Lake Trout in Swan Lake, Montana:

A Summary of the Efforts of the Swan Valley Bull Trout Working Group 2005-2017

Prepared by:

Wade Fredenberg

Fisheries Biologist, U.S. Fish and Wildlife Service

and

Leo Rosenthal

Fisheries Biologist, Montana Fish, Wildlife & Parks

May 1, 2018

Photo credit: Joel Sartore for National Geographic with Wade Fredenberg

Table of Contents

List of Tables

List of Figures

INTRODUCTION AND BACKGROUND

Study Area (adapted from Cox 2010)

Swan Lake (47.9628° N, 113.9033° W) is a glacially formed lake in the Flathead River drainage in northwest Montana at an elevation of 940 m with a surface area of 1,335 ha (Figure 1). The Swan River is the primary tributary and outlet of the lake, entering in the southwest and exiting to the north. The Swan River flows 22 km out of Swan Lake, entering Flathead Lake in the town of Bigfork. In 1902, the Swan River was dammed approximately 1.6 km upstream of the confluence with Flathead Lake (Baxter et al. 1999).

A fish ladder was constructed around Bigfork Dam in the 1950s. Lake trout would have had access to Swan Lake by migrating upstream from Flathead Lake until the fish ladder at Bigfork Dam was physically closed off in 1992. It is uncertain whether lake trout initially populated Swan Lake by illegal introduction(s) or by natural colonization events. Two lakes in the upper Swan River drainage approximately 50 km upstream from Swan Lake, Holland Lake and Lindbergh Lake (Figure 2), also contain bull trout populations. Lake trout were first verified in Lindbergh Lake in 2009 and Holland Lake in 2012, by Montana Fish, Wildlife & Parks (FWP) (L.R. Rosenthal, unpublished data).

The morphometry of Swan Lake is characterized by two deep (>30m) basins at the north and south ends and a shallower mid-lake section (Figure 3). Mean depth is 16 m and maximum depth is 43 m. Bottom substrate is dominated by fine sand and silt in depositional zones, with several reefs consisting of larger substrates scattered throughout the lake, particularly in the mid-lake region. Shoreline substrate is dominated by glacial till, with a section of large angular cobble and boulders along Montana Highway 83 on the southeast edge of the lake.

Dissolved nutrient levels (TDS=112 mg/l) in Swan Lake are relatively high among lakes containing lake trout populations (Shuter et al. 1998; McDermid et al. 2010). Swan Lake is dimictic and stratifies during summer months, with the thermocline at approximately 18 m in late summer. Hypolimnetic oxygen deficiencies have been recorded in the deep basins with the highest deficits (e.g., <0.1% O_2 saturation) in the south basin (Butler et al. 1995). Oxygen deficiencies in the hypolimnion are attributed to nutrient inputs from the Swan River from historical logging and road construction (Butler et al. 1995).

Swan Lake contains a diverse fish assemblage with several native and nonnative species. Native fish species include westslope cutthroat trout *Oncorhynchus clarkii lewisi*, bull trout *Salvelinus confluentus*, mountain whitefish *Prosopium williamsoni*, pygmy whitefish *Prosopium coulterii*, northern pikeminnow *Ptychocheilus oregonensis*, peamouth *Mylocheilus caurinus*, redside shiner *Richardsonius balteatus*, longnose sucker *Catostomus catostomus*, largescale sucker *Catostomus macrocheilus*, and slimy sculpin *Cottus cognatus*. Introduced species include lake trout *Salvelinus namaycush*, kokanee *Oncorhynchus nerka*, rainbow trout *Oncorhynchus mykiss*, brook trout *Salvelinus fontinalis*, northern pike *Esox lucius*, brook stickleback *Culaea inconstans*, and central mudminnow *Umbra limi*. Introduced Mysis shrimp *Mysis diluviana* are also part of the food web in Swan Lake.

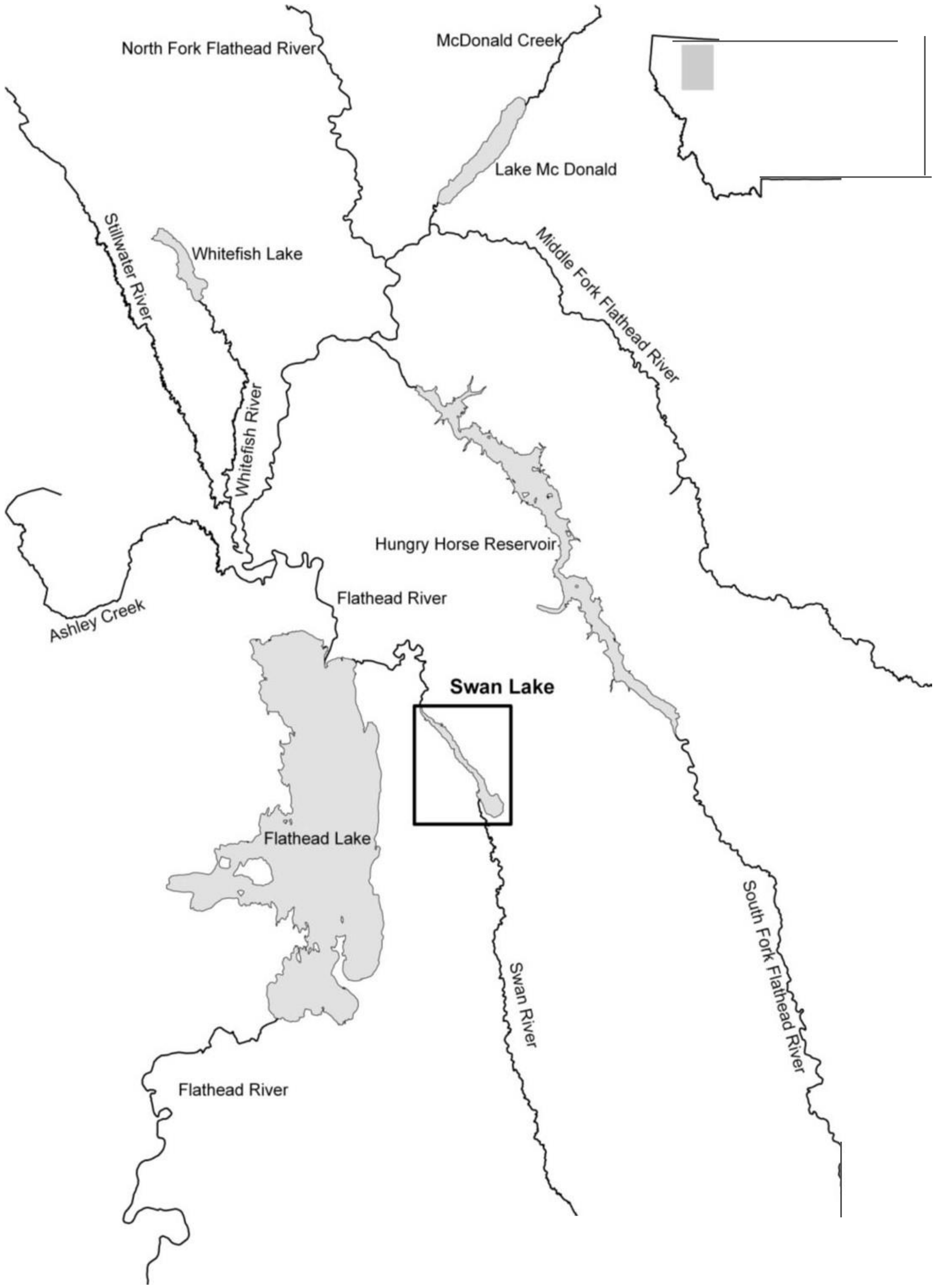

Figure 1. Location of Swan Lake in the Flathead River drainage, northwest Montana (from Cox 2010).

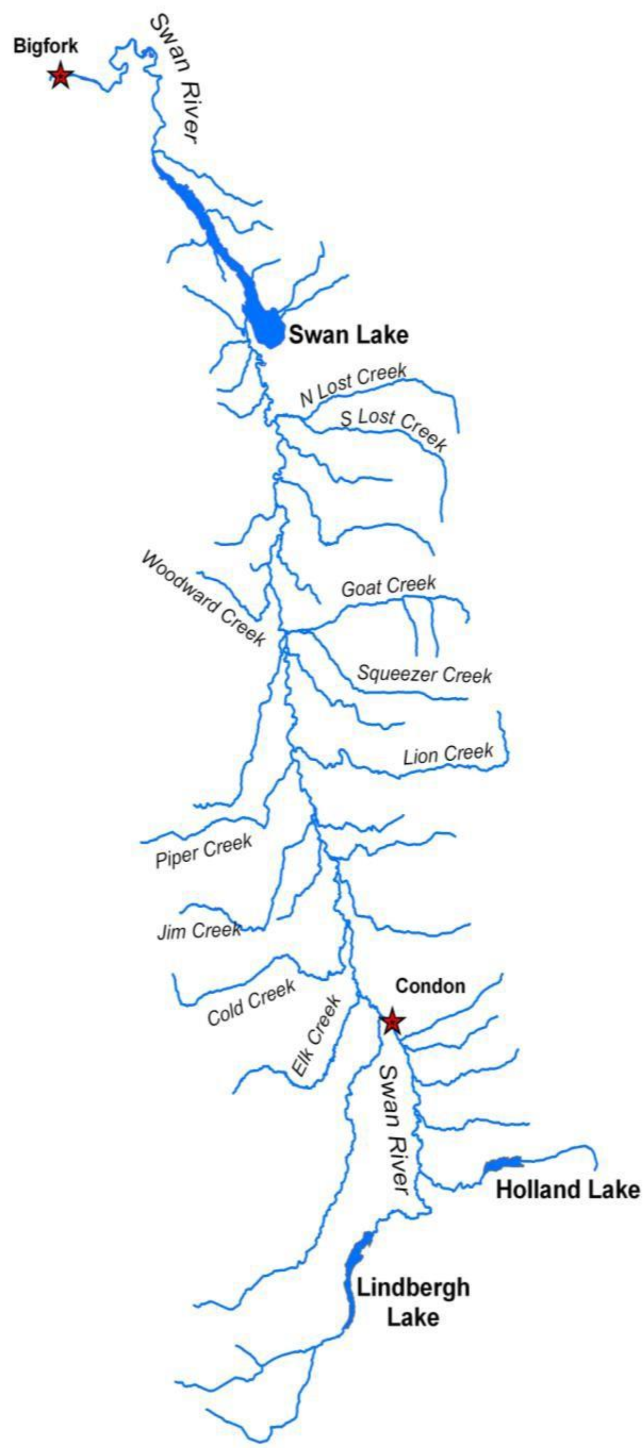

Figure 2. Map of the Swan River drainage including Swan, Holland and Lindbergh Lakes.

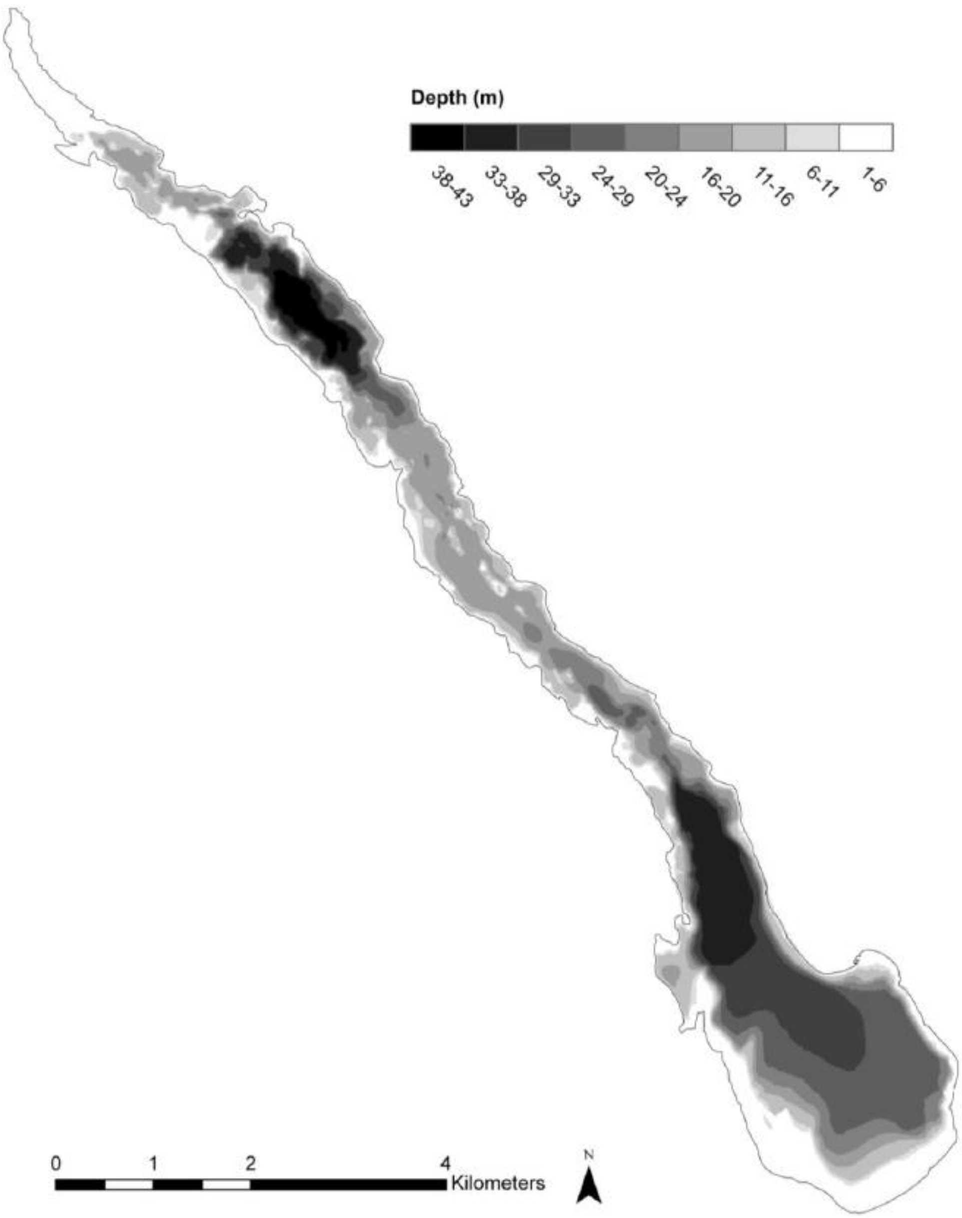

Figure 3. Bathymetry of Swan Lake (from Cox 2010).

