

Quartz Lake Lake Trout Suppression Project 2016 Progress Report



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Quartz Lake Lake Trout Suppression Project

ABSTRACT

Approximately one-third of the USFWS-designated natural lake core areas supporting threatened bull trout *Salvelinus confluentus* are found in Glacier National Park (GNP). However, bull trout populations on the west side of GNP have declined in recent decades and are at high risk of extirpation in several lakes due to the establishment of invasive lake trout. In 2009, the U.S. Geological Survey and the National Park Service began suppressing lake trout in Quartz Lake (352 ha) to reduce impacts to bull trout and other native fishes. In 2016, we removed 1,338 lake trout, more than double the catch in 2015. A total of 8,604 lake trout have been removed since the project began in 2009. We attribute the increase in catch in 2016 to our ability to set considerably more net in the spring juvenile removal effort using a new custom built commercial style gill net boat and hydraulic net lifter. The boat was air-lifted into the lake in the spring of 2016. When comparing 2015 to 2016, juvenile catch appears to be proportional to the amount of net set. The data indicate an increasing average size of juveniles in the spring catch and an absence of new recruits, evident in the length-frequency data. This could signal the beginning of an impact to juvenile recruitment from the adult removal efforts. However, we set a similar amount of net as in previous years in the fall adult lake trout removal effort but captured twice the number of adults over 2015. We had been enjoying a consistent decline in adult catch since the project began, so the 2016 catch was surprising. The maximum size of adult lake trout has consistently declined, but the median size has held fairly steady and we continue to catch mature lake trout in the fall netting efforts that are large enough to have spawned in previous years. However, it has clearly become more difficult for skilled anglers to catch adult lake trout for sonic-tagging efforts in the spring, suggesting an overall decline in mature fish. We were unable to catch any of sufficient size to tag in 2016. We will increase our sonic-tagging efforts in 2017 to determine if new spawning areas have developed and estimate our exploitation of adult lake trout. We were unable to conduct bull trout redd counts in 2016 due to high water, but recent counts and angler catch rates suggest a stable bull trout population. Likewise, angler catch rates of westslope cutthroat trout remain robust (1.2 fish/hr in 2016). Overall, it appears as though we are successfully meeting our objective of maintaining stable native fish populations through removal of lake trout and most metrics indicate we are reducing both juvenile and adult lake trout abundance in Quartz Lake. Additional years of netting will be required to better clarify trends in the lake trout population as well as the overall effectiveness of our strategy of removing both adult and juvenile lake trout annually using targeted gill netting to collapse the population.

INTRODUCTION

Aquatic invasive species threaten the biodiversity of native aquatic ecosystems worldwide, and are considered the one of greatest threats to native biodiversity in North America (Vitousek et al. 1997). Invasions of introduced taxa often disrupt the structure and function of ecosystems, reduce biological diversity among native species, and impose huge economic costs. Therefore, understanding how to reduce or eliminate invasive species in native ecosystems is critical for conserving native aquatic species and ecosystems.

Lake trout are large, long-lived, top-level predators native to deep, cold, oligotrophic lakes of Canada and northern parts of the United States, including the Great Lakes (Behnke 2002). During the late 19th and early 20th century, lake trout were widely introduced into lakes and reservoirs outside their native range (Crossman 1995). More recently, the species has expanded its range in the western United States through dispersal and unauthorized translocations (Behnke 2002). Bull trout and lake trout have similar morphologies, diets, and growth rates, and occupy similar trophic positions as top-level predators, resulting in strong potential for competitive or predatory interactions. In the Pacific Northwest, native bull trout populations have generally declined in systems where lake trout have been introduced (Donald and Alger 1993; Fredenberg 2002; Martinez et al. 2009).

Introduced to Flathead Lake in 1905, non-native lake trout have dispersed to many additional lakes in the wider Flathead watershed, including nine lakes west of the Continental Divide in GNP that historically supported bull trout (Fredenberg 2002; Downs et al. 2011). Fredenberg (2002) reported a broad bull trout decline and a corresponding increase in non-native lake trout from 1969 to 2000 in four lakes (Logging, Bowman, Harrison, Kintla) in GNP. In the same study, bull trout catch data in Quartz Lake remained constant because it was the only lake where lake trout were absent (Fredenberg 2002). Similarly, recent bull trout redd surveys (2003-2010) show continued decline in adult abundance in many GNP waters, with some counts representing less than 10 reproducing individuals (Downs et al. 2011). Combined, these data show that several native bull trout populations have drastically declined in western GNP with several adfluvial populations at imminent risk of extirpation due to adverse interactions with invasive lake trout.

STUDY AREA

Quartz Lake is a glacially formed lake located in the headwaters of the Columbia River Basin, Montana. Quartz Lake is the fifth largest lake west of the Continental Divide in GNP (Fredenberg et al. 2007), with a surface area of 352 ha and a maximum depth of 83m (Figure 1). The lake is at an elevation of 1,346 m and is positioned in a narrow glaciated valley that is supplied by perennial flow from snow and glacial runoff from the Lewis Range. The limnetic zone substrate is dominated by a mixture of cobble and boulder. Quartz is an oligotrophic, dimictic lake with stratification occurring in late June and destratification in early October. Three avalanche chutes along the northern shore line have deposited large rock substrates during the spring and winter months suitable for lake trout spawning.

The native fish assemblage in the Quartz drainage consists of bull trout, westslope cutthroat trout *Oncorhynchus clarkii lewisi*, mountain whitefish *Prosopium williamsoni*, longnose sucker *Catostomus catostomus*, largescale sucker *Catostomus macrocheilus*, slimy sculpin *Cottus cognatus*, and reidside shiner *Richardsonius balteatus*. Lake trout is the only non-native fish species in the drainage and was first detected in Lower Quartz Lake in 2003 and in Quartz Lake in 2005 (Fredenberg et al. 2007).

