Large Lake Sampling Program Completion Report for Leech Lake: 2021

Section of Fisheries

Division of Fish and Wildlife

500 Lafayette Road

St. Paul, MN 55155-4020

By

Carl Pedersen, Large Lake Specialist

Walker Area Fisheries Office

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Prepared by: Digitally signed by Carl Pedersen
Date: 2022.03.18 10:12:28 -05'00'

Date Carl Pedersen, Large Lake Specialist

Approved by: Doug Schultz Digitally signed by Doug Schultz
Date: 2022.03.18 11:27:28 -05'00'

Date Doug Schultz, Area Fisheries Supervisor

Approved by: Ted Sledge Digitally signed by Ted Sledge
Date: 2022.03.18 13:25:24 -05'00'

Date Ted Sledge, Regional Fisheries Manager

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INTRODUCTION

Statewide, Minnesota's ten largest Walleye (*Sander vitreus)* lakes account for 18% of total angler pressure (Carlson 2014) and 40% of the annual Walleye harvest (MNDNR 1997). Prior to 1983, fisheries assessments on these lakes were infrequent and highly variable in their methods. As a result, these surveys were unreliable for assessing fishery status as well as any fishery response to management actions. Recognizing the importance of these systems and the need for robust data to effectively identify and evaluate trends in fish stocks, the Minnesota Department of Natural Resources initiated the Large Lake Program (LLP) in 1983. Goals of the LLP include annual fishery surveys using standardized methods to facilitate comparisons among years and lakes, to detect management needs and evaluate management actions, and to enhance public outreach.

Sampling guidelines for the large lakes were outlined in the Large Lake Sampling Guide (Wingate and Schupp 1984). Since being published in 1984, large lake sampling methods have been adapted on a lake-specific basis to ensure information collected is valid for both research and management applications; ineffective sampling gears or those with poor reliability have been eliminated or de-emphasized. In some cases, additional targeted sampling has been added to augment methods delineated within the LLP. The primary focus of the LLP and its survey methods is to promote sound management of Walleye, Yellow Perch, and Northern Pike populations while garnering additional but less targeted information on other species.

Leech Lake is the third largest lake within state boundaries and is one of eleven lakes monitored by the LLP (MNDNR 1997). The lake is renowned among anglers as an exceptional multi-species fishery; however, most anglers target Walleye (Pedersen and Schultz 2020). Declines in Walleye and Yellow Perch populations during the early to mid-2000s prompted the development of a 2005-2010 Fisheries Action Plan for Leech Lake (Rivers 2005). Since then the lake has been managed with extensive citizen engagement and adaptive management as needs are identified, including updates and improvements to the Leech Lake Management Plan in 5 year increments (Schultz 2010, Ward 2015) with the most recent update covering 2021-2025 (Pedersen 2020). The focus of this plan includes the entire fish community with a strong focus on maintaining strong Walleye recruitment.

In Minnesota's large lakes, strong year classes, as indexed by gillnet catch rates of age-1 through age-3 Walleye, are defined as cohorts having a relative abundance in the upper 75th percentile of long-term observed values. Strong year classes of Walleye have typically occurred every 3 to 5 years in the large lakes with some variation. Factors limiting the frequency of strong year classes include prey abundance (Forney 1974), temporary climate shifts (Schupp 2002), high abundances of adults (Ricker 1975) and impacts of aquatic invasive species (Kumar et al. 2016, Staples et al. 2017). Variability in angler catch and harvest rates have typically paralleled occurrence of strong or weak year classes as they reach the fishery at age-3. Recruitment variability, or the variability in the size or strength of a Walleye year class, is influenced by a host of factors. These include spawner abundance (Ricker 1975), spawning conditions (Hansen et al. 1998), juvenile density (Hansen et al. 2012), length and intensity of growing season (Venturelli et al. 2010), predation (Hansen et al. 1998; Quist et al. 2003), and prey abundance (Chevalier 1973), among others. The decline of the Leech Lake Walleye fishery during the early to mid-2000s was a product of several consecutive below-average year classes. Factors that likely contributed to declines in recruitment during this time include increases in Walleye predation by double-crested cormorants (Schultz et al. 2013), increases in angler pressure and harvest of Walleye including mature adults during the late 1990s and early 2000s (Sledge 1999, Sledge 2000).

Mixed ages of Walleye were infrequently stocked at low densities in isolated locations from 1922 through 1987. Stocking was discontinued from 1988-2004, and the strongest year class observed to date occurred in 1988 and 2005. Varying densities of Walleye fry were stocked during 2005 – 2014 as part of the most recent efforts to rebuild the Walleye population. The number of spawning females in the lake in the three years prior to 2014 facilitated the decision to discontinue stocking since 2015. Since then catch rates of young-of-year (YOY) Walleye sampled and recruitment to older ages indicate a recovered Walleye fishery that is capable of producing strong year classes with natural reproduction, including an historical high YOY catch rate in 2017.

Aquatic invasive species currently found in Leech Lake include banded mystery snail *Viviparus georgianus*, curly-leaf pondweed *Potamogeton crispus*, Eurasian watermilfoil *Myriophyllum spicatum*, *Heterosporosis sp*., rusty crayfish *Orconectes rusticus*, zebra mussels *Dreissena polymorph* and starry stonewort *Nitellopsis obtusa*. Invasive plant species are not widely distributed within Leech Lake, but Eurasian watermilfoil has established outside of harbors and colonized portions of the larger bays and main lake. Starry stonewort was first discovered in 2021 in Steamboat Bay and attempts to reduce its abundance were undertaken by a collaborative effort between Cass County, the Leech Lake Band of Ojibwe-Division of Resource Management (DRM) and the MNDNR. Zebra mussel expansion appears to have now occurred throughout the lake with adults identified in MNDNR sampling gear and citizen reports from all portions of the lake. Other aquatic invasive species are increasing in prevalence throughout Minnesota and pose a likely risk. Anglers and boaters alike are encouraged to properly dispose of bait in the trash, to drain all water from bait containers, livewells, and watercraft, and properly inspect and remove all vegetation from their watercraft, anchor, and trailer when leaving a lake.

STUDY AREA

Leech Lake has approximately 112,000 surface acres. In 1884, a dam was built on the Leech Lake River, raising the water level about two feet and increasing the surface area from 106,000 acres to its present size (Wilcox 1979). The maximum depth of the lake is 150 feet; however, nearly 80 percent of the lake is less than 35 feet deep. Leech Lake has approximately 58,000 littoral acres (≤15 feet).

Leech Lake is located in three glacial zones and has an irregular shape with a variety of large and small bays. The lake varies considerably from a morphological perspective. Some large bays, such as Steamboat, Boy, and Headquarters, display eutrophic water characteristics (high in productivity) whereas other large bays, such as Walker, Kabekona, and Agency have properties more congruent with oligotrophic lakes (low in productivity). The main portion of the lake (including Sucker, Portage, and Traders bays), is mesotrophic (moderate in productivity). The shoreline length based on remote sensing technology is 201 miles. Approximately 23% of the shoreline consists of a windswept gravel-rubble-boulder mixture, nearly all of which is suitable Walleye spawning habitat (Wilcox 1979). Numerous off-shore gravel-rock-boulder reefs are also present.

The diversity of the shoreline and substrate, as well as its extensive littoral zone, provides excellent spawning and nursery habitats for a number of species. Walleye, Northern Pike *Esox lucius* and Muskellunge *E. masquinongy* are the principal predators and are common throughout the lake. Although most fish species are found in every portion of the lake, Walleye and Muskellunge abundances are highest in the mesotrophic areas. Northern Pike are most prominent in vegetated bays. Yellow Perch *Perca flavescens* are abundant throughout the lake and are the primary forage for most predators. Tullibee (Cisco) *Coregonus artedi* and Lake Whitefish *C. clupeaformis* are an important forage species for larger predators and are typically found in the mesotrophic and oligotrophic areas. Juvenile Tullibee (Cisco) also comprise larger proportions of predator diets when large year classes are present. Other species present in the lake include: Black Crappie *Pomoxis nigromaculatus*, Bluegill *Leopmis macrochirus*, Bullheads *Ameiurus spp.*, Bowfin *Amia calva*, Burbot *Lota lota*, Hybrid Sunfish (Bluegill x pumpkinseed), Largemouth Bass *Micropterus salmoides*, Pumpkinseed *L. gibbosus*, Rock Bass *Ambloplites rupestris*, Smallmouth Bass *M. dolomieu*, Shorthead

Redhorse *Moxostoma macrolepidotum* and White Sucker *Catostomus commersoni*, as well as numerous minnow and darter species.

YOUNG-OF-YEAR ASSESSMENT

Introduction

Assessment of young-of-year Walleye in Leech Lake is historically done with 3 primary sampling strategies; beach seining, offshore trawling and fall electrofishing.

From 1983 through 1992 seining was conducted at as many as 16 stations in an attempt to refine station selection and from early July through early September in an attempt to refine time period selection. These evaluations resulted in the establishment of five long-term stations and the selection of the four week time period in July. A minimum of 40 seine hauls were conducted annually at the five stations throughout July from 1983 through 2010. Seining was not conducted in 2011 due to a state shutdown, and in 2012 stations were not sampled according to standardized protocols due to staffing shortages. In 2012, each of the five stations was seined on three occasions in mid-July solely to collect YOY Walleye for stocking evaluations. The four week time period in July was revised to the middle two weeks of July (Julian Weeks 28-29) in 2013 when catch rates of YOY Walleye have been most consistent, and this is now the standardized time period. Standardized Julian time periods established for all three assessment techniques were weeks when stations were most consistently sampled since 1983. While the goal is to sample each year during the same Julian week for each gear, staff availability and weather conditions do not always allow for this sampling schedule; non-standard samples are excluded from the historical time series when applicable. Seine catch rates can be strongly influenced by several factors such as weather patterns, fish behavior and fish size. Furthermore, seining occurs relatively early in the life-history stages before numerous first-year mortality processes have fully acted on the cohort. For these reasons seining is reserved for collecting early information on YOY growth and is not used for estimating year class strength.

From 1987 through 1989 trawling was conducted at as many as 9 stations in an attempt to refine station selection. Three of these nine stations are now the standardized locations. The relationships between YOY Walleye and YOY Yellow Perch catch rates in various gears and recruitment to the adult population remain subject to the numerous mortality processes driving recruitment variability. Due to the COVID-19 pandemic and the inability for staff members to maintain a safe social distance trawling was not completed in 2020 but was completed in 2021.

From 2005 through 2007 fall electrofishing was conducted at as many as 16 stations in an attempt to refine station selection. There were 12 standard stations from 2008 to 2014. Currently eleven standardized locations are used to improve on year class strength estimation. In 2015, one station was discontinued due to safety concerns with shallow water and inconsistent rocks throughout the site. Electrofishing results have shown to be a useful metric for predicting Walleye year class strength on some of Minnesota's other large lakes and is showing that it compares to trawling with nearly identical predictive power to estimate year class strength on Leech Lake. Based on examples from other large lakes, as zebra mussels continue to expand in the lake trawling may not be feasible and a shift to using electrofishing results to predict year class strength may be necessary.

The objectives of this assessment include: 1) Index the relative abundance of YOY Walleye and Yellow Perch; 2) characterize early growth rates for both species; and 3) estimate Walleye year class strength (YCS).

Methods

Seining

Two seine hauls were completed at each of the five stations (Figure *1*; SE-1: Whipholt Beach, SE-2: Stony Point, SE-3: Traders Bay, SE-4: Ottertail Point, and SE-5: Five Mile Point) once per week over a two week time period in mid-July (Julian Weeks 28-29). Two hauls per week were made at each station using a bag seine (100-ft. long, 5-ft. deep, 0.25-in. untreated mesh) for a total of 20 seine hauls. The area seined was determined by assuming the distance from shore covered by the seine was 90 feet, which compensated for the bow in the seine created by water resistance during pulling. This figure was then multiplied by the distance of the pull (150 feet) and resulted in an area of 13,500 ft^2 (0.310 acres) per seine haul. All gamefish were identified to species and a representative sample measured (TL, mm). All non-gamefish were identified to species if possible, up to 20 per species were measured (TL, mm) and the remainder counted. Gamefish were recorded as either YOY or age-1 or older. When necessary, seine hauls were sub-sampled due to large numbers of fish captured. In these instances a representative portion of fish in a volumetric sub-sample were processed as stated above, and the total number obtained in the sub-sample was expanded to the total volume sampled. Age-0 Walleye and age 1+ sportfish were individually measured before sub-sampling occurred. An additional sample of YOY Yellow Perch as well as all YOY Smallmouth and Largemouth Bass were retained for daily growth determination. This was done to establish a baseline before zebra mussels are widely distributed throughout the lake and will be described separately at a later date.

Trawling

In a typical year trawling is conducted at the three long-term stations (Figure 1) using a semi-balloon bottom trawl (25-ft. head rope, 0.25-in. mesh cod end liner) in mid-August (Julian Weeks 33-34). Eight hauls are conducted at Five Mile Point (TR-1), six at Goose Island (TR-2), and six at Whipholt Beach (TR-3), for a total of 20 hauls. Hauls at the three long-term stations consist of five-minute tows at a fixed speed of 3.5 mph for a total effort of 100 minutes of trawl time. Trawled depths range from 6-12 feet depending on transect and location. Fish are identified, measured, and enumerated as per the methods described for shoreline seining. This was not done in 2020 due to COVID restrictions but was done in 2021.

Fall Electrofishing

Electrofishing was conducted using an MLES-Infinity pulsed-DC electrofishing boat (twin spider array anode) in mid-September (Julian Weeks 37-38). Standardized stations consisted of four clusters of sites, three of which contain three transects and one contains 2 transects (Figure *1*). The transects are located on the east side of the main basin near Bear Island and Brevik, the south side of the main basin near Roger’s Point, the west side of the main basin near Stony Point, and the southern portions of Walker Bay. The 11 transects were approximately 3-5 feet deep on sand/gravel/cobble shorelines. Transects consisted of 20 minutes of continuous on-time from the starting point. Up to 25 age-0 Walleye per transect were measured (TL, mm) and released and the remainder were counted and released. All age-1 Walleye captured were measured (TL, mm) and released.

Growth Indices

Growth of YOY Walleye and Yellow Perch sampled from seining, trawling, and electrofishing are indexed by mean length sampled by week from July through September. Mean lengths are determined for Julian weeks 28-29 for seining, 33-34 for trawling, and 37-38 for electrofishing, when fish are available.

Walleye Year Class Strength

Year class strength (YCS) is an index of the respective relative strength of Walleye year classes by age from age-0 through age-3. For example, to predict YCS of the most recent cohort a model of YCS as a function of age-0 gillnet and trawl catch rates fit to 3 most recent years data is used; model predictions give the predicted mean YCS for this cohort based on that sampling years trawling and age-0 gillnet CPUE.

As of 2015, a method for calculating YCS values became standardized among large lakes in Minnesota. This YCS model is a mixed-effects version (Kutner et al. 2004) of the model presented by Maceina and Pereira (2007), which is a 2-way ANOVA that has age and year class as fixed-effect categorical explanatory factors, and age-specific log-transformed CPUE for a cohort as the response (a small constant may be added to CPUE if there are zero catches). The Cohort effect in the YCS model is modeled as a random effect under the assumption that YCS on the $\log_e$ scale is distributed as Normal($0,\sigma_{YCS}$). Additionally, there is a random effect for Sample Year, assumed distributed as Normal($0,\sigma_{catch}$); this accounts for variation in gill net catchability among years. The model for CPUE of age *i* from year class *j* is:

$$\ln\left(CPUE_{ij}\right) = \mu + A_i + \Upsilon_j + \Psi_{i+j} + \varepsilon_{ij}$$

The μ is an intercept term, A_i is a fixed-effect parameter for fish age, Υ_j is the random-effect for cohort, and the Ψ_{i+j} is a random effect for sample year gill net catchability, and the ε_{ij} are assumed to be Normal($0, \sigma^2$). The $\log_e$ scale YCS estimates are the predicted realizations of the random effect for each cohort (these are often referred to as "BLUPs", which stands for Best Linear Unbiased Predictor); the back-transformed values are divided by their mean so the YCS values reported have a mean of exactly one.

