Status and Management of Cisco, Lake Trout, Smelt and Walleye in Long Lake of Phelps, Vilas Co. Wisconsin

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We are grateful for the support of the Board of Directors and riparian members of the Long Lake of Phelps Lake District throughout the planning, research, and field work of this project. We are also grateful for their, and the Wisconsin Department of Natural Resources' support of and participation in the development of this document. See comprehensive list of Acknowledgements on page v of the Executive Summary.

Executive Summary

Long Lake is an 886-acre oligotrophic drainage lake in northern Wisconsin, Vilas County, with a mean depth of 30 feet and a maximum depth of 95 feet. The lake has in the past supported coldwater fish species, e.g. cisco (*Coregonus artedi*), and cool and warmwater species, e.g. walleye (*Sander vitreus*), smallmouth bass (*Micropterus dolomieu*), muskellunge (*Esox masquinongy*), yellow perch (*Perca flavescens*), bluegill (*Lepomis macrochirus*), and other Centrarchidae species. (Wisconsin DNR, file data, Woodruff, WI). The exotic cold-water fish species rainbow smelt (*Osmerus mordax*) was first found in the Long Lake December 31, 1999, likely the result of an unapproved introduction occurring sometime

Long Lake near Phelps (foreground) aerial view looking southeast (Big Sand lake in background). *Aerial Photo by Josh Wilson, Long Lake of Phelps.*

within that decade. Within 10 years after smelt were first discovered in the lake, significant changes were observed in the fisheries data collected by the Wisconsin Department of Natural Resources (WDNR) including the apparent loss of consistent recruitment of walleye, and the suspected decrease and possible demise of the native cisco population. In an attempt to manage the smelt to a lower level and facilitate a recovery of potentially affected native fish species, the Wisconsin Department of Natural Resources began regularly stocking smelt predators into the lake including yearling lake trout (*Salvelinus namaycush*) beginning in 2005, large fingerling walleye in 2007, and large fingerling musky in 2013. In November 2015 the Long Lake of Phelps Lake District (LLPLD) contacted Fred Binkowski, Senior Fisheries Scientist at the University of Wisconsin-Milwaukee School of Freshwater Sciences (UWM/SFS), to inquire whether UWM/SFS could assist the District in addressing some of their members' concerns about the impact of smelt on the lake's fish and aquatic community. LLPLD's concerns included a) whether native cisco were persisting following the invasion by smelt; b) knowing whether DNR stocked lake trout were surviving, eating smelt, and attempting to spawn in the lake; c) knowing whether the smelt could be eliminated, reduced, or controlled somehow; d) knowing whether walleye were successfully producing hatches following the invasion by smelt; and e) knowing the current temperature and dissolved oxygen conditions in the lake's hypolimnion. LLPLD was willing to invest in research to address these concerns, and to supplement WDNR fisheries management surveys and efforts on Long Lake.

LLPLD approved annual funding for 4 years of fisheries research agreements with UWM/SFS during 2017-2020. Fred Binkowski and colleague Ron Bruch of the SFS planned and implemented a series of actions and assessments to address LLPLD's original fisheries concerns. Through their research Binkowski and Bruch were able to show: a) that, despite the smelt invasion, native cisco persist in Long Lake and the population is a good position to continue to reproduce and persist as an important deep-water forage species following any decline in the smelt with the addition of 10,000 large fingerling cisco reared at UWM/SFS and stocked into Long lake in October 2017; b) that some of the stocked lake trout have survived, are eating smelt and growing well, and appear to be spawning in the lake, but since 2012 are dying as adults at a very high rate after being caught as bycatch in the increasingly popular summer deep-water walleye trolling fishery; c) that the smelt population in the lake appears to be in decline structurally and possibly from a biomass standpoint due to heavy predation by walleye and lake trout; d) that walleye of all sizes are extensively eating smelt, and, despite the continued presence of smelt, are reproducing in the lake as evidenced by the discovery of a relatively strong hatch in 2018 and possibly one in 2016 (both non-stocking years); and e) Long Lake remains a healthy oligotrophic lake with sufficient dissolved oxygen in the hypolimnion to support coldwater fish species.

Fisheries Recommendations/Options (highest to lowest priority):

1. *Continue stocking Black Oak Lake strain yearling size lake trout into Long Lake every 2-3 years at a rate 10/acre for the purposes of Black Oak strain lake trout gene pool preservation and smelt control.*

2. *Eliminate trolling on Long Lake to minimize/eliminate the high mortality of lake trout due to by-catch in the walleye trolling fishery.*

3. *Continue stocking extended growth fingerling walleye every other year in odd years at a rate of 10/acre.*

4. *If lake trout mortality due to walleye trolling is not minimized/eliminated, stock additional smelt predators, e.g. brook trout or brown trout to help control the smelt population.*

5. *Determine the age composition and longevity of the Long Lake walleye population, the relative strength walleye year classes, and relative success or failure of walleye hatches/stocking events since approximately 2005.*

6. *Initiate a standardized lake trout adult population assessment in Long Lake to track survival and growth of stocked lake trout and determine if lake trout are naturally reproducing in Long Lake.*

7. *Develop and conduct a standardized annual fall trawl survey on Long Lake to assess walleye year class strength to complement the standard fall shoreline shocking survey conducted annually by WDNR and Tribal Biologists; including checking the otoliths of a subsample of at least 40 young of year walleye for OTC (Oxytetracycline) marks to determine the percentage of YOY that are stocked (OTC marked) and the percentage of YOY that are natural (no mark) annually.*

8. *Develop and conduct annual standardized smelt trawling assessment in late June to track smelt size distribution and relative abundance.*

9. *Conduct UWM/SFS standard cisco gill net survey (2.5" SM, 500 feet, 1 night set of Carter/Mason property and 1 additional site in south basin) annually in late August to collect data on catch per effort, size distribution, relative condition, diet, and presence or absence of stocked fin-clipped cisco.*

10. *Assess the quality of the lake trout spawning habitat off Swislow Point and Katey's Point and determine whether habitat enhancement is needed to maximize potential for successful and sustaining lake trout natural reproduction.*

11. *Collect boney structures (otoliths, scales, fin bones) over time from stocked fin-clipped known age cisco for age validation.*

12. *Continue WDNR vertical gill net surveys according to their standard survey design*

Accomplishments and Findings

Cisco

- 10,000 extended growth fin-clipped fingerling cisco raised at UWM/SFS were stocked into Long Lake October 17, 2017.
- The stocking of these cisco was considered critical to long term maintenance of the cisco population in the lake as a primary component of the cold-water forage fish community (due to initial concerns about the potential loss of cisco in Long Lake).

- Native cisco have been captured in gill nets set in all deep areas of Long Lake indicating a relatively robust population of native cisco persists in the lake.
- Native cisco sampled for age in 2018 were estimated to be 9-22 years old with numerous year classes from years smelt have been abundant in the lake.
- Cisco appear to be pulling off hatches despite an abundance of smelt in the lake.
- Cisco in Long Lake were found to be extensively feeding on fingerling perch and bluegill in August 2018 and 2019 indicating their preferred prey, large zooplankton, may be cropped off by smelt.

Lake Trout

- Stocked lake trout are initially surviving well if stocked from a location close to deep water, i.e. the Carter property, but do not survive well if stocked into the shallow bay off the public boat launch.
- Lake trout are consuming smelt extensively, and are growing well, reaching maturity in 5 years, 1 to 2 years sooner than lake trout in other northern WI inland lakes.
- Lake trout do not appear to be surviving well over time in Long Lake due to high mortality from being caught by anglers deep-water trolling for walleye.
- Eleven of the 13 lake trout captured for the UWM/SFS telemetry studies were found to have died within 2 to 18 months after being surgically fitted with radio and/or sonic telemetry tags and released.
- Sonic telemetry data clearly show tagged lake trout during summer-early fall moving from deep cold waters to the warm surface water (i.e. being caught and brought to the surface by anglers), followed by apparent death and non-movement of tag afterwards.

- Lake trout in Long Lake appear to be attempting to spawn in mid to late October in 10 to 56 feet of water on the rocky points called “Swislow Point” (off the DiMarco property) on the southeast shore, and “Katie’s Point” on the northwest shore near the mouth of Kime’s Creek.
- Although lake trout appear to be spawning in Long Lake, egg deposition and spawning success have not been documented, and it is likely consumption of Thiaminase-rich smelt by lake trout may be causing early mortality syndrome (ELS) of lake trout eggs or fry.

Smelt

- After first being discovered in Long Lake in the late 1990s, smelt continue to be relatively abundant in the lake and appear to be the primary forage of lake trout and walleye in the lake.
- Smelt in Long Lake are generally small in average size (<4 inches), slow growing, and up to 6 years of age with most fish 1 to 3 years of age.
- During 2013-2018 smelt produced hatches in 5 of 6 years in Long Lake.
- Smelt in Long Lake appear to be “dwarfing”, i.e. maturing at a small size (as small as 3.5”), and maintaining small size distribution, likely due to extensive predation by walleye and lake trout.

- Smelt in Long Lake are exhibiting a total annual mortality rate of 67%, i.e. 2/3 of the smelt in the lake are dying/disappearing each year due to predation and natural mortality.
- Long Lake smelt population metrics indicate that predation may be having an impact on the smelt population size structure and mortality, and that the DNR's strategy to control smelt in the lake by building up walleye and lake trout populations in the lake may be beginning to show signs of success.

Walleye


Kevin Keane Photo

- Walleye in Long Lake (of all sizes sampled in 2019, 7-25") are eating smelt extensively and growing well.
- Walleye appear to be able to successfully reproduce in Long Lake despite the presence of smelt in the lake.
- Age samples (otoliths or ear stones) from walleye collected in 2019 showed walleye naturally produced a relatively robust year class in 2018 (a non-stocking year; DNR stocks extended growth walleye fingerlings in odd years since 2005).
- Age samples in 2019 also included walleye from the 2016 and 2008 year classes, also non-stocking years.
- The dependence upon and heavily utilization of smelt as the primary forage for walleye of all sizes, including fingerling walleye, could potentially change the behavior of walleye in the fall making them less susceptible to fall shocking surveys. WDNR and Tribes have been regularly conducting fall walleye young of year shoreline shocking surveys since 1987 with results capturing few to no young of year in most falls since the mid-1990s.

Acknowledgements

The research and work summarized in this report were strongly supported and funded by the Long Lake of Phelps Lake District and their riparian owner members. Numerous members volunteered time to participate in and help with sampling efforts, and/or provided access to and across their properties to facilitate project needs including Jeff Mason, Joan Carter, Mark Swislow, Steve DiMarco, Dan Anderson, Kevin Keane, John Rowe, Ann Spangler, Dale & Jan Engberg, Barbara Schoenecker, Mike & Trudy Wambay, Frankenthal family, Gross family, and Bernholdt, Frank, and Schlessinger families. The Wisconsin Department of Natural Resources Fisheries Management staff, Mike Vogelsang, Steve Gilbert, Eric Wegleitner, and Tim Tobias contributed valuable information that helped shape project objectives, activities, and analysis, as well as assistance with some of the lake trout angling sampling.

Note

For the purposes of identifying key shoreline features and locations during this study, names were subjectively assigned to several "points" on the lake. Along the southeast shoreline the large northernly point was designated "Swislow" Point, and the next main point along the same shoreline to the southeast was designated "Rowe" Point (forming the north side of the bay into which Thoroughfare Creek enters). Along the northwest shore, directly across the lake from "Swislow" Point, the point through which Kime's Creek enters the lake was designated "Katey's" Point. The exact locations of all of these sites are illustrated in the full report in Figure 24.

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Background

Long Lake is an 886-acre oligotrophic drainage lake in northern Wisconsin, Vilas County, with a mean depth of 30 feet and a maximum depth of 95 feet (Figures 1, 2, 24). The lake has in the past supported native coldwater fish species, e.g. cisco (*Coregonus artedi*), and cool and warmwater species, e.g. walleye (*Sander vitreus*), smallmouth bass (*Micropterus dolomieu*), muskellunge (*Esox masquinongy*), yellow perch (*Perca flavescens*), bluegill (*Lepomis macrochirus*), and other Centrarchidae species. (Wisconsin DNR, file data, Woodruff, WI).

Figure 1. Long Lake near Phelps

Figure 2. Long Lake near Phelps (foreground) aerial view looking southeast (Big Sand lake in background). *Aerial Photo by Josh Wilson, Long Lake of Phelps.*

The exotic cold-water fish species rainbow smelt (*Osmerus mordax*) (Figure 3) was first found in the Long Lake December 31, 1999, likely the result of an unapproved introduction occurring sometime within that decade (WDNR, https://dnr.wi.gov/lakes/invasives/AISDetail.aspx?roiseq=22554863). Within 10 years after smelt were first discovered in the lake, significant changes were observed in the fisheries data collected by the Wisconsin Department of Natural Resources (WDNR) including the apparent loss of consistent recruitment of walleye, and the suspected decrease and possible demise of the native cisco population (WDNR, Woodruff, WI, Unpublished Data; Personal Communication, Stephen Gilbert, WDNR, Woodruff, WI). Introduced rainbow smelt have been shown to contribute to the reduction or extirpation of yellow perch and cisco in some lakes in Ontario and Wisconsin (Evans and Waring 1987; Hrabik et al. 19 98). Researchers have also found that reducing introduced rainbow smelt through increased predation, facilitated by predator protection from angling harvest, led to restoration of successful walleye and cisco hatches and year classes (Krueger and Hrabik 2005).

Figure 3. Smelt from Long Lake

In an attempt to manage the smelt to a lower level and facilitate a recovery of potentially affected native fish species, the Wisconsin Department of Natural Resources began regularly stocking smelt predators into the lake (Table 1) including yearling lake trout (*Salvelinus namaycush*) beginning in 2005, large fingerling walleye in 2007, and large fingerling musky in 2013.

The WDNR's objectives for the stocking of these fish species were to increase the predator base in Long Lake that potentially would impact smelt through predation; and to establish a naturally reproducing lake trout population as an element of the cold-water fish community in the lake (Personal Communication, WDNR Steve Gilbert, Woodruff, WI). Lake trout brood fish from the native population in nearby Black Oak Lake were used as a gamete source to provide the greatest potential for long-term successful natural reproduction (NR) of lake trout in Long Lake, and to develop an additional NR population of the genetically unique Black Oak Lake strain of lake trout (Piller et al. 2005).

In November 2015 the Long Lake of Phelps Lake District (LLPLD) contacted Fred Binkowski, Senior Fisheries Scientist at the University of Wisconsin-Milwaukee School of Freshwater Sciences (UWM/SFS), to inquire whether UWM/SFS could assist the District in addressing some of their members' concerns about the impact of smelt on the lake's fish and aquatic community. LLPLD's concerns included a) the impact of smelt on native cisco; b) whether DNR stocked lake trout were surviving, eating smelt, and attempting to spawn in the lake; c) whether the smelt could be reduced, eliminated or controlled somehow; d) the impact of smelt on walleye recruitment; e) knowing the current temperature and dissolved oxygen conditions in the lake's hypolimnion. LLPLD was willing to invest in research to address these concerns, and to supplement WDNR fisheries management surveys and efforts on Long Lake.

Table 1. Lake Trout, Walleye, and Muskellunge Stocking for smelt control and fish community management in Long Lake, Vilas County, 2005 to 2019

Year	Species	Strain	Age Class	Year Class	Number Stocked	Average Total Length (in)	Fin Clip or Mark*
2019	walleye	Mississippi Headwaters	Large fingerling	2019	8854	6.5	OTC
2018	Lake trout	Black Oak lake	yearling	2017	10643	7.3	LP
2017	walleye	Mississippi Headwaters	Medium fingerling	2017	9739	3.7	OTC
2017	walleye	Mississippi Headwaters	Large fingerling	2017	1639	6.8	OTC
2017	lake trout	Black Oak Lake	yearling	2016	10,074	7.4	Ad
2017	muskellunge	Upper WI River	Large fingerling	2017	54	10.8	PIT
2015	muskellunge	Upper WI River	large fingerling	2015	86	11.8	No fin clip or mark
2015	walleye	Mississippi Headwaters	large fingerling	2015	8855	7.8	OTC
2013	muskellunge	Upper WI River	large fingerling	2013	218	9.2	No fin clip or mark
2013	Lake trout	Black Oak Lake	Yearling	2012	4389	7.1	RV
2013	walleye	Mississippi Headwaters	Large fingerling	2013	8719	6.6	OTC
2012	Lake trout	Black Oak lake	yearling	2011	8327	6.5	LV
2012	walleye	Private Hatchery	large fingerling	2012	3000	?	No fin clip or mark
2011	walleye	Mississippi Headwaters	large fingerling	2011	8718	7.2	OTC
2010	walleye	Private Hatchery	large fingerling	2010	3000	?	No fin clip or mark
2009	walleye	Mississippi Headwaters	Large fingerling	2009	8720	7.4	OTC
2008	walleye	Private Hatchery	large fingerling	2008	3000	?	No fin clip or mark
2007	walleye	Mississippi Headwaters	Large fingerling	2007	7229	8.0	OTC
2005	walleye	Mississippi Headwaters	small fingerling	2005	43778	1.5	OTC
2005	Lake trout	Black Oak Lake	Yearling	2004	5573	6.4	No fin clip or mark

**LP = left pectoral fin removed; Ad = adipose fin removed; RV = right ventral fin removed; LV = left ventral fin removed; OTC = Oxytetracycline mark given to otoliths (ear stones) of fry; PIT = PIT (passive integrated transponder) tag inserted in each fish*

Objectives

1. **Rear and stock cisco into Long Lake to restore/supplement the native cisco population**
2. **Determine whether a native cisco population persists in the lake post smelt invasion**

Figure 4. Native cisco from Long Lake near Phelps

Cisco (Figure 4) were likely the historical foundation of the cold-water forage fish community in Long Lake supporting predator fish (e.g. walleye, musky, stocked trout) that could feed in the deep cold waters below the thermocline during the open water season (Figure 17 illustrates the summer thermocline and seasonal temperature-depth profiles of Long Lake). Long Lake is a deep lake with steep shorelines where only approximately 10% of the lake bottom is 15 feet or less in depth. Given the limited near shore fish production areas in the lake, the fish community, to remain healthy, needs a consistent source of forage fish (cisco) in the deep water in addition to forage produced and available primarily in the limited shallow near-shore waters (minnows, suckers, etc.). Smelt became very abundant in Long Lake within ten years after their discovery in 1999 and there was concern for the persistence of the native cisco in Long Lake. Rise in smelt abundance has been shown in other temperate inland lakes to be followed by a reduction in cisco abundance (Loftus and Hulsman 1986; Evans and Loftus 1987; Hrabik et al. 1998). LLPLD was interested in stocking cisco in Long Lake to restore or bolster the native stock, and in determining whether native cisco persisted in the lake.