There are no putative natural fish barriers in the Quartz drainage, although several high gradient cascades serve as potential intermittent barriers between Lower Quartz and Middle Quartz lakes. The

discovery of lake trout in Lower Quartz Lake prompted construction of an artificial gabion barrier approximately 100 m downstream of Middle Quartz Lake in 2004 to conserve the upstream native fish assemblages in Middle Quartz, Quartz, and Cerulean lakes. Unfortunately, lake trout were detected in Quartz Lake in 2005 before the barrier was completed. The long term functionality of a barrier remained important to the success of lake trout suppression in Quartz Lake and consequently the NPS removed the existing structure which had fallen into disrepair and constructed a new barrier structure in 2012 to deter further invasions.



Figure 1. Location of Quartz Lake in the North Fork of the Flathead River Drainage, Glacier National Park.

METHODS

Gillnetting

All lake trout captured during 2016 were measured for total length (TL, mm). We recorded weight (g) from all mature lake trout and collected genetic samples from a sub-sample of juveniles for future analysis, with the intent of estimating the number of breeders in the existing lake trout population. Additionally, otoliths, genetic samples, and weights were taken from all bull trout and westslope cutthroat trout bycatch mortalities. All lake trout were killed and their air bladders were punctured before they were returned to the lake as biomass.

Spring

The 2016 lake trout suppression program followed the same general schedule utilized in previous years. Gillnetting was comprised of two annual netting periods; spring (25 May-29 June) and fall (11 October-31 October). During spring gillnetting, crews netted from Monday-Friday for a five week period. Juvenile and subadult lake trout were captured using small mesh (19 mm, 26 mm, and 32 mm bar measure) 91 m-long sinking monofilament gill-nets targeting. Nets were set at all hours of the day and were generally deployed for 4-6 hours in depths greater than 40m. The short deployment interval and deeper net sets were purposefully used to reduce incidental bycatch mortality of bull trout and westslope cutthroat trout. In previous years 28 mm bar mesh nets were used, however, selectivity analysis in 2013 revealed the peak length selected by the mesh sizes used overlapped with the other mesh sizes being used, therefore the use of 28 mm bar measure mesh was dropped beginning in 2014. In 2013, catch rates of short (33 m) experimental 19 mm bar measure gill-nets with the standard twine diameter of 0.20 mm were compared to catch rates of 19 mm bar measure gill-nets containing finer 0.10 mm twine diameter (Fredenberg 2014). It was determined the finer 0.10 mm twine diameter had a significantly higher catch per unit effort than the 0.20 mm twine diameter (Fredenberg 2014) and finer mesh nets were used exclusively starting in 2014. However, the durability of the 0.10 mm nets was problematic and the cost of replacing nets would be unreasonable, therefore, beginning in 2015, full length (91 m) nets of 19 mm, 26 mm and 32 mm bar measure mesh and 0.15 mm twine diameters were used in the spring. The spring objective is to maximize removal of juvenile lake trout as young as possible in order to reduce recruitment to the adult population.

Fall

The second netting event (fall netting) targeted mature adult lake trout, primarily on the two known spawning areas as determined by prior telemetry efforts (2009-2014). The fall netting objective is to remove as many adults as possible in order to reduce the number of juveniles produced in subsequent years. Fall netting in 2016 occurred from 11 October-31 October and was nearly continuous. Adult lake trout were captured with large mesh (57 mm, 64 mm, and 70 mm bar measure), 91 m-long sinking monofilament gill-nets set in relatively shallow (<10m) areas of known spawning sites. Once completely set, these nets were allowed to fish for approximately one hour before we started to pick up the end of the net that was set first. This provided for a 1.5-2 hour soak time for all portions of the net. Short set times were used to minimize bycatch mortality of native fish, primarily westslope cutthroat trout and bull trout. We generally made a total of 4-6 sets/night.

RESULTS AND DISCUSSION

Telemetry

We were unable to catch any lake trout of sufficient size (presumed to be mature; >550mm) for sonic tagging in 2016. The single adult lake trout tagged in 2015 was recaptured and killed during fall gill

netting in 2016. As the suppression years have progressed from 2010-2016, anglers have found it increasingly difficult to capture mature size lake trout for sonic tagging. While lake trout catch per angling hour declined substantially between 2010 and 2015, the relationship increased in 2016 (Figure 2). We are unsure why this occurred, but it is consistent with our increased catch in the fall gill nets. It could be the result of a number of factors including but not limited to: 1) increased knowledge by the crew in how to effectively target lake trout in Quartz Lake with angling gear and/or 2) a strong year-class of newly-recruited adults working their way through the system. Additional netting and angling data is needed to determine if this is a single-year anomaly or represents an emerging trend. The bull trout catch per angler hour has generally remained stable, with the exception of a dip in the relationship in 2015 (Figure 2). Also notable is that both species seem to track together in terms of their relative catchability by anglers over time.

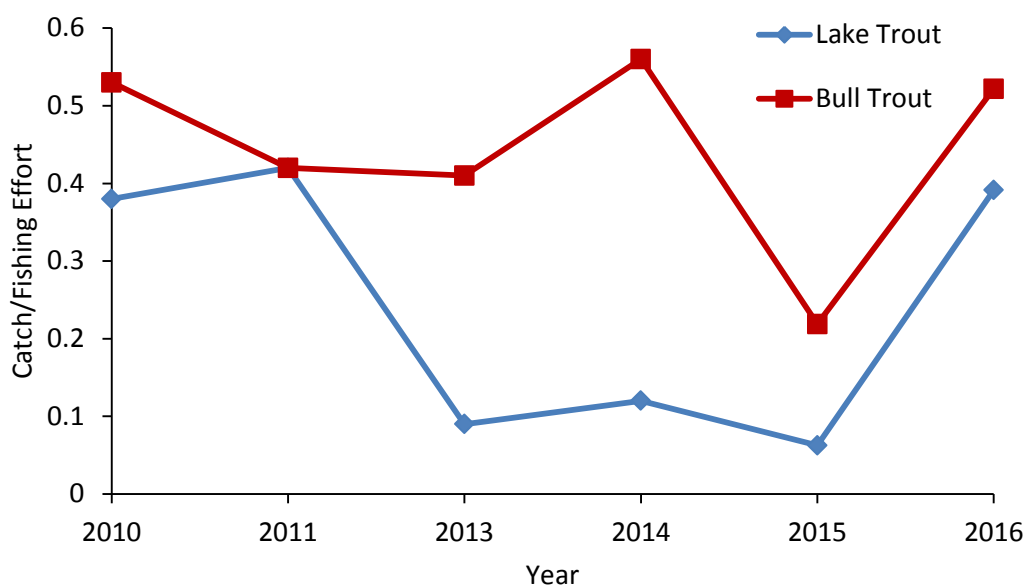


Figure 2. Catch per angler hour for lake trout and bull trout in Quartz Lake, Montana 2010-2016.

