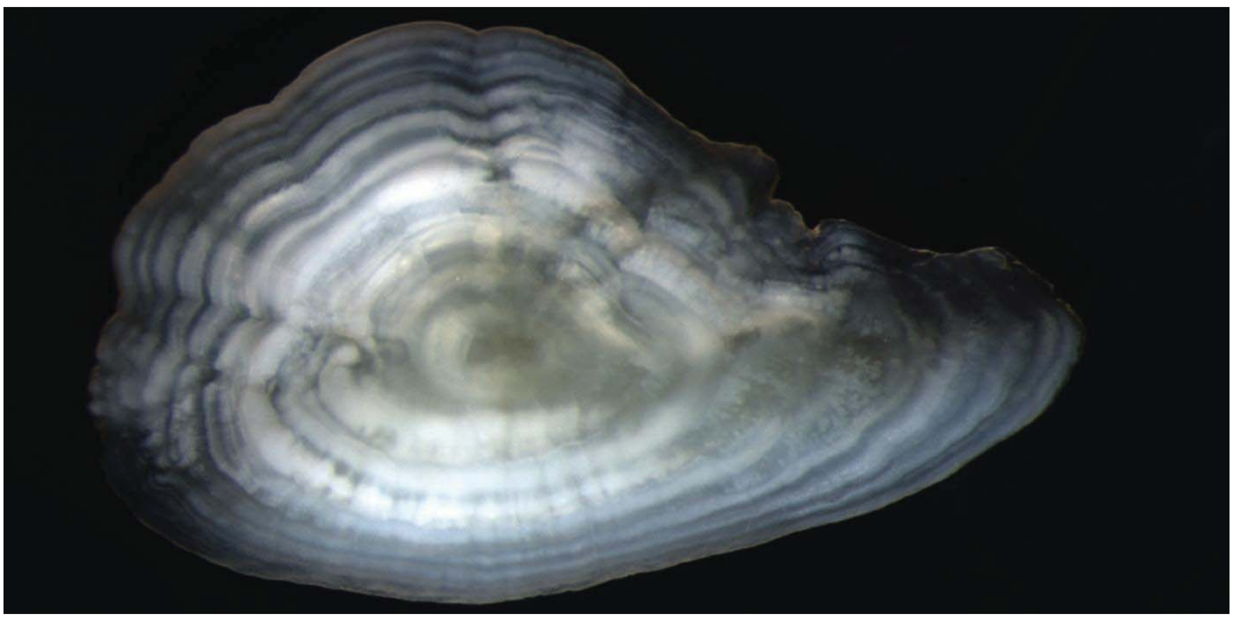
Fish Ages and Ecology from Lakes in Glacier National Park



Final Report to Glacier National Park

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Executive Summary

Four fish populations from Glacier National Park were aged to support ongoing research and monitoring. These populations were: Cosley Lake lake trout, Hidden Lake Yellowstone cutthroat trout, Logging Lake westslope cutthroat trout, and Sherburne Reservoir northern pike. These populations previously were sampled as part of a survey of mercury contamination in park waters, making fish ages useful to help assess the causes of any future changes in fish mercury levels. Further, all four populations are utilized by anglers and have additional aspects which make them of conservation interest. The project was focused on lake trout from Cosley Lake where additional investigations were made. The life history and morphology results from these fish show that two varieties were present: regular lake trout (leans) and a dwarf variety resembling humpers. Gill net and $\delta^{13}C$ data show that the dwarf lake trout occurred mostly in deeper waters while the leans ranged widely in depth but generally occurred in shallower waters than the dwarfs. $\delta^{15}N$ values are consistent with invertebrate and fish diets in the dwarfs and leans, respectively. The presence of dwarf lake trout in park waters is of considerable scientific and conservation interest as humpers are rare and have never been observed in such a small lake. The presence of two varieties in Cosley Lake also may have relevance in terms of their differing vulnerabilities to angler harvest. Other findings include that northern pike from Sherburne Reservoir may have irregular recruitment, and that the Hidden Lake cutthroat trout grew more slowly and matured at a later age than those from Logging Lake.

Introduction

The indeterminate growth of fishes makes age data critical for monitoring, management, and research. Glacier National Park (GNP) contains an abundance of fish bearing waters, yet relatively few determinations of fish age have been made. The current project was initiated to help provide needed information on fish age and growth to facilitate ongoing research, monitoring, and management.

In recent years GNP has conducted gill net surveys of several lakes to determine population trends and baselines, and in association with some of these surveys fish tissue was collected for mercury analysis in 2008 and 2010. Because biomagnified contaminants like methyl mercury are diluted (and thus are lower) in fast growing fish (Stafford and Haines 2001), age determination is an important aspect for evaluating long term trends in this contaminant. In particular, future mercury assessments will benefit from being able to discern if any changes in fish mercury levels are related to changes in fish growth through time. Age data are also useful for assessing changes in fish growth related to varied factors such as introduced species, climate change, and angler harvest. Age together with maturity data provide information on the sensitivity of a population to changes in mortality. Other uses of age data include detecting variable recruitment as well as discerning life history diversity within a population.

Four populations were aged: Cosley Lake lake trout, Sherburne Reservoir northern pike, Logging Lake westslope cutthroat trout, Hidden Lake Yellowstone cutthroat trout. In addition, a pilot study was conducted on two burbot from Saint Mary Lake collected in 2008. These are believed to be native populations with the exception of the Yellowstone cutthroat trout from Hidden Lake. These five populations were surveyed for mercury contamination in 2010 (Saint Mary Lake was sampled for mercury in 2008 as well) and are utilized by anglers, making them of particular interest from a recreational and contaminant perspective. These populations also have other aspects which warrant age data.

Cosley Lake contains what is believed to be a native population of lake trout. Besides the genetic work of Wilson and Hebert (1998), which shows they are derived from the Waterton Lake glacial refuge, little is known about these fish. The lake trout of Cosley Lake could have particular conservation interest as these fish are believed to represent a rare example of native lake trout in the contiguous western United States. Further, surveys in 2010 (to assess mercury levels) and a larger survey in 2012 (to assess abundance, size structure, and species composition) revealed a curious abundance of smaller yet slightly deep bodied lake trout within samples that exhibited a large range of sizes. These smaller lake trout may be similar to the humper (a dwarf) morphotype which is known from only a few lakes in the native range of lake trout (Eshenroder 2008). The possible presence of a dwarf variety in Cosley Lake is most easily evaluated using age data. If confirmed, the presence of a humper analogs in Cosley Lake would increase the conservation and scientific value of these fish as humpers are rare and have never been observed in such a small (~ 1 km), modestly deep lake. Further, the potential presence of two lake trout varieties in Cosley Lake may warrant management consideration in terms of the fishing regulations.