For year classes younger than age-3 (2019-2021 cohorts), the YCS is a prediction, or incomplete assessment, based on limited observations; these predictions are representative of ultimate YCS. Predictive models based on young-of-year sampling alone will continue to be refined in response to additional data collection, such as electrofishing, or changing environmental conditions that could limit gear effectiveness. For example, colonization of zebra mussels at trawling sites could reduce the effectiveness of trawling for YOY Walleye (E. Jensen, MN DNR, personal communication), while factors that reduce water clarity could adversely affect electrofishing. Year class strength values between the 25^{th} to 75^{th} percentile ranges are classified as average. Values that exceed the 75^{th} percentile are classified as strong, while values that fall below the 25^{th} percentile are classified as poor. Year classes are considered fully recruited to the fishery once sampled during fall at age-3.

Factors Affecting Recruitment

The mean length of Walleye sampled electrofishing in mid-September (Julian weeks 37-38) were compared to initial fry density, the year class strength index, and the length/ intensity of the growing season (growing degree days; GDD_{50}=GDD ≥ 50°F). Annual GDD_{50} values were calculated using water temperature data from the main basin of Leech Lake. The length and intensity of the growing season (GDD_{50}) was calculated by giving each day in which the mean water temperature was ≥ 50°F one degree day, and an additional degree day for every degree over 50°F; example 55°F = 5 degree days.

Results

Twenty seine hauls (6.2 acres) were completed from July 12-21, 2021 at five standard stations, sampling 17 different species (Table 1). Seining is traditionally done Julian weeks 28 and 29 which would have been the Weeks of July 5^{th} and July 12^{th}. The majority of seining occurred during the standard weeks but due to staffing issues arising from COVID-19 protocols seining took place outside the standard sampling weeks on

July 21st. No YOY Walleye were caught and the YOY Yellow Perch catch rate was 744 fish/acre (Table 1, Figure 2 and Figure 3). Twenty trawls (100 minutes) were completed from August 9-17, 2021 at the three index stations, sampling 17 different species (*Table 2*). Overall catch rates of YOY Walleye and Yellow Perch were 105 fish/hour and 6,735 fish/hour, respectively (*Table 2*, *Figure 2 and Figure 3*). Catch rates were within the interquartile range for YOY Walleye and YOY Yellow Perch. Eleven transects (220 minutes) were electrofished from September 9-22, 2021. The overall catch rate of YOY Walleye was 53 fish/hour (Table 3, Figure 2), which is below the long-term average of 92 fish/hour. Average YOY Walleye lengths were 7.1 (electrofishing) inches in 2021, compared to long-term average of 6.2 inches. (Figure 4). The average YOY Yellow Perch length was 2.0 (trawling) inches in 2021, which above the long-term average (Figure 5). Year class strength is estimated at 1.6 for 2021. (Table 3; Figure 6). The first true measure of year class strength occurs when each year class is fully recruited to the gear after age 3.

Discussion

Walleye recruitment in natural lakes is highly variable across years and is influenced by a number of physical and biological factors. High abundances of adult Walleye can suppress ensuing year classes via predation (Chevalier 1973) and competition (Madenjian et al. 1996; Beard et al. 2003). Similarly, high adult abundances of other species, such as Yellow Perch or Northern Pike, can exert enough predation on a Walleye year class to significantly influence its outcome (Hansen et al. 1998, Nate et al. 2003). Spring warming rates have a strong influence on incubation times, egg survival and hatch rates, and food availability for newly-hatched fry (Madenjian et al. 1996; Hansen et al. 1998). Furthermore, first-winter survival of YOY Walleye is size-specific and therefore strongly influenced by growth rates during the first year (Forney 1976, Madenjian et al. 1996, Kampa and Hatzenbeler 2009). The larger an individual becomes during its first growing season, the higher the likelihood it survives its first winter and eventually recruits to the fishery (Madenjian et al. 1996; Hansen et al. 2012). The young-of-year Walleye catch rates for electrofishing were below average in 2021 but the lengths were above average in the fall sample. This hopefully will translate to over winter survival.

While the trawl catch rates are currently the indicator used for Walleye YOY abundance, electrofishing in mid-September has the potential to more accurately index Walleye year class strength than trawling (Schultz et al. 2007). This is because a strong relationship is evident between year class strength and average length of YOY Walleye sampled electrofishing (Figure 7). This relationship underscores the influence first-year growth has on eventual recruitment to the fishery and highlights the potential utility of fall electrofishing when assessing recruitment in the future after zebra mussels establish and reduce the effectiveness of trawling as has been observed elsewhere, such as Mille Lacs Lake (E. Jensen, MN DNR, personal communication).

Although the 2021 and 2019 year classes are not fully recruited to the fishery, they are both currently predicted to be above average in strength. The 2018 year class appears to be below average based on trawl and electrofishing YOY catch rates in 2018 but still above the lower objective range. The consistency within the fishery the past several years has been a reflection of the steady recruitment during the same time period. Fluctuations in predator year classes are expected in healthy natural systems and can provide short-term relief to prey species, which is necessary for supporting future recruitment. This is the case in Leech Lake. The three year moving average for year class strength is still well above management objective thresholds even with a weak 2018 year class.

While stocking efforts during 2005-2014 approximately doubled, average total fry density relative to pre-2005 estimates, recruitment of stocked year classes was limited by natural trade-offs associated with density. Increased stocking rates did not result in more young Walleye recruiting to the fishery. A curve-linear relationship between total fry density and recruitment suggests density-dependent effects are structuring recruitment to age-3. Competition between YOY fish for food and space increases as total fry density increases, with a trade-off being slower growth rates. As previously indicated this is important because overwinter survival for YOY Walleye is a significant bottleneck that is highly correlated to size (Toreys and Coble 1979; Copeland and Carline 1998; Pratt and Fox 2002). Thus, larger YOY are more likely to survive their first winter and smaller YOY are more likely to succumb to mortality, and abiotic (i.e. cool summers) or management activities (i.e. higher fry densities via stocking) that reduce first-year growth will inherently reduce the likelihood of individual survival. This explains why higher stocking levels did not result in stronger year classes of Walleye. First-year growth is also temperature-dependent (Neuheimer and Taggart 2007; Venturelli et al. 2010), and longer and warmer summers can buffer but not negate the effect of higher fry densities on growth. The summer of 2021 saw very warm temperatures early in the growing season that persisted throughout the summer as can be seen in the historical high in growing degree days (Figure 7 and 9). Lastly, another important consideration when contemplating appropriate fry densities is the prey population. Juvenile Walleye, whether stocked or natural, that do not survive and recruit to the fishery will consume prey until mortality occurs. Consequently, elevated fry densities not only fail to increase recruitment because of density-dependent limitations but also exert added and unnecessary demands on the prey base.

Due to the high degree of variability in YOY Walleye survival, forecasting recruitment (i.e. year class strength) based on YOY metrics will inherently be accompanied by uncertainty. For example, variability exists among Minnesota's ten largest Walleye lakes as to which YOY Walleye sampling methods are the best predictor of ensuing YCS. Fall electrofishing catch rate is the best metric on Cass, Kabetogama, Rainy, and Vermillion lakes to predict YCS. Conversely, trawling has been the best gear on Lake of the Woods, Leech, Mille Lacs, and Winnibigoshish lakes. Upper Red Lake is the only lake where seining is the best gear to predict Walleye YCS, and all three gears are good predictors on Lake Pepin. Therefore, while over 30 years of annual survey work has determined the best gear(s) for predicting Walleye YCS in each of these systems, no estimate is without variability from year to year or lake to lake because of the dynamic mortality processes that influence recruitment. Furthermore, changes in lake ecology, such as the introduction of an invasive species, have the potential to alter these predictive relationships.

Future management decisions should consider actions that optimize YOY growth and recruitment potential while minimizing effects on the prey base. Walleye hatch rates were estimated for a number of Minnesota lakes as part of a study evaluating fry densities in Walleye egg-take lakes (Logsdon 2016). These data show Walleye hatch rates observed in Leech Lake are similar to other quality Walleye populations in Minnesota. Higher densities of stocked fry and total fry have not translated to stronger year classes. Lower fry densities have the highest potential for strong year classes during longer, warmer summers but also the greatest risk for weak year classes during cool, short summers. The management plan objective of establishing YCS values (3-year moving average) above the 25th percentile includes the goals of predation relief and minimizing density dependent effects on juvenile Walleye. In short, the "boom-bust" potential of a year class observed in the past appears to be strongly tied to fry density and growing season, and this variability has been largely mitigated by increases in spawner stock in response to harvest regulations and enhanced population stability. Although climatological variables will always influence YCS, employing adaptive management strategies that result in increased fry densities should only be considered if the weight of evidence suggests it is appropriate.

GILLNET SURVEY

Introduction

Gillnet surveys on Leech Lake have been completed annually between early and mid-September starting in 1983. Gillnets are the most effective tool for assessing four species (Walleye, Yellow Perch, Northern Pike, and Tullibee (Cisco)). However, information on other species is also collected. Since 1983, four nets have been set at standard locations within each major bay (Wingate and Schupp 1984). Four nets were added in the central area of the main basin (Pelican Island) in 1984 for a total of 36 net sets per year. Analyzed data collected with gillnets demonstrate trends in population metrics, such as relative abundance, mature female biomass (pounds/acre), age- and size-structure, growth rates, mortality rates, and recruitment. Gillnet catch rates are also used to establish population management goals that can be quantitatively evaluated over time.

Methods

Standard experimental gillnets were set at 36 sites throughout the lake from early through mid-September. Experimental nets (50-ft. panels of 0.75, 1.00, 1.25, 1.5, and 2.0-inch bar mesh; 250-ft. total net length) are used to reduce size-selective biases encountered when using nets of a single mesh size. Standardized methods include net design, net location, net orientation, and time of year. Four gillnets were set in daily groups of 9 general clusters (Figure 10). Western bay sets included net stations 1-16 and main lake sets included net stations 17-36. While most data are summarized lake wide, differences in catch rates, growth, and spawner stock between the main lake and western bays result in these data being summarized both by basin and lake wide.

All fish captured were identified to species, measured (TL, mm), and weighed (g). Sex and maturity data were recorded for all Walleye, Yellow Perch, Tullibee (Cisco), and Northern Pike when possible. Data was recorded separately for each of the five mesh sizes within each net. Weights and lengths were converted from metric units to English units in the majority of analyses and reporting.

Ages were estimated using sagittal otoliths from all Walleye collected. Otoliths have been used to age Walleye since 1990. Cleithera were removed from a sub-sample of ten Northern Pike per 25-mm length intervals from each basin. Cleithera have been used to age Northern Pike since 1990. Otoliths were removed from a sub-sample of five Yellow Perch, per sex and per mesh panel, from each net. Otoliths have been used to age Yellow Perch since 2001. In most cases, sub-sampling for Yellow Perch otolith collection only occurred within the 0.75 and 1.00-inch mesh sizes. Otoliths were removed from a sub-sample of ten Tullibee (Cisco) per 25 mm length group per basin. Cisco ages were determined starting in 2008. Age assignment was basin-specific for each species because differences were observed in population metrics among basin types, particularly growth rates (Schupp 1978).

Size structure for Walleye, Yellow Perch, and Northern Pike was summarized using various metrics. Walleye size structure was summarized by quantifying the percentage of Walleye sampled in gill nets ≥20 inches. The 20 inch threshold was selected as angler dissatisfaction with protective size regulations is often in response to the portion of their catch that they are required to release; this metric is intended to address that concern. Yellow Perch size structure was summarized by quantifying the percentage of Yellow Perch sampled in gill nets ≥8 inches. The 8 inch threshold was selected, as summer and winter anglers start harvesting Yellow Perch in greater numbers on Leech Lake at 8 inches (Pedersen and Schultz 2017). Northern Pike size structure was summarized by quantifying the percentage of Northern Pike sampled in gill nets ≥22 inches. This threshold was selected, as summer and winter anglers had traditionally started harvesting Northern Pike on Leech Lake at 22 inches, prior to implementation of the 22-26 inch protected slot limit in 2018.

Northern Pike and Yellow Perch recruitment is determined by annually monitoring gill net catch rates of age-3 and age-4 individuals, respectively. Age-3 Northern Pike are a size (approximately 18-19 inches) at which all individuals in a year class are large enough to be sampled by gill nets, yet are smaller than most anglers elect to harvest. Therefore, age-3 gill net catch rates are a good index of recruitment. During annual assessment in September, age-4 Yellow Perch are a size (approximately 7 inches on Leech Lake) at which most all individuals in a year class are large enough to be sampled in a gill net yet are smaller than most anglers elect to harvest. Therefore, age-4 gill net catch rates are a good index of recruitment.

Walleye condition was assessed using relative weight (*Wr*), which compares the weight of a fish relative to its length (Murphy et al. 1990). Mature female biomass (pounds/acre) was estimated using Anderson's (1998) gill-net catchability model (q_{abg} model). The length and age at which an individual has a 50% chance of being mature was estimated for Walleye and Yellow Perch (Gangl and Pereira 2003). These two biological performance indicators (BPI) are sensitive to changes in population mortality, which can be indicative of overharvest (Gangl and Pereira 2003) or other stressors (Schultz et al. 2013). The other BPI calculated included female length at age-3 (Gangl and Pereira 2003).

Results

Standard experimental gillnets were set at 36 sites from September 6-17, 2021. Seventeen different species were sampled (Table 4), of the four target species, catch rates for Walleye and Tullibee (Cisco) are historically higher in the main lake sets, while catch rates for Yellow Perch and Northern Pike are typically higher in the western bays (Figure 11). Catch rates for Walleye and Yellow Perch followed historic trends by basin in 2021. Northern Pike catch rates were higher in the main lake and Tullibee (Cisco) catch rates higher in the western bays. Long-term gillnet catch rates for all species are summarized in Appendix 1.

Walleye

A total of 436 Walleye were sampled in gillnets. The overall catch rate of 12.1 (fish/net) was above the 2020 catch rate (11.0 fish/net) and the three year average was above the management objective of 7-10 fish/net. The pounds per net in 2021 (17.1 pounds/net) was above the 2020 rate (15.5 pounds/net) and was above historic the average (11.2 pounds/net) (Figure 12 and Figure 13). Catch rates have ranged from 4.6 fish/net (1993) to 13.4 fish/net (1988), and 5.3 pounds/net (1983) to 20.4 pounds/net (2015). Catch rates were lower in the western bays (11.7 fish/net) compared to the main lake (12.5 fish/net) (Figure 11). The high catch rate was partially driven by fast growth for age-0 Walleye making them more vulnerable to the gill nets.

Total length of Walleye sampled ranged from 7 to 31 inches (Table 5, Table 6;and Figure 14) and ages ranged from 0 to 16 years old (Table 7; Figure 15). Age and length frequency distributions represented a balanced population, with age-2 (2019 year class) and age 4 (2017 year class) being the most frequently sampled. The percentage of Walleye sampled that were ≥20 inches was 14% similar to the 2020 value, and with the three year average still within the management objective range of 10-20% (Figure 16). The average lengths of age-1, age-2 and age-4 Walleye were similar to the long term average (Table 8) while the age-3 Walleye were more than an inch larger than the long term averages.

All males were mature by 16 inches and age-5, while all females were mature by 21 inches and age-7 (Table 6 and Table 7). Condition (*Wr*) in 2021 was 80, which is down from 2020. The three year average was below the management plan objective range of 82-86 (Figure 17). The 2021 mature female density (pounds/acre) was 1.7 while the three year running average was 1.9 was within the management plan objective range (1.5 to 2.0 pounds/acre; Figure 18).

Female mean length at age-3 in 2021 (16.9 inches) was above the threshold of 15.6 inches (Figure 19). Female length at 50% maturity in 2021 (17.8 inches) was above the threshold of 17.4 inches (Figure 19). Female age at 50% maturity in 2021 (3.9 years) was below the threshold of 4.0 years (Figure 19).

Yellow Perch

A total of 378 Yellow Perch were sampled in gillnets. Catch rates in 2021 were 10.5 fish/net and 2.0 pounds/net (Table 4, Figure *12*. Gillnet catch rates (number/net) of selected species in Leech Lake, 1983-2021. Horizontal lines represent the 25th and 75th quartiles. and Figure 13), and were lower than the long-term averages of 19.8 fish/net and 4.3 pounds/net. The catch rate was down from 2020 (14.4 fish/net). Previous catch rates ranged from 9.4 fish/net (2016) to 37.7 fish/net (1995), and 2.2 pounds/net (2016) to 8.1 pounds/net (1995). The Yellow Perch gill net catch rate (3-year moving average) remained below the management plan objective threshold (25th percentile; Figure 12).

