Scientific Review Panel Evaluation of the National Park Service Lake Trout Suppression Program in Yellowstone Lake

August 25–29, 2008

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Front cover: Deputy Superintendent of Yellowstone National Park, Chris Lehnertz, presents before the panel (*bottom*). Fisheries technicians Stu Brown (*left*) and Stacey Sigler (*right*) display their catches aboard the NPS Freedom (*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) launched a major suppression program to curtail potential negative consequences to the native Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) and the Yellowstone Lake ecosystem. In August 2008, the NPS convened a scientific review panel to evaluate the suppression program and provide direction for future suppression and recovery activities. The review panel met August 25–29, 2008 at Chico Hot Springs, Montana. This is a report of the findings and recommendations of the panel.

Panel Objective

The objective of the panel was to critically evaluate the lake trout suppression program in Yellowstone Lake, including its effects on lake trout and Yellowstone cutthroat trout populations and associated ecosystem responses, and provide direction for future suppression and recovery activities.

Panel Charge

I. Evaluate the effectiveness of the lake trout suppression program.
II. Review emerging technological opportunities for suppressing lake trout.
III. Provide alternatives for the future direction of the program.

Overview of 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.

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Presenters

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Patricia Bigelow–National Park Service, Yellowstone National Park
Mark Haroldson–USGS Northern Rocky Mountain Science Center
Todd Koel–National Park Service, Yellowstone National Park
Lynn Kaeding–U.S. Fish & Wildlife Service , Montana Fish & Wildlife Management Assistance Office
Gregory Pederson–USGS Northern Rocky Mountain Science Center
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John Syslo–USGS Montana Cooperative Fishery Research Unit
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Discovery of lake trout in Yellowstone Lake, 1994

Nonnative lake trout (*Salvelinus namaycush*) were first documented in Yellowstone Lake during the summer of 1994 (Kaeding et al. 1996). Lake trout are efficient predators that have been associated with substantial declines of native trout in other lacustrine habitats where they have been introduced and become established (Donald and Alger 1993; Fredenberg 2002; Martinez et al. 2009). In 1994, Yellowstone Lake was believed to support the largest remaining genetically unaltered assemblage of Yellowstone cutthroat trout, which played a keystone role in the lake ecosystem. For example, 42 avian and mammalian species, including the bald eagle (*Haliaeetus leucocephalus*) and the grizzly bear (*Ursus arctos horribilis*), used Yellowstone cutthroat trout as a food resource (Schullery and Varley 1995).

NPS PHOTO

Pelicans *(above)* and Caspian terns *(bottom right)* are piscivorous avifauna that feed on Yellowstone cutthroat trout.

Prior to the introduction of lake trout to Yellowstone Lake, piscivorous avifauna were probably the most important predators of Yellowstone cutthroat trout in that drainage (Gresswell 1995; Stapp and Hayward 2002). The size and biomass of fish consumed per day varied among 20 or more bird species using this resource (Swenson 1978; Swenson et al. 1986; Schullery and Varley 1995), but the total biomass of Yellowstone cutthroat trout consumed by piscivorous avifauna may have exceeded 100,000 kg annually (Davenport 1974; Gresswell 1995). Between 1972 and 1982, up to 23% of the breeding season (April–August) diet of bald eagles in the Yellowstone Lake area was Yellowstone cutthroat trout (Swenson et al. 1986), and during the peak spawning period (May–July) in Yellowstone Lake (Ball and Cope 1961; Gresswell et al. 1997), eagles consumed Yellowstone cutthroat trout almost exclusively.

Other piscivorous birds included American white pelican (*Pelecanus erythrorhynchos*), osprey (*Pandion haliaetus*), great blue heron (*Ardea herodias*), common merganser (*Mergus merganser*), California gull (*Larus californicus*), common loon (*Gavia immer*), Caspian tern (*Hydroprogne caspia*), Barrow's goldeneye (*Bucephala islandica*), bufflehead (*Bucephala albeola*), belted kingfisher (*Megaceryle alcyon*), and double-crested cormorant (*Phalacrocorax auritus*). All of these birds bred in the Yellowstone Lake area and were dependent on the abundant food source provided by Yellowstone cutthroat trout spawners and larval offspring. With the possible exception of the cormorant, these birds primarily focused on fish in shallow portions of the littoral area and tributaries where the Yellowstone cutthroat trout were the most common fish (Schullery and Varley 1995; McEneaney 2002).

A demographic model using values from published articles suggested that, historically, about 7% of the Yellowstone cutthroat trout population were consumed annually by mammalian predators in Yellowstone Lake (Stapp and Hayward 2002). Yellowstone cutthroat trout are especially vulnerable to predation during the spawning period and have been documented to be seasonally important in the diet of grizzly bears in the lake area (Mealey 1980; Mattson and Reinhart 1995; Haroldson et al. 2005). In contrast, river otter (*Lontra canadensis*) are believed to be dependent on Yellowstone cutthroat trout throughout the year (Crait and Ben-David 2006). During the summer, Yellowstone cutthroat trout are the primary prey consumed by river otters near the spawning tributaries and in the lake itself. Crait (2005) recently documented that river otters influence the prevalence and growth of riparian plants by transferring lake-derived nutrients into the

CASEY KOLESKI

Molly Payne, Chelsey Young, and Phil Doepke remove fish from gillnets aboard the NPS Freedom.

riparian areas surrounding Yellowstone Lake.