3. **Determine if stocked lake trout are surviving and consuming smelt.**
4. **Determine if and where lake trout are attempting to spawn in Long Lake**

Figure 5. Lake trout from Long Lake near Phelps caught by an angler, May 2019.

As previously discussed, fish predation has been shown to facilitate the reduction of smelt in smelt-invaded lakes. The primary native fish predators in Long Lake are walleye, musky, smallmouth and largemouth bass (*Micropterus salmoides*), yellow perch, black crappie (*Pomoxis nigromaculatus),* and northern pike (*Esox lucius*). Of these species, those most prone to consistently eat smelt would likely be walleye. Walleye historically were considered to be "warm-water" fish species, although now they are considered to be a "cool-water" species, i.e. as they can tolerate and effectively feed in the deep cold water (40-55° F) below the thermocline during the summer growing season. Their optimal summer feeding temperatures are 55-74°F, significantly warmer than for smelt or trout (Becker 1983). Smelt is considered a cold-water species, like trout and salmon, with an optimum temperature range of 43-56°F (Becker 1983) which is the exact range of temperatures within the hypolimnion of Long Lake between the lake bottom (down to 95 feet) and the bottom of the thermocline (~20-30ft) in Long Lake in summer (see Figures 17 and 18, and the section on lake stratification, temperatures, and dissolved oxygen on pages 11-13). Lake trout stocked by the WDNR are known to be a voracious fish predator (Becker 1983), and therefore an important smelt consumer and a key species for long-term reduction and control of smelt in Long Lake (Figure 5). LLPLD was keenly interested in determining whether the lake trout stocked were surviving and eating smelt; how well they were growing; and whether they were attempting to spawn on the lake. Long-term goals of the WDNR included establishing a naturally reproducing population of the Black Oak strain lake trout in Long Lake, as well as in Lake Lucerne (Forest Co, WI) and Big Carr Lake (Oneida Co, WI) (Personal Communication, Steve Gilbert, WDNR, Woodruff, WI). The native lake trout in Black Oak Lake (Vilas Co ~17 miles northwest of Long Lake) are a unique genetic strain of this species found only in Black Oak Lake, a relatively small sized lake in which to find natural lake trout (Pillar et al. 2005). Lake trout were initially stocked in Long Lake in 1908 and then again in 1961 and 1964. Other trout species, brown, brook and rainbow, were stocked into Long Lake by WDNR in relatively large numbers from 1971-1995 prior to smelt first being found in the lake in 1999 (Table 2).

Table 2. WI DNR record of Lake, Brook, Brown and Rainbow Trout stocked in Long Lake of Phelps, Vilas Co. WI, 1908-2018

Year	Species	Strain (Stock)	Age Class	Stocking Date	Stocking Site	Number Fish Stocked	Marks Given	Average Length (in)
2018	Lake Trout	Black Oak	Yearling	18-May-18	Joan Carter Property	10643	LP	7.3
2017	Lake Trout	Black Oak	Yearling	17-May-17	Joan Carter Property	10074	A	7.4
2013	Lake Trout	Black Oak	Yearling	16-May-13	Joan Carter Property	4389	RV	7.1
2012	Lake Trout	Black Oak	Yearling	26-Apr-12	Boat Landing	8327	LV	6.5
2005	Lake Trout	Black Oak	Fingerling	13-Oct-05	Boat Landing	5573		6.4
1995	Brown Trout	Unspecified	Fingerling	9-Oct-95		10,000		5.5
1994	Brown Trout	Unspecified	Fingerling	5-Oct-94		10,000		6.4
1993	Brown Trout	Unspecified	Fingerling	5-Oct-93		10,000		6
1992	Brown Trout	Unspecified	Fingerling	Fall 92		10,000		6
1991	Brown Trout	Unspecified	Fingerling	00 Sep 91		10,380		7
1989	Brown Trout	Unspecified	Fingerling	10-Oct-89		8500		7
1989	Brown Trout	Unspecified	Fingerling	29-Sep-89		37,500		4
1988	Brown Trout	Unspecified	Fingerling	28-Sep-88		20,000		7
1987	Brown Trout	Unspecified	Fingerling	13,14,15,19 Oct 87		132,000		7
1986	Brown Trout	Unspecified	Fingerling	6,8,9,10 Oct 86		25,000		7
1985	Brown Trout	Unspecified	Fingerling	2-Oct-85		25,000		7
1980	Rainbow Trout	Unspecified	Yearling	8-May-80		1,500		8
1979	Rainbow Trout	Unspecified	Yearling	10-May-79		5,000		9
1978	Rainbow Trout	Unspecified	Yearling	11-May-78		10,000		10
1977	Rainbow Trout	Unspecified	Yearling	30-Apr-77		10,000		
1976	Rainbow Trout	Unspecified	Yearling	5, 10 May 76		10,000		
1975	Brook Trout	Unspecified	Yearling	22, 23 Apr 75		10,000		
1974	Brook Trout	Unspecified	Yearling	19-Mar-74		10,000		7
1972	Brook Trout	Unspecified	Yearling	9-May-72		4,000		9
1971	Brook Trout	Unspecified	Yearling	20-May-71		7359		
1964	Lake Trout	Unspecified	Yearling			6090		
1961	Lake Trout	Unspecified	Fingerling			24120		
1908	Lake Trout	Unspecified	Fry			300000		

Lake trout in Wisconsin's inland lakes spawn in the fall on rocky or boulder strewn reefs or drop offs in water from 10 to 60 feet. They do not make nests nor care for the eggs or young, as they are broadcast spawners laying their eggs into the crevices of rocks on the spawning areas where the eggs are protected and incubate through the winter hatching in February and March (Becker 1983). Having enough rocky substrate in the proper locations is key to potential reproductive success. Understanding where the lake trout stocked in Long Lake are attempting to spawn will provide important information for future management if spawning area enhancement is an action deemed necessary for establishing a naturally reproducing population of lake trout in Long Lake.

5. Determine the current status of size, age, growth and mortality of smelt in Long Lake

Figure 6. Smelt (close to maximum size) from Long Lake

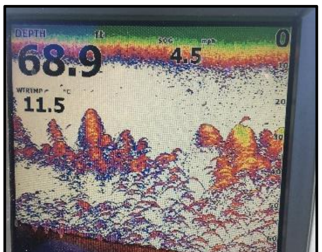


Figure 7. "Smelt Balls" as seen on fish finder, June 2017, Long Lake

Except for encounters with smelt by ice anglers and WDNR Fisheries staff, live smelt from Long Lake (Figure 6) have seldom if ever been physically seen by most lake users. Anglers fishing on the lake regularly see the large "smelt balls' on their sonar screens (Figure 7) and may see smelt in the stomachs of walleye they catch and clean if they look for them. WDNR does not conduct any standardized smelt assessment on the lake so, at the start of this project, no data could be found to provide insight into the size and age distribution, and growth and mortality rates of smelt in Long Lake. Some research had been done on Long Lake by the Michigan State University in the early 2010s to characterize and model the diet and impact of smelt in the lake. The researchers found primarily plankton and no walleye fry or larvae in the diet of the 50 smelt they sampled (McDonnell 2011). Work by researchers from the University of Wisconsin-Madison on two other smelt lakes in the area, Sparkling Lake and Crystal Lake, found a significant decline in the abundance of important large-bodied zooplankton such as Daphnia (water fleas) due to heavy smelt predation, and an increase in abundance of smaller-bodied zooplankton such as calanoid copepods (Beisner et al. 2003). Daphnia are an important forage for walleye fry, cisco and many other forage and gamefish species. High abundance of smelt in an inland lake the size of Long Lake could potentially disrupt the aquatic food chain, negatively affecting the growth and survival of numerous desired fish species as well as the growth and survival of the smelt population itself. Examining the age and size distributions, and growth and mortality rates of smelt in Long lake could provide key insight into the status of smelt in the lake and whether predation of other fish on smelt, and potential over-grazing by smelt of the zooplankton community has had an impact on the health and status of the lake's smelt population.

6. Determine if there is any evidence of natural reproduction of walleye in Long Lake since smelt were found in the lake, and if walleye in Long lake are consuming smelt.

Figure 8. Walleye from Long Lake *(Photo from LLPLD Facebook page)*

Studies have shown a decrease in walleye recruitment in lakes invaded by smelt through the 1990s and early 2000s (Mercado-Silva et al. 2007). Although the exact mechanisms of this observed phenomenon have not been thoroughly documented, it was suggested that smelt may compete with larval walleye for food (e.g. daphnia), and that smelt, also fish predators, may forage on walleye fry and/or larvae. In addition, smelt, which are high in a vitamin B disrupting enzyme Thiaminase, have been shown to cause early mortality syndrome of the eggs and fry of lake trout that consume large quantities of smelt (Marcquenski and Brown 1997; Brown et al. 1998), although this may not be the case with walleye (Honeyfield et al. 2007). Annual fall standard shoreline electrofishing surveys conducted by WDNR and Tribal Biologists on Long Lake 1995-2019 (except 2018) show that before and after smelt were first found in the lake, natural walleye recruitment appears to have been sporadic to non-existent (WDNR unpublished data, Woodruff, WI). Determining whether walleye from Long Lake (Figure 8) are successfully reproducing or not, and if they are, in which years, is important information for better understanding the status and impact of the smelt population, and for long-term management and maintenance of the walleye population in the lake. Since 2007 WDNR has worked to maintain the walleye population in Long Lake by stocking extended growth fingerling walleye (~7" long) every other year in odd years, with additional stocking of extended growth fingerlings in 2008, 2010, and 2012 by the LLPLD. WDNR surveys have shown the walleye population in Long Lake is currently at a relatively high level (WDNR unpublished data, Woodruff, WI), and the lake is known by anglers for its large trophy-sized walleye.

Methods

Cisco

Figure 9. Collecting cisco eggs on North Twin Lake, Nov 21, 2016

Figure 10. Fin clipping extended growth fingerling cisco at the UWM/SFS Fisheries lab prior to stocking into Long Lake on October 18, 2017

During the evening of November 21, 2016 wild spawning cisco brood stock were collected and spawned from North Twin Lake in Vilas County, Wisconsin (3 miles west of Long Lake) (Figure 9). The lake water temperature was 5.1°C (41.2°F). Eggs were fertilized, treated with Bentonite to reduce clumping, and brought back to the Great Lakes Aquaculture Center (at UWM/SFS) for incubation @ 4.1°C (39.4°F) in a quarantine wet lab. Hatching occurred between January 11-17, 2017. The fish were reared in 4 oval fiberglass tanks (in quarantine) at

12°C (53.6°F). After VHSv (viral hemorrhagic septicemia virus) test results came back negative, a Fish Health Certificate was issued On March 6, 2017. On March 20, 2017 all fish were transferred into a general population in a medically separated wet lab and reared in 8-foot round fiberglass tanks at 15°C (59.0°F). Fish were reared on a diet of Ziegler 3.0 mm to an average size of 178 mm (7.0"), anaesthetized and fin clipped (left ventral clip) (Figure 10) and later stocked into Long Lake on October 18, 2017 as extended growth fingerlings. A random sample of cisco were measured to the nearest mm and average weight was calculated using a cisco standard weight equation, log10 Ws = −5.517 + 3.224 log10 TL (Fisher and Fielder 1998). Cisco were hauled in a standard insulated fish hauling tank, equipped with constant water quality monitoring technology, by Mike Preul and crew from the Mole Lake Sakaogon Chippewa Band. On October 17, 2017 the cisco were stocked off the shoreline of the Carter/Mason property on the northwest shore of the lake (Figures 19 and 24). This location is preferred as the shoreline drops off rapidly into 80+ feet of water giving the stocked fish an opportunity to quickly move to deep water and their preferred habitat.

WDNR Fisheries Research standard graded mesh vertical gill nets were fished as part of the WDNR's long term cisco monitoring study in June 2018. Four nets, 2 gangs together in two separate locations (NE deep basin, SW deep basin) in Long lake were fished for 24 hours and lifted on June 26, 2018 by WDNR. UWM/SFS 2.5" stretch mesh (SM) gill nets, two 250 foot long by 6 feet deep panels targeting cisco were fished in one gang for 18-24 hours and lifted on August 30, 2018 and August 20, 2019 set in 30 to 60 feet of water on the bottom along the Carter/Mason property on the northwest lake shore. All cisco captured were counted and a subsample was collected for length and weight measurements, sex and stage determination, otolith collection for age, and qualitative stomach content analysis. Other gill net sets were made at random locations at depths from 30 to 70 feet throughout both main deep basins in the lake as exploratory sampling for cisco and lake trout.

Lake Trout

Angling (trolling) and 2.5" SM gillnets (description above) were used in attempts to capture lake trout from Long Lake. Angling forays were conducted August 29-30, 2017 (1 boat), October 24-25, 2017 (1 boat), June 24-26, 2018 (3 boats), and August 19-21, 2019 (1 boat). Standard Great Lakes style lake trout trolling equipment and baits were used. Trollers fished 8-10 hours per day running 6 to 12 lines per boat placing baits (stick baits and spoons) at various depths running from 25 to 60 feet over depths of 60 to 95 feet. UWM/SFS standard 2.5" SM gill nets targeting lake trout were fished on the bottom in 20-85 feet of water at various exploratory 4-24 hour set at locations in both basins June 25-27, 2018. Gill nets were also fished on a suspected lake trout spawning area, Swislow Point (see Figure 24), November 2-6, 2018 and October 17-18, 2019.

All captured lake trout were immediately "fizzed" after being brought to the surface by inserting a No. 20 hypodermic needle through the skin below the lateral line along the central axis of the fish and into the swim bladder to release expanded gas from the bladder. Fish were then placed in a temperature-controlled live tank (iced water in a 30-gallon cooler) on the boat and transferred to a temperature-controlled holding tank at the on-shore surgery and processing site. All tank temperatures were held between 9-11°C (48.2-51.8°F). Fish were measured to the nearest mm in total length and weighed to the nearest gram. All fish large enough to have sonic and/or radio tags implanted within were anaesthetized in a 0.8 gr/10 liter bath of MS-222. During surgery each fish was kept under light sedation and aerated by running a pumped stream of anesthetized water (0.4 gr/10 liter) over the gills. To see if lake trout were consuming smelt, stomachs of lake trout surgically fitted with tags were viewed through the abdominal incision to see if any smelt could be seen through the stomach wall.

Figure 11. Surgical implantation of an F1840 ATS radio tag with trailing antennae into a lake trout from Long Lake. Insert shows a V-16 T/P-4H sonic tag.

If an individual fish weighed 2.3 kg (5.1 lb) or more, both radio and sonic tags were surgically implanted. If less than 2.3 kg, the fish was fitted with either a radio tag (1.0 kg or 2.2 lb minimum fish weight) or a sonic tag (1.3 kg or 2.9 lb minimum fish weight) (Figure 11) to maintain a maximum tag weight (in air) to fish body weight percentage of no more than 2%. Radio tags used were ATS (Advanced Telemetry Systems) F1840 tags (20 gr or 0.7 oz air weight) set to a 14 hour on, 10 hour off duty cycle with a 900 day life expectancy (Aug 2017, June 2018) and continuous with a 1.8-666 day life expectancy (Nov 2018). All radio tags were within the 50 kHz range. Sonic tags used were Vemco V16-T/P-4H tags (26 gr or 0.9 oz) air weight, -5 to 35° C (23-95° F) temp range, maximum depth 34 meters (111 ft), 120 second nominal ping rate, 80-160 second random delay) with a battery life of 10 years and which are temperature and pressure sensitive to provide, in addition to location data, constant depth and body core temperature of tracked fish.

Figure 12. Tagged lake trout in recovery tank.

All released lake trout were also fitted with an internal PIT tag and an external Floy spaghetti tag, both inserted at the base of the dorsal fin. External Floy tags had "DNR Woodruff" and a unique tag number printed on the tag barrel.

Following processing, surgery, and tagging, fish were held until full recovery, and then for an additional 1 to 4 hours prior to being released back into the lake, in a temperature controlled (between 9-11°C) 100-gallon stock tank (Figure 12). For release, fish were transported in the temperature-controlled tank on the boat to one of the two deepest basins in the lake and released from a bobbin-weave dip net (See Figures 23 and 24).


Figure 13. Fred Binkowski operating ATS R2000 hand-held radio tag receiver.


Figure 14. Vemco VR2W stationary sonic tag receiver secured in cage and connected to shore via 1/8" cable being deployed

Radio tagged fish were tracked using a hand-held ATS R2000 receiver (Figure 13) on average 2x/month (daylight hours) during the open water non-spawning season, and 2-3x/day (10 am-midnight) in the fall (November 1-6, 2018, and October 17-21, 2019) while assessing spawning movement. During tracking and after a fish's tag signal was initially heard, the fish was tracked to the the point of greatest radio signal strength where GPS coordinates were marked with and stored within a Lowrance ti7 fish finder at the along with the water depth at that location. Sonic tagged fish were tracked continuously from November 2017 through June 2019, then from September 2019 through May 2020 using an array of 7 stationary VR2W-69kHz Coded Acoustic Receivers (Figure 14) positioned around the lake (Figure 24). Occasionally an 8th receiver would be deployed to provide additional coverage in certain targeted areas. Individual fish depth and body core temperature, and general location, and later littoral and hypolimnion bottom temperatures, were the primary data collected by the stationary receivers. The receivers were deployed in the shadow of shoreline points on the lake which provided the capability to discern the general location of tagged fish within the lake (see Figure 24). While hand tracking with radio telemetry equipment, sonic tagged fish were also actively tracked using a hand-held VR100 - 8 Channel DSP Manual Tracking Acoustic Receiver with a VH110 Directional Hydrophone or a VH165 Omnidirectional Hydrophone (Figure 15).


