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

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Robert E. Gresswell

USGS Northern Rocky Mountain Science Center

Bozeman, Montana

Scientific Review Panel Members

David Beauchamp (USGS, Washington Cooperative Fish and Wildlife Research Unit); Phaedra Budy (USGS, Utah Coop. Fish and Wildlife Research Unit); Daniel Goodman (Montana State University), Robert E. Gresswell (USGS, Northern Rocky Mountain Science Center); Christopher Guy (USGS, Montana Cooperative Fishery Research Unit); Michael Hansen (University of Wisconsin - Stevens Point); Michael L. Jones (Michigan State University); Jeff Kershner (USGS, Northern Rocky Mountain Science Center); Patrick Martinez (Colorado Division of Wildlife); Dirk Miller (Wyoming Game and Fish Department); David Phillip (Illinois Natural History Survey); Stephen Riley (USGS, Great Lakes Science Center); Peter W. Sorensen (University of Minnesota); Jack E. Williams (Trout Unlimited, Ashland, Oregon).

Presenters

Julie Alexander (Montana State University); 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 (Montana Fish & Wildlife Management Assistance Office, U.S. Fish & Wildlife Service); Gregory Pederson (USGS - Northern Rocky Mountain Science Center, James Ruzycki (Oregon Department of Fish and Wildlife); John Syslo (USGS Montana Cooperative Fishery Research Unit); Lusha Tronstad (University of Wyoming); John Varley (Montana State University.

INTRODUCTION

Following the discovery of nonnative lake trout *Salvelinus namaycush* in Yellowstone Lake during the summer of 1994, the U.S. National Park Service 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 2009, the National Park Service 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, 2009 at Chico Hot Springs, Montana. This is a report of the findings and recommendations of the panel.

REVIEW PANEL OBJECTIVE

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.

SCIENCE 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 SCIENCE PANEL RECOMMENDATIONS

Recommendation 1. Intensify existing lake trout suppression efforts for a minimum of 6 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 to maintain and increase agency administrative commitment to meet benchmarks and increase effectiveness of lake trout removal and the conservation of the Yellowstone Lake ecosystem through the coming decades.

BACKGROUND

Discovery of lake trout in Yellowstone Lake, 1994

Nonnative lake trout *Salvelinus namaycush* were first discovered 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. in press). In 1994, Yellowstone Lake was believed to support the largest remaining genetically unaltered assemblage of Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri*, and this native trout played a keystone role in the lake ecosystem.

For example, 42 avian and mammalian species, including the bald eagles *Haliaeetus leucocephalus* and the grizzly bears *Ursus arctos horribilis*, used Yellowstone cutthroat trout as a food resource (Schullery and Varley 1995). Prior to the introduction of lake trout to Yellowstone Lake, piscivorous avifauna probably were 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 consisted of Yellowstone cutthroat trout (Swenson et al. 1986) and during the peak spawning period in Yellowstone Lake (May-July, 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 breed in the Yellowstone Lake area and are 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 focus on fish in shallow portions of the littoral area and tributaries where the Yellowstone cutthroat trout is the most common fish (Schullery and Varley 1995; McEneaney 2002).

Model reconstructions suggest 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 near the spawning tributaries and 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 riparian areas surrounding Yellowstone Lake.

