Scientific Review Panel Members

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Phaedra Budy—USGS, Utah Cooperative Fish and Wildlife Research Unit
Christopher S. Guy—USGS, Montana Cooperative Fishery Research Unit
Michael J. Hansen—University of Wisconsin–Stevens Point
Michael L. Jones—Michigan State University
Patrick J. Martinez—US Fish and Wildlife Service
Cory Suski—University of Illinois–Champaign-Urbana
Jack E. Williams—Trout Unlimited, Medford, Oregon

Presenters

Jeff Arnold—National Park Service, Yellowstone National Park
Patricia E. Bigelow—National Park Service, Yellowstone National Park
Brian D. Ertel—National Park Service, Yellowstone National Park
James P. Fredricks—Idaho Department of Fish and Game
Jackson A. Gross—USGS Northern Rocky Mountain Science Center
Dennis Hickey—Hickey Brothers Fisheries, LLC, Baileys Harbor, Wisconsin
Todd M. Koel—National Park Service, Yellowstone National Park
Leo R. Rosenthal—Montana Department of Fish, Wildlife and Parks
Todd Stuth—Hickey Brothers Fisheries, LLC, Baileys Harbor, Wisconsin
John M. Syslo—USGS Montana Cooperative Fishery Research Unit

Facilitator

Scott Bischke—MountainWorks, Bozeman, Montana

In 1995, the year following the discovery of lake trout (*Salvelinus namaycush*) in Yellowstone Lake, the National Park Service (NPS) initiated a suppression program focused on limiting the negative effects of this nonnative predator on native Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*). Following suggestions of a panel of nationally renowned scientists (Schullery and Varley (1995), the suppression program was based on gill nets set by US Fish and Wildlife Service (until 1996) and NPS crews.

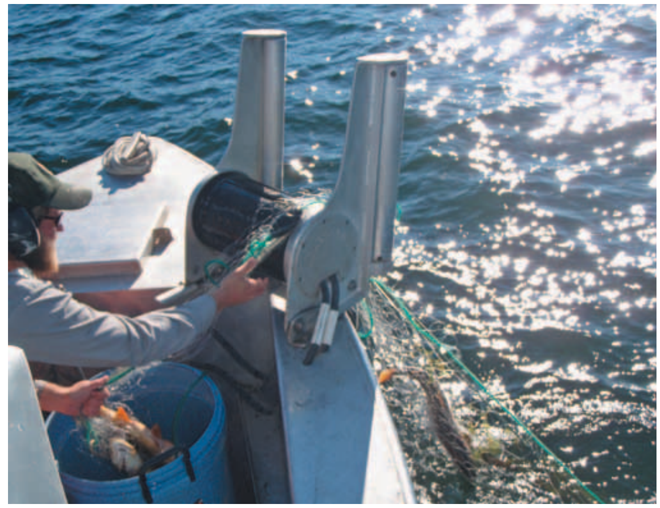
The suppression program expanded as the lake trout population increased, and in August 2008, a scientific review panel was convened by the NPS to evaluate suppression and recovery activities and provide future direction for the program. The panel recommended that the suppression effort should be increased, and monitoring and research of the Yellowstone cutthroat trout and lake trout populations should be expanded. The panel also suggested that a formal lake trout suppression plan needed to set benchmarks, increase effectiveness, and enhance conservation of the Yellowstone Lake ecosystem.

Because of new information from contracted fishing, lake trout population modeling, three more years of suppression effort, and proposed actions in a native fish conservation plan, the NPS convened a subsequent scientific review of the program from June 14 to 16, 2011.

The goal of the 2011 workshop was to seek further guidance and recommendations for future cutthroat trout restoration activities on Yellowstone Lake. Specifically, the panel was asked to (1) evaluate the effectiveness of the lake trout suppression program, (2) review the relevance of the panel's 2008 recommendations and assess progress to date, and (3) provide guidance for future direction of the program.

Effectiveness of the Current Program

Based on information collected since 2008, the panel concluded that substantially greater effort would be needed to achieve suppression of lake trout within six years. The lake trout population currently appears to be below carrying capacity and it will likely increase unless suppression effort increases. Therefore, lake trout suppression should



NPS

Gillnetting for lake trout on Yellowstone Lake.

remain the top priority of NPS fishery resources. The Yellowstone cutthroat trout population continues to decline, and recovery of the Yellowstone cutthroat trout is the ultimate measure of program success. Information gaps concerning the lake trout population persist, especially regarding lake trout movement patterns and spawning areas. Although contract fishing is highly effective and expected to improve, administrative and staffing barriers continue to limit program effectiveness.

Progress on Panel's 2008 Recommendations

Recommendation 1. Intensify existing lake trout suppression efforts for a minimum of six years. *Panel Response*. Contract fishers have been integrated into the suppression program, but although the NPS procured more funds for contract fishers, overall effort (including contracted fishers) in 2010 remained below 2007 levels (25,000 100-m net nights). The recently developed Native Fish Conservation Plan includes benchmarks (quantitative responses and performance metrics) for both Yellowstone cutthroat trout and lake trout (Koel et al. 2010). The panel noted that a successful and complete adaptive management strategy also calls for an explicit statement of hypotheses that the management strategy and associated monitoring metrics are intended to evaluate. Hypotheses should constitute predictions of effects of specific management strategies so that management actions can be designed to be informative, and monitoring metrics can be designed to allow discrimination among alternative hypotheses. Since 2008, the NPS has supported research into alternative technologies for lake trout removal. The panel recommends that this endeavor continue, but should not occur at the expense of ongoing lake trout suppression.

Although telemetry studies to identify lake trout movement patterns and spawning areas had not been initiated prior to this assessment, this information is relevant to the suppression program, and efforts to raise funds and initiate this research began in autumn 2011. Improvements in Yellowstone cutthroat trout and lake trout monitoring programs have been initiated, but the final design has not been completed. Refinement of the program should improve interpretation of lake trout spatial patterns. Analytical reconstruction of the lake trout population has been completed, but ambiguities remain. The panel believes that an accurate and precise mark-recapture estimate of lake trout population abundance would provide crucial information for evaluating the success of the suppression program.

Recommendation 2. Maintain and enhance Yellowstone cutthroat trout monitoring programs.

Panel Response. Visual monitoring of Yellowstone cutthroat trout spawners in small roadside streams has yielded an index of relative abundance through time. In addition, annual fall gillnetting continues to provide data for relative temporal comparisons. Although the weir at Clear Creek has not been functional since 2007, partnership with the Department of Engineering at Montana State University (MSU) has resulted in conceptual designs for reconstruction of the weir. Funding has been allocated to the MSU Institute on Ecosystems for weir reconstruction in 2012. The panel believes that monitoring of spawning Yellowstone cutthroat trout at Clear Creek continues to be a priority, and the Native Fish Conservation Plan has a benchmark based on the number of spawners entering Clear Creek (Koel et al. 2010).

Whirling disease occurrence and spread is no longer being monitored because the Whirling Disease Initiative administered by the Montana Water Center at MSU was discontinued and an alternative funding source has not been found.


JAY FLEMING

Hickey Brotheries Fisheries, LLC, setting an entrapment net.

Recommendation 3. Initiate a statistically robust lake trout monitoring program.

Panel Response. Existing lake trout demographic data have been reviewed and analyzed (Syslo et al. 2011). Although monitoring with gill nets to assess distribution of Yellowstone cutthroat trout and lake trout in near-shore areas across the lake basin has continued, previous analyses suggest that inadequacies in standardized sampling limit the ability to detect lake trout population response to suppression. A standardized sampling program is being developed to detect changes in the Yellowstone cutthroat trout and lake trout populations in relation to the lake trout suppression program. A mark-recapture estimate of the lake trout population has not occurred, but an accurate and precise estimate would provide crucial information for evaluating the results of the suppression program.

Recommendation 4. Develop a lake trout suppression plan.

Panel Response. The Native Fish Conservation Plan provides important guidance for the suppression program and ultimate restoration of the Yellowstone cutthroat trout (Koel et al. 2010), but some issues require further attention. For example, the potential for reintroduction of lake trout from Lewis Lake has not been specifically addressed. Furthermore, analysis of the angler database to examine spatial and temporal changes in lake trout fishery statistics for Yellowstone Lake has not been initiated.

Issues associated with facilities and policies for supporting the lake trout suppression program have been partially addressed. However, adequate housing for contract fishers and increased NPS staff is lacking, and storage space for fishery gear is limited


NPS/A. LOHMEYER

Fisheries staff remove fish from a gill net near Carrington Island in Yellowstone Lake.

at Lake Village. Seasonal staffing and infrastructure maintenance issues hinder suppression activities beyond mid-October, but lake trout often remain vulnerable later in the year. The difficulty of providing higher grades or term positions to experienced personnel impedes the retention of a trained seasonal workforce. Speed restrictions in the South Arm and Southeast Arm of Yellowstone Lake substantially increase the time required to set and retrieve nets, which decreases efficiency in those areas.

Some issues related to the suppression program have not been addressed. Although the scientific review panel formed in 2008 continues to provide critical guidance to the lake trout suppression program, a science advisory committee that can provide timely annual support and review has not been organized.

Guidance on Future Directions

Suppression. The panel recommends that the NPS increase effort to 57,000 100-m net nights annually. This is a conservative estimate based on upper confidence limits of point estimates of effort needed to reduce the lake trout population growth below replacement ($\lambda < 1.0$) in five years (Syslo et al. 2011). It is projected to result in an unsustainable fishing mortality rate of $F \approx 0.59$. It could be accomplished with increased contract fishing or using NPS resources more effectively (additional funding may be required). One approach would include maintaining staff at levels that support two netting crews (boats) for seven days a week. Experienced NPS staff may be increased by providing funding incentives for returning summer employees.

The panel recommends that NPS suppression efforts be continued at this level for a minimum of 10 years or until suppression goals, as outlined in the Native Fish Conservation Plan (Koel et al. 2010) are met. Evidence suggests that a measurable decline in lake trout abundance is likely within five years. However, a maintenance program of reduced effort and monitoring will be required until advances in suppression technology are available. Knowledge of spawning locations will be vital to a cost-effective maintenance program. Moreover, introduction (reintroduction) of lake trout into Yellowstone Lake from Lewis Lake must be prevented. Planning for potential solutions to this issue should not be delayed.

