Lake Trout Suppression in Yellowstone Lake: Science Review Panel

Interim Scientific Assessment, 2014 Performance Year
A Report to the Superintendent of Yellowstone National Park

Fisheries technician Jay Fleming holding a spawning lake trout netted on the NPS *Hammerhead*. NPS Photo

Cover: Spawning lake trout. Photo © Jay Fleming
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May 12-16, 2015

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Final Report, December 2015

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INTRODUCTION

In an effort to restore native Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) to their ecological prominence in Yellowstone Lake, nonnative lake trout (*Salvelinus namaycush*) have been actively suppressed by the National Park Service since 1996. Gill nets have been the primary tool for capturing lake trout, and up to 20 kilometers of gill nets may be used at any time. By 2015, more than 1.7 million lake trout had been removed. Models based on removal estimates suggest lake trout abundance began to decline in 2012, but the number of lake trout caught annually remains high (≈300,000 in 2012-2014). Monitoring suggests a positive response by Yellowstone cutthroat trout in response to declines in lake trout abundance.

Following a recommendation of a Scientific Review Panel in 2011, the National Park Service initiated a science review team that would meet annually to evaluate results from the previous year and review plans for the upcoming year. The Interim Science Assessment Panel was meant to compliment, not replace, the less frequent Science Panel reviews (2008 and 2011). At the same time, the team was to provide review and input concerning suppression activities, not to approve or disapprove of those activities. The Interim Science Assessment Panel met in May 2015 to evaluate 2014 activities and provide feedback concerning future plans for the suppression program.

WORKSHOP GOAL

The workshop goal is to evaluate 2014 activities and provide feedback regarding plans for the 2016 field season.

DELIVERABLE

The key product will be a report to the Superintendent of Yellowstone National Park, to be completed by July 15, 2015.

PANEL RESPONSES TO QUESTIONS FROM THE NATIONAL PARK SERVICE

IS THERE EVIDENCE THAT LAKE TROUT SUPPRESSION IS SUCCEEDING RELATIVE TO THE CONSERVATION PERFORMANCE METRIC?

- Lake trout catch rates in suppression netting programs have declined for the third consecutive year; decreasing from highs in 2011 of 8.2 fish per unit of effort (one unit of effort = 100 meters of net set for one night) in small-mesh gill nets and 6.0 fish per unit of effort in large-mesh gill nets, to 5.1 and 1.8, respectively, in 2014.

- Suppression effort remained well above target levels in 2014; 20% higher than in 2013.

- Catch-curve analyses suggest total annual mortality has been near or above 0.5 for the past two years. A more sophisticated statistical catch-at-age analysis suggests even higher recent mortality rates. Total instantaneous mortality rates from statistical catch-at-age analysis were 1.18 in 2013 and 1.33 in 2014, corresponding to annual mortality rates of 0.69 and 0.73 for large lake trout that are fully vulnerable to the fishing gear.

- Population growth rate (lambda) is estimated to be well below the primary performance metric. A demographic analysis concluded that the current population growth rate is well below one (i.e., the replacement level); therefore, the lake trout population is probably declining. In contrast to this evidence, the catch rates in assessment nets (also known as distribution nets), which harvest far fewer lake trout, were higher in 2014 than 2013. A plausible explanation for this conflicting result is that 2014, like 2011, was a cold year which may have resulted in lake trout being distributed closer to the shoreline of the lake, and thus more susceptible to capture in the assessment nets. Catch rates in these nets were also unusually high in 2011. The Science Panel recommended further investigation of the association between water temperature and assessment net catch rates, possibly to enable standardization of these catch rates to account for temperature effects.

IS YELLOWSTONE CUTTHROAT TROUT RECOVERY SUCCEEDING RELATIVE TO CONSERVATION PERFORMANCE METRICS?

- The catch per unit effort (CPUE) of Yellowstone cutthroat trout in distribution netting continues to rise (increased 282% since 2010).

  –The Science Panel believes a statistical comparison of the current distribution-netting assessment and discontinued fall-gillnetting program would be valuable, and results should be presented during the 2016 Scientific Assessment of the Lake Trout Suppression Program in Yellowstone Lake.

  –A conversion factor should be developed to ensure comparability between the two monitoring techniques and facilitate evaluation of Yellowstone cutthroat trout recovery in Yellowstone Lake using benchmarks stipulated in the Native Fish Conservation Plan (Koel et al. 2010).

- Results from the distribution netting suggest the proportion of younger (smaller) Yellowstone cutthroat trout is increasing (strong recruitment in last three years).

- Results from the Volunteer Angler Report (VAR) in 2014 suggest an increase in angler CPUE; however, it remains below the secondary benchmark stipulated in the Native Fish Conservation Plan (Koel et al. 2010).

  –The Science Panel believes trends in angler use and harvest are compromised by inconsistencies in methodology including modification of methods used for estimating the number of anglers and angling effort, and the decision to discard correction factors integral to the VAR system.

  –The VAR has not been validated since 1976; but during the past 39 years there have been changes in species composition and relative abundance of sport fishes in Yellowstone Lake (since 1994), institution of an angling license fee (1997), and implementation of a catch-and-release-only angling regulation for Yellowstone cutthroat trout (2001).