Management actions that reduced angler harvest of Yellowstone cutthroat trout in the 1970s may have had indirect positive effects on grizzly bears, and the number of streams frequented by bears increased between 1974–75 and 1985–87 (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 during 1990–95 (Reinhart et al. 2001). More recently (1989-2000), 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 lake trout introduction and establishment extend beyond a reduction in abundance of Yellowstone cutthroat trout in the lake, or even the dynamics of the Yellowstone Lake ecosystem. Indeed, Yellowstone cutthroat trout only remain in about 42% of the historic range of the subspecies, 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, the Yellowstone Lake assemblage accounted for about 86% of the historic range of Yellowstone cutthroat trout (on an areal basis) in lakes, and it is possibly the largest remaining undammed watershed with genetically unaltered Yellowstone cutthroat trout. Furthermore, the life-history diversity of this system is complex (Gresswell et al. 1994; Gresswell et al. 1997), including migratory individuals that move 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, by the early 1990s, the Yellowstone cutthroat trout population in the lake was robust, and size and age structure of the population suggested that it 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 dollars (Varley and Schullery 1998). In addition to the ecological, recreational (angling), 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 National Park Service 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 potential management actions to reduce that threat (McIntyre 1998). The panel concluded that protection of a robust population of Yellowstone cutthroat trout would require aggressive action to suppress lake trout. If the lake trout population was not suppressed, loss of Yellowstone cutthroat trout from 1994 levels would equal or exceed 50% within 20 years (circa 2015), and exceed 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 Lake, including: (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) using ‘Judas fish,’ (13) using of sterile male lake trout, (14) directed angling, (15) lake-wide gillnetting, and (16) capturing lake on spawning grounds (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. Additionally, the panel assumed that some new technology or approach might become useful in the future. Control of lake trout was expected to require permanent effort, and in the short term, the lake trout population would be expected to expand even if the control effort was effective. In the long term, the panel predicted that 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. Additional 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 immediately essential, 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 for, but not as critical to the immediate need as the information described earlier (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).

INFORMATION FOR THE CURRENT ASSESSMENT

Yellowstone cutthroat trout

Yellowstone cutthroat trout monitoring had been conducted on Yellowstone Lake for decades prior to the discovery 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 volunteer mail survey (the Volunteer Angler Report) has been in use continuously since 1975, and comparisons among years can be used to evaluate changes through time (Figure 1).

A second set of data available for comparison of Yellowstone cutthroat trout population structure is associated with the experimental gillnetting program, initiated in 1969 (Figure 2). Procedural changes occurred several times, but since 1978, nets have been set in late September at 11 sites in Yellowstone Lake (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 related to the annual Yellowstone cutthroat trout spawning migration in Clear Creek, a tributary entering the lake along the east shore (Gresswell et al. 1994; Gresswell et al. 1997). Run timing, the number of spawners, and size and age structure information dates back to 1945 at Clear Creek (Figure 3).

Several other streams, including 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 9–11 tributary streams in West Thumb and along the west shore of the lake (Reinhart 1990; Reinhart et al. 1995; Koel et al. 2005).

The annual fall gillnetting assessment in Yellowstone Lake suggests a decline in the abundance of Yellowstone cutthroat trout (Figure 2). An average of 15.9 Yellowstone cutthroat trout per net was caught in 1994, but by 2002, estimates had declined to only 6.1 Yellowstone cutthroat trout per net (Koel et al. 2005). Reductions averaged 11% per year between 1994 (the year lake trout were first discovered in Yellowstone Lake) and 2002. Recent results (7.4, 7.5, 9.0, and 9.2 Yellowstone cutthroat trout per net in 2003, 2005, 2007, and 2009, 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).

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

Following the establishment of lake trout in Yellowstone Lake, the number of Yellowstone cutthroat trout entering Clear Creek during the annual spawning migration dropped from an average of 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 recorded 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 lake trout appear to be directly linked to the observed declines of Yellowstone cutthroat trout in the spawning streams, whirling disease may also contribute. 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 since 2001, few wild-reared fry have been observed in the lower portions of the watershed (Koel et al. 2005). The number of Yellowstone cutthroat trout spawners captured at the Pelican Creek weir averaged almost 24,300 for 3 years between 1980 and 1982. The weir is no longer operational; however, recent sampling with nets near the historical weir site suggests that very few Yellowstone cutthroat trout spawners from the lake enter the tributary (Koel et al. 2005). Interestingly, nonmigratory (fluvial) Yellowstone cutthroat trout are still prevalent in the headwaters of Pelican Creek despite high densities of *Myxobolus 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 to evaluate the effectiveness of the initial years of the suppression program. Model results suggested that predation was 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 in 1996, about 15 metric tons of Yellowstone cutthroat trout (129,000 fish), or about 14% of the vulnerable Yellowstone cutthroat trout production were consumed. Furthermore, the lake trout removed by gillnetting in 1999 alone would have consumed another 23 metric tons of Yellowstone cutthroat trout (200,000 fish; Ruzycki et al. 2003).