Figure 15. Vemco VR-100 hand-held sonic receiver (right), with VH110 directional hydrophone (left) and VH165 omnidirectional hydrophone (center).

Both radio and sonic tags were tested for signal distance and strength at various distances (with hand-held radio and sonic, and stationary sonic receivers) in water depths from 30 to 95 ft prior to deployment. When initially tracking telemetered fish in the open water season, parallel transects 250 feet apart in a boat running perpendicular to the main fetch of and across the lake, continuing down the length of the lake until fish were found. Once individual fish patterns were determined, fish were located by searching areas typically frequented by individual fish until they were located and marked. Every hand-held receiver tracking foray continued until all radio tagged fish could be located. When a fish with both sonic and radio tags was located with the radio receiver, sonic hand-held tracking was used to verify the depth and the body core temperature of the fish at that location, with the fish's radio tag data, GPS coordinates, along the total water depth all recorded and stored within the Lowrance ti7 unit.

Smelt

In an attempt to capture a random sample of smelt from Long Lake numerous gear types were deployed including frame dip nets pulled vertically and towed horizontally, graded mesh gill nets (SM sizes .75, 1.0, 1.5, 2.0, 2.5"), hand-held dip nets during the smelt spawning season, a 12' head rope bottom otter trawl, and a 16' foot headrope bottom otter trawl. The 16' trawl (Figure 16) was found to be more effective and utilized then to capture smelt samples in June, August, and October 2019. All captured smelt were measured in total length to the nearest mm, and weighed to the nearest 0.01 gr. A subsample of smelt from June sampling and all the smelt from October sampling were sexed and staged for maturity. Otoliths for age were collected from a stratified random sample within 10 mm length bins from fish captured in the October 2019 sample. Otoliths were mounted and sectioned, and ages were estimated by Connie Isermann at the UW-Stevens Point Fisheries Analysis Center. An age-length key was used to assign ages to all smelt captured in the October 2019 sample. Age data were used to estimate length at age, and to build a catch curve for estimating instantaneous and total annual mortality rates, and survival rates.

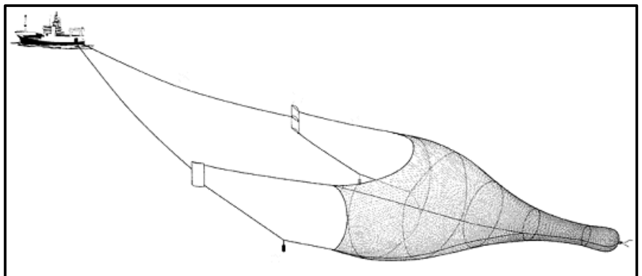


Figure 16. Representative illustration showing deployment of an otter trawl.

Walleye

Walleye were captured as by-catch in gill netting and trawling operations targeting cisco, lake trout, and smelt. A random sample of walleye ranging from fingerling to adult size captured during netting operations October 18, 2019 was collected for size and age, and diet analysis. In addition, two larger adult walleye captured via angling in May 2019 were also collected and processed for size and age, and diet analysis. All walleye were measured in total length to the nearest mm. Otoliths were removed, dried and stored, and stomach contents were identified to lowest taxa possible and all consumed smelt were counted and measured in total length to the nearest mm.

Temperature and Dissolved Oxygen Profiles

Temperature and dissolved oxygen data were collected in Long Lake seasonally at a consistent location in 95 feet of water directly northwest of Swislow Point (Figure 24). Temperature (°C) and Oxygen (mg/l) were collected with a YSI Model 57 Oxygen Meter with a YSI 5739 Probe at the surface and descending depths every 5 feet until the bottom was reached.

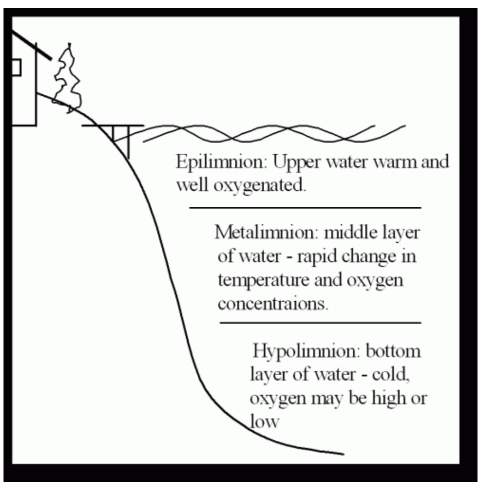
Results

Temperature and Dissolved Oxygen Profiles

Profiles of temperature and dissolved oxygen by depth taken in Long Lake show that the lake is very healthy, exhibiting the classic low productivity of oligotrophic lakes, i.e. extensive areas of water greater than 30 feet of depth and narrow littoral or shoreline zone, as well as sufficient cold temperatures and dissolved oxygen (DO) in deep water during the entire summer and early fall to support coldwater species like cisco and lake trout (Figures 17, 18). The key coldwater smelt eating species in Long Lake, lake trout, are normally found at depths corresponding to 6–13.8°C (42.8-55.4°F) and DO > 4 mg/L (Martin and Olver, 1980). Another important coldwater species in Long Lake, cisco, would also be found in the same zone as lake trout, although cisco can tolerate slightly higher temperatures up to 62°F (17°C) (Becker 1983).

A summary by Michigan State University of the temperature and dissolved oxygen characteristics of lakes like Long Lake in the upper Midwest includes the following information (Michigan State University, 2020):

"Dissolved oxygen and temperature are two fundamental measurements of lake productivity. The amount of dissolved oxygen in the water is an important indicator of overall lake health.



This figure shows how lakes over 30 feet deep can be divided into three layers during the summer.

For approximately two weeks in the spring and fall, the typical lake is entirely mixed from top to bottom, with all the water in the lake being 4 degrees Celsius [39.2°F]. *In the winter there is only a few degrees difference between the water under the ice (0 degrees Celsius) and the water on the bottom (4 degrees Celsius). However, in the summer most lakes with sufficient depth (greater than 30 feet) are stratified into three distinct layers of different temperatures. These layers are referred to as the epilimnion (warm surface waters)* [near-shore zone] *and hypolimnion (cold bottom waters) which are separated by the metalimnion, or* ***thermocline layer, a stratum of rapidly changing temperature****. The physical and chemical changes within these layers influence the cycling of nutrients and other elements within the lake.*

During summer stratification the thermocline prevents dissolved oxygen produced by plant photosynthesis in the warm waters of the well-lit epilimnion from reaching the cold dark hypolimnion waters. The hypolimnion only has the dissolved oxygen it acquired during the short two-week spring overturn. This finite oxygen supply is gradually used by the bacteria in the water to decompose the dead plant and animal organic matter that rains down into the hypolimnion from the epilimnion, where it is produced. With no opportunity for re-supply the dissolved oxygen in the hypolimnion waters is gradually exhausted. The greater the supply of organic matter from the epilimnion and the smaller the volume of water in the hypolimnion the more rapid the oxygen depletion in the hypolimnion. Highly productive eutrophic lakes with small hypolimnetic volumes can lose their dissolved oxygen in a matter of a few weeks after spring *overturn ends and summer stratification begins. Conversely, low productive oligotrophic lakes with large hypolimnetic volumes can retain high oxygen levels all summer."*

Figures 17 and 18 illustrate the summer, early fall, and late fall temperature and dissolved oxygen profiles in Long Lake which illustrate well several key characteristics of Long Lake as an oligotrophic lake:

- By early June Long Lake was typically stratified with a well-established thermocline. Again – the thermocline is the depth zone of rapid temperature decrease in the lake which physically separates the water of the warm surface layer (epilimnion) and the cold deep layer (hypolimnion). During the time period the thermocline is in place (typically in water depths between 20 to 30), the two layers of water, surface and deep, do not mix, and oxygen readily present from plants and the atmosphere in the surface layer can not move into the cold deep layer.
- During the present study, water temperatures in the epilimnion (warm surface layer) in summer averaged in the mid-70s F, while temperatures in the hypolimnion (cold deep layer) averaged in the mid-40s F.
- Lake trout and cisco need cold water (generally < 55°F), and water with oxygen levels >4 mg/liter to live in. All of the hypolimnion (cold deep water from 25 to 95 feet) provided the needed temperatures for the entire summer-early fall period of stratification (when a thermocline is present). By early fall though, the dissolved oxygen in the depths below 60 feet decreased below the 4 mg/liter needed by lake trout and cisco due to the oxygen being used up by the bacterial decomposition of organic matter near the bottom.
- During the thermocline period a small dip in oxygen was consistently observed in Long Lake within the thermocline due to the large amount of plankton and often fish using oxygen that were occupying these depths.
- In the fall as days became shorter and air temperatures cooled, the water temperatures in the shallow epilimnion also dropped. As the temperature of the surface waters cooled the density differences between water in the epilimnion and the hypolimnion decreased. "Turn-over" occurred on Long Lake in October 2017, 2018 and 2019 after epilimnion temperatures decreased to 50°F assisted by strong fall winds which created enough wave energy in the lake to cause mixing of the waters in the surface epilimnion with waters in the deep hypolimnion. Water temperatures were nearly constant at this time from the surface to the bottom and oxygen levels once again increased throughout the water column except for a consistent lag near the bottom due to ever present decomposition factors.
- Generally, temperature and dissolved oxygen data from Long Lake indicate that the lake remains a healthy oligotrophic system.

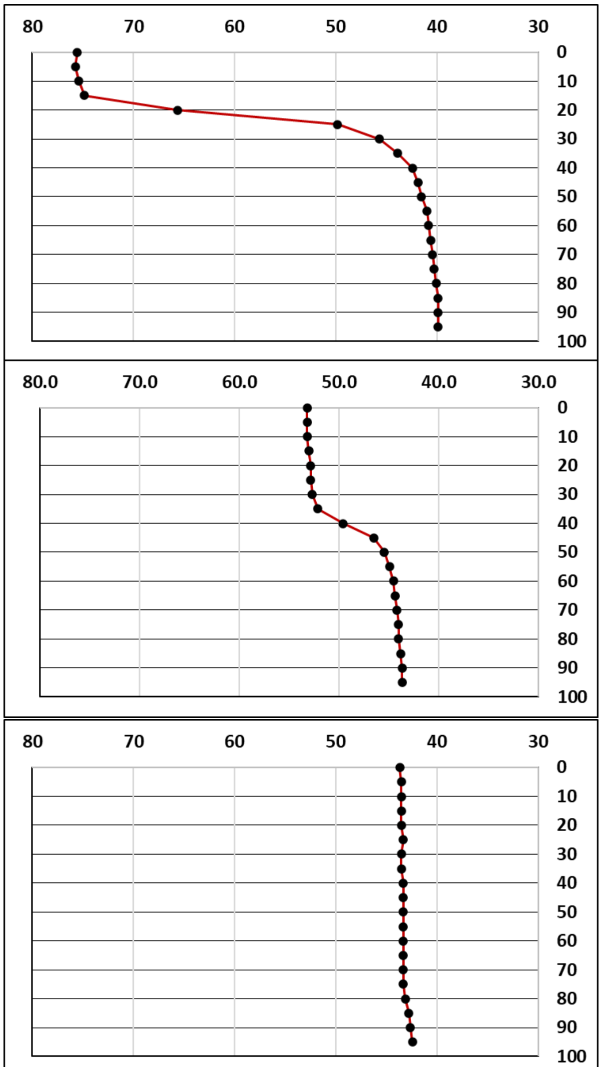


Figure 17. Temperature profiles (°F) of surface (top header of each chart) to 95 ft (bottom of each chart), Long Lake. Top chart July 7, 2018, middle chart Oct 23, 2017, bottom chart Nov 3, 2018. X-Axis (horizontal listing) across the top of each chart is temperature °F between 80°F on the left and 30°F on the right. Note stratification (thermocline or region of highest temperature gradient) in top chart from July between depths of 20 to 30 feet. Also note the reduction of the thermocline in October (middle chart) and the complete mixing with constant temperature from surface to bottom by November.

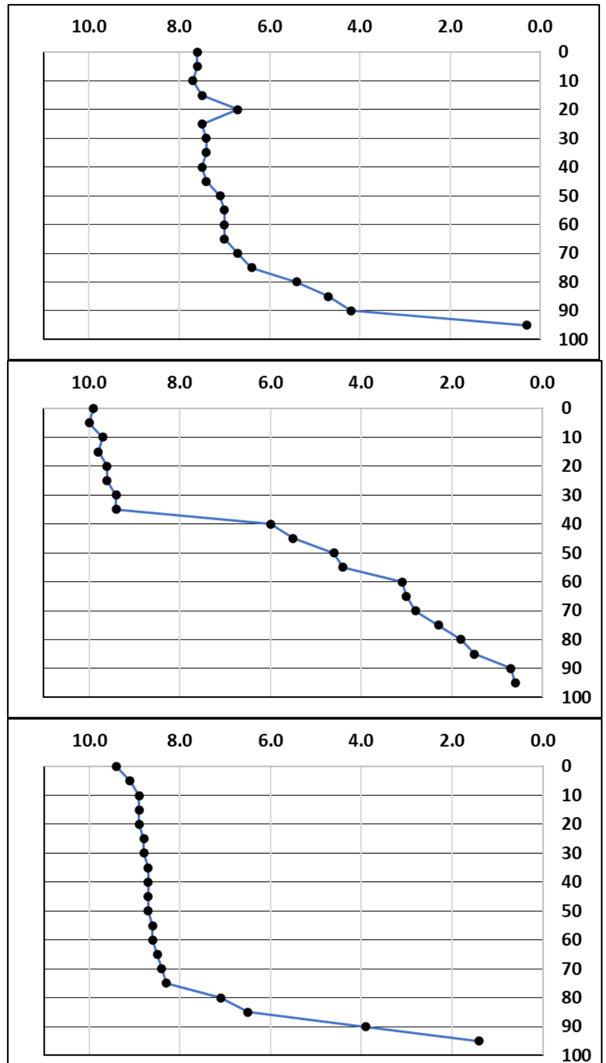


Figure 18. Dissolved oxygen (DO) profiles (mg/liter), surface (top header of each chart) to 95 ft (bottom of each chart), Long Lake. Top July 7, 2018, Middle Oct 23, 2017, bottom chart Nov 3, 2018. X-Axis (horizontal listing) across the top of each chart is DO between 10 mg/l on the left and 0 mg/l on the right. Note DO levels at or above 4 mg/l in entire water column down to 90 ft in July (top); Oct (middle) DO levels are reduced to below the 4 mg/l needed by lake trout and cisco in waters deeper than 60 ft; in Nov (bottom) that after turnover DO levels are refreshed with all water greater than 90 feet having 4 mg/l or more.

Cisco

Figure 19. Cisco being stocked off fish hauling truck into Long Lake off Carter/Mason property deepwater stocking site, October 18, 2017.

With the eggs collected and fertilized from cisco captured in North Twin Lake in November 2016, approximately 10,000 extended growth cisco were reared at the UWM/SFS aquaculture lab and stocked into Long lake on October 18, 2017 (Figure 19). At stocking the cisco averaged 178 mm (7.0 in) in total length and an estimated average of 50 grams in weight which is twice the size in length, and 5 times the average weight of wild cisco fingerlings (Fisher and Fielder 1998). The stocking rate into Long Lake was 1.12 fish/acre.

Native cisco were captured in every 2.5" SM exploratory gill net set, and in both UWM/SFS standard cisco gill net sets off the Carter/Mason property in Long Lake during August 2018 and August 2019 (Figure 20), indicating the presence of native cisco throughout the lake in the hypolimnion. Native cisco were also captured by DNR in their standard vertical gill net sets fished in June 2018. Table 3 lists the numbers of native Long Lake cisco captured and sampled for age, growth and diet in June and August 2018 and August 2019. All native cisco captured and dissected were adult females. No males were found within the random samples of fish examined.

Figure 20. Native cisco, age 9-22 years, from Long Lake near Phelps, August 2018.

Cisco sampled in June and August 2018 averaged 327 mm (12.9") in total length (both samples) and 16 and 17 years of age respectfully. Cisco sampled in August 2019 averaged 336 mm (13.2") in total length but were not aged (Tables 4-7).

Date	Gear	Mesh Size	Effort	No. Cisco Caught	No. Cisco Kept	CPE	CPE Unit
26-Jun-18	DNR GMVGN	variable	2 gangs	10	10	5	No/gang
30-Aug-18	SFS SCGN	2.5" SM	500 ft	23	9	4.6	No/100 ft
20-Aug-19	SFS SCGN	2.5" SM	500 ft	20	8	4	No/100 ft

Table 3. Cisco captured, kept, CPE from standard DNR gill nets, and standard UWSFS cisco gill nets, 2018 and 2019.

Sample Date	Ave TL (mm)	Ave TL (in)	Ave Wt (gr)	Ave Wt (oz)	Ave Age	N
Jun-18	327	12.9	301	10.6	16	10
Aug-18	327	12.9	306	10.8	17	9
Aug-19	336	13.2	351	11.9	--	8

Table 4. Average length, weight, estimated age, and sample size of cisco sampled from Long Lake 2018 and 2019.