Besides the mercury research project and angler harvest, varied aspects created interest in aging the other three primary populations. Sherburne northern pike inhabit the only reservoir in the park and are a rare example of native northern pike in the contiguous western U.S. The introduced cutthroat trout of Hidden Lake are of possible concern due to their potential to interbreed with native westslope cutthroat trout. Cutthroat trout from Logging Lake are of interest because this lake, along with many other low lying lakes on the west side of the park, has been invaded by introduced lake trout which may be impacting the cutthroat trout and other fishes. Given the proposed suppression of lake trout in Logging Lake, establishing the pre-treatment growth patterns in the cutthroat trout provides information to help judge the results of any management actions. Additionally, two burbot from Saint Mary Lake were aged as pilot to determine the feasibility of aging this species for future investigations using whole otoliths cleared in clove oil.

Methods

The four primary populations were sampled in 2010 except for the lake trout from Cosley Lake which was sampled in both 2010 and 2012. The Saint Mary Lake burbot for the pilot study were collected in 2008. The lake trout from Cosley Lake were captured on August 10, 2010 and July 31, 2012. Cutthroat trout were captured in Logging Lake on August 25 and September 25, 2010 and from Hidden Lake on August 3, 2010. Northern pike from Sherburne Reservoir were captured September 28, 2010 and burbot from Saint Mary Lake on September 4, 2008.

The fish used in this study generally were captured using gill nets with the exceptions of all cutthroat trout from Logging Lake and one lake trout from Cosley Lake in 2010, all of which were captured by angling. The primary net design was 38.1 X 1.8 m experimental multifilament nylon with five 7.6 m panels consisting of bar measured mesh 19 mm (#104 twine), 25 mm (#139 twine), 32 mm (#104 twine), 38 mm (#104 twine), and 51 mm (#139 twine) deployed on the bottom. In Cosley Lake in 2010 a sinking monofilament gill net was used with similar dimensions to the multi-filament nets, but with panels of 13 mm, 19 mm, 25 mm, 38 mm, and 64 mm mesh. Additionally, one of the two sets in Hidden Lake was made with a floating gill net. Nets were deployed with the small mesh towards shore.

In the field various measures were made on the fish and their otoliths were collected. Total length (TL), mass, gender, and maturity were determined. Otoliths were stored dry in scale envelopes. Otoliths were not collected from five of the 16 lake trout captured in Cosley Lake during the 2010 survey.

Additional information was collected from the lake trout of Cosley Lake. Morphometric measures were made in 2012 including the length of the pectoral fin and a measure of body depth (distance between the insertions of the dorsal and pelvic fins). In 2010 pectoral fins were measured on four fish. Dorsal muscle tissue was collected and analyzed for stable isotopes of carbon (as $\delta^{13}C$), stable isotopes of nitrogen (as $\delta^{15}N$), total carbon (C), and total nitrogen (N) from 16 fish collected in 2010 using the approach and facilities described in Stafford et al. (2014). The C/N ratio was used to estimate lipid content using the formula from Post et al. (2007). $\delta^{13}C$ values were lipid corrected using the procedure in Stafford et al. (2014) to address changes associated with lipid synthesis. $\delta^{13}C$ then served as a measure of feeding depth as 1) $\delta^{13}C$ in lakes decreases with depth amongst invertebrate taxa, within benthic invertebrate populations, amongst fishes, and sometimes within fish populations (Vander Zanden and Rasmussen 1999; Stafford 2002; Stafford et al. 2014), and 2) $\delta^{13}C$ changes little if at all between trophic levels (see references in Vander Zanden and Rasmussen 1999). In the aforementioned taxa $\delta^{15}N$ also varies with depth but increases, and also elevates ~3.2 units per trophic level (Vander Zanden and Rasmussen 1999; Stafford et al. 2014). Accordingly, raw $\delta^{15}N$ provides an integrated measure of depth and trophic position. To isolate the trophic position component, lake trout $\delta^{15}N$ was adjusted to the lipid corrected $\delta^{13}C$ mean value using the $\delta^{15}N$ versus $\delta^{13}C$ relationship in primary consumers from Vander Zanden and Rasmussen (1999).

All fish were aged using otoliths. Lake trout and northern pike otoliths were cast in epoxy, thin sectioned, and polished. Cutthroat trout and burbot otoliths were clarified whole in clove oil. Otoliths were viewed with reflected light against a black background in isopropyl alcohol using a dissecting scope, except the burbot otoliths were viewed with transmitted light in a clear container containing isopropyl alcohol. Each otolith was photographed at least once using a digital camera attached to the dissecting scope. Increments were enumerated regardless of whether plus growth was evident or not, and as such these increment counts are equivalent to age. No back calculations were performed, thus reported lengths are at capture.

Result and Discussion

Aging Uncertainty

All of the fish in this study were possible to age, but considerable variation existed in the readability of otoliths within and among populations. The lake trout and cutthroat trout often contained difficult to read (opaque) inner rings, while inner rings from northern pike generally were more visible but their otoliths exhibited irregular growth patterns which created some uncertainties. Check marks were present in all of the four major collections which were generally discernable from annuli but undoubtedly caused some aging errors. Plus growth generally was evident except in the Hidden Lake cutthroat trout (see otolith picture on title page). These high elevation, summer spawning fish appear to initiate growth very late in the season as their otoliths generally had no or little plus growth evident as of August 3rd.

The extent of actual aging error is unknown. Subjectively, it was felt that most fish were aged within a year of their actual age per decade. Accordingly, most fish age 0-9 would be plus or minus 1 year of their actual age while most fish age 20-29 would be plus or minus 3 years etc.