Aquatic food web

Tronstad (2008) documented that the zooplankton assemblage in Yellowstone Lake shifted from small copepod-dominance in the years prior to the lake trout introduction to large cladoceran-dominance after lake trout were established. Zooplankton species were 17% longer on average after lake trout became established, and phytoplankton biomass and biovolume decreased 2 - 9 times. Between1976 and 2006, light transparency increased 1.6 m (Tronstad 2008). Tronstad (2008) concluded that the lake trout have essentially created a fourth trophic level in Yellowstone Lake. In terms of nutrient cycling, effects of the decline of Yellowstone cutthroat trout on nutrient transport and uptake were much greater in the tributary streams than in Yellowstone Lake (Tronstad 2008).

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 Yellowstone National 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).

Lake trout spawning areas

As the lake trout population expands in Yellowstone Lake, recruitment is expected to spread as new spawning areas are pioneered. 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 to 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 spawning. 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.

NPS Suppression Program 1995-2008

The NPS lake trout suppression program on Yellowstone Lake began immediately after lake trout were discovered 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 gill nets 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 3 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.

By1999, 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. Over 70,000 lake trout were removed from Yellowstone Lake in 2007 (Figure 4).

Currently, NPS fisheries personnel employ three basic gillnetting strategies: control, spawner, and distribution sets. The majority of effort (95%) is focused on control sets (May through October), and the primary target is smaller lake trout (<450 mm TL) in water 40- 65 m deep. Small-mesh, monofilament gillnets ranging from 28 mm to 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 day (June-August) in recent years, up to 24 km of gill nets were set in Yellowstone Lake 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 usually reduced and effort is shifted toward targeting lake trout preparing to spawn. The length of control nets declines to about 9.5 km daily during mid-September through mid-October. In 2008, control nets removed 66,136 lake trout (87% of the total catch) from Yellowstone Lake (Figure 5).

Spawner sets target spawning lake trout from late August through early-October when the fish move onto the spawning grounds. Monofilament gillnets (51-89 mm bar mesh) are used at locations in West Thumb, Breeze Channel, and Flat Mountain Arm, and substantial numbers of gravid lake trout have been captured consistently at these sites (Figure 5). Other locations throughout the lake have been sampled periodically in an attempt to locate other lake trout spawning sites and prespawning staging areas. More than 9,900 lake trout were removed from Yellowstone Lake during the spawner netting in 2008 (Figure 5), and catch-per-unit-effort continues to increase despite concomitant increases in effort. These nets extend beyond the perimeter of the local spawning areas, and nonspawning lake trout (34% of the number removed in spawner nets in 2008) are also captured (Figure 6).

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, lake trout caught in spawner sets tended to be larger, and approximately 96% were removed from the lake prior to completion of spawning.

Distribution sets have usually deployed in August in order to monitor distribution of lake trout in Yellowstone Lake and estimate the lake trout to Yellowstone cutthroat trout ratio at various depths and locations of the lake. Although these nets are set at fixed locations, deployment has been inconsistent through the years. Currently, there is no statistically robust monitoring program for evaluating distribution and relative abundance of lake trout in Yellowstone Lake.

Bycatch of Yellowstone cutthroat trout in gill nets is minimized by altering the locations, mesh sizes, and depths of gill-net 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, there was 3.5-fold increase in Yellowstone cutthroat trout bycatch in the 25-mm bar mesh in control nets in 2006, and in 2007, bycatch almost doubled in the next largest size nets (32-

mm bar mesh). 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 an increasing trend of smaller Yellowstone cutthroat trout in recent years.

Effects of Suppression Program on Lake Trout

Because the lake trout population size is unknown, it has been difficult to determine the proportion that has been removed. Alternatively, several population metrics have been used to assess the effects of the suppression program on lake trout density (Syslo, unpublished data). Harvest has increased through time (0.74 kg/ha in 2007), and the median length of lake trout caught in control gill nets (juveniles ages 3-5) lake trout 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 do not provide irrefutable evidence that lake trout abundance in Yellowstone Lake has been reduced by the suppression program, it appears that suppression has at least reduced the rate of population increase (Syslo, unpublished data).