Total length of sampled Yellow Perch ranged from 5 inches to 12 inches (Table 5, Table 6 and Figure 14) and ages ranged from 2 to 7 years old (Table 7; Figure 15). The 2017-2019 year classes made up 80% of the Yellow Perch sample, there are 6 year classes present in the gill net catch. Of all Yellow Perch sampled, 31% were ≥8 inches, 16% were ≥9 inches, and 6% were ≥10 inches. The 3-year moving average percent sampled in gill nets ≥8.0 inches was 24% and was below the 30% management plan objective (Figure 20), but is expected to increase as the 2017 and 2018 year classes grow into these size ranges. The average lengths of Yellow Perch were similar to historic means for all ages. (Table 8).

The catch rate of age-4 Yellow Perch in 2021 was 3.2 fish/net (2017 year class). The gill net catch rate (3-year moving average) of age-4 Yellow Perch (3.8 fish/net) is above the management plan objective threshold (3.0 fish/net, 25th quartile), (Figure 21).

Length of female Yellow Perch at 50% sexual maturity were 6.4 inches (Figure 22). All males sampled in 2021 were mature except for 1 fish, while most females were mature by 7 inches and age-4 (Table 6 and Table 7). Males tend to reach sexual maturity before they are effectively sampled by gillnets.

Northern Pike

A total of 147 Northern Pike were sampled in gillnets. The overall catch rate was 4.1 fish/net and 9.0 pounds/net; (Figure 12. Gillnet catch rates (number/net) of selected species in Leech Lake, 1983-2021. Horizontal lines represent the 25th and 75th quartiles.and Figure 13). Catch rates in 2021 were below the long-term averages of 4.7 fish/net and 11.9 pounds/net. Previous catch rates ranged from 3.6 fish/net (1993) to 6.2 fish/net (1995), and 7.9 pounds/net (1984) to 19.0 pounds/net (1995). The three year moving average catch rate in 2021 (4.5 fish/net) was within the 2021-2025 management objective range of 4.1-5.3 fish/net (Figure *12*. Gillnet catch rates (number/net) of selected species in Leech Lake, 1983-2021. Horizontal lines represent the 25th and 75th quartiles.). Catch rates were higher in the main lake basins (4.4 fish/net) than the western bays (3.8 fish/net; Table 4; Figure 11).

Total length of Northern Pike in the sample ranged from 10.4 to 34.5 inches (Table 5, Table 6; Figure 14) and ages ranged from 0 to 7 years old (Table 7; Figure 15). The 2016 to 2019 year classes made up 84% of all Northern Pike sampled. Of all Northern Pike sampled in 2021, 35% were 22 inches or longer, 23% were between 22 and 26 inches, and 15% were 26 inches or longer. The 3-year moving average percent of Northern Pike sampled in gill nets ≥22 inches was 39% in 2021 which exceeds the 30% management plan objective threshold (Figure 23). The average lengths of female age-2 through age-5 Northern Pike from the 2021 sample were similar to long term averages.

All males captured were mature by 15 inches and age-1, while all females were mature by 18 inches and age-4 (Table 6 and Table 7). The gill net catch rate of age-3 Northern Pike 1.4 fish/net was just above the 75th quartile while the 3-year moving average (1.3 fish/net) was within the management objective range (1.0 to 1.6 fish/net, age-3), indicating stable recruitment (Figure 24).

Tullibee (Cisco)

A total of 261 Tullibee (Cisco) were sampled in gillnets. The overall catch rate was 7.3 fish/net and 3.6 pounds/net (Table 4, Figure 12. Gillnet catch rates (number/net) of selected species in Leech Lake, 1983-

2021. Horizontal lines represent the 25th and 75th quartiles. and Figure 13). Catch rates (fish/net) had dropped each year since 2016 and were below the historical average (5.5) in 2019 until they rebounded in 2020 (10.2). Previous catch rates ranged from 0.6 fish/net (2006) to 18.5 fish/net (1987), and 0.2 pounds/net (2006) to 7.2 pounds/net (1985). In 2021, the catch rate in the western bays was 15.5 fish/net while the catch rate in the main lake was 0.7 fish/net (Table 4, Figure 11).

Tullibee (Cisco) in the sample ranged from 7 to 17 inches (Table 5, Table 6; Figure 14) and 1 to 15 years old (Table 7, Figure 15). Twelve year classes were represented in the 2021 sample, with the 2019 and 2018 year classes making up 73 percent of the population.

Other Species

Other species sampled in 2021 included Black Bullhead (*Ameiurus melas*), Black Crappie, Bluegill, Bowfin, Brown Bullhead (*Ameiurus nebulosus*), Burbot (*Lota lota*), Hybrid Sunfish, Lake Whitefish, Largemouth Bass, Pumpkinseed, Rock Bass, White Sucker, and Yellow Bullhead (*Ictalurus natalis*) (Table 4*).* Species not sampled in 2021 that have been previously sampled include, Muskellunge, Shorthead Redhorse, and Tiger Muskellunge (*Esox masquinongy x Esox lucius*; AppendixTable A *1*).

Discussion

Walleye abundance (number/net) is above the upper end of the management objective range, while Walleye biomass (pounds/net) has been at or above the 75th quartile for the past 10 years. The 2021 Yellow Perch gill net catch rate was below the management objective of at least 15 fish/net as was the 3 year moving average. If elevated prey demand on Yellow Perch by Walleye is causing the low perch abundance then a response by the perch population to changes in Walleye harvest regulations can potentially be expected. Catch rates of Northern Pike in 2021 as well as the 3 year moving average were within the management objective goal range. Tullibee (Cisco) catch rates were well above the interquartile range and did not seem to be overly affected by the long summer experienced in 2021.

Biological performance indicators (BPIs), or population response metrics, were developed to monitor exploitation of Minnesota's large lake Walleye populations (Gangl and Pereira 2003). BPI threshold levels can indicate overharvest or, more precisely, increased mortality. Signs of increased mortality include increased growth and earlier maturity rates by length and age (Rose et al. 1999). During 2000-2010, age-3 females were growing faster than had been previously observed, and maturing at shorter lengths and younger ages than previously observed. Schultz et al. (2013) found statistical differences in Walleye recruitment, growth, and maturity among the 1992–1997, 1998–2004, and 2005–2011 time periods, which represent pre-colonization, population buildup, and the management eras of the double-crested cormorant population. The differences in these metrics across the respective time periods were potential Walleye population responses to increased mortality, and some of these metrics were strongly associated with changes in cormorant abundance. Similar percid population responses were observed on Lake Huron (Fielder 2008, 2010). Results from the 2021 sampling season show that the female average length at age-3, (3 year running average) was above the threshold for the first time in 10 years. Values for female length at 50% maturity were above the threshold and female age at 50% maturity were both below the threshold, indicating there is the potential for a stress limiting response by the population (Figure 19) that needs to continue to be evaluated in future years.

The metrics associated with the 2021-2025 Leech Lake Management Plan (Pedersen 2020) met or exceeded the majority of management plan objectives. The consistency in the Walleye population since the late-2000s suggests a positive response to current management actions. The protected slot limit on Walleye had successfully protected mature females and had increased the reproductive capacity of the population; however, the combination of protection and consistent recruitment of year classes had led to a surplus of spawner stock. Maturation of the 2013 year class contributed to the higher than expected mature female densities. Given this status, a less restrictive harvest regulation was considered. Starting on the 2019 Walleye open water season, the protected slot limit was removed and anglers were allowed to keep 1 fish over 20 inches with a four fish bag limit. The 2017 and 2019 year classes appear to be strong and should help maintain the Walleye fishery in the coming few years. Walleye recruitment has also become consistent since 2007. This is similar to initial post-regulation recruitment patterns observed on Lake Winnibigoshish (Schultz and Staples 2010) and also on Upper Red Lake (Kennedy 2013). Density is an important factor regulating growth, maturity, and recruitment (Spangler et al. 1977; Muth and Wolfert 1986; Schueller et al. 2005). Changes in the Walleye population on Leech Lake have led to considerable improvements to the recreational fishery as indicated by summer and especially winter creel surveys conducted during 2008-2011, 2014, 2014-15, 2015-2016, 2016 and 2019 (Schultz 2009; Schultz 2010b; Vondra and Schultz 2011, Ward and Schultz 2012, Stevens and Ward 2015, Stevens 2016, Pedersen and Schultz 2017, Pedersen and Schultz 2020).

Statewide declines in Yellow Perch have been observed. Suspected causes include increases in predation by gamefish, increases in competition at early life stages by insectivores such as Bluegills, and near shore spawning habitat loss, among others (Bethke and Staples 2015). Specific causes of sustained declines in Yellow Perch abundance in Leech Lake are unclear, but elevated predation by juvenile and adult Walleye and increases in total harvest of Yellow Perch by anglers are both suspected. Prey demand by the Walleye population has been sustained at a high level for several years whereas angler harvest, and in particular winter harvest, has not. Additionally, predation by cormorants had been held constant during this period of Yellow Perch decline with the exception being 2018-2020. Record Yellow Perch harvest by anglers was documented during the 2010-11 and 2014-15 winter angling seasons, with winter harvest exceeding that of summer for the first time in the creel history (Schultz and Vondra 2011; Stevens and Ward 2015). Harvest of Yellow Perch in the 2015-2016 winter creel survey (24,322 pounds) was down significantly from the 2014-2015 season (85,195 pounds). Some of this variability can be attributed to late ice on and in particular early ice off; the majority of perch harvest occurs during the late ice fishing season (Stevens 2016). Very poor ice conditions in the winter of 2019-2020 also led to a significant drop in winter pressure and harvest. As an example, winter harvest of perch averages 68,167 fish (30,788 pounds). During the winter creel of 2019-20 there were only 17,854 perch (3,808 pounds) estimated harvested (Pedersen and Schultz 2020). Although many anglers continue to perceive cormorant consumption of Yellow Perch to have a significant influence on recruitment, consumption by cormorants had been reduced by 90% relative to 2004 levels and are similar to pre-2000 levels (Schultz et al. 2013). Recently logistical difficulties with early season cormorant control is resulting in slightly higher total annual fish consumption by cormorants despite reaching management targets.

Recent Walleye year classes have consistently been near or above the long-term average in terms of strength, with the exception of 2018, which has resulted in a consistent high forage demand by juvenile Walleye. Pierce et al. (2006) documented density-dependent responses in both Walleye and Yellow Perch populations with changes in Walleye stocking rates and that Walleye predation associated with differing stocking rates as a plausible explanation for most changes observed in the prey base. This is because juvenile Walleye have higher metabolic rates and energy demand, on a per-pound basis they consume more than adult Walleye (Kitchell et al. 1977; Hartman and Margraf 1992; Madon and Culver 1993). Furthermore, management actions that can elevate juvenile Walleye densities may lead to reduced Walleye growth (Forney 1976; Pierce et al. 2006; Kampa and Hatzenbeler 2009), reduced Walleye recruitment (Fayram et al. 2005; Jacobson and Anderson 2007; Hansen et al. 2012), and exert unnecessary predation pressure on Yellow Perch (Nielsen 1980; Lyons and Magnuson 1987; Knight et al 1984; Pierce et al. 2006). Recent steps taken to reduce predation pressure on Yellow Perch include specifying conditions within the 2016-2020 management plan which were carried over into the 2021-2025 management plan update in which a stocking action would be appropriate or necessary. These conditions center on poor Walleye recruitment and expanded Walleye fry density research relating to mature female spawner abundance. The removal of the protected slot limit for Walleye was also intended to provide some predatory relief to Yellow Perch populations.

Increases in Northern Pike density, particularly increases in 'hammer handle' sized pike, are currently being observed statewide (MNDNR 2018). These trends have resulted in implementation of new statewide regulations based on specific regulations and management goals by zones to address concerns by anglers starting with the open water fishing in 2018. Despite statewide trends, lake-wide Northern Pike catch rates on Leech Lake have varied by less than three fish/net since 1983, indicating a stable population but one that could benefit from the new zone regulations over time.

Peaks in Tullibee (Cisco) catch rates are often highly variable, and typically are associated with strong year classes of age-1 and/or age-2 fish. This was the case in 2021 with 36% of the sample age 2 or younger compared with 56% of the catch being 2 or younger in 2020 and 8% in 2019. Juvenile Cisco can comprise larger proportions of predator diets when large year classes are present, thereby providing predation relief to Yellow Perch (Forney 1974) and other prey species (Schultz et al. 2013). Cisco populations are often limited by thermal regimes. As a coldwater species, Cisco require elevated oxygen levels. During warm summers oxygen levels particularly in the shallower, windswept main lake basin will decrease due to the reduced ability of water to retain oxygen at higher temperatures. In addition, as coldwater species such as Cisco become physiologically stressed by warmer temperatures oxygen demand is increased (Pörtner 2001; Pörtner and Knust 2007). In instances such as this without sufficient thermal refuge Cisco can be subject to episodes of summer kill. Consequently, the Cisco population in Leech Lake is constrained by summer climate trends particularly in the main basin where oxygen-rich coldwater habitat is limited but spawning habitat is abundant. The majority of the Tullibee caught in the 2021 sample were in the western bays with a catch rate of 15.5 fish per net compared to on 0.7 fish per net in the main basin (Figure 11). This has the potential for impacts on other species, specifically the growth rates of predatory species.

OTHER WORK

Centrarchid Sampling

Standardized large lake sampling gears such as gill nets are intended to target Walleye, Northern Pike, Yellow Perch, and Tullibee (Cisco). This gear does not adequately sample Centrarchids (bass, sunfish and crappie) and alternate sampling techniques have been evaluated. Based on criteria stated within the Fisheries Management Plan for Leech Lake 2016-2020, spring assessments were to be conducted every three years, with sampling methodology, location, and timing becoming standardized by 2018. The intent of this sampling was to monitor Leech Lake centrarchids for potential changes in size structure and catch rates. The initial lake-wide Centrarchid survey was completed in 2012 with subsequent surveys in 2015 and 2018. The next targeted Centrarchid sample was originally scheduled for 2021 but will be in postponed until 2022 to avoid conflicts with muskellunge spawn take operations on Leech Lake.

Water Quality

Water samples were collected at stations number one (Walker Bay) and five (Stony Point) on July 27, 2021. The Minnesota Department of Agriculture Chemistry Laboratory in St. Paul, Minnesota analyzed the samples collected for chlorophyll a, total phosphorus, pH, alkalinity, total dissolved solids and conductivity. From these data a mean TSI (trophic state index) is calculated.

There has been no noticeable long-term changes in water quality since the inception of the Large Lake Program (Table 9) with the exception of some moderate increases in alkalinity attributed to air quality standards implemented in the 1980s (Stoddard et.al. 1999). Water clarity data is available from the University of Minnesota Remote Sensing and Geospatial Analysis Laboratory and Water Resources Center (2017). Water quality monitoring data is also available from the Minnesota Pollution Control Agency (2018). Water clarity is expected to increase as adult zebra mussels continue to expand and become established throughout the lake.

Monthly dissolved oxygen profiles were collected in 4 of the major bays and the main lake from June through October with an additional sample taken in June. Traditionally the first sample of the year is taken in mid-May (Figure 25, Figure 26, Figure 27, Figure 28, and Figure 29). In general, Walker Bay is less productive with greater water clarity than the main lake (Stony Point site). Walker, Kabekona, and Agency bay sample sites exceed 80 feet deep and stratify annually around early to mid-July. Stratification refers to a substantial change in temperature mid-water column caused by a difference in water density commonly referred to as the thermocline. The location off Stony Point, similar to Portage, Sucker, Boy, and Headquarters bays, rarely exceed 30 feet and does not stratify due to constant mixing by wind. This means the water temperature and oxygen levels are very similar throughout the entire water column.

The Leech Lake Association began a program of monthly water sampling in 2017 that includes an algal community sampling component. Initially RMB Environmental Laboratories analyzed the samples collected by volunteers. In 2019, the Leech Lake Association secured a grant through Cass County to continue the phytoplankton (algal) sampling and contracted the National Resources Research Institute to complete the analysis. The 2021 samples were contracted through PhycoTech and analysis is still ongoing at the time or writing this report but initial results are provided in figures 44 and 49. The goal of the sampling is to develop some baseline data at the early stages of infestation of zebra mussels to track potential changes in the lake, more details will be provided in the zooplankton section of this report.