The panel recommends that gillnetting should continue to be the primary suppression technique. Exploration of other techniques (e.g., trap netting, electrofishing, and methods focused on embryos and larvae) is encouraged, but not in lieu of the prescribed level of suppression effort until cost effectiveness can be demonstrated. The panel advises against angler incentive programs in Yellowstone Lake to avoid developing a constituency for lake trout in the lake. Support for maintaining lake trout in Yellowstone Lake could thwart the lake trout suppression program. Analysis of data from Lake Pend Oreille suggests the angler incentive program was successful initially, but has been surpassed by gillnetting removals.

Although the response of Yellowstone cutthroat trout to lake trout suppression may be affected by a variety of factors, juvenile survival will likely increase within 1 to 2 years. An increase in spawners in tributaries (a performance metric in the Native Fish Conservation Plan) will likely take longer (>5 years).

The panel believes that Yellowstone cutthroat trout mortality associated with suppression activities should be minimized as much as possible. The number of Yellowstone cutthroat trout saved from lake trout predation currently exceeds the number lost through by-catch, but by-catch is only acceptable when lower than gains from lake trout removal. By-catch of Yellowstone cutthroat trout will increase with increasing suppression effort, so the panel recommends tracking the level of by-catch as a function of the total lake trout removed.

Assessment. A population estimate is needed (and feasible) to provide a benchmark for progress toward suppression goals, but the panel does not rate completion of this research above the suppression effort. Although randomized recapture effort requires some compromise with suppression, an accurate and precise lake trout population estimate will facilitate evaluation of the suppression program.

Analyses to date suggest that inadequacies in the monitoring program limit the ability to detect how the lake trout population has responded to suppression. Standardized sampling associated with lake trout suppression has not been an NPS priority but is necessary for evaluating the program's effectiveness. Development of a standard operating procedure for the monitoring program has been contracted with researchers at Montana State University.

The panel recommends that a science advisory committee (a sub-group of the current science review panel) be engaged for an annual program review. A full scientific review (similar to that in 2008 and 2011) should occur every three years.

Long-term monitoring data from Yellowstone Lake is crucial to understanding Yellowstone cutthroat trout population trends, but mortality of Yellowstone cutthroat trout should be minimized. The monitoring program should justify the number of Yellowstone cutthroat trout sampled given NPS assessment goals, and, if necessary, the monitoring program should be modified to reduce mortality. This issue requires further investigation and should be reviewed annually by the science advisory committee.

Research projects prioritized. The panel has ranked the following list of research needs that relate to accomplishing restoration goals, but the first research priority greatly outweighs the others: (1) determine lake trout spawning areas to guide suppression efforts; (2) estimate lake trout population demographics using mark-recapture; (3) investigate alternative lake trout suppression techniques (proof of concept and modeling); (3) assess whirling disease prevalence from Yellowstone cutthroat trout by-catch using PCR analysis; (4) evaluate the effects of climate change (e.g., drought); (5) assess the effects of recycling dead lake trout on secondary productivity in Yellowstone Lake; (5) examine competition between juvenile Yellowstone cutthroat trout and lake trout; and (6) evaluate the validity of the Volunteer Angler Report based on current information needs.

Funding for research projects. The panel recommends that the NPS create a funding advisory board and suggests that the NPS examine new avenues to increase funding and collaborate with non-governmental organizations to access additional funding. NGOs could pursue increased funding from Congress for lake trout suppression activities and assist in acquiring outside funding.

Allocation of resources. Suppression effort must be greatly increased, and it is the top priority. If funding is insufficient to meet recommended levels of suppression effort, the remainder of the program is moot. Monitoring is a core component of the adaptive management strategy, but it is a second priority. Research is important, but reaching the target level of lake trout suppression effort should take priority over exploring other research questions.

Yellowstone cutthroat trout enhancement. Enhancement programs (e.g., remote site incubators, supplementation, and reconnecting tributaries to the Yellowstone Lake) should be considered last-ditch efforts to be applied only if lake trout cannot be suppressed after substantial increases in effort are maintained over a 10-year period, or Yellowstone cutthroat trout do not respond to lake trout suppression. The panel is concerned about genetic integrity and the possible unintended ecological consequences of this management action. Enhancement programs should not be undertaken without thorough genetic analysis of source stock and a comprehensive risk assessment. Input from neighboring states of Idaho, Wyoming, and Montana should be encouraged.

Summary of 2011 Scientific Review Panel Recommendations

Suppression

- Increase effort to 57,000 100-m net nights annually and continue suppression at this level for a minimum of 10 years or until suppression goals (Native Fish Conservation Plan, Koel et al. 2010) are met.
  - Increase the number of experienced NPS staff by providing funding incentives for returning summer employees.
  - Maintain staff at levels that support two netting crews seven days per week.
- Prevent further introductions of lake trout from Lewis Lake into Yellowstone Lake.

Assessment

- A population estimate is needed as a benchmark for performance toward suppression goals.
- Standardized sampling is necessary for evaluating the effectiveness of the program.
- Engage a science advisory committee (a sub-group of the scientific review panel) for an annual program review.
- Undertake a full science panel review (similar to 2008 and 2011) every three years.
- Justify the number of Yellowstone cutthroat trout sampled and modify the monitoring program to reduce mortality. This question requires further investigation and should be reviewed annually by the science advisory committee.

Research Projects Prioritized

1. Identify lake trout spawning areas to guide suppression efforts.
2. Estimate lake trout population density by mark-recapture.
3. Investigate alternative suppression techniques.
4. Quantify whirling disease prevalence from Yellowstone cutthroat trout by-catch using PCR analysis.
5. Evaluate the effects of climate change.
6. Assess the effects of dead lake trout on secondary productivity in Yellowstone Lake.
7. Quantify potential competition between juvenile Yellowstone cutthroat trout and lake trout.
8. Evaluate the validity of the Volunteer Angler Report based on current information needs.

Research Projects Funding

- Create a funding advisory board.
- Examine new avenues for funding within the NPS.
- Collaborate with the NGO community.
- Encourage NGOs to pursue increased funding from Congress for lake trout suppression.
- Work with academic institutions and government research organizations.
- Solicit funds from the Yellowstone Park Foundation and other foundations.
- Consider development of a funding program targeted specifically for lake trout suppression.


JAY FLEMING

Spawning Yellowstone cutthroat trout.

Lake trout suppression program, 1995–2011

In February 1995, approximately eight months after nonnative lake trout (*Salvelinus namaycush*) were discovered in Yellowstone Lake, the National Park Service convened an advisory panel of nationally renowned scientists to assess the potential consequences of the introduction of lake trout into the Yellowstone Lake ecosystem and suggest response alternatives (McIntyre 1995). Subsequently, the NPS initiated a suppression program to limit the effects of lake trout on native Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) (see page 9).

The suppression program expanded in response to a rapid increase in the lake trout population, and a scientific review panel was convened by the NPS in August 2008 to evaluate suppression and recovery activities and to provide future direction for the program. The panel was supportive of the program but recommended that suppression effort be increased and that monitoring and research of the Yellowstone cutthroat trout and lake trout populations should be expanded. The panel suggested that a formal lake trout suppression plan would engender administrative commitments by the NPS to meet benchmarks, increase the effectiveness of the removal effort, and enhance conservation of the Yellowstone Lake ecosystem.


NPS/T. KOEL

Hickey Brothers Fisheries, LLC, personnel set the lead line for a trap net near Breeze Point in Yellowstone Lake.


NPS

Fisheries technician Chelsey Young displays lake trout caught in NPS nets.

By 2011, the NPS had implemented several of the panel's recommendations and developed a new plan for native fish conservation. Lake trout suppression effort was increased above the 2008 level by employing contract fishers, but the combined effort remained below levels achieved in 2006 and 2007. Estimates of lake trout fishing mortality and population growth rates have been used to estimate the effort necessary to reduce population growth (Syslo et al. 2011). In June 2011, the NPS released a Native Fish Conservation Plan and Environmental Assessment for Yellowstone National Park with an adaptive management strategy that included specific benchmarks for continued lake trout suppression and restoration of the cutthroat trout population in Yellowstone Lake (Koel et al. 2010).

Given new information from contracted fishing, lake trout population modeling, three more years of suppression, and actions proposed in the Native Fish Conservation Plan (Koel et al. 2010), the NPS sought further scientific review of the program. This report summarizes recommendations developed during a June 14–16, 2011, review of the Yellowstone lake trout suppression and cutthroat trout restoration programs.

The Effects of Invasive Lake Trout in Yellowstone Lake

TWO CONSEQUENCES of invasive species are damage to valued ecological resources and substantial economic effects or costs to reverse, or at least minimize, the damage. Nonnative lake trout threaten the native population of Yellowstone cutthroat trout in Yellowstone lake, and the National Park Service is devoting scarce funds to prevent them from eliminating the ecological and recreational benefits that the Yellowstone cutthroat trout provide to the ecosystem and park visitors.

The Yellowstone cutthroat trout population in the Yellowstone Lake ecosystem represents one of the largest genetically unaltered assemblages of the subspecies across its range. Because of the large size of Yellowstone Lake (about 34,000 hectares), the presence of a healthy population of Yellowstone cutthroat trout reduces the prospect that the subspecies may require protection under the Endangered Species Act. Because Yellowstone Lake represents about 88% of the lake habitat historically occupied by Yellowstone cutthroat trout, a stable population of cutthroat trout in the lake would help to ensure the future of the subspecies.

Lake trout pose a threat to the Yellowstone cutthroat trout in Yellowstone Lake and their role in the lake ecosystem. Indices of expanding lake trout abundance and corresponding indicators of declining cutthroat trout numbers call for increased effort and expense to forestall and ultimately reverse present trends.

Managers have become increasingly aware that preventing the introduction or spread of invasive species is the most effective way to preserve native species and their ecosystem roles. This may seem obvious, especially in a national park, but an inadvertent or intentional introduction of a nonnative species carries the risk of foreseeable and unforeseen consequences. Although the effects of nonnative lake trout on native trout are well known, the extent of cascading effects throughout the Yellowstone Lake ecosystem from the reduction of Yellowstone cutthroat trout has been unprecedented. Furthermore, even seemingly innocuous species may carry diseases or parasites, or be accompanied by unwanted species hitchhiking in their transport water, that could prove devastating to native species.