Management actions reduced angler harvest of Yellowstone cutthroat trout in the 1970s, and subsequently, grizzly bear activity increased along spawning streams. The number of streams frequented by bears during the spawning season was higher in 1985–1987 than during a similar study conducted in 1974–1975 (Reinhart and Mattson 1990). Following the introduction of lake trout, however, numbers of spawning Yellowstone cutthroat trout and indices of bear use declined on streams near the developments of Grant Village and Lake (Reinhart et al. 2001). More recently, Haroldson et al. (2005) documented lakewide declines in the number of Yellowstone cutthroat trout spawners and the number of bears fishing.

Potential repercussions of the establishment of lake trout extend beyond a reduction in the abundance of Yellowstone cutthroat trout in the lake, or even the dynamics of the Yellowstone Lake ecosystem. Indeed, Yellowstone cutthroat trout remain in only about 42% of their historic range, and only about 28% of the range still supports genetically unaltered populations (Gresswell 2009; May et al. 2007). With a surface area of about 34,000 ha, Yellowstone Lake accounted for about 86% of the historic range (on an areal basis) of Yellowstone cutthroat trout in lakes, and it is possibly the largest remaining undammed watershed with genetically unaltered Yellowstone cutthroat trout. The life-history diversity of Yellowstone cutthroat trout in this system is also complex (Gresswell et al. 1994; Gresswell et al. 1997), including migratory individuals that move from the lake into the Yellowstone River headwaters (inlet of the lake) and the outlet (Kaeding and Boltz 2001; Ertel, unpublished data).

In addition to the important ecological role of the Yellowstone cutthroat trout in Yellowstone Lake, this assemblage supported a popular fishery that attracted anglers from around the world. Despite decades of overharvest and an egg-taking operation that removed 800 million eggs during the first half of the 20th century, the Yellowstone cutthroat trout population in the lake was robust by the early 1990s. The size and age structure of the population at that time closely resembled the historic composition (Gresswell et al. 1994). The economic value of the fishery in the lake for 1994 was estimated to be over $36 million (Varley and Schullery 1998). In addition to the ecological, recreational, and economic values, a substantial alteration of the fish assemblage in Yellowstone Lake would also have negative repercussions for the aesthetic, or nonconsumptive, values associated with the Yellowstone cutthroat trout in the ecosystem (Gresswell and Liss 1995; Varley and Schullery 1998).

Science assessment workshop, 1995

Given the potential ramifications of this issue, the NPS convened a panel of scientists in February 1995 to provide an objective evaluation of the threat posed by lake trout to the Yellowstone cutthroat trout and to examine a number of possible management actions to reduce that threat (McIntyre 1998). The panel concluded that protection of a robust population of Yellowstone cutthroat trout would require aggressive lake trout suppression. If the lake trout population was not suppressed, the 1994 Yellowstone cutthroat trout population could decline 50% or more within 20 years and 70% within 100 years. Although there was only a slight chance that lake trout could be eliminated from Yellowstone Lake, it was suggested that expansion of lake trout in the lake could feasibly be controlled. Furthermore, suppression during the next 20 years might limit the loss of Yellowstone cutthroat trout to less than 30% of 1994 levels, and in 100 years, it might be possible to limit the loss of Yellowstone cutthroat trout to 10–20% of pre-lake trout levels (McIntyre 1998).

The review panel compiled a list of 16 potential methods for lake trout suppression in Yellowstone

Potential Lake Trout Removal Methods–1995

1. Status quo angling
2. Destroying lake trout embryos
3. Providing cover for juvenile Yellowstone cutthroat trout
4. Release of sterile sea lampreys in Yellowstone Lake
5. Attracting lake trout to sound or chemicals
6. Trap-netting
7. Long-line fishing
8. Using divers or remotely operated vehicles to remove lake trout
9. Supplementing the Yellowstone cutthroat trout population
10. Stocking "buffer" species
11. Using chemical toxicants
12. Tracking "Judas fish"
13. Introducing sterile male lake trout
14. Directed angling
15. Lake-wide gillnetting
16. Capturing lake trout on spawning grounds

Lake (McIntyre 1998). Mechanical removal methods, either gillnetting or some combination of gillnetting and trapping, were deemed most likely to be successful for controlling lake trout abundance. It was suggested that control measures could be initiated in 1995 in conjunction with experimental gillnetting for obtaining additional information necessary for program improvement. The panel also assumed that some new technology or approach could become useful in the future. Control of lake trout was expected to require permanent effort, and in the short term, the lake trout population was expected to expand even if the control effort was having an impact. The panel predicted that over the long term the lake trout population would stabilize at a level governed by the effectiveness of the suppression program. It was assumed that a well-designed suppression program would provide the information needed for assessing the level of success (McIntyre 1998).

According to the review panel, most information required to evaluate the program could be obtained by initiating an experimental gillnetting program for lake trout and refining the existing monitoring program for Yellowstone cutthroat trout. Suggestions included:

1. refining existing (1994) gillnetting, creel census, and spawning stream census methods to gather data for cohort and catch-curve analyses for both species;
2. combining extensive surveys of Yellowstone cutthroat trout spawning streams with intensive investigation of three spawning streams around the lake; and
3. monitoring lake trout abundance and assessing population dynamics (age-determination, mortality, recruitment, spawning dynamics, diet) and growth rates.

Additional information for refining the program would be gained from netting, tagging, and radio tracking. For example, spawning areas could be located by implanting captured lake trout with radio tags. Although not as critical to the immediate need as the information described above, understanding the dynamics of the system by identifying spawning areas and reproductive success of the lake trout in Yellowstone Lake, describing the genetic structure of the Yellowstone cutthroat trout metapopulation, and partitioning sources of Yellowstone cutthroat trout mortality were also identified as important (McIntyre 1998).