  –The Science Panel recommends a comprehensive analysis of angler use statistics and validation of the VAR system to ensure these data are useful for monitoring recovery of Yellowstone cutthroat trout in Yellowstone Lake.

- There appears to be an increase in the number of Yellowstone cutthroat trout spawners in 11 streams monitored visually, but spawner abundance in Clear Creek remains unknown.

  –The Science Panel is sympathetic with the difficulties in implementing the new monitoring system at Clear Creek, but data from this spawning population were integral to assessing the negative effects of lake trout on the Yellowstone cutthroat trout population and are critical for evaluating recovery of the native trout.



–The Science Panel recommends an independent estimate of the number of Yellowstone cutthroat trout spawners be initiated in 2016 and conducted simultaneously with ongoing efforts to improve operation of the sonar fish counting system. Although a total count of spawners might provide information necessary to calibrate sonar estimates, a visual estimate of spawners in a study section of Clear Creek could be used as an index of spawner density even if an estimate with the sonar counter is unobtainable.

DOES THE SCIENCE PANEL SUGGEST ANY MODIFICATIONS TO THE 2010 PERFORMANCE METRICS?

- The Science Panel reviewed the performance metrics described in Table 5 of the 2010 Yellowstone National Park Native Fish Conservation Plan and concluded that the population growth rate and assessment net catch rate metrics were not appropriately aligned. Specifically, the primary and secondary catch rate metrics seem unrealistically low and inconsistent with the expected trends in population levels implied by the target population growth rates.

- The Science Panel recommends modifying the primary and secondary catch rate metrics to align with the population growth rate targets by computing the expected change in catch rates in 10 years, given a rate of population decline implied by the primary and secondary target population growth rates. The current primary metric should be changed from 0.01 fish per unit of effort to 0.20. The secondary metric should be changed from 0.10 fish per unit of effort to 0.71.

WHAT SHOULD BE CHANGED IN SUPPRESSION?

- The Science Panel remains persuaded that the trade-off between trapnetting and gillnetting favors including trapnetting for the reasons articulated last year.

  –Data presented this year indicate trapnetting targets females disproportionately to males (larger amount of life-time egg production).

  –Bycatch mortality of Yellowstone cutthroat trout is lower in trap nets.

  –Trap nets can be used to strategically target lake trout and reduce mortality of Yellowstone cutthroat trout (e.g., shallow water sets in South Arm).

- The Science Panel recommends a quantitative comparison of potential suppression effects of trapnetting and gillnetting which accounts for the contribution of each gear to reductions in lifetime egg production potential for lake trout, given comparable circumstances and levels of effort.

- The Science Panel recommends that effort in South and Southeast arms be maintained or increased (as indicated).

  –Lake trout CPUE is higher than elsewhere.

  –Size of lake trout is larger than elsewhere.

  –Suppression in these areas avoids potential for creating and protecting a refuge population of lake trout.

WHAT SHOULD BE CHANGED IN MONITORING?

- The Science Panel strongly endorses the use of similar assessment methods for Yellowstone cutthroat trout as currently used for lake trout (i.e., quantify annual mortality, population growth rate [lambda], CPUE in distribution nets, and maintain a data timeline) so sustained changes in abundance and recruitment can be detected.

- The Science Panel also reiterated its recommendation to monitor and quantify Yellowstone cutthroat trout spawners at Clear Creek. The CPUE of adult Yellowstone cutthroat trout in distribution nets continues to rise, with an increase in the proportion of smaller (presumed to be younger) Yellowstone cutthroat trout that suggests strong recruitment in the last three years. Angler CPUE increased in 2014; the number of spawners in 11 streams that are monitored visually has increased, but data from Clear Creek are lacking.


YAKIMA

WHAT SHOULD BE CHANGED IN RESEARCH?

- Research efforts intended to supplement primary suppression techniques (gill nets and trap nets) for invasive lake trout should focus on:

  –Locating and characterizing primary sites of lake trout spawning within Yellowstone Lake, and subsequent assessment of the quantity and quality of habitat available for lake trout egg deposition and hatching success is critical. If suitable spawning substrates are confined to shallow sites in a limited number of areas, it may be feasible to use methods focused on early life-history stages to reduce overall lake trout reproduction and recruitment. If suitable lake trout spawning substrates prove to be widespread throughout the lake or abundant in deeper waters, suppression of the egg or fry stages may not be feasible.

  –Methods to reduce lake trout reproduction by destroying eggs or embryos (including an electrical grid to destroy developing embryos and a suction dredge to pull eggs and embryos from the spawning substrate) require further testing to assess effectiveness in suppressing hatching success and recruitment. Alternate methods for destroying lake trout eggs or embryos at spawning sites include toxicants (e.g., rotenone and H_2S) or suffocation (e.g., tarps). Ongoing collaboration between the NPS and research personnel may contribute to the reduction and control of lake trout numbers in the future.

- Alternate methods of controlling lake trout abundance may prove to be effective for population suppression only after growth of the lake trout population has been reduced substantially. Declining numbers of reproducing adults may condense successful spawning to a few sites; and subsequently, intense application of effective, alternate control methods would likely contribute to suppression.

SPECIFIC COMMENTS RELATED TO NATIONAL PARK SERVICE QUESTIONS

1. Should NPS continue to focus suppression netting on large adult lake trout?

   Yes; large adults contribute a disproportionate number of potential recruits to the population, so each large adult killed, if female, has a higher contribution to suppression than a large number of juveniles killed.