Gillnetting

Approximately 49.2 km of net was deployed in 2016, including 35.4 km during the spring and 13.4 km during the fall, resulting in a total of 1,338 lake trout being removed (1,297 juveniles and subadults, 41 adults). This brings the total number of lake trout removed from the system to 8,604. Although the number of days fished has remained similar, the kilometers of net deployed has varied from year to year. The program used information gained in earlier years of the program in an adaptive fashion to more efficiently remove juveniles during spring netting over time. From 2012 through 2015 the program set a relatively consistent amount of net that capitalized on knowledge of the most effective habitats to capture juvenile lake trout while minimizing catch of bull and cutthroat trout. In general, we are most effective at achieving these objectives in the wider southwest basin of the lake, in waters in excess of 40m deep. The physical nature of setting and pulling these deep nets by hand was also a limitation on our ability to increase our efficiency in removing lake trout. The purchase of a new custom fabricated 21' commercial-type gill netting boat with a generator-powered Crossley net lifter allowed us to deploy over twice the amount of net in the spring of 2016 in a similar number of days as previous years (Table 1). The new boat allowed for the connecting of multiple gangs of nets together to

(generally 3 nets/gang X three to seven gangs at a time) which increased the total amount of net that could be fished each day. More net could be fished due to the dramatic reduction in time and manpower required to set and retrieve the nets. The increased amount of net fished led a similarly proportional increase in the number of juvenile lake trout removed in 2016.

The new boat also improved the safety and moral of the crew, particularly during the colder, nighttime adult removal efforts in the fall. Because the spawning sites are concentrated to two or three areas of the lake, each of which is less than 2.25 ha in area, they can be most efficiently fished with a finite amount of gill net (Table 1). We have found that in general catch declines with each successive night of netting a particular spawning area and catch rebounds again if we “rest” the spawning area for a night or two. Because we are targeting fairly shallow areas of the lake (3-10m deep) in these efforts, it is likely the spawning lake trout we don’t capture on a given night display some avoidance behavior for a limited time after the boat and nets have been on the spawning area.

Table 1. Annual kilometers of net set during spring and fall gillnetting from 2009-2016 in Quartz Lake, Montana.

Year	Spring	Fall	Total
2009	--	38	38
2010	23.3	27.3	50.6
2011	28.1	12.8	40.9
2012	18.7	10.2	28.9
2013	17.6	14.0	31.6
2014	17.8	17.3	35.1
2015	16.9	11.9	28.8
2016	36.2	13.0	49.2

Spring

Spring netting in 2016 removed a total of 1,296 juvenile lake trout, a dramatic increase in the number of juveniles removed from 2015 when only 554 juveniles were captured and removed. The increase in juvenile catch is most likely attributable to the increased amount of net that could be fished each day and evaluation of standardized catch rates between 2015 and 2016 support this conclusion. An overall declining trend in catch rate of juvenile lake trout from 2013 to present is apparent (Figure 3). Juvenile length at capture has steadily increased since 2014, when we began using a standardized net mesh distribution (19, 26, and 32 mm bar measure) in a light-green tint with fine twine diameter (0.15”) (Table 2; Figure 4). Previously, the smallest mesh (19mm) captured the majority of the juveniles removed each year, but in 2016 the 26mm mesh captured the majority. This suggests we are having an impact on juvenile recruitment because fewer younger fish are recruiting to our gear as a proportion of our total juvenile catch (Figure 4). Despite this size shift, the 19mm mesh (smallest) remains an effective size while the largest mesh (32mm) is only marginally effective at this point. Statistical analysis failed to detect a significant trend in declining juvenile catch rate over time (Kendall’s tau = -0.67; $p > 0.05$), but our sample size of valid years is small (2013-2016) (Figure 3). Based on the length-frequency analysis and the age and growth analysis of Fredenberg (2014), it appears as though a strong year class of what are likely now 4-5 year old lake trout are moving through the system (Figure 4). Due to our selective use of gill net mesh sizes to minimize bycatch of native fish, this age group will likely not be vulnerable to gill net removal again until they reach maturity and are vulnerable to our adult removal nets. This will take several years.

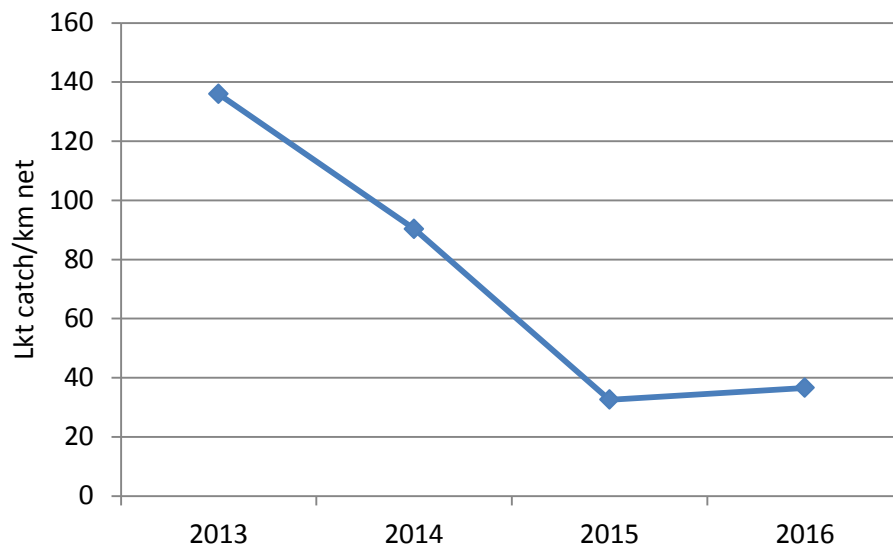


Figure 3. Catch-per-unit-effort (lake trout captured per km of net set) during spring juvenile lake trout removal efforts in Quartz Lake.