The 1995 panel concluded that, despite a high level of uncertainty, the probability of eliminating lake trout was low and that the introduced predator would reduce the Yellowstone cutthroat trout population in Yellowstone Lake. At the same time, the group suggested that there was a high probability that lake trout abundance could be limited by initiating an aggressive control program using mechanical means. Because the complete removal of lake trout was doubtful, a long-term commitment would be required to control lake trout abundance. It was agreed that the Yellowstone cutthroat trout population would decline even if lake trout could be suppressed, but a lake trout suppression program could reduce the expected loss of Yellowstone cutthroat trout by 50% or more. It was assumed that most of the information needed to increase the effectiveness of initial control measures could be obtained from the control program itself, but some modification of the existing monitoring program would be required to evaluate changes in the Yellowstone cutthroat trout population (McIntyre 1998).

Yellowstone cutthroat trout

Yellowstone cutthroat trout monitoring had been conducted on Yellowstone Lake for decades prior to the establishment of lake trout (Gresswell and Varley 1988). For example, angler use and harvest data have been collected annually since 1950 (Moore et al. 1952; Jones et al. 1987). Although methods have changed through time, a voluntary survey (the Volunteer Angler Report) has been in use since 1975, making possible the evaluation of changes over time (Figure 1).

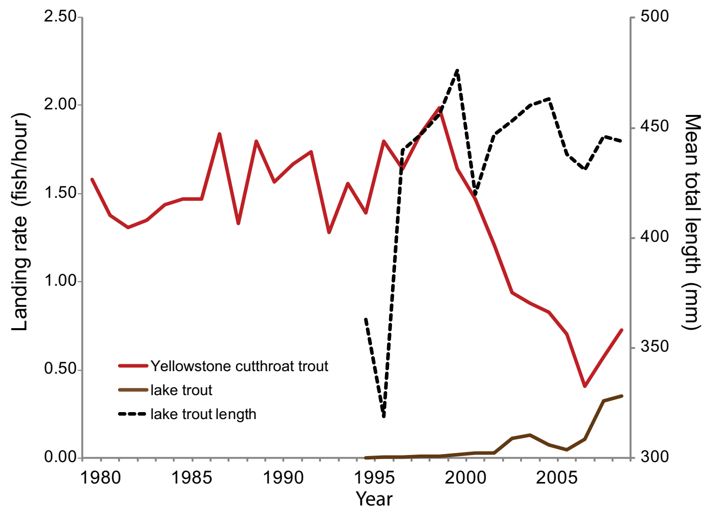

Figure 1. Creel survey estimates of landing rate (number captured per hour) of Yellowstone cutthroat trout and lake trout, and the mean total length of lake trout landed by recreational anglers, Yellowstone Lake, 1978–2008.

A second set of data available for assessing the Yellowstone cutthroat trout population structure comes from the experimental gillnetting program initiated in 1969 (Figure 2). Procedural changes occurred several times, but nets have been set in late September at 11 sites in Yellowstone Lake since 1978 (Gresswell 2004). These sites were not selected using a statistically robust sampling strategy, but methodological consistency allows comparison of relative abundance and size and age structure through time.

Spawner surveys have been conducted at most of the 68 streams where spawning has been observed. Perhaps the longest and most complete record is for the annual Yellowstone cutthroat trout spawning migration in Clear Creek, a tributary entering along the east shore of the lake (Gresswell et al. 1994; Gresswell et al. 1997). Run timing, the number of spawners, and size and age structure information for Clear Creek dates back to 1945 (Figure 3).

Pelican, Arnica, Chipmunk, and Grouse creeks were sampled periodically in the 1950s, and the weir on Pelican Creek was used periodically in the 1970s and 1980s. Other information useful for evaluating the relative 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; Reinhart et al. 1995; Koel et al. 2005).

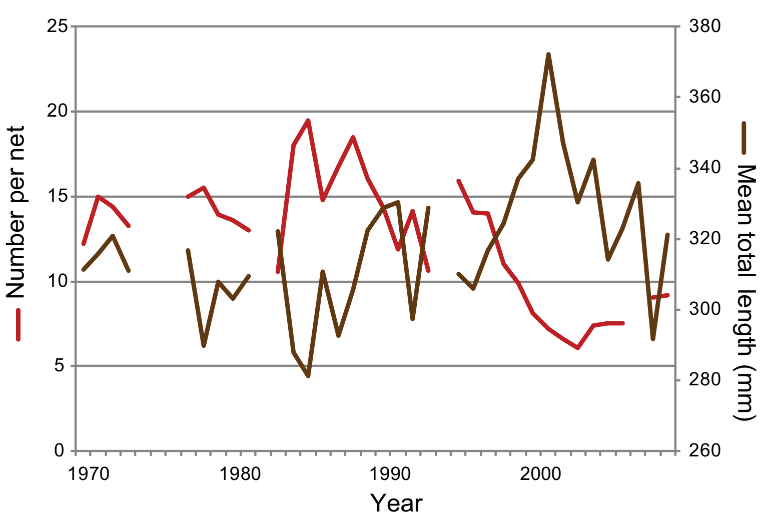

Figure 2. Mean number and mean length of Yellowstone cutthroat trout captured in experimental gillnets set in late September, 1969–2008.

The annual fall gillnetting assessment in Yellowstone Lake suggests a decline in the abundance of Yellowstone cutthroat trout (Figure 2). The average number caught per net dropped from 15.9 in 1994 to 6.1 in 2002 (Koel et al. 2005), an average decline of 11% per year. More recent results (7.4, 7.5, 9.0, and 9.2 Yellowstone cutthroat trout per net in 2003, 2005, 2007, and 2008, respectively) provide the first indication that the Yellowstone cutthroat trout assemblage in the lake may be responding positively to lake trout suppression (Koel et al. 2005).