Cosley Lake Lake Trout

The age and maturity data from Cosley Lake revealed the presence of two life history types: dwarfs and regular lake trout. The largest dwarf fish was 419 mm TL while the leans were capable of reaching lengths greater than twice as long. The dwarfs began to slow down substantially their growth beginning around age 10 while the leans began to slow appreciably in growth around age 15 (Figure 1). Further, the dwarfs had a much smaller size at maturity than the leans. Leans matured in the ~500-600 mm TL range while dwarfs mostly matured somewhere between 232 and 326 mm TL (assuming some of the immature fish in the 205 to 231 mm TL range were dwarfs), but the lack of fish in the 232 to 326 mm TL range precludes further interpretation (Figure 2).

Unquantified morphometric features seem to distinguish the dwarfs from the leans. Photos show that the leans had a relatively straight head profiles while in the dwarfs the profiles tended to bend downward from the front of the eye towards the snout giving them a blunt nosed appearance (see dwarf picture on title page). Further, the dwarfs seem to have smaller distances from the top of the eye to the head margin than the leans. Both the head profile and eye position differences observed in the Cosley Lake fish have been used to distinguish leans and humpers in other lakes (Eshenroder 2008). Photographs from 2012 could be used to quantify these morphometric differences if they are of further interest.

Morphometric measurements may also help identify the varieties in Cosley Lake, but in the sample the apparent lack of leans within the size range of the dwarfs creates uncertainties. To address this issue morphometric measures were used from lake trout captured in Flathead Lake (Confederated Salish and Kootenai Tribes Natural Resources Department, unpublished data). The introduced lake trout of Flathead Lake exhibit dwarf and lean life histories, and existing genetic data suggests this is a plastic response rather than a result of genetic segregation (Stafford et al. 2014). In Flathead Lake, the dwarfs had deeper bodies (Stafford et al. 2014) and slightly longer pectoral fins than the leans (Confederated Salish and Kootenai Tribes Natural Resources Department, unpublished data). These two morphometric features scale similarly between the leans from Flathead Lake and Cosley Lake, suggesting that smaller Flathead Lake leans can be used as a reasonable surrogate for the Cosley Lake leans < 518 mm TL (which were absent from the morphometric data). The Cosley Lake dwarfs had longer pectoral fins and, to a lesser extent, deeper bodies at a given TL than the leans from Flathead Lake (Figures 3 and 4). Assuming the leans from Cosley Lake < 518 mm TL show similar allometric relations to the leans from Flathead Lake, it appears that in Cosley Lake the dwarfs have longer pectoral fins and slightly deeper bodies than the sympatric leans. These differences correspond to differences between leans and humpers observed elsewhere (Eshenroder 2008). When Cosley Lake is surveyed in the future, it is recommended that additional morphmetric measures be made (especially from smaller lake trout) to further evaluate the differences between the life history types. Additionally, it should be noted that the morphological differences between the Cosley Lake varieties are probably more pronounced than those from Flathead Lake, and further the Flathead Lake dwarfs do not show the pronounced downward bending head profile of the Cosley Lake dwarfs (personal observation).

Maturity, growth, capture depth, and morphological information were used to evaluate the possibility that some of the younger lake trout within the dwarf portion of the growth curve were actually leans. Maturity was determined for 54 of the 57 Cosley Lake lake trout (which does not include three fish 550, 610, and 670 mm TL which were measured and released). In the 327-419 TL mm range all fish were mature except cos12-37 (396 mm TL) and cos12-41 (358 mm TL), suggesting these could be smaller leans (Figure 2). The growth data show that cos12-41 at age 8 was a bit of a fast grower within the dwarfs and could fall within the lean growth curve, and was also in the youngest age class within the 327-419 mm TL range. Morphologically, cos12-41's pectoral fin (54 mm) was typical and body depth was rather deep (69.4 mm) relative to the dwarf sample, and it did not fit the morphometric patterns of the leans from Flathead Lake (Figure 3 and 4). Further, a photograph of this fish shows that it had a high set eye and a curved head profile, and it was caught in the deepest net set where dwarfs predominate (depth of capture versus life history type is covered later in this document). Based on the available information, it seems this fish was indeed a dwarf and its immature status was a result of its young age. Cos12-37 at age 17 and 396 mm TL certainly fits the dwarf growth pattern and not that of the leans. The photograph (shown on title page) also shows this fish had a high set eye and curved head profile. Further, this fish was caught in the deepest set where dwarfs predominate. Given the growth pattern, morphology, depth of capture, and advanced age of cos12-37, the immature classification of this fish was considered a data recording error and it was assumed to be mature in further analyses.

Native humpers have moderately higher lipid values than leans of a similar size (Eschmeyer and Phillips 1965), but the small data set available at the current time from the Cosley Lake varieties precludes making firm conclusions on this subject. Within the overall sample, there was no evidence that % lipid increased with size, contrasting with observations from the native range (Eschmeyer and Phillips 1965). While it is somewhat evident that the fish in dwarf size range had higher lipid levels than the leans of slightly larger sizes, the difference was small (Figure 5). Also, it should be noted that as a result of the low lipid levels the lipid correction procedure had a minimal influence on δ^{13}C (mean change after lipid correction = 0.16).

Some insights into the depth distribution of the two forms can be made with the gill net and small δ^{13}C data set from 2010 available at this time. In 2012, the shallowest net set (3.0 to 13.4 m) collected six leans and no dwarfs, a deeper set (18.3 to 21.9 m) collected four leans and six dwarfs and four leans, while the deepest set (22.3 to 25.9 m) collected five leans and 14 dwarfs (including cos12-37). (Three other net sets were made in 2010 and 2012, but ranged too widely in depth to be useful in this context). The emergent pattern from the net data is that the leans occurred over a wide range of depths but diminished with depth, while the dwarfs were biased deeper in their distribution. This interpretation is coherent with the δ^{13}C ratios from muscle tissue. The δ^{13}C ratio of the fish in the 354-370 mm TL range was lower and much less variable than the 452-848 mm TL range (Figure 6). As deep water foods are lower in δ^{13}C (Vander Zanden and Rasmussen 1999; Stafford 2002; Stafford et al. 2014) and δ^{13}C changes little between trophic levels (see references in Vander Zanden and Rasmussen 1999), the δ^{13}C patterns are coherent with deep water feeding by the dwarfs and utilization of a wide range but generally shallower feeding depths by the leans.