Two other strategies have become standard for invasive species management: early response and eradication. In the case of lake trout in Yellowstone Lake, the NPS responded quickly, convening a panel of experts to assess the threat and identify a course of action that was quickly implemented. The experience gained from these efforts and lake trout suppression efforts in other lakes is being vigorously applied at Yellowstone Lake. Whether early efforts slowed the growth of the lake trout population may be debatable, but intervention put the National Park Service in a learning mode, facilitating the efficient application of existing resources while exploring new strategies.

Although prevention is the best strategy to avert species invasions, eradication is the second best option and outcome, if feasible. Although eradication of lake trout from Yellowstone Lake may be unrealistic given the immense size of the lake, the Native Fish Conservation Plan for Yellowstone National Park specifies complete eradication of lake trout as the primary desired condition for Yellowstone Lake (Koel et al. 2010). Invasive species management suggests that all control efforts should have eradication as their goal. This ensures that the urgency and message regarding efforts to remove the invading species is clear to all agencies, administrators, and personnel involved, and especially to the public. Information about lake trout populations in the species' native range indicates that it is vulnerable to overharvest by netting and angling. Although lake trout may be somewhat less vulnerable to overharvest outside their native range, information is emerging that suggests that lake trout populations can be effectively controlled.

Preventing the arrival of other invasive species that may imperil Yellowstone cutthroat trout through predation, competition, or disease, or indirectly by altering native food web relationships to favor invasive species, will require education and the implementation of strict preventive policies. In addition to the effects on Yellowstone Lake's native ecosystem that have resulted from the decline of Yellowstone cutthroat trout, further declines or loss of this subspecies from the lake has conservation implications for its perpetuation throughout its current range. The introduction of lake trout in Yellowstone Lake illustrates the far-reaching effect of an invasive species on native species and provides lessons about invasive species management including prevention, early intervention, and implementing effective control strategies.

Lake trout suppression overview, Yellowstone Lake

Presented by Patricia E. Bigelow

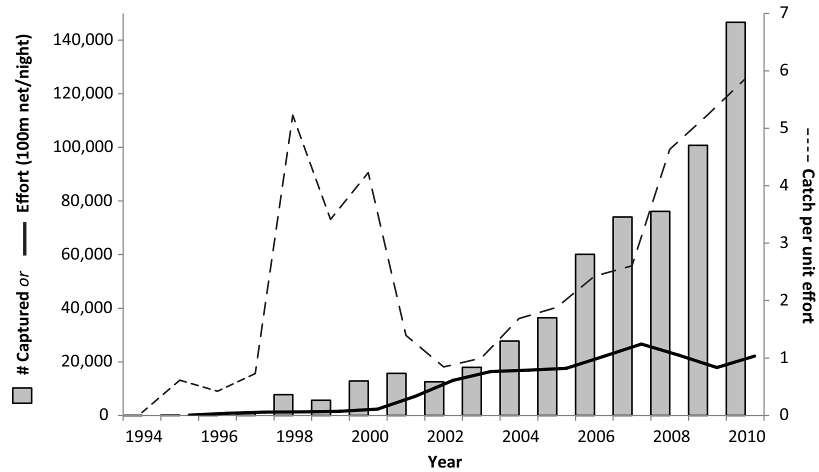


Figure 1. Total number of lake trout removed, catch of lake trout per unit effort, and total effort for all methods, Yellowstone Lake, 1994–2010.

Since the NPS lake trout suppression program in Yellowstone Lake was initiated in 1995, the number of lake trout captured in gill nets has increased. From 1995 to 2000, important information was collected concerning the distribution of lake trout within the lake, lake trout food habits and bioenergetics, the growth and size structure of the lake trout population, and the effects of lake trout on the Yellowstone cutthroat trout population (Ruzycki et al. 2003). Initial attempts to locate additional lake trout yielded few, and Yellowstone cutthroat trout by-catch was high. During this period, most lake trout were captured in the West Thumb of Yellowstone Lake, and a spawning area was identified along the western shore of the West Thumb near Carrington Island.

With the hiring of additional staff and acquisition of a specially designed gillnetting boat in 2001, the intensity of the suppression program increased substantially (Koel et al. 2005). The number of lake trout removed annually increased steadily, and more than 70,000 lake trout were captured in both 2007 and 2008 (fig. 1). Effort reached its highest level (28,405 100-m net nights) in 2007 (fig. 1).

Recommendations from the 2008 scientific review (Gresswell 2009) included increasing the suppression effort for at least six years, and the NPS was urged to augment the program by adding contract fishers. Total effort has not reached the record level reported in 2007 but has increased since 2008. Lake trout removals and catch-per-unit-effort (CPUE) have also increased since 2008, and 146,306 lake trout were removed in 2010 (fig. 1). About 25,400 (17% of the 2010 catch) were captured in large-mesh (>44 mm bar mesh) gill nets and trap nets, primarily from late August to early October when lake trout were spawning.

Contract fishers were first used for three weeks in June and July 2009. This pilot study continued in 2010 with 5 weeks of gillnetting in the spring and 5 weeks in autumn. In that year, gillnetting by contractors added 31,665 lake trout to the number removed by the NPS crews. Contract crews also experimented with the use of four large deep-water trap nets that removed 2,580 lake trout.

Most gillnetting by NPS crews is focused on juvenile lake trout from ice-out through mid-August. Nets are composed of 25-, 32-, and 38-mm mesh sizes and are set on the bottom in deep water (15-55 m), extending 1.5–2.0 m up into the water column where juvenile lake trout are abundant. Nets are usually checked and reset weekly (mean duration in 2010 = 6.4 nights), but some are checked more frequently. During 2010, up to 17.6 km of small-mesh gill nets were deployed daily from early June through mid-August. About 91% of all lake trout removed by NPS crews in 2010 were captured in small-mesh gill nets.

As spawning approaches, adult lake trout become more active and more concentrated, making them more susceptible to netting. Consequently, by mid-August each year, effort shifts from small-mesh nets that primarily capture juvenile fish to large-mesh nets (44-, 51-, 57-, 64-, and 70-mm bar measure) that primarily capture adult lake trout. The large-mesh nets are usually set at depths of 3–37 m, and in shallow water as the water cools in autumn.

To reduce incidental capture of Yellowstone cutthroat trout, the large-mesh nets are checked more frequently than are the small-mesh nets. In 2010, mean set duration was increased to 5.1 nights so that more large-mesh nets could be soaked at any time. Over the years, netting effort and catch-per-unit-effort during the autumn spawning period have increased (fig. 2).

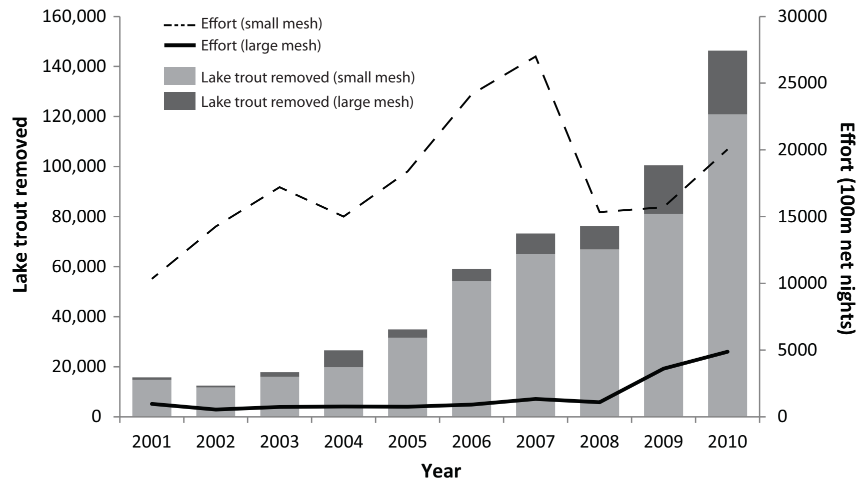


Figure 2. Total number of lake trout removed and total effort for large- and small-mesh gill nets, Yellowstone Lake, 2001–2010.

Contract netters used small-mesh (25-, 32-, and 38-mm bar measure) and large-mesh (44-, 51-, 57-, and 64-mm bar measure) gill nets, but their set durations were shorter than those of NPS crews (mean set length = 2.6 days). Of the 31,665 lake trout caught by contract netters, most (61%) were captured in small-mesh nets, the other 39% in large-mesh nets. Data from pilot studies in 2009 and 2010 suggest that contract fishers were more effective at capturing large fish than were NPS crews. Contractors were directed to focus their effort on large adult lake trout during the second 5-week period in 2010 in order to capture mature fish before spawning. The number of lake trout removed by contract fishers was generally lower than the number removed by NPS crews for the same period, but the number of adult lake trout removed increased in 2010.

In 2010, four trap nets were fished concurrently with gill nets in western portions of the lake. To focus on removal of larger adult lake trout, traps were constructed of larger meshes and were set in shallower water (17–28 m). Although Yellowstone cutthroat trout are more common and more vulnerable to capture in shallow water, trap nets were designed to capture fish alive, so most cutthroat trout captured in them could be released unharmed. Total catch for trap nets was lower than anticipated in 2010 (2,580 lake trout in 10 weeks), but the ability to focus on larger lake trout while avoiding coincidental mortality of Yellowstone cutthroat trout is an advantage of this gear. Furthermore, the proportion of female lake trout captured in trap nets (60%) was greater than the proportion of females captured in gill nets (43%), and the mean length of females in trap nets was 30 mm greater than that of the males. Continued experimentation with trap nets (locations, mesh sizes, and trap configuration) was scheduled for 2011.

The crews have reduced by-catch through modifications in netting locations, depths fished, and mesh sizes, but capture and incidental death of Yellowstone cutthroat trout does occur. In 2010, NPS crews released alive 37% of 2,689 Yellowstone cutthroat trout captured in gill nets, and contractors released 58% of 2,147 Yellowstone cutthroat trout captured in gill nets. Contract fishers are able to release a greater percentage of Yellowstone cutthroat trout alive because their nets are checked more frequently. Although this strategy reduces the amount of net fished on a given day, short duration sets are needed when fishing in shallower water where Yellowstone cutthroat trout are more common.

Survival of Yellowstone cutthroat trout was highest (96.4%) when they were captured in trap nets during the 2010 pilot study, although they trout were uncommon in the trap nets (56 captured in 2010) set in shallow water. Because Yellowstone cutthroat trout are less likely to be caught in trap nets and more likely to survive capture if caught in them, this type of gear appears to be a practical means of removing larger lake trout in shallow water where by-catch of Yellowstone cutthroat trout caught in gill nets could be excessive.