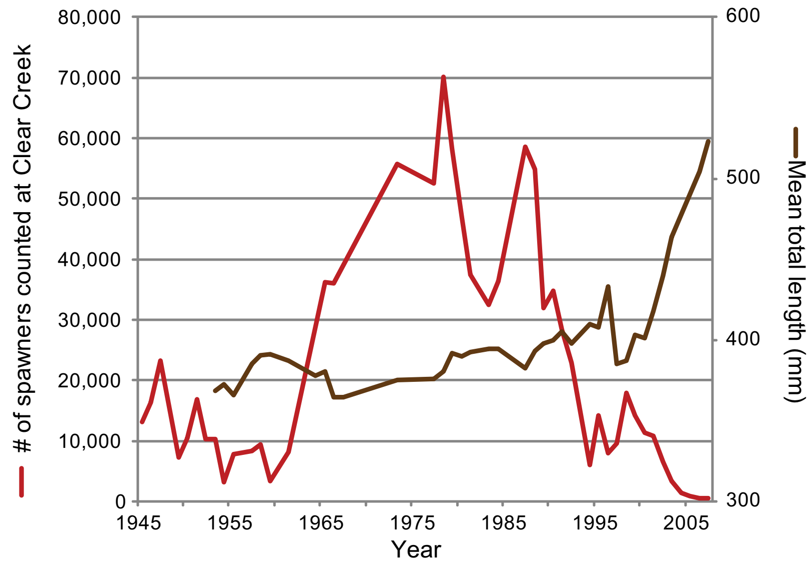

Figure 3. Counts and mean length of Yellowstone cutthroat trout spawners entering Clear Creek, 1945–2008.

Summaries of length data collected during the fall gillnetting assessments from 1997 to 2004 suggest that as the number of adult Yellowstone cutthroat trout declined, the proportion of individuals >325 mm total length(TL) increased (Koel et al. 2005). In 2004, however, abundance of fish 325-425 mm also declined. A reduction in this size range, which encompasses most Yellowstone cutthroat trout spawners in the lake (Gresswell and Varley 1988; Gresswell et al. 1997), suggests a possible reduction in the subspecies' reproductive potential in the lake. In contrast, from 2002 through 2004, the numbers of juvenile Yellowstone cutthroat trout (100–325 mm) increased in the gillnet samples, especially in the lake's southern arms (Koel et al. 2005).

Following the establishment of lake trout in the lake, the average number of Yellowstone cutthroat trout entering Clear Creek during the annual spawning migration dropped from 43,580 between 1977 and 1992 (Gresswell et al. 1994) to 3,828 between 2001 and 2004 (Figure 3; Koel et al. 2005). The number of spawners in 2006 was the lowest in the 60-year period of record (489; Koel et al. 2007). Similar declines in the abundance of spawners have been noted in smaller tributaries in the northwestern portion of the lake (Koel et al. 2005).

Although the presence of lake trout appears to be directly linked to the observed declines of Yellowstone cutthroat trout in the spawning streams, whirling disease may also be a factor. Up to 20% of all juvenile and adult Yellowstone cutthroat trout in Yellowstone Lake are infected with *Myxobolus cerebralis* (Koel et al. 2006), but infection does not appear to be uniform throughout the watershed. For example, *Myxobolus cerebralis* had been detected in Pelican Creek (the second largest tributary to Yellowstone Lake), Clear Creek, and the Yellowstone River downstream from the lake, but the Yellowstone River upstream of the lake inlet and 13 other spawning tributaries have tested negative for the parasite (Koel et al. 2006). Risk of infection is highest in the Yellowstone River and Pelican Creek (Koel et al. 2006). Recent data suggest that >90% of the fry from Pelican Creek are infected with the parasite, and few wild-reared fry have been observed in the lower portions of the watershed since 2001 (Koel et al. 2005). The number of Yellowstone cutthroat trout spawners captured at the Pelican Creek weir averaged almost 24,300 during 1980–82. The weir is no longer operational; however, recent sampling with nets near the historical weir site suggests that very few spawners from the lake still enter the tributary (Koel et al. 2005). Nonmigratory (fluvial) Yellowstone cutthroat trout are still prevalent in the headwaters of Pelican Creek despite high densities of *M. cerebralis* (J. Alexander, unpublished data).

Lake trout predation

Ruzycki et al. (2003) used a bioenergetics model to estimate the effects of lake trout predation on Yellowstone cutthroat trout in Yellowstone Lake and evaluate the effectiveness of the initial years of the suppression program. The results suggested that predation focused on Yellowstone cutthroat trout that were approximately 27–33% of the lake trout body length and juvenile Yellowstone cutthroat trout were especially vulnerable (Ruzycki et al. 2003). Expanded estimates suggested that the average lake trout consumed 41 Yellowstone cutthroat trout annually, and that the lake trout consumed about 15 metric tons of Yellowstone cutthroat trout (129,000 fish), or about 14% of the Yellowstone cutthroat trout production. The lake trout removed by gillnetting in 1999 alone would have consumed 23 metric tons of Yellowstone cutthroat trout (200,000 fish; Ruzycki et al. 2003).

Aquatic food web

Tronstad (2008) documented that after lake trout became established, the zooplankton assemblage in Yellowstone Lake shifted from small copepod-dominance to large cladoceran-dominance, zooplankton species were 17% longer on average, phytoplankton biomass and biovolume were 2–9 times lower, and light transparency increased 1.6 m between 1976 and 2006. Tronstad concluded that the lake trout have essentially added a fourth trophic level in Yellowstone Lake. The effects of the Yellowstone cutthroat trout decline on nutrient transport and uptake were much greater in the tributary streams than in Yellowstone Lake (Tronstad 2008).


NPS PHOTO/STACEY SIGLER 2007

Lake trout prey extensively upon the smaller, Yellowstone cutthroat trout.