Aquatic Invasive Species (AIS)

A survey of Leech Lake boat harbors in 2004 found established beds of Eurasian water milfoil (EWM) in several harbors between Stony and Rogers points and were immediately treated with aquatic herbicide. Harbors were typically checked annually for EWM by DNR personnel and treated when necessary from 2004 to 2014. This invasive species continues to be discovered in new harbors and open water areas throughout the entire lake. Since infestation has spread from isolated portions of the lake, treatment plans beyond 2016 are the responsibility of the individual Leech Lake harbor or shoreline owners. EWM is now considered widespread across the main basin harbors of Leech Lake, and now is establishing in open areas of the main lake despite previous annual control efforts. Sucker Bay has seen the largest recent infestation. The northern part of the bay can be impacted when strong winds from the south dislodge plant fragments and they accumulate in the public access and resort harbor.

While conducting EWM harbor searches during 2009 curly-leaf pondweed (CLP) was identified and removed from a harbor near Whipholt Beach. This is not the first occurrence of CLP, as it has been previously documented in the Leech Lake River embayment near Federal Dam. Like EWM, CLP can be an aggressive invasive aquatic plant and DNR personnel will continue to monitor CLP presence in Leech Lake.

Rusty crayfish are native to the Ohio River drainage basin and were first recorded in the late 1980s. Staff began reporting the number of rusty and native crayfish entangled per gill net during the annual gill net assessment in 2002 after rusty crayfish numbers had expanded. Crayfish entanglement rates in 2019 were significantly lower than the highest entanglement rates seen in 2018 but rebounded in 2020 and remained stable in 2021 (Figure 30). Yellow Perch and Rusty Crayfish abundance are somewhat correlated, as an inverse relationship exists between the two species (Figure 31).

The DNR Division of Ecological and Water Resources spent 1,069 hours conducting 5,025 watercraft inspections at public accesses in 2021. The Cass County Soil and Water Conservation District (SWCD) also contributed watercraft inspection hours on area lakes. In 2021 Cass County SWCD spent 2,290 hours conducting 5,903 watercraft inspections on Leech Lake.

In 2016, zebra mussel veligers (larval stage) were found in two separate zooplankton samples, one sample from Kabekona Bay and one from Portage Bay, on two different sampling days. No veligers were found in 2017 samples. However, in early October 2017 a sailboat that had been moored in Walker Bay during the summer of 2017 was found with attached juvenile zebra mussels. Veligers were found in zooplankton samples in 2018 in a number of different samples throughout the year. In 2019, veligers were again found in low numbers in various zooplankton samples and the first scattered reports of adult zebra mussels occurred throughout the summers of 2019 and 2020, with considerable and widespread increases in reports during 2021. Based on these reports and the presence of veligers in all zooplankton sampling sites, the infestation is spread throughout the lake with zebra mussels reported in all major bays. In 2020 a few adults were found on a temperature monitor suspended in the 40 foot deep trench located a mile northeast of Stony Point in the main basin of the lake. In 2021 that temperature monitor was completely covered with adult zebra mussels. Expansion is occurring as expected and reports will continue to expand throughout the lake.

While conducting aquatic vegetation removal for a resort in Steamboat bay, the private company contracted identified starry stonewort in the harbor. The MNDNR aquatic invasive species specialist confirmed the presence of starry stonewort in the harbor and also identified an area approximately 8 acres outside the harbor in a channel and wild rice bed that was also infested. In the fall of 2021 Cass County, MNDNR and the Leech Lake Band DRM collaborated to conduct a removal project of the identified infestation. A Diver Assisted Suction Harvest (DASH) contractor was brought in and an attempt to remove as much of the infestation as possible was done with the DASH system and hand pulling. Since the removal was done late in the year much of the algae had retreated so hand pulling was not as successful for biomass removal as hoped. However, the DASH team was able to remove much of the reproductive structures, rhizomes and star shaped bulbils. They were removed from the lake and transported to an offsite disposal site. Planning is being undertaken for future work to continue to track the infestation and evaluate its potential impacts on the wild rice in the lake.

Double-Crested Cormorant management

The DNR continues to assist the Leech Lake Band DRM in maintaining the number of cormorants at 500 reproducing pairs which equates to a total fall population at or below 2,000 cormorants. The 2021 spring and fall estimated cormorant numbers were 2,258 and 636, respectively (Figure 32). A total of 1,390 were removed during 2021 (Figure 33) with no diet samples being taken.

A study conducted from 2004-2011, Schultz et al. (2013) concluded that total feeding effort and fish consumption was reduced by nearly 90% from 2004 population levels. In 2004, the cormorant population consumed 16.81 pounds/acre and by 2011 total fish consumption was reduced to 1.61 pounds/acre. Respectively, average fledged and nestling diets were comprised of Yellow Perch (61.0% and 77.4%), Cisco spp. (12.3% and 9.4%), minnows *Notropis* spp. (9.9% and 2.2%), Trout-perch *Percopsis omiscomaycus* (4.1% and 0.4%), and Walleye (4.6% and 3.6%), though considerable seasonal and temporal variability were observed. In 2017 it was estimated that cormorants consumed 3.43 pounds/acre and 2017 diets were mostly similar to Schultz et al. (2013). However, trout-perch were more prevalent in diets than previous years, age-0 Walleye consumption appeared to be the highest observed in a single year, and the longest Walleye and Yellow Perch in cormorant diets were observed in 2017 (Mortensen et al. 2018a). Total fish consumption during 2018 was estimated to be 4.85 pounds/acre, this is above the 3.5 pounds/acre target maximum allowable consumption rate (Mortensen et al. 2018b). In 2019, fish consumption by cormorants was estimated to be 4.05 pounds/acre (Mortensen et al. 2019); the low frequency of high-calorie Tullibee (cisco) in 2019 diets was suspected to be the primary cause of inflated total consumption estimate despite reaching the management target for the colony. In 2020 total fish consumption was estimated to be 3.99 pounds per acre and 3.74 pounds per acre in 2021. Impacts to Walleye recruitment were observed when consumption rates previously exceeded 3.5 pounds/acre, the estimate has exceeded this level from 2017-2021 (Figure 33). This will be considered in future cormorant and fisheries management decisions concerning Leech Lake.

Plankton Sampling

Since 2012 zooplankton have been sampled monthly at five locations from mid-May through mid-October. An additional sample was added in 2016 in May and June to coincide as closely as possible with Walleye egg hatching. Sampling stations include sites in Walker Bay, Kabekona Bay, Agency Bay, Stony Point (Main Lake), and Five Mile Point (Portage Bay). The samples are taken at the deepest depth in each respective area. After locating each site, a net with a 30 cm mouth diameter and 80 μm mesh is lowered so that the bucket of the net is approximately 0.5 meters from the bottom. The net is raised at 0.5 to 1 meters per second to the surface. The sample is rinsed from the bucket into a plastic bottle and preserved with 95% denatured ethanol.

The DNR Division of Ecological and Water Resources Biology Lab in the past has processed the samples. The lab has experienced some retirements and staffing was not brought up to previous levels. As a result at the time of writing this report the 2021 samples have not been processed and may not get processed until sometime later data from the 2020 is provided.

Samples were prepared in the lab by filtering them through 80 μm mesh and rinsing specimens into a graduated beaker. Water is added to a volume that provides at least 150-200 organisms per 5 ml aliquot. The beaker is swirled to ensure thorough mixing. A 5 ml aliquot is withdrawn from each sample using a bulb pipet and transferred to a counting grid. Individual zooplankters were identified to the lowest taxonomic group possible, counted, and measured using a dissecting microscope and a computerized analysis system. Density (number/liter), biomass (μg/liter), percent composition by number and weight, mean length (mm), mean weight (μg) and total count of each taxon identified was generated by an analysis system and recorded in the DNR zooplankton database (J. Hirsch, DNR personal communication).

Samples are also examined for presence and abundance of zebra mussel veligers, either prior to or after zooplankton processing. Samples are filtered through 80 micron mesh and rinsed into a beaker. Sufficient water is added to dilute the sample so that veligers will be visible under microscopic examination. Dilution volumes are dependent on the amount of material in each sample. Depending on the volume of diluted sample, either the whole sample or a subsample is examined. For subsampling, the sample is mixed and an aliquot is withdrawn with a pipet. The aliquot is either examined in a gridded petri dish or counting chamber. All veliger analysis is done using cross polarized light microscopy (G. Montz, MNDNR, personal communication).

The number and biomass of other zooplankton sampled at each of the five sites throughout the time series is variable and without discernible trends (Table 10 and Figure 34). Data in 2020 showed a similar overall density (number/liter) and biomass (μg/liter) sampled at most stations and during most months, when compared with 2013-present data (Figure 34, Figure 35, Figure 36, and Figure 37). Species diversity was similar between years with the number of species sampled ranging from 17 to as many as 20 species each year Table 11, Table 12). Determining how zebra mussels will specifically impact zooplankton densities and biomass in Leech Lake is difficult, there are some lakes in Minnesota that can be used for general comparison. Lake Carlos in Douglas County has zooplankton data dating prior to the discovery of zebra mussels in 2009. Zooplankton densities and biomass were roughly half in 2015 what they were pre-infestation (Figure 38 and Figure 39).

No spiny waterflea (*Bythotrephes longimanus*) were found in any of the samples up through 2020. When spiny waterflea are present, small cladocerans commonly decline or disappear (Yan and Pawson 1997). Most individual taxa identified were typical of lakes in this region; however one somewhat rare species has been sampled in each from 2015 to 2019. *Daphnia longiremis* is a cold/deep water daphnia which spends most of its life below the thermocline. Other regional lakes this species has been sampled in include Cass, Ten Mile, and Carlos. The other rare species sampled previously was a large copepod, *Limnocalanus macrurus*, which is a glacial relict, although it was not found since 2014. This species has only been sampled in the large deep lakes in the state, such as Lake of the Woods, Rainy, Namakan and Sand Point Lakes. These are two species that will be closely monitored when assessing how climate change, AIS, and other influences affect the lake.

In 2017 and 2018, the Leech Lake Association funded the sampling and analysis of the phytoplankton community in Leech Lake. In 2019-2021, the Leech Lake Association worked with the MNDNR to secure a grant through Cass County to continue the phytoplankton sampling program. The hope is this collaborative agreement will continue to provide another valuable piece of information concerning the often ignored lower trophic levels of the food web as the lake moves from a pre-infested to a post-infested stage concerning zebra mussel impacts. Samples were collected at 4 of the standard zooplankton sites (Walker Bay, Kabekona Bay, Agency Bay and the Main Lake (Stony Point)) four times from June to August in 2017 and only two sites (Walker Bay and Main Lake (Stony Point)) in 2018-2021 using a 2-meter integrated sampler. Individual samples were processed by PhycoTech, Inc. Analysis included identification to genus and enumeration of individual genera per liter (unit/L) (Figure 40, Figure 41, Figure 42, Figure 45, Figure 46, and Figure 47).

The phytoplankton assemblage in both the Main Basin of Leech Lake and Walker Bay showed seasonal patterns in all years (Figures 1 and 2), typical of mesotrophic lakes, although the timing of the dominance of different functional groups varied among years. In most years, the communities in both basins were dominated by green algae (G), diatoms (DY), and chrysophytes (DY) early in the summer. By June or July, cyanobacteria (BG), including some toxin-forming species (HABs) were well represented in the phytoplankton communities in both basins (Figures 1 and 2). While the species identified as toxin-forming are capable of producing a variety of toxic substances, they do not always do so, and the exact triggers that initiate toxin production are unknown. Cyanobacteria (BG and HAB) remained dominate through the remainder of the sampling period each year (Figures 1 and 2). The phytoplankton community in Walker Bay mirrored that of the community in the Main Basin of Leech Lake most years, although Walker Bay typically has lower relative abundance of toxin-producing taxa (HABs) (Rantala 2022).

Muskellunge

Since 2015, the MNDNR has worked with Muskellunge tournament participants on Leech Lake to collect creel information. In 2020 the COVID-19 pandemic affected this data collection. The Don’s Portage Bay Classic was canceled, the Frank Schneider banquet was canceled and creel forms were collected in the parking lot as anglers returned their bump boards. While the Brainerd Muskies Inc., Muskie Shootout did take place, due to safety concerns creel forms were not collected. In 2021 the Don’s Portage Bay took place as did the Frank Schneider and Muskie Shootout. The DNR was able to obtain creel interviews from Don’s Portage Bay Classic and Frank Schneider but due to COVID impacts at the Walker Area fisheries office no information was collected from the Shootout. Information was collected from 41 anglers from the Classic and 169 anglers/angler teams from the Frank Schneider Memorial. Information on hours fished, the number and size of fish that were caught was collected. Lengths of tournament Muskellunge caught on Leech in 2021 ranged from 20 to 50 inches (Figure 5050). The average number of hours it took tournament anglers to catch a Muskellunge was 64 hours/fish (Figure 5151). The MNDNR greatly appreciates the willingness of tournament anglers to participate in these surveys enabling collection of data that would otherwise be very time consuming and costly. The hope is to continue these surveys and build long term data sets that can be used to monitor Muskellunge populations in Leech Lake.

Muskellunge from Miller Bay near Whipholt are currently collected and spawned for the statewide broodstock program every four years. Fish were caught using nine trap nets from April 27 through May 7, 2021. Of the nets deployed, four were 5 x 6-ft-frame trap nets with 50-ft leads and six were 3 x 6-ft-frame trap nets with 100-ft leads. Water temperature ranged from 43-51 ºF throughout this effort. Trap netted fish were transported 1.75 miles from Miller Bay to net pens at Anderson's South Shore Resort marina. Fish were separated based on sex and condition. Gametes were collected from fish that were ripe; fish that were green were held to allow for ripening. After spawning, fish were measured to total length, scales were removed for genetic analysis, and the fish were checked to see if they contained a passive integrated transponder tag (PIT tag). If no tags were found one was inserted under the skin at the base of the dorsal fin so individual fish could be identified in subsequent spawning seasons and identified as potential recaptures during the spawn take operation.

A total of 20 individual fish were captured throughout this time period, of which 12 were female and 8 were male. Females ranged in length from 42-49 inches, while males ranged from 37-45 inches. An estimated 312,714 eggs were taken. Fertilization rates of the eggs were calculated at 40% resulting in an ultimate estimate of 91,511 fry being produced for statewide distribution. In the fall of 2021, a total of 600 fingerlings at a rate of 7.0 fish/pound were stocked at the Battle Point public access per the management plan recommendation following egg take. The next Muskellunge egg take is scheduled for spring 2025.

Emergent Vegetation Mapping

The emergent plant zone is the shallow portion of Leech Lake, generally less than six feet deep, where emergent plants such as bulrush (*Schoenoplectus spp*.), wild rice (*Zizania palutris*) and other emergents may grow. These species are important for a number of reasons. Bulrush and wild rice provides critical fish and wildlife habitat plus they are difficult to regenerate once they are removed. Wild rice is also a very significant cultural resource.

The plan was to map portions of the lake when time permitted in the standard survey schedule, starting with the western bays, working towards the east. Crews started emergent vegetation mapping on the lake in mid-summer once the majority of emergent plants were visible above the water line. Shingobee, Pumphouse, Miller, Walker, Agency, Kabekona and a portion of Steamboat Bays were mapped by the end of the 2019 field season. Sucker, Traders, Millers, Headquarters, Boy, a portion of Portage Bay and the main lake basin were mapped during the 2020 field season. The remainder of the lake was mapped in 2021 and provide more detailed analysis will be provided in the 2022 annual report.

Stocking Considerations

Criteria in the 2021-2025 Management Plan state that future Walleye stocking will be considered based on two main criteria: 1) if the 3-year moving average (of the most recent year class strength index values) falls below the 25th percentile, 7.5 million Walleye fry will be stocked the following year or 2) if the spawner biomass is below 1.25 or above 2.75 pounds/acre, a low-density fry stocking would be considered the following year if Walleye condition and Yellow Perch abundance is not low. This action would be for research purposes to expand upon the range of total fry density observations (currently 237-908 fry/littoral acre) and their effects on recruitment. The 3-year moving average for Walleye year class strength exceeds the 25th percentile (Figure 6), Walleye condition and Yellow Perch abundance are below management objectives so stocking 7.5 million Walleye fry is not warranted. Walleye fry stocking in 2022 would place further stress on the Yellow Perch population, especially considering the numbers of YOY Walleye that were produced from the historical high 2017 year class and strong 2019 year class (Figure 2).