Table 2. Mean length over time of juvenile lake trout removed in spring suppression efforts from Quartz Lake.

	2013	2014	2015	2016
Low 95%	228.6	221.3783	241.1529	270.6988
Mean	229.8	222.7632	243.3372	272.0564
Up 95%	231.1	224.1481	245.5215	273.4139

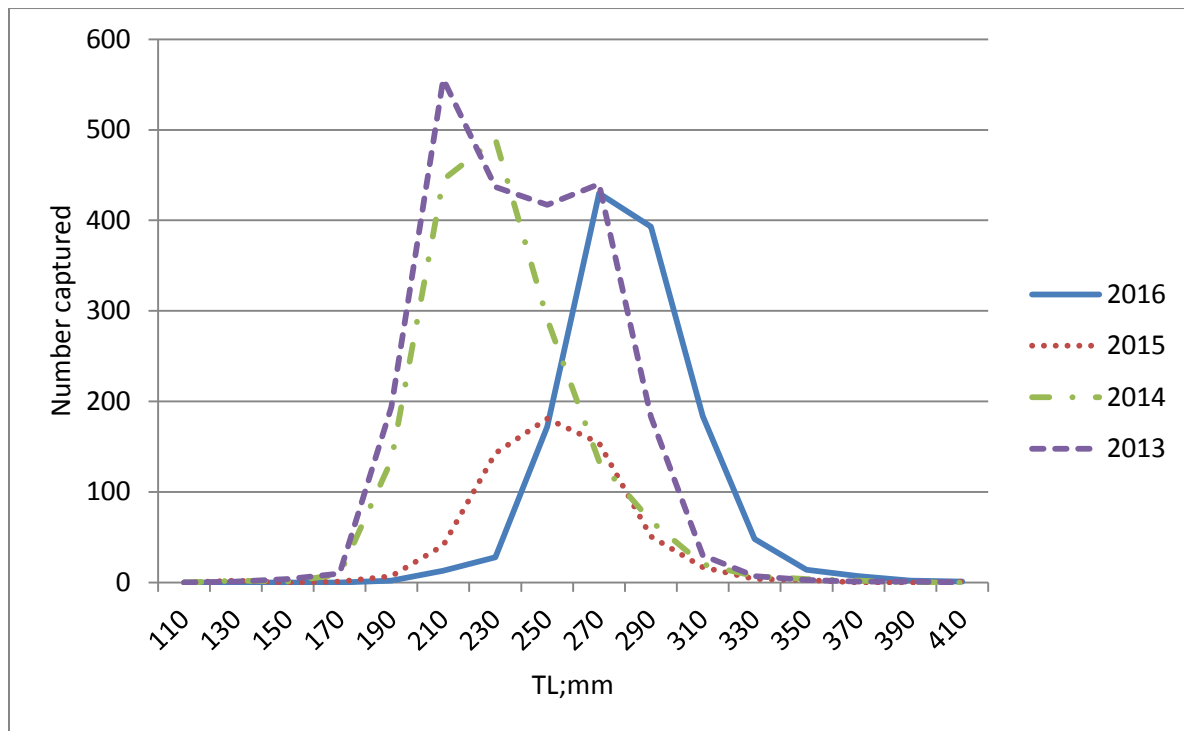


Figure 4. Length frequency histogram of juvenile lake trout captured in standardized gill nets over time (19mm, 26mm, 32mm bar measure mesh and 0.15" twine diameter) during spring in Quartz Lake, Montana. The only difference in net mesh size was the use of 28mm mesh in addition to the other three mesh sizes in 2013. The 28mm mesh was dropped beginning in 2014.

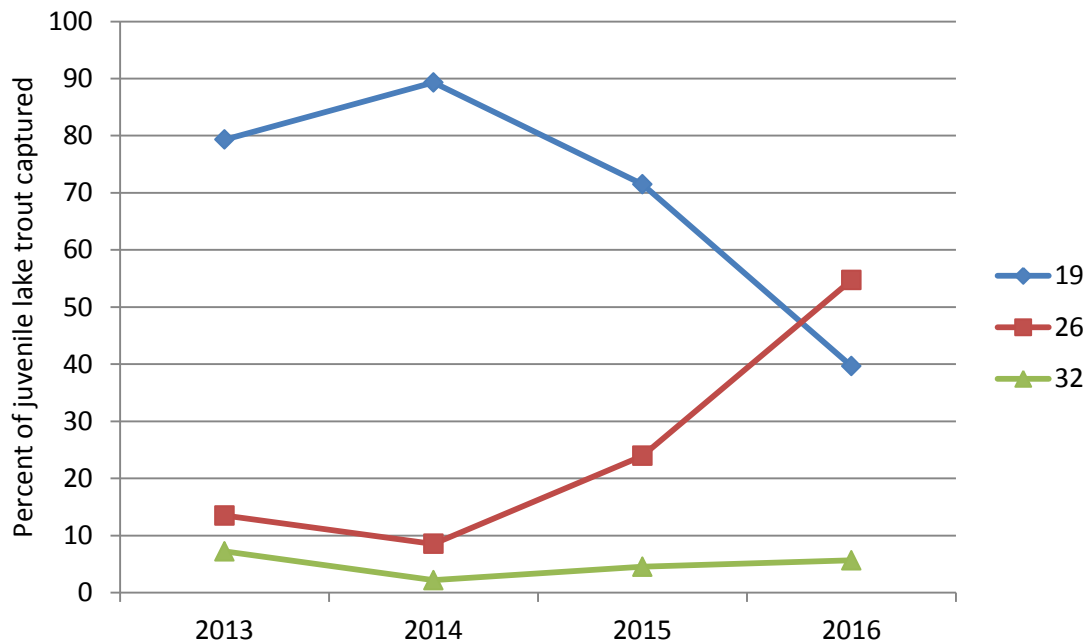


Figure 5. Percent of total juvenile lake trout catch in the spring attributable to each net mesh size in Quartz Lake. The only difference in net mesh size was the use of 28mm mesh in 2013 in addition to the other three mesh sizes. 28mm mesh was dropped beginning in 2014.