Lake trout population modeling in Yellowstone Lake

Presented by John M. Syslo

A lack of information concerning lake trout population abundance has hindered precise evaluation of the effectiveness of the lake trout suppression program. Consequently, the 2008 scientific review panel recommended a rigorous mark-recapture study to estimate the level of short-term removal necessary to initiate population decline and develop a benchmark against which future population estimates could be compared. To date, however, the NPS's top priority has been to use limited funding for suppression activities.

As an alternative to a population estimate, Syslo et al. (2011) analyzed temporal variation in individual growth, body condition, length and age at maturity, fecundity, and mortality to develop a statistical catch-at-age model. Population metrics suggested that despite more than a decade of lake trout removal, the lake trout population was not being overharvested. Nonetheless, the population growth rate was lower than it would have been without suppression activities (Syslo et al. 2011). Furthermore, fishing effort would need to be doubled (above the 2007 record high) to reduce population growth rate below the replacement level (Syslo et al. 2011).

Yellowstone Lake monitoring program

Presented by Jeff Arnold

Although several studies on Yellowstone Lake have provided information that can be used to assess change through time (Gresswell and Varley 1988), none incorporated a probabilistic design necessary to develop a lake-wide scope of inference until 1997. In that year, a more statistically robust monitoring program was initiated to evaluate distribution of Yellowstone cutthroat trout and lake trout in near-shore areas across the lake basin (Ruzycki et al. 2003). Sixteen sample sites were randomly selected from a sampling frame of 280 sites distributed in four regions around the lake. Six monofilament gill nets were set overnight at each site and nets were arranged with one small-mesh net and one large-mesh net at each of three depth strata (3–10 m, 15–25 m, and 30–50 m; Ruzycki et al. 2003). Large-mesh nets were 3.3-m deep and 68.6-m long with 13.7-m panels of 57-, 64-, 70-, 76-, and 89-mm bar-measure netting (Ruzycki et al. 2003), and small-mesh nets were 2-m deep and 76-m long with equal-length panels of 19-, 25-, 32-, 38-, and 51-mm bar-measure netting (Ruzycki et al. 2003). This program included sets before and after thermal stratification.

Although sampling was done each August, this program was not consistently carried out over time. Shallow-water sets were eliminated in 1998 and site selection was modified several times. From 1998 to 2000, both random sites and fixed sites were sampled. In 2002 and 2003, all sites were selected randomly from 1-km sections in four regions of the lake, and the same sites were resampled in 2004, 2005, and 2007. Small-mesh and large-mesh nets were set in pairs in two depth strata (below the thermocline) at each site.

Much of the original montoring design was reinitiated in 2010 to ensure adequate assesment of both lake trout and Yellowstone cutthroat trout. The shoreline of the lake (excluding non-motorized zones but including the islands) was divided into four regions and 181 1-km sections, and 24 random sites were selected. Small-mesh and large-mesh nets were set in pairs at three depth strata, and shallow-water sets were reincorporated into the program. Sampling occurred in August, and new sites were selected randomly each year. Objectives of the reinvigorated program were to: (1) measure recruitment of Yellowstone cutthroat trout into Yellowstone Lake; (2) assess the size and age structure of Yellowstone cutthroat trout and lake trout populations; (3) evaluate the growth rate of Yellowstone cutthroat trout and lake trout; and (4) determine the fecundity of Yellowstone cutthroat trout and lake trout in the lake. Otoliths and scales were collected for age estimation.

USGS-BRD Biological Research for the Parks program funding is supporting NPS collaboration with John Syslo and Christopher Guy (MSU) to analyze data from 1997 to 2010 and develop a standardized monitoring program that will detect meaningful changes in the Yellowstone cutthroat trout and lake trout populations in response to lake trout suppression.

Status and trends of Yellowstone cutthroat trout in Yellowstone Lake

Presented by Brian D. Ertel

With some modifications over time, data have been collected since 1975 from the Volunteer Angler Report to evaluate changes in angler metrics (fig. 3). Starting in the late 1990s, the landing rate for Yellowstone cutthroat trout declined to a low of <0.50 fish/hour in 2006, and despite increases since that time, landing rate has remained <1.0 fish/hour since 2002. For the 15 years prior to the discovery of lake trout in Yellowstone Lake, anglers landed an average of 1.5 cutthroat trout/hour. Mean length of Yellowstone cutthroat trout captured by anglers has been at historical highs (>400 mm) since 2000.

A monitoring program using experimental gill nets was initiated in 1969, and nets have been set in late September at the same 11 sites (5 nets per site) since 1978 (Gresswell 2004). Sites were not selected randomly, but methods have remained unchanged to enable comparison of relative abundance and size and age structure of Yellowstone cutthroat trout through time (fig. 4). Since 1998, the number of Yellowstone cutthroat trout captured per net has remained below the historical lows recorded from 1977 to 1997. Length structure has also changed substantially since the late 1990s. The greatest changes occurred from 2000 to 2010, when the proportion of Yellowstone cutthroat trout 330 mm to 450 mm drastically declined, and those >460 mm greatly exceeded historical levels (Koel et al. 1995; B. Ertel, NPS, unpublished data).

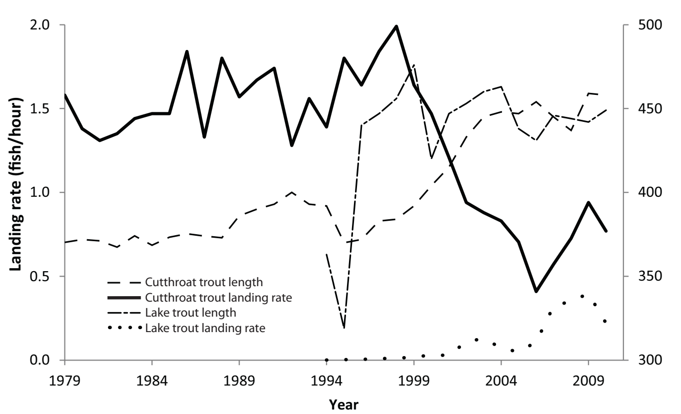


Figure 3. Creel survey estimates of landing rate (number captured per hour) and mean total length of Yellowstone cutthroat trout and lake trout landed by recreational anglers, Yellowstone Lake, 1978–2010.

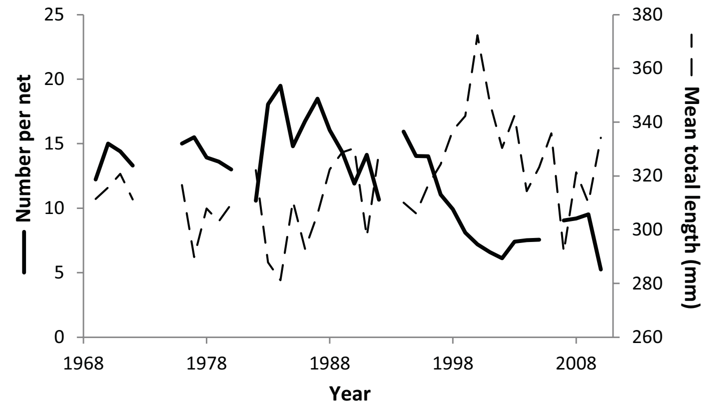


Figure 4. Mean number per net and mean length of Yellowstone cutthroat trout captured in experimental gill nets set in late September, 1969–2010.

Spawner surveys have been conducted in many tributaries where spawning occurs. The longest and most complete record has been collected at the weir and trap in Clear Creek, a tributary entering along the east shore of the lake (fig. 5). Data on run timing, the number of spawners, and the size and age structure of Yellowstone cutthroat trout entering Clear Creek dates back to 1945 (Gresswell et al. 1997). In 1993, the number of spawners dropped below 20,000 for the first time since the mid-1960s, and between 2003 and 2007, the number of spawners declined to historical lows (about 500 trout spawners from 2006 to 2007; Koel et al. 2008). From the 1970s to the 1990s, the size structure of the spawning population shifted to larger fish, apparently as a result of reductions in angler harvest. From 2000 to 2008, however, few fish <380 mm entered Clear Creek, and the proportion of the run >450 mm was historically high (fig. 5). Large Yellowstone cutthroat trout were rare in previous decades, but by 2003 almost half of the spawners entering Clear Creek were >450 mm. Unfortunately, the weir was damaged during spring runoff in 2008 and had to be removed.

Other information useful for evaluating the abundance of Yellowstone cutthroat trout spawners is available from annual visual surveys conducted since 1989 on 9 to 11 tributary streams in West Thumb and along the west shore of the lake (Reinhart 1990; Haroldson et al. 2005; Koel et al. 2005). Trends in the number of Yellowstone cutthroat trout spawners were similar to those at Clear Creek in most monitored streams.

Native Fish Conservation Plan, adaptive management strategy, and potential funding sources

Presented by Todd M. Koel

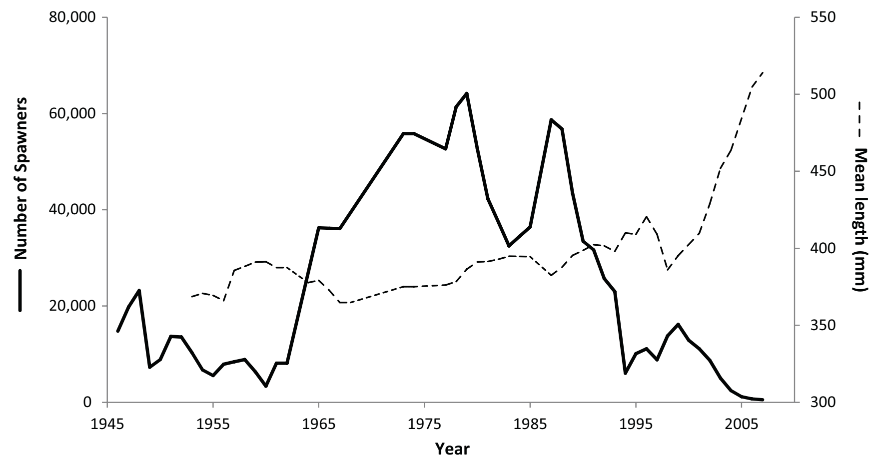


Figure 5. Counts and mean length of Yellowstone cutthroat trout spawners entering Clear Creek, 1945–2008. (The weir was removed because of damages that occurred during flooding in 2008 and has not been replaced.)