2. Should NPS increase suppression within protected wilderness areas (the South and Southeast arms) of Yellowstone Lake?

   Yes; lake trout CPUE in the South and Southeast arms is higher than in other areas, and the size of lake trout is higher than in other areas. Suppression in the southern arms will avoid the potential for a refuge population of lake trout to establish in these areas.

3. Should alternative methods of lake trout suppression (embryo and fry suppression) be applied to spawning areas as they are found lakewide?

   No; methods for embryo and fry suppression are still in the research and development phase, and researchers are in the process of locating spawning areas. Once spawning sites have been located and evaluated (depth, substrate type, and relative density of use by lake trout), they will need to be prioritized for future treatment.

4. Should NPS pursue genetic methods of lake trout and/or Yellowstone cutthroat trout population assessment?

   No; the Science Panel considered this research to currently be a low priority, as it will not yield information that will directly contribute toward suppression of lake trout or protection of Yellowstone cutthroat trout.

5. Should NPS be ensuring Yellowstone cutthroat trout spawning stream connectivity to the lake, especially during drought years?

   No; the position of the Science Panel is unchanged. Spawning stream dynamics vary with the natural cycle of the lake, and this variability is a basic component of Yellowstone cutthroat trout population ecology.

6. Should NPS be introducing Yellowstone cutthroat trout embryos using remote site incubators to spawning tributaries where, to date, there has been no evidence of use by spawning adults?

   No; the position of the Science Panel is unchanged. Hatchery operations and subsequent stocking of Yellowstone Lake were curtailed in 1954 because there was no evidence the program was contributing to the Yellowstone cutthroat trout population. Furthermore, despite cessation of stocking and an increased harvest, the number of spawners in Clear Creek actually increased over tenfold by the 1960s.

7. What lines of research should be pursued to enhance lake trout suppression efficiency and ensure Yellowstone cutthroat trout recovery?

   The Science Panel does not support additional new research projects (beyond suggestions made above) at this time.

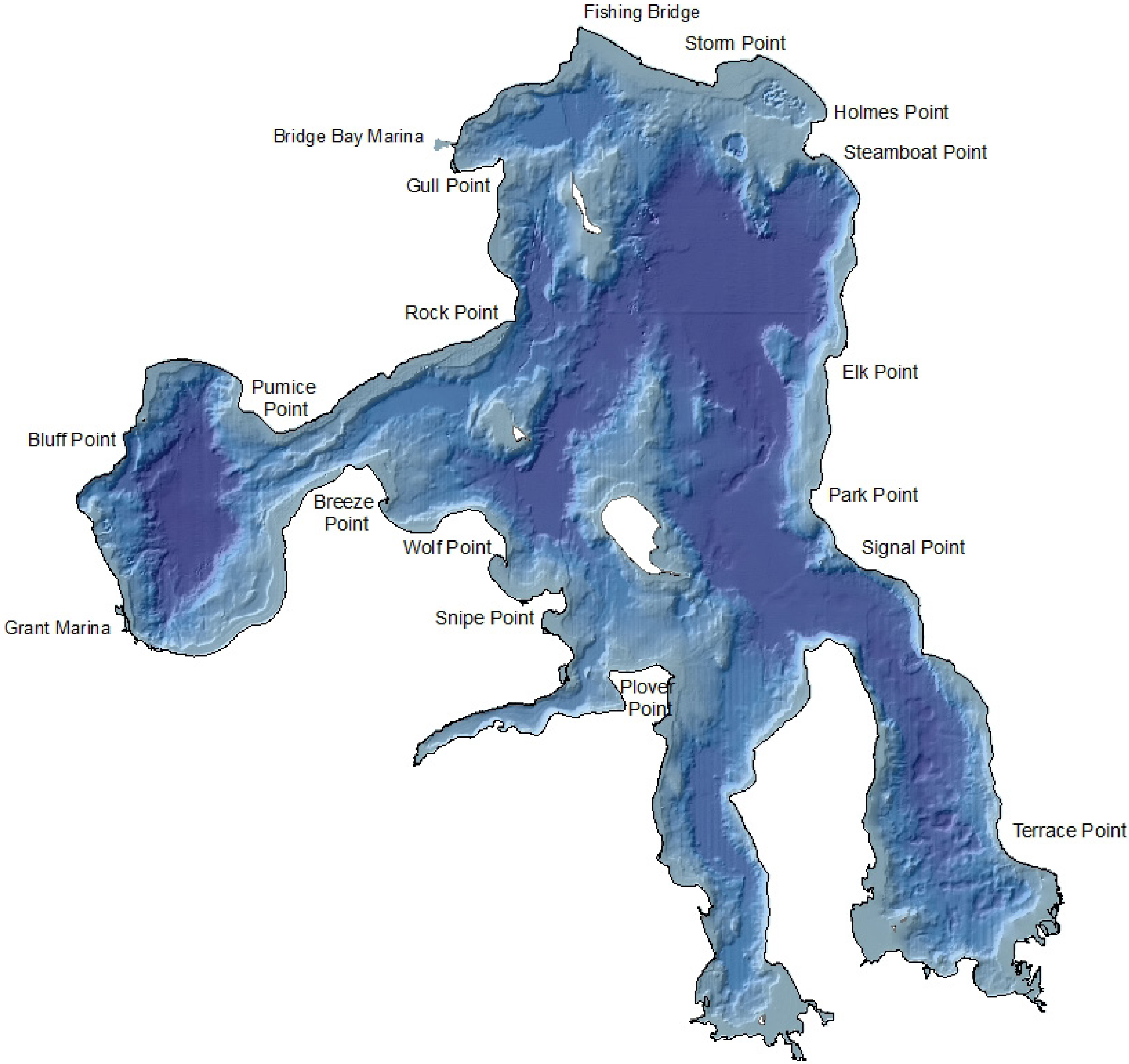
STRUCTURE OF FUTURE MEETINGS AND REPORTS