History of the Swan Lake Fishery

Angler Surveys - A creel survey of Swan fisheries was conducted over a one-year period in 1982-1983 by Leathe and Enk (1985). The survey estimated angler harvest of 14,430 kokanee, 1,237 northern pike, 738 bull trout, 284 rainbow trout and 237 cutthroat trout over the course of a year. Anglers were asked what species they were targeting. Anglers in 180 parties that specifically targeted bull trout reported a catch rate of 0.26 fish per hour and harvest rate of 0.09 fish per hour. Leathe and Enk (1985) also reported estimated harvest of 585 bull trout from the mainstem Swan River in 1983.

The Swan River was closed to bull trout fishing in 1994. In 1995, another on-site Swan Lake creel survey, using the same methodology as the 1983 survey, estimated that 8,833 angler days were expended on Swan Lake to harvest a total of 10,670 fish (Rumsey and Werner 1997). About 82% of harvested fish were kokanee, 9% northern pike, 5% bull trout, 2% cutthroat trout, and 2% rainbow trout. About 13% of anglers named bull trout as the species they preferred to fish for. Anglers kept an estimated 482 bull trout in 1995, about 53% of which were considered adult fish over 18 inches (457 mm). Bull trout anglers released about 86% of the bull trout they caught. Anglers were estimated to have harvested about 4% of the adult bull trout population of Swan Lake in 1995.

The pressure estimate from the on-site survey in 1995 was very close to the statewide mail survey estimate of 9,253 angler days on Swan Lake in the same time period. Subsequent tracking of angler use through statewide mail survey, which was conducted in odd-numbered years, indicated an increasing trend of angler use on Swan Lake in 1995-2003 with a peak estimate of 12,716 angler days in 2001 (FWP 2002). After a relatively high use era from 1999-2003, statewide mail survey tracking showed angler use declined in 2005 through 2011, to an estimated 5,720 angler days in 2011. It's likely that angler use was strongly linked to the kokanee fishery, although a declining bull trout fishery and more heavily regulated bull trout harvest could have been contributing factors. The statewide mail survey was discontinued and is no longer available as a tracking tool.

Bull Trout - Swan Lake historically supported one of the strongest bull trout populations in Montana. As early as 1891, the Kalispell Inter Lake published an account of a road being built to Swan Lake as: "It will furnish an outlet to one of the finest resorts in the state as the lake abounds in fish and there is an unlimited amount of game." (Inter Lake 6/26/1891). On July 13, 1900 another story in the Inter Lake related the following: "O. Denney and Fred Herrig returned yesterday from the head of Swan Lake where they have been fishing. Mr. Denney brought back with him a fish story weighing 27 pounds. He also brought the fish, a salmon trout." "Salmon trout" was the commonly used name for bull trout at the turn of the 20th century.

As demonstrated above, throughout the 1900's and as recently as the mid-1990's the Swan (Lake and River) was an important bull trout fishery. The Swan took on an elevated profile during deliberation over ESA listing in the 1990's, as an oft-cited example of a managed landscape that maintained a strong bull trout population despite an intensive history of road building and logging.

After ESA-listing (1998), Swan Lake was the only bull trout fishery in Montana where angler harvest of bull trout was permitted.

Kokanee – Kokanee salmon are an important game fish species in Swan Lake, as well as an important food source for bull trout and lake trout. Kokanee were introduced into Swan Lake by the state of Montana in the 1940's. In Swan Lake, the majority of kokanee spawning occurs along the shoreline, with limited evidence of historic use in direct tributaries. Kokanee are largely self-sustaining in Swan Lake, though up to 100,000 per year were also stocked in the lake from 1999-2005. This was done to supplement the kokanee population during a time in which kokanee eggs were taken by hatchery personnel from Swan Lake for propagation and stocking of other water bodies. Planting of kokanee was suspended after 2005, due in part to the establishment of lake trout. As mentioned previously in this report, kokanee have historically been the most sought-after fish by anglers in Swan Lake. *Mysis* shrimp were introduced into Swan Lake in 1975 (Rumsey 1988) and rapidly became established. The *Mysis* introduction was justified at the time as a way to improve forage conditions for kokanee. Some Swan Lake kokanee may have benefitted from *Mysis* establishment, as large kokanee (up to 500 mm) are more frequently observed now than prior to *Mysis*.

Rainbow and Cutthroat Trout - Westslope cutthroat trout are the only native *Oncorhynchus* species in Swan Lake. However, rainbow trout were introduced by stocking as early as 1925 and spread by natural recruitment throughout the system to become the primary salmonid in the Swan River, both upstream and downstream of Swan Lake. Rainbow trout freely interbred with cutthroat, which led to widespread loss of the pure native cutthroat trout in the Swan. Most of the remaining genetically pure populations of westslope cutthroat trout in the Swan system are isolated above barriers that rainbow trout can't surmount. Westslope cutthroat trout were routinely stocked in Swan Lake prior to the establishment of lake trout, but those plants were discontinued after 2007 as lake trout numbers increased.

Northern Pike - Northern pike were illegally introduced into Swan Lake in the 1970's. They established a reproducing population and a popular fishery in the lake as early as 1983 (Leathe and Enk 1985). Despite the likelihood that bull trout and other native fish may form part of the pike diet, there appears to be enough spatial and/or temporal separation to preclude pike from dramatically impacting the bull trout population in this system, at least at current levels. We base this conclusion on the fact that northern pike have never become numerous in the lake and bull trout were relatively abundant in the 1990's, even with an emerging pike population. While never a robust pike fishery, Swan Lake has provided a popular niche fishery, particularly for anglers pursuing large pike, with most of the pressure focused on the south end of the lake where habitat is most suitable.

Lake Trout - The Montana Bull Trout Scientific Group concluded in their 1996 status report that: "Swan Lake supports an introduced *Mysis* shrimp population and, if lake trout were also introduced, it is likely they would rapidly become the dominant fish species." As fate would have it, beginning in 1998, anglers started reporting catches of lake trout in both the Swan River and Swan Lake. Between 1998 and the end of 2003, at least eleven lake trout, all between 500-750 mm long, were documented as taken from Swan Lake or the Swan River (S. Rumsey, unpublished data).

In September 2003, the first lake trout caught from Swan Lake by FWP was taken while biologists conducted gill net sampling. The small size of the fish (~225 mm and age 2+ or 3+) was regarded as the first strong evidence that lake trout in Swan Lake were reproducing, since it would be presumed difficult for anglers to capture and transplant lake trout that small. From that evidence, momentum toward formation of the collaborative Swan Valley Bull Trout Working Group was initiated.

Preliminary Survey Activities (2005) - In the summer of 2005, the United States Forest Service (USFS) employed a "Bull Trout Ranger" to contact Swan Lake anglers while they were out on the water and interview them about their angling habits and preferences. A total of 269 anglers in 132 boats were surveyed, primarily during July and August. Angler preference, by species, was 59% northern pike, 17% no preference, 8% kokanee, 8% either kokanee or bull trout, 3% rainbow trout, 2% bull trout specifically, and the remaining 3% divided between cutthroat trout, lake trout, or yellow perch (Ruby and Gardner 2005). Most anglers were from Flathead (35%), Lake (25%), or Missoula (14%) County with 8% from Out-of-State. About 62% of Swan Lake anglers said they do not specifically fish for bull trout, while 38% said they do. In part, the Bull Trout Ranger was used to provide public education and in 2005, 57% of anglers stated they were unaware of the presence of lake trout in Swan Lake. Upon being presented with additional information, two-thirds of anglers (68%) said they would support lake trout suppression, while 23% opposed and the rest (9%) were undecided.

During that same timeframe (July-August, 2005), the United States Fish and Wildlife Service (USFWS) conducted education and outreach efforts on angler groups entering or exiting Swan Lake at the public landing. Part of that effort involved recruiting volunteers from each group to participate in a fish identification quiz. The quiz included ten realistic artist renderings of fish commonly found in Swan Lake. Both an adult bull trout and juvenile bull trout were included. A total of 188 anglers completed the quiz. Ninety-five percent of anglers correctly identified rainbow trout and 60% correctly identified westslope cutthroat trout. Another 55% were correct on kokanee and 54% on adult bull trout. Conversely, less than half of anglers (40% correct) identified lake trout. Mountain whitefish (36% correct) and brook trout (35% correct) were also incorrectly identified most of the time. The juvenile bull trout was correctly identified only 25% of the time, with more anglers (34%) thinking it was a brook trout than a bull trout. We concluded that species identification confusion amongst the three *Salvelinus spp.* is likely to be an ongoing problem for anglers and regulations. At the time of this survey bull trout harvest was still legal and anglers were allowed to keep one bull trout daily from Swan Lake.

Additional outreach efforts conducted in 2005 included the development, printing, and distribution of 5,000 copies of a brochure, largely designed to provide informational background on the lake trout threat and discuss possible remedial alternatives. We also retained a consultant (an outdoor writer), both to help us develop the brochure and provide additional advice in the form of an education plan on how to best manage the public relations.

Also, in 2005, though the Swan Valley Bull Trout Working Group (SVBTWG) had not yet been formally established, a number of preliminary actions were being implemented. The USFS awarded a contract to produce a GIS-linked bathymetric and substrate map of Swan Lake, which was completed in 2006. We also used USFS contracting to hire two SCUBA Divers to examine and help verify potential lake trout spawning habitat in Swan Lake. Lake McDonald in Glacier National Park was used as a training site for that effort, since USFWS and Montana State University (MSU) had previously verified spawning substrate there.

From mid-October to mid-November 2005, three floating Merwin traps were deployed at strategic locations in Swan Lake to capture pre-spawn lake trout for sonic tagging. No lake trout were captured, but baseline species composition information was recorded. The nets fished for a total of 142 net-nights and captured 3,825 fish of eighteen species (or their hybrids). Almost half of the catch (46%) was comprised of mountain or pygmy whitefish, 28% was kokanee, 13% was redside shiners, 7% was northern pikeminnow and the remaining aggregate 6% was comprised (in descending order of abundance) by 2% brook trout, 1% rainbow trout, 1% bull trout (including brook trout X bull trout hybrids), 1% peamouth, and 1% largescale sucker. Incidental catch (fewer than 10 individuals each) of westslope cutthroat trout, yellow perch, hybrid *Oncorhynchus*, northern pike, central mudminnow, slimy sculpin, brook stickleback, and pumpkinseed sunfish was also recorded.

FORMATION & ACTIVITIES OF THE SWAN VALLEY BULL TROUT WORKING GROUP - 2005-2017

In the Fall of 2005, interested collaborators signed a memorandum of understanding (MOU) to officially form the Swan Valley Bull Trout Working Group (SVBTWG) (Attachment 1). Charter signees were FWP (Region 1), Montana Department of Natural Resources and Conservation (DNRC), Confederated Salish and Kootenai Tribes (CSKT), Trout Unlimited Montana State Council (TU), USFWS (Montana ES State Office), and USFS (Flathead National Forest). The Management Goal agreed to by the participants was as follows:

> *"The management goal for bull trout in Swan Lake and the Swan River drainage (including Holland and Lindbergh Lakes) is to ensure the long-term, self-sustaining persistence of bull trout as the dominant piscivore within this ecosystem. In order to accomplish that goal, we will emphasize the migratory life history strategy of bull trout; strive to maintain genetic diversity; and protect or enhance current distribution and abundance of bull trout local populations. Attainment of the management goal should result in a continuing opportunity to sustain recreational fishing opportunities for bull trout."*

With the formal establishment of the SVBTWG the partners (listed above) began pooling resources (financial as well as in-kind contributions of personnel and equipment) as well as recruiting additional partners (e.g., USGS Cooperative Fisheries Research Unit at Montana State University, Flathead Valley Chapter Trout Unlimited) to collectively guide and explore options for lake trout suppression and associated bull trout recovery effort in the Swan. While operating rules were not formally designated, the SVBTWG unofficially operated as a consensus-based collaborative with leadership by USFWS or FWP and meetings at least annually or more often as needed.

The signed MOU that created the SVBTWG automatically sunset after three years (September 2008) and was not renewed, but the SVBTWG remained active with the same structure and goals and continues as of this report.

Initiation of Gill Net Sampling and Sonic Tagging Research 2006-2007 – In 2006, MSU graduate student Ben Cox began sampling and tracking lake trout for a Masters level research project under the supervision of the USGS Fisheries Coop Unit. A total of 27 net sets (84 individual 76 m nets) captured 194 lake trout, of which we marked (PIT Tags) and released 103, including 6 with sonic tags (SVBTWG 2007). Captured lake trout indicated at least two strong year classes of juvenile fish (mode at 250 and 340 mm) and scattered adults up to 600 mm total length. Based on these results, we determined that higher sampling efficiency was necessary to more accurately assess the lake trout population in Swan Lake. In early 2007 we conducted a “Benefit and Risk Analysis” associated with the potential use of gill nets and traps to suppress lake trout in Swan Lake (Fredenberg and Rumsey 2007). A major objective was to enable an accurate estimate of the size and structure of the lake trout population. Of primary concern was the potential overexploitation of Threatened bull trout and other sport fish species. The assessment concluded that bycatch could be effectively managed through timing windows and attention to specific netting techniques and the recommendation was adopted to proceed with larger scale netting operations.