The Native Fish Conservation Plan and Environmental Assessment (Koel et al. 2010) and Finding of No Significant Impact (signed May 18, 2011) have been completed for Yellowstone National Park. Restoring Yellowstone cutthroat trout in Yellowstone Lake was given the highest conservation priority. Under the preferred alternative, the lake trout suppression effort, including both NPS crews and contract fishers, would be increased for at least six years, and effort would be continued beyond that period to limit lake trout abundance to a level that would allow recovery of the Yellowstone cutthroat trout population. According to the plan, the NPS will use an adaptive management strategy to meet benchmarks based on lake trout mortality to attain desired future conditions.

Although lake trout suppression may require a variety of techniques, the short-term emphasis will remain on gillnetting and trap netting from ice-off through October. Furthermore, suppression efforts may be modified depending on results, but improving efficiency is vital to the continued feasibility of the program. Input and guidance from independent scientific review panels will periodically be used to evaluate program direction and success.

Collaboration with other government entities and non-governmental organizations will be used to ensure financial support and provide leadership for research. An important area of interest is alternative technologies that can be incorporated into the suppression program, with an emphasis on techniques for targeting developing embryos and larvae in spawning areas. Telemetry studies for determining lake trout movement patterns and spawning areas will be imperative for applying these emerging technologies.

Because of concerns about stranding Yellowstone cutthroat trout larvae in tributaries prior to emigration (especially during late July through September), tributaries will be monitored to ensure connectivity to the lake (Koel et al. 2010). If migrating Yellowstone cutthroat trout become stranded, NPS managers intend to reconnect the tributary to the lake by removing gravel (Koel et al. 2010). Furthermore, if lake trout suppression is successful but Yellowstone cutthroat trout recruitment does not respond, remote-site incubators will be used to reintroduce Yellowstone cutthroat trout into tributaries where natural reproduction is lacking.

One significant aspect of the Native Fish Conservation Plan is the use of metrics to measure the relative success of the management strategy for restoring Yellowstone cutthroat trout in Yellowstone Lake (Koel et al. 2010). These metrics are linked to the effects of the suppression program on lake trout and the subsequent response of Yellowstone cutthroat trout. Identifying specific quantitative responses will be crucial to the success of an adaptive management strategy. Population responses will be evaluated by monitoring activities, including Yellowstone cutthroat trout spawning assessments at Clear Creek and tributaries in the Grant and Lake areas, and the enhanced gillnet monitoring program for lake trout and Yellowstone cutthroat trout. A variety of biological characteristics (including the presence of whirling disease and other fish pathogens) will be assessed for a subsample of fish captured in the monitoring program. Angling metrics for the two species will also be monitored.

Broader perspectives on lake trout suppression

Lake Pend Oreille, Idaho

The Lake Pend Oreille lake trout suppression program is part of a more general fishery recovery program intended to: (1) restore the kokanee (*Oncorhynchus nerka*) population and fishery, (2) restore the trophy rainbow trout (*Oncorhynchus mykiss*) fishery, (3) stabilize or increase the bull trout (*Salvelinus confluentus*) population and restore fishing opportunity, and (4) maintain or enhance the westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) population. The recovery program includes an angler incentive program that targets lake trout and rainbow trout >330 mm. Contract fishers use trap nets and gill nets to capture lake trout. For 15 weeks in winter and spring, small-mesh nets are used to remove small lake trout, and for 15 weeks in autumn, trap nets and large-mesh gill nets are focused on lake trout spawning areas. Spawning sites were identified with acoustic telemetry conducted from 2007 to 2010 (27–47 tags annually). Two boats were used for five weeks during the peak of spawning. After spawning, effort is concentrated on smaller lake trout in the northern portion of the lake.

The total number of lake trout removed from 2006 to 2010 was 115,033, including 57,832 from angling and 57,201 from the combined netting program. Removals by netting increased from 2006 to 2009, with little change between 2009 and 2010 (≈17,000 lake trout removed annually). Angling was effective during the first three years of the program; about 17,000 lake trout were harvested in 2007, but angler harvest was much lower in 2009 and 2010 (≈ 7,500 and 8,500, respectively). During the three years when spawner netting and angling both occurred, 80% of the mature lake trout were removed, and standardized trap-net data suggest that the catch declined 68% decline from 2007 to 2010.

Adult lake trout abundance in Lake Pend Oreille has declined about 70% since 2008, and juvenile netting is expected to reduce recruitment into the adult population. The decline in angler harvest of 457–559 mm lake trout suggests that a reduction in recruitment may already be occurring. At this point, researchers believe that effects will be evident in 2013 because: (1) 2008 was the first year spawning sites were targeted; (2) eggs fertilized in 2008 will be vulnerable to juvenile nets (age 4); and (3) juvenile lake trout that escaped the initial juvenile netting in nursery areas in 2009 will begin to mature.

Rainbow trout abundance has not fluctuated substantially during the study period, and growth is robust. Apparently, exploitation rates (19–23%) are insufficient to reduce the rainbow trout population despite an unlimited harvest limit and financial incentives to harvest fish. Researchers suggest that continued predation on kokanee by rainbow trout would reduce the rate of kokanee recovery.

The lake trout suppression program appears to be having positive effects on the kokanee population, because estimated spawner escapement increased from a low <10,000 in 2007 to more than 100,000 in 2010. Incidental mortality of gillnetted bull trout remains high (24-29%), but direct mortality of bull trout captured in trap nets is only 6%. Although by-catch (1-6% of bull trout >400 mm) does not likely have a major effect on the bull trout population, efforts to reduce incidental mortality are ongoing.

The apparent success of the lake trout suppression program in Lake Pend Oreille is a result of continual evaluation and adaptation of netting strategies and a strong funding base. Converting from hourly to overnight gillnet sets, willingness to continually explore new netting locations, and changes in net design (e.g., low-profile nets, varying mesh sizes and twine diameter, scaled-down trap net design, and higher profile nets on spawning sites) are among the factors that are contributing to success. Because Lake Pend Oreille is in the Columbia River drainage, consistent funding support has been secured from the Bonneville Power Administration and Avista Corporation (as mitigation for the Cabinet Gorge Dam).

Swan Lake, Montana

Swan Lake is located in the Flathead River drainage in northwest Montana. The Swan River flows into the lake and proceeds downstream into Flathead Lake. The lake has a surface area of 1,311 hectares, and although much of the lake is shallow, two zones >20 m deep are located in the southeast and northwest of this long, narrow lake. The lake supports a stable population of bull trout, and limited harvest of this species (which is listed as threatened under the Endangered Species Act) is permitted. Lake trout were first reported by anglers in 1998 and caught during routine gillnetting in 2003, which suggested that reproduction was occurring in the lake.

The Swan Valley Bull Trout Working Group was initiated in 2005 with representatives from Montana Fish, Wildlife and Parks; the US Fish and Wildlife Service; the Confederated Salish and Kootenai Tribes; the Montana Department of Natural Resources and Conservation; Montana Trout Unlimited; and the US Forest Service. The group concluded that the lake trout would become the predominant fish species in Swan Lake if left unchecked. Furthermore, the lake trout could continue invading upstream to become established in two other important bull trout refugia, Lindbergh and Holland lakes.

In 2006, the working group began research into potential means of suppressing the lake trout without jeopardizing the bull trout population. In 2009, Montana Fish, Wildlife and Parks released an Environmental Assessment that supported a three-year experimental lake trout suppression program with two netting periods each year. The first is a three-week, basin-wide gillnetting effort beginning in late August that is focused below the thermocline (>20 m depth). These are short-duration sets by contract fishers intended to minimize bull trout mortality. All salvageable fish are sent to local food banks. The second period consists of large-mesh nets set by agency personnel at suspected spawning sites. These nets are also checked frequently to reduce bull trout mortality.

The goal of the program is to achieve ≥50% mortality of lake trout in Swan Lake. Trends in body condition, population density, and length of spawning lake trout are being used to evaluate the effectiveness of the program. Population trends of bull trout, kokanee, and opossum shrimp (*Mysis diluviana*) are being monitored to evaluate the program's effects on other members of the aquatic community.

In 2009, contract fishers lifted nets twice daily for 15 days. In 2010, 25 lifts in 17 days of netting focused on spawning fish (Rosenthal 2011). The total number of lake trout removed in 2010 (10,500) was almost twice the number captured in 2009 (5,400). A strong year-class in 2009 apparently contributed to the larger catch in 2010, and the harvest of lake trout in 2009 appears to have reduced the proportion of lake trout in the 205-mm size class. Furthermore, the age structure of spawning fish shifted toward smaller individuals. Netting focused on lake trout spawners began about two weeks earlier in 2010 than in 2009, and contract fishers were used during this period. The number of males increased somewhat, and the number of females more than quadrupled in 2010. By-catch of bull trout remains low (8% of all fish captured), but 42% (88) of 212 captured bull trout were dead. Results were similar in spawner nets, where 36 of 87 bull trout (41%) died (Rosenthal 2011).

In 2010, 1,071 kg of lake trout were donated to local food banks in the area, and 181–272 kg of lake trout were delivered to local wildlife rehabilitation centers. These activities have resulted in positive feedback from the Swan Lake community and support for the lake trout suppression program, which requires approximately $100,000 annually for contracts and operating costs. Employees of Montana Fish, Wildlife and Parks; the US Forest Service; and the US Fish and Wildlife Service provide in-kind contributions of their time. All nets and equipment were purchased by the US Fish and Wildlife Service and Montana Fish, Wildlife and Parks. Operational funding has also been provided by other Swan Valley Bull Trout Working Group members.

Contract fishing perspectives across multiple systems

Hickey Brothers Fisheries, LLC, of Baileys Harbor, Wisconsin, has been contracted for numerous research and suppression projects across the United States. For example, they have recently been working on lake trout age, growth, and migration studies in Lake Michigan and walleye (*Sander vitreus*) research in Noxon Reservoir, Montana (2004). Hickey Brothers crews are currently involved in lake trout suppression programs in Lake Pend Oreille and Upper Priest Lake in Idaho, Swan and Quartz lakes in Montana, and Yellowstone Lake (Yellowstone National Park) in Wyoming.