The DNR will review the status of these metrics annually with the Leech Lake Fisheries Input Group. Regulation and stocking adjustment(s) over time should be used cautiously to avoid compulsive responses to short-term dynamics common to and frequent in Walleye populations, as over-reactive modifications could be detrimental to population balance and, in particular, the fishery it supports.

Panfish Regulation

For a number of years members of the Leech Lake Fisheries Input Group requested a proposal to reduce the bag limit for Bluegill and Black Crappie to a 5 fish bag limit. Creel data demonstrate that over 60% of Black Crappie caught are harvested by Leech Lake anglers compared to only 6% of Largemouth Bass (Pedersen and Schultz 2017). Black Crappie and Bluegill are vulnerable to overharvest due to congregating during the spawning season. Anglers were asked during the 2016 summer creel on Leech Lake if they supported a bag limit reduction to 5 for Sunfish and Black Crappie and 50% supported the reduction while 24% did not support the reduction. Based on angler interest in maintaining a high quality panfish fishery and the potential for overharvest a proposal to reduce bag limits was developed and was open for public comment in 2020 with a potential implementation date in May 2021. Stakeholders were given the opportunity to comment on reduced bag limit options over the summer and fall of 2020. There were 55 people that provided Leech Lake specific comments. Only 5 (9%) commenters preferred to retain the statewide bag limit while 50 (91%) were in favor of a reduced bag limit. The Leech Lake Fisheries Input Group also unanimously agreed to move forward with a bag limit reduction at their 2020 spring update meeting. This is further supported by strong public preference for expanded use of special regulations for sunfish management. Overall, 86% of the 2,553 general comments from local and on-line stakeholders supported the use of special regulations to manage for quality sunfish and the 5 fish limit was acceptable to a majority of stakeholders (67%). The DNR commissioner's office accepted the proposal and the reduced bag limits were implemented in the spring of 2021.

SUMMARY

Recent management actions have maintained improvements in the Leech Lake Walleye population. Management Plan objectives related to the Walleye population include abundance, reproductive potential, size structure, recruitment, angler catch rate (fish/hour), angler harvest (total pounds), and condition. All 2021 Walleye management objectives associated with annual large lake sampling activities were met or exceeded. The Walleye gillnet catch rate was 12.1 fish/net, the 3-year moving average was above the objective range. Mature female density was 1.7 pounds per acre with the 3-year moving average within the management objective range (1.5 to 2.0 pounds/acre). Of the Walleye sampled in gillnets, 14% were ≥20 inches and the 3-year moving average was within the management objective range. Walleye recruitment (3-year moving average) has met or exceeded the objective threshold for the past nineteen consecutive years. Although the 2019-2021 year classes are not yet fully recruited to the fishery, the 2018 year class appears to be a weaker year class. The 2017 year class is strong and the 2019 year-class is predicted to be above management goals. The predictions for the 2020 year class that is going to be a below average year class but the 2021 year class looks to be above average with large young fish entering the winter. Walleye condition (3-year moving average) met the lower objective range.

The majority of strong year classes of Walleye since 2010 will provide harvest opportunities as long as adequate prey are available and other factors do not contribute to unusually high mortality. The Walleye regulation (protected slot limit (PSL) 18-26") that was in place from 2005-2013 contributed to improved fishing quality by increasing the number of older, larger Walleye in the population for anglers to catch and for reproduction. The Walleye regulation in place from the 2014-2018 fishing seasons (PSL 20-26", bag and possession limit unchanged) effectively protected mature Walleye but there were concerns that it was protecting more large fish than were needed to produce good year classes and also negatively impacting the Yellow Perch population. As a result the regulation was modified in 2019. The current regulation is a four fish bag limit with only 1 over 20" allowed in possession. This regulation is expected to increase harvest an average of 35% (Schmalz 2018), which should be acceptable given the continued recruitment and recent strong year classes present in the fishery assuming angling pressure does not drastically increase.

Walleye regulations employed over the past 15 years have resulted in a more stable adult population and therefore more consistent fry production. This has resulted in less recruitment variability, especially in recent years as the adult population has stabilized. The number of wild fry that had been produced annually from 2007 to 2014 averaged 317 fry/littoral acre (range 61-779). Walleye fry densities ranging from 300-600 fry/LA have resulted in the greatest number of individuals recruiting to the fishery thus far. Wild fry production will continue to vary with environmental conditions, and this variability is both normal and beneficial to the long-term maintenance of the fishery, which includes the prey base. Given the relatively consistent range in wild fry production following build-up of mature female spawner density, the observed density-dependent relationships between total fry density, growth and recruitment, and the evidence implicating cormorants as strong contributors to population declines in the early 2000's, continued annual stockings are no longer warranted. The 2016-2020 management plan defined how and when stocking should be used as a management tool in the future and these protocols were carried into the 2021-2025 management plan.

Cormorant management efforts since 2005 benefitted juvenile Walleye and Yellow Perch survival and led to short-term increases of Yellow Perch. High angler Yellow Perch harvest and relatively high Walleye predation on juvenile Yellow Perch are suspected causes of the current declining trend in Yellow Perch abundance; the latter theory is supported by the consistently lower condition values of adult Walleye since 2007 and the negative relationship between total Walleye fry density and Yellow Perch recruitment based on age-4 gill net catch rates but is still not a definite cause of the low perch numbers. The higher cormorant predation observed in 2018 to 2021 could negatively affect perch recruitment and will be evaluated in the coming years.

In addition to the current stability of the Walleye population, Leech Lake continues to support numerous sportfish populations that appear relatively healthy or unchanged, and the lake remains a destination for many anglers pursuing quality multi-species angling opportunities. Three-year moving averages for Northern Pike abundance, size structure, and recruitment all remain within or exceed management objective ranges or thresholds. These suggest a relatively balanced population but one that should benefit from the new statewide regulations implemented in the spring of 2018. That change included a 22 to 26 inch protected slot limit with a 10 fish bag limit, with no more than 2 in possession over 26 inches. The Yellow Perch abundance has been below objective thresholds for 9 years (3-year moving averages) but did show some minor improvement in 2019. The Yellow Perch length at maturity values have exceeded the objective threshold for twelve consecutive years. Anglers frequently report catching quality Bluegill and Black Crappie. Leech Lake continues to be a destination for several Largemouth Bass, Muskellunge, and Walleye fishing tournaments each year. There has been anecdotal and creel survey evidence of an increase in Smallmouth Bass catches in Leech Lake as well.

A crappie possession limit of 5 and Sunfish possession limit of 5 will took effect on March 1, 2021 as part of a statewide Quality Sunfish Initiative. This regulation will be evaluated utilizing future creel surveys and targeted spring sampling. The proposed regulations are intended to reduce exploitation and maintain and/or improve size structure and abundance of both species. Strong concerns have been expressed by lakeshore owners, area guides, fishing industry personalities and Leech Lake Fisheries Input Group members concerning harvest impacts to the exceptional size quality of both species.

Although the monitoring and treatment of Eurasian water milfoil (EWM) likely slowed the spread of this invasive plant, it continues to be found at new locations around the lake each year in both harbors and areas of the main lake proper. This demonstrates that control of invasive species on such an expansive body of water as Leech Lake is very difficult once an infestation has occurred. The discovery of starry stonewort also is a concern considering its impacts to aquatic vegetation, specifically impacts to the culturally important wild rice is unknown. Constant awareness by users and property owners alike is paramount to prevent further spread and establishment of invasive species. Even though Leech Lake has been officially listed as infected by EWM, zebra mussels and starry stonewort it is vital to remain diligent to prevent the spread of these species from Leech Lake and the introduction of new species such as Spiny Water Fleas that could cause even greater variations in the current status of the lake's fishery.

RECOMMENDATIONS

Leech Lake supports a diverse fish population and maintains good water quality. However, human development continues to expand throughout the area and, as more people relocate to this area and recreate on and around Leech Lake, the opportunities for further effects from human activities will continue to increase. Habitat protection measures should continue to be a priority to ensure the ecological resilience of Leech Lake and the entire Leech Lake Watershed is not compromised. This can be done through scrutinizing development proposals within the entire Leech Lake River watershed. Projects that are approved should use techniques that minimize impacts to the resource. Landowners within the watershed should be encouraged to use Best Management Practices (BMPs), especially along the lakeshore.

In 2017, a joint effort between Hubbard and Cass counties was undertaken to collectively develop and adopt a comprehensive management plan for the Leech Lake River Watershed. This project includes participation from governmental agencies as well as input from citizen groups and individuals to identify priority issues to be considered as part of the plan to effectively manage and protect the Leech Lake River Watershed.

Education and communication efforts are extremely valuable in changing attitudes and perceptions about what does or does not impact ecosystem health. Participation by individuals representing various groups and organizations through the Leech Lake Management Planning Process assists in disseminating annual fish survey information to their respective organizations. Other forms of public engagement that will continue to be pursued include volunteers, media outlets, Leech Lake Updates, and more.

Monitoring of aquatic invasive species should continue. Additional educational contacts should be made to those that use the harbors and lake access points, with increased effort during high use periods. Cooperation of the all lake user groups is critical. While it is unfortunate zebra mussels were found in Leech Lake in 2016, there are still other AIS that have not been confirmed such as spiny water flea, which have already established in other Minnesota systems. Attendance of a DNR volunteer boat inspector training session, participating on the Cass County Invasive Species Task Force, continued boat inspections at public accesses, requiring all watercraft participating in fishing tournaments to have an AIS inspection, increased AIS signage at public accesses, and educating those staying at resorts are all measures that are being taken to slow the spread of invasive species.

Annual monitoring of fish populations, zooplankton and water quality analyses should continue. Specific focus should be given to the Walleye population and fishery responses to regulation changes and if it impacts and benefits the fishery as anticipated. The primary regulation goal is to return spawner stock biomass into the management objective range while allowing additional harvest opportunity for anglers. It is also anticipated the regulation change will positively benefit the perch population as total Walleye biomass in the lake is reduced by harvest. These outcomes will be evaluated annually and adjustments to the adaptive management of Leech Lake will continue.

The next Muskellunge egg collection and put-back stocking event is scheduled for 2025. Double-Crested Cormorant management efforts should continue as prescribed by the management plan for this species. The discontinuation of programmed Walleye fry stocking is still recommended as natural reproduction has demonstrated the ability of the current spawning population to successfully produce strong year classes which are reaching the fishery. This will also allow the prey base to continue to recover.

Funding to complete an additional creel survey in 2019 was secured in order to monitor pressure, catch, catch rates, harvest, and harvest rates for all species with an emphasis on evaluating the new Walleye regulation. The next creel survey was scheduled for 2020 but was canceled due to concerns over employee safety and the COVID-19 pandemic. The next scheduled creel survey is the summer of 2024 and winter of 2024-25.

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TABLES

Table 1 Seine catch rates (CPUE, number/haul) of all species and ages captured, Leech Lake, 2021.

2021				Mean	Length			
		Total	Number	length	(inches)		Catch rates	
Species	Age	number	measured	(inches)	Min	Max	num/haul	num/acre
Iowa Darter	All	2	1	1.1	1.1	1.1	0.1	0.3
Johnny Darter	All	537	111	1.8	0.9	2.3	26.9	86.6
Black Crappie	YOY	7	7	1.0	0.7	1.7	0.4	1.1
Black Crappie	> 1	1	1	5.0	5.0	5.0	0.1	0.2
Bluegill	All	9	9	2.8	2.3	3.2	0.5	1.5
Bluntnose Minnow	All	271	83	2.3	1.7	2.8	13.6	43.7
Largemouth Bass	YOY	30	17	2.1	1.8	2.9	1.5	4.8
Logperch	All	110	65	2.9	1.8	3.8	5.5	17.7
Longnose Dace	All	3	3	1.6	1.5	1.7	0.2	0.5
Mimic Shiner	All	3513	291	2.1	1.6	2.6	175.7	566.6
Pumpkinseed	All	1	1	4.4	4.4	4.4	0.1	0.2
Rock Bass	YOY	2	2	0.9	0.9	0.9	0.1	0.3
Smallmouth Bass	YOY	445	92	1.8	1.3	2.6	22.3	71.8
Spotfin Shiner	All	182	88	2.1	1.4	3.2	9.1	29.4
Spottail Shiner	All	1,498	82	1.6	1.2	3.4	74.9	241.6
Tullibee (Cisco)	YOY	17	17	2.6	2.3	2.8	0.9	2.7
Walleye	YOY	0	0	N/A	N/A	N/A	0.0	0.0
White Sucker	YOY	34	33	2.4	1.8	2.8	1.7	5.5
Yellow Perch	YOY	4612	254	1.7	1.2	2.4	230.6	743.9
Yellow Perch	> 1	364	177	3.6	2.2	7.3	18.2	58.7

Table 2 Trawl catch rates 2021 and historic trawl catch rates (CPUE, number/hour) of all species and ages captured, Leech Lake, 2007 to 2021.

2021					Length range			
		Total	Number	Mean length	(inches)		Catch rates	
Species	Age	number	measured	(inches)	Min	Max	num/haul	num/hour
Johnny Darter	All	3	2	2.1	2.1	2.1	0.2	1.8
Bluegill	YOY	56	56	1.3	0.9	1.7	2.8	33.6
Bluegill	> 1	1	1	2.8	2.8	2.8	0.1	0.6
Bluntnose Minnow	All	203	83	2.5	2.0	3.1	10.2	121.8
Burbot	YOY	1	1	2.2	2.2	2.2	0.1	0.6
Largemouth Bass	YOY	17	17	3.1	2.6	3.8	0.9	10.2
Logperch	All	264	125	3.1	1.9	4.0	13.2	158.4
Mimic Shiner	All	57	51	2.1	1.8	2.8	2.9	34.2
Northern Pike	All	5	5	21.7	19.3	23.5	0.3	3.0
Pumpkinseed	All	2	2	4.6	3.1	6.1	0.1	1.2
Smallmouth Bass	YOY	76	75	2.7	1.9	3.9	3.8	45.6
Spottail Shiner	All	174	51	3.4	1.2	4.5	8.7	104.4
Tadpole Madtom	All	9	9	2.8	2.4	3.4	0.5	5.4
Trout-Perch	All	8	8	3.7	3.3	4.3	0.4	4.8
Tullibee (Cisco)	YOY	2	2	2.7	2.4	3.0	0.1	1.2
Walleye	YOY	175	175	5.7	3.4	6.9	8.8	105.0
Walleye	> 1	27	27	15.9	8.7	24.5	1.4	16.2
White Sucker	All	3	3	8.6	3.6	11.1	0.2	1.8
Yellow Perch	YOY	11,225	226	2.0	0.2	2.7	561.3	6,735.0
Yellow Perch	> 1	4,300	199	4.0	2.6	12.2	215.0	2,580.0

	Year														
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020 [1]	2021
Black crappie YOY	0		0	0	1	1	1	1	1	11	2	47	2		0
Bluegill	3	0	1				0	0	1	15	1	31	10		34
Bluntnose Minnow	45	274	20	3	8	16	7	42	2	24	37	136	88		122
Largemouth Bass YOY	2	0	15	8	7	0	5	16	11	22	33	2	53		10
Logperch	202	199	81	49	9	22	22	124	160	246	199	92	70		158
Mimic shiner	560	1,637	211	43	100	186	2,254	37	169	5	19	8	27		34
Smallmouth bass YOY	4	1	5	0	3	2	2	25	26	34	34	24	69		46
Spottail shiner	402	265	445	47		146	1	134	159	994	1,337	94	163		104
Trout-perch	8	14	795	18	5	8	0	1	53	824	119	142	228		5
Walleye YOY	31	508	153	80	40	148	346	356	258	349	773	69	361		105
Walleye 1+	6	43	30	31	21	22	15	58	31	67	35	44	28		16
Yellow Perch YOY	15,051	9,098	8,898	5,226	16,430	704	6,049	2,777	2,605	4,241	8,239	1,417	4,601		6,735
Yellow perch 1+	895	3,227	1,554	521	113	158	89	3,301	463	2,749	1,215	2,676	2,583		2,580

[1] Trawls not conducted in 2020 due to safety concerns with COVID-19

Table 3. Catch-per-effort (CPE) of age-0 through age-3 Walleye in selected gears and the associated year class strength (YCS) index for Leech Lake, 1980-2021. Estimates are incomplete until Walleye are fully recruited to gill nets at age-3.