Fall

Fall netting removed a total of 41 lake trout of which 37 were mature (Figure 6). We also captured a total of 11 bull trout during the fall removal efforts. Both of these numbers are increases over the 2015 catch but still support an overall declining trend in total catch. Statistical analysis demonstrated a significant decline in the total catch of mature lake trout in the fall since the program began in 2008 (Kendall's tau = -0.64; $p < 0.05$). When compared in a standardized format (catch/km net) a similar trend is apparent (Figure 7). It is worth noting that the catch and catch rate of lake and bull trout follow similar patterns over time.

There has been little change in the mean and median size of adult lake trout over time, although it is apparent that we have consistently reduced the maximum size of the lake trout captured each year during the spawner netting effort (Figure 8). The median length of adult lake trout has remained between 600-650mm over the course of the project. It would be expected that the average size of spawners should decline in response to heavy, size selective harvest on the adults (Coleman et al. 2000). Indeed, Fredenberg (2014) demonstrated such a decline in earlier years of the project using a cumulative length-frequency analysis. However, more recent data show a slight rebound in median length at capture (Figure 8), eliminating any indication of a trend in declining length at capture in the fall net sets. Increasing the effectiveness of the fall adult removal effort will be a project goal in 2017. Evaluation of adult sex-ratio over time reveals little about the progress of the program (Figure 9). Male lake trout were more abundant in the catch in most years with the exception of 2014 and 2015 when we captured and removed more females. Based on the work of Fredenberg (2014), male lake trout don't begin to mature until age-7, which correlates with the last un-persecuted spawning class of lake trout (2008) in Quartz Lake. It would not be unexpected to see a pulse of adult lake trout over the next several years as this year class reaches maturity. Based on the maturity schedule and the year we began removing adults (2009), we would anticipate seeing a decline in adult recruitment beginning sometime from 2017-2020.

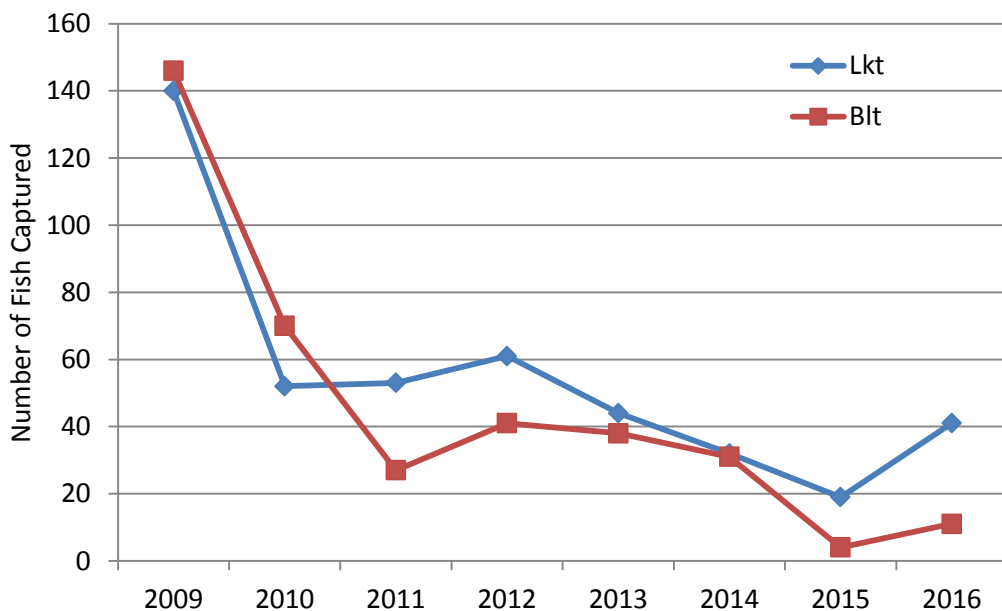


Figure 6. Total number (all adult size mature, immature, and unknown status) of lake and bull trout caught during fall adult removal gillnetting (2009-2016) in Quartz Lake, Montana.

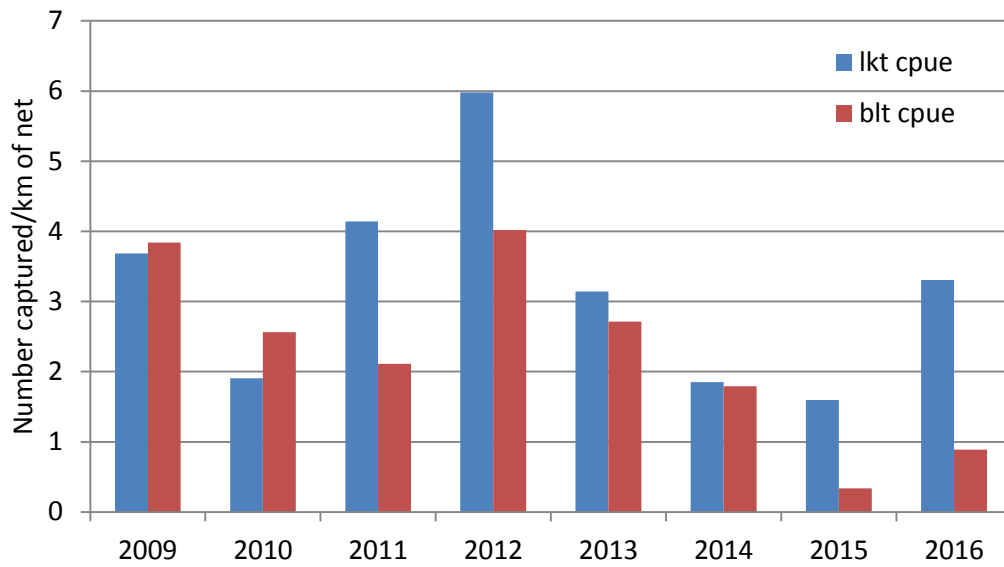


Figure 7. Catch-per-unit-effort for lake and bull trout captured during fall removal efforts in Quartz Lake, Montana.