Suppression technology: new techniques, methods applicable to Yellowstone Lake

Methods for nonnative fish suppression in lakes have included netting, chemicals, migration barriers, and electricity. Methodologies such as gillnetting, piscicide application, and movement barriers are costly and have negative environmental consequences (Martinez et al. 2009). Unintended consequences include mortality on non-target organisms from gillnetting and piscicides, food-web alterations, and the obstruction of native fish spawning migrations and nutrient distribution in a watershed. By-catch of Yellowstone cutthroat trout in Yellowstone Lake is a major concern of the gillnetting operation, and methods must be continually monitored to ensure that by-catch is not excessive. Moreover, the expense of equipment and a trained workforce necessary to achieve the level of effort necessary to reduce population growth below replacement is substantial. Finally, if an invasive species can be diminished, an efficient and cost-effective means is critical to prevent resurgence of the invader.

Electrofishing has been used in Yellowstone Lake to target spawning adults of the lake trout population and reduce recruitment. Electrofishing is practical for removing adult fish in shallow water, but is not effective in deep water. In 2008, the NPS chose to curtail the program because of safety concerns associated with electrofishing at night. If safety concerns can be addressed, electrofishing could provide an additional method for removing adult lake trout when they are vulnerable while congregated in shallow water for spawning.

In general, traditional suppression technologies focus on removal of adult and subadult lake trout >300 mm; strategies that target developing embryos and larvae have not been investigated extensively (Gross et al. 2009). However, a technique for destroying lake trout embryos on spawning grounds could provide an important tool for suppressing lake trout numbers. This suppression method could be used together with methods that target free-swimming fish (e.g., gill nets or electrofishing), or alone after the lake trout population has been substantially reduced.

NPS/T. KOEL

Gillnetting contractors Hickey Brothers Fisheries, LLC, fishing for lake trout on Yellowstone Lake.

To this end, a research program was initiated in 2008 to: (1) critically assess the ecological effectiveness, cost-effectiveness, and safety of alternative methods to destroy lake trout embryos; and (2) based on initial assessments, develop a practical methodology and associated equipment to destroy lake trout embryos in natural settings. An initial literature review identified several potential strategies for suppression and eradication of fish during early life-history stages (Gross et al. 2011). Five approaches to suppress lake trout and other invasive salmonids (electricity, carbon dioxide, UV light, dredge-less vacuums, and acoustic energy) have been tested (Gross et al. 2011). Preliminary results were promising, but experiments under natural conditions are needed to determine the potential efficacy and evaluate unintended consequences.

The major findings of the scientific review panel in response to questions from NPS staff are summarized below.

Current effectiveness of the program

- Substantially greater effort will be needed to achieve suppression of lake trout within six years.
- The lake trout population is below carrying capacity, and the population will likely increase without increased suppression.
- Lake trout suppression should remain the top priority of NPS fishery resources.
- The Yellowstone cutthroat trout population continues to decline ; its recovery is the ultimate measure of program success.
- Information gaps persist, especially the assessment of lake trout movement patterns and identification of lake trout spawning areas.
- Contract fishing is highly effective and expected to improve.
- Administrative and staffing barriers limit program effectiveness.

Progress on the panel's 2008 recommendations

Recommendation 1. Intensify the existing lake trout suppression effort for a minimum of six years.

Progress made:

- Increase resources:
  - Contract fishers have been integrated into the suppression program.
  - The NPS procured more funds for contract fishers, but overall effort (including contracted fishers) remains below 2007 levels (25,000 100-m net nights).
- Setting benchmarks for lake trout suppression:
  - Native fish conservation plan includes benchmarks (quantitative responses and performance metrics) for both Yellowstone cutthroat trout and lake trout (Koel et al. 2010).
  - A successful adaptive management strategy and associated monitoring metrics requires hypotheses for evaluation.
- Hypotheses should constitute predictions of the effects of specific management strategies:
  - Hypotheses should be set at the outset of the management actions.
  - Hypotheses should be designed to be informative.
  - Monitoring metrics should be designed to allow discrimination among alternative hypotheses.
- Experiment with alternative technologies for lake trout removal:
  - The NPS has supported this research, and this endeavor should continue, but should not occur at the expense of ongoing lake trout suppression.

Limited progress made:

- Telemetry studies are still relevant, and efforts to raise funds have been initiated.
- Refinement of monitoring design should improve interpretation of lake trout spatial patterns.
- Analytical reconstruction of population has been completed (Syslo et al. 2011), but ambiguities remain.


NPS

The use of contract fishers contributed to addressing the 2008 recommendation to intensify suppression effort for at least six years.

Recommendation 2. Maintain and enhance Yellowstone cutthroat trout monitoring programs.
Progress made or continued:
- Visual monitoring of spawners in small roadside streams has been maintained and has yielded a relative index through time.
- Annual fall gillnetting continues to provide data for relative comparisons through time.

Limited progress made:
- Partnership with MSU Department of Engineering has resulted in conceptual designs for reconstruction of the Clear Creek weir. Funding has been allocated to MSU Institute on Ecosystems for weir reconstruction in 2012.
  - Monitoring at Clear Creek continues to be relevant, and the Native Fish Conservation Plan has a benchmark based on the number of Yellowstone cutthroat trout spawning entering Clear Creek (Koel et al. 2010).
- Whirling disease occurrence and spread is no longer being monitored because the Whirling Disease Initiative administered by the Montana Water Center was discontinued, and an alternative funding source has not been found.

Recommendation 3. Initiate a statistically robust lake trout monitoring program.
Progress made or continued:
- Existing data have been reviewed and analyzed (Syslo et al. 2011).
- Monitoring to assess distribution of Yellowstone cutthroat trout and lake trout in near-shore areas across the lake basin has continued, but previous analyses suggest that inadequacies in standardized sampling limit the ability to detect how the lake trout population has responded to suppression.
- John Syslo and Christopher Guy (MSU) are working closely with NPS staff to develop a standardized sampling program that will detect changes in the Yellowstone cutthroat trout and lake trout populations.

Limited progress made:
- A mark-recapture estimate of population size has not occurred. An accurate and precise mark-recapture estimate would provide crucial information for evaluating success of the suppression program.
- Analysis of existing hydroacoustics data has not occurred; the relevance of this exercise is therefore uncertain.


NPS/T. KOEL

Hickey Brothers Fisheries, LLC, staff check a trap net set in the West Thumb of Yellowstone Lake.

Recommendation 4. Develop a lake trout suppression plan.
Progress made:
- The scientific review panel formed in 2008 continues to provide guidance to the program.
- The Native Fish Conservation Plan and Environmental Assessment (Koel et al. 2010) required substantial effort, and plan completion is an important accomplishment.
- The NPS is collaborating with outside partners including the USGS, MSU, and several NGOs (including the East Yellowstone Chapter of Trout Unlimited, Montana Trout Unlimited, the National Parks Conservation Association, and the Greater Yellowstone Coalition), and a Memorandum of Understanding is pending.
- Outside funding has been available to support suppression, but future funding is uncertain.
- A second scientific review panel was convened in 2011.
- NPS interpretive staff have developed visitor programs about the effects of lake trout on the Yellowstone Lake ecosystem and the lake trout suppression program in the lake.
- Enhancement of program capabilities has been partially successful but some issues require further attention:
  - The possibility of another planting of lake trout from Lewis Lake has not been addressed.

- ◦ Analysis of the angler database to examine spatial and temporal changes in lake trout fishery statistics for Yellowstone Lake has not been completed.
- Issues associated with facilities and polices for supporting lake trout suppression program have been partially addressed:
  - ◦ Adequate housing for contract fishers and increased NPS staff is lacking.
  - ◦ Storage space for fishery gear is limited at Lake Village.
  - ◦ Seasonal staffing and infrastructure maintenance issues limit the continuation of beyond mid-October, but lake trout often remain vulnerable until later in the year.
  - ◦ Retention of a trained seasonal workforce is difficult because of problems associated with providing higher grades or term positions to experienced personnel.
  - ◦ Speed restrictions in the South and Southeast arms of Yellowstone Lake substantially increase time required to set and retrieve nets, thereby decreasing efficiency in those areas.

Limited progress made:

- A science advisory committee has not been established.
- Safety issues associated with night electrofishing have curtailed its use. Although specific issues have been identified, cost-benefit analyses comparing night electrofishing and focused gillnetting have not been initiated. For example, would the purchase of a new electrofishing boat rectify the situation, and if so, is funding available?

Guidance on Future Directions

Suppression

- Provide a specific recommendation regarding the level of suppression required to cause a rapid reduction in lake trout abundance.
  - ◦ Based on the analysis by Syslo et al. (2011), the panel recommends that the NPS increase effort to 57,000 100-m net nights annually This is a conservative estimate based on upper confidence limits of point estimates of effort required to reduce population growth below replacement ($\lambda < 1.0$) in five years.

NPS/B. KLEIN

Seasonal staff such as National Park Service biological science technician Kate Olsen (right) comprise most of the workforce for native fish conservation

- The recommended level of effort is estimated to result in a fishing mortality rate of (F) ≈ 0.59.
- While this analysis represents the current state of the art, it is based on assumptions that should be evaluated and updated as more information becomes available.
- The recommended level of effort will reduce the risk of failure.
- The recommended level of effort could be accomplished with increased contract fishing or using NPS resources more effectively (additional funding may be required).
  - Increase the number of experienced NPS staff by providing funding incentives for returning summer employees.
  - Maintain staff at levels that support two netting crews (boats) seven days a week.