The small δ^{15}N data set from 2010 suggests that the large leans were piscivorous while the dwarfs fed on invertebrates. The δ^{13}C adjusted δ^{15}N value for the 354-370 mm TL fish was 5.7 and for the 452-848 mm TL fish was 10.2. Given that δ^{15}N increases ~3.2 per trophic transfer (Vander Zanden and Rasmussen 1999), the leans were ~1.4 trophic levels higher than the dwarfs, consistent with piscivory and invertebrate feeding, respectively (Figure 7; Figure 8 contains the raw δ^{15}N values for comparison). Stomach samples were taken in 2012, and processing of these samples is recommended to validate these isotopic findings.

The isotopic patterns in the small sample of 205-231 mm TL lake trout were unexpected. The δ^{13}C values suggest they were feeding shallow waters (Figure 6), contrasting to the pattern seen in deeper lakes like Flathead Lake where the small lake trout are predominantly deep.

Although no location regarding the maximum depth of Cosley Lake was located, based on field observations it probably has a maximum depth around 35-40 m. A possible explanation for the $\delta^{13}C$ results is that given the very clear water and moderate depth of Cosley Lake that even the deepest areas are illuminated sufficiently to leave the very small lake trout vulnerable to predation, thus these fish have a tendency to seek shelter in the structurally more complex steep/inshore areas. The 205-231 mm TL fish were captured in a net set from 5.2 to 21.3 m off a point on the steeply sloping south shore which alone provides limited information to aid the isotopic interpretation of depth. However, given the small mesh sizes were inshore it is likely these fish were captured in the shallow or possibly mid depth position of the net on a steeply facing slope. The $\delta^{15}N$ results (Figures 7 and 8) for the very small fish were unexpectedly high for unknown reasons, but could be related to feeding on fish eggs or very small fishes.

The relative abundance of each life history type remains unclear. Gill nets and angling captured 29 dwarfs (including one by angling) and 27 leans (the lean tally includes three larger fish which were measured and released; not included in either tally are the four very small fish which were retained). The similar sample size of each variety, however, does not necessarily equate to similar abundances in the lake due to potential TL and depth related biases in the gill net data. The mesh sizes of the net (deployed for two sets) used in 2010 ranged from 12.5 to 63.5 mm bar mesh and captured 15 fish (and one fish was captured by angling), and the four nets in 2012 ranged from 19 to 51 mm bar mesh and captured 44 fish. These mesh sizes tend to be less efficient at capturing large fish, however large fish tend to be more vulnerable to intercepting the nets as they typically move greater distances. In the collections no leans were captured in the 232 to 451 mm TL range (and fish < 232 mm TL could not be categorized by variety), suggesting that the overall efficiency of the gill nets was highest for larger fish (i.e. leans). Another consideration is that the average gill net depth was 15.6 m which is probably somewhat shallower than the average depth of the lake and thus collections may have slightly favored leans given their more shallow biased distribution. Overall, it is felt that the dwarfs may be more common than leans in Cosley Lake, but no firm conclusions on this matter have been made at the current time. An analysis incorporating gill net selectivity and movement versus TL could be used to gain some traction on this issue if it is of further interest.

Several aspects of the current investigation provide potentially useful information regarding the status and management of lake trout in Cosley Lake. Given the rather even representation of age classes within both life history types, it appears that recruitment was quite consistent which is not surprising for fish spawning in a relatively stable lake environment. Further, the relatively high number of older fish within each life history type suggests that mortality rates were low. The implication is that angler harvest is not overtly affecting the abundance of either variety of lake trout at the current time.

Several aspects of the current investigation suggest that fishing mortality does have a greater potential to impact the lean population, particularly if leans are indeed less common. Most anglers fish from the north shore (where the campground is located) which drops off more gradually than the south side, and this situation means that most angling pressure occurs in shallow waters where leans predominate. The later maturity of leans also suggests they are more vulnerable to angler harvest at the population level as the oldest immature dwarf was age 8 and the immature leans ranged from age 11 to 22. Current fishing regulations allow for the harvest of five lake trout per day in Cosley Lake. If over harvest of the lean population becomes a concern, it is recommended that a lower harvest limit be imposed on lake trout $\geq$ 406 mm TL (16 inches).

A remaining question is the native versus introduced status of the lake trout in Cosley Lake. In the files of the Belly Ranger Station no records of lake trout stocking were located in 2010, but a letter from Mr. Wasem dated 1963 notes stocking of rainbow trout , brook trout, and cutthroat trout in both Glenns Lake (just upstream of Cosley Lake) and Cosley Lake. The stocking of rainbow trout was confirmed by the capture of one individual in 2010, and no brook trout or cutthroat were evident in either 2010 or 2012. A search of GNP's main archives located no information on lake trout stocking in Cosley Lake by government or private interests despite the fact a commercial tent camp was located on Cosley Lake prior to 1910 (Diedre Shaw, GNP, personal communication). Existing genetic data indicate that lake trout in Cosley Lake were derived from the Waterton Lake glacial refuge (Wilson and Hebert 1998). Accordingly, if lake trout were established by stocking a nearby native lake almost certainly was the source, however, most lake trout stocking was made with fish from eastern North America. If lake trout are native, the waterfalls below the lake would seem to be a fish barrier raising the question of how lake trout colonized the lake. However, in a glacial/post glacial setting the waterfall could have been passable due to valley glacial and/or alluvial fill or glacial damming. The presence of Rocky Mountain whitefish in Cosley Lake strongly suggests natural colonization of the lake by fishes was historically possible. No records have been located of mountain whitefish stocking anywhere in GNP (Chris Downs, GNP, personal communication), and further this species was never widely stocked in Montana waters - particularly in remote setting such as Cosley Lake. There is some evidence that lake trout may have been stocked into the native lake trout population of Cosley Lake. According to Synder and Oswald (2005): "There are records of stocking lake trout of unknown origin into Cosley and Glenns lakes, so the genome of these populations may contain introduced alleles." No direct references were provided by the authors making it difficult to evaluate its basis for this assertion.