							Year Class Strength[2]			
Year Class	Age-0 Trawl CPE (fish/hr)	Age-0 Efishing CPE (fish/hr)	Age-0 Gillnet CPE (fish/net)	Age-1 Gillnet CPE (fish/net)	Age-2 Gillnet CPE (fish/net)	Age-3 Gillnet CPE (fish/net)	Observed Year Class Strength	3-year running average	Lower 85% confidence interval	Upper 85% confidence interval
1980						1.31	1.13		0.67	1.89
1981					0.66	1.11	0.67		0.44	1.01
1982				0.81	0.61	0.92	0.56	0.79	0.39	0.80
1983			0.22	2.42	1.89	1.36	1.40	0.87	1.01	1.93
1984			0.33	0.72	0.89	0.33	0.48	0.81	0.33	0.69
1985			0.03	0.56	0.39	4.00	0.74	0.87	0.53	1.04
1986			0.08	2.39	3.39	1.83	1.83	1.02	1.33	2.51
1987	49		0.11	0.53	0.78	0.94	0.45	1.01	0.31	0.64
1988	128		1.81	4.47	4.08	3.14	2.60	1.63	1.90	3.54
1989	62		0.06	0.94	1.03	0.47	0.53	1.19	0.37	0.75
1990	72		0.03	1.47	0.78	0.69	0.71	1.28	0.50	1.00
1991	58		0.47	1.53	1.36	1.17	1.08	0.77	0.78	1.50
1992	103		0.00	0.22	0.50	0.14	0.15	0.65	0.09	0.24
1993	16		0.00	0.11	0.11	0.11	0.01	0.41	-0.02	0.05
1994	493		0.08	2.89	5.00	2.06	2.54	0.90	1.87	3.48
1995	183		0.51	2.00	1.51	2.00	1.33	1.29	0.96	1.83
1996	262		0.14	0.66	2.00	1.33	0.87	1.58	0.62	1.21
1997	5		0.29	4.22	2.86	1.43	1.83	1.34	1.34	2.51
1998	139		0.47	1.08	0.89	0.94	0.70	1.13	0.49	0.98
1999	348		0.56	1.14	1.61	1.47	1.05	1.19	0.76	1.46
2000	28		0.14	0.97	0.36	0.31	0.32	0.69	0.22	0.47
2001	103		0.64	1.31	1.00	0.92	0.82	0.73	0.59	1.15
2002	38		0.31	1.08	1.31	0.94	0.86	0.67	0.61	1.20
2003	27		0.08	0.61	0.42	0.28	0.30	0.66	0.20	0.44
2004	3		0.00	0.44	0.19	0.67	0.25	0.47	0.16	0.38
2005	247	60	0.03	2.69	3.36	1.61	1.86	0.80	1.36	2.55
2006	240	35	0.69	4.67	3.50	2.94	2.60	1.57	1.91	3.55
2007	31	27	1.47	2.06	2.47	1.72	1.59	2.02	1.15	2.18
2008	508	42	0.00	0.72	1.31	1.03	0.75	1.64	0.53	1.05
2009	153	164	0.03	0.92	0.92	0.89	0.66	1.00	0.47	0.93
2010	80	56	0.03	1.47	2.14	1.69	1.31	0.90	0.94	1.80
2011	40	175	0.03	1.67	1.47	1.64	1.18	1.05	0.85	1.64
2012	148	237	0.56	1.83	1.67	2.72	1.44	1.31	1.05	1.98
2013	346	88	0.06	1.58	1.78	1.86	1.21	1.28	0.87	1.67
2014	356	109	0.06	1.81	1.10	0.64	0.75	1.13	0.53	1.05
2015	258	97	0.28	1.89	1.69	1.74	1.30	1.09	0.94	1.79
2016	349	116	0.27	2.53	2.49	1.22	1.52	1.19	1.10	2.09
2017	773	132	0.08	2.63	2.44	2.58	1.90	1.57	1.36	2.56
2018[1]	69	56	0.11	0.75	1.11	0.89	0.66	1.36	0.42	0.97
2019[1]	361	104	0.17	3.33	4.13		2.38	1.65	1.14	3.11
2020[1,3]		10	0.16	1.19			0.80	1.28		
2021	105	53	0.94				1.57	1.58		
Mean	182	92	0.29	1.65	1.67	1.36	1.11	1.11	0.78	1.54

[1] Year class strength estimates are incomplete until Walleye are fully recruited to gill nets at age-3

[2]Year class strength estimates calculated with a mixed effects model (Kutner et al. 2004) version of Maceina and Pereira (2007) model. As of 2015, this method became standardized among large lakes by the MNDNR.

[3]Trawling was not done in 2020, trawl catch rates are used to calculate YCS so estimated values are not available for 2020

Table 4. Gillnet catch-per-effort (fish/net) summary by species and basin for Leech Lake, 2021.

	Western Bays		Main Lake		Whole Lake	
		1983-2021		1983-2021		1983-2021
Species	2021	Mean	2021	Mean	2021	Mean
Black Bullhead	0.0	7.0	0.0	1.7	0.0	4.1
Black Crappie	0.2	0.3	1.4	0.5	0.9	0.4
Bluegill	0.3	0.7	1.2	0.4	0.8	0.5
Bowfin	0.1	0.1	0.1	0.0	0.1	0.1
Brown Bullhead	0.4	1.6	0.0	0.9	0.2	1.3
Burbot	0.0	0.0	0.1	0.1	0.0	0.0
Hybrid Sunfish	0.1	0.0	0.0	0.0	0.0	0.0
Lake Whitefish	0.1	0.1	0.0	0.0	0.1	0.1
Largemouth Bass	0.1	0.1	0.4	0.1	0.3	0.1
Muskellunge	0.0	0.0	0.0	0.0	0.0	0.0
Northern Pike	3.8	5.1	4.4	4.5	4.1	4.7
Pumpkinseed	1.1	1.0	0.6	0.6	0.8	0.7
Rock Bass	1.4	2.8	0.3	0.3	0.8	1.4
Shorthead Redhorse	0.0	0.0	0.0	0.0	0.0	0.0
Smallmouth Bass	0.1	0.0	0.1	0.0	0.1	0.0
Tiger Muskellunge	0.0	0.0	0.0	0.0	0.0	0.0
Tullibee (Cisco)	15.5	5.3	0.7	5.7	7.3	5.5
Walleye	11.7	6.3	12.5	9.8	12.1	8.3
White Sucker	1.2	1.3	1.1	1.5	1.1	1.4
Yellow Bullhead	2.9	2.1	0.4	0.8	1.5	1.4
Yellow Perch	11.6	24.2	9.6	16.2	10.5	19.8
Total	50.4	58.2	32.5	43.2	40.4	50.2

Table 5. Length-frequency distribution of all species sampled in experimental gillnet sets, Leech Lake, 2021.

Length	Black Crappie	Bluegill	Bowfin	Brown Bullhead	Burbot	Hybrid Sunfish	Lake Whitefish	Largemouth Bass	Northern Pike	YOY Northern Pike	Pumpkinseed	Rock Bass	Smallmouth Bass	Tullibee (Cisco)	Walleye	YOY Walleye	White Sucker	Yellow Bullhead	Yellow Perch
3		1									9								
4		3									11	2							1
5	3	1						1			2	2	1	1				1	86
6	2	10						1			6	2		6		1		1	106
7	3	9						1			1	4	1	5		29		2	69
8	3	2				1		2			1	1		51		5	3	6	57
9	5	1		1				4				8		85	9		2	7	35
10	6			1						3		7		25	20		6	16	16
11	5			2						1		1		57	20		3	13	8
12	2			1										20	43		2	5	
13				1										7	54		3	3	
14	2													2	40				
15					1				6					2	31		3		
16									7						21		7		
17									14						38		6		
18			1						11						31		2		
19			1						14						35		1		
20							1		27						22		2		
21			1				1		13						13		1		
22									7						7				
23									8						3				
24									7						5				
25									7						5				
26									5										
27									7						3				
28									3										
29									1										
30									4										
31															1				
32									1										
33																			
34									1										
35																			
≥36																			
Total	31	27	3	6	1	1	2	9	143	4	30	27	2	261	401	35	41	54	378
Min. length	5.4	4.0	18.7	10.0	16.7	8.3	20.6	5.4	10.4	11.5	3.5	4.7	5.3	6.9	9.3	6.7	8.3	5.6	4.9
Max. length	14.7	9.2	21.7	13.8	16.7	8.3	21.9	10.0	34.5	11.5	8.1	11.2	7.1	16.9	31.6	8.1	21.4	13.2	11.9
Mean length	9.6	6.6	20.0	11.5	16.7	8.3	21.2	8.4	21.3	11.5	5.0	8.6	6.2	11.1	16.1	7.5	14.5	10.4	7.3
# measured	31	27	3	6	1	1	2	9	143	4	30	27	2	261	401	35	41	54	378
Not measured	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*Note: Totals shown may differ from the total number of fish in the catch, due to rounding of fractions used in the estimation of length frequency from a subsample of measured fish. YOY = Young of year, fish born in that sampling year.

Table 6. Length- frequency distribution of immature (I) and mature (M) Walleye, Yellow Perch, Northern Pike, and Cisco, by sex from gill nets in Leech Lake, 2021.

	Walleye				Yellow Perch				Northern Pike				Tullibee (Cisco)			
	F		M		F		M		F		M		F		M	
Length (in.)	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
4					1											
5					42	8	1	35								
6			1		39	33		34					1			
7	4		25		1	52		16					4		2	
8			5			53		4					3		2	
9	3		6			34		1					13	11	11	16
10	9		11			13		3			3		11	31	6	37
11	5		15			8					1		1	9		15
12	15		28											38		19
13	24		27	3										14		6
14	28		6	6										5		2
15	14		2	15						1		5		1		1
16	5	2		14					1	1		5		2		
17	10	9		19					1			13				
18	3	7		21						3		8				
19	1	17		17						6		8				
20	1	10		11						14		13				
21		8		5						6		7				
22		5		2						6		1				
23		3								6		2				
24		4		1						7						
25		5								7						
26										5						
27		3								7						
28										3						
29										1						
30										4						
31		1														
32										1						
33																
34										1						
35																
≥36																
Total	122	74	126	114	83	201	1	93	2	79	4	62	33	111	21	96

Table 7. Age- frequency distribution of immature (I) and mature (M) Walleye, Yellow Perch, Northern Pike, and Tullibee (Cisco), by sex from gill nets in Leech Lake, 2021.

	Walleye				Yellow Perch				Northern Pike				Tullibee (Cisco)			
	F		M		F		M		F		M		F		M	
Age	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
0	4		31								4					
1	16		26						1	1		2	6		2	
2	72		66	11	31	17		22		11		23	14	24	15	33
3	13	4	2	13	35	41	1	40	1	26		24	13	44	4	43
4	10	26	1	41	14	83		17		10		13		4		7
5	6	8		15	2	36		9		16				16		7
6	1	9		6	1	23		4		12				14		4
7		6				1		1		3				4		1
8		10		7										1		
9		1		7										2		
10		1		8												
11		3		2										1		
12		3		1												1
13		1		1												
14				1												
15														1		
16		2		1												
17																
18																
19																
20																
21																
Total	122	74	126	114	83	201	1	93	2	79	4	62	33	111	21	96

Table 8. Average length at age for Walleye, Yellow Perch and Northern Pike, by sex from gill nets in Leech Lake, 2021. The long-term average is also indicated. Otoliths have been used to age Walleye since 1990 and Yellow Perch since 2001. Cleithera have been used to age Northern Pike since 1990. Lengths are not indicated in the current year if less than five individuals were sampled.

	Age										
	0	1	2	3	4	5	6	7	8	9	10
Walleye											
Female											
1990-present	7.3	10.4	13.2	15.6	18.1	19.4	20.4	21.6	22.8		
2021		10.8	13.7	16.9	18.2	19.0	20.9	20.6	23.7		
Male											
1990-present	7.2	10.3	13.1	15.3	16.7	18.0	18.7	19.1	19.7		
2021	7.5	10.7	13.2	16.9	17.0	18.6	19.6		19.5		
Yellow Perch											
Female											
2002-present		5.3	6.1	6.8	7.9	8.9	9.7	10.4	10.8	11.4	10.8
2021			6.0	6.8	7.9	9.0	9.8				
Male											
2002-present		5.5	5.9	6.2	6.9	7.6	8.8	9.2	9.8	10.2	10.2
2021			5.8	6.3	6.7	7.8	8.8				
Northern Pike											
Female											
1990-present	10.2	15.7	19.5	21.8	24.1	26.0	28.5	30.3	31.4	32.2	32.4
2021			20.9	20.9	23.6	25.7	29.1				
Male											
1990-present	9.7	14.8	18.1	19.9	21.2	22.0	22.4	23.5	23.3	25.1	23.0
2021			17.3	19.6	21.3						

Table 9. Mean chlorophyll-a (Chlor-a), total phosphorous (Total P), pH, alkalinity, total dissolved solids (TDS), Secchi depth, and mean calculated trophic state index (TSI) by basin, Leech Lake, 1984-2021.

	Main Lake							Western Bays						
Year	Chlor-a (ppb)	Total P (ppm)	pH	Alkalinity (ppm)	TDS (ppm)	Secchi (ft.)	Mean TSI	Chlor-a (ppb)	Total P (ppm)	pH	Alkalinity (ppm)	TDS (ppm)	Secchi (ft.)	Mean TSI
1984	4.0	0.022	8.5	133	169	4.3	37	4.0	0.011	8.5	132	147	8.7	44
1985														
1986	3.0	0.011	8.5	134	158	4.7	33	3.0	0.006	8.6	135	160	9.3	39
1987	3.0	0.014	8.4	131	154	3.9	39	4.0	0.014	8.5	147	153	8.2	41
1988	3.0	0.031	7.9	133	169	7.7	39	3.0	0.017	8.0	46	377	7.9	42
1989	3.0	0.017	7.9	132	172	7.6	34	3.0	0.008	8.5	128	176	9.8	39
1990	3.0	0.015	8.6	130	168	7.3	36	3.0	0.015	8.4	130	164	12.2	39
1991	1.0	0.020	8.5	127	180	7.7	29	1.0	<0.005	8.6	126	172	7.9	36
1992	2.0	0.016	8.4	139	178	11.4	34	3.0	0.010	8.5	139	168	13.2	35
1993	6.4	0.013	8.6	140	156	8.5	37	4.9	0.014	8.6	128	180	13.0	40
1994	5.5	0.023	8.6	138	170	6.0	38	2.9	0.016	8.7	140	168	8.0	44
1995	11.9	0.018	8.6	136	192	8.9	38	6.5	0.012	8.7	136	180	11.5	43
1996	3.1	0.055	8.5	133	176	8.9	37	2.4	0.020	8.7	136	224	10.6	44
1997	3.1	0.041	8.5	132	172	9.9	42	4.4	0.044	8.6	133	192	13.6	42
1998	6.5	0.028	8.6	131	152	8.0	40	4.2	0.029	8.7	133	172	12.8	44
1999	5.1	0.028	8.6	129	172	7.5	49	3.8	0.025	8.6	135	180	13.0	45
2000	4.2	0.028	8.5	139	180	6.0	49	2.4	0.019	8.6	138	176	17.2	41
2001	5.6	0.033	8.7	125	170	7.0	49	4.0	0.016	8.8	126	168	11.0	43
2002	5.4	0.020	8.7	133	164	6.5	49	4.1	0.020	8.8	136	176	11.0	44
2003	7.2	0.020	8.4	139	160	6.5	50	4.1	0.010	8.6	140	160	11.0	44
2004	3.4	0.013	8.5	143	176	9.0	44	2.4	0.010	8.7	146	176	13.1	40
2005	4.4	0.016	8.6	143	172	5.0	50	3.7	0.016	8.6	141	176	8.5	45
2006	8.4	0.016	8.5	140	148	6.0	51	4.2	0.010	8.5	135	144	10.0	44
2007	8.9	0.019	8.5	144	168	8.2	48	3.6	0.011	8.6	143	168	10.5	42
2008	3.4	0.013	7.9	146	172	6.5	39	5.2	0.012	8.5	148	168	10.5	38
2009	7.6	0.019	8.4	143	188	6.7	37	5.1	0.011	8.4	148	196	10.6	43
2010	7.0	0.017	8.5	144	188	6.0	43	3.4	0.012	8.6	143	188	11.0	36
2011[1]														
2012	7.3	0.030	8.2	141	188	6.5	45	4.5	0.024	8.4	140	180	10.5	40
2013	8.7	0.023	8.5	142	152	7.2	44	5.8	0.011	8.4	141	140	10.9	37
2014	7.6	0.024	8.5	144	196	8.0	43	4.7	0.018	8.5	145	166	13.0	38
2015	5.1	0.018	8.5	143	158	7.5	41	3.2	0.012	8.6	142	160	12.5	35
2016	4.7	0.023	8.5	145	168	6.0	45	7.7	0.016	8.5	146	164	16.0	37
2017	8.3	0.020	7.8	143	166	6.8	44	4.7	0.012	8.0	143	388[2]	10.5	38
2018	8.5	0.019	8.5	146	204	6.0	44	4.7	0.011	8.6	142	196	9.0	38
2019	6.6	0.021	8.4	142	176	9.5	42	3.5	0.012	8.6	143	160	8.2	38
2020	4.6	0.02	8.5	141	156	10	46	3.6	0.011	8.5	145	164	8	42
2021	6.2	0.019	8.4	140	168	9	41	3.2	0.011	8.6	142	168	11	35
Mean	5.5	0.0	8.4	137.9	171.0	7.3	41.9	3.9	0.0	8.5	136.0	177.3	10.9	40.4

[1]Water quality data was not collected in 2011 due to state shutdown from July 1-20.