Effects on other predators in Yellowstone Lake ecosystem

Declines in Yellowstone cutthroat abundance appear to have had negative effects on predators throughout the Yellowstone Lake ecosystem (Varley and Schullery 1995; Stapp and Hayward 2002; Crait and Ben-David 2006). For example, American white pelicans have maintained the breeding colony in the Southeast Arm of Yellowstone Lake (T.McEneaney, NPS, personal communication), but large numbers are now foraging on the Yellowstone River 80 km north of the park and on the Madison River west of Bozeman, Montana. Indices of grizzly bear use on monitored spawning streams have decreased (Haroldson et al. 2005), and estimates of Yellowstone cutthroat trout consumption by bears (2,226 trout annually, Felicetti et al. 2004) are <2% of estimates of trout consumed by lake trout in the 1990s (Ruzycki et al. 2003; Felicetti et al. 2004).


NPS PHOTO

Grizzly bear consumption of Yellowstone cutthroat trout on monitored spawning streams has decreased considerably.

Lake trout spawning areas

As the lake trout population expands and new spawning areas are pioneered in Yellowstone Lake, recruitment is expected to spread. Using a hierarchical conceptual framework to integrate wave energy theory and information about the geomorphology of Yellowstone Lake, Bigelow (2009) developed a habitat suitability model for predicting the areas where the likelihood of successful lake trout spawning was greatest. In fact, only 4% of the lake was classified with a high potential for supporting lake trout spawning, and these high-probability patches occurred almost exclusively leeward of land masses. To further refine predictions of spawning habitat, substrate information was collected at the microhabitat scale. For example, videography substantiated the occurrence of small patches of suitable substrate in a known spawning area and one of the high-probability patches, but no suitable substrate was found within a second probable spawning area. A second approach entailed examining the composition of substrate along 78 transects dispersed throughout Yellowstone Lake. Results suggested that sediment-free, rocky substrate suitable for spawning was rare, and it was almost exclusively located within patches predicted to have a high probability as spawning areas. Although additional sampling effort will be required to identify potential spawning sites throughout the lake, it appears that output from the habitat suitability model can be used to focus sampling in those areas with a higher probability of containing suitable spawning gravel.

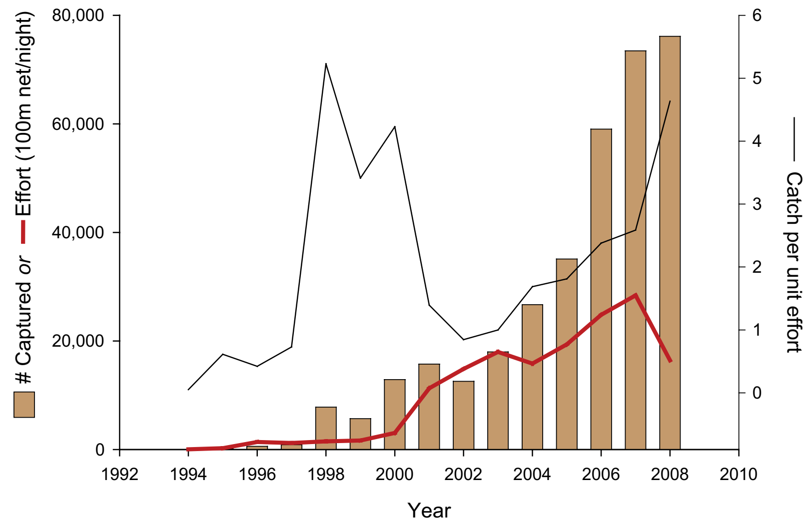

Figure 4. Annual estimates of the total number of lake trout removed, catch per unit effort, and total effort for all methods, Yellowstone Lake, 1994–2008.

National Park Service Suppression Program 1995–2008

The NPS lake trout suppression program on Yellowstone Lake began immediately after lake trout were documented in 1994. Initial attempts to locate additional lake trout yielded few lake trout, and Yellowstone cutthroat trout bycatch was high. Furthermore, Yellowstone cutthroat trout were found in much deeper portions of the lake than previously believed. Based on these results and suggestions from the 1995 review panel, efforts in 1995 and 1996 concentrated on determining lake trout distribution and population age structure. A variety of gillnets was used to determine the most effective mesh sizes and water depths. Yellowstone cutthroat trout bycatch was greatly reduced. Most lake trout were captured in the West Thumb of Yellowstone Lake, and a lake trout spawning area was identified near Carrington Island.

During the next three years (1997–1999), gillnetting effort and efficiency increased. Effort was focused in areas, and at depths within areas, where catches were greatest, and the length of individual nets was increased. By leaving nets set over longer periods, handling time decreased and the total catch increased.

By 1999, more than 15,000 lake trout had been captured from Yellowstone Lake; however, a direct relationship between netting effort and catch suggested that the population was expanding rapidly. In 2001, additional staff was hired and a boat designed specifically for gillnetting on Yellowstone Lake was purchased; gillnetting effort increased approximately sevenfold over the 1999 level. More than 70,000 lake trout were removed from Yellowstone Lake in 2007 and 2008 (Figure 4).

Currently, NPS fisheries personnel employ three gillnetting strategies: control, spawner, and distribution sets. The majority of effort (95%) is focused on control sets (May–October), and the primary target is smaller lake trout (<450 mm TL) in water 40–65 m deep. Small-mesh, monofilament gillnets (28–38 mm bar measure) are used in order to maximize removal of lake trout and minimize by-catch of Yellowstone cutthroat trout. The number of lake trout removed has steadily increased since 1994. Effort and catch per unit effort have varied somewhat (Figure 4), but on a typical June–August day in recent years, up to 24 km of gillnets were set for lake trout. Lake trout carcasses are returned to the lake to avoid removing nutrients from the system and to increase handling efficiency.