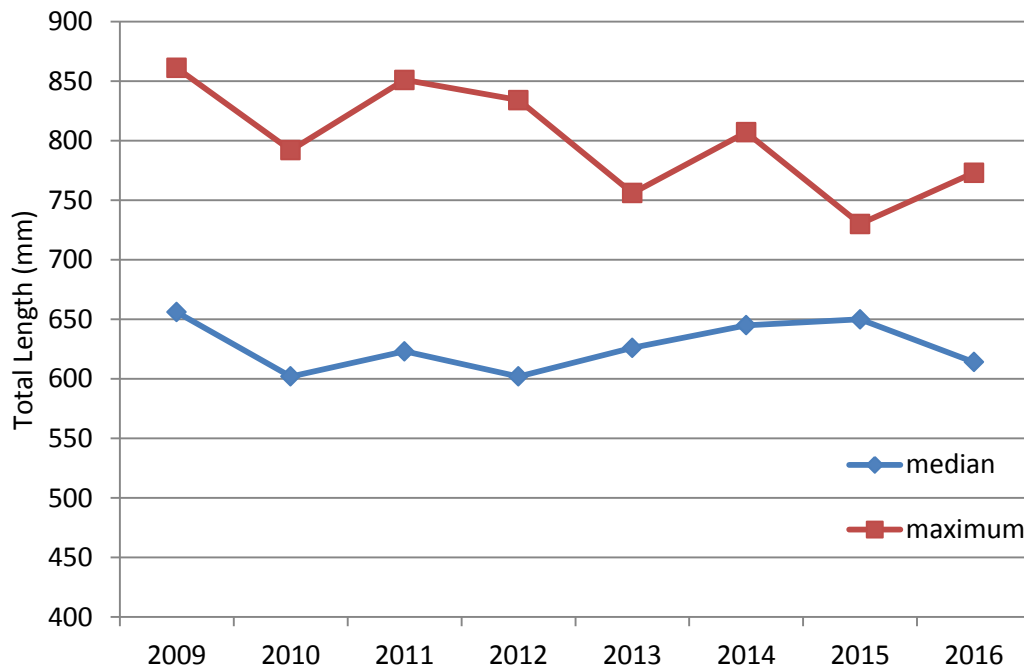


Figure 8. Maximum and median lengths of adult lake trout captured during fall removal efforts over time in Quartz Lake, Montana.

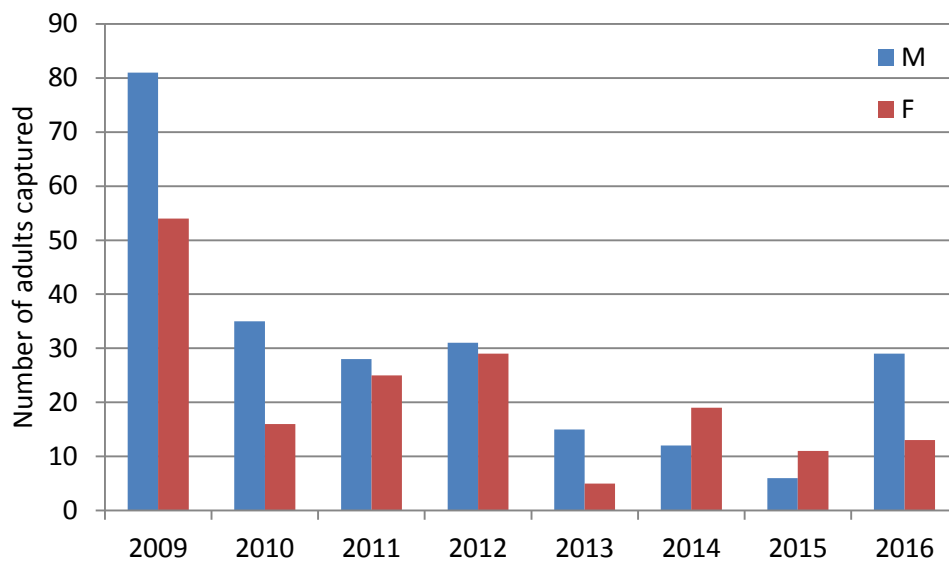


Figure 9. Sex ratio of adult lake trout captured in spawning areas over time in Quartz Lake, Montana

Bycatch

Bycatch of non-target native species remains a concern for the project and is closely monitored. Bull trout redd counts have continued on an annual basis to monitor for any negative project impacts to the bull trout population. However, we were unable to conduct a redd count in 2016 due to high water. Correlation analysis of redd count data on count year from 2003-2015 failed to show a significant trend (Kendall's tau=0.11; $p>0.05$), suggesting the bull trout population in Quartz Lake remains stable. Additionally, the redd count from 2014 was a historic high ($N = 66$) and in 2015 the count was above the ten year average of 30 redds (39 redds in 2015), further supporting the conclusion that our netting efforts have not adversely impacting bull trout to date (Figure 10). We presume that the declining catch and catch rate of bull trout (Figures 5 and 6) are a reflection of our ability to avoid capture of adult bull trout in our removal efforts rather than an actual reduction in abundance.

An adaptive management approach has been used to decrease the number of bull trout and other species incidentally caught and to decrease overall by-catch mortality. To minimize bull trout bycatch mortality, soak times for spring and fall netting have been kept relatively short to give inadvertently captured fish the best chances of survival. Although gill-net mesh sizes and efforts have generally been standardized to allow year to year comparisons, we have made slight modifications over the years to try to reduce bull trout bycatch. An example of this includes the removal of the 45 mm and 51 mm bar measure gill-nets in 2011. Analysis from 2009 and 2010 revealed that these mesh sizes accounted for the greatest number of adult bull trout mortalities, while 57 mm, 64 mm, and 70 mm bar mesh gill-nets accounted for the vast majority of the adult lake trout catch.

In 2014 all of our juvenile gill-net meshes were changed from the standard 0.20 to 0.15 twine diameter. The intent was to increase the catch rate of juvenile lake trout. However, this finer mesh has also increased the catch rate of juvenile mountain whitefish. Juvenile nets are fished in the deeper waters of Quartz Lake (>40m) to avoid most native species, but large schools of juvenile whitefish are still encountered at these depths and mortality is high (90+%) when this occurs.