It is recommended that genetic testing be conducted to determine the native versus introduced status of lake trout in Cosley Lake and, if it is a native population, if any introgression between the native and possibly stocked fish has occurred. If the population was established by transferring Waterton Lake derived lake trout from another location, a genetic bottleneck should be evident associated with a presumably small and fairly recent (~1 century or less) starting population. Genetic testing could also determine whether the two life history types in the lake have a genetic basis, or represent phenotypic plasticity as has been observed in the introduced lake trout of Flathead Lake (Stafford et al. 2014). If the two varieties have a genetic basis, concerns are increased regarding the greater vulnerability of leans to angling mortality as their population size is reduced in a two population scenario. Further, comparisons of the Cosley Lake fish to other lake trout populations derived from Waterton Lake could be used to evaluate if introduced alleles are present in the lake trout of Cosley Lake. If these fish are genetically pure their conservation value is increased as many Waterton Lake derived population have a history of stocking using fish from other lineages. Single nucleotide polymorphism (SNPs) markers recently have been developed for lake trout (Gordon Luikart, University of Montana, personal communication) and provide an appropriate tool to address the genetic questions posed herein.

Sherburne Reservoir Northern Pike

The northern pike sample was small (eight fish) and thus these interpretations should be considered preliminary. The Sherburne northern pike fit the growth pattern described for a Norwegian population aged with metapterygoid bones which is probably the most accurate way to age northern pike (Sharma and Borgstøm, 2007). The oldest fish (age 14) was not the largest fish, however relative to the age 7 fish this fish had otoliths that were thick and heavy. This is typical of old/slow growing fish, suggesting the advanced age of this fish was not an aging artifact. Northern pike from Sherburne exhibited a curious age distribution: although fish ranged from one to 14 years, most (five of eight) were age 7. This age data is suggestive of variable recruitment amongst years (Figure 9). If confirmed with a larger sample size, a possible explanation could be recruitment failure or entrainment losses associated with the operation of Sherburne Dam. If this issue is of further interest, a larger collection of northern pike aged with otoliths and metapterygoid bones is recommended as a follow up investigation.

Logging Lake Cutthroat Trout

The growth, maturity, and strength of year class patterns in cutthroat trout from Logging Lake are coherent with the ecology of this setting, but are based on a modest sample size which tempers the certainty of these observations. Compared to many other relatively large GNP lakes, Logging Lake seems to have a greater proportion of littoral areas (particularly on the east side of the lake where the fish were captured) which may facilitate cutthroat growth. Further, the low elevation of this lake relative to many other GNP lakes may also promote fish growth. Cutthroat trout growth was higher in Logging Lake than in Hidden Lake probably primarily owing to the high elevation/unproductive conditions present in Hidden Lake. The Logging Lake cutthroat trout grew throughout their life, and slowed little if at all in their growth between ages 3 and 8. The age 3 year class had considerable growth variation especially given the young age of these fish. The causes of this variation are unknown, but could be related to differing periods of stream residency prior to outmigration into the lake, differences in growth associated with inlet versus outlet spawning, or changes in growth associated with the onset of maturation. The Logging Lake cutthroat trout matured between ages 3 and 4, coherent with their relatively high growth rates. The presence of two strong year classes (ages 3 and 6) suggests variable recruitment which often occurs in fish spawning in highly fluctuating hydrological environments such as the inlet stream (Figure 10).

Hidden Lake Cutthroat Trout

The Hidden Lake cutthroat trout were similar to those in Logging Lake in that they continued to grow throughout their life, but the Hidden Lake fish grew more slowly, matured later, and also seem to show slightly less variable recruitment. The growth and maturity differences between the two populations likely were primarily a result of the differing environments and associated food webs, but also possibly the different cutthroat trout subspecies present. Growth rates were lower in the Hidden Lake fish than those from Logging Lake, suggesting the Hidden Lake population is more vulnerable to increased mortality. The age at maturity data also suggest the Hidden Lake cutthroat trout are more vulnerable: Hidden Lake fish matured between age 6 and 8 while cutthroat trout from Logging Lake matured between age 3 and 4. Like the Logging Lake cutthroat trout, those from Hidden Lake continued to grow throughout their lives and show little evidence of slowing in growth with age. Despite their slower growth, the greater longevity of the Hidden Lake cutthroat trout allowed them to reach slightly larger sizes than those from Logging Lake. The presence of a strong age 5 (five fish) year class and weak year classes for age 4 (one fish), 6 (one fish), and 7 (no fish) is suggestive of variable recruitment, although this was not evident in the older fish. The abundance of older year classes suggests that mortality rates were low (Figure 10). Some caution is warranted regarding the interpretation of the Hidden Lake data as the fish were captured in the vicinity of a spawning area (the outlet) which may have biased the sample.

Saint Mary Lake Burbot

The two burbot otoliths were readable after soaking for three weeks in clove oil, but the otoliths did not clear sufficiently to provide a clear view of the inner most (~2) rings. A 559 mm TL fish was aged at 11 and a 455 mm TL fish at 10. Based on this pilot study it was concluded that clove oil is an acceptable clearing solution but there are probably better clearing solutions that could be used for future investigations. Alternatively, the otolith break and burn method is widely used for burbot and is still much faster than thin sections.

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Figure 1. TL versus age for lake trout from Cosley Lake.

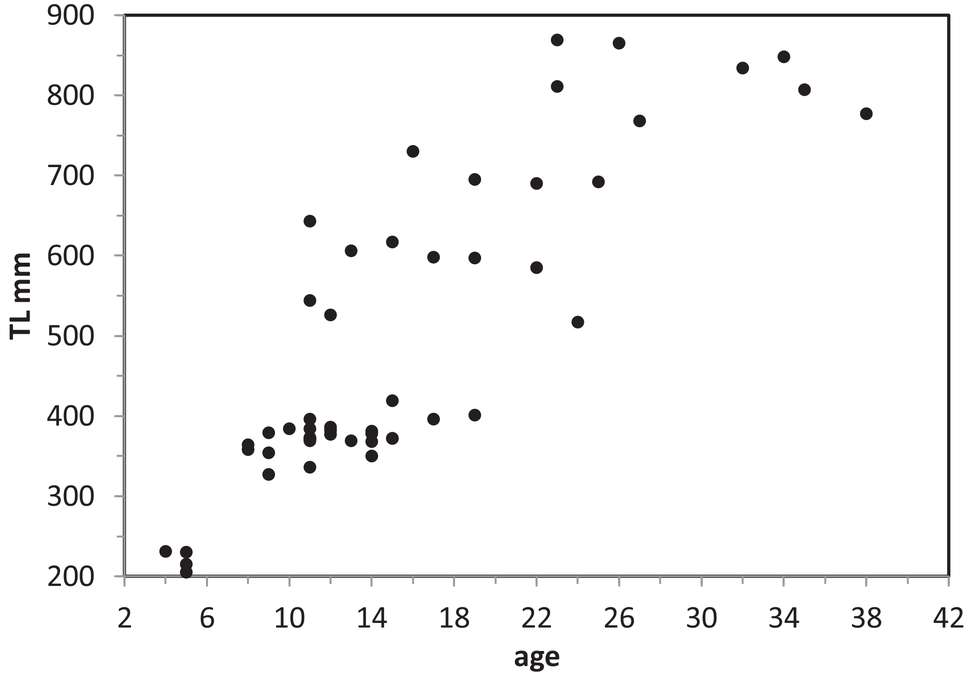

Figure 2. TL versus maturity for lake trout from Cosley Lake.