Beginning in the middle of August, the number of control nets is reduced, and effort is shifted toward spawning lake trout. From then through early October, substantial numbers of gravid lake trout have consistently been captured in West Thumb, Breeze Channel, and Flat Mountain Arm. Other locations throughout the lake have been sampled periodically in an attempt to identify additional lake trout spawning sites and pre-spawning staging areas. Because these nets extend beyond the perimeter of the local spawning areas, non-spawning lake trout are also captured. Catch-per-unit-effort has continued to increase during the spawning period despite concomitant increases in effort.

Recent results emphasize the importance of targeting spawning areas in Yellowstone Lake. Although only about 5% of the total effort has been expended on spawner sets since 2004, these nets accounted for 27%, 13%, 11%, 13%, and 13% of the total gillnet catch, during 2004–2008, respectively. Furthermore, spawning lake trout tended to be larger, and approximately 96% of those caught were removed from the lake prior to completion of spawning.

Currently, there is no statistically robust monitoring program for evaluating distribution and relative abundance of lake trout in Yellowstone Lake. Although gillnets (distribution sets) have been deployed at fixed locations for that purpose during August in some years, deployment has not been consistent through time. Additional information on distribution, relative abundance, and size structure of both Yellowstone cutthroat trout and lake trout has been collected lakewide with hydroacoustic equipment over multiple years, but to date, analysis is incomplete.

Bycatch of Yellowstone cutthroat trout is minimized by altering the locations, mesh sizes, and depths of gillnet sets. For example, control nets (representing the vast majority of netting effort) are set at water depths where Yellowstone cutthroat trout are generally not found. When nets are set in shallow water, they are checked daily, instead of weekly, so that Yellowstone cutthroat trout can be released alive. Despite these efforts, Yellowstone cutthroat trout bycatch in the 25-mm bar mesh control nets increased 3.5-fold in 2006, and bycatch almost doubled in the next largest size nets (32-mm bar mesh) in 2007. In 2008, bycatch remained high in 25-mm nets as well. Results from experimental gillnets set in September to monitor Yellowstone cutthroat trout have also suggested a trend toward an increased proportion of smaller trout in recent years.

Effects of suppression Program on lake trout

The unknown size of the lake trout population size has made it difficult to determine the proportion that has been removed; however, several population metrics have been used to assess the effects of the suppression program on lake trout density (Syslo, USGS, unpublished data). Harvest has increased through time (0.74 kg/ha in 2007), and the median length of lake trout caught in control gillnets (juveniles ages 3–5) has declined. In contrast, the median length for spawning adults (ages 6+) has increased. Concomitantly, estimates of total annual mortality have increased for juvenile lake trout and decreased for adults, and individual growth rates have declined (Syslo, unpublished data). Although population metrics suggest that lake trout abundance in Yellowstone Lake has continued to expand, it appears that suppression has reduced the rate of population increase (Syslo, USGS, unpublished data).

NPS PHOTO/JIM PEACO 2008

During the workshop, park employees and outside researchers like John Varley, former chief of the Yellowstone Center for Resources in Yellowstone National Park, presented pertinent data to the panel.

Importance of the current program

- Cutthroat trout population declines negatively affect the Yellowstone Lake ecosystem.

Accomplishments of the current program

- Suppression
  - A large number of lake trout has been removed, which has helped reduce lake trout population growth.
  - The efficiency of the suppression program has increased since 1995, and continuing the program will remove more lake trout in the future.
  - A strong constituency of lake trout anglers does not currently exist.
- Research and monitoring
  - Long-term monitoring of the Yellowstone cutthroat trout population has been maintained.
  - Thorough records concerning the lake trout suppression program have been maintained.

Supplementary factors

- Ecosystem
  - The Yellowstone Lake ecosystem is relatively accessible.
  - Despite current concerns, the Yellowstone Lake ecosystem is considered one of the most intact ecosystems in the USA.
  - The Yellowstone Lake ecosystem is relatively simple and closed, and this should increase the probability of success.
- Institutional
  - The NPS staff in Yellowstone National Park is committed to lake trout suppression.
  - The NPS is committed to the rigorous application of science to the lake trout suppression issue.
  - External review of the lake trout suppression program was initiated by NPS staff.
  - Volunteers are used in the lake trout suppression program.
  - Potential facilities and buildings for support of the lake trout suppression program already exist on site.
  - Approximately $300k was dedicated to suppression activities in 2008.
- Extrinsic factors
  - Lake trout suppression has been attempted in a similar system, Lake Pend Oreille, Idaho, and early results suggest that suppression is attainable.
  - Yellowstone Lake is extremely popular and admired as an icon of nature in the USA and throughout the world.
  - Existing knowledge about lake trout biology in other ecosystems can be applied to the lake trout suppression program in Yellowstone Lake.
  - The lake trout is very vulnerable to overexploitation, as evident from examples of over-fishing in other large ecosystems, e.g., Laurentian Great Lakes, Great Slave Lake.
  - Numerous agencies and nongovernmental organizations support efforts to restore the status of Yellowstone cutthroat trout and the integrity of the Yellowstone Lake ecosystem.
  - The Yellowstone Lake ecosystem is not yet irreparably degraded, so time is still available to suppress lake trout before irreparable harm occurs.