In 2007 USFWS employed Hickey Bros., a professional gillnetting team from Wisconsin utilizing a Great Lakes style netting boat with a hydraulic net lifter. This greatly improved efficiency and in three weeks during September 2007, a total of 2,117 lake trout were captured, of which roughly 1,400 were PIT-tagged and released alive. Lake trout up to 850 mm in length were captured, with strong year classes again indicated around modes of 240 and 340 mm. Deep-water trap nets were also tested but proved ineffective at that time, in part due to the low density of lake trout large enough to be captured in the large mesh of the trap nets. The objective of this research, in part, was to conduct a mark-recapture estimate and to use these marked fish to establish growth rates and other metrics. However, an extremely low number of short-term recaptures from that marking event led to concern that either the survival was low for marked fish and/or excessive emigration was occurring. (Note: In subsequent years, movement of PIT-tagged fish upstream into the upper Swan River and likely into Holland and Lindbergh Lakes as well as downstream into Flathead Lake was documented). Nineteen lake trout were implanted with sonic transmitters and 130 subsequent relocations of the 25 sonic tagged fish occurred during the 2007 spawning season (mid-October to mid-November). A probable spawning area was located on the cobble slides along the Highway 83 riprap on the southern end of the lake.

Lake Trout Depletion and Associated Research 2008 – In May of 2008, the SVBTWG, having determined that lake trout suppression was potentially feasible and necessary, released a Draft Environmental Assessment (EA) for the purpose of conducting a lake trout depletion estimate in Swan Lake. We proposed initially to use the Hickey Bros staff and equipment to conduct standardized gillnetting for a 3-week period in late August into early September 2008 to recapture PIT-tagged fish from 2007, as well as explore a depletion method for assessing the size and age structure of the lake trout population. We indicated that this effort could inform future suppression efforts (which could be authorized through subsequent EA process). An affirmative June 27, 2008 Decision Notice recommended implementation of the project.

About this same time, we contracted with the MSU Department of Ecology to use modeling and genetic techniques to assess some of the founder aspects of the lake trout colonization in Swan Lake. That study concluded, in part, that the results were consistent with the Swan Lake population being descended from a very small number of individuals, likely originating from Flathead Lake (Kalinowski 2008). The estimated number of founders was 2.3, indicating a high probability that the entire population came from as little as one pair of adults. As a result, the lake trout population exhibited a striking lack of genetic diversity.

The 2008 depletion effort was carried out as planned, in conjunction with Cox' MSU research study. Results again indicated strong recruitment (year class modes at 240 mm and 340 mm, determined to correspond with age classes 3 and 4) and verified that large fish over 500 mm were relatively uncommon. All lake trout had high condition factors, indicating food resources were still abundant. Bycatch of bull trout and other species was manageable with the targeted lake trout making up 87% of the total gill net catch. Roughly 1,500 pounds of cleaned lake trout was donated to the Flathead Food Bank. The depletion estimate indicated that a population of roughly 7,300-10,500 lake trout greater than 165 mm (i.e., Age 3 and older) was present at the start of netting and the removal of 3,784 individuals reflected a 36-52% exploitation rate.

Sonic tracking of mature lake trout refined our targeting of the Highway 83 cobble slides as a primary spawning ground. Mesh traps roughly the diameter of a five-gallon bucket were buried in the substrate at high use locations prior to lake trout spawning and then retrieved by SCUBA divers. The traps collected 356 lake trout eggs (in 58 traps) at depths of 5 to 25 feet. The 2008 spawner netting efforts resulted in 100 direct bull trout mortalities, with early morning sets catching nearly double the number of bull trout as evening sets. Direct mortality rates of bull trout increased by fish length as well as by mesh size. In 2008, we also conducted standard fish health sampling on 60 lake trout. All fish tested negative for all common pathogens.

Three-year Suppression Experiment 2009-2011 – In January 2009, we published a Draft EA proposing a 3-year Experimental Suppression effort to use gill nets (set by professional contractors) in two annual events (3 weeks in late August-early September targeting juveniles, followed by 3 weeks in October targeting spawning adults) to suppress lake trout. The stated objective was to determine if that level of gillnetting effort was sufficient to control expansion of the lake trout population in Swan Lake and benefit the kokanee and bull trout populations. After public review, a Decision Notice was issued by the FWP Regional Supervisor in Kalispell on August 3, 2009 recommending the project be implemented. The collective resources of the SVBTWG ensured that funding was available to support at least the first two years of the effort. This project constituted the official beginning of the lake trout suppression effort in Swan Lake.

The rest of this report focuses primarily on the results obtained in the 8-year period from 2009-2016 when active lake trout suppression was implemented. Also, in 2009, lake trout were first detected upstream in Lindbergh Lake, confirming earlier angler reports.

In 2010, Cox's M.S. thesis: "Assessment of an Invasive Lake Trout Population in Swan Lake, Montana" was completed. Cox (2010) described estimates of abundance, size structure, age structure, growth, condition, maturity, fecundity, and mortality of the population. He also conducted Matrix-model simulations that indicated the lake trout population would continue to grow without suppression efforts and that population growth was likely highly sensitive to changes in age-0 survival. He further elucidated information on the spawning locations and suggested the most effective suppression strategy should focus on sub-adult and adult lake trout, recommending suppression efforts should be increased.

Five-year extension of the Suppression Experiment 2012-2016 – In May 2012, a Draft EA was published to provide a 5-year extension (2012-2016) to the Swan Lake Experimental Lake Trout Removal project. It was accompanied by a 3-year summary report of the previous actions (Rosenthal et al. 2012). The stated purpose was to allow for sufficient time to fully assess the existing suppression project. Following a 30-day public comment period in which 127 written comments were received (108 in support) a July 2, 2012 Decision Notice was issued authorizing continuation. Public concern largely involved operational costs and inadvertent bull trout bycatch. The Decision Notice continued to require annual reporting and the stipulation that after two years a bull trout bycatch threshold should be established.

In the years 2009-2011, a total of 21,330 lake trout (150-900mm total length) were removed, exhibiting an initial upsurge in numbers from 2009-2010 followed by a decline in 2012. The 2012 decline was taken as a possible indication of declining recruitment (Rosenthal et al. 2012). Bycatch of other species, and bull trout in particular, was analyzed in the 3-year report.

Annual reports continued to track progress in 2012-2016. The annual progress report for 2013 (Rosenthal and Fredenberg 2014) included a more detailed analysis of the bull trout bycatch issue. That assessment concluded that bycatch of bull trout associated with lake trout suppression netting at the existing level was likely to remain at 300-400 bull trout per year, with tag return data and other information supporting the conclusion that roughly half the gillnetted bull trout (150-200) survived. Based on a cohort analysis, we estimated that the bycatch due to gillnetting could remove, at most, up to 150 bull trout redds from the system.

Beginning March 1, 2012, FWP closed the bull trout harvest fishery on Swan Lake. The estimated direct angler harvest of bull trout from Swan Lake prior to 2012, based on a 2009 creel survey, was 176 fish per year. That was down from a 1995 estimated harvest of 482 bull trout, under less restrictive regulations. Since the magnitude of gill net bull trout bycatch mortality (150-200 per year as of 2013) was similar to the angler harvest (176 fish per year in 2009) and the two were additive during the period when both were occurring (2008-2011), we concluded the elimination of angler harvest would reduce bull trout mortality, beginning in 2012. This has been further reduced by cessation of suppression gillnetting starting in 2017 (continuing to date).

In 2012, lake trout were first detected by FWP gill net sampling in Holland Lake and the Lindbergh Lake population appeared to be expanding. A United States Geological Survey (USGS) study was initiated in 2013, to track 9 adult lake trout in Lindbergh Lake and 3 in Holland with sonic transmitters. For a variety of reasons, including equipment failure and manpower shortages (Federal government-wide shutdown), limited information was gained from those studies.

In 2014-2015, FWP initiated a second sonic transmitter study tracking 48 tagged lake trout over two years during the spawning season on Swan Lake. Exploratory spawner netting in 2014, based in part on tracked locations of these tagged fish, led to the discovery of a second major spawning area near a shoal on the northern end of Swan Lake (Rosenthal, Fredenberg, and Steed 2015 and 2016). At the north end location, we captured a cohort of very large (800-950 mm) adult lake trout that had largely disappeared from samples of the south spawning area since the initial 2009-2010 period. Several of those fish contained now-dead transmitters from that earlier work. That experience illustrated the absolute necessity of continuing to search for and adaptively exploit spawner concentrations.

Completion of the 2009-2016 suppression experiment - In the final annual progress report for the 8-year (2009-2016) experimental effort we summarized the data (Rosenthal and Fredenberg 2017). A total of 59,752 lake trout were removed from Swan Lake during the study (roughly 7,500 per year). An assessment of our existing monitoring indices found that while mortality rates near 50% (our minimum target) were likely approached for age-3 and age-4 lake trout as well as for adults on the known spawning grounds, a gap in exploitation likely existed for intermediate age classes (i.e., age-5, 6, and 7) and non-spawning fish. Combined with the rather recent (2014-2015) discovery of a secondary spawning location and minimal exploitation of the newly documented spawning shoals prior to 2015, our conclusion was that lake trout suppression efforts in Swan Lake during 2009-2016, at the level we were able to implement, were not effective in creating the desired downward trend in the lake trout population. However, there was also little evidence of population expansion, though catch per unit effort of adult size lake trout did appear to increase as new spawning areas were identified. Bull trout and kokanee trends experienced some declines during the study period as well, but those indices have recently fluctuated around stability. The paucity of juvenile bull trout bycatch in the last two sampling events (2015-2016) was taken as a possible indicator that further declines in the adult bull trout population may be likely in the near future (Rosenthal and Fredenberg 2017).

The purpose of this 2018 summary report is to contextualize the scientific reports into a readily digestible, historical overview that will support future decision making. In 2017, operational funding ran low and the MEPA authorization to proceed under the 2009 EA and its 2012 extension had expired. Consequently, the SVBTWG lake trout suppression action was suspended after the 2016 season. Ongoing monitoring continues of both juvenile and adult bull trout (through tributary estimates and redd counts) as well as kokanee spawning surveys and *Mysis* assessments. The long-term spring gill net monitoring of Swan Lake was not robust enough to detect anything other than major trends, so it has been revamped to be more sensitive to fluctuations in the lake trout population.

Complementary Research Efforts – Management efforts to suppress lake trout populations or arrest their expansion throughout the Western States initially employed primarily the technique of targeted angling regulations, since lake trout in their native range are susceptible to overharvest (Martinez et al. 2009). But gradually, management agencies have adopted more direct lake trout suppression techniques, such as gillnetting. It has long been a concern that high levels of lake trout productivity and resultant predation by this apex predator on both native and introduced sport fishes in novel western lake habitats can lead to undesirable consequences, such as cascading food web collapse (Spencer et al. 1991, Ellis et al. 2010). Syslo (2015) analyzed and reported on the near-collapse of Yellowstone cutthroat trout and the intensive multi-million dollar effort at lake trout suppression in Yellowstone Lake that was initiated after nonnative lake trout were discovered there in 1994. Within the Pacific Northwest native range of bull trout, lake trout suppression efforts largely based on gillnetting techniques have also been initiated in Lake Pend Oreille, Idaho (Hansen et al. 2010), Upper Priest Lake, Idaho (Ryan 2016), Flathead Lake (Hansen et al. 2016) and Quartz Lake (Fredenberg 2014) as well as other lakes in Glacier National Park.

There has been a broad exchange of scientific and management information in the northwest United States through both published and unpublished literature. Much of that exchange has focused on lake trout biology, efficacy of ongoing control efforts, and testing and evaluation of innovative lake trout control methods. Practitioners began in the early 2000's to exchange information both informally and formally at Montana Chapter American Fisheries Society (AFS) meetings. This exchange of information has both benefited new programs as well as increasingly pointed toward the difficulty of suppressing a species that, while not native in these systems, is exceptionally well-adapted to the deep, cold lakes of Yellowstone Park and the Columbia headwaters.

Swan Lake stands out in that colloquium as both a problem and an opportunity. On the one hand, the fairly recent introduction of lake trout to Swan Lake (surmised circa 1990) and their early discovery (1998) initially led us to believe that we could suppress the population prior to it reaching carrying capacity and subsequently causing the kinds of cascading ecosystem effects (e.g., kokanee and bull trout collapse) commonly exhibited elsewhere. In addition, Swan Lake is a more manageable sized lake and ecosystem than Yellowstone, Flathead or Lake Pend Oreille. On the other hand, the Swan Lake population of lake trout has proven surprisingly resilient and the SVBTWG has been led to frequently debate the merits and cost-effectiveness of the recent suppression efforts. It has become evident that at least one faction of the angling public has a serious dislike for gill-net based suppression. While we believe we have managed the bycatch issue appropriately, it is still an issue we need to contend with.

To that end, we are constantly searching for new and better tools to add to the toolbox to partially or completely replace gillnetting. One of the most promising methods is to suppress the viability of lake trout embryos, either in the female prior to fertilization or during the early developmental stages after fertilization. Gross et al. (2011) assessed putative methods for destruction of lake trout embryos in situ and after examining electroshocking, application of carbon dioxide, ultraviolet radiation, suction dredging, and seismic technology found all of them were difficult to administer and not as effective as hoped. Of these, direct application of electricity was most effective.