PANEL ASSESSMENT

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 have been removed, which has helped to reduce lake trout population growth.
  - 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 presently 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 a relatively simple and closed, and this should increase the probability of success.
- Institutional
  - The National Park Service staff in Yellowstone National Park is committed to lake trout suppression.
  - The National Park Service is committed 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.
    - There is approximately $300k current funding dedicated to suppression activities.
- 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 (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 the Yellowstone Lake.
- The Yellowstone cutthroat trout is a keystone species in the Yellowstone Lake ecosystem.
- 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 (e.g., Flathead Lake) into which it has been introduced, and it has been described as a keystone species (e.g., an ecosystem organizer) in lakes where it is a native species. As long as lake trout are abundant in Yellowstone Lake, the native food web will be in jeopardy.
- Enhanced lake trout suppression should proceed immediately before Yellowstone cutthroat trout decline further.
- Recent observations suggest that lake trout abundance may be increasing despite existing control efforts and that Yellowstone cutthroat trout abundance continues to decline. 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 point towards continued 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 it would be extremely risky to reduce control efforts from current levels, expanding the current level of effort and obtaining new information to increase program effectiveness are both needed.
- The scope of the Yellowstone cutthroat trout decline requires rededication of National Park Service 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.

Panel Response I: Evaluate effectiveness of lake trout suppression program

In response to the request to evaluate the effectiveness of the lake trout suppression program, the Science 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: Review emerging technological opportunities for suppressing lake trout

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

- In addition to direct removal, there are many options for suppressing lake trout that show promise, but none is ready for immediate implementation.
- Alternative technologies for suppressing lake trout should be integrated into a carefully prioritized research program (national, not restricted to Yellowstone National Park) to support future decisions.

Panel Response III: Provide Alternatives for the Future Direction of the Program

In response to the request to provide alternatives for the future direction of the Yellowstone Lake trout suppression program, the Science 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/harvest pressure necessary to achieve decline of the lake trout population in Yellowstone Lake cannot be precisely determined with the present data, but it is certain that the pressure must be increased.

Panel Recommendations

Top Priorities for the Lake Trout Suppression Program

The scope of the Yellowstone cutthroat trout decline requires rededication of National Park Service 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 (note that the recommendations are presented from highest priority to lowest):

Recommendation 1. Intensify existing lake trout suppression efforts for a minimum of 6 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 mark-recapture study from many locations around the lake 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 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 the program effectiveness.
- Analyze the available hydroacoustics data (consider contracting that work out if NPS staff are over-committed).
- Repeat the hydroacoustics work, adjusting methods as needed based on the analysis of existing data.

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

- Initiate 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 waters of the park.

- Reduce potential for introductions of other invasive species (e.g., boat cleaning station, education, gear cleaning, live well inspections, and mandatory inspection of boats).
- Develop angler database and communicate with the sportfishing community.
- Purchase an electrofishing boat that is safe and effective.
- Utilize interpretive staff to improve public education regarding invasive species and the impacts to Yellowstone Lake ecosystem.

Beginning September 2, 2008

- Start contract talks with professional fishers
- Engage the professional fishing operation at some level for 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 50 fish for telemetry for investigation of spawning areas and population spatial distribution (the number 50 is subject to revision on the future 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 on the future advice of the science advisory board after a formal statistical power analysis is done).