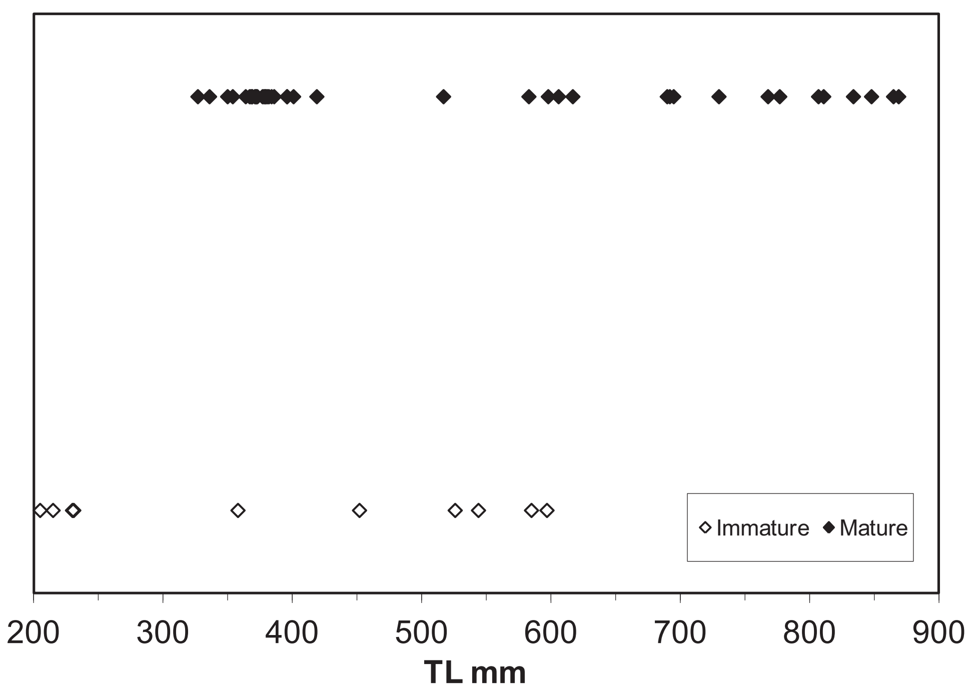

Figure 3. Pectoral fin length versus TL for lake trout from Cosley Lake and Flathead Lake.

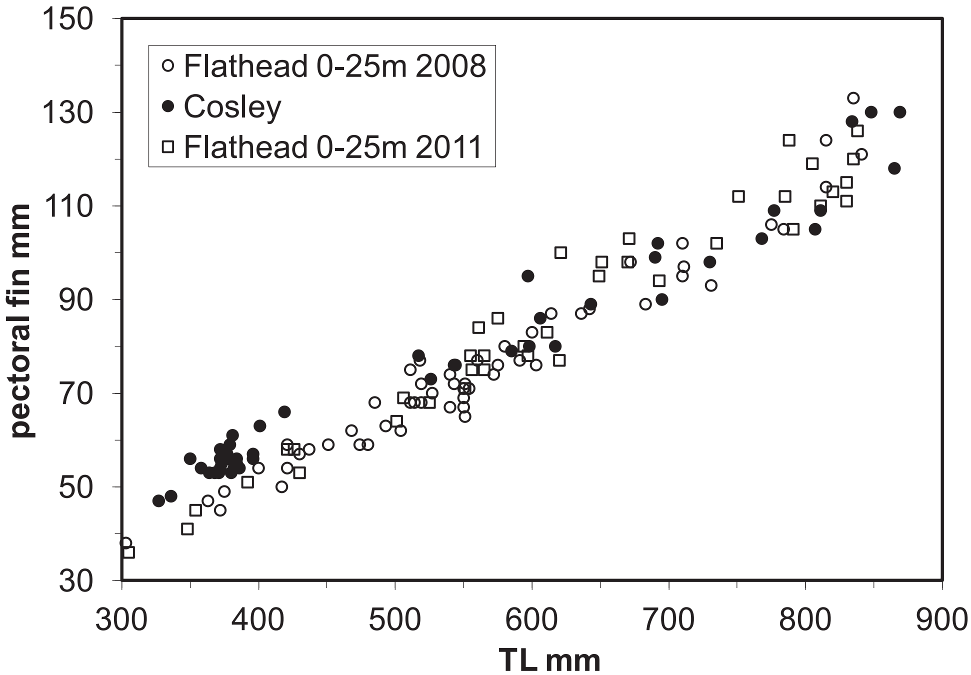

Figure 4. Distance between dorsal and pelvic insertion versus TL for lake trout from Cosley Lake and Flathead Lake.