The USFWS conducted an independent assessment of the feasibility of utilizing SCUBA-assisted spear fishing to suppress invasive lake trout (USFWS 2012). Most of the work was conducted in Glacier

National Park, although visual assessments were also completed in Swan, Holland and Lindbergh lakes. While some potential to spear adult lake trout on the spawning grounds was documented, the applicability was ultimately judged to be rather site-specific and most likely limited to conditions where spawning lake trout predictably concentrate over limited available substrate.

In September 2011, the SVBTWG produced another EA and proposed a 3-year supplemental study to assess the efficacy of using modified electrofishing equipment to destroy lake trout embryos after they're deposited in the spawning substrate in Swan Lake. The research, directed by the USGS Cooperative Fisheries Research Unit at MSU, was approved and conducted in 2011-2013. Brown and Guy (2013) used lab experiments with rainbow trout embryos to confirm voltage gradients and duration of exposure necessary to kill eggs buried at various depths in the substrate. Ultimately, they were not able to design a cost-effective prescription for applying this methodology in the field in Swan Lake, but it still shows some promise if delivery can be improved.

Syslo et al. (2013) published a paper in the North American Journal of Fisheries Management that assessed "Comparison of Harvest Scenarios for the Cost-Effective Suppression of Lake Trout in Swan Lake Montana." The conclusions reached through modeling were that empirically-derived exploitation rates (2008-2011) calculated through depletion estimates were high (0.80 for juveniles and 0.68 for adults) compared to other lakes in the western U.S. The models indicated that if only one or the other strategies (either juvenile or adult suppression) were to be chosen, the harvest of juveniles was likely to be more efficacious over time. However, simultaneous harvest of both cohorts (juvenile and adult) was required to cause the modeled population to collapse (95% reduction). The models further explored a variety of methods and considered overall cost-effectiveness.

SVBTWG Funding and Expenditures 2008-2016 - As mentioned previously in this report, funding for lake trout suppression related activities in Swan Lake has been a collaborative effort by the SVBTWG. This collaborative approach has been successful at demonstrating the level of interest and commitment from each agency/organization in preserving the bull trout population in the Swan drainage. However, this collaborative approach to funding also underscores one of the great challenges in implementing a long-term suppression program, in that funding projects of this nature through collaborative contribution incorporates a high degree of uncertainty from one year to the next. Costs incurred by the project are found in Table 1. Annual expenditures for the project included both the contract with Hickey Bros., as well as agency staff time associated with actual field work, EA writing, report writing, public outreach, etc. (labeled as "In kind"). Additionally, research projects such as the aforementioned sonic telemetry (2014-2015) and the lake trout egg/embryo destruction also added to overall budget. While these projects were separate from the actual suppression activities, they were either considered necessary for the success of this suppression project (sonic telemetry) or represented an additional tool to increase population mortality (egg/embryo destruction).

The collaborative funding sources for the Swan lake trout suppression activities can be found in Table 2. The table is separated into two time periods. The first is the four-year time period from 2008-2011, which captures the 2008 depletion population estimate and the 2009-2011 experimental removal contracts. The second period (2012-2016) represents the five-year extension of experimental suppression, the egg/embryo study, and the 2014-2015 sonic telemetry study.

Funding sources for SVBTWG activities were as diverse as the contributors and ultimately dictated, to a large extent, the level and intensity of annual effort. Funds contributed from FWP were a combination of management dollars and BPA mitigation funds associated with hydropower production. These funds were used to pay for gillnetting contracts, sonic telemetry research, the MSU egg/embryo destruction study, and operational costs associated with the gillnetting project (i.e., ice, equipment, housing, etc.). Funds contributed from the USFS were largely associated with the Collaborative Forest Landscape Restoration Program (CFLRP) and were used to help pay for the gillnetting contract. Funds from Montana/Flathead Valley TU, the MT DNRC, and the Trust for Public Lands were used to help pay for gillnetting contracts and field housing. Funds acquired from the USFWS helped purchase the nets used for the project, paid for gillnetting contracts, and paid for field housing for staff.

Table 1. Total expenditures for lake trout suppression related activities in Swan Lake 2008-2016.

Year	Contract Amount	In Kind Contribution
2008	$47,568	$50,000
2009	$64,375	$50,000
2010	$86,875	$50,000
2011	$86,875	$50,000
2011-2013 Egg/Embryo Study	$254,500	
2012	$110,362	$50,000
2013	$102,824	$50,000
2014	$102,824	$50,000
2014-2015 Sonic Telemetry	$48,696	
2015	$102,824	$50,000
2016	$102,824	$50,000
Total Spent	**$1,110,547**	**$450,000**

Table 2. Direct appropriations contributed to Swan Lake suppression activities 2008-2016.

Funding Source	Year	Amount
MT Fish, Wildlife & Parks	2008-2010	$150,000
US Forest Service	2009-2010	$119,200
US Fish and Wildlife Service	2009-2011	$30,577
MT Department of Natural Resources	2010-2011	$6,000
MT Trout Unlimited	2010-2011	$5,000
MT Fish, Wildlife & Parks	2012-2015	$428,558
US Forest Service	2012-2016	$317,000
US Fish and Wildlife Service	2014-2016	$40,000
MT Department of Natural Resources	2012-2013	$5,000
Trout Unlimited (MT and Flathead Valley)	2013-2015	$16,000
Trust for Public Lands	2015	$18,000

DISCUSSION

Lake Trout

Monitoring- As previously described, lake trout were first documented in the Swan drainage in 1998. The first report came from an angler who had caught a 29" (736 mm) lake trout upstream of Swan Lake near the mouth of Woodward Creek. From 1998-2003, FWP received several other reports of lake trout being caught in the Swan drainage. However, it wasn't until September 2003, that lake trout started showing up in some of FWP's monitoring. Recognizing that lake trout were an increasing threat to the other fish populations in Swan Lake and the Swan River, FWP increased monitoring in Swan Lake in 2004 through 2006. In 2006 the SVBTWG funded a graduate study (Cox 2010) which formed the beginning of a new era in lake trout data from Swan Lake. Once the graduate study began, FWP discontinued the fall lake trout monitoring, as the data generated from the graduate study and subsequent 2009-2016 removal experiment was considered more robust.

The spring gill net survey was established by FWP in 1995 with the goal of monitoring a variety of fish species in Swan Lake. The survey is comprised of 6 sinking and 5 floating gill nets. Lake trout catch is typically calculated as the number of lake trout per sinking gill net (n=6). The lake trout catch data is variable in the spring survey, with 2006 being the first year they were detected by the survey and becoming a routine part of the overall catch (Figure 4). This variability is likely the result, in part, of low sample size. Additionally, the standardized net locations were established before lake trout were documented in Swan Lake, and therefore were not designed to be representative of typical lake trout habitat.

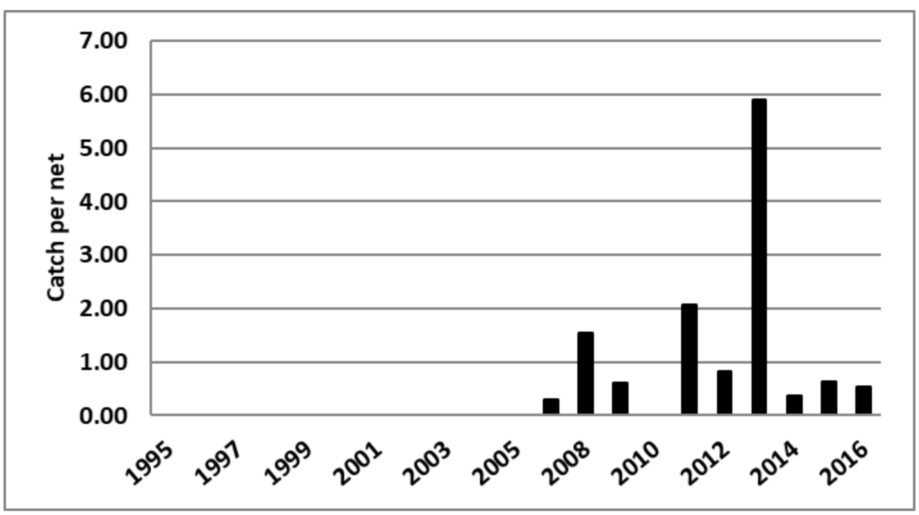

Figure 4. Lake trout catch per net in FWP's standardized spring gill net surveys 1995-2016.

Recognizing that lake trout are now a likely long-term component of the Swan Lake fishery, and that much interest will now be focused on lake trout trends, FWP initiated a new gill net survey in 2017. Building on lessons learned from Yellowstone Lake, this new survey will provide lake trout monitoring data that is independent of any future lake trout suppression activities. This will allow any future suppression activities to actively target lake trout concentrations without constraints imposed in the past by the need for standardization. It is anticipated that the new survey will provide consistent data and become a standardized tool for rigorous evaluation of future suppression techniques. The new survey was adapted from the Ontario Ministry of Natural Resources' Summer Profundal Index Netting (SPIN) survey (Sandstrom and Lester 2009). The SPIN survey was designed to monitor lake trout populations in both small and large water bodies in the Great Lakes region. The survey relies on stratified random sampling of habitats beneath the thermocline in a thermally stratified lake. In the case of Swan Lake, 30 sites are randomly selected each year, with effort proportionally divided between the north and south basins. In 2017, we attempted both 2-hour net sets and overnight net sets to compare catch rates. Overnight sets produced lake trout catch rates roughly five times higher than the 2-hour and will likely become the standard methodology in upcoming years.

Catch Analysis and Modeling Results from the Suppression Experiment- A complete description of the lake trout suppression data was provided in the 2016 SVBTWG annual report (Rosenthal and Fredenberg 2017; Figures 1-6). That report presents total lake trout catch (juvenile and spawner numbers), lake trout catch per unit effort (juvenile and spawner netting), lake trout relative weight, and modeled lake trout mortality rates. Additionally, the 2016 annual report compares the lake trout data to the evaluation criteria established in the 2009 EA. In most cases, the lake trout removal experiment did not meet the predetermined evaluation criteria, which, in brief were to: 1) Achieve total annual lake trout mortality of at least 50%, 2) Exhibit detectable trends in density (CPUE), condition, and length of spawning lake trout which would support a case for population decline, and 3) Observe stable or increasing trends in kokanee, bull trout, and *Mysis* (as an indicator) that support the fishery.

After eight years of targeted gillnetting, a total of 59,752 lake trout were removed from Swan Lake, an average of nearly 7,500 per year. Incidental bycatch of other fish species was relatively low, typically totaling only 5-10% of the overall net catch in the juvenile netting and somewhat higher in spawner netting (Rosenthal and Fredenberg 2017; Table 3). Modeled lake trout exploitation rates suggest that this level of gillnetting effort probably created mortality rates approaching or exceeding 50% for age-3 and age-4 lake trout at least in some years. Netting on predetermined spawning areas was somewhat effective at reducing adult lake trout on known spawning areas. However, some age classes (e.g., age-5 and age-6) were considerably less vulnerable to the netting and it is suspected that unknown spawning areas likely exist. Therefore, the desired total annual mortality rate of 50% across the lake trout population was likely not achieved. Indices examining how this level of effort affects the lake trout population showed no significant trend with regard to lake trout abundance or relative weight. However, netting on known spawning areas did appear effective in removing the larger, older individuals. These data suggest that, going forward, lake trout mortality rates will need to be increased if any alternative strategy can be expected to produce declines in overall lake trout abundance.

Bull Trout

Monitoring - Bull trout redd counts in four Swan River index tributaries (Elk, Goat, Squeezer, and Lion creeks) began in 1982 and are conducted annually (Figure 5). The index redd counts provide trend information of the adult bull trout population over the past 35 years. From 1982 to 1992 the redd count total for the four index reaches ranged from about 200-400 and was non-trending (FWP unpublished data). Beginning about 1993, the redd count index increased and ranged from about 400-600 redds annually, indicating a more robust population from about 1993 through about 2009. It is believed this increasing trend in the population resulted largely from more restrictive fishing regulations that reduced angler harvest of bull trout, starting in about 1994, when the Swan River was closed to bull trout harvest. Additionally, starting in the late 1970's an abundant forage base of *Mysis* and small kokanee likely contributed to a high-density bull trout population. However, after 2009, a general decline in bull trout populations occurred. Index redd counts from 2010 through 2017 generally ranged from about 200-300, roughly half of the 1993-2009 period and more similar to the 1980's levels.

Because of increasing interest in bull trout beginning in the early 1990's, in part generated by the pending ESA listing and subsequent elevated management importance, annual basinwide total redd counts (including all ten streams where bull trout redds were commonly observed) were initiated in the Swan in 1995 (Figure 6). The basinwide trend tracked closely with the index counts, which are calculated to represent about 65% of the total basinwide redd count (Weaver 1998). The basinwide redd count exceeded 800 redds in 1997 and 1998, indicating a spawning population of about 2,500 or more adults annually (3.2 adults per redd is the standard conversion; see e.g., Downs et al. 2006). Since alternate year spawning has historically been considered the usual pattern for adfluvial fish in the Flathead Basin (Fraley and Shepard 1989), the spawning population may represent only about 50% of the total adult bull trout population in the system in a given year. Using that standard, the Swan Lake bull trout population was estimated at around 5,000 adult bull trout (2.2 per surface acre) in the late 1990's.

Starting in about 2009, basinwide redd counts have generally trended lower, ranging from 300-500, with a bottom of 312 in 2011. This represents an adult bull trout population less than half of the 1990's peak levels. It should be noted that these are estimates. Despite the declines, the Swan Lake bull trout population still remains relatively healthy compared to surrounding core areas and is roughly consistent with abundance of the early 1980's (Figure 5).