[2]Strong weather event potentially led to unusally high reading

Table 10. The phytoplankton number per liter and percent of the Total Phytoplankton Abundance (TPA) is provided for each major classification from sites on Leech Lake, 2021.

Walker Bay (percent of total phytoplankton abundance)

Date	Bacillariophyta	Chlorophyta	Cryptophyta	Chrysophyta	Cyanophyta	Dinoflagellates	Other
5/16/2021	58.00	1.00	8.00	23.00	1.00	9.00	
6/20/2021	15.00	7.00	35.00	3.00	24.00	16.00	1.00
7/18/2021	23.00	15.00	5.00	12.00	40.00	5.00	
8/15/2021	5.00	26.00	3.00	6.00	58.00	2.00	
9/26/2021	8.00	12.00	16.00	15.00	47.00	2.00	

Main (percent of total phytoplankton abundance)

	Bacillariophyta	Chlorophyta	Cryptophyta	Chrysophyta	Cyanophyta	Dinoflagellates	Other
5/16/2021	54.00	3.00	16.00	9.00	13.00	5.00	
6/20/2021	31.00	6.00	15.00	2.00	33.00	12.00	
7/18/2021	1.00	20.00	27.00	4.00	42.00	6.00	
8/15/2021	11.00	21.00		1.00	67.00		
9/26/2021	13.00	7.00	2.00		76.00	2.00	

FIGURES

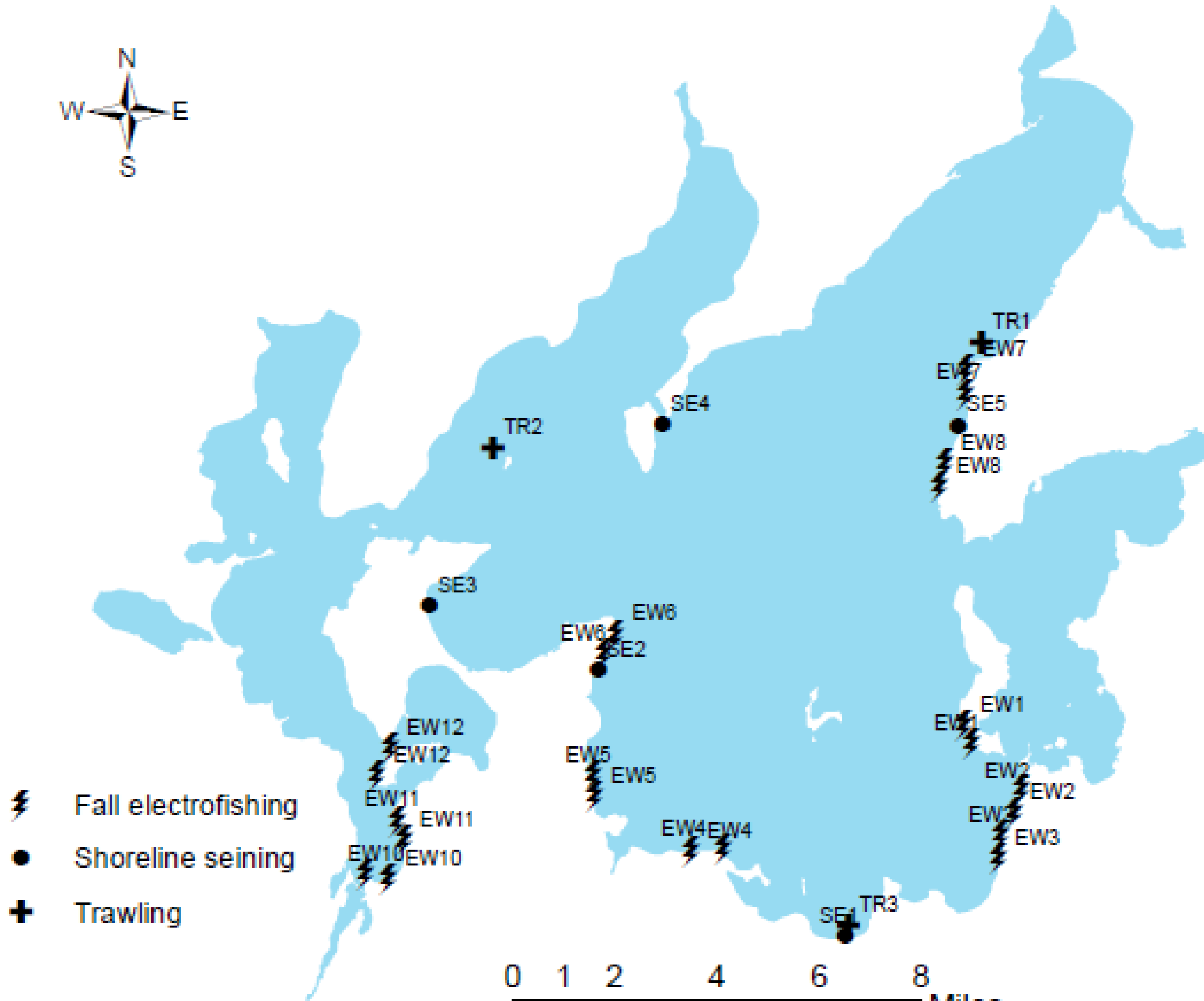


Figure 1. Long-term sampling stations targeting young-of-year Walleye and Yellow Perch in Leech Lake.

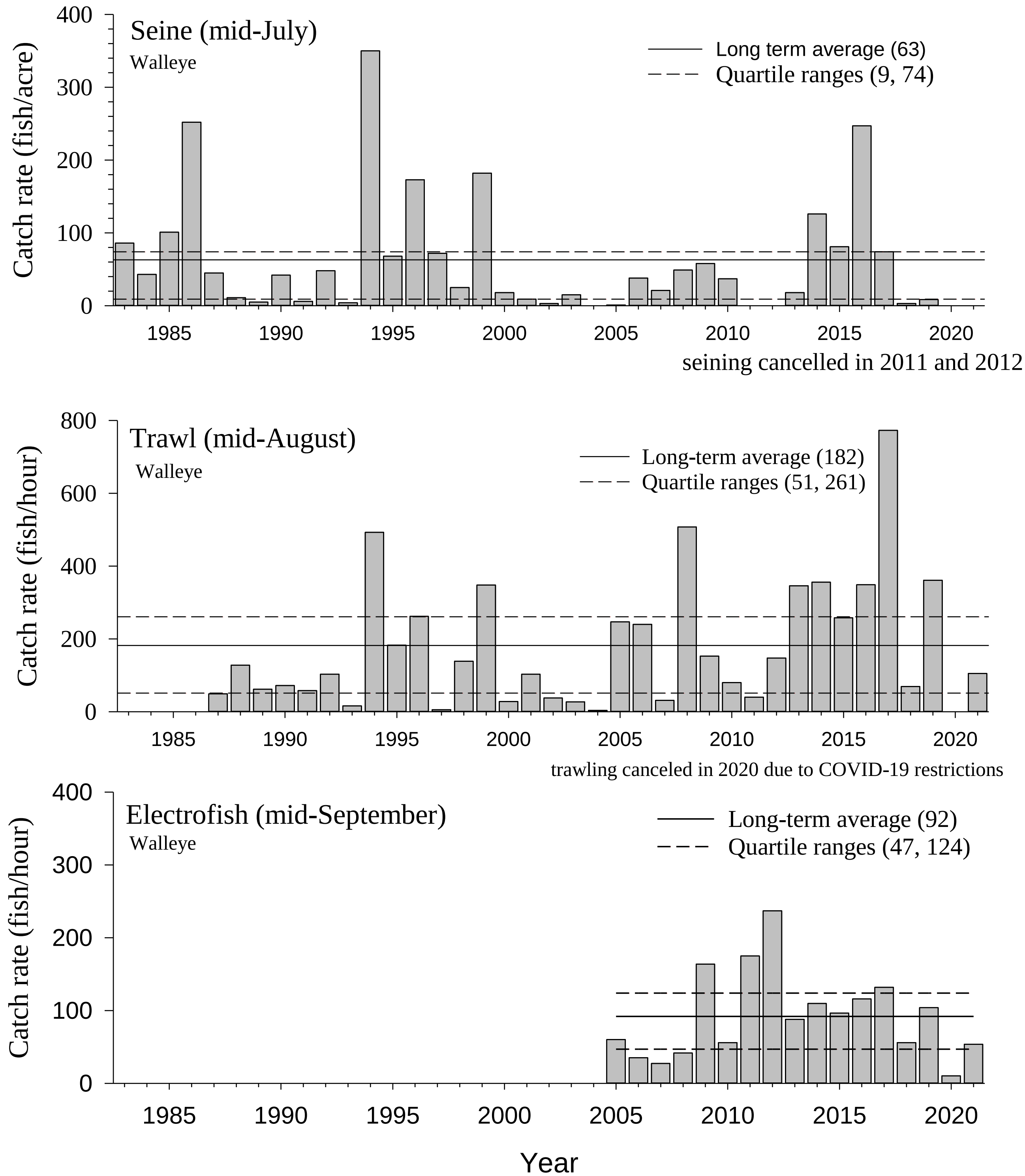


Figure 2. Catch-per-effort (bars) and long-term averages (lines) of young-of-year (YOY) Walleye sampled seining (top), trawling (middle), and electrofishing (bottom), Leech Lake, 1983-2021.

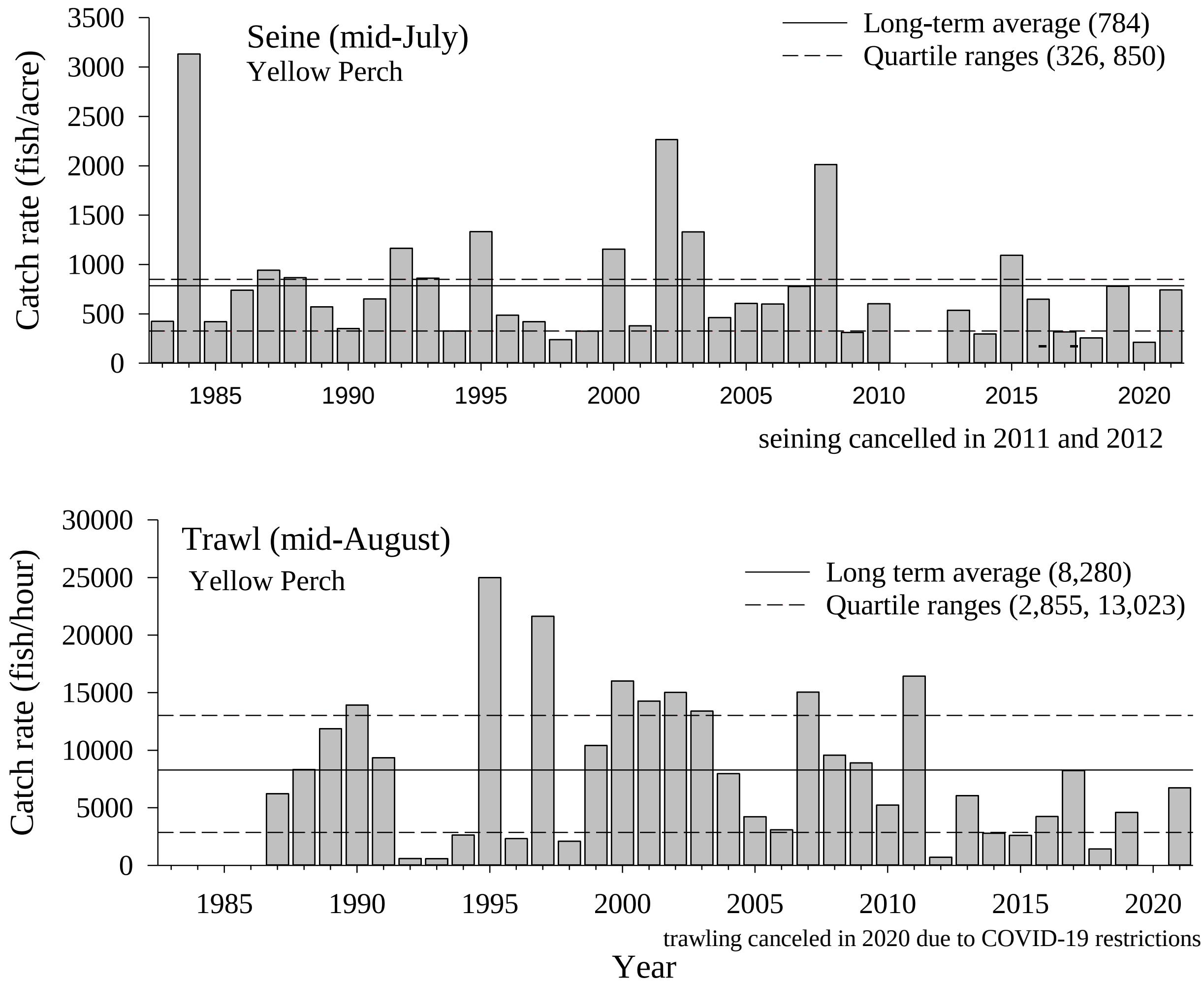


Figure 3. Catch-per-effort (bars) and long-term averages (lines) of YOY Yellow Perch sampled at standardized seining and trawling locations, Leech Lake, 1983-2021.