- Next panel meeting April 5-8, 2016.
- Report format to be modified as suggested and delivered by June 15, 2016.
- NPS will provide Science Panel with briefing book (synthesis of 2015 suppression, monitoring, and research findings) by March 22, 2016.

LITERATURE CITED

Koel, T.M., J.L. Arnold, P.E. Bigelow, and M.E. Ruhl. 2010. Native lake trout conservation plan/environmental assessment. National Park Service, Yellowstone National Park, Wyoming, USA.

APPENDIX A: MAP OF YELLOWSTONE LAKE



APPENDIX B: AUTHORS

ROBERT E. GRESSWELL

U.S. Geological Survey, Northern Rocky Mountain Science Center

Bob Gresswell has been studying habitat relationships and life-history organization of cutthroat trout for more than 40 years. He is currently a research biologist with the U.S. Geological Survey, Northern Rocky Mountain Science Center in Bozeman, Montana; he also serves as an affiliate assistant professor in the Department of Ecology at Montana State University. Bob's interest in the role of disturbance in shaping the aquatic systems has led to research on the interactions among landscape-scale environmental features, instream habitat characteristics, and cutthroat trout abundance and distribution. Currently his research is focused on the effects of invasive species, fire, timber harvest, and climate change on the persistence of native trout in the Intermountain West. He has been involved with the lake trout issue in Yellowstone Lake since these invaders were first discovered in 1994.

CHRISTOPHER S. GUY

U.S. Geological Survey, Montana Cooperative Fishery Research Unit

Chris Guy is the Assistant Unit Leader for the Montana Cooperative Fishery Research Unit, and professor in the Department of Ecology at Montana State University. He conducts research within the broad context of fish ecology and fisheries management. A consistent research theme has been on native fish assemblage restoration, a prominent ecological and societal issue within the USA and globally. Within that theme, he has two areas of emphasis: conservation of large-river fishes and suppression of invasive species (for conservation of native fishes). These areas encompass a broad diversity in ecosystem types and fish assemblages, from large warm-water rivers to alpine lakes. Given the mission of the Cooperative Research Unit program, he willingly assists natural resource agencies with their research needs. As a faculty member at Montana State University, he serves on university committees, teaches graduate courses and seminars, and guest lectures in a variety of graduate and undergraduate courses.

MICHAEL J. HANSEN

U.S. Geological Survey, Hammond Bay Biological Station

Mike Hansen is a supervisory fishery research biologist with the Hammond Bay Biological Station in Millersburg, Michigan. Previously, Hansen was a Professor of Fisheries at the University of Wisconsin-Stevens Point, and was appointed as a U.S. Commissioner to the Great Lakes Fishery Commission in 2004 by President George W. Bush and in 2010 by President Barack Obama. Mike's research focuses on fish population dynamics, with an emphasis on lake trout and walleye in the Great Lakes region. He has served as an external consultant for managing lake trout as an invasive species in Lake Pend Oreille, Idaho; Flathead Lake, Montana; and Yellowstone Lake, Yellowstone National Park, Wyoming.

MICHAEL L. JONES

Michigan State University

Mike Jones is the Peter A. Larkin Professor of Quantitative Fisheries in the Department of Fisheries and Wildlife at Michigan State University (MSU), and co-Director of MSU's Quantitative Fisheries Center. His research focuses on population dynamics and management of economically important fisheries, primarily within the Laurentian Great Lakes. He is especially interested in the importance of uncertainty and risk for fishery management, and the role structured decision-making processes such as Adaptive Management or Decision Analysis can play in informing wise decisions in the presence of significant risk. He has extensive experience with the population dynamics of lake trout and other salmonine species in the Great Lakes, and has developed models to inform decisions about lake trout restoration and sea lamprey control, the latter being a key impediment to successful restoration of Great Lakes lake trout populations. He has been at MSU since 1997, prior to which he lived and worked in Canada as a government research scientist and environmental consultant.

J. ELLEN MARSDEN

University of Vermont

Ellen Marsden is a professor in the Rubenstein School of Environment and Natural Resources at the University of Vermont. Ellen received her MS degree and PhD from Cornell University, and then directed the Lake Michigan Biological Station of the Illinois Natural History Survey for six years. She has been on the faculty of the University of Vermont since 1996 and is currently Chair of the Wildlife and Fisheries Biology Program. She has conducted research on bird migration, evolutionary genetics of frogs, genetics and early life history of lake trout, alternative control methods for sea lamprey, ecology of exotic species, and population dynamics of lake whitefish. Her current research projects include use of artificial reefs to enhance lake trout spawning in Lake Huron, research to enhance suppression of an invasive lake trout population in Yellowstone Lake, and establishing an acoustic telemetry array in Lake Champlain to track lake trout movements and evaluate the effects of lacustrine habitat fragmentation on fishes.