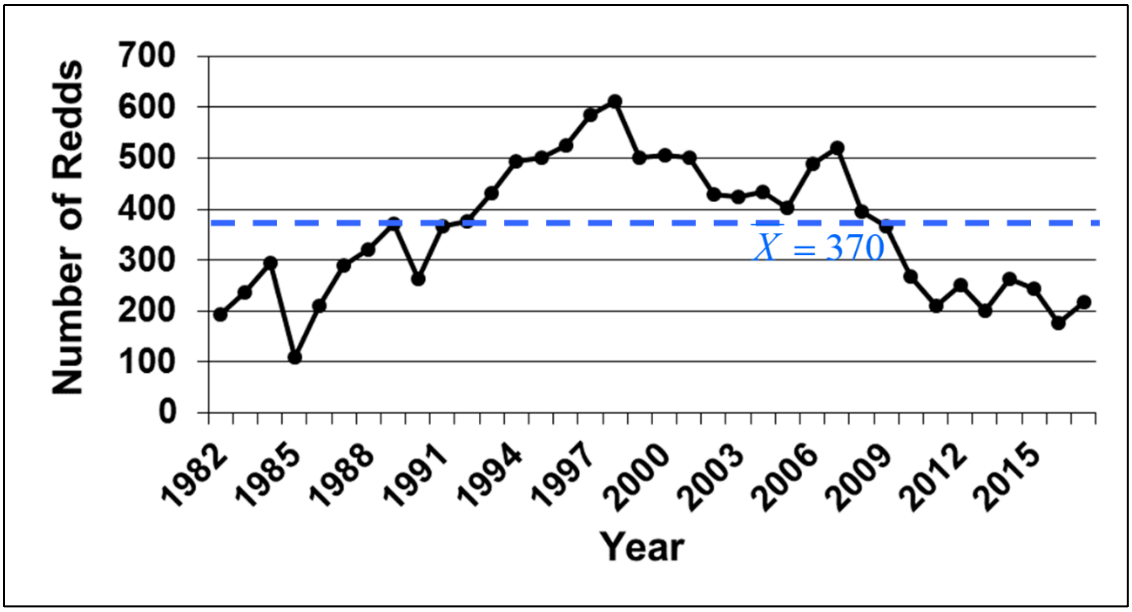

Figure 5. Swan Lake bull trout redd counts in the four index tributaries 1982-2017.

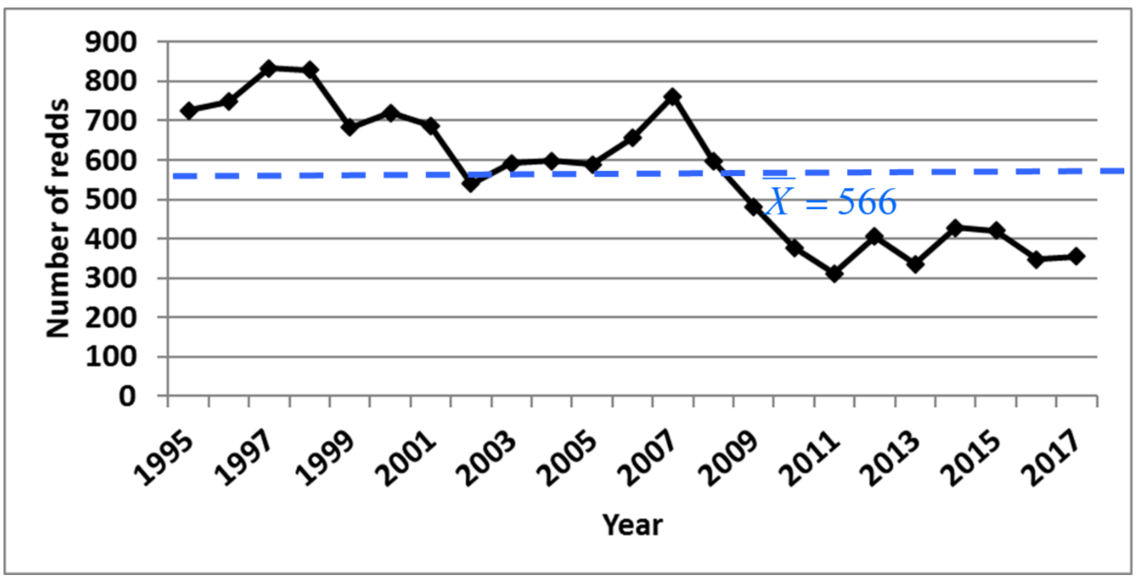

Figure 6. Swan Lake bull trout redds in basinwide counts 1995-2017.

Catch Analysis and Modeling Results from the Suppression Experiment – In-depth analysis of the bull trout bycatch associated with the lake trout suppression action is provided in two of the annual reports (Rosenthal and Fredenberg 2014 and 2017). The report for the 2013 field season (Rosenthal and Fredenberg 2014) contains an Appendix with analysis of the bycatch for the period 2007-2013. In that report, we used a cohort analysis procedure to ascertain the cumulative effects of the annual netting on individual bull trout age cohorts. Because the life cycle of bull trout includes a period of stream residency, they are only vulnerable to gill nets in the lake starting at age 3 or older. They also largely drop out of the spawning population (senescence and cumulative mortality, natural and otherwise) by age 9. Thus, there is an approximate 6-year period of lake residency (age 3-8) where bull trout might be vulnerable to gill net bycatch in the lake. That is further affected by the fact that mature fish (typically ages 5-8) leave the lake for a portion of the year in their migration to spawning tributaries. It is that timing window (approximately late July-early September) that we targeted for juvenile lake trout netting, in part to reduce incidental bycatch of adult bull trout.

Our 2014 analysis, beginning with bull trout that emerged from redds deposited in 1998 and proceeding with bull trout that emerged from redds deposited in 2009, concluded that the bycatch from gillnetting had the potential to reduce the annual redd count by a maximum of 130-150 redds per year (Rosenthal and Fredenberg 2014). That was considered a maximum possible impact, due to a number of the assumptions we made in the calculation. We did not recalculate the projected redd impact for 2014 and beyond, but it's safe to assume that the values did not rise, given that overall bull trout bycatch (and thus its impact) declined steadily in 2014-2016 (Rosenthal and Fredenberg 2017, Table 12 and Figure 7). The impact of bycatch on bull trout redd counts could continue to be felt in future years as well, since the last year of lake trout suppression netting (2016) could have caused mortality of age 3 bull trout that could continue to spawn as late as 2021.

As noted in the 2014 analysis (Rosenthal and Fredenberg 2014), there is not necessarily a direct relationship between redd counts and year class strength. Efforts to correlate the two variables has resulted in only a weak relationship (Rosenthal and Fredenberg 2014; Figure 4). Some years, obviously, are more conducive than others to embryo survival due to variable winter conditions and flow patterns. There is additional variability introduced in the environment for the first couple of years the juveniles spend in the spawning and rearing (SR) stream (e.g., habitat complexity, flow variation, competition and predation). Still more uncertainty is introduced in the process of emigration through the Swan River foraging, migrating and overwintering (FMO) habitat to the lake. We evaluated some of those factors in the 2014 analysis and found that despite a one-third decline in average basinwide bull trout redd counts between two eras (mean = 458 redds in 2001-2007 vs mean = 310 redds in 2008-2011) we could detect only a minor change in average juvenile abundance in four monitoring streams (3.45 juvenile bull trout/100 m^2 vs. 3.34 juvenile bull trout/100 m^2). This suggested that even at reduced redd count levels, there may have been sufficient numbers of spawners to fully seed the available habitat. Additional data on redd counts and juvenile recruitment will continue to be collected annually.

We also noted (Rosenthal and Fredenberg 2014) that legal angler harvest of bull trout from Swan lake was eliminated starting in early 2012. Since gill net bycatch and angler catch essentially have the same population level effect (mortality resulting in reduced population size and lower redd counts) they are interchangeable in terms of their impact on the population. The recent level of angler harvest (estimated at 176 bull trout per year in 2009; FWP 2010, unpublished) was roughly equivalent to calculated bycatch mortality in the gill nets in 2007-2013 (estimated at 127-206 per year; Rosenthal and Fredenberg 2014, Table 4). Thus, in simple terms, angler harvest (which had been viewed as sustainable for over a century) was simply replaced by the gill net harvest (with overlap of both in 2007-2011).

Starting in 2017, for the first time in over a century the Swan Lake bull trout population is essentially subject to near- zero human harvest. With the termination of the lake trout suppression experiment after 2016, the only direct human-caused bull trout mortality remaining in the Swan is due to poaching, incidental hooking mortality, and a minor amount of monitoring netting. For context, it's important to note that as recently as 1983, Leathe and Enk (1985) had estimated bull trout harvest in the Swan at 1,323 fish (partitioned as 738 in the lake and 585 in the river). The majority of these fish would have been adult or near-adult size fish (reported average length of 458 mm (range 298-708 mm). This level of harvest was demonstrably sustainable at that time.

In 2017, we noted that a steep decline in the bull trout gill net bycatch had occurred over the 2014-2016 period (Rosenthal and Fredenberg 2017). Despite adjustments to mesh sizes, net placement, diurnal timing and other factors that were specifically designed to minimize bull trout bycatch, none of that could explain the steep decline in bull trout bycatch observed. Beginning from 2012, when a peak of 437 bull trout were captured in combined spawner and juvenile gill net bycatch, there was a 70% decline to bycatch of only 132 bull trout in 2016. Essentially the same methods, intensity and timing were used. As a result, we further examined the structure of the catch by cohorts (using assigned ages to length groups based on previous age-growth data). This analysis provided some support for the hypothesis that the years with the strongest basinwide redd counts (i.e., 2006-2008, n = 598-762) resulted in significantly higher cohort gill net bycatch than more recent years with lower redd counts (i.e., 2009-2012, n = 297-481).

As indicated previously, we did not detect a similar decline in tributary juvenile abundance, so there appear to either be limitations in our juvenile indices (a possibility that is being examined by FWP) or other factors at play. Of concern is that age-4 bull trout gill net bycatch (which we view as perhaps the most reliable indicator of year-class strength in the lake, as it focuses on subadult sized fish that are fully recruited to our gear) declined nearly 97% from 2012 to 2016.

These findings are partially supported by the information generated from the ongoing PIT-tagging work conducted on captured and released bull trout. As noted in our 2017 report: "At least 26 bull trout of the total 132 captured in 2016 (a minimum of 19.7%) had been previously caught during this project and implanted with PIT Tags" (Rosenthal and Fredenberg 2017). This indicates that we are recycling a significant proportion of the bull trout population, those that survive their initial encounter with the nets. In 2016 we caught the highest proportion of marked fish handled in the bycatch to date, which could also be taken as another possible indicator that the bull trout numbers in the lake have declined. As previously noted (Rosenthal and Fredenberg 2014), the tagged fish recaptured after being at large for a year or more (up to 4 years) have provided corroborating information on growth rate and maturity of bull trout in Swan Lake and support for the premise that our assessments of relative well-being at time of release (assigned on a numerical score from 0 [dead] to 3 [vigorous]) accurately reflect post-netting survival. At least one exceptional bull trout survived gillnetting and release four times over a period of multiple years.

Taken in total, we are concerned that the gill net bycatch trends indicate juvenile and subadult year classes of bull trout in Swan Lake (age-3-4-5) are declining at a rate much steeper than what would be expected by changes in redd counts and juvenile abundance indices in the upstream system. Since the indicators of decline have appeared in the earliest cohorts (age-3 and age-4) they simply cannot be explained by gill net bycatch. These steep declines in subadult indicators cause concern for the future. We were somewhat encouraged that the 2017 basinwide bull trout redd counts were in line with recent years (n = 355 basinwide). However, if recent predation or competition pressure in Swan Lake causes juvenile and subadult survival to decline further, we could witness a decline in bull trout redd counts in the near future.

Other Bycatch Species

Monitoring- Swan Lake contains a diverse fish assemblage comprised of both native and non-native fish species. The spring gillnetting survey, established in 1995, was designed to monitor trends in most of the common fish species in Swan Lake. The survey appears to do an adequate job for most species but does not sample kokanee or lake trout very well. Kokanee are known to be pelagic and are usually suspended in schools in a portion of the water column near the thermocline. Therefore, neither floating nor sinking gill nets sample kokanee adequately. Typically, vertical gill nets that hang like a curtain would be set to capture kokanee. Lake trout are a relatively new species to Swan Lake and they often occupy the deepest portions of the lake. The standardized gill net locations were established long before lake trout were first documented and most are set shallower than the preferred lake trout zone. As a result, the spring gill net survey captures relatively few lake trout. Results from 22 years of this spring gill net survey do not indicate either upward or downward trends for most species, with the exception of rainbow trout, which appear to have increased in recent years (Figure 7).

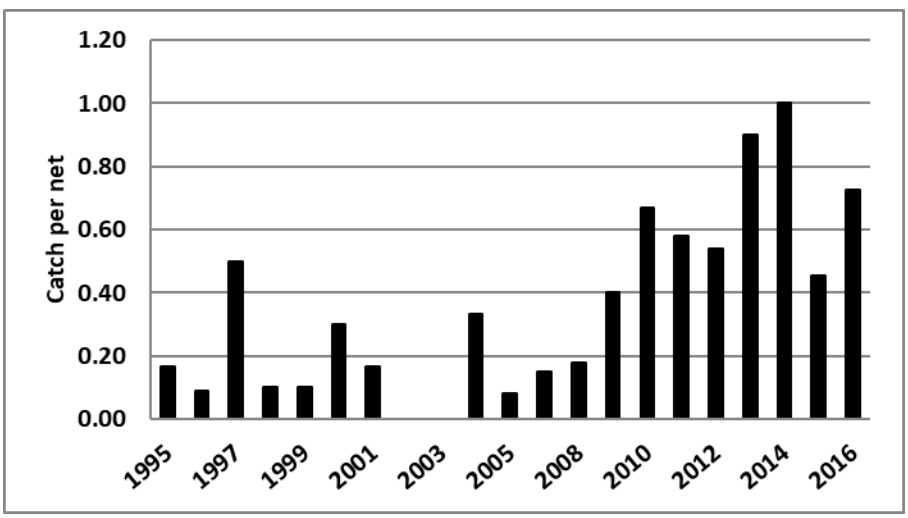

Figure 7. Rainbow trout catch per net data from Swan Lake spring gill net surveys 1995-2016.