TL (mm)	TL (in)	Wt (gr)	Sex	Maturity	Age	Year Class	Stomach Contents
297	11.7	203	F	Mat	17	2001	chronomids
311	12.2	259	F	Mat	14	2004	chronomids
320	12.6	232	F	Mat	14	2004	chronomids
322	12.7	312	F	Mat	13	2005	chronomids
324	12.8	290	F	Mat	16	2002	chronomids
327	12.9	307	F	Mat	17	2001	unk larval fish
332	13.1	272	F	Mat	22	1997	chronomids
340	13.4	354	F	Mat	17	2001	chronomids
344	13.5	399	F	Mat	9	2009	empty
354	13.9	377	F	Mat	17	2001	chronomids

Table 5. Length, weight, sex, estimated age, and stomach contents of cisco sampled from Long Lake June 26, 2018

TL (mm)	TL (in)	Wt (gr)	Sex	Maturity	Age	Year Class	Stomach Contents
293	11.5	206	F	Mat - Gravid	16	2002	1 fnlg yellow perch
305	12.0	243	F	Mat - Gravid	16	2002	1 fnlg yellow perch
310	12.2	286	F	Mat - Gravid	15	2003	1 fnlg yellow perch
327	12.9	343	F	Mat - Gravid	15	2003	6 fnlg yellow perch
333	13.1	378	F	Mat - Gravid	18	2000	2 fnlg yellow perch
340	13.4	293	F	Mat - Gravid	14	2004	empty
340	13.4	337	F	Mat - Gravid	21	1998	empty
347	13.7	288	F	Mat - Gravid	16	2002	1 fnlg yellow perch
347	13.7	380	F	Mat - Gravid	21	1998	empty

Table 6. Length, weight, sex, estimated age, and stomach contents of cisco sampled from Long Lake August 30, 2018

TL (mm)	TL (in)	Wt (gr)	Sex	Maturity	Stomach Contents
311	12.2	281	F	Mat - Gravid	zooplankton (daphnia?), unk fish
320	12.6	305	F	Mat - Gravid	zooplankton (daphnia?), unk fish
330	13.0	354	F	Mat - Gravid	empty
334	13.1	296	F	Mat - Gravid	1 perch fnglng, 1 bluegill fnglng, daphnia?
343	13.5	334	F	Mat - Gravid	3 bluegill fnglng
344	13.5	363	F	Mat - Gravid	zooplankton (daphnia?), unk fish
344	13.5	395	F	Mat - Gravid	unk fish
365	14.4	482	F	Mat - Gravid	1 bluegill fnglng

Table 7. Length, weight, sex, and stomach contents of cisco sampled from Long Lake 20 August 20, 2019

Stomach contents of cisco examined in June 2018 consisted primarily of chironomid larvae (bottom dwelling lake fly larvae), fingerling yellow perch in August 2018, and fingerling bluegill and zooplankton in August 2019 (Figure 21; Tables 5, 6 and 7).

No stocked cisco were captured during cisco netting operations in 2018 or 2019.

Figure 21. Fingerling yellow perch (l) and bluegill (r) found as dominant food items in stomachs of Long Lake cisco August 2018 and 2019.

Lake Trout

Capture Results - Through the total effort of angling and gillnetting combined from August 2017 – October 2019, 16 lake trout were captured of which 6 had a sonic tag implanted within the body cavity, 4 had a radio tag implanted, 3 had both a sonic and a radio tags implanted, 1 was PIT tagged only, and 2 died after being removed from the gear (Figures 22 and 23, Table 8). One of the mortalities was a fish deep hooked in the gills after being caught angling, and the other was a fish that was severely injured in the gill net after being attacked by a large predator (musky?) ultimately causing its death. All the lake trout captured in gill nets were caught only by their teeth and maxillaries which allowed them to continue to ventilate their gills and remain alive and well in the net prior to removal. None were actually "gilled" as the mesh size (2.5 inch stretch mesh) was too small to allow the fish to be caught in the net at the point of their gills.

Figure 22. mature female Lake trout captured in a gill net, fit with radio and sonic tags and released August 20, 2019.

Figure 23. Mark Swislow, LLPLD Board Member, releasing the first lake trout fit with telemetry tag back into Long Lake, August 29, 2017.

Table 8. Lake trout captured during netting and angling operations on Long Lake August 2017 to October 2019; total length, weight, sex (color coded), maturity, fin clip, stocking year, age at capture, radio and/or sonic tag numbers, PIT and floy tag numbers, capture gear.

Date	TL (mm)	TL (in)	Wt (kg)	Wt (lbs)	Sex/Mat	Clip	Year Stocked	Age at capture	Radio Tag	Sonic Tag	PIT Tag No.	Floy Tag No.	Gear
29-Aug-17	557	21.9	1.43	3.2	M/Mat	RV	2013	5	none	6405/06	982000409791627	2001	angling
29-Aug-17	528	20.8	1.24	2.7	M/Mat	RV	2013	5	none	6407/08	982000409792125	2002	angling
29-Aug-17	553	21.8	1.55	3.4	M/Mat	RV	2013	5	none	6409/10	982000409791693	2003	angling
29-Aug-17	552	21.7	1.48	3.3	M/Mat	RV	2013	5	none	6411/12	982000409791538	2004	angling
29-Aug-17	613	24.1	2.45	5.4	F/Mat	RV	2013	5	50.104	6413/14	982000409792101	2005	angling
29-Aug-17	445	17.5	0.67	1.5	Unk	RV	2013	5	none	none	982000409792319	none	angling
30-Aug-17	595	23.4	2.18	4.8	M/Mat	RV	2013	5	50.063	none	982000409791835	2006	angling
30-Aug-17	552	21.7	1.67	3.7	M/Mat	RV	2013	5	50.002	none	982000409791713	2007	angling
30-Aug-17	491	19.3	1.02	2.2	M/Mat	RV	2013	5	none	6414/15	982000409791980	2008	angling
30-Aug-17	618	24.3	2.25	5.0	M/Mat	RV	2013	5	none	none	Dead - not tagged	none	angling
24-Oct-17	538	21.2	1.35	3.0	M/Mat	RV	2013	5	none	6421/22	452F240753	2009	angling
24-Jun-18	510	20.1	1.10	2.4	M/Mat	LV	2012	7	50.084	none	4B162B0908	2010	angling
24-Jun-18	549	21.6	1.63	3.6	M/Mat	RV	2013	6	50.045	none	6C00013849	2011	angling
3-Nov-18	651	25.6	2.54	5.6	M/Mat	RV	2013	6	50.142	6425/26	4B1620150E	2012	gill net
3-Nov-18	625	24.6	2.13	4.7	M/Mat	RV	2013	6	none	none	Dead - not tagged	none	gill net
20-Aug-19	573	22.6	2.2	4.9	F/Mat	RV	2013	7	50.21	6403/04	6C00012856	2013	gill net

Fifteen of the 16 lake trout captured had a right ventral fin clip, i.e. fifteen fish from the 4389 fish (2012 year class) stocked in mid May 2013 off the Carter/Mason Property on the northwest shore (see Figure 24) close to deep water, while one of the captured fish had a left ventral fin clip, i.e. one of the 8327 fish (2011 year class) stocked in late April 2012 off the public boat landing adjacent to shallow water at the northeast end of the lake (see Figure 24). None of the 5573 lake trout stocked in October 2005 (2005 year class; unmarked) off the public boat landing were captured during angling or netting operations.

Of the 16 lake trout that were captured, sex and maturity was determined on 15, 2 mature females (both gravid with developed eggs) and 13 mature male with developed testes. Average total length of all lake trout captured during the study was 559 mm (22.0 in, SD 53 mm) and average weight was 1.7 kg (3.7 lbs, SD 0.6 kg). Grouping captured fish by season's growth or age (i.e size at the end or beginning of a growing season) showed that at age 5, or five season's growth, the lake trout averaged 549 mm total length (21.6 in, SD 51 mm) and 1.7 kg in weight (3.5 lbs, SD 0.5 kg), and at age 7, or 7 season's growth, 616 mm in total length (24.3 in, SD 40 mm) and 2.3 kg in weight (5.0 lbs, SD 0.2 kg) (Table 9)

Table 9. Lake trout, Long Lake, August 2017-August 2019, average total length, average weight for all fish captured, and for fish grouped as 5 year old fish (5 season's growth) and 7 year old fish (7 season's growth).

	Ave TL (mm)	SD Ave TL (mm)	Ave TL (in)	Ave Wt (kg)	Ave Wt (lbs)	SD Ave Wt (kg)	n
All Captured Lake Trout	559	53	22.0	1.7	3.7	0.6	16
5 Season's Growth	549	51	21.6	1.6	3.5	0.5	11
7 Season's Growth	616	40	24.3	2.3	5.0	0.2	3

Smelt Consumption by Lake Trout in Long Lake - Lake trout consumption of smelt was documented as smelt could clearly be seen through stomach walls in 9 of 13 lake trout via incisions made to implant internal sonic and/or radio telemetry tags. Smelt were found in the stomach of 1 of the 2 lake trout that died during sampling.

Radio and Sonic Telemetry Results, Tag Testing - The array of stationary passive sonic receivers (Figure 24) was initially deployed November 1, 2017. Radio and sonic tag reception tests showed that radio tags could be heard in 90 feet of water up to 500 feet distance from the specific location of the tag, and up to 1000 feet with a tag in 30 feet of water. Sonic tags could be consistently heard by both the handheld and stationary receivers at distances up to 1000 feet i.e. all transmitted signals not interfered with by tag collision (i.e. two tags sending a signal at the same time resulting in neither full pinging sequence to be recorded by a receiver) were received, but intermittent signals could be received up to 5000+ feet depending upon the absence or presence of background noise from motor boats or wave action. Although the sonic tags were programmed to send out signals at random time intervals to minimize tag collision, tag collision did frequently occur resulting in frequent gaps of minutes to rare gaps of several hours in the receiver data for individual tags. The number of pinging sequences received from individual tags per hour was 2-3 times less during the primary boating season (June-August) due to sound interference from boat motor noise. Reception under the ice was exceptionally good and a receiver strategically placed could successfully receive full tag pinging sequences from over 15,000 feet. The occurrence and frequency of signals from individual sonic tagged fish recorded within various time periods (e.g. spawning period) by individual receivers was used to discern the general location(s) of individual fish during those periods.

Radio and Sonic Telemetry Results, Summer-Early Fall Patterns - Telemetry data, stationary and hand-held sonic and hand-held radio, showed consistent patterns of lake area usage by telemetered lake trout outside of the fall spawning season. While tagged lake trout were found throughout the lake in the hypolimnion during the period of thermocline (June to mid October), fish generally were found most often in 1 of 4 different general areas of the lake (Figure 24). Area 1 towards the southwest end of the lake off the point of "Bonnie Lodge" and area 4 at the northeast end of the lake often held high concentrations of smelt depending on the wind direction, and when smelt were packed into these areas, tagged lake trout were often found there. Area 2, the center of the southwest deep basin between Rowe Point and Hazen's Lodge was the area most commonly used by telemetered lake trout outside of the spring and fall non-thermocline seasons if a persistent strong wind was not blowing in either direction along the fetch of the lake. Area 3 along the northwest shore, northeast of area 2, was a secondary common use area by some of the telemetered fish. These patterns were consistent enough that finding tagged fish became very efficient as radio and hand-held sonic telemetry data were collected and plotted on the lake map in the ti7 Lowrance unit.

Fish regularly moved from one identified common use area to another. On August 20, 2019 male lake trout with radio tag 50.142 and sonic tag 6425/26 was located within Area 2 (Figure 24) in the south west deep basin at 13:00. The signal while very strong lasted only a few minutes indicating the fish was moving. After relocating the fish 500 feet to the northeast, the signal was soon lost again. After finding the fish again several more times as it continued moving, the general direction of movement of the fish was discerned and the fish was "followed" along this track for 1 hour moving northeast until it finally stopped in the far northeast corner of the lake in 40 ft of water in the bay off the boat landing where it remained for at least 45 minutes until tracking was discontinued. While continuing to track the fish at the end of its foray, the Ti7 Lowrance sounder showed massive schools of smelt in this bay on this same day during which there was a consistent 10-15 mph southwest wind blowing into this bay.

Radio and Sonic Telemetry Results, Fall, Spawning Sites and Patterns - Sonic array data collected by the receiver array in November 2017 indicated that 3 of the 6 living sonic tagged lake trout, 2 males (6411/12, 6415/16) and 1 female (6413/14) were concentrated in early November near Swislow Point, a rocky steep point in 40 to 60 feet of water along the central northeast shoreline of the lake (see Figure 24). The array also showed that 2 of these 3 fish (6413/14, 6415/16) moved from Swislow Point south to an area directly off the mouth of Thoroughfare Creek and Bonnie Lodge on November 6 staying in this area for 2 days till November 8. The remaining 3 sonic tagged fish, 3 males (6405/06, 6409/10, 6421/22) were already at the area off Thoroughfare Creek and Bonnie Lodge on November 1 where they remained until November 8.

Sonic array data collected in the fall of 2018 showed a similar pattern with the three remaining live sonic tagged fish, 1 female (6413/14) and 2 males (6409/10, 6411/12) concentrating off Swislow Point in mid to late October in 10 to 56 feet of water before moving to and remaining in the area off Thoroughfare Creek and Bonnie Lodge for 4-5 days from October 24-29 (males) and for 2 days from November 5-6 (female).

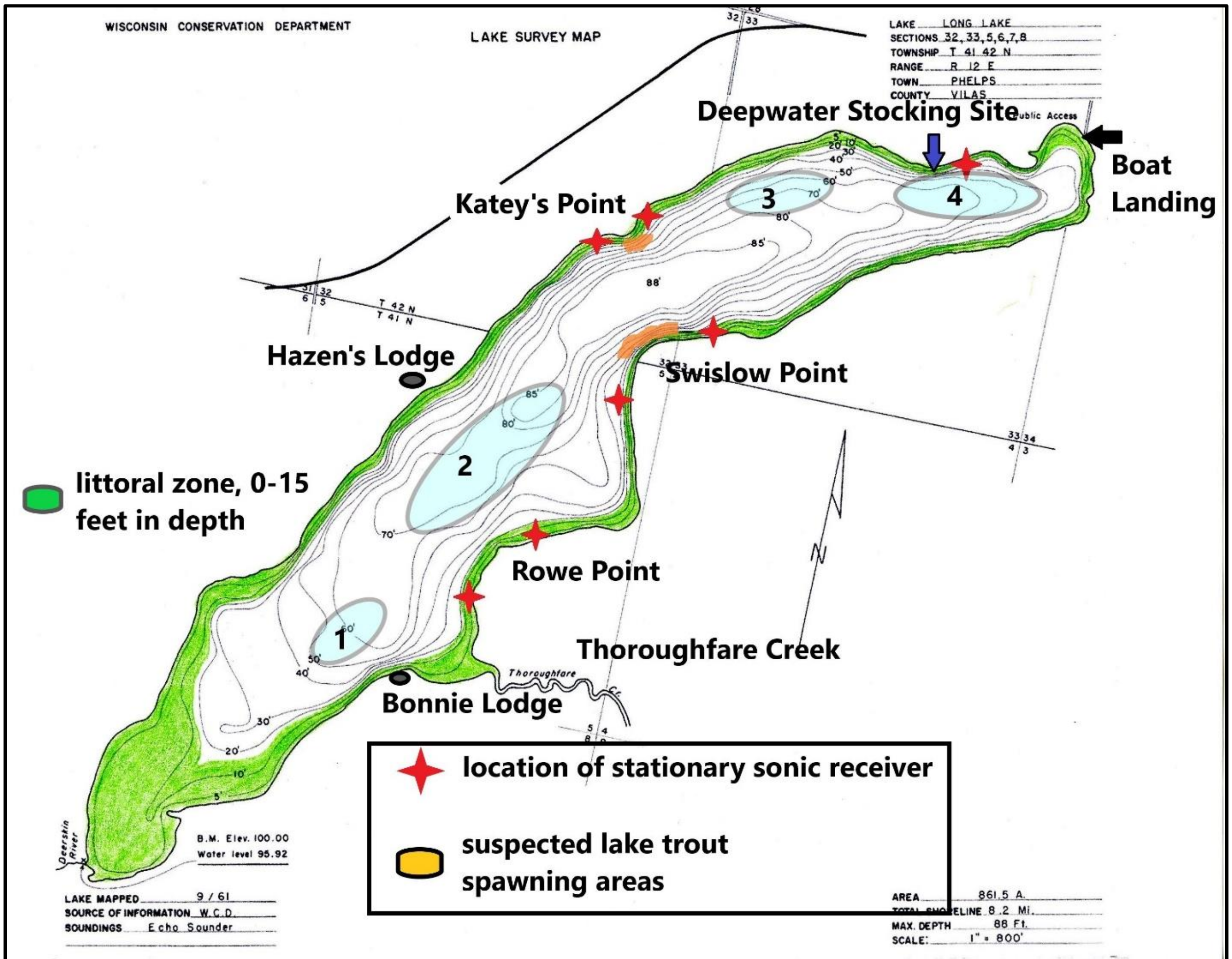


Figure 24. Map of Long Lake near Phelps, Vilas County, Wisconsin showing depth contours, littoral zone, local reference points, deep-water stocking site (Carter/Mason property), boat landing, locations of stationary VR2W sonic receivers, suspected lake trout spawning areas, major lake trout summer-early fall use areas (1-4).

Radio and sonic tagged lake trout were actively tracked with the hand-held sonic and radio receivers from November 1-6, 2018 to pin-point the precise location during this time period of radio tagged fish including the only female tagged at the time (female 6413/14, which carried both sonic and radio tags). On November 1 and 2, 2018 this female was holding very close to Swislow Point at various depths from 20 to 60 feet on and off the bottom. Sonic telemetry data from stationary receivers collected October 1 through November 6 also showed that female 6413/14 was in close proximity to Swislow Point through most of the month of October through November 4. On November 3 and 4 she went into what appeared to be a resting (post spawn?) mode on the bottom in 57 feet of water in a bay area directly adjacent (south) of Swislow Point. Radio telemetry data verified the sonic array data detailed above for female 6413/14, by documenting her movement from Swislow Point after November 4 one mile to the south to spend 2 days actively moving (post spawn feeding?) in the area off Thoroughfare Creek – the same area she was found in early November 2017 by the sonic array. During the period female 6413/14 was off Thoroughfare Creek and Bonnie Lodge, sonar readings on the Lowrance ti7 showed large concentrations of smelt in the area, 15 to 65 feet down over water depths of 30 to 75 feet.