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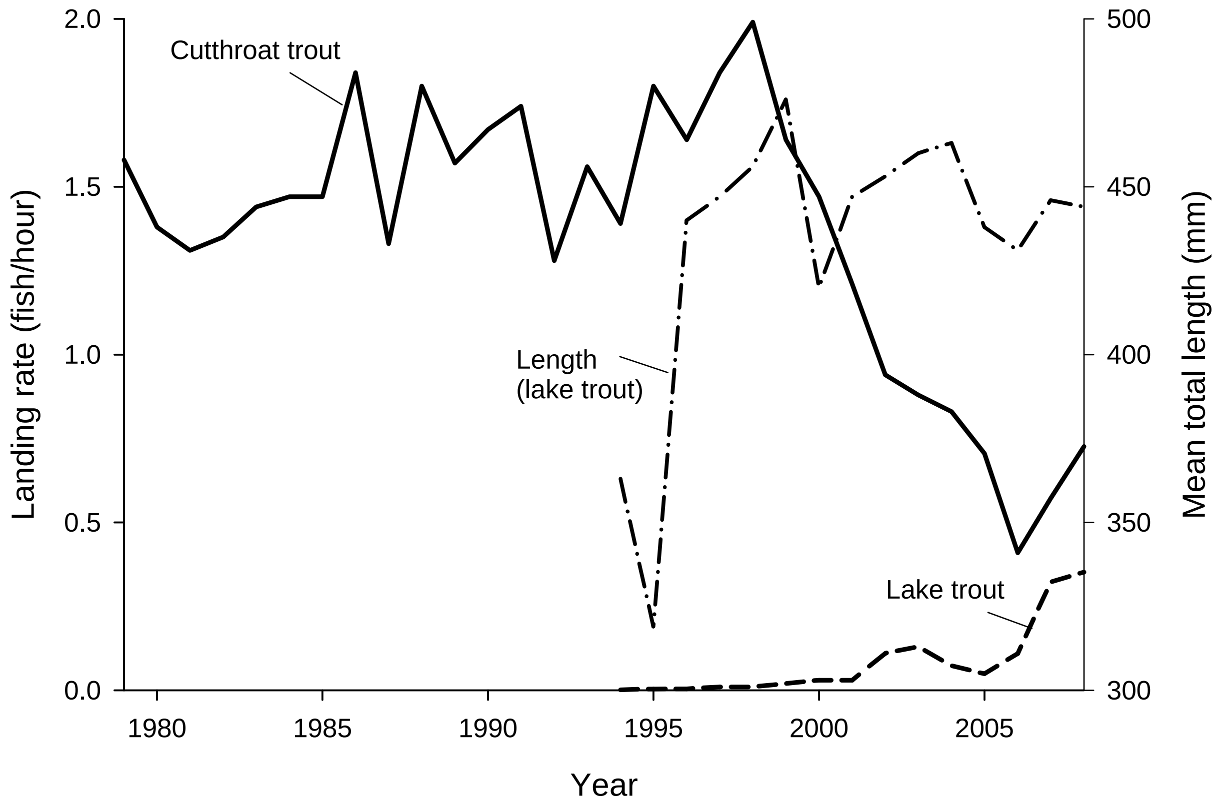

Figure 1. Creel survey estimates of landing rate (number captured per hour) of Yellowstone cutthroat trout and lake trout, and the mean length (mm, total length) of lake trout landed, Yellowstone Lake, 1978-2008.