Kokanee are a species of particular interest in Swan Lake. These introduced Pacific Salmon represent an important recreational game fish, and also an important food source for both bull trout and lake trout. Adult kokanee numbers are monitored annually by counting redds along an index reach of shoreline in Swan Lake in late November. The redd count trend shows a period of declining abundance, beginning in 2007, and reaching an all-time low in 2011 (Figure 8). Subsequent years showed some increase in abundance but the recent trend appears to have stabilized at a level which is considerably lower than what has historically been observed. Reduced abundance could reflect a new normal due to additional predators in the lake.

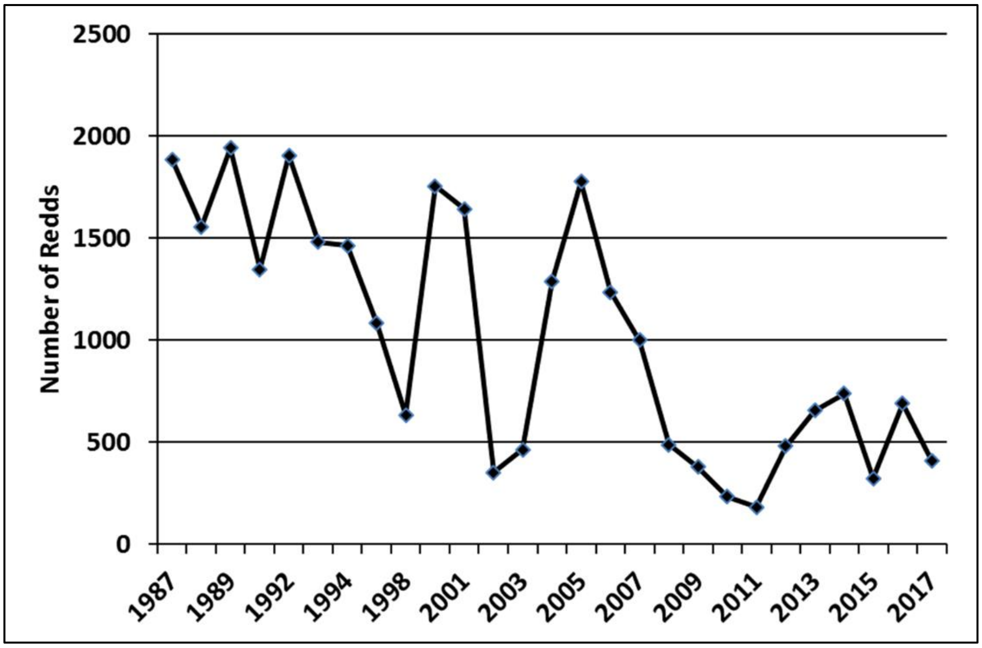

Figure 8. Kokanee redd counts in Swan Lake 1987-2017.

Catch Analysis and Modeling Result From the Suppression Experiment- The 2009-2016 lake trout removal experiment was designed to maximize the catch of lake trout while minimizing the incidental bycatch of all other fish species. Nonetheless, non-target fish species were inevitably caught as part of the project. Table 3 was previously presented in the 2016 annual report and it documents all non-target fish species captured during both netting events (juvenile and spawner netting) throughout the duration of the removal experiment. As mentioned previously in this report, bull trout bycatch has been declining for four straight years (2013-2016) and may translate to lower redd count numbers in the near future. No other obvious trends regarding other fish species in Swan Lake are indicated by the bycatch data. Of some interest is the observation of increased bycatch of both sucker species (longnose and largescale) and northern pikeminnow during the spawner netting portion of the project. This observation, paired with stomach content examinations, documented that these fish species are following lake trout to spawning areas to consume recently expelled eggs. Table 3 further demonstrates how effectively we employed timing, location, and mesh size selection to minimize bycatch and how gillnetting can be a highly selective tool for mechanical removal of unwanted fish species. It is noteworthy, however, that some of the strategic decisions made to avoid bycatch may have impaired the overall effectiveness of the lake trout suppression effort.

Table 3. Bycatch of non-target fish species captured during juvenile and (spawner) netting events 2009-2016. Abbreviations are: BULL (Bull Trout), KOK (Kokanee), MWF (Mountain Whitefish), PWF (Pygmy Whitefish), LNSU (Longnose Sucker), NPM (Northern Pikeminnow), CSU (Largescale Sucker), RBT (Rainbow Trout), PIKE (Northern Pike). Most non-target fish were released alive.

Species	2009	2010	2011	2012	2013	2014	2015	2016
BULL	238 (26)	212 (87)	237 (104)	334 (103)	168 (135)	146 (161)	74 (174)	52(80)
KOK	205 (23)	414 (110)	159 (46)	521 (114)	388 (300)	138 (431)	166 (76)	499 (84)
MWF	107 (0)	28 (5)	31 (2)	67 (0)	104 (2)	93 (4)	15 (1)	70 (1)
PWF	139 (0)	63 (0)	9 (0)	79 (0)	27 (0)	11 (0)	28 (0)	2 (0)
LNSU	86 (50)	49 (306)	65 (145)	17 (207)	7 (157)	31 (213)	3 (234)	16 (118)
NPM	27 (36)	14 (136)	31 (131)	2 (68)	1 (132)	4 (147)	0 (141)	6 (71)
CSU	0 (58)	0 (109)	0 (111)	0 (54)	0 (96)	0 (147)	1 (134)	1 (244)
RBT	6 (3)	5 (10)	7 (11)	0 (11)	1 (11)	6 (16)	4 (19)	10 (30)
PIKE	0 (2)	0 (0)	0 (7)	0 (2)	1 (7)	0 (3)	0 (8)	0 (3)

CONCLUSIONS

1. SVBTWG Accomplishments

The SVBTWG has registered significant accomplishments in the thirteen years of its existence. As the information in the annual technical reports describes, we have succeeded in assembling diverse funding sources from partners with mixed interests, marshaled a wide array of agency and public support and in-kind human resources, adjusted and adapted to changing circumstances, all the while resulting in the removal of nearly 60,000 lake trout from the Swan Lake ecosystem. We have learned that suppression of an invasive species is a long-term proposition and that ultimate success requires sound science, perseverance, adequate tools and funding, and institutional support. Success also depends on an informed and supportive public, including a Swan Lake user group whose resources are ultimately being impacted. To date, we recognize that have not achieved our ultimate management goal: "*To ensure the long-term, self-sustaining persistence of bull trout as the dominant piscivore within this ecosystem"*, but we believe we have made steps in that direction.

As a byproduct of this SVBTWG effort to date, we have provided wide-ranging science-based information on population dynamics, genetics, life history, movement, spatial distribution, food habits, reproduction, and competitive interaction, not only for introduced lake trout, but for Threatened bull trout, kokanee, and other species as well. We have learned some of what works and what doesn't work in terms of sampling and gill net suppression, while greatly refining the science behind selective netting techniques in a mixed-species aggregation and successfully targeting lake trout while minimizing bycatch of nontarget species. And finally, the previous body of work has laid the foundation for prescribing future lake trout management alternatives in Swan Lake.

2. Science of Lake Trout Suppression- Other Systems

The science of lake trout suppression is in its' infancy. For most of the 20th century there have been massive scientific and financial investments in restoring lake trout in their native ecosystems of the Midwest and Canadian Shield. It has only been since the dawning of the 21st century that significant interest and investment has been expended in controlling the unwanted expansion of lake trout into novel ecosystems that the species is well suited to outside their native range, bull trout habitats in particular. The record is also clear, that lake trout are incompatible with the maintenance of historically robust populations of bull trout (Martinez et al. 1999, USFWS 2015b).

The scientific and financial investment in lake trout suppression in Swan Lake (Syslo et al. 2013) is dwarfed to date by similar programs conducted in much larger waters such as Yellowstone Lake (Syslo 2015), Lake Pend Oreille (Hansen et al. 2010, Ryan 2016) and even Flathead Lake (Hansen et al. 2016). The lessons learned and new research findings acquired in those programs, as well as techniques employed in suppression actions in Glacier National Park (Fredenberg 2014), Upper Priest Lake, and Swan Lake are being universally shared and adapted toward the common goal of reducing the impacts of introduced lake trout on native ecosystems. Each of these lakes present unique challenges with their own constraints, be they financial, social, biological, logistic or combinations of these elements. Swan Lake is one data point in that continuum. Swan Lake is a midsized, historically high productivity adfluvial bull trout habitat that is an excellent candidate to be a proving and testing grounds for promising lake trout suppression techniques that emerge. With the foundation that we have established over the past decade of work, many of the important questions that would necessarily be asked to test new techniques can be answered.

In the bigger picture, we feel it is important to provide a greater context for potential future success or failure of any ongoing lake trout suppression effort in Swan Lake (and Holland and Lindbergh upstream). It is clear in this regard that “size matters”, as lake trout suppression programs in Flathead Lake (125,250 acres), Lake Pend Oreille (94,400 acres), and Yellowstone Lake (87,000 acres) are all being implemented along with a proportionally higher level of public visibility and involvement and much higher commitments of dedicated funding (see e.g., Bigelow et al. 2017, CSKT 2014).

To date, the Lake Pend Oreille lake trout suppression action is generally viewed as a success. Wahl et al. (2016) cites lake trout reduction to the lowest standing level in seven years and a rebounding kokanee population in terms of both numbers and biomass (resulting in reopening of a kokanee sport fishery) as the strongest indicators to date. However, lake trout removal is ongoing and will continue for the foreseeable future.

In Yellowstone Lake, Wyoming (where bull trout are not present) models showed the lake trout population continued to expand through at least 2011 (Syslo 2015). Increased netting effort since 2012 began to reduce lake trout numbers and biomass (total weight) in Yellowstone Lake (Bigelow et al. 2017). There are early signs of a partial recovery of Yellowstone cutthroat trout which are exhibiting increased recruitment (Arnold et al. 2017), but the goal of long-term sustainability and ultimate success is still in flux. The Yellowstone program is investing heavily in discovery and implementation of alternatives to gillnetting. USGS investigators are critically assessing the ecological effectiveness, cost effectiveness, and safety of alternative methods to destroy lake trout embryos in natural settings and they are working to develop a practical methodology and associated equipment for field use to accomplish effective lake trout suppression (Doepke et al. 2017).

In Flathead Lake, the chosen approach to lake trout suppression has been gradual, and while exploitation has slowly ramped up (e.g., in 2016 for the first time over 100,000 lake trout were removed; CSKT and Hansen 2017) no change in the overall population has yet been detected. CSKT managers working on Flathead Lake have adopted a much longer-term strategy (decades, not years) to achieve an eventual target of a 75% reduction in age-8 and older lake trout (CSKT 2014). Unlike the other programs, CSKT is striving to reach an ecological balance, rather than sacrificing the lake trout fishery entirely.

In Glacier National Park, Montana, the National Park Service has been conducting lake trout suppression with gill nets on Quartz Lake (869 acres) for a decade and recently on Logging Lake (1,114 acres). The Quartz Lake effort is viewed as at least a partial success from the standpoint that a formerly robust bull trout and westslope cutthroat trout population has been maintained and lake trout catch has declined (Fredenberg 2014). The Quartz Lake project is ongoing and its long-term sustainability will be determined in future years. In the case of Logging Lake, the lake trout expansion has been underway for at least 30 years and a formerly robust bull trout population has been reduced to remnant status

(D'Angelo et al. 2017). In that case, the initial objectives were to implement a rather intensive and rapid reduction in lake trout. That effort is accompanied by supplementation of juvenile bull trout from the nearest neighbor (Quartz Lake) source through a hatchery assist, with the objective of more rapidly restoring bull trout to dominant status. It's too early to assess the ultimate success of the Logging Lake program.

In addition to these projects, gill net suppression of lake trout has been ongoing for two decades in Upper Priest Lake, Idaho (~1,400 acres), and the most recent bull trout trend information (gill net bycatch and redd counts) indicates bull trout numbers are increasing (Ryan 2016). The difficulty in implementing this project has been that an open source of lake trout from downstream Priest Lake (~23,400 acres) can freely migrate upstream into Upper Priest Lake (similar to Holland and Lindbergh lakes in some respects). Deliberations have been underway for several years on whether or not to proceed with a lake trout suppression program in Priest Lake, Idaho (Ng et al. 2016).

3. ESA and Related Threat Management for Swan Lake Bull Trout Recovery

The initial impetus behind lake trout suppression actions in Swan Lake was not simply borne of desire to manage the sport fishery differently. The Threatened listing of bull trout under the Endangered Species Act in 1998 coincided almost precisely with the appearance of lake trout in Swan Lake. Prior to ESA listing, a basinwide threat assessment conducted for the Montana State Bull Trout Management Plan had predicted that: *"The greatest potential threats to this population (Swan Lake) are from illegal introductions and introduced fish species already present. Emphasis must be placed on the threat of illegal introductions, primarily because of the proximity of lake trout in Flathead Lake and the recent history of large numbers of illegal introductions in northwest Montana. Swan Lake supports introduced Mysis shrimp and if lake trout were also introduced, it is likely they would rapidly become the dominant fish species as they have in many other similar habitats (Montana Bull Trout Scientific Group 1996)."*

The Scientific Group report (MBTSG 1996) goes on to state*: "Overall, the Swan Bull Trout population is currently one of the healthiest in the State and is of major importance to the conservation and recovery of the species in Montana."* That remains true today. But, even in the early 1990's, there were numerous examples, including some in the Flathead Basin (e.g., Flathead Lake) where the combination of *Mysis*, kokanee and lake trout had fueled cascading ecosystem changes (Spencer et al. 1991).