Basis for science panel recommendations:

- Lake trout threaten the ecological role of Yellowstone cutthroat trout in Yellowstone Lake.
- The Yellowstone cutthroat trout is a keystone species (e.g., an ecosystem organizer) in Yellowstone Lake.
- There are pressing ecological reasons to suppress lake trout in Yellowstone Lake. The lake trout is an invasive species that is almost certainly responsible for declines in Yellowstone cutthroat trout abundance in Yellowstone Lake. This species has also demonstrated the capacity to alter food webs in other systems into which it has been introduced (e.g., Flathead Lake). As long as lake trout are abundant in Yellowstone Lake, the native food web will be in jeopardy.
- Lake trout suppression should be enhanced before Yellowstone cutthroat trout decline further.
- Recent observations suggest that lake trout abundance is increasing despite existing control efforts and that the Yellowstone cutthroat

trout is in jeopardy. It is common in predator-prey systems for rapid changes to occur once a preferred prey species becomes scarce. Ironically, an illustrative example of this concerns the rapid disappearance of lake trout from lakes Huron and Michigan in the face of exploitation and sea lamprey predation. Existing data do not allow a quantitative assessment of the future trajectory for Yellowstone cutthroat trout in Yellowstone Lake, but common sense indicates that there is no basis for complacency. Efforts to monitor the status, trend, viability, and environmental factors affecting Yellowstone cutthroat trout in Yellowstone Lake must continue.

- It is obvious, in light of the previous point, that accurate information on the status of the Yellowstone cutthroat trout population in Yellowstone Lake is crucial to the future of this program. All currently available information on Yellowstone cutthroat trout trends points toward decline, but the surveys are not congruent. Robust information on population status and trends will be vital to determining whether progress is being made or increased efforts are required.
- The program cannot succeed on the present budget. Available evidence suggests that the lake trout population is not declining under the current suppression program, but monitoring data are needed to evaluate program success. Because reducing control efforts from current levels would be extremely risky, expanding the current effort and obtaining new information to increase program effectiveness are both needed.
- The scope of the Yellowstone cutthroat trout decline requires rededication of NPS resources and expansion of partnerships and programs to restore the Yellowstone Lake ecosystem.
- This long-term problem requires improvements in short-term tactics and long-term strategies.

A Yellowstone cutthroat trout

Panel Response I: Effectiveness of lake trout suppression program

In response to the request to evaluate the effectiveness of the lake trout suppression program, the panel finds:

- The lake trout suppression program to date has reduced lake trout predation on Yellowstone cutthroat trout by decreasing the growth of the lake trout population.
- The current Yellowstone cutthroat trout population would be significantly smaller and the current lake trout population would be significantly larger if the lake trout suppression program had not been implemented.
- The Yellowstone cutthroat trout population in Yellowstone Lake will likely continue to decline if lake trout suppression is not enhanced.
- The suppression program, to date, has not been sufficient to drive the lake trout population into decline.

Panel Response II: Emerging technological opportunities

In response to the request to review emerging technological opportunities for suppressing lake trout, the panel finds:

- In addition to direct removal, many options for suppressing lake trout show promise, but none is ready for immediate implementation.
- Alternative technologies for suppressing lake trout should be integrated into a carefully prioritized, nationwide, research program to support future decisions.

Panel Response III: Alternatives for the program's future direction

In response to the request to provide alternatives for the future direction of the Yellowstone Lake trout suppression program, the panel finds:

- Important data gaps (e.g., location of lake trout spawning areas and seasonal movement patterns in Yellowstone Lake) must be filled before the program can become more effective.
- An intensified suppression program could drive the lake trout population into decline.
- The level of removal necessary to achieve decline of the lake trout population in Yellowstone Lake cannot be precisely determined with the present data, but the harvest must be increased.

Top priorities for the lake trout suppression program

The scope of the Yellowstone cutthroat trout decline requires rededication of NPS resources and expansion of partnerships and programs to restore the Yellowstone Lake ecosystem. The science panel provides the following four recommendations for improvement of the lake trout suppression program in Yellowstone Lake from highest to lowest priority:

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

- Increase current personnel and fiscal resources available for lake trout suppression in Yellowstone Lake.
- Employ professional fishers to augment current gillnetting effort.
- Identify lake trout distribution and movement patterns to increase effectiveness of suppression efforts (e.g., telemetry, distribution netting, and hydroacoustics).
- Initiate a telemetry study in order identify additional spawning sites.
- Set benchmarks for lake trout control.
- Experiment with alternative suppression options while monitoring effectiveness.

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

- Maintain Yellowstone cutthroat trout monitoring program at Clear Creek.
- Continue monitoring Yellowstone cutthroat trout spawning migrations in roadside streams around the lake.
- Continue annual fall gillnetting program for monitoring Yellowstone cutthroat trout around the lake.
- Continue monitoring the presence and spread of whirling disease in the Yellowstone Lake watershed.

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

- Complete review and statistical analysis of existing data and identify important data gaps.
- Continue, and possibly enhance, the current distribution-netting program.
- Conduct a rigorous mark-recapture estimate of the population size with sufficient precision to provide:
  - an estimate of the level of short-term removal necessary to initiate decline.
  - a benchmark against which future population estimates can be compared.
    - Implement a formal adaptive process with testable models and hypotheses and specific timeframes for evaluation.
    - Identify trigger points to guide management actions.
    - Develop incremental goals to guide program effectiveness.
- Analyze the available hydroacoustics data in the near future.
- Repeat the hydroacoustics work, adjusting methods as needed based on the analysis of existing data.

Recommendation 4. Develop a lake trout suppression plan that will increase agency administrative commitment to meet benchmarks, increase the effectiveness of the lake trout removal effort, and the conservation of the Yellowstone Lake ecosystem through the coming decades.

NPS PHOTO/AUDREY SQUIRES 2007

The lake trout suppression program has reduced lake trout predation on Yellowstone cutthroat trout by decreasing the growth of the lake trout population.