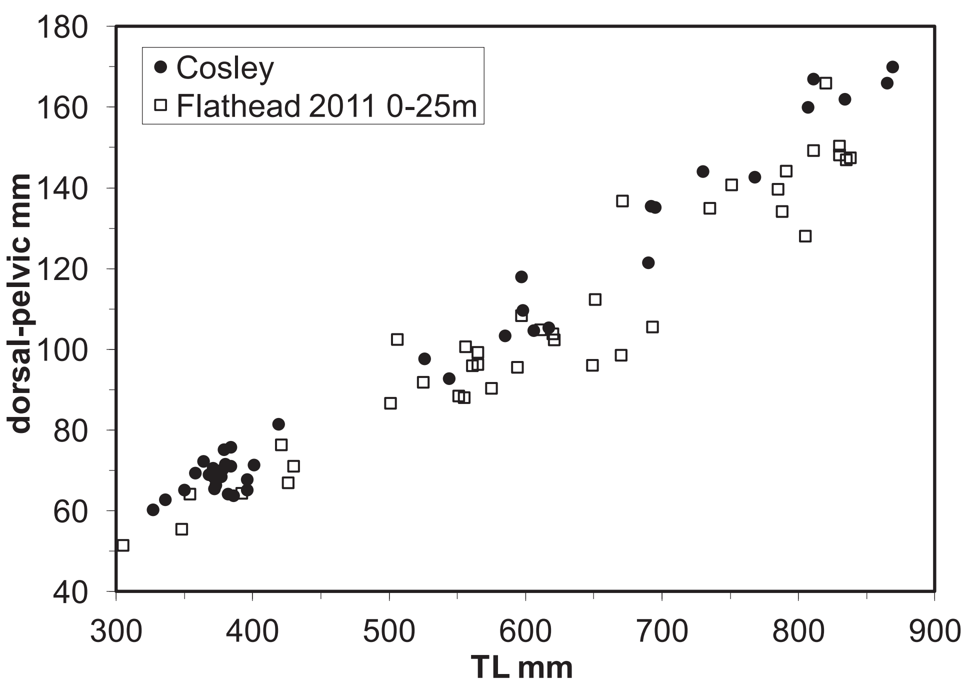

Figure 5. Estimated lipid versus TL for lake trout from Cosley Lake.

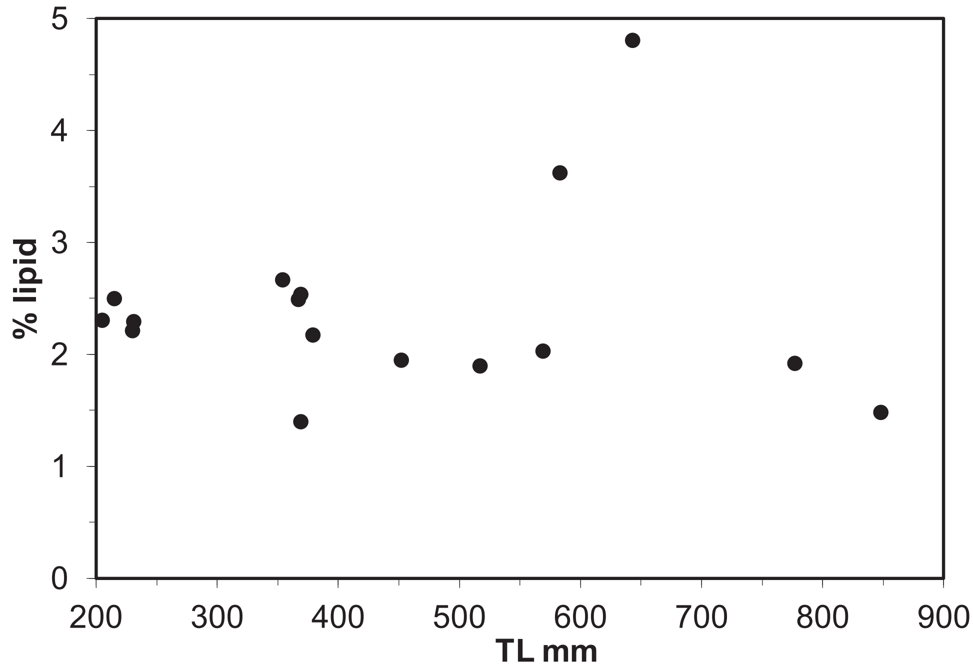

Figure 6. $\delta^{13}C$ (lipid corrected) versus TL for lake trout from Cosley Lake.

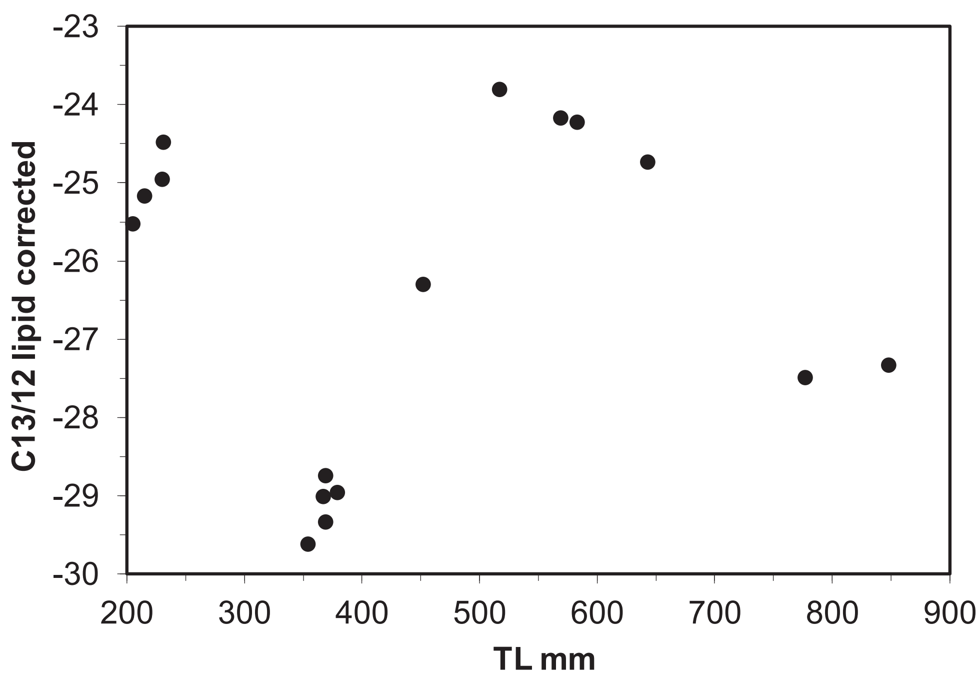

Figure 7. $\delta^{15}N$ (adjusted by $\delta^{13}C$) versus TL for lake trout from Cosley Lake.