The ESA listing of bull trout in 1998 was followed by development of a U.S. Draft Bull Trout Recovery Plan in 2002, and then a heavily revised 2015 Final Recovery Plan (USFWS 2015a) and Implementation Plan (USFWS 2015b). Through that process and associated interest in the species, a lot of scientific deliberation has gone into the invasive species threats and lake trout in particular, in relation to bull trout in the Columbia Headwaters Recovery Unit (western Montana and northern Idaho). In 2016, in response to questions posed by members of the SVBTWG, the USFWS provided a working Draft of Bull Trout Recovery Criteria for the Swan Lake Core Area. That document concluded that even in the existing status (in 2016), demographic status (i.e., abundance and distribution) of bull trout in the

Swan Lake Bull Trout Core Area exceeded the 2002 recovery criteria: *"a recovered Swan Lake core area should support at least 5 local populations with 100 or more adults each (effective population size > 50) and contain 2,500 or more adult bull trout in total (effective populations size > 1,250)."* However, the Final Recovery Plan (USFWS 2015a) changed Recovery Criteria from demographically based to threat-based standards. For the Swan Lake core area, a single primary threat is listed in the RUIP (USFWS 2015b), as follows: "*Nonnative fishes (3.1) - Lake trout represent the single largest primary threat to bull trout, overwhelming the FMO habitat in Swan Lake. Lake trout invasion and expansion in the past 20 years, coupled with a robust Mysis population from a 1970's introduction, has compromised bull trout survival (predation) and introduced competition for a limited prey base (primarily kokanee) available to piscivores."* At this time, in order for the Swan Lake Core Area to meet 2015 recovery standards, the lake trout threat must be successfully addressed.

4. Holland and Lindbergh Lakes

These two bull trout core areas upstream of Swan Lake (i.e., Holland and Lindbergh lakes) remain areas of concern. While data indicate these ecosystems have stand-alone bull trout populations (hence their designation by the USFWS as independently functioning core areas) there is no doubt that those populations are intricately linked to the health and well-being of bull trout in Swan Lake. As so-called "simple" core areas, each with a single spawning and rearing stream, bull trout in Holland and Lindbergh lakes are intrinsically more vulnerable than the more complex and diverse Swan Lake Core Area which has at least ten documented spawning and rearing populations. We witnessed rapid invasion of both Holland (i.e., documented 2012) and Lindbergh (i.e., documented 2009) lakes by lake trout, after the population in Swan Lake expanded. In both cases, the invasion probably occurred less than two decades after lake trout presence was first noted in 1998 in Swan Lake. There is no doubt that Swan Lake is the likely source, as there are no physical barriers in the system and we documented tagged lake trout from Swan Lake dispersing far upstream in the Swan River. To date, we've lacked adequate resources to evaluate those populations. At this time, there is concern that a feedback mechanism may occur whereby lake trout produced in either Holland or Lindbergh lakes could contribute recruitment to Swan Lake, or vice versa. We know from returns of tagged fish that Swan Lake is contributing recruitment to Flathead Lake. Lindbergh Lake is the larger of the two systems (~725 surface acres, or roughly ¼ the size of Swan Lake) and is occupied by kokanee, bull trout, and lake trout. It does not contain *Mysis*, and is therefore not considered to be at the same risk of rapid conversion as Swan Lake. It could be argued that the bull trout population in Holland (~408 surface acres) is at higher near-term risk, as it is a small population with a very restricted amount of spawning and rearing habitat located only in Holland Creek. Holland Lake also contains *Mysis*, so lake trout expansion may be more rapid.

5. Future of Lake Trout Suppression in Swan Lake

The eight-year experimental removal of lake trout in Swan Lake both furthered the science of lake trout suppression and provided necessary baseline information to support future alternatives for lake trout management in Swan Lake. This project has concluded that the amount of gillnetting effort (3 weeks of juvenile netting and 3 weeks of spawner netting) conducted in 2009-2016 was insufficient to cause a decline in lake trout abundance and did not lead to a subsequent increase in bull trout, as evaluation criteria required. Therefore, we conclude that if gillnetting is the sole suppression action, as it has been, the level of lake trout suppression (alternatively measured as mortality or exploitation) expended in 2009-2016 should be viewed as the minimum and a starting point for any future suppression activities.

Any alternative going forward must result in a greater level of lake trout exploitation if it is to be successful. We have also concluded that there is strong evidence that bull trout bycatch is correlated with gillnetting effort and increases in bull trout bycatch may confound any potential benefits of a reduced lake trout population. This risk-benefit relationship must continue to be thoroughly explored prior to implementation of any future gillnetting alternative.

Similar to defining the netting effort, the 2009-2016 suppression experiment provided information on manpower requirements, approximate cost and expenditures, and the challenges of long-term funding. This information is also essential in planning for any future lake trout suppression alternatives, as long-term financial commitment will be critical for success. In the past, projects were spontaneously staffed by availability, added to existing staff workloads, or were contracted out. This model has proven challenging over the years and it is apparent that a successful suppression effort will likely require dedicated personnel committed solely to Swan Lake.

6. Taming the "Wicked Problem" of Lake Trout Expansion in the Swan Ecosystem

In many respects, the Swan Lake scenario has all the hallmarks of what has been described in social science as a "Wicked Problem." Wikipedia provides the following definition:

> *A "**wicked problem**" is a problem that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize. The use of the term "wicked" here has come to denote resistance to resolution, rather than evil. Another definition is "a problem whose social complexity means that it has no determinable stopping point". Moreover, because of complex interdependencies, the effort to solve one aspect of a wicked problem may reveal or create other problems.*

The phrase "wicked problem" was originally used in social planning. Its modern sense was introduced in 1967 by C. West Churchman in a guest editorial he wrote in the journal *Management Science* (Churchman 1967). The term has since been applied to everything from climate change to pandemics. Conklin (2005) has written liberally on the subject and in a 2005 book he generalized the concept of wickedness to areas other than planning and policy.

There are many parallels between the social science paradigms presented by the "wicked problem" and the solutions we seek to lake trout suppression and bull trout recovery. The cover of Conklin's (2005) book highlights the following quote, attributed to Laurence J. Peter:

*"Some problems are so **complex** that you have to be highly intelligent and well informed **just to be undecided** about them."*

Conklin (2005) illuminated some of the parameters of the six defining characteristics of wicked problems, and we found them appropriate to apply to our closing analysis of the lake trout suppression dilemma:

<u>You don't understand the problem until you have developed a solution</u>: *"Every solution that is offered exposes new aspects of the problem. There is no definitive statement of "THE PROBLEM" and furthermore, what the problem is depends on who you ask. Different stakeholders have different views about what the problem is and what constitutes an acceptable solution" (Conklin 2005).*

In the current Swan Lake circumstances, it is evident that the description of THE PROBLEM is largely influenced and varies by the individual mandates of the SVBTWG partners. While all of the partners care about and pledged their support to perpetuate native bull trout in the Swan through a 2005 MOU, the impetus for beginning the project in 2005 was largely driven by the 1998 ESA Threatened listing of bull trout. This date just happened to coincide with the year the first evidence of lake trout was discovered from Swan Lake.

FWS (USFWS 2015b) portrays the recent lake trout expansion as the single largest primary threat to the long-term stability and recovery of bull trout in three important bull trout core areas (Swan, Holland, and Lindbergh lakes). Thus, FWS contends that lake trout suppression is not optional, but a matter of using the best available science in carrying out the mandate of the ESA to recover the species. FWP has an obligation to maintain a balanced sport fishery (native bull trout and cutthroat trout as well as nonnative kokanee, northern pike, yellow perch, and rainbow trout) in order to satisfy the dual agency mission of: "providing recreational fishing opportunity while conserving our valuable native fisheries resources" (FWP 2013). However, FWP has reiterated many times that lake trout are not part of the desired recreational fishery in Swan, Holland and Lindbergh lakes, and efforts to conserve native fish species outweigh the option of managing for a lake trout sport fishery. The management directive in the FWP Statewide Fisheries Management Plan (FWP 2013) is to: "….continue to evaluate tools to effectively reduce numbers (of lake trout) to benefit native fish and recreationally important kokanee."

The Forest Service, like FWS is required by law to be responsive to ESA concerns, but must also manage the Flathead National Forest for multiple use objectives that include timber harvest and recreation. Montana DNRC has similar mandates under State law and in addition is guided by their 2010 Habitat Conservation Plan. However, neither land management agency has a mandate requiring them to manage undesirable fish species.

Trout Unlimited (State and Flathead Valley Chapter) advocates on behalf of native fish but also has a strong interest in recreational angling. Where the two mandates might conflict, as in Swan lake, TU has come down squarely on the side of native bull trout. The same is true for the CSKT, and they have demonstrated this native fish priority in their management approach to Flathead Lake.

Finally, the USGS Cooperative Fisheries Research Unit at Montana State University maintains a scientific interest in the project. While all of the cooperating groups/agencies of the SVBTWG may have different mandates and mission statements, all of these partners share the same obligation to be responsible with fiscal resources. Whether it be sportsman dollars, taxpayer money, or private donations, all parties have been tasked with responsible use of funds and the public trust.

As a partial consequence of the disparate guidance and mandates from the partners in the SVBTWG, the definition of THE PROBLEM itself is elusive and an acceptable solution is still largely undefined. There's a general sense that we'll know it when we see it, but there is also a high likelihood that some SVBTWG members could be satisfied with a wider range of outcomes than others.

<u>Wicked problems have no stopping rule</u>: *"Since there is no definitive "The Problem" there is also no definitive "The Solution." The problem-solving process ends when you run out of resources, such as time, money, or energy, not when some optimal or 'final and correct' solution emerges" (Conklin 2005).*

This is a very apt description of the current stalemate experienced by the SVBTWG, which has ceased applying lake trout suppression methods since 2016 and is currently contemplating what, if any, future actions to initiate. After 8 years of extensive experimental efforts to suppress lake trout, we ran out of time, money and in some cases the energy to continue to adapt and reformulate a strategy to continue. We are relatively certain that the result of the lake trout suppression experiment (2009-2016) was not adequate to cause a long-term decline in the lake trout population. We are far less certain as to whether we were close to that goal and whether we can reformulate and adapt the experimental program to achieve long-term success. Limited funding and resources are currently committed to future efforts.

<u>Solutions to wicked problems are not right or wrong</u>: *"They are simply 'better', 'worse', 'good enough' or 'not good enough'. The determination of solution quality is not objective and cannot be derived from following a formula. Judgments are likely to vary widely and depend on the stakeholders' independent values and goals (Conklin 2005).*

As described above, there is a diversity of opinion amongst SVBTWG members as to what ultimately constitutes a solution. A portion of the working group members believe that were it not for the 8-year experimental lake trout suppression effort, the lake trout population would be far larger than it is and that as a result, bull trout (and kokanee) might be on the brink of collapse. But, we have not achieved consensus on the question of whether the current lake trout status would have been the same had we not removed nearly 60,000 lake trout. Much of that debate centers around the question of whether lake trout have reached carrying capacity in Swan Lake. If they have, then the 8-year netting program may have simply been an example of a fishery approaching maximum sustained yield. Even worse, there is some concern that we have artificially stimulated compensatory growth in the lake trout population. While the SVBTWG members generally agree that the suppression experiment did not achieve the ultimate goal of causing a lake trout decline resulting in a positive bull trout response, neither has the bull trout population collapsed. As described, there is still scientific uncertainty about the solution quality and that leaves room for different interpretations of what is 'better', 'worse', 'good enough' or 'not good enough'.

__Every wicked problem is essentially unique and novel:__ *"No two wicked problems are alike, and the solutions will always be custom designed and fitted. Over time one acquires wisdom and experience about the approach to wicked problems, but one is always a beginner in the specifics of a new wicked problem" (Conklin 2005).*

While the general outline of the problem is the same, wherever lake trout have been introduced as a competitor/predator on top of existing native bull trout, the bathymetry of each lake and its suitability for bull and lake trout (Meeuwig et al. 2008), as well as quantity and quality of available lake trout spawning habitat (Fredenberg 2014), water quality, and angler utilization all influence lake trout population dynamics. Additionally, the species complex and the food web varies from lake to lake (Meeuwig et al. 2011) and the presence of *Mysis* and kokanee are potent drivers of lake trout expansion, such that results are seldom predictable (e.g., Dux et al. 2011, Ferguson et al. 2012, Cox et al. 2013). To add another layer of complexity, each stream/lake ecosystem exhibits different capacity to support bull trout spawning and rearing, and those capabilities are often unrelated to the size and quality of the lake habitat that supports lake trout.

__Every solution to a 'wicked problem' is a one-shot operation:__ *"You can't learn about the problem without trying solutions, but every solution you try is expensive and has lasting unintended consequences which are likely to spawn new wicked problems (Conklin 2005).*

Ultimately, in the case of Swan Lake, we have only tried one solution, which was the 2009-2016 gillnetting experiment that was conducted with a consistent intensity and pattern, based on our collective best judgement and using the resources available to us at the time. We must guard against using the information in this summary report to support broad-based conclusions. It is not accurate to imply that because we did not meet our lake trout suppression goals in an 8-year experiment that: "Suppression doesn't work." Some of the parallel projects we are tracking on other water bodies and under different circumstances (e.g., Lake Pend Oreille; see Hansen et al. 2010, Ryan 2016) indicate greater likelihood of success, using methods similar to our experimental effort.

What we have learned, in part, is that the balance between a level of gillnetting adequate to suppress lake trout without causing an excessive level of bycatch, particularly of desirable nontarget species like bull trout and kokanee, requires a fine-scale approach to implementation. Put another way, the proper application of this tool requires a scalpel employed with precision, not a chainsaw employed with reckless abandon. There are still a considerable number of untested lake trout suppression options.