A total of 38 bull trout were captured via gillnetting in 2016, 27 (71%) of which were captured during spring and 11 (29%) during fall. These proportions are similar to those observed in 2015. Of the 38 bull trout captured, 20 (53%) were classified as adults ($\geq 400\text{mm}$) and 18 (47%) were juveniles or subadults. These proportions are similar to those observed in 2015. Additionally 20 adult sized bull trout were captured during spring angling. A total of nine bull trout were incidentally killed in gillnetting efforts in 2016 (24% of total bull trout captured), including 4 adults and 5 juveniles. Although the bull trout mortality rate observed in the spring netting was lower (22%) than that observed in the fall netting (27%) (despite considerably longer net soak times and deeper set depths in the spring), the difference can be explained by a single fall adult bull trout mortality that was already in poor condition when he entered the net. This individual was a recaptured male that we had already captured and spawned twice during our egg take efforts in Quartz Creek a couple of weeks earlier. He was in poor shape after his release from the spawn take. We will continue to look for ways to reduce bull trout bycatch and mortality in 2017.

Bycatch of non-target species was similar to the previous five years with the exception of the increased catch of both mountain whitefish and longnose suckers (Table 3). Bycatch mortality varied by species and season of capture. We captured 99% of the total mountain whitefish catch in our spring nets. Due to the longer set times, the pressure differential encountered while being pulled up from deep waters ($>40\text{m}$), and the difficulty in removing the small and fragile young mountain whitefish from the nets, their mortality is near 100%. Adjusting the mesh size to avoid the whitefish is not possible because although the 1.5" mesh captured 78% of these fish, it also accounted for 40% of the juvenile lake trout catch. Similarly, juvenile mountain whitefish were caught in some of the deeper sets ($>50\text{m}$) we made in 2016, making it highly unlikely we can target deeper water to avoid them. Although bycatch of mountain whitefish in spring nets was high in 2016 (Table 3), it should be noted that we fished more than twice the amount of net as we have in most previous years. Both sucker species were also captured but appeared to tolerate the netting fairly well as we observed relatively few direct mortalities in the spring nets. Westslope cutthroat trout did not fare well when captured in the spring nets and experienced a minimum of 50% mortality in the spring nets. Most of the fish that were released alive were released in poor condition.

Table 2. Annual bycatch and bycatch mortality for juvenile (mature) bull trout in Quartz Lake, Montana for years 2009-2016.

Year	Bycatch	Mortality
2009	38(108)	14(13)
2010	28(95)	13(30)
2011	10(46)	3(8)
2012	20(45)	3(9)
2013	50(38)	22(7)
2014	24(34)	6(5)
2015	9(11)	1(1)
2016	18(20)	5(4)

Table 3. Annual bycatch of bull trout (BLT), westslope cutthroat trout (WCT), mountain whitefish (MWF), largescale sucker (LSS), and longnose sucker (LNS) during spring (fall) netting events from 2009-2016 in Quartz Lake, Montana.

Year	BLT	WCT	MWF	LSS	LNS
2009	--(146)	--(28)	--(498)	--(2)	--(351)
2010	53(70)	11(33)	185(55)	24(52)	216(249)
2011	29(27)	0(7)	100(17)	26(24)	285(27)
2012	24(41)	0(35)	124(51)	18(30)	143(74)
2013	52(38)	8(29)	229(25)	88(48)	237(18)
2014	27(31)	3(37)	1,237(21)	112(40)	135(41)
2015	16(4)	4(22)	690(1)	49(4)	153(5)
2016	27(11)	14(38)	1,208(11)	68(10)	563(21)

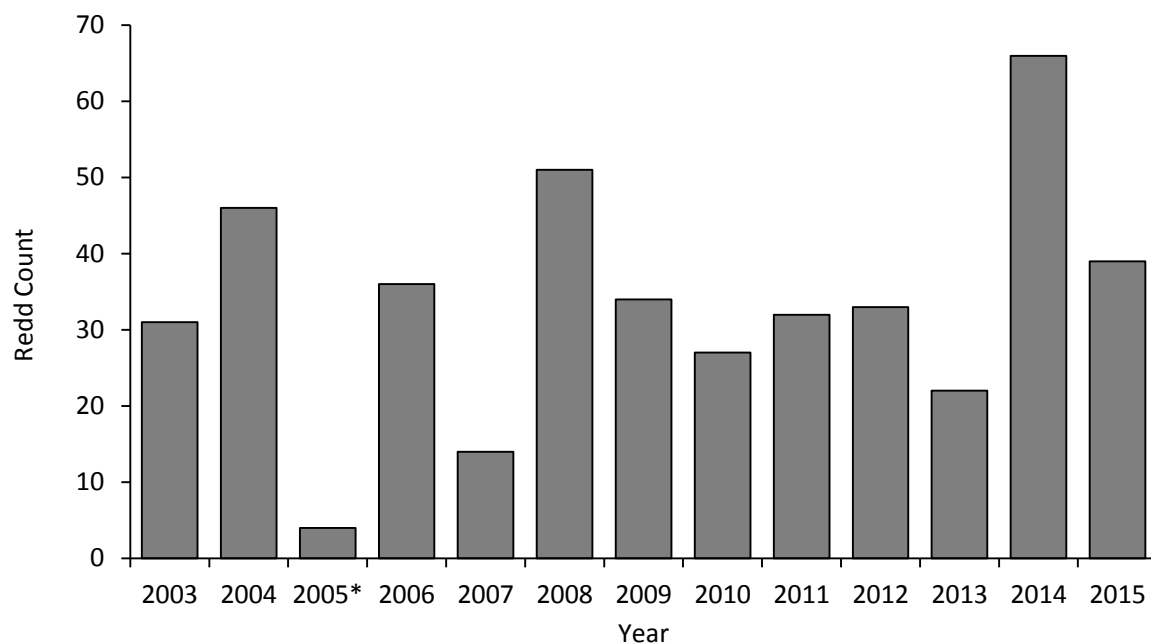


Figure 10. Bull trout redd counts from 2003 through 2015 in Quartz Creek upstream of Quartz Lake, Glacier National Park, Montana. *Redds were obscured by high flows in 2005 (Meeuwig and Guy 2007) and a count was not possible due to high water in 2016.