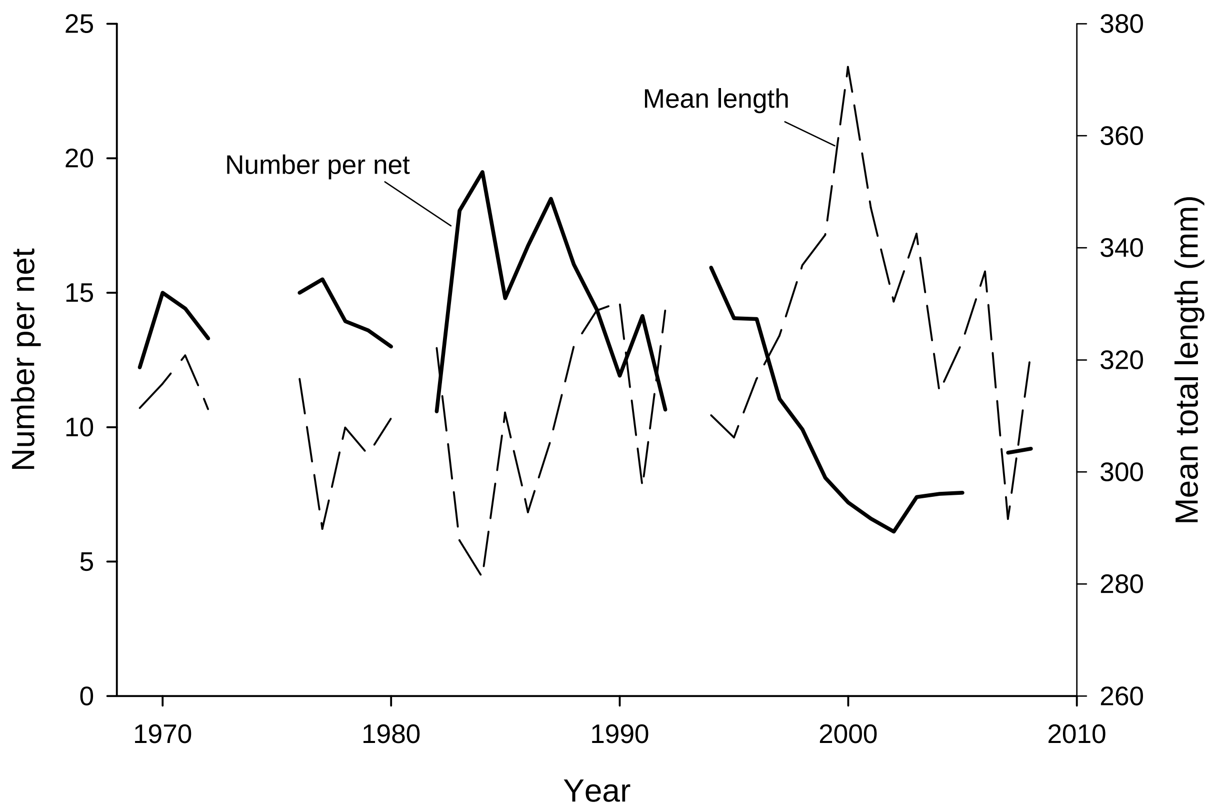

Figure 2. Mean number and mean length of Yellowstone cutthroat trout captured in experimental gill nets set in late September, 1969-2008.