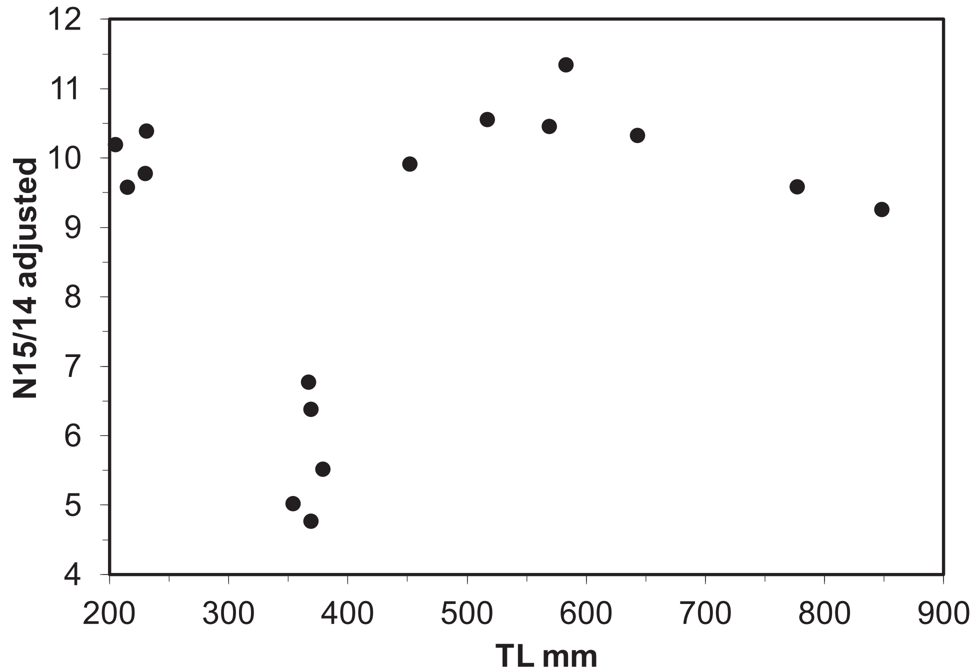

Figure 8. $\delta^{15}N$ (raw) versus TL for lake trout from Cosley Lake.

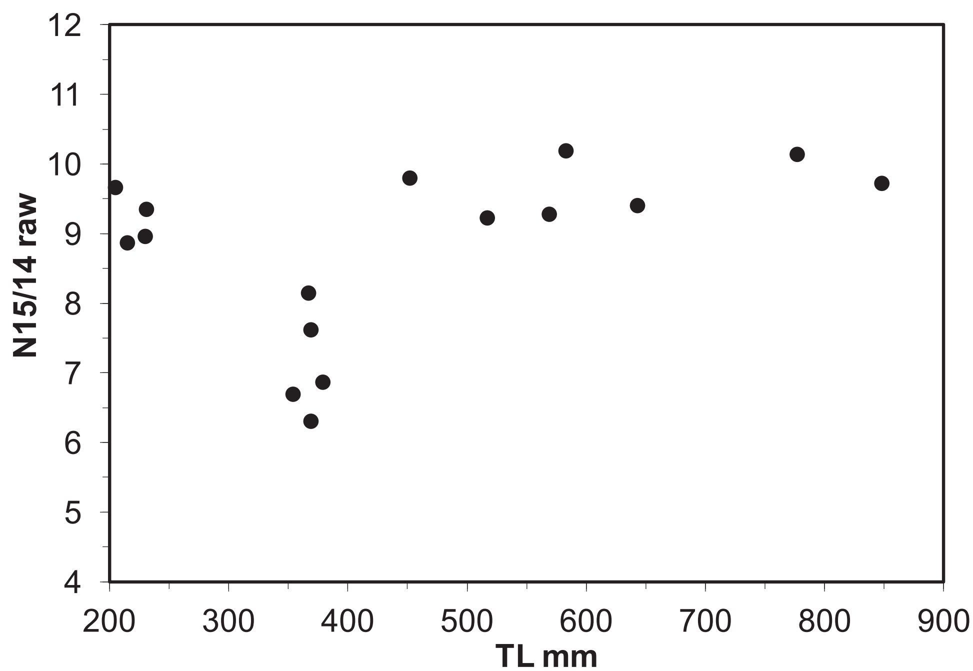

Figure 9. TL versus age for northern pike from Sherburne Reservoir.

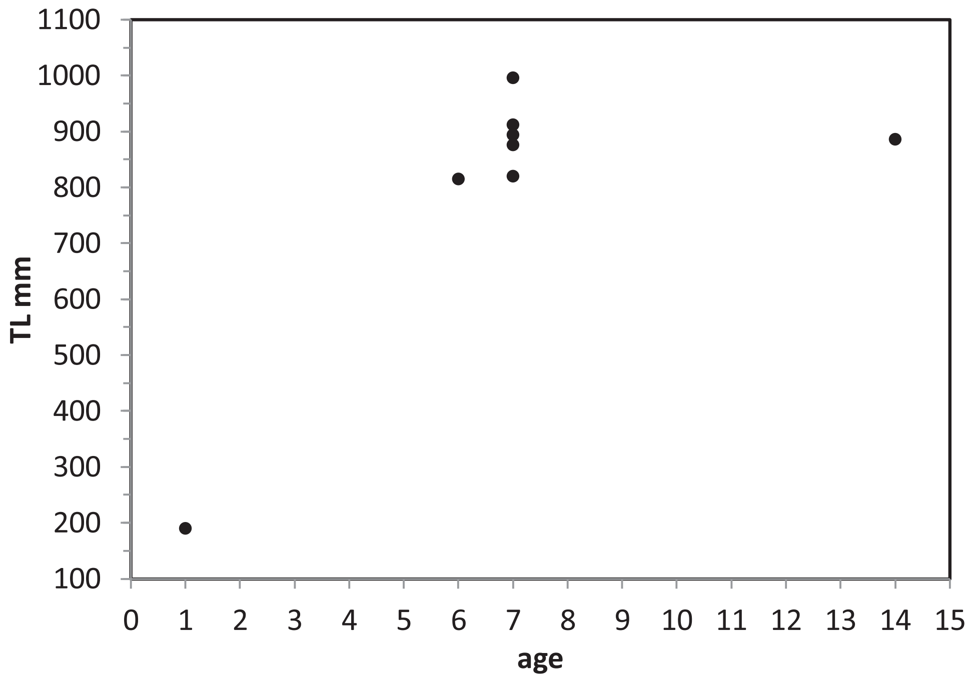

Figure 10. TL versus age for cutthroat trout from Logging and Hidden Lakes.