PATRICK J. MARTINEZ

Colorado Division of Wildlife and U.S. Fish and Wildlife Service, retired

Pat Martinez was an Aquatic Researcher for 20 years with the Colorado Division of Wildlife. His research focused on the food webs and management of fishes in large reservoirs and major rivers of western Colorado. His reservoir research focused on interactions of salmonid sport fishes and their prey, including lake trout predation on kokanee and *Mysis*. Invasive species, including smallmouth bass, northern pike, and crayfish and their impacts to native and endangered fishes, became the focus of his work in rivers in northwestern Colorado. In 2010, Pat became the Nonnative Fish Coordinator at the U.S. Fish and Wildlife Service for the Upper Colorado River Endangered Fish Recovery Program. In this position, he led development of the Upper Colorado River Basin Nonnative and Invasive Aquatic Species Prevention and Control Strategy, and helped establish a multi-state, multi-agency standardized protocol for operation of the Recovery Program's fleet of electrofishing boats and rafts.

JOHN M. SYSLO

Michigan State University

John Syslo is a postdoctoral research associate with appointments at the Montana Cooperative Fishery Research Unit at Montana State University and the Quantitative Fisheries Center at Michigan State University. His research focuses on applied fish population dynamics, with an emphasis on stock assessment and simulation modeling to evaluate the consequences of potential management actions in the face of uncertainty. His MS and PhD research, conducted at Montana State University, focused on lake trout and Yellowstone cutthroat trout population dynamics in Yellowstone Lake. Specific topics included estimating abundance and mortality, evaluating trophic interactions, and developing simulation models to evaluate the response of the lake trout and Yellowstone cutthroat trout populations to lake trout removal.

APPENDIX C: PRESENTATION ABSTRACTS

MONITORING PERFORMANCE METRICS ON YELLOWSTONE LAKE

Jeffrey L. Arnold

Progress toward Yellowstone cutthroat trout recovery and desired conditions for Yellowstone Lake was assessed annually through: 1) lakewide population assessments of Yellowstone cutthroat trout and lake trout conducted via distribution gillnetting at three depth strata in August; 2) Yellowstone cutthroat trout spawning assessments by making visual counts on tributary streams from May through July; and 3) Yellowstone cutthroat trout catch success reported by lake anglers during the fishing season.

Lakewide Yellowstone Cutthroat Trout Population Assessment

Each fall, the NPS conducts distribution netting of Yellowstone cutthroat trout and lake trout in Yellowstone Lake to estimate age and size class structure, distribution, recruitment, and mortality from the lake trout suppression program. Twenty-four sites are sampled within the motorized portions of the lake, including West Thumb, the main basin surrounding Dot and Frank islands, the northern shore and area surrounding Stevenson Island, and the east shore and two southern arms. At each sampling site, large-mesh and small-mesh nets are set in shallow water, at mid-depth, and at more than 40 meters deep. Box sizes on the large-mesh nets range from 57-89 millimeters, while sizes on small-mesh nets range from 19-51 millimeters.

The distribution nets caught 1,071 Yellowstone cutthroat trout in 2012; 1,259 Yellowstone cutthroat trout in 2013; and 1,421 Yellowstone cutthroat trout in 2014. These catches are more than double those in 2011. The increase in catch each year was primarily due to an influx of young, juvenile Yellowstone cutthroat trout within the system; however, increased catches of large, older-age fish also occurred. Yellowstone cutthroat trout had a mean total length of 358 millimeters in 2012, 382 millimeters in 2013, and 405 millimeters in 2014. These mean lengths were much lower than those observed in earlier years. In 2014, most (53%) Yellowstone cutthroat trout were large adults, 430-620 millimeters in total length, while juveniles and subadults (29%) were less than 325 millimeters in total length.

Using the two shallow nets from each of the distribution sites, we calculated the mean number of Yellowstone cutthroat trout caught per 100 meters of net per night (with 95% confidence intervals listed in parenthesis). Catch per unit effort (CPUE) increased from an average of 11.8 (8.7-15.0) in 2010 to 28.4 (23.7-33.0) in 2014. The 2014 catch exceeds the secondary desired condition for the program's adaptive management strategy of 26 Yellowstone cutthroat trout per net. The large recruitment of young Yellowstone cutthroat trout detected through distribution netting during 2012 through 2014 is an indication the Yellowstone cutthroat trout population is beginning to recover. Factors contributing to the increased number of young fish may include the greatly increased effort to suppress lake trout, as well as improved winter snow conditions and stream runoff in recent years.