During the period of optimum water temperatures for lake trout spawning in the fall of 2019, October 17-21, female 6413/14, which had been found on Swislow Point in late October-early November in 2017 and 2018, was found across the lake on a different very steep and rocky point (Katey's Point", see Figure 24) where a small creek (Kime's Creek) enters the lake. By the fall of 2019 when intensive tracking of telemetered fish was planned during the spawning season, high mortality of telemetered lake trout during the periods of July - August 2018, and July -September 2019, resulted in the opportunity to track only 2 sonic and radio tagged fish (male 6425/26 tagged Nov 3, 2018) and the female 6413/14), and 1 sonic tagged fish (male 6409/10) to provide data on spawning movements in 2019. (See section below detailing suspected lake trout mortalities due to walleye trolling).

Radio and Sonic Telemetry Results, Lake Trout Spawning Behavior - Sonic data on 2 of the telemetry tagged lake trout that were alive during both the 2018 and 2019 spawning seasons, male (6411/12) and female (6413/14), showed distinct movement patterns similar to lake trout spawning behaviors that have been described in the literature as ***hovering or surface finning***, ***traveling***, ***sinking***, ***spawning*** (gamete release), and ***ascending*** (Binder et al. 2015). After living in the hypolimnion at depths of 30 to 60 feet for months through the summer and early fall, both male 6411/12 and female 6413/14 began spending hours in the evening and during the night at the lake surface or within 10 feet of the surface in early October after littoral water temperatures had decreased to 55°F (12.8°C). In 2018, male 6411/12, after consistently living in water depths, from September 27 to October 6, of 37 to 62 feet with a body core temperature of 41 to 46°F (5.0 to 7.8°C), made his initial ascent to the surface at 20:16 (CDST) on October 6 when littoral zone temperature (bottom at 3 ft) was 54.7°F (12.6°C) (Temperature profiles illustrated in Figure 25). This initial ascent to the surface was preceded on October 6, 2018 by 3 separate 5 to 10-minute forays between 13:32 and 18:27 from depths of 40-50 feet to depths of 20 to 28 feet. During a final ascending foray beginning at 18:47 on October 6 male 6411/12 spent 84 minutes at depths of 11-25 feet before coming to the surface for 5 minutes, then descended to and spent the next 182 minutes at depths of 4.5 to 27 ft (average 17.1 ft) before finally surfacing again at 23:28. Male 6411/12 spent the next 176 minutes close to the surface (average depth of 7.9 ft) before retiring at 02:24 on October 7 to 45.7 ft of water where it remained motionless (resting?) until 04:04 on October 7 at an average depth of 37.1 ft until 12:36. The fish repeated the early part of this pattern ("***finning"***? and "***traveling***"?) during the evening and nights of October 7-8 to 15-16, 2018 (total of 9 nights), although after the fish came to the surface in this period it spent the entire night primarily at or close to the surface, interrupted only by bouts where it quickly "***sank***" from depths of 0-3 ft to depths of 10 to 57 feet typically remaining at those depths for less than 3 minutes ("***spawning***"?) before quickly moving back to the surface ("***ascending***"?). During 11 sinking episodes recorded during the nights of October 12-13 through 15-16, where male 6411/12 began at or near the surface, he sank an average of 35 feet in 6.0 minutes, spent 1 minute or less at the bottom of the descent, then spent an average of 7.4 minutes rising back to the surface. Total time from the surface to the bottom and back to the surface averaged 13.0 minutes (Table 10, Figure 26). Generally, the deeper the final descent depth the faster he sank (Figure 27).

Female 6413/14 displayed very similar ascending and descending behavior patterns although she displayed this behavior only through the course of 2 nights, October 7-8 and 8-9, 2018. During 10 of these bouts, starting at depths from 0 to 22 feet she "***sank"*** an average of 14 feet to bottom depths of 9 to 35 feet, like the male, spending little time at the bottom (***"spawning?)*** before using an average of 7.5 minutes to ascend back to or close to the surface ("***ascending***") with an average total time of 15 minutes to move to the bottom and back up again (Table 11 and Figure 28). She displayed the same descent timing pattern as the male, generally the deeper the descent the faster she sank (Figure 28). Average core body temperature of female 6413/14 increased from 41.6°F (5.3°C) on October 7 to 51.8°F (11.0°C) on October 8 after initiating surfacing ("***finning***"?) behavior on October 7. Average core body temperature of both female 6413/14 and male 6411/12 increased and then decreased regularly over the period of October 9-13 as each fish would spend time in the warmer surface waters during the nights and in the colder deeper waters during the day (Figure 25).

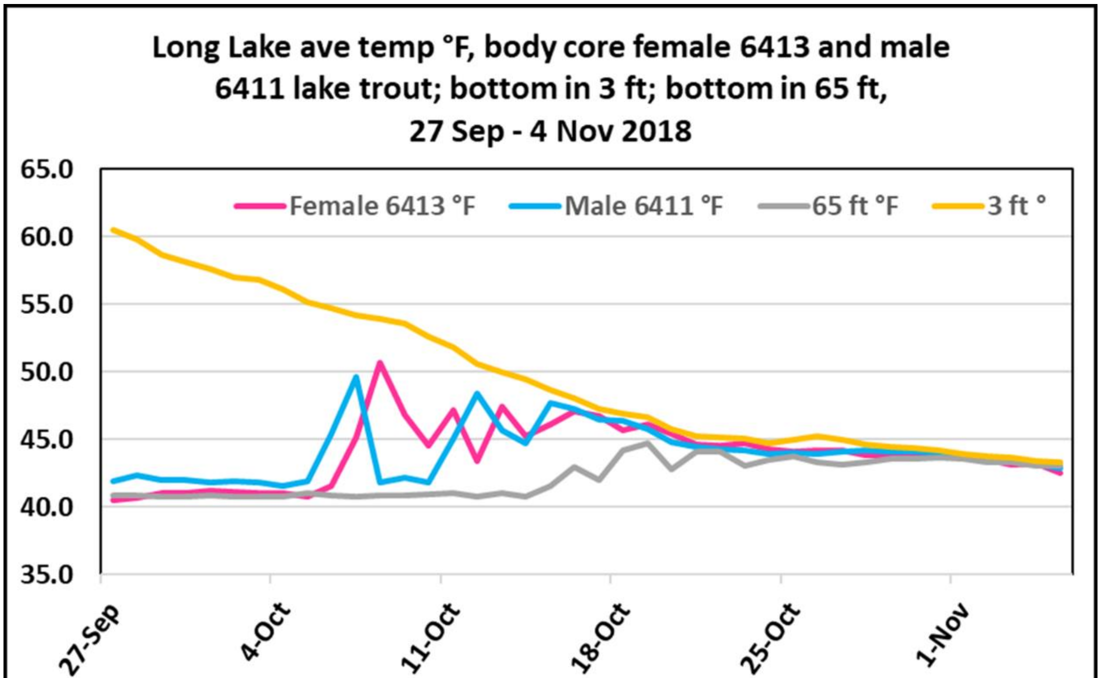


Figure 25. Average daily water temperatures of littoral zone, hypolimnion, and body core temperatures of female 6413/14 and male 6411/12, Long Lake near Phelps, Sep 27 – Nov 4, 2018.

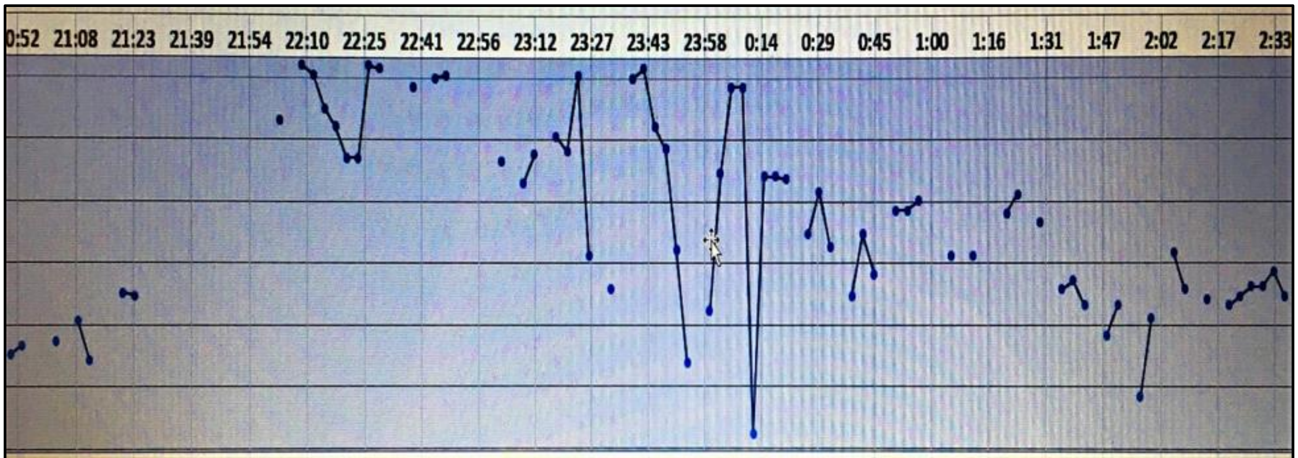


Figure 26. Depths and suspected spawning bouts exhibited by lake trout male 6411/12, Oct 13, 20:52 through Oct 14, 02:33, x-axis is military time scale CSDST; y-axis is depth from surface (top) to 60 feet (bottom) at 10 foot intervals (horizontal lines), Long Lake near Phelps. Blue shaded background means hours of darkness.

Table 10. Time and depths characteristics of possible spawning bouts of male lake trout 6411/12 Oct 12-16, 2018, Long Lake near Phelps.

Date	Start Depth (ft)	Starting "Surface" Time (CDST)	Time reached "Bottom" (CDST)	"Bottom" Depth (ft)	Total Sink Distance ft	Sink Time (min)	End "Re-surface" Time (CDST)	Rise Time (min)	Total Rise Distance (ft)	End "Surface" Depth	Seconds Down	Seconds Up	sec/ft down	sec/ft up	Total Time (min)
12-Oct-18	0.0	0:57	1:00	44.3	44.3	0:03	1:06	0:06	34.3	10.0	180	360	4	10	0:09
13-Oct-18	0.0	23:24	23:33	34.3	34.3	0:09	23:39	0:06	34.3	0.0	540	360	16	10	0:15
13,14 Oct 18	0.0	23:42	23:54	46.2	46.2	0:12	0:06	0:12	46.2	0.0	720	720	16	16	0:24
14-Oct-18	1.5	0:09	0:12	57.7	56.2	0:03	0:15	0:03	41.8	15.9	180	180	3	4	0:06
15-Oct-18	0.0	21:39	21:45	10.9	10.9	0:06	21:54	0:09	10.9	0.0	360	540	33	50	0:15
15-Oct-18	2.0	22:15	22:21	33.3	31.3	0:06	22:24	0:03	29.3	4.0	360	180	12	6	0:09
15-Oct-18	3.0	22:57	23:00	15.9	12.9	0:03	23:09	0:09	9.4	6.5	180	540	14	57	0:12
15,16 Oct 18	0.0	23:39	23:48	44.3	44.3	0:09	0:00	0:12	44.3	0.0	540	720	12	16	0:21
16-Oct-18	0.0	0:42	0:45	39.3	39.3	0:03	0:51	0:06	38.8	0.5	180	360	5	9	0:09
16-Oct-18	0.0	1:12	1:21	26.9	26.9	0:09	1:30	0:09	26.9	0.0	540	540	20	20	0:18
16-Oct-18	0.5	1:33	1:36	39.3	38.8	0:03	1:42	0:06	15.4	23.9	180	360	5	23	0:09
Average	**0.0**			**41.6**	**41.6**	**6.0**		**7.4**	**38.3**	**3.3**	**480**	**480**	**11.8**	**12.2**	**0:13**

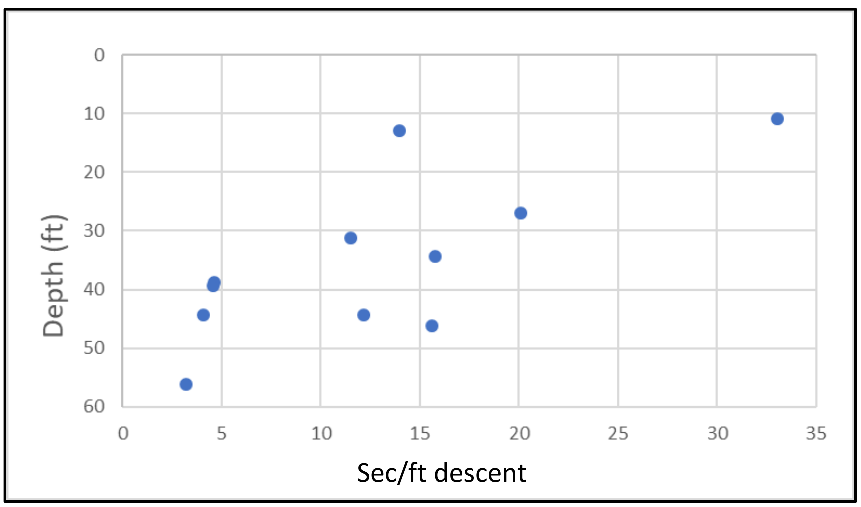


Figure 27. Relationship between depth and possible spawning bouts, and rate of descent from surface to spawning depth, male lake trout 6411/12, Long Lake of Phelps, Oct 2018

Table 11. Time and depths characteristics of possible spawning bouts of female lake trout 6413/14 Oct 7-8, 2018, Long Lake near Phelps.

Date	Start "Surface" Depth (ft)	Start "Surface" Time CDST)	Time Reached "Bottom" (CDST)	"Bottom" Depth (ft)	Total Sink Distance ft	Sink Time (min)	"Re-surface" Time (CDST)	Rise Time (min)	Total Rise Distance ft	End High Depth (ft)	Seconds Down	Seconds Up	sec/ft down	sec/ft up	Total Time (min)
7-Oct-18	4.5	19:18	19:27	23.9	19.4	0:09	19:30	0:03	20.4	3.5	540	180	28	9	0:12
7-Oct-18	5.0	21:12	21:15	24.9	19.9	0:03	21:24	0:09	24.9	0.0	180	540	9	22	0:12
7-Oct-18	0.0	21:23	21:36	9.0	9.0	0:13	21:39	0:03	8.0	1.0	780	180	87	23	0:16
7-Oct-18	0.0	21:24	21:27	14.9	14.9	0:03	21:33	0:06	14.9	0.0	180	360	12	24	0:09
8-Oct-18	0.0	0:12	0:15	9.0	9.0	0:03	0:21	0:06	7.0	2.0	180	360	20	51	0:09
8-Oct-18	21.9	8:03	8:06	34.8	12.9	0:03	8:18	0:12	23.9	10.9	180	720	14	30	0:15
8-Oct-18	10.9	8:18	8:27	29.8	18.9	0:09	8:48	0:21	6.9	22.9	540	1260	29	183	0:30
8-Oct-18	8.5	18:21	18:33	18.9	10.4	0:12	18:39	0:06	12.9	6.0	720	360	69	28	0:18
8-Oct-18	6.0	18:51	19:00	14.9	8.9	0:09	19:03	0:03	12.4	2.5	540	180	61	15	0:12
8-Oct-18	10.4	23:48	23:57	28.8	18.4	0:09	0:03	0:06	16.9	11.9	540	360	29	21	0:15
Average	**6.3**			**20.0**	**13.7**	**7.3**		**7.5**	**14.6**	**5.4**	**427**	**460**	**36**	**43**	**0:15**

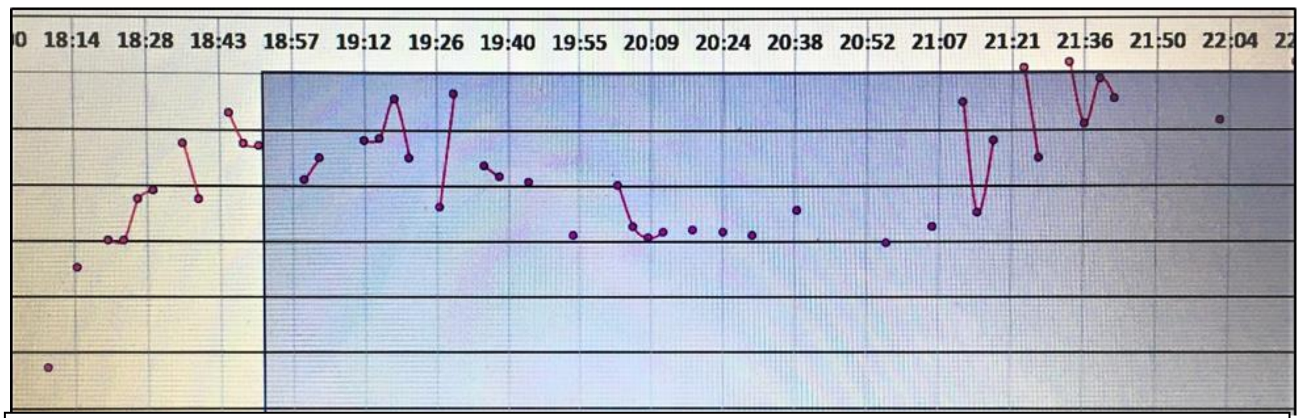


Figure 28. Depths and suspected spawning bouts exhibited by lake trout female 6413/14, Oct 7, 18:09 through 22:03, x-axis is military time scale CSDST; y-axis is depth from surface (top) to 60 feet (bottom), at 10 foot intervals (horizontal lines), Long Lake near Phelps. Blue shaded background means hours of darkness