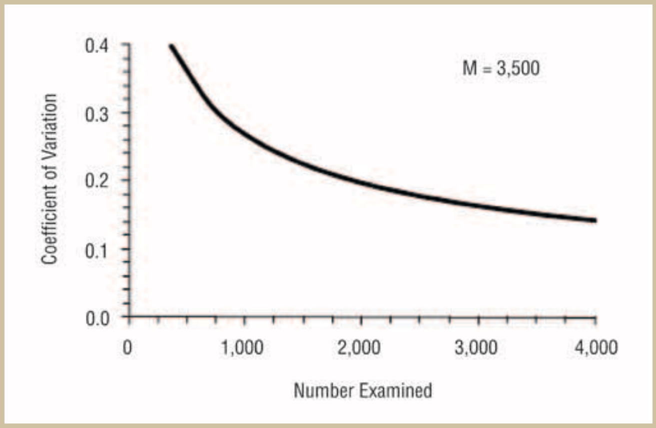
- Mortality rates predicted for the recommended level of effort are consistent with documented overfishing of lake trout populations (F ≈ 0.60) and are similar to removal rates that have been effective in reducing lake trout population growth in Pend Oreille (F ≈ 0.60).
- This level of effort is necessary for the NPS goal of "rapid reduction" (defined as measurable progress within five years) of lake trout in Yellowstone Lake.
- Given the recommended level of suppression, provide specific recommendations regarding how long that the NPS should expect to sustain this effort.
  - The panel recommends that suppression efforts be continued at this level for a minimum of 10 years, or until suppression goals (as outlined in the Native Fish Conservation Plan, Koel et al. 2010) are met.
  - A measurable decline in lake trout abundance is likely within five years if the recommended level of suppression is implemented and sustained.
  - Some level of maintenance effort (presumably less than current levels) will be necessary indefinitely after suppression goals are met.
- Provide recommendations regarding the suppresion methods (e.g., gillnetting, trap netting, angling, or new techniques) that should be used.
  - The panel recommends that gillnetting should continue to be the primary suppression technique.
  - Exploration with other techniques (e.g., trap netting, electrofishing, and methods focused on embryos and larvae) is encouraged, but not in lieu of the prescribed level of gill net suppression effort (57,000 100-m net nights) until cost effectiveness can be demonstrated.
  - The panel advises against angler incentive programs in Yellowstone Lake which could develop a constituency for lake trout in the lake. Analysis of data from Lake Pend Oreille suggests that success of the angler incentive program was substantial initially, but has been surpassed by gillnetting removals.
- Assess management options for the system if lake trout are suppressed.
  - The panel believes that a maintenance program of reduced effort and monitoring will be required until new advancements in suppression technology become available.
  - Knowledge of spawning locations will be vital to a cost-effective maintenance program.
  - Further transfer of lake trout into Yellowstone Lake from Lewis Lake must be prevented. Planning for potential solutions to this issue should not be delayed.
- Estimate how many years are needed to detect a positive response in Yellowstone cutthroat trout if lake trout are suppressed.
  - Response may depend on other controlling factors, but if not:
    - Juvenile survival will likely increase rapidly (within 1 or 1–2 years).
    - Spawners in tributaries will likely increase slowly (>5 years).
- Provide recommendations on the acceptable level of Yellowstone cutthroat trout mortality resuting from suppression efforts.
  - Yellowstone cutthroat trout mortality associated with suppression activities should be minimized.
  - Numbers of Yellowstone cutthroat trout saved from lake trout predation currently exceeds numbers lost to by-catch.
  - By-catch is acceptable until it exceeds gains due to lake trout removal.
  - By-catch of Yellowstone cutthroat trout will increase with increasing suppression effort, so the panel recommends tracking the level of by-catch as a function of the total number of lake trout removed.

Assessment

- Determine the need for a lake trout population estimate. Is a lake trout population estimate needed for guiding suppression efforts? What are the realities of obtaining an estimate?
  - A population estimate is needed (and possible) to provide a benchmark for performance toward suppression goals (see below). However, the panel does not rate completion of this research above suppression efforts.
  - Randomized recapture effort requires some compromise with suppression, but an accurate and precise lake trout population estimate would facilitate evaluation of the suppression program.
  - The panel recognize the following realities and opportunities for obtaining a lake trout population estimate:
    - Suppression netting and distribution netting can be used for recapture in mark-recapture studies.
    - The tagging portion of a mark-recapture study could be completed in conjunction with a planned (but currently unfunded) USGS telemetry study.
    - Population estimates are not required annually.
- Evaluate the lake trout and cutthroat trout monitoring objectives and draft a plan for long-term monitoring on Yellowstone Lake.
  - Analyses to date suggest that inadequacies in the standardized Yellowstone Lake monitoring program limit the ability to detect how the lake trout population has responded to suppression.
  - Standardized sampling has not been a NPS priority through the duration of lake trout suppression but is necessary for evaluating the effectiveness of the program.
  - A standard operating procedure for the monitoring program is being developed in collaboration with researchers at MSU to provide:
    - Clearly defined objectives;
    - Clearly defined metrics to measure Yellowstone cutthroat trout and lake trout population responses to the suppression program; and
    - Monitoring data that will be analyzed annually relative to the performance metrics.

Mark-recapture Estimate for Lake Trout in Yellowstone Lake

Based on supplemental information provided to the panel), the lake trout caught in trap netting would likely be the limiting number in a mark-recapture study. In 2010, 4 trap nets yielded 2,580 lake trout, but 4 more nets are being set in 2011, which should enable capture of twice as many lake trout. Assuming that 5,200 lake trout were marked during trap netting, precision estimates were generated for a hypothesized lake trout abundance of 300,000 fish (Syslo et al. 2011). Results suggest that recapture sampling will need to be increased above the base level of distribution netting that was deployed in 2010, which yielded a sample of 358 lake trout (lowest point for the curve on the x-axis below). Commercial fishers gillnetting effort could be layered on top of the base design for distribution netting to increase the number of fish examined during recapture sampling. If the commercial fishers can add enough fishing effort to increase the number of fish examined to C = 2,000 fish, the mark-recapture estimate of abundance would have a CV = 20% (R = 23, if N = 300,000), which is excellent precision for mark-recapture studies and would provide sufficient precision to judge progress of the lake trout suppression program. Based on catches by commercial fishers to date, a recapture sample of 2,000 lake trout seems attainable. Keys to success for the mark-recapture study are: (1) mark lake trout from trap nets set to maximize the number of fish captured, tagged, and released; and (2) distribute recapture sampling throughout the lake using the distribution netting design (i.e. a stratified-random design).



NPS/C. BARKER

A native fish restoration field team hiking to a remote reach of upper Grayling Creek, 2009.

- Determine if additional scientific panel reviews are necessary and develop an associated timetable.
  - The panel recommends that a science advisory committee (a sub-group of the current scientific review panel) be engaged for annual program review.
  - A full scientific review (similar to the 2008 and 2011 panels) should occur every three years.
- Provide a recommendation concerning the acceptable level of Yellowstone cutthroat trout mortality directly related to monitoring.
  - Long-term monitoring data from Yellowstone Lake are crucial to understanding Yellowstone cutthroat trout population, but mortality of Yellowstone cutthroat trout should be minimized.
  - The monitoring program should justify numbers of Yellowstone cutthroat trout sampled given NPS assessment goals, and the monitoring program should be modified to reduce Yellowstone cutthroat trout mortality.
  - This question requires further investigation and should be reviewed annually by the science advisory committee.

Research Projects Prioritized

The scientific review panel has ranked the following list of research needs that are directly related to accomplishing restoration goals. while emphasizing that the first research priority greatly outweighs all of the others.

1. Identify lake trout spawning areas to guide suppression efforts (telemetry; see page 24).
2. Estimate lake trout population density by mark-recapture (trap nets can be used for the mark sample, and suppression gill nets can be used for the recapture sample; see page 22).
3. Investigate alternative lake trout suppression techniques (proof of concept and modeling).
4. Quantify whirling disease prevalence from Yellowstone cutthroat trout by-catch using PCR analysis.
5. Evaluate effects of climate change (e.g., drought).
6. Assess effects of recycling dead lake trout on secondary productivity in Yellowstone Lake.
7. Quantify the potential competition between juvenile Yellowstone cutthroat trout and lake trout.
8. Evaluate the validity of the Volunteer Angler Report to meet current information needs.

Research Projects Funding:

- Provide a strategy for acquiring the needed funding.
  - The panel recommends that the NPS create a funding advisory board and suggest that the NPS (see page 26):
    - Examine new avenues to increase funding within the NPS;
    - Collaborate with the NGO community to access additional funding;
    - Encourage NGOs to pursue increased funding from Congress for lake trout suppression activities;
    - Work with academic institutions and government research organizations;
    - Solicit funds from the Yellowstone Park Foundation and other foundations; and
    - Consider development of a funding program targeted specifically for lake trout suppression.

Allocation of Resources

- Prioritize spending recommendations.
  - Suppression effort must be greatly increased and is the top management priority.
    - Adequate funding is a necessity.
    - If funding is insufficient to meet recommended levels of suppression effort, the remainder of the program is moot.
  - Monitoring is a core component of the adaptive management strategy, but is a second priority.
  - Research is important, but reaching the target level of effort for lake trout suppression should take priority over exploring research questions.

Yellowstone Cutthroat Trout Enhancement

- Evaluate the efficacy of Yellowstone cutthroat trout enhancement projects (e.g., remote site incubators, supplementation, and reconnecting tributaries to the Yellowstone Lake).

Using Telemetry to Evaluate Movement Patterns of Lake Trout

Although suppression efforts have been successful at removing large numbers of lake trout from Yellowstone Lake, juveniles comprise most of the catch because adult lake trout have been more difficult to capture. Given the reproductive potential of spawning lake trout and the positive relationship between lake trout body size and consumption of Yellowstone cutthroat trout, targeted removal of adults will produce numerous benefits towards population suppression. One way to increase capture of adults from Yellowstone Lake is to focus removal efforts on spawners.

Throughout their native range, lake trout exhibit well-defined, predictable spawning behavior. Lake trout spawn from September to November and require substrate of a specific size (often 10-20 cm), depth (2-10 m), and slope (20-45°) and wave exposure (Bigelow 2009). More importantly, lake trout are aggregate spawners, with hundreds or more of mature fish congregating in distinct spawning areas that remain consistent across years (Healey 1978; Martin and Oliver 1980; Dux et al. 2011). Therefore, identification of spawning shoals within Yellowstone Lake represents an opportunity to focus removal efforts on mature adults, thereby reducing the number of offspring produced.

Although several areas in the lake attract large numbers of gravid lake trout, only two have been confirmed as spawning shoals. Additional spawning shoals can be located based on wave energy theory and information about the lake's geomorphology, which suggest that about 4% of the lake has high potential for supporting lake trout reproduction, a large area (Bigelow 2009).

Recent advances in remote animal monitoring have allowed researchers to collect real-time, high-resolution (sub-meter) data on the behavior, physiology, and ecology of free-swimming fishes. Fish residing in deep water lakes, such as Yellowstone Lake, can be monitored with stationary, autonomous receivers and acoustic tags arranged throughout the lake in a stationary array. Stationary hydrophones in an array have a 'listening radius' of 500–800 m. Any fish implanted with an acoustic transmitter that enters this radius will have its identification code, date, and time logged in the receiver,. By strategically placing receivers at key locations in a lake, movements and activity patterns of tagged individuals across time can be observed, and clustering of tagged fish during known spawning times can be quantified, thereby identifying potential spawning shoals.