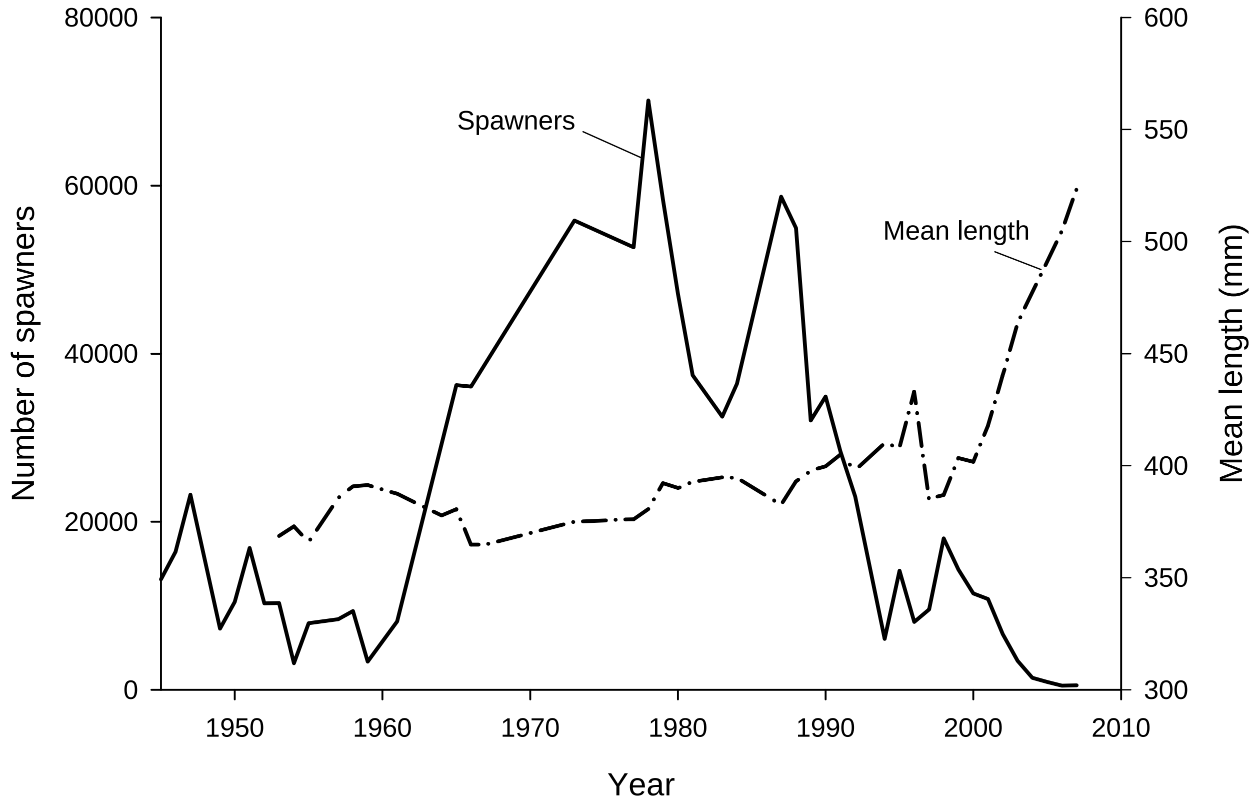

Figure 3. Counts and mean length of Yellowstone cutthroat trout spawners entering Clear Creek, 1945-2008.