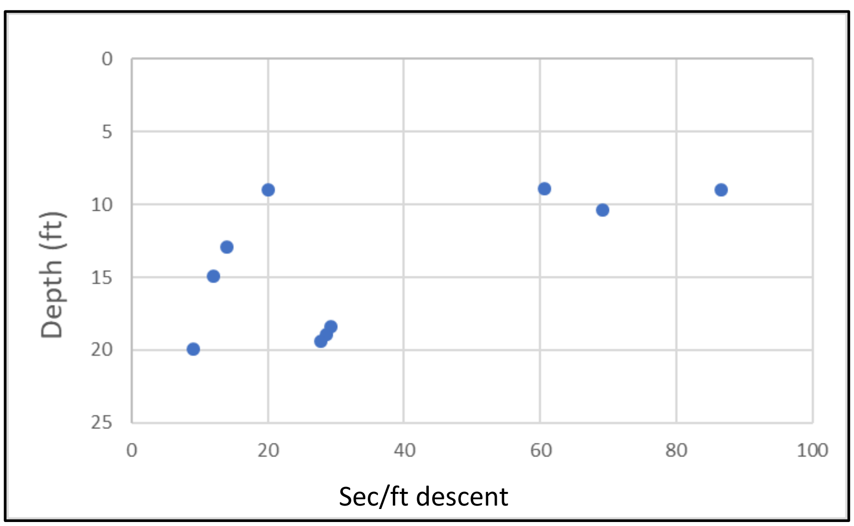


Figure 29. Relationship between depth and possible spawning bouts, and rate of descent from surface to spawning depth, female lake trout 6413/14, Long Lake of Phelps, Oct 2018

Sonic and Radio Telemetry Results, Lake Trout Mortalities - Sonic telemetry data from the receiver array indicated that 7 of the 9 lake trout with implanted sonic tags were dead (not moving/permanently stationary) within 38 to 724 days after initially being tagged and released (data from 6 of the dead fish listed in Table 12). One fish tagged in August 2017 was permanently stationary by the time the receiver array was first deployed November 1, 2017. Sonic data clearly showed that the remaining 5 sonic tagged lake trout that eventually stopped moving (died) were moving freely throughout the lake in waters of their optimal temperature (anywhere in winter, spring and late fall, and below the thermocline in summer and early fall) prior to becoming permanently stationary (dead). During summer and early fall periods of thermocline and warm surface waters, and when very active deep-water trolling by anglers for walleye in 2018 and 2019 was observed, sonic telemetry data also clearly showed 4 of the remaining 5 tagged lake trout moved up (were pulled up) through the water column leaving their required cold waters of the hypolimnion, through the thermocline

Table 12. Tag and release dates, permanently stationary (death) dates, before and after body core temps, final resting depths and days at large prior to death of 6 of 9 sonic tagged lake trout on Long Lake near Phelps, Aug 2017-Oct 2019.

Date Tagged and Released	Sex/Mat	Sonic ID Code	Sonic Sensor Type	Radio Tag Freq	Ave Body Core Temp before surfacing	Date at Surface (Date of Death)	Ave Body Core Temp after surfacing	Final "Resting" depth (ft) after sinking to bottom	Days at large from release to death
20-Aug-19	F/Mat	6403/04	Temp/Press	50.210	42.0	27-Sep-19	63.0	45.0	38
29-Aug-17	M/Mat	6405/06	Temp/Press	None	42.0	8/2/2018^		65.0	338
29-Aug-17	M/Mat	6407/08	Temp/Press	None		11/1/2017*		73.5	64
29-Aug-17	M/Mat	6411/12	Temp/Press	None	42.3	23-Aug-19	69.3	15.0	724
30-Aug-17	M/Mat	6415/16	Temp/Press	None	45.0	28-Jun-18	74.1	2.0	302
24-Oct-17	M/Mat	6421/22	Temp/Press	None	52.2	30-Jul-18	70.7	2.5	279

^ Fish's ascent to surface was not recorded but was "missing" for 14 minutes prior to death

* Fish was dead by the time the receiver array was deployed on Nov 1, 2018

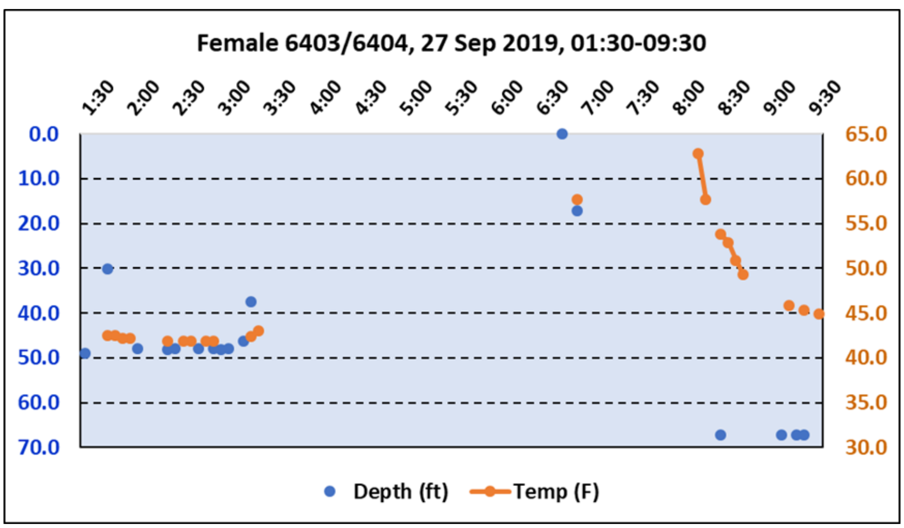


Figure 30. Depth and body core temperature of female lake trout 6403/04, Sep 27, 2019, 01:30 to 09:30, Long Lake near Phelps. Data collected by one receiver while other 7 receivers were pulled for maintenance. Gap in data a function of tag signal collision and fish location in the lake in relation to single receiver deployed. Depth on left y-axis (blue dots), body core temperature (°F) on right y-axis (orange dots).

and into the warm surface waters (epilimnion) of the lake to the surface. All 4 of these fish (and tags) remained at the surface for minutes to hours before descending to depths of 2 to 75 ft where they remained permanently stationary (dead) afterwards. The final fish of the 5 did not show a movement to the surface, but after a 14 minute gap in the sonic data, was found to be permanently stationary (dead) on the bottom in 65 feet of water. Fish 6415/16 which was brought to the surface and became permanently stationary in 2 ft of water on July 4, 2018 completely disappeared from the lake along with its tag on July 6 – possibly taken by an Eagle (based on observations made by lake residents). The final depths of all dead fish were verified as the lake bottom with the hand-held sonic receiver. Depths and body core temperatures of female 6403/04 and male 6421/22 before and after being brought to the surface and becoming permanently stationary are illustrated in Figures 30 and 31. Constantly recording temperature data from tags from dead fish 6421/22 (resting in 2.5 ft of water along the northwest shore of the lake) and dead fish 6405/06 (resting in 65 ft of water in the northeast corner of the lake) are used to track 24/7/365 (signal on average every 3 minutes) littoral and hypolimnion water temperatures of Long Lake (Figure 25).

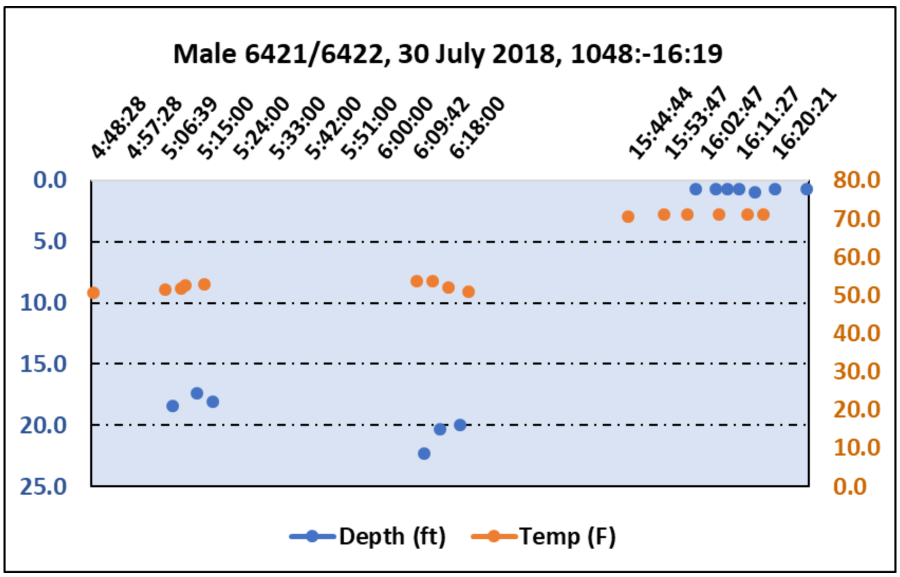


Figure 31. Depth and body core temperature of male lake trout 6421/22, July 30, 2018, 04:48 to 16:30, Long Lake near Phelps. Gap in data a function of tag signal collision and fish location in the lake in relation to receivers deployed. Depth on left y-axis (blue dots), body core temperature (°F) on right y-axis (orange dots).

Smelt

Smelt in Long lake appeared to remain relatively abundant in Long Lake through the duration of the study, 2017-2019, based on consistent observations of large schools of, what was initially assumed and later verified through trawl sampling to be, smelt on the Lowrance ti7 fish finder employed while collecting various data on the water (Figure 32). Large schools of smelt, could be seen as “smelt balls” on the Lowrance unit throughout the open water season on the lake (Figure 32, left panel), although at night in the summer and especially following the breakdown of the thermocline in mid to late October, the large concentrations appeared to occasionally disperse to a more uniform distribution through the water column (Figure 32, right panel). When trawling for smelt, the best catch rates occurred during the summer and early fall, when the large concentrations were more likely to be seen, and in areas where smelt balls could be seen and marked on the Lowrance unit. Occasionally the smelt balls encountered in the summer and early fall were so dense and expansive that the sonar signal could not sound through the mass of fish, appearing to instead be marking an extensive reef rising up from the lakebed out of waters 50 to 80 feet or more of depth. When trawling, the smelt balls would dissipate after the trawl was run through an area holding large concentrations of smelt.

Smelt concentrations were seen during the period of an established thermocline, generally June through mid-October, always below the thermocline and typically at depths of 20 to 60 feet below the lake surface. Bottom trawling was most successful for smelt along the lake contour running parallel to shore at 35 to 45 feet of depth when the smelt concentrations were seen across the lake at that depth strata.

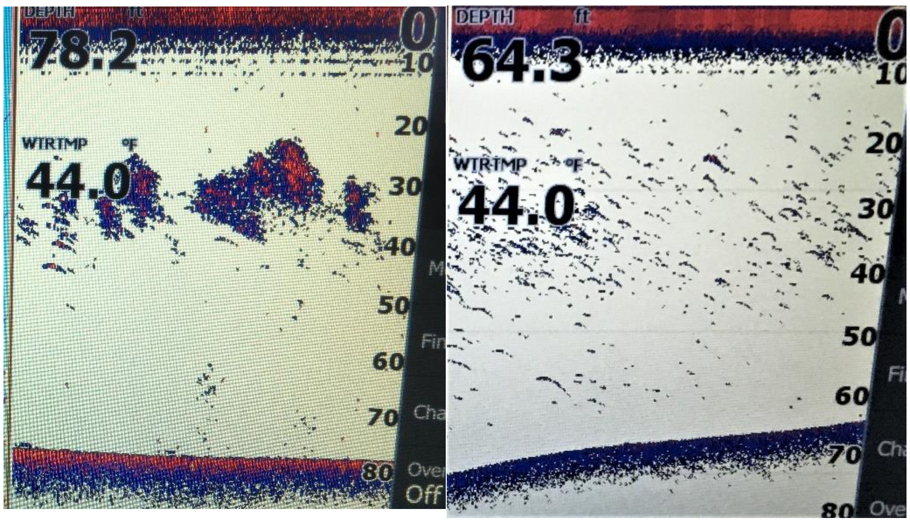


Figure 32. Smelt concentrations in Long Lake as observed on Lowrance Fish Sonar, May 2, 2019 (left), Nov 3, 2018 (right).

Although a variety of gear types were used in attempts to capture smelt, only summer trawling was sufficiently effective to provide the qualitative data needed to meet study objectives. Captured smelt of Long Lake averaged in June, August and October 2019, 80 mm (3.2"), 94 mm (3.7"), and 104 mm (4.1") total length respectfully (Table 13). Smelt weights in June, August, and October 2019 averaged 2.88 gr (0.10 oz), 4.18 gr (0.15 oz), and 5.86 gr (0.21 oz) respectfully.

Length frequency distributions show the progression of growth of smelt in the population throughout the 2019 growing season; and also show the dominance of smaller smelt (<4") in the population as well as the apparent relative absence of larger smelt (>4") (Figure 33).

Table 13. Sample dates and sizes, average total length (mm and in) and standard deviation, average weight (gr) and standard deviation, maximum and minimum total lengths of smelt captured in Long Lake in June, August and October 2019 via trawling.

Sample Date	No. Captured	Ave TL (mm)	Ave TL (inches)	ST Dev (mm)	Min TL (mm)	Max TL (mm)	Ave Wt (gr)	St Dev (gr)
19-Jun-19	281	80	3.2	20	49	140	2.88	2.68
20-Aug-19	299	94	3.7	8	69	143	4.18	1.51
19-Oct-19	50	104	4.1	15	66	138	5.86	2.83

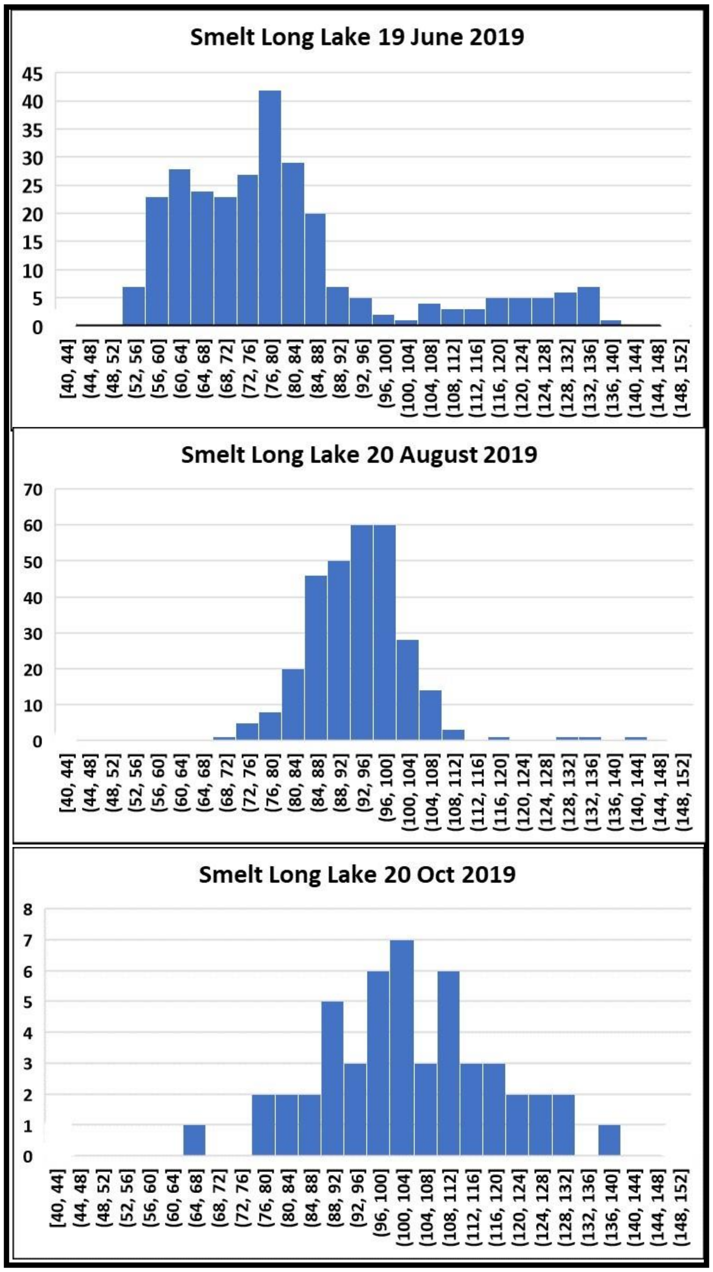


Figure 33. Total length frequencies of smelt in Long Lake near Phelps, June, August, October 2019. Y-axis is number of smelt, x-axis is total length (mm). Bottom trawl (16' headrope) samples.

Age estimates from otoliths collected showed the 2019 population of smelt in Long Lake was comprised primarily of individuals from 3 year classes (2016, 2017, 2018) with some individuals as well from the 2013 and 2015 year classes. Estimated average length at age ranged from 82 mm (3.2") for age 1+ (2 season's growth) to 138 mm (5.4") for 5+ fish (6 season's growth) (Table 14). Total annual mortality rate was estimated at 67%, i.e. 2/3 of the smelt population is dying each year in Long Lake from predation and other natural mortality factors (Figure 34).

Table 14. Estimated total length at age (mm and in) and standard deviation (mm), season's growth, and sample size of smelt from Long Lake (otolith samples collected October 2019).