- Enhancement programs should be considered "last-ditch" efforts that are to be applied only if (1) lake trout cannot be suppressed after substantial increases in effort are maintained over a 10-year period, and (2) Yellowstone cutthroat trout do not respond to lake trout suppression.
  - The panel is concerned about genetic integrity and unintended ecological consequences of this management action.
- Enhancement programs should not be undertaken without thorough genetic analysis of source stock and a comprehensive risk assessment. Input from the states of Idaho, Wyoming, and Montana is encouraged.
- The panel recognizes the positive environmental education and public relations aspects that result from enhancement programs, including thepotential impact on funding.

Summary

- Substantial progress has been made on the 2008 recommendations from the scientific review panel.
- Suppression of lake trout is a Yellowstone National Park issue that is not just a fisheries issue.
- A rapid response by Yellowstone cutthroat trout will require that suppression effort be doubled for the next 10 years.

Acoustic telemetry can be used to monitor the movement and activity patterns of lake trout in Yellowstone Lake with a goal of identifying spawning shoals. The panel recommends implanting at least 150 mature lake trout with tags. Implanting an additional 50 depth-sensing tags would provide insight on spawning locations. These fish should be monitored with 50 to 75 stationary, autonomous receivers placed in the lake at suspected spawning locations, and at "choke points" in the lake. Receivers can be repositioned after deployment if lake trout do not inhabit a particular area of the lake. Monitoring of tagged lake trout should continue for 2 to 4 years to increase confidence in the persistence of suspected spawning locations and allow for repositioning of receivers during several spawning periods to maximize the number of shoals located.

Analyses of the telemetry data collected from tagged lake trout will be used to generate several outcomes:

1. Location of spawning shoals within Yellowstone Lake. By downloading data from receivers regularly, particularly in autumn prior to spawning (likely every 4–7 days), clusters of tagged lake trout can be identified. These clusters will represent suspected spawning shoals that likely contain large numbers of mature individuals. This information can be conveyed to the NPS or contracted netters quickly, thereby allowing removal gear to be positioned at areas to target removal of spawning fish.
2. Improved understanding of the spatial ecology and activity patterns of lake trout. Acoustic transmitters for adult lake trout have a battery life of approximately 2–5 years,. These data on movements and activity can be analyzed to quantify movement rates, dispersal rates, habitat use, and activity patterns that will improve our understanding of lake trout biology in Yellowstone Lake and potentially enhance removal efforts. In addition, cues (e.g., water temperature and photoperiod) that motivate lake trout to begin spawning and initiate movements to spawning shoals can be better defined.
3. Targeted removal and destruction of lake trout offspring. Previous research has demonstrated that several techniques can be used after spawning to reduce the number of viable lake trout embryos in the wild. For example, developing embryos can be damaged by electrical current directed into the substrate or acoustic shock in water column. Aquatic vacuums can be used to remove fertilized eggs or embryos from substrate. Although these technologies may have great potential to supplement population suppression of adult lake trout, they cannot be used until the location of spawning shoals have been identified.

Increasing Capabilities through Partnerships

A SUCCESSFUL lake trout suppression program in Yellowstone Lake will require additional resources beyond those allocated in existing NPS programs. Yellowstone National Park staff has increased fisheries budgets and competed for needed funds through the Yellowstone Park Foundation. Nonetheless, non-traditional funding sources are needed to increase the gillnetting effort, develop new suppression technologies, research enhanced suppression activities, and monitor the results of the program.

Partnerships can help fill the gap between existing capabilities and program needs. Developing cooperative agreements between Yellowstone National Park and non-governmental partners will help declare a common commitment and clear the way for additional support. NPS staff are pursuing agreements with the Yellowstone Park Foundation, Trout Unlimited, the Greater Yellowstone Coalition, and the National Parks and Conservation Association. This agreement will describe appropriate avenues of assistance to the park and encourage their expansion. Partner organizations can also help with specific funding needs. For example, the Wyoming Council of Trout Unlimited has created a "Save the Yellowstone Cutthroat Trout Fund" and raised more than $27,000 to purchase needed telemetry equipment.

These non-governmental groups can provide help in numerous ways. Volunteers are available to assist monitoring and control efforts. Trout Unlimited volunteers have helped pick gill nets and measure collected fish. These organizations also have local members available to assist with monitoring programs. These organizations can collaborate with the NPS to develop project proposals for foundation grants or other outside sources. Independent of the NPS, these organizations can lobby for increased program budgets to support the NPS lake trout suppression program in Yellowstone National Park.

Other governmental agencies can help fill the capacity gap. The U.S. Geological Survey (USGS) has been active for several years with experimental programs for nonnative fish suppression, including a pilot study targeting lake trout spawning areas in Yellowstone Lake. With improved knowledge of lake trout staging and spawning areas, control efforts beyond gill nets and traps may become more feasible. The USGS has assisted with design, funding, and implementation of research that supports lake trout suppression, and should be called upon for assistance with future projects as well.


NPS

Graduate research assistant Joe Skorupski (left) and NPS Fisheries Technician Derek Rupert sampling for aquatic macroinvertebrates on East Fork Specimen Creek.

Universities and local schools offer partnership opportunities for research and monitoring. The high visibility of and interest in Yellowstone National Park should attract and sustain a variety of local and national partners. Montana State University and the University of Wyoming have played key roles in applied research and have provided analyses critical for this scientific panel review.

In the end, staff from Yellowstone National Park needs to reach beyond traditional areas for support by working with non-governmental organizations and other government agencies. Fully restoring Yellowstone cutthroat trout throughout the Yellowstone Lake ecosystem is a national-scale conservation priority that will require a long-term collective commitment and innovation to achieve success.

The NPS should also consider developing a funding pool for an applied fisheries research program in the park. This pool could be supported, in part, by an endowment with seed money from a private donor. The NPS could offer a partial funding match for researchers who apply for grants from other sources. other possible sources are the National Science Foundation, Trout Unlimited programs such as "Embrace a Stream", the USGS–USFWS Science Support Partnership, the USGS Quick Response Program, the NPS Request for Proposals program, and smaller grants from the American Fisheries Society, often in collaboration with university students. NPS staff and the science advisory committee would develop, and revise regularly, a prioritized list of research and information needs consistent with management and conservation goals. All grant pre-proposals would be reviewed by an external panel. Programs such as the Colorado River Research and Monitoring Center and the Columbia Basin Fish and Wildlife Program could serve as models for a research funding pool.

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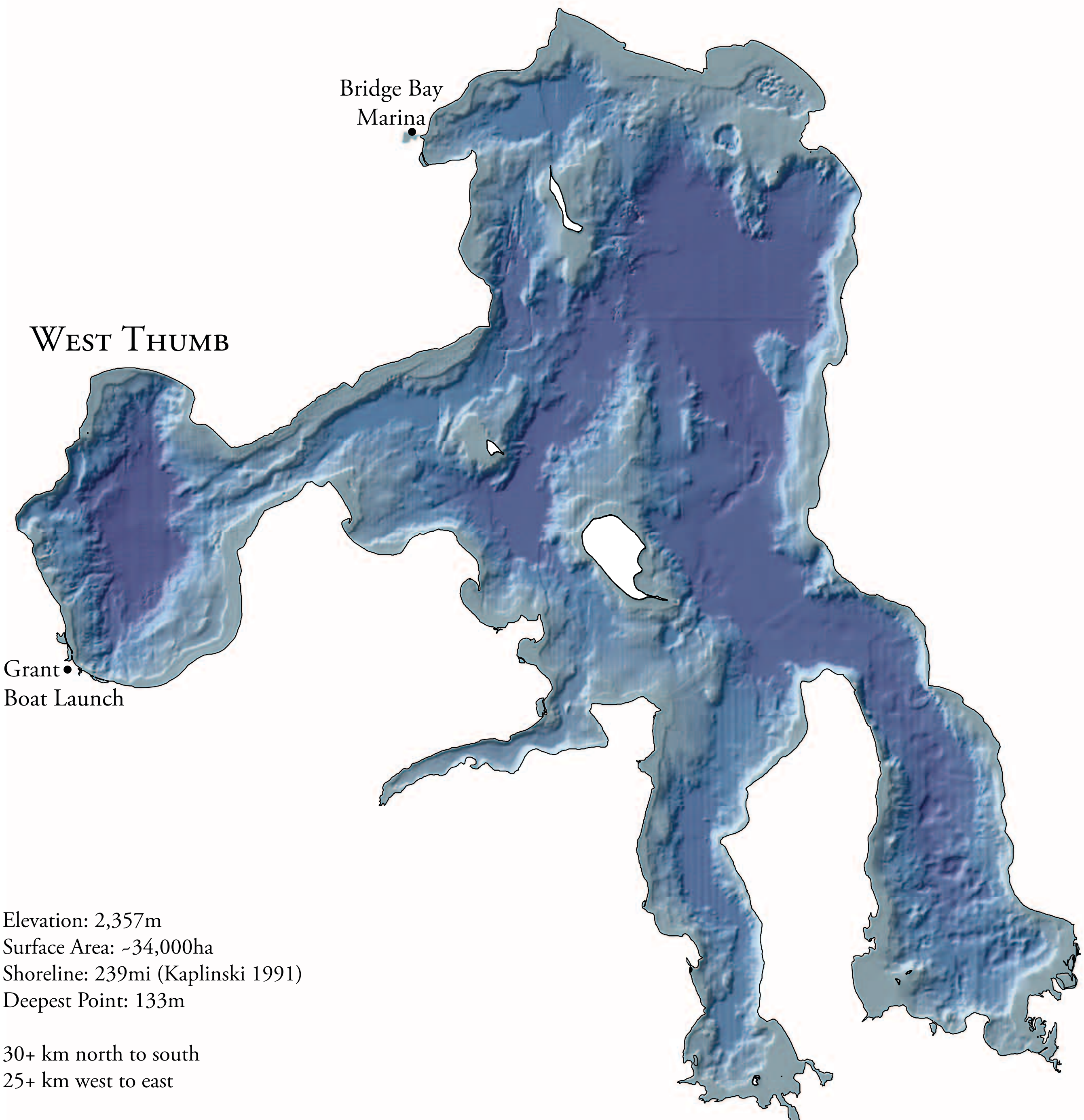
NPS

Yellowstone Lake.

Yellowstone Lake



Elevation: 2,357m
Surface Area: ~34,000ha
Shoreline: 239mi (Kaplinski 1991)
Deepest Point: 133m

30+ km north to south
25+ km west to east

Covered in ice an average of ~160 days/year (Gresswell et al. 1997)

5 2.5 0 5 Kilometers