We are not aware of any irreversible unintended consequences from our past action. However, the documentation of an illegal walleye introduction (Rosenthal et al. 2015) could be one such example. To date, we have found only two individual walleye, both males, and no evidence of a lasting impact (e.g., reproduction). But, if illegal introductions were conducted by anglers who did so out of frustration with our lake trout suppression effort, then that is an example of unintended consequences and a possible indicator that we need to do even more and better outreach as well as potentially increasing enforcement.

Wicked problems have no given alternative solutions: *"There may be no solutions, or there may be a host of potential solutions that are devised, and another host that are never even thought of. Thus, it is a matter of creativity to devise potential solutions, and a matter of judgment to determine which are valid, which should be pursued and implemented" (Conklin 2005).*

Ultimately, this report was intended as a foundation to further the debate about alternative solutions. Such solutions may or may not incorporate a revised element of targeted gillnetting, which can be deployed in an almost endless variety of ways (Syslo et al. 2013). If gillnetting is used, the result does not necessarily need to be more expensive. But, it does need to provide greater efficiency and better outcomes in terms of cost-effectiveness, further reduction in bycatch, and must also contain an element of independent monitoring, such as the SPIN netting. It is highly likely that any program going forward will need to employ a combination of techniques, potentially including methods of suppressing the high reproductive rate of lake trout through some form of egg viability reduction.

It has been said by one of the coauthors (LR) that: "The best thing about the SVBTWG effort to date has been the highly collaborative approach with no one agency in charge. But the worst thing about the effort has also been that nobody's in charge and ultimately accountable."

Conklin (2005) provides some sound advice in recommending that it may be better and perhaps more achievable to try to "Tame a Wicked Problem" by "simplifying it to make it more manageable." In this Swan Lake example, we must continue to employ the latest scientific advancements to lead to solutions that may not yet have been contemplated, but which may ultimately prove to be more cost-effective, publicly acceptable, and biologically meaningful. We believe that the ultimate solution will be a multi-faceted lake trout management and suppression program that is not as one-dimensional as our gillnetting experiment, but rather incorporates several elements, including using some new tools that when deployed collectively will cause lake trout to decline and support bull trout recovery.

REFERENCES CITED

Arnold, J.L., P.D. Doepke, B.D. Ertel and T.M. Koel. 2017. Fish population responses to the suppression of nonnative lake trout. Yellowstone Science 25(1). Yellowstone National Park, Wyoming.

Baxter, C.V., C.A. Frissell, and R. F. Hauer. 1999. Geomorphology, logging roads, and the distribution of bull trout spawning in a forested river basin: implications for management and conservation. Transactions of the American Fisheries Society 128:854-867.

Bigelow, P.E., P.D. Doepke, B.D. Ertel, C.S. Guy, J.M. Syslo, and T.M. Koel. 2017. Suppressing Non-native Lake Trout to Restore Yellowstone Cutthroat Trout in Yellowstone Lake. Yellowstone Science 25(1). Yellowstone National Park, Wyoming.

Brown, P.J. and C.S. Guy. 2013. Use of mobile electrofishing to induce mortality in lake trout embryos: report of activities during the 2012 project year.

Butler, N.M., J.A. Craft, and J.A. Stanford. 1995. A diagnostic study of the nutrient loading at Swan Lake, Montana. Swan Lake clean lakes project, phase one. Flathead Lake Biological Station open file report 139-95. Yellow Bay, Montana.

Churchman,C.W.1967."Wicked Problems". Management Science. 14 (4).

Conklin, J. 2005. "Wicked Problems & Social Complexity. Dialogue Mapping: Building Shared Understanding of Wicked Problems. Wiley.

Cox, B.S. 2010. Assessment of an invasive lake trout population in Swan Lake, Montana. Master's thesis. Montana State University, Bozeman.

Cox, B.S., C.S. Guy, W.A. Fredenberg, and L.R. Rosenthal. 2013. Baseline demographics of a non-native lake trout population and inferences for suppression from sensitivity-elasticity analyses. Fisheries Management and Ecology.

Confederated Salish and Kootenai Tribes (CSKT). 2014. Executive Summary – Final environmental Impact Statement. Proposed strategies to benefit native species by reducing the abundance of lake trout – Flathead Lake, Montana. CSKT Division of Fish, Wildlife, Recreation, and Conservation. Pablo, Montana.

Cox, B.S., C.S. Guy, W.A. Fredenberg, and L.R. Rosenthal. 2013. Baseline demographics of a non-native lake trout population and inferences for suppression from sensitivity-elasticity analyses. Fisheries Management and Ecology.

D'Angelo. V.S., A.S. Lamont and C.C. Muhlfeld. 2017. Lake Trout Suppression and Bull Trout Preservation in the Logging Lake Watershed, Glacier National Park. USGS Northern Rocky Mountain Science Center, West Glacier, Montana.

Doepke, P.D., T.M. Koel, C.S. Guy, A.S. Poole, N.A. Thomas, and A.V. Zale. 2017. Lake Trout Suppression Alternatives to Gillnetting. Yellowstone Science 25(1). Yellowstone National Park, Wyoming.

Downs, C.C., D. Horan, E. Morgan-Harris, and R. Jakubowski. 2006. Spawning demographics and juvenile dispersal of an adfluvial bull trout population in Trestle Creek, Idaho. North American Journal of Fisheries Management 26:190-200.

Dux, A.M., C.S. Guy, and W.A. Fredenberg. 2011. Spatiotemporal distribution and population characteristics of a nonnative lake trout population, with implications for suppression. North American Journal of Fisheries Management 31:187-196.

Ellis, B.K. and 9 others. 2010. Long-term effects of a trophic cascade in a large lake ecosystem. Proceedings of the National Academy of Sciences (PNAS).
Online at: < http://www.pnas.org/content/108/3/1070>.

Ferguson, J.M., M.L. Taper, C.S. Guy, and J.M. Syslo. 2012. Mechanisms of coexistence between native bull trout (*Salvelinus confluentus*) and non-native lake trout (*Salvelinus namaycush*): inferences from pattern-oriented modeling. Canadian Journal of Fisheries and Aquatic Science 69:755-769.

Fredenberg, C.R. 2014. Efficacy of suppressing non-native lake trout in an isolated backcountry lake in Glacier National Park. M.S. Thesis, Montana State University, Bozeman.

Fredenberg, W. and S. Rumsey. 2007. Benefit and risk analysis. 2007 trap net and gill net survey – Swan Lake, Montana. U.S. Fish and Wildlife Service, Kalispell.

Gross, J., R.E. Gresswell and M. Webb. 2011. Destruction of lake trout *Salvelinus namaycush* embryos in natural settings to enhance persistence of native trout. Final Report to: U.S. Fish and Wildlife Service, Denver, Colorado.

Hansen, M.J., B.S. Hansen, and D.A. Beauchamp. 2016. Lake Trout (*Salvelinus namaycush*) suppression for Bull Trout (*Salvelinus confluentus*) recovery in Flathead Lake, Montana, North America. Hydrobiologia online. Springer International Publishing Swizerland.

Hansen, M.J., D. Schill, J. Fredericks, A. Dux. 2010. Salmonid predator-prey dynamics in Lake Pend Oreille, Idaho, USA. Hydrobiologia (2010) 650:85-100.

Kalinowski, S.T. 2008. Invasion of lake trout into Swan Lake, MT: Number of founders and number of current breeding adults. Draft report to: Montana Fish, Wildlife and Parks, Kalispell.

Leathe, S.A. and M.D. Enk. 1985. Cumulative effects of microhydro development on the fisheries of the Swan River drainage, Montana. I. Summary Report. Project 82-19. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana. Prepared for Bonneville Power Administration, Portland, Oregon.

Martinez, P.J., P.E. Bigelow, M.A. Deleray, W.A. Fredenberg, B.S. Hansen, N.J. Horner, S.K. Lehr, R.W. Schneidervin, S.A. Tolentino and A.E. Viola. 2009. Western Lake Trout Woes. Fisheries 34(9), September 2009.

McDermid J. L., B. J. Shuter, and N. P. Lester. 2010. Life history differences parallel environmental differences among North American lake trout (*Salvelinus namaycush*) populations. Canadian Journal of Fisheries and Aquatic Sciences
67:314-325.

Meeuwig, M.H., C.S. Guy, and W.A. Fredenberg. 2008. Influence of landscape characteristics on fish species richness among lakes of Glacier National Park, Montana. Intermountain Journal of Sciences 14(1-3):1-17.

Meeuwig, M., C. Guy, and W. Fredenberg. 2011. Trophic relationships between a native and nonnative predator in a system of natural lakes. Ecology of Freshwater Fish.

Montana Bull Trout Scientific Group. 1996. Swan River drainage bull trout status report (including Swan Lake). Prepared for: The Montana Bull Trout Restoration Team, Montana Fish, Wildlife, and Parks, Helena.

Montana Fish, Wildlife and Parks. 2002. Montana Statewide Angling Pressure. Mail Survey 2001. 4 Volumes. Bozeman, Montana.

Montana Fish, Wildlife and Parks. 2013 (FWP). Statewide Fisheries Management Plan 2013-2018. Montana Fish, Wildlife and Parks, Helena.

Ng, E.L., J.P. Fredericks and M.C. Quist. 2015. Population Dynamics and Evaluation of Alternative Management Strategies for Nonnative Lake Trout in Priest Lake, Idaho. North American Journal of Fisheries Management 36:40–54.

Rosenthal, L., W. Fredenberg, J. Syslo, and C. Guy. 2012. Experimental removal of lake trout in Swan Lake, MT: 3-year summary report. Prepared for Swan Valley Bull Trout Working Group. Montana Fish, Wildlife and Parks, Kalispell.

Rosenthal, L. and W. Fredenberg. 2014. Experimental removal of lake trout in Swan Lake MT: 2013 Annual Report. Prepared for Swan Valley Bull Trout Working Group. Montana Fish, Wildlife and Parks, Kalispell.

Rosenthal, L., W. Fredenberg and A. Steed 2015. Experimental removal of lake trout in Swan Lake MT: 2014 Annual Report. Prepared for Swan Valley Bull Trout Working Group. Montana Fish, Wildlife and Parks, Kalispell.

Rosenthal, L., W. Fredenberg and A. Steed 2016. Experimental removal of lake trout in Swan Lake MT: 2015 Annual Report. Prepared for Swan Valley Bull Trout Working Group. Montana Fish, Wildlife and Parks, Kalispell.

Rosenthal, L. and W. Fredenberg. 2017. Experimental removal of lake trout in Swan Lake MT: 2016 Annual Report. Prepared for Swan Valley Bull Trout Working Group. Montana Fish, Wildlife and Parks, Kalispell.

Ruby, M. and B. Gardner. 2005. Swan Lake Bull Trout Ranger Report. Summer 2005. A report of the Swan Valley Bull Trout Working Group, U.S. Forest Service, Bigfork Montana.

Rumsey, S. 1988. Mysis monitoring in western Montana lakes 1983-1987. Montana Fish, Wildlife and Parks. Kalispell, Montana.

Rumsey, S. and T. Werner. 1997. Swan Lake, Montana angler creel survey - 1995. Montana Fish, Wildlife and Parks. Helena.

Ryan, R. 2016. Panhandle Region 2015 Fishery Management Annual Report. Idaho Fish and Game, Coeur d'Alene.

Sandstrom, S. J. and N. Lester. 2009. Summer Profundal Index Netting Protocol; a Lake Trout Assessment Tool. Version 2009.1. Ontario Ministry of Natural Resources. Peterborough, Ontario.

Shuter, B. J., M. L. Jones, R. M. Korver, and N. P. Lester. 1998. A general, life history based model for regional management of fish stocks: the inland lake trout *Salvelinus namaycush* fisheries of Ontario. Canadian Journal of Fisheries and Aquatic Sciences 55:2161-2177.

Spencer, C., R. McClelland, and J. Stanford. 1991. Shrimp introduction, salmon collapse and bald eagle displacement: cascading interactions in the food web of a large aquatic ecosystem. Bioscience 41:1-14-21.

Swan Valley Bull Trout Working Group. 2007. 2006 progress report.

Syslo, J.M. 2015. Dynamics of Yellowstone cutthroat trout and lake trout in the Yellowstone Lake ecosystem: a case study for the ecology and management of non-native fishes. PhD Dissertation. Montana State University, Bozeman.

Syslo, J.M., C.S. Guy, and B.S. Cox. 2013. Comparison of harvest scenarios for the cost-effective suppression of lake trout in Swan Lake, Montana. North American Journal of Fisheries Management 33:1079-1090.

U.S. Fish and Wildlife Service (USFWS). 2012. Assessment of the feasibility of using spearfishing to suppress invasive lake trout in Montana lakes, 2012-2014. Ecological Services Kalispell Sub Office, Kalispell, Montana.

U.S. Fish and Wildlife Service (USFWS). 2015a. Recovery plan for the coterminous United States population of bull trout (*Salvelinus confluentus*). Portland, Oregon.

U.S. Fish and Wildlife Service (USFWS). 2015b. Columbia Headwaters Bull Trout Recovery Unit Implementation Plan. Portland, Oregon.

Wahl, N. M.P. Corsi, J.R. Buchanan, W.J. Ament, and W.H. Harryman. 2016. Lake Pend Oreille Research 2014, Lake Pend Oreille Fishery Recovery Project – Annual Progress Report 2014. IDFG Report #16-14. Idaho Fish and Game, Coeur d'Alene.

Weaver, T. 1998. Interoffice Memorandum: 1997 bull trout spawning run - Flathead Lake Population; Swan Lake Population; Hungry Horse Reservoir; Disjunct Populations. Montana Fish, Wildlife and Parks, Kalispell.