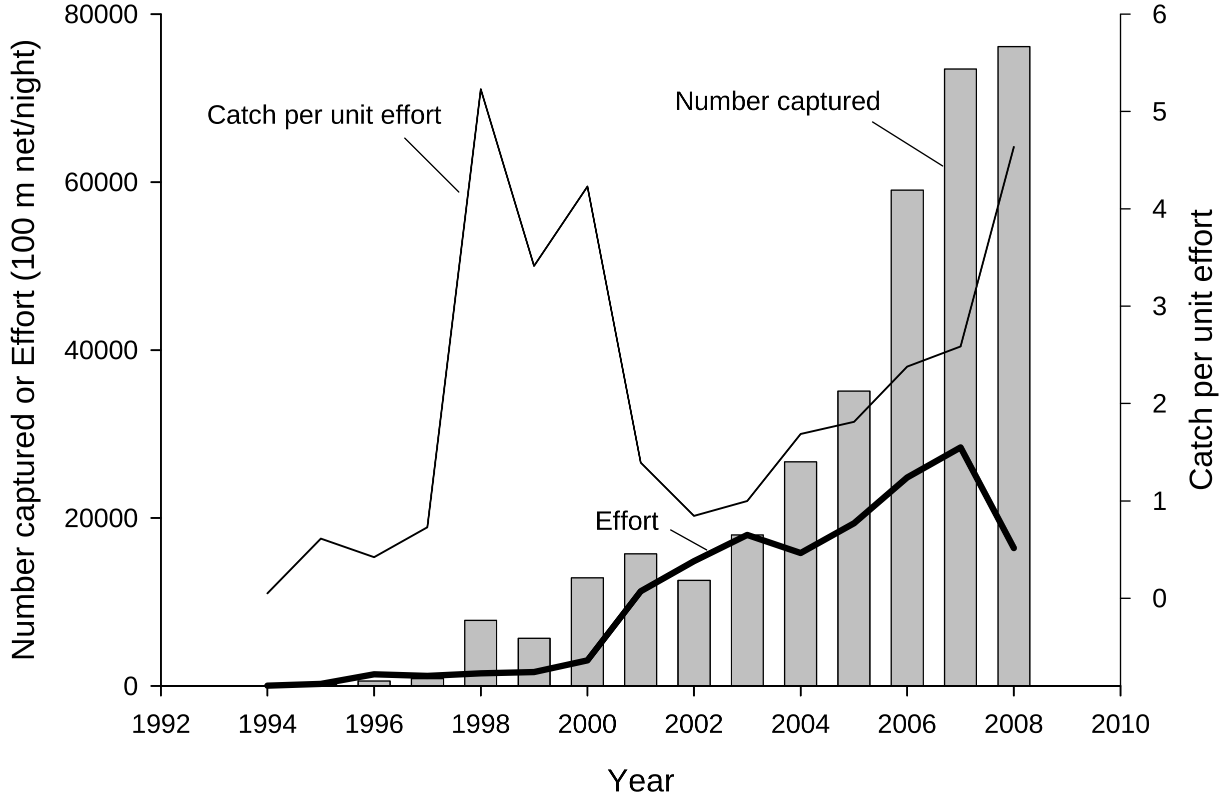

Figure 4. Annual estimates of the total number of lake trout removed, catch of lake trout per unit effort, and total effort for control nets, Yellowstone Lake, 1994-2008.

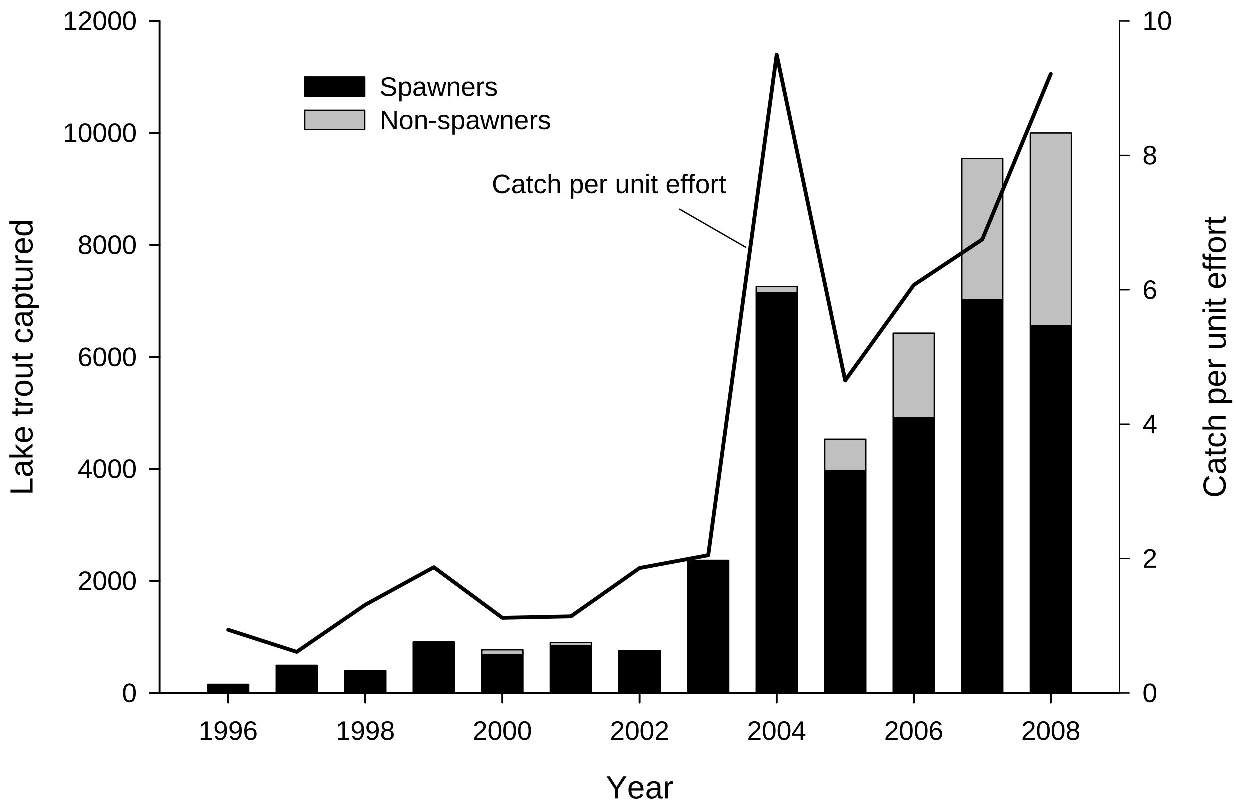

Figure 5. Total number of lake trout (spawners and non-spawners) and total catch of lake trout per unit effort in gill nets set specifically to capture spawners, Yellowstone Lake, 1996-2008.