Yellowstone Cutthroat Trout Tributary Spawning Assessment

For over 50 years, spawning Yellowstone cutthroat trout were counted as they ascended Clear Creek, a large tributary on Yellowstone Lake's eastern shore. In 2008, spring flood waters damaged the weir, rendering it inoperable. Since that time, efforts have been made to restore the ability to count spawning Yellowstone cutthroat trout at the site. In

2012, the NPS completely renovated the weir site, including removing badly damaged components of the old weir, reengineering and reconstructing the bulkhead on the southern stream bank, constructing a new shed and bridge, and rehabilitating stream bank erosion caused by the configuration of the old weir. The project did not include reconstructing the weir itself because the NPS installed a sonar (acoustic) fish counting system (Sound Metrics Corporation, model ARIS 3000) in 2013. During 2013 and 2014, fisheries staff learned to use system operating software, identified locations where the sonar could effectively capture fish images, and evaluated the solar energy supply.

Since 1988, the abundance of spawning Yellowstone cutthroat trout has also been visually estimated by people walking along 9-11 tributaries on the west side of Yellowstone Lake. These surveys indicated a significant decrease in spawning-age Yellowstone cutthroat trout in Yellowstone Lake. In the late 1980s, more than 70 Yellowstone cutthroat trout were typically observed during a single visit to one of the streams, compared to only one or two Yellowstone cutthroat trout in recent years. One exception is Little Thumb Creek, a tributary in the West Thumb near Grant, where more than 70 Yellowstone cutthroat trout were seen during one week in 2012, more than 50 were seen in 2013, and more than 120 were seen in 2014. The desired conditions for Yellowstone Lake are an average of at least 40-60 spawning Yellowstone cutthroat trout observed per stream visit across all 11 tributaries.

Lakewide Lake Trout Population Assessment

A total of 394 lake trout were caught by distribution nets in 2012, 347 were caught in 2013, and 575 were caught in 2014. The mean total length for lake trout was similar among years (309-330 millimeters), but the range in sizes decreased with fish less than 200 millimeters and greater than 500 millimeters being caught less frequently each year. Most captured lake trout were immature fish, less than 425 millimeters in total length. The mean number of lake trout captured per 100 meters of net varied from 2.9 (95% confidence intervals 2.1-3.7) in 2013 to 4.9 (3.4-6.3) in 2014, but was not significantly different among years. The highest CPUE (6.3) occurred in West Thumb during 2012, along the east shore and in the southern arms during 2013 (3.6), and in the main basin during 2014 (6.6). Catch per unit effort for lake trout was lowest along the north shore.

Yellowstone Cutthroat Trout Angler Success

Since 1979, park visitors who purchase a fishing permit have been given a survey card on which to report waters fished, time spent fishing, and species and sizes of fish caught. About 5% of these anglers (approximately 2,000 per year on average) have completed and returned the cards to the park's fisheries program. Yellowstone Lake receives over 20% of the parkwide angling effort. In Yellowstone Lake, Yellowstone cutthroat trout catch rates were as high as 2 fish per hour in the 1990s, but decreased substantially in the early 2000s to only 0.6 fish per hour in 2012. However, more recent angling reports from Yellowstone Lake are encouraging. In 2014, anglers reported catching 1.2 Yellowstone cutthroat trout per hour. This catch rate is still below the desired condition of 1.5-2.0 Yellowstone cutthroat trout per hour, but is higher than the previous 12 years.

LAKE TROUT SUPPRESSION NETTING OVERVIEW FOR 2014

Patricia E. Bigelow

Lake trout gill net suppression effort has met or exceeded target levels for the last three years and was again increased in 2014 (20% over 2013). Most of the total increase (29% of 2013) occurred using large-mesh gill nets in an attempt to increase mortality on that portion of the population and to compensate for dropping trap netting from the program. However, there also was a 14% increase in small-mesh gill net effort over 2013 levels. Catch per unit effort (CPUE) continued to decrease in 2014: down from 8.2 in 2011 to 5.1 in 2014 for large-mesh nets, and down from 6.0 in 2011 to 1.8 in 2014 for small-mesh nets. Decreases are likely due to a combination of increased effort, as well as actual declines in lake trout numbers. A reconstructed length frequency of catch suggests a decrease in numbers of large lake trout caught, despite increased effort targeting this segment of the population. Effort expended in the distant reaches of the lake was increased in 2014; but high CPUE and catch, especially in the non-motorized portions of the South and Southeast arms, suggest effort in these areas needs to be further increased.

Unfortunately, concurrent with this increase in effort, especially effort targeting larger lake trout, Yellowstone cutthroat trout bycatch has also increased, roughly four-fold over earlier years. Approximately 20,000 Yellowstone cutthroat trout were caught in gill nets in 2014; and at least 60% of those were killed.

Trap nets were fished in 2010-2013, but dropped from the program in 2014. Direct comparison of large-mesh gill net and trap net catch is complicated because there is no equivalent measure of effort between the two. Therefore, comparisons were made based on what one crew would accomplish on an average day if they were lifting just large-mesh gill nets compared to lifting just trap nets. Efficiency, based on both number and biomass of lake trout caught, were similar between gear types, possibly favoring trap nets in 2011 and large-mesh gill nets in 2012. However, trap nets appeared to catch a larger portion of the large females in both 2011 (2.4:1 F:M) and 2012 (2.0:1 F:M) than did large-mesh gill nets (1.5:1 M:F in 2011 and 1.1:1 M:F in 2012). In 2011, this difference led to a potential of 7.6 million eggs removed via gill nets versus 15.7 million eggs removed via trap nets. Another benefit of using trap nets is the greatly reduced Yellowstone cutthroat trout mortality associated with this gear. Yellowstone cutthroat trout mortality ranged 5-7% in the trap nets, whereas it ranged 54-63% in the gill nets.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LAKE TROUT EMBRYO SUPPRESSION ACTIVITIES IN 2014

Philip D. Doepke

The lake trout suppression program implemented two new tools to preserve the ecosystem around Yellowstone Lake. Both of these, an electrical array and a suction dredge, targeted lake trout egg and early life history stages.