- Establish a science advisory committee to facilitate annual reviews of program direction and effectiveness.
- Ensure facilities and policies meet the needs of the lake trout suppression program, including short-term program expansion (e.g., alternative uses of hatchery building, boathouses, and employee housing).
- Collaborate with outside partners to increase funding and support.
- Identify the core needs and fund them.
- Enhance program capabilities.
  - Actively manage against lake trout in all park waters.
  - Reduce the potential for introduction of other invasive species (e.g., boat cleaning station, education, gear cleaning, live well inspections, and mandatory inspection of boats).
  - Develop the angler database and communicate with the sportfishing community.
  - Purchase an electrofishing boat that is safe and effective.
  - Collaborate with the interpretive staff to improve public education regarding invasive species and the impacts to the Yellowstone Lake ecosystem.

Beginning September 2, 2008

- Start contract talks with professional fishers.
- Engage the professional fishing operation at some level for the next field season.
- Set up a science advisory committee to provide ongoing advice on a regular basis.

2009

- Prioritize research program to guide management and evaluate effectiveness.
  - *Spring*—Instrument a minimum of 50 fish for telemetry to investigate spawning areas and population spatial distribution. (The number 50 is subject to revision based on the advice of the science advisory board after a formal statistical power analysis is done.)
  - *Fall*—Locate previously tagged fish.
- As soon as trap nets can be deployed:
  - Tag (not telemetry) and release a minimum of 2,000 fish for a mark–recapture program. (The number 2,000 is subject to revision based on the future advice of the science advisory board after a formal statistical power analysis is done.)

NPS PHOTO/HARLAN KREDIT 2008

The professional fishers of Hickey Brothers Fisheries, LLC, were contracted in the summer of 2009 to augment the current lake trout suppression efforts.

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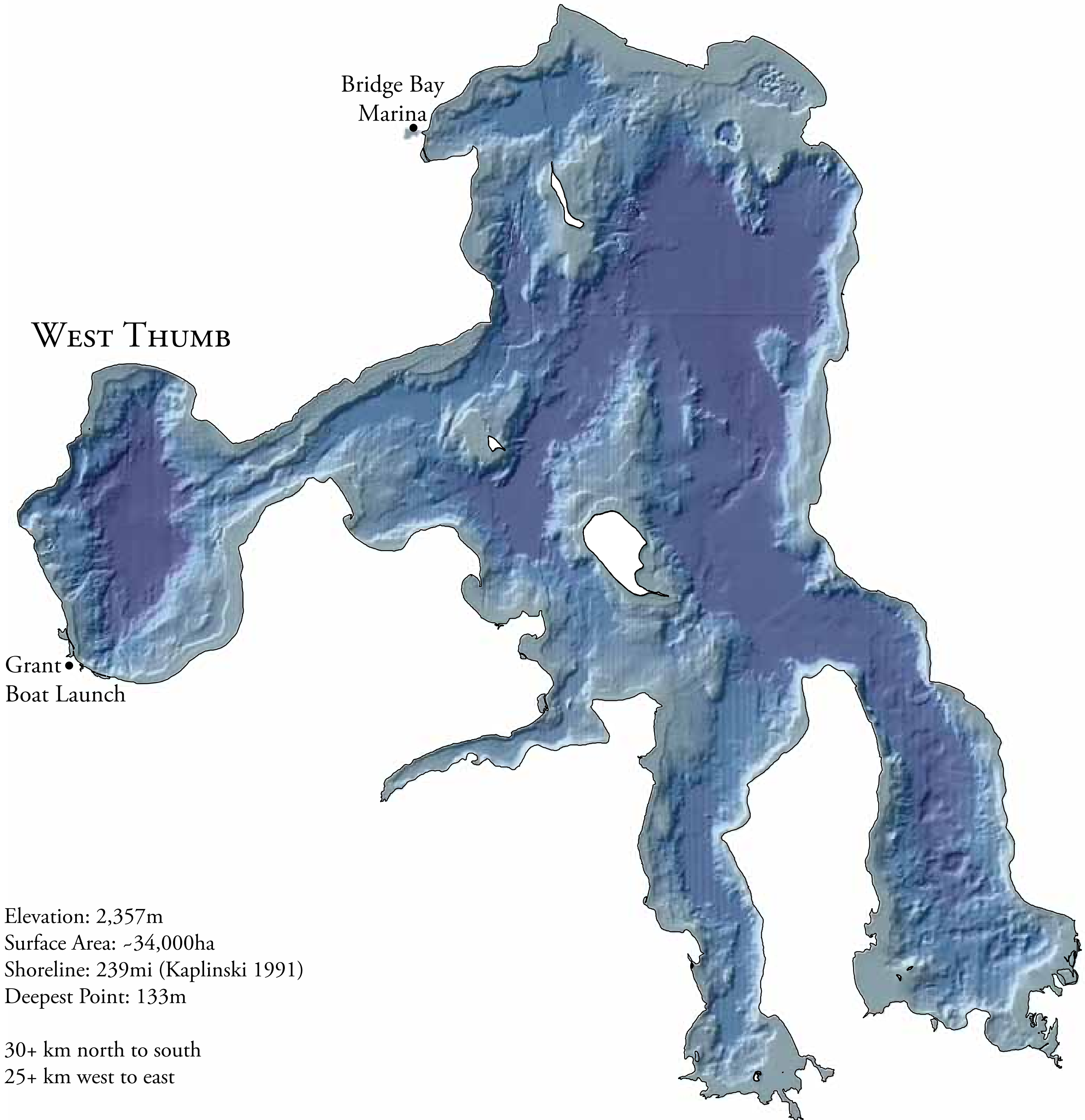
Yellowstone Lake



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