Age	Season's Growth	Year Class	Mean TL (mm)	Mean TL (in)	n	SD
0+	1	2018*	61	2.4	86	
1+	2	2018	82	3.2	7	8.2
2+	3	2017	102	4.0	27	9.9
3+	4	2016	113	4.4	12	9.9
4+	5	2015	125	4.9	3	6.7
5+	6	2014			0	
6+	7	2013	138	5.4	1	

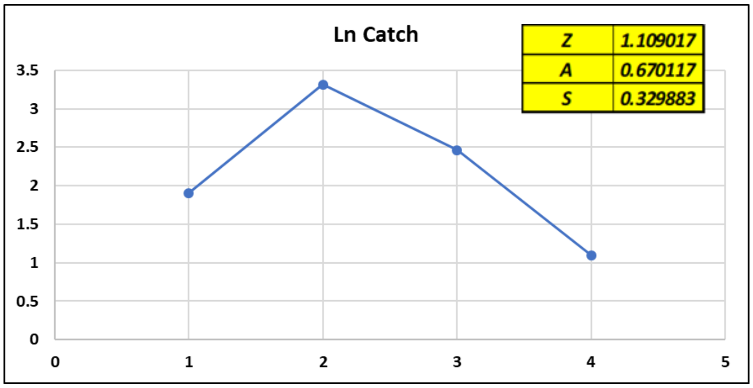


Figure 34. Catch curve, instantaneous and total annual mortality rates, and annual survival rate of smelt population in Long Lake near Phelps. Age on x-axis, Ln Catch on the y-axis.

Sex and maturity was determined for a random sample of 53 smelt (21 females and 32 males) from the June 2019 collection. Females were found to be mature beginning at 81 mm (3.2") up to the largest female collected, 135 mm (5.3") (Figure 35). Males were found to be mature beginning at 90 mm (3.5") up to the largest male collected, 140 mm (5.5"). Average size of females in the sexed subsample was 105 mm (4.1"), SD 18 mm, and average size of males was 118 mm (4.6"), SD 17 mm.

Figure 35. Mature female smelt, 83 mm (3.3") from Long Lake near Phelps, June 19, 2019. Ovary with eggs visible along body cavity wall.

Walleye

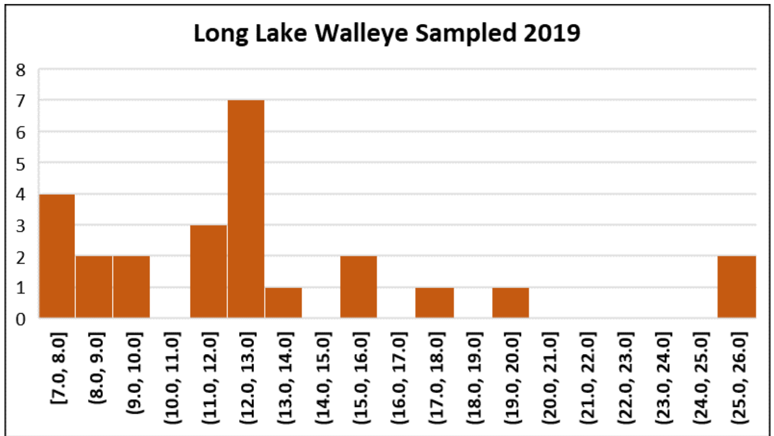


Figure 36. Size and number of walleye sampled for length, sex, maturity, age, and stomach contents, Long Lake near Phelps, May (two 25” fish) and Oct 2019 (remaining fish).

Twenty three walleye randomly collected from 2.5” SM gill nets and bottom trawl samples in October 2019 ranged in size from 7.0” (177 mm) to 19.7” (501 mm), and two walleyes sampled via angling in May 2019 were 25.1 and 25.2”(638 and 640 mm). Ages of walleye sampled ranged from 0+ (1 season’s growth, 2019 year class) to age 12 (2008 year class). Seven year classes were found in the sample: 2019, 2018, 2017, 2016, 2015, 2011, and 2008. Fish from 2018 and 2016 would be considered fish produced through natural reproduction in the lake. Fish from 2019, 2017, 2015, 2011, and 2008 could be natural or stocked as the DNR or LLPLD stocked walleye into the lake in those years, but natural reproduction could also have occurred in one or more of those years. The most abundant sized walleye in the trawl and gill net samples (all fish captured, not just kept) was the distinctly sized 7 to 10” fish from the 2018 year class, indicating a relatively strong year class was produced naturally in Long Lake in the spring of 2018 (Figures 36 and 37, Table 15).

Figure 37. Walleye aged to be 1+ years old (2 season’s growth) in October 2019 from a large hatch that occurred in 2018, a non-stocking year based on ages determined from otoliths, Long Lake near Phelps.

Walleye of all sizes, 20 out of the 25 fish sampled, were found to have 1 to 7 smelt in their stomachs (Table 15). Consumed smelt ranged from 60 – 135 mm (2.4-5.3”), averaging 78 mm (3.1”) in total length, SD 19 mm. While the two very large walleye captured via angling had the largest smelt in their stomachs (135 mm, 5.3”), there was no relationship between walleye size and smelt prey size for the remaining fish sampled that ranged 7.0” (177 mm) to 19.7” (501 mm).

Table 15. Walleye sampled from Long Lake near Phelps, May and October 2019, Long Lake near Phelps, date sampled, total length, assigned age (season growth), year class assignment, stocked year or not, and stomach contents.

Date sampled	TL (in)	Sex	Maturity	Assigned Age	Year Class	Stocked Year	Stomach Contents
10/18/19	7.0	M	imm	0	2019	Yes	empty
10/18/19	8.8	M	imm	1	2018	No	80 mm smelt
10/18/19	9.5	F	imm	1	2018	No	82 mm smelt
10/18/19	8.9	F	imm	1	2018	No	60 mm smelt
10/18/19	7.1	M	imm	1	2018	No	50 mm smb
10/18/19	9.6	F	imm	1	2018	No	78, 80 mm smelt
10/18/19	7.5	M	imm	1	2018	No	65 mm smelt
10/18/19	7.4	M	imm	1	2018	No	empty
10/18/19	11.8	U	u	2	2017	Yes	103 mm smelt
10/18/19	13.6	F	imm	2	2017	Yes	95 mm smelt
10/18/19	12.4	F	imm	2	2017	Yes	85 & 67 mm smelt
10/18/19	12.0	F	imm	2	2017	Yes	digested smelt
10/18/19	12.6	F	imm	2	2017	Yes	70 mm smelt
10/18/19	12.0	F	imm	2	2017	Yes	75, 75, 75 mm smelt
10/18/19	11.8	F	imm	2	2017	Yes	70 mm smelt
10/18/19	12.4	F	imm	2	2017	Yes	75 mm smelt
10/18/19	11.6	F	imm	2	2017	Yes	85 mm smelt
10/18/19	12.5	F	imm	3	2016	No	70 & 70 mm smelt
10/18/19	12.4	M	imm	3	2016	No	digested smelt
10/18/19	15.2	M	mat	4	2015	Yes	empty
10/18/19	15.9	M	mat	4	2015	Yes	85 mm smelt
10/18/19	17.5	F	mat	4	2015	Yes	80 mm smelt, 6-60 mm smelt
10/18/19	19.7	F	mat	5	2015	Yes	digested smelt
5/7/19	25.2	F	mat	9	2011	Yes	empty
5/7/19	25.1	F	mat	12	2008	No	135, 135 mm smelt

Discussion

Cisco

At the onset of the project, it was not known with any confidence what the status of the native cisco population was in Long Lake. Although WDNR conducted vertical gill net surveys for cisco over the years in Long Lake, these surveys were not extensive, usually two gangs of nets set for one night. The data collected were certainly valuable for determining the presence or absence of cisco in the lake and allowed catch per effort to be calculated which in turn provided a sense of the relative abundance of cisco. Despite having these data, the WDNR still had concerns about the status of the cisco population in the lake which prompted them to suggest to LLPLD in 2015 that rearing and stocking cisco should be the first priority action to address potential impacts smelt may have been having on Long Lake fisheries. To that end, and despite grueling cold weather and working conditions encountered during cisco gamete collection operations on nearby North Twin Lake in late November 2016, UWM/SFS, due to Fred Binkowski's extensive aquaculture experience with Corregonid species, gametes were successfully collected, fertilized eggs hatched and reared, and eventually 10,000 large fingerling cisco were stocked into Long Lake in October 2017. These fish were twice as long and 5 times heavier in weight compared to wild fingerling cisco in northern Wisconsin lakes in the fall, providing the maximum likelihood of their survival in Long Lake.

After project gill net surveys in 2018 showed that native cisco persisted in the Long Lake, the cisco situation in the lake looked more optimistic. Native cisco were captured in every experimental gill net (2.5" stretch measure) set in any area of Long Lake below the thermocline (below ~25 feet) during surveys conducted June through mid-October of 2018. One of the most consistent 2.5" SM gill net sets (500 feet bottom horizontal set) for cisco was directly off the Carter/Mason property in 30 to 60 feet of water set parallel to shore. This is the location of the deep-water stocking site utilized for all lake trout stocking since 2013, and where the cisco were stocked in 2017. Given the consistent catch of native cisco at this site, especially in late August, the site could be considered as an additional standard annual index netting site for cisco using 500 ft of 2.5" SM gill nets. The data collected during this standard survey would supplement data from WDNR surveys which are conducted every 3 or more years. August sampling would also produce information on cisco diet which would provide key insights into the status of, and possible impact of smelt on the deep-water zooplankton and fish forage communities.

Finding fingerling yellow perch and bluegill as the dominant forage items in cisco stomachs in August 2018 and 2019 was likely the first qualitative and quantitative documentation by anyone anywhere of cisco utilizing these species of fish as a major forage item. Aside from some scattered anecdotal information in the literature, cisco have not been documented to be piscivorous. The typical diet reported in the scientific literature is primarily a variety of zooplankton (Becker 1983; Davis and Todd 1998; Johnson et al. 2004). Finding heavy reliance on fingerling perch and bluegill in the diet of cisco in Long Lake is very interesting and suggests several aquatic community factors that may be at play in the lake: 1) the zooplankton populations, especially the larger zooplankton species that the cisco prefer to eat may be in short supply in Long Lake due to heavy grazing of zooplankton by the abundant smelt population thereby forcing the cisco in the lake to search for alternative forage (fish); 2) a large year class of yellow perch in Long Lake in 2018 was suggested by the large numbers of fingerling perch captured in the WDNR vertical gill nets fished in June 2018; which again showed up as the dominant forage item in cisco stomach samples in August 2018; 3) dominance of bluegill fingerlings in cisco stomachs in August 2019 indicates that yellow perch may have had a poor hatch and bluegill may have had a large hatch in 2019; and 4) the fact that cisco, a cold-water fish, was preying heavily on fingerling perch and bluegill in August 2018 and 2019 in Long Lake suggests that the perch and bluegill fingerlings may have been pelagic at that time in a zone of water (lower portion of the thermocline) with temperatures cold enough (maximum of 63-64°F (17-18°C)) for cisco to survive in.

The estimated ages of the cisco sampled in Long Lake, 9-22 (1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2009 year classes), indicate that cisco appear to have been producing successful hatches and year classes since smelt were first found in Long Lake despite the abundance of smelt in the lake. While, as referred to earlier, cisco numbers have been shown to diminish in smelt invaded lakes in northern

Wisconsin (Loftus and Hulsman 1986; Evans and Loftus 1987; Hrabik et al. 1998), the mechanism for this phenomenon has not been determined and could possibly vary from one lake to another depending on the health and abundance of the cisco in the lake. In any event, if the age estimates are accurate, it appears that the cisco population in Long lake is robust enough to continue on, albeit as a population of slow growth individuals, in the face of smelt. *(Although cisco otoliths have not yet been validated for age accuracy, the fin clipped cisco in Long Lake are likely the only known-age cisco population in the wild from within the specie's native North American range. The stocked cisco in Long Lake will provide researchers an opportunity over time to collect otoliths, scales, and fin bones to validate the aging accuracy of these cisco boney structures.)*

Cisco historically were the dominant forage fish for walleye, musky and perhaps other native piscivores in Long Lake, that can utilize the cold deep waters of the hypolimnion in search of prey. Given the relatively small littoral area of Long Lake, i.e. the limited "weed' growing areas less than 15 feet deep (see Figure 24), littoral production of forage fish, minnows and small pan or gamefish, would be less than in a lake with greater area of water less than 15 feet. Subsequently, a key to the long-term success of the major fish predators in Long Lake such as walleye would be having a robust deep-water forage-fish population, i.e. cisco, to supplement the nearshore warmwater forage fish community and insure walleye of all sizes have enough food for survival, good growth, and healthy and successful reproduction. Smelt that have invaded Long Lake and other lakes in northern Wisconsin, were likely stocked (unapproved) by some individuals who thought the lake could use additional forage in the deep-water. If and when smelt are controlled down to a significantly lower level of biomass in Long Lake through predation by walleye, lake trout, and other predators (which appears to be already occurring), having a healthy cisco population will likely be critical to sustaining and maintaining healthy (consistent reproduction/recruitment, good growth and survival) populations of walleye and lake trout in the lake.

Cisco Management Recommendations/Options (highest to lowest priority):

1. *Conduct UWM/SFS standard cisco gill net survey (2.5" SM, 500 feet, 1 night set of Carter/Mason property and 1 additional site in south basin) annually in late August to collect data on catch per effort, size distribution, relative condition, diet, and presence or absence of stocked fin-clipped cisco.*

2. *Collect boney structures (otoliths, scales, fin bones) over time from stocked fin-clipped known age cisco for age validation.*

3. *Continue WDNR vertical gill net surveys according to their standard survey design*

Lake Trout

Based on historical records, it appears lake trout may not have been native to Long Lake, despite the lake having the required habitat. i.e. an abundance of deep, cold, well oxygenated water; cisco as a deep-water forage fish; and several deep rocky fall wind-swept points as potential spawning areas. They were initially stocked in the lake in 1908 as fry (1-2" fish) and then again in the 1960s fingerlings (6"), with both of these events likely using brood fish from the Great Lakes, which may not have been the best genetic match for a lake like Long Lake to provide the best chance ultimately for reproduction and long-term success. The lake trout found in Black Oak Lake, 17 miles northeast of Long Lake, appear to be the best genetic match, and yearling fish (7-7.5”) of this strain stocked into Long Lake should provide the best opportunity to ultimately produce a naturally reproducing lake trout population in the lake. Lake trout will be the critical predator species in Long Lake for long-term smelt control as they spend the entire year in cold water chasing smelt to eat.

Keys to ensuring lake trout are successful in Long Lake are: 1) maximum survival of young lake trout immediately post-stocking; 2) maximum survival of lake trout to adulthood and old age; 3) having enough predation pressure on smelt in the lake to reduce smelt in the diet of lake trout sufficiently through the course of the year to in-turn minimize/eliminate the negative impact of Thiaminase of consumed smelt on lake trout reproduction; and 4) having adequate quantity and quality of spawning and nursery habitat in the lake for successful and consistent reproduction.

1) Ensuring maximum survival of young lake trout immediately post-stocking - Maximizing survival of stocked lake trout immediately post-stocking has already been addressed by the WDNR beginning in 2013. Collecting lake trout gametes from Black Oak Lake is not an easy task and the WDNR, while successful in this endeavor in most years, has not been successful in every attempt, nor is the WDNR able to attempt to collect these gametes and raise lake trout for stocking every year. Given these challenges, the WDNR is always concerned about ensuring that the fish stocked survive the stocking experience to produce the intended fishery in the receiving lake. After stocking lake trout off the public boat landing on Long Lake in May 2005 and 2012, and after seeing predation by walleye and other predators on the stocked lake trout in the bay off the landing in 2012, the WDNR searched for and found a site on private property that allowed the large stocking trucks access to the water’s edge and the stocked fish quick access to deep water close to shore. The Carter/Mason property on the northwest shoreline met the needed requirements for a successful stocking and was utilized beginning in 2013. The fact that 15 of the 16 lake trout captured during this study have been exclusively from the fish stocked in 2013 validates the WDNR’s decision to change stocking sites to the Carter/Mason property in 2013.

2) Ensuring maximum survival of lake trout to adulthood and old age - In an effort to maximize survival of stocked lake trout to maturity and old age in Long Lake, the WDNR implemented a 30” minimum size limit on lake trout when they began the lake trout program there in 2005. At 30” a lake trout in Long Lake would likely be 15 years old or older and, given they likely would have matured at age 5 or 6, each fish surviving through the years from initial stocking should have the opportunity to spawn and potentially produce young for many years before they were susceptible to being removed from the lake via angler harvest. Of course, natural mortality, i.e. disease and predation, occurs with all fish species, along with fishing mortality where the species is directly or indirectly targeted and captured by fishing effort. Nieland et al. (2008) suggested that in order to sustain native lake trout stocks in Lake Superior, all mortality of lake trout (natural and fishing related) should not exceed 40% of the adult stock per year. In theory, by eliminating fishing mortality of lake trout stocked into Long Lake through a high minimum size limit of 30”, the WDNR and lake users were likely confident the lake trout in the lake would be well protected to live for a long time, eat a lot of smelt, and possibly successfully reproduce over time. A new regulation implemented by the WDNR in 2012 though allowed anglers to legally troll as a fishing method in lakes across northern Wisconsin and it appears this is negatively impacting survival of lake trout in Long Lake.

Long Lake has a relatively high walleye population density with excellent size structure (DNR Woodruff, WI, Personal Communication) which has since 2012 drawn an increasing number of trolling anglers to the lake throughout the open water season, but especially summer through early fall. Since trolling became legal on lakes in Vilas County in 2012 anglers have learned that walleye suspended in deep water, down to 60 feet or more feeding on smelt, can be effectively caught on deep water trolling gear. Whereas walleye, as a cool-water fish, are not limited to living in the deep cold water of the lake as they can survive quite well in warmer waters above the thermocline, lake trout, as a cold-water fish have no choice but to stay in the hypolimnion, or deep cold waters of the lake below the thermocline in summer and early fall. The lake trout, like the walleye, follow and feed on the same large schools of smelt in the deep waters throughout this time making them quite susceptible to being caught by anglers trolling the deep waters for walleye.