The first tool, a portable electrical array, with dimensions 3.4 by 6.4 meters, was used to electroshock each of the known lake trout spawning sites (Carrington Island, Snipe Point, and Olson Reef) in early October. Timing was chosen in order to send a lethal electrical shock to lake trout eggs at their earliest and most fragile stages of development. The second tool, a suction dredge (originally designed for placer gold mining), was used to vacuum lake trout eggs from the rock substrate at one suspected and three known spawning sites. The suction dredge was used after the electrical array and into late October.

In their first year of use, both tools appeared successful at reducing the potential lake trout reproduction in Yellowstone Lake. Many dead lake trout eggs were observed after the electrical shock had been delivered. The suction dredge collected just over 5,000 eggs that were either spawned after the electrical shock had been delivered or were situated too deep in the substrate for a lethal electrical shock to reach them. Additional benefits of the dredge are its ability to locate areas of high lake trout egg deposition and to verify the presence or absence of eggs in potential spawning areas. Use of both tools is planned for 2015; their effectiveness will be evaluated by researchers Chris Guy and Nathan Thomas at Montana State University.

INVESTIGATING THE MATURATION CYCLE OF INVASIVE LAKE TROUT *SALVELINUS NAMAYCUSH* IN YELLOWSTONE LAKE

Nicholas A. Heredia, Robert E. Gresswell, Molly A. H. Webb, Philipp T. Sandstrom, Bahram Farokhkish, and Kristopher J. Warner

Since the introduction of lake trout to Yellowstone Lake in 1994, the National Park Service has been actively removing these invasive predators via gillnetting. More recently, emphasis has shifted toward alternative suppression techniques. Following 13 years of removal efforts, we investigated the reproductive development of lake trout at various sizes to enhance removal efforts. To determine stage of maturity and potential for consecutive-year or alternate-year spawning by lake trout, we evaluated gonadosomatic indices (GSI) and gonad development via histological analysis for data collected from mid-June through early October 2014.

There was no significant difference among GSIs for small female lake trout (< 550 millimeters total length throughout the year (Bonferroni multiple comparisons; $P > 0.2$ for all pairs-wise comparisons of sample periods [8]). In contrast, GSIs for female lake trout 550–649 millimeters total length increased significantly (one-way ANOVA; $F = 23.7$; $P < 0.05$) during the last sample period (early October; Bonferroni multiple comparisons; $P \leq 0.05$ for all pair-wise comparisons between the last sample period and every preceding sample period). Gonadosomatic indices of male lake trout increased in early summer, decreased during late summer, and then increased again in early fall; however, statistically significant differences were limited to lake trout < 550 millimeters total length. Gonadosomatic indices of small males were significantly higher in July than in June and September (one-way ANOVA; $F = 14.7$; Bonferroni multiple comparisons; $P < 0.05$ for all pair-wise comparisons). Histological analyses suggest that although all males over 450 millimeters total length were capable of spawning during September and October sample periods, only 27% of sampled females were gravid during the same periods in 2014.

DEVELOPMENT AND APPLICATION OF SNP MARKERS TO ESTIMATE THE NUMBER LAKE TROUT SPAWNERS IN YELLOWSTONE LAKE

Gordon Luikart and Steve Amish

Along with collaborators at UC Davis (M. Miller lab), we developed a new molecular genetic technique (RAD-Capture) using next generation sequencing technology to genotype hundreds of single nucleotide polymorphism (SNP) loci. We conducted next generation RAD (Restriction-Site Associated DNA) sequencing of lake trout from across the species range to identify a subset of informative loci for RAD-Capture. Lake trout is the first species we are applying this new, lower cost technology for genotyping hundreds of SNPs. Initial results are promising and show 90% of ~ 270 individual lake trout DNA sampled were successfully genotyped for 480 RAD loci (out of ~ 500 loci tested).

Along with the new molecular genetic tool, we are applying novel statistical techniques to estimate the number of adult spawners from each of several year classes or cohorts (N_b) of lake trout. These estimates should be useful for detecting changes in adult population size (spawner abundance) and evaluating whether gill net (and redd/embryo) suppression has been successful at reducing the effective number of spawning lake trout (i.e., the number of spawners producing offspring that live to be sampled at age two).

For this research, we hypothesized that the lake trout population size and spawner abundance has significantly declined since 2010 due to intensive suppression of lake trout, which intensified around 2006-2008. We also hypothesize that there are no genetically-distinct (partially isolated) spawning groups because lake trout movement (dispersal) between spawning areas is relatively high.

We expect to have initial estimates of N_b (and population spatial structure) for two or three cohorts (2008-2010) in the fall of 2015. We will need approximately 150 additional fin clip samples, collected from each of the five cohorts (e.g., 2009-2013), to achieve reasonably high statistical power to detect and quantify a population decline (i.e., a drop in abundance of spawners). For clarity and sampling guidelines, we note that a fish from the 2013 cohort was produced by spawners in 2012 and would be two years old during this sampling season (2015). Young fish of two-five years old are crucial to sample because they are far easier to age (compared to fish greater than five years old) and because they represent the recent spawner abundance, which we hope is relatively small and declining. Genetic estimators work best (with greatest precision) when N_b is relatively small.