Conclusion

There are some encouraging signs in the data collected to date which suggest our netting efforts are negatively impacting adult lake trout abundance and juvenile recruitment. Mature lake trout abundance has declined since the project began as evidenced by a declining trend in our annual fall gill net catch. We have not been able to reliably catch lake trout of sufficient size to radio tag for the past several years whereas it was fairly easy when the project began in 2009. There has also been a consistent reduction in the maximum size of lake trout captured each year. In addition, Fredenberg et al. (2017) documented changes in population growth rate indicative of a population in long-term decline. All of these are positive indicators that we are negatively impacting the adult population.

Further, estimates of the number of breeding adults in the population (N_b), based on genetic material collected from juveniles removed in the program, is consistent with our observed numbers of

spawners removed each year. That is, genetic data suggest an estimated Nb of <60 breeding adults for the years 2007-2010 (G. Luikart, University of Montana, personal communication) with a declining trend in Nb over time.

Of concern however is our continued ability to capture some large lake trout during the fall spawner netting effort, many of whom based on their size have likely spawned previously and avoided our nets. In addition, we saw an increase in the catch of mature lake trout on the spawning areas in 2016. We need to make a greater effort in the spring of 2017 to capture and radio tag adult lake trout in Quartz Lake to track during fall spawning movements. It is possible spawning is occurring in new locations that we are not aware of.

Similarly, catch per unit effort for juvenile lake trout targeted in spring removal efforts has continued to decline since the project switched to a consistent size range (1.5", 2.0", and 2.5" stretch mesh), green tinted, fine diameter twine (0.15") nets. Based on the positive shift in the average size of juvenile lake trout captured in our nets over this timeframe along with a similarly shifting length frequency histogram, we speculate that we may be observing the beginning of an impact to recruitment of younger individuals into the lake trout population. The length frequency histogram does not show recruitment of "new" smaller juveniles behind the current crop of older juveniles we are currently capturing. Netting in 2018 should help better inform this possibility.

Fredenberg (2014) concluded the project needed to increase exploitation rates to achieve further reduction in lake trout abundance, which prompted the NPS to purchase and fly in a new boat in 2017 specifically designed for gill netting lake trout. This has clearly improved our ability to remove juvenile lake trout in the spring by setting much more net, but does not make a meaningful difference in how much net we can effectively fish in the fall effort. It is clear that despite having a new boat with a much larger netting capacity, we are limited in our fall netting efforts by the size of the spawning areas, number of known spawning areas, and bycatch potential of bull and westslope cutthroat trout. In addition, lake trout catch rates decline over time during fall efforts when we net the same areas night after night to the point where we have to take a couple of nights off to rest the spawning areas so the lake trout will return and be vulnerable to our netting once again.

Westslope cutthroat trout angler catch rates remain high (1.2 fish/hr in 2016) with fish generally in excellent condition. Adult bull trout abundance, based on redd count data, appears to be stable and strong. Bull trout angler catch rates remain similar to when the project started (0.53 fish/hr in 2010 and 0.52 fish/hr in 2016). In contrast with these data, the fall bull trout netting CPUE has mirrored the decline in lake trout CPUE on the spawning grounds. One possible explanation is that over time we have impacted fish habitat use patterns across species during our fall netting efforts.

Overall, it appears as though we are successfully meeting our objective of maintaining a stable bull trout population through removal of lake trout. Additional years of netting will be required to better elucidate any suspected decline in juvenile lake trout recruitment and the overall effectiveness of our strategy of removing both adult and juvenile lake trout each year as a means to collapse this population.

ACKNOWLEDGEMENTS

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LITERATURE CITED

- Behnke, R. J. 2002. Trout and salmon of North America. The Free Press, New York.
- Coleman, F. C., C. C. Koenig, G. R. Huntsman, J. A. Musick, A. M. Eklund, J. C. McGovern, R. W. Chapman, G. R. Sedberry, and C. B. Grimes. 2000. Long-lived reef fishes: the grouper-snapper complex. *Fisheries* 25: 14-21.
- Crossman, E. 1995. Introduction of the lake trout in areas outside its native distribution: a review. *Journal of Great Lakes Research* 21(Supplement 1):17-29.
- Donald, D.B. and D.J. Alger. 1993. Geographic distribution, species displacement, and niche overlap for lake trout and bull trout in mountain lakes. *Canadian Journal of Zoology* 71:238-247.
- Downs, C.C., C. Stafford, H. Langner, and C.C. Muhlfeld. 2011. Glacier National Park fisheries inventory and monitoring bi-annual report, 2009-2010. National Park Service, Glacier National Park, West Glacier, Montana.
- Fredenberg, C.R., C.C. Muhlfeld, C.S. Guy, V.S. D'Angelo, C.C. Downs, and J.M. Syslo. 2017. Suppression of Invasive Lake Trout in an Isolated Backcountry Lake in Glacier National Park. *Fisheries Management and Ecology* 24: 33-48.
- Fredenberg, C. R. 2014. Efficacy of suppressing non-native lake trout in an isolated backcountry lake in Glacier National Park. Master's Thesis. Montana State University, Bozeman.
- Fredenberg, W. A. 2002. Further evidence that lake trout displace bull trout in mountain lakes. *Intermountain Journal of Sciences* 8:1-11.
- Fredenberg, W., M. H. Meeuwig, and C. S. Guy. 2007. Action plan to conserve bull trout in Glacier National Park. Final Action Plan Report. U.S. Fish and Wildlife Service, Creston, Montana and the U.S. Geological Survey, Montana Cooperative Fishery Research Unit, Montana State University, Bozeman.
- 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* 34:424-442.
- Meeuwig, M. H., C. S. Guy. 2007. Evaluation and action plan for protection of 15 threatened adfluvial populations of bull trout in Glacier National Park, Montana. Final scientific report to US Fish and Wildlife Service, Kalispell, Montana.
- Stafford, C. P., J. A. Stanford, F. R. Hauer, and E. B. Brothers. 2002. Changes in lake trout growth associated with *Mysis relicta* establishment: a retrospective analysis using otoliths. *Transactions of the American Fisheries Society* 131: 994-1003.
- Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. *Science* 277:494-499.