Sonic telemetry data collected during 2017-2019 clearly show 7 of 9 (78%) of the lake trout captured and fitted with sonic tags through the course of the current study were, within 38 to 724 days post release, brought to warm surface waters of the lake from the deep cold waters they require during the summer-early fall walleye trolling season, after which dying and sinking to various depths and locations. Likewise, radio telemetry data collected during 2017-2019 also clearly show that 4 of the 4 lake trout (100%) captured and fitted with just a radio tag died and sank within 90 to 720 days after being released. Of the 13 total lake trout captured and fit with sonic and/or radio telemetry tags for this study, 10 suddenly died (77%) after living and swimming around quite well for months to years after being released.

After each documented mortality event the fish (and their implanted sonic and/or radio tag) remained motionless thereafter. The mechanisms resulting in the death of these fish could include a) thermal stress of the fish after being caught via angling (trolling) in deep water and pulled from its required cold temperatures below the thermocline from depths of 30 to 60+ feet into warm water above the thermocline; b) the potential of further stress of the fish while being taken off the hook and handled by the angler; c) potentially additional thermal stress if the fish is held for recovery in a live well that is filled with warm surface water; and d) further (final) thermal stress due to the inability of a released lake trout to swim back down 25 to 30 feet into deeper cold water due to over-inflation of its air bladder after being initially brought to the surface from areas of higher atmospheric pressure below the thermocline.

Mortality of lake trout as by-catch to the deep-water walleye trolling fishery on Long Lake will need to be significantly reduced or eliminated to provide the maximum probability that lake trout will become established in sufficient numbers in the lake over time to continue to contribute to long-term smelt control.

To ultimately measure the success and survival of stocked lake trout in Long Lake, index assessments will likely need to be conducted on a regular basis over time. The WDNR standard gear for assessing lake trout population on Black Oak Lake is 2.5 SM horizontal gill nets fished during the fall close to the spawning season at the spawning sites. This same gear was employed with success during the present study to fish for lake trout, during the fall spawning season in Long Lake. Given the identification of the two sites in Long Lake which appear to have lake trout spawning activity, these locations could possibly be utilized as lake trout population index sampling sites for monitoring the status of the population over time, as done by WDNR in other inland lake trout lakes in northern Wisconsin.

3) Maintaining sufficient predation pressure on smelt in the lake to reduce smelt in the diet of lake trout adequately through the course of the year to in-turn minimize the negative impact of Thiaminase from consumed smelt on lake trout reproduction – Smelt is an invasive fish native to the Northeast coast living primarily in salt water, but spawning in fresh water. Ironically management agencies in the Northeast are looking for ways to save and restore their rainbow smelt populations as the numbers have dwindled possibly due to overfishing and habitat changes (US News 2020). Smelt, as an invasive species, in the Great Lakes waters have been shown to disrupt successful reproduction of lake trout that consume large quantities of smelt. Smelt naturally contain a high amount of an enzyme called Thiaminase in their body. When smelt make up the majority of the prey consumed by lake trout and other salmon and trout, the Thiaminase breaks down the vitamin B12 (Thiamine) in the lake trout which in turns causes poor survival of lake trout eggs and fry, a condition called Early Mortality Syndrome (EMS) (Brown et al. 1998, Rinchard et al. 2009). Whether walleye that consume large quantities of smelt experience EMS is not known for certain although a recent scientific study on walleye in Tennessee reservoirs suggests that they may not (Honeyfield et al. 2007). The states around Lake Michigan have been stocking lake trout into the lake by the millions over the last 60+ years. Lake trout natural reproduction was not documented though until recently and only after the smelt (and alewife – another exotic ocean species high in Thiaminase) populations in Lake Michigan decreased to the point where they no longer are the primary prey item of the lake trout. The decrease and, in the case of smelt, near elimination, was brought on by years of heavy predation on smelt by salmon and trout stocked in the lake initially for alewife control, and then later to sustain a major trout and salmon recreational fishery. The current study results have shown that lake trout in Long Lake are feeding extensively on smelt and growing well. The desire to reduce or eliminate the smelt population in Long Lake will require consistent and heavy predation of smelt by lake trout and walleye, which in turn means the continuation of the stocking of sufficient numbers of lake trout and possibly walleye into the lake to maintain an effective smelt predator base. Protecting these predators from excessive harvest or fishing induced mortality will also be an important factor. Long-term natural reproduction of lake trout in Long Lake may very well depend upon significantly reducing the smelt population (with predation being the current method of choice) as well as the amount of smelt in the lake trout diet. The WDNR has been able to consistently stock extended growth walleye every other year into Long Lake since 2005, but have not been able to consistently stock lake trout since 2005. If lake trout become less available for stocking on a consistent basis at or above the historic stocking rate (~10/acre), other salmonids such as brook trout (*Salvilinus fontinalis*), and/or brown trout (*Salmo trutta)* could be considered as supplemental short-term smelt predators to help reduce and control the smelt population in the lake, and to diversify and enhance (short-term) the lake's recreational coldwater fishery. Brook and brown trout have been stocked into Long Lake in the past (pre-smelt, see Table 2). Neither of these species would reproduce in the lake, likely living a maximum of 5-10 years, allowing them to be safely used as an additional short-term smelt control predator.

4) Ensuring sufficient quantity and quality of lake trout spawning and nursery habitat in the lake for successful and consistent reproduction – Lake trout in Long Lake are displaying behaviors that strongly indicate they are attempting to spawn at, at least, two locations in the lake, Swislow Point on the east shore and Katey's Point on the west shore, both steep rocky drop-offs along the respective shorelines. The populations of natural reproducing lake trout in the two primary inland native lake trout lakes in northern Wisconsin, Trout Lake and Black Oak Lake, both spawn in very distinct and limited areas of the respective lakes (Personal Communication, Steve Gilbert, WDNR, Woodruff, WI). Thus, it is possible that having two sites that lake trout will utilize for spawning in Long Lake may be enough for quantity.

Although side-scan sonar readings and anchor drags conducted in 2019 on each of these sites verified rock on the bottom, it is not definitively known at this time the quality of the spawning substrate at Swislow and Katey's Point. Lake trout require clean rocky areas of lake bottom with substrates ranging from gravel to boulders (10" in diameter or more) for successful egg dispersal into the interstitial spaces between the rocks to minimize predation by other fish and crayfish (Becker 1983). Remote operated vehicles with cameras, or divers with cameras, would be able to document the quality of the substrate for lake trout spawning at the two areas identified in in Long Lake. This information could be used to decide whether additional rock substrate would need to be placed on one or both areas to improve the spawning habitat there.

Lake Trout Management Recommendations/Options (highest to lowest priority):

1. *Continue stocking Black Oak Lake strain yearling size lake trout into Long Lake every 2-3 years at a rate 10/acre for the purposes of Black Oak strain lake trout gene pool preservation and smelt control.*

2. *Eliminate trolling on Long Lake to minimize/eliminate the high mortality of lake trout due to by-catch in the walleye trolling fishery.*

3. *If lake trout mortality due to walleye trolling is not minimized/eliminated, stock additional smelt predators, e.g. brook trout or brown trout to help control the smelt population.*

4. *Initiate a standardized lake trout adult population assessment in Long Lake to track survival and growth of stocked lake trout and determine if lake trout are naturally reproducing in Long Lake.*

5. *Assess the quality of the lake trout spawning habitat off Swislow Point and Katey's Point and determine whether habitat enhancement is needed to maximize potential for successful and sustaining lake trout natural reproduction.*

Smelt

While the scope of this study did not include the very technically difficult and expensive task of estimating the abundance of smelt in Long Lake, it did include estimating some key metrics about the smelt population which in turn provided insight into whether increasing the abundance of smelt predators in the lake was impacting the smelt population. Relatively large numbers of extended growth walleye fingerling and yearling lake trout have been stocked into Long Lake by the DNR since the mid 2000s (Table 1) to increase the number of piscivores in the lake that would eat smelt to in turn reduce or control the smelt population. Growth and mortality rates of smelt in Long Lake (how fast they are growing and how fast they are dying), and the size at maturation provide a snapshot of the health of the smelt population in the lake and strongly indicate that the increased number of predators are already impacting the smelt.

Fish populations overharvested (or heavily preyed upon), especially where the larger fish in the population are consistently removed, and/or where food supplies are or become limited, have been shown to exhibit various compensatory mechanisms in response to removals, such as slower growth and smaller size at maturation (Swain et al. 2007). Rainbow smelt are native to the coasts and rivers of Maine and the maritime provinces of Canada. They spawn in freshwater thus utilizing the sea-run rivers in that area to reproduce, and have been legally and illegally, as well as naturally, introduced into numerous freshwater lakes in that region. Once in these lakes, the smelt have exhibited over time slower growth and maturation at a younger age and size (O'Malley et al. 2017), often reaching maximum sizes of only 76-127 mm (3-5") (Maine Dept of Inland Fisheries & Wildlife, 2020), similar to the slow growth and relatively small maximum sizes of smelt currently found in Long Lake. In New Brunswick, Canada, a form of rainbow smelt, known as Lake Utopia Dwarf Rainbow Smelt, exists which also displays slow growth similar to smelt in Long Lake, and is known to prey exclusively on zooplankton despite having the opportunity to feed on fish (COSEWIC, 2008), similar to the diet of smelt in Long Lake observed by McDonnell (2011).

The length distributions of smelt from Long Lake when tracked from the start to the end of the growing season in 2019 also showed smelt in the population up to 150 mm (5.9") with fair numbers still there in spring samples (mid-June) in the 109 to 138 mm (4.3-5.4") range. By late summer though these larger smelt were all but gone in the August sample, but returned in October in greater abundance than seen in spring , due to growth of individual fish comprising the population in 2019. This transition of the smelt length frequency distribution in Long Lake from spring to fall in 2019 could be due to heavy predation by walleye, lake trout, and other fish predators through the summer growing season. Smelt found in stomachs of the larger walleye and of all the lake trout examined were either measured or observed to be larger fish, 120-145 mm (4.7-5.7"), indicating these predators (large walleye, and adult lake trout) preferred to eat the larger smelt, despite the fact that smelt greater than 109 mm (4.3") comprised only 12% of the population in June, and 2% in August, finally increasing (more bigger smelt due to growth) to 38% in October.

The total annual mortality, estimated at 67%, means that 2/3 of the smelt in Long Lake are disappearing from the population each year, most likely due to predation by walleye and lake trout, and perhaps other predatory fish. Predation has been found to be one of the major mechanisms driving forage fish population fluctuations (Jacobsen and Essington, 2018). Invasive abundant populations of rainbow smelt in northern Wisconsin have been significantly reduced and, in some cases, possibly extirpated following extensive stocking and protection of smelt predators in the lakes (Krueger and Hrabik, 2005). Lake Lucerne, an oligotrophic lake similar in size, shape, and depth to Long Lake near Crandon, WI (60 miles southeast of Long Lake) saw a complete collapse of its smelt population by the early 2000s after WDNR stocked 247,000 brown trout in the lake (starting at the peak of smelt abundance) from 1991 to 2005 (Personal Communication Mike Preul, Mole Lake Sakaogon Chippewa Band, Crandon, WI, and Greg Matske, WDNR, Florence, WI).

The data from the current study on Long Lake strongly indicate the smelt in the lake are being impacted by predation. Although no estimates of the abundance of smelt in Long Lake exist, nor are they likely ever to be developed, the current population in the lake, regardless of its relative abundance is showing signs of stress, and signs that the WDNR's strategy of building up predators in the lake to control the smelt is working. For this strategy to continue working to possibly drive the smelt to an even lower level, large numbers of predators, primarily walleye and lake trout, need to be maintained in the lake. Stocking and high minimum angling size limits (18" for walleye and 30" for lake trout) have been the primary tools used by the WDNR to date for building and maintaining a strong predator base. Additional protections though of the lake trout from by-catch mortality in the walleye trolling fishery need to be implemented to ensure lake trout can consistently be a major cold-water smelt predator in the lake. Without these protections, Long Lake could slip back into greater smelt abundance and imbalance in the fish community.

Smelt Management Recommendations/Options (highest to lowest priority):

1. *Continue stocking Black Oak Lake strain yearling size lake trout into Long Lake every 2-3 years at a rate 10/acre for the purposes of Black Oak strain lake trout gene pool preservation and smelt control.*

2. *Eliminate trolling on Long Lake to minimize/eliminate the high mortality of lake trout due to by-catch in the walleye trolling fishery.*

3. *Continue stocking extended growth fingerling walleye every other year in odd years at a rate of 10/acre.*

4. *If lake trout mortality due to walleye trolling is not minimized/eliminated, stock additional smelt predators, e.g. brook trout or brown trout to help control the smelt population.*

5. *Develop and conduct annual standardized smelt trawling assessment in late June to track smelt size distribution and relative abundance.*

Walleye

Walleye, along with lake trout, as has been discussed earlier, is a key predator for ensuring smelt are effectively controlled long-term in Long Lake. As such, maintaining a healthy and relatively high biomass of walleye in the lake is important. The WDNR has done an excellent job in building up a robust walleye population in the lake through their stocking of the higher surviving extended growth (7”) walleye fingerlings every other year in odd years since 2007. WDNR estimated that Long Lake in 2017 had a walleye population ≥15” of nearly 5 adults/acre, of which nearly 4/acre were over 20” (WDNR Unpublished data, Woodruff, WI).

Walleye historically in Long Lake have been relatively abundant and maintained themselves through natural reproduction as the lake has excellent walleye spawning substrate (gravel, rock and cobble) along large tracts of its shorelines. WDNR shoreline fall shocking surveys for walleye fingerlings initiated on Long Lake in 1987 resulted in relatively good catches of walleye fingerlings during 1987-1991, but relatively poor catches of fingerlings in the surveys almost every year since then, except 2001 (WDNR, unpublished data, Woodruff, WI). Smelt, after first being found in Long Lake in 1999 and exploding in abundance in the early 2000s, were believed to have contributed to the apparent poor catches of walleye fingerlings in fall shocking surveys since 1995.

The impact of smelt on walleye, as discussed earlier, was suspected to be through smelt predation on walleye fry and/or smelt overgrazing of zooplankton necessary for walleye fry survival and growth.

Sampling done through the current study in the fall of 2019 documented, though, that a significant natural year class of walleye was produced in Long Lake in 2018, and possibly in 2016 as well, both non-stocking years. Walleye otoliths, which were used to estimate the ages (hatching year) of the 2018 and 2016 fish sampled, have been validated and proven to show the true age of the species (Koenigs et al. 2015). A fall shocking survey was not conducted on Long Lake in 2018 and the survey done in 2016 captured zero fingerlings.

While the fall shoreline shocking survey for fingerling walleye is a standard method for assessing walleye year class strength used by WDNR since the late 1980s, the method is known to produce variable results with error, especially in years when the walleye hatch on a lake is less than extremely large (WDNR unpublished data, Oshkosh, WI). The data from the current study also suggest that walleye behavior in the fall in lakes in northern WI with well-established smelt populations, may be different than that in non-smelt walleye lakes, possibly reducing the capture efficiency of shoreline shocking in the smelt lakes. Walleye of fingerling (7") and yearling (7-10") size captured in the fall of 2019 in Long Lake and examined for stomach content were nearly all found to be preying heavily on smelt. The large schools of smelt in Long Lake were found in the fall primarily off-shore, which may also keep the walleye fingerlings off-shore and away from the nearshore zone (1-3 feet of water immediately along the shoreline) where the standard fall shocking surveys are conducted. If the walleye fingerling are indeed offshore in the fall chasing smelt, and given the possible inherent shortcomings of fall shoreline shocker surveys for fingerling walleye, fall shoreline shocker surveys may not reflect the true strength of the walleye year classes in the lake.

An aspect of smelt-walleye interaction also documented in the current study is the heavy predation by walleye of all sizes (at least ≥7") on smelt. Smelt (as an introduced non-native species) in Lake Oahe, South Dakota, a 370,00 acre 200 foot deep reservoir on the Missouri River in South Dakota, are the most important forage for the large naturally produced (not stocked) walleye population in the reservoir (Bryan 1995). Recent declines in the smelt population in the reservoir due to flooding impacts have prompted the South Dakota Game, Fish and Parks Commission to propose increasing walleye bag limits to encourage greater harvest of walleye to reduce the walleye population and relieve predation pressure on the smelt so its population can recover (South Dakota Game, Fish and Parks Commission, 2020).

The phenomenon of walleye and smelt surviving, reproducing, and interacting in Oahe lake in South Dakota, along with the walleye and smelt data collected on Long Lake as a part of the current study, has several implications for what may or may not be happening in Long Lake (as well as other smelt invaded lakes in northern Wisconsin):

- Rainbow smelt and walleye can successfully coexist, reproduce, and maintain healthy populations in the same freshwater lake under certain conditions.
- When smelt are in a lake, walleye of all sizes will extensively utilize them as a primary prey item.
- Abundant smelt in relatively small freshwater lakes like Long Lake can overgraze important large zooplankton such as water fleas, which are important forage items for walleye fry, potentially impacting walleye fry survival and walleye year class strength, as well as negatively impacting smelt growth and survival;
- Walleye can successfully reproduce with smelt in Long Lake, as shown by the documentation of the relatively robust 2018 year class;

- Walleye predation on smelt in Long Lake, along with predation by lake trout on smelt, appears to have impacted the smelt population to the extent that the smelt are "dwarfing" and the walleye, can, at least in some years, reproduce successfully.

Walleye Management Recommendations/Options (highest to lowest priority):

1. *Continue stocking extended growth fingerling walleye every other year in odd years at a rate of 10/acre.*

2. *Determine the age composition and longevity of the Long Lake walleye population, the relative strength walleye year classes, and relative success or failure of walleye hatches/stocking events since approximately 2005.*

3. *Develop and conduct a standardized annual fall trawl survey on Long Lake to assess walleye year class strength to complement the standard fall shoreline shocking survey conducted annually by WDNR and Tribal Biologists; including checking the otoliths of a subsample of at least 40 young of year walleye for OTC (Oxytetracycline) marks to determine the percentage of YOY that are stocked (OTC marked) and the percentage of YOY that are natural (no mark) annually.*

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