LAKE TROUT SPAWNING AND EARLY LIFE HISTORY IN YELLOWSTONE LAKE

J. Ellen Marsden, Lee Simard, Robert E. Gresswell, Patricia E. Bigelow, Dylan Olsen, and John Janssen

Suppression of lake trout in Yellowstone Lake is currently focused on gillnetting and trap-netting juvenile and adult fish. Targeting early life stages (eggs and fry) could enhance progress toward population suppression if spawning sites can be identified, are limited in extent, and are accessible to control methods. Use of egg bags in fall and fry traps in spring of 2013-14 and 2014-15 at Carrington Island indicated that egg densities are low relative to the Great Lakes, and most of the fry had hatched and probably left the island prior to ice-out. We used a remotely-operated vehicle (ROV) equipped with an electroshocker and suction sampler in spring 2014, to identify five sites with good spawning substrate; fry were collected with the ROV at one of these sites (Olsen Reef) in addition to Carrington Island. Three additional sites surveyed had substrate unsuitable for egg retention or incubation. Egg bags and surface-deployed egg collectors were deployed in fall 2014 at ten sites, in addition to Carrington Island, that had good rocky substrate; eggs were found only at Snipe Point, Olsen Reef, and Carrington Island. A benthic sled designed for sampling interstitial eggs and fry will be used in spring and fall 2015, to locate new areas of good substrate and sampling for evidence of spawning. Potential sites will be identified using bathymetric data and acoustic telemetry data. Suitable sites will be sampled to measure egg and fry density, and evaluate egg survival. If spawning appears to be focused at a few, accessible sites, they can be targeted for suppression methods currently under development.

USE OF STATE SPACE MODELS TO IDENTIFY SPAWNING LOCATIONS OF LAKE TROUT IN NEAR SHORE HABITAT IN YELLOWSTONE LAKE

Jason G. Romine

Identification of lake trout spawning areas could be critical for the removal of lake trout within Yellowstone Lake, Yellowstone National Park. Once identified, spawning locations could be targeted for egg, larvae, and fry removal to reduce the survivorship of lake trout during these stages. To identify lake trout spawning areas, we used an acoustic telemetry system (VPS) capable of estimating fish positions in two-dimensional space. Telemetry data were then analyzed using a Bayesian state space model to infer behavioral states (transitory and spawning) of acoustically telemetered lake trout within the VPS array. Kernel density analysis was then used to highlight areas of high spawning probability to guide removal efforts.

RESPONSE OF THE LAKE TROUT POPULATION TO MECHANICAL REMOVAL IN YELLOWSTONE LAKE, YELLOWSTONE NATIONAL PARK

John M. Syslo

Data collected through the history of the lake trout suppression program were used to evaluate the response of the lake trout population to harvest. First, lake trout assessment netting data were used to examine patterns in CPUE, total annual mortality, and population characteristics (i.e., compensatory responses in body condition, individual growth, and length at 50% maturity) through time. Next, a more sophisticated analysis (statistical catch at age analysis; SCAA) was used to estimate mortality, abundance, and catchability from combined gill net and trap net catches. Finally, a matrix simulation model was used to determine the rate of fishing mortality required to reduce lake trout population growth rate (lambda) below replacement (i.e., lambda < 1.0). Assessment netting CPUE was variable through time; however, the estimate from 2014 was significantly greater than 2012 or 2013. Estimates of total annual mortality using catch curves for lake trout sampled in assessment netting increased from 0.24 (0.17-0.21; 95% CI) in 1997 to 0.53 (0.47-0.58) in 2013 and declined to 0.48 (0.36-0.57) in 2014. Body condition, individual growth, and length at maturity did not exhibit temporal trends. Fully selected instantaneous fishing mortality (F) estimated by SCAA increased from 0.02 (0.02-0.03; 95% CI) in 1998 to 1.17 (1.03-1.30) in 2014. This rate of fishing mortality in 2014 corresponds to a total annual mortality rate of 0.73 for large lake trout that are fully vulnerable to the fishing gear. Abundance of lake trout two-years-old and greater increased from 129,382 (111,592-147,171; 95% CI) in 1998 to 809,858 (676,720-942,996) in 2012 and declined to 485,468 (359,020-611,916) in 2014. The matrix simulation model indicated mean lambda was reduced to 1.0 at F = 0.45, and the upper 95% confidence limit for lambda was reduced to 1.0 at F = 0.77. Given fishing mortality estimated for 2014 (F = 1.17) population growth rate was 0.63 (0.44-0.82; 95% CI). The mean estimate of catchability (q) from the SCAA indicated the fishing effort required to reduce the upper 95% confidence limit for lambda to 1.0 is 49,000 units (100 meter net nights). A conservative estimate using the lower 95% confidence limit for q indicates effort exceeding 55,000 units would reduce the upper 95% confidence limit for lambda to 1.0. The level of fishing effort exerted in 2013 and 2014 exceeded both targets and likely suppressed lake trout population growth.