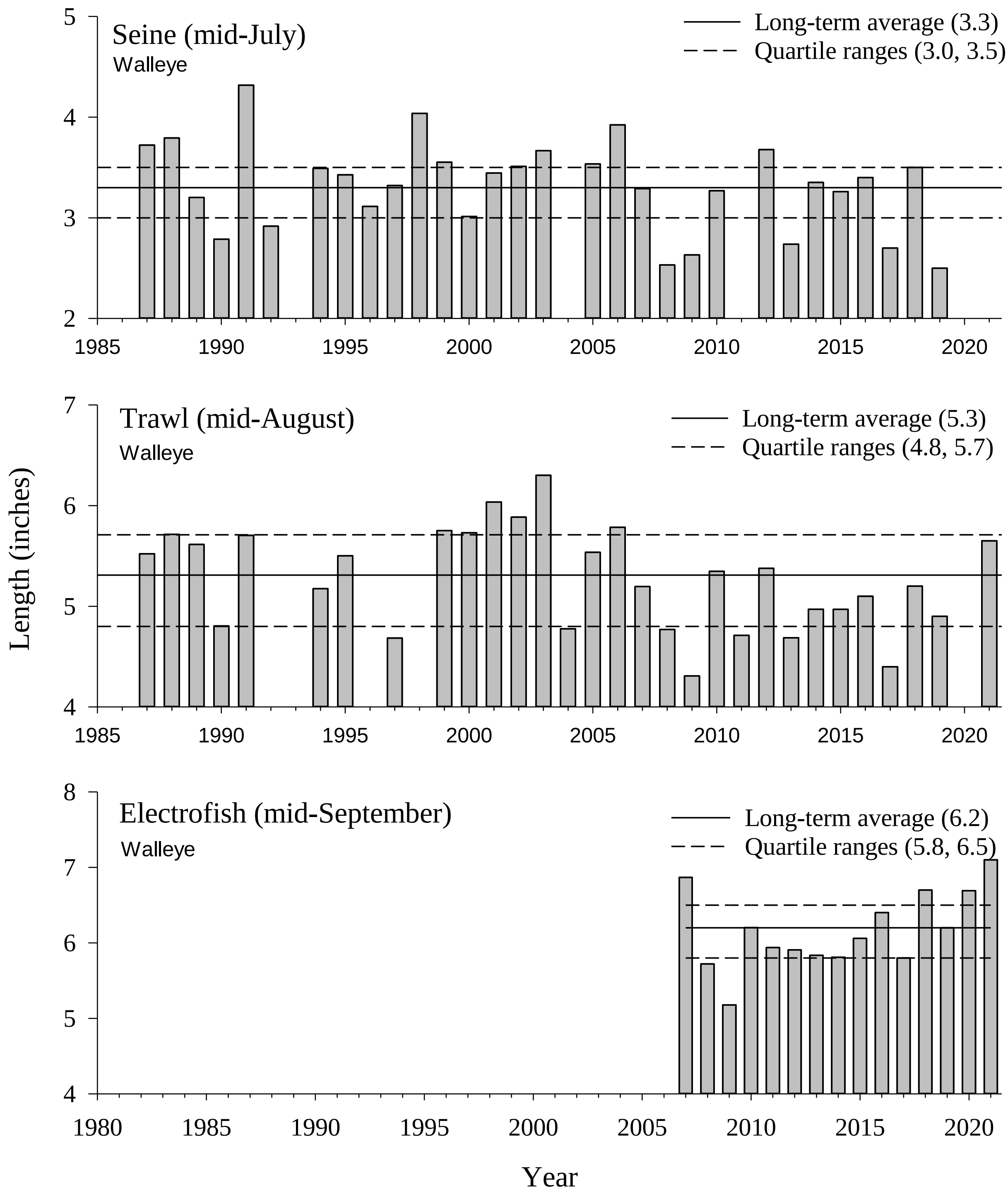


Figure 4. Average annual growth rates of YOY Walleye sampled seining (top), trawling (middle), and electrofishing (bottom) in Leech Lake, 1987-2021. Growth rates are standardized by Julian Weeks 28-29 (seining), 33-34 (trawling), and 37-38 (electrofishing).Trawling was not conducted in 2020 due to COVID-19 restrictions

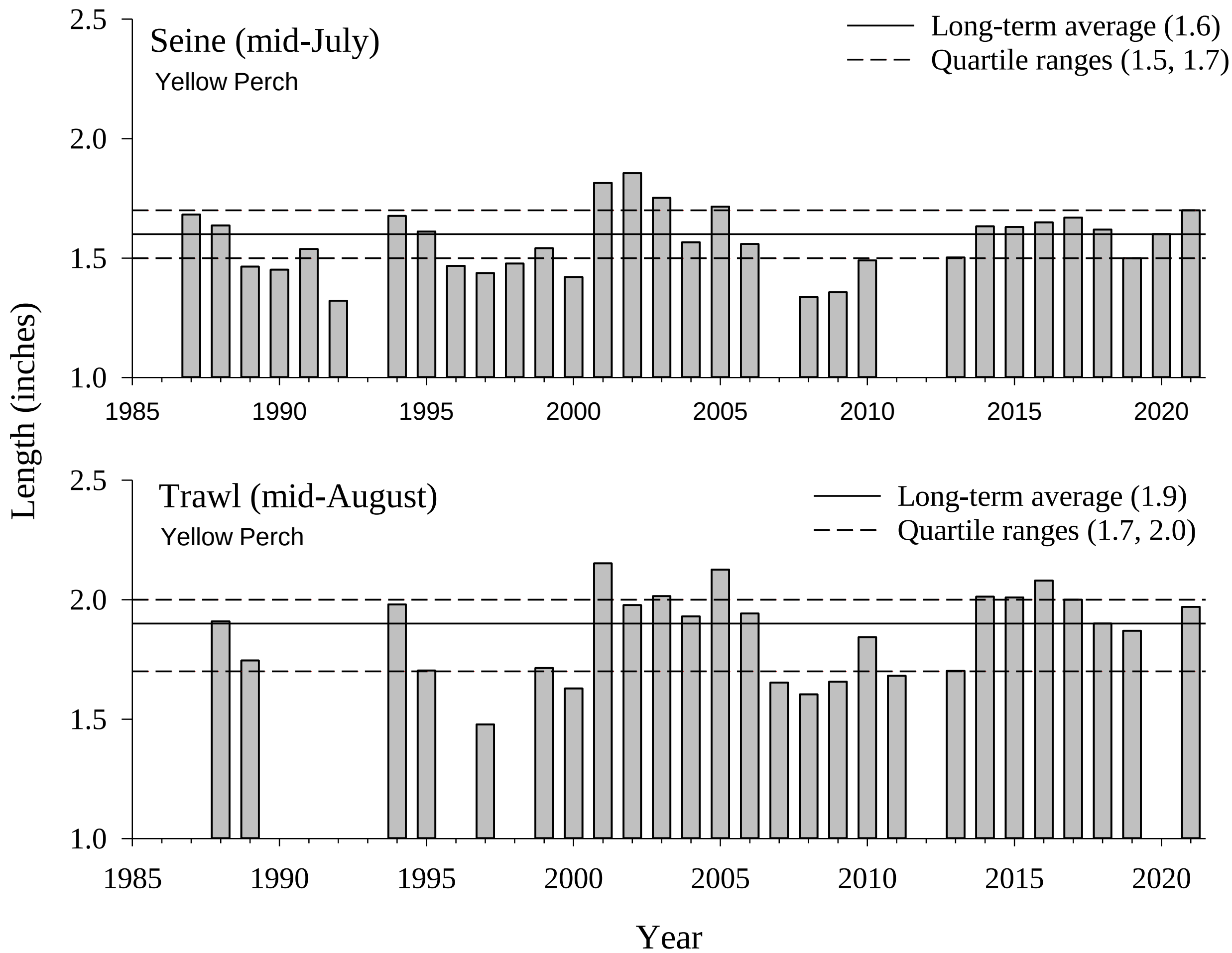


Figure 5. Average annual growth rates of YOY Yellow Perch sampled seining (top) and trawling (bottom) in Leech Lake, 1987-2021. Growth rates are standardized by Julian Weeks 28-29 for seining and 33-34 for trawling.

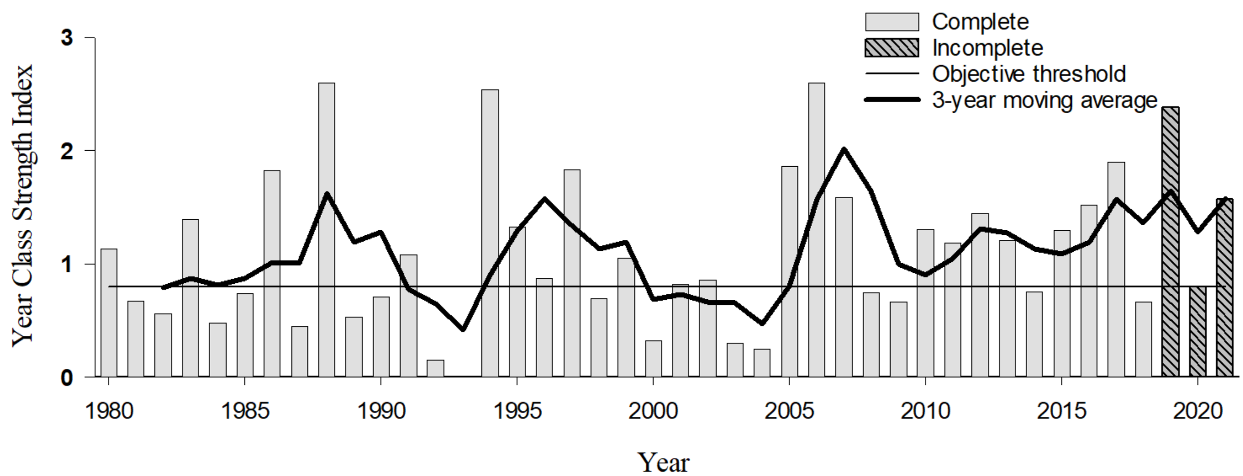


Figure 6. Year class strength index of Walleye in Leech Lake, 1983-2021. Fully recruited (shaded bars) incomplete (hatched bars) year classes are indicated. The horizontal line represents the Management Plan Objective Threshold of the 25th percentile through 2021. The darker line represents the 3-year moving average. Walleye are considered fully recruited to the fishery at age-3.

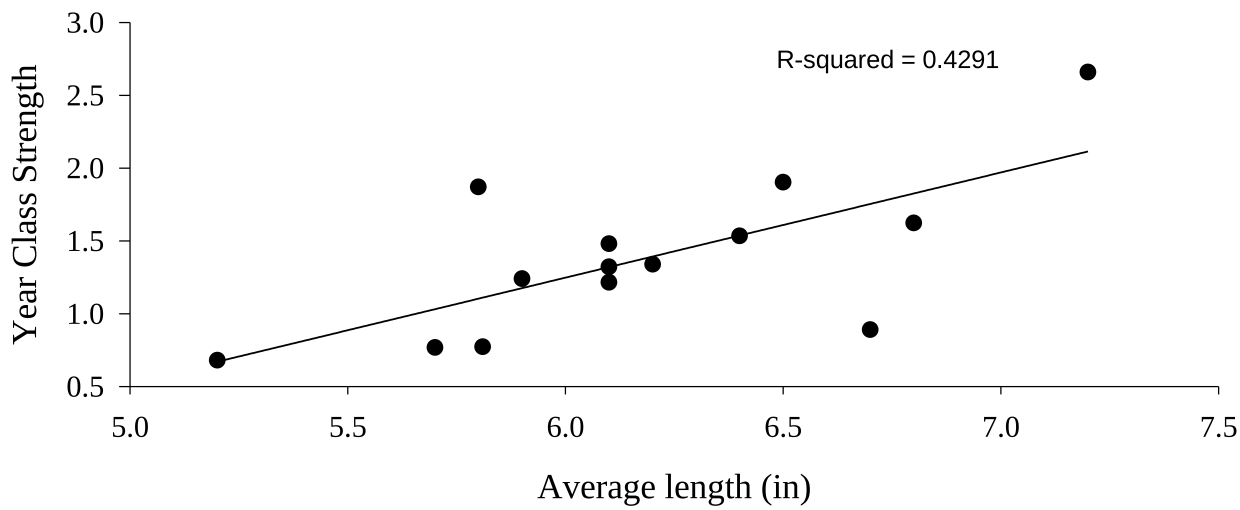


Figure 7. The average length (in) of YOY Walleye sampled by electrofishing in mid-September and the resulting Walleye year class strength in Leech Lake, 2005-2018. The 2019-2021 year classes have not fully recruited to the fishery.

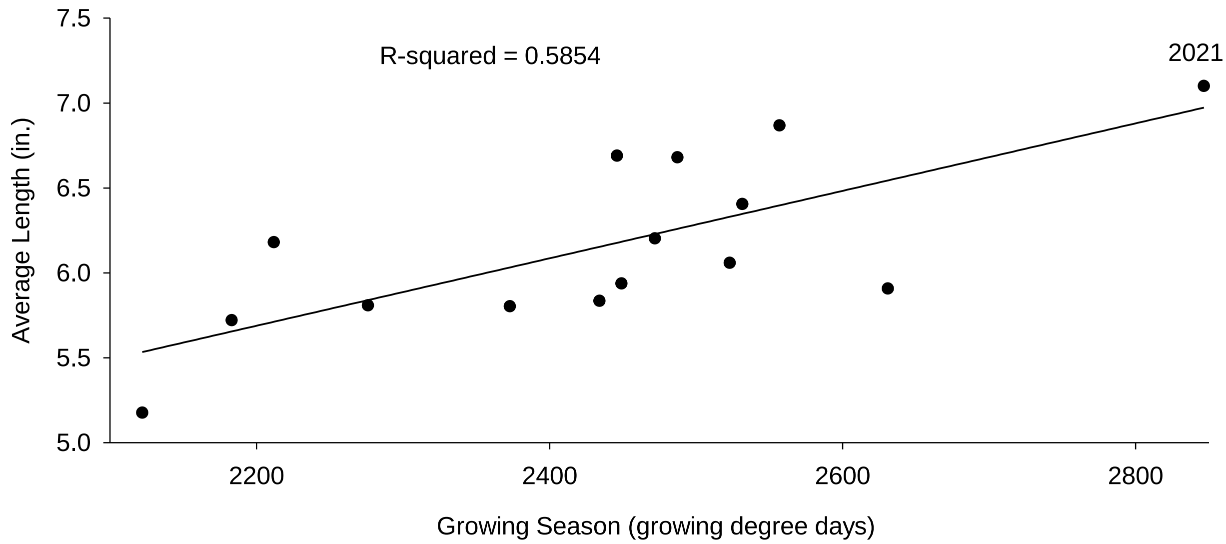


Figure 8. Growing degree-days (GDD_{50}) and the average length (in) of YOY Walleye sampled by electrofishing in mid-September at Leech Lake, 2006-2021.

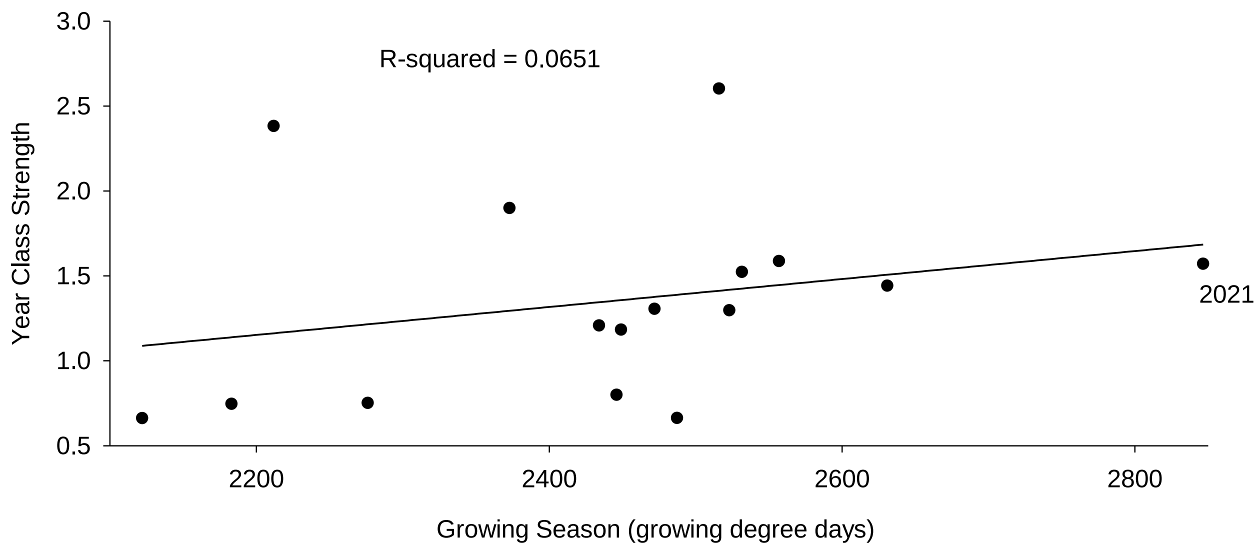


Figure 9. Growing degree-days (GDD_{50}) and the resulting observed Walleye year class strength in Leech Lake, 2006-2021 (YCS estimates for 2019-2021 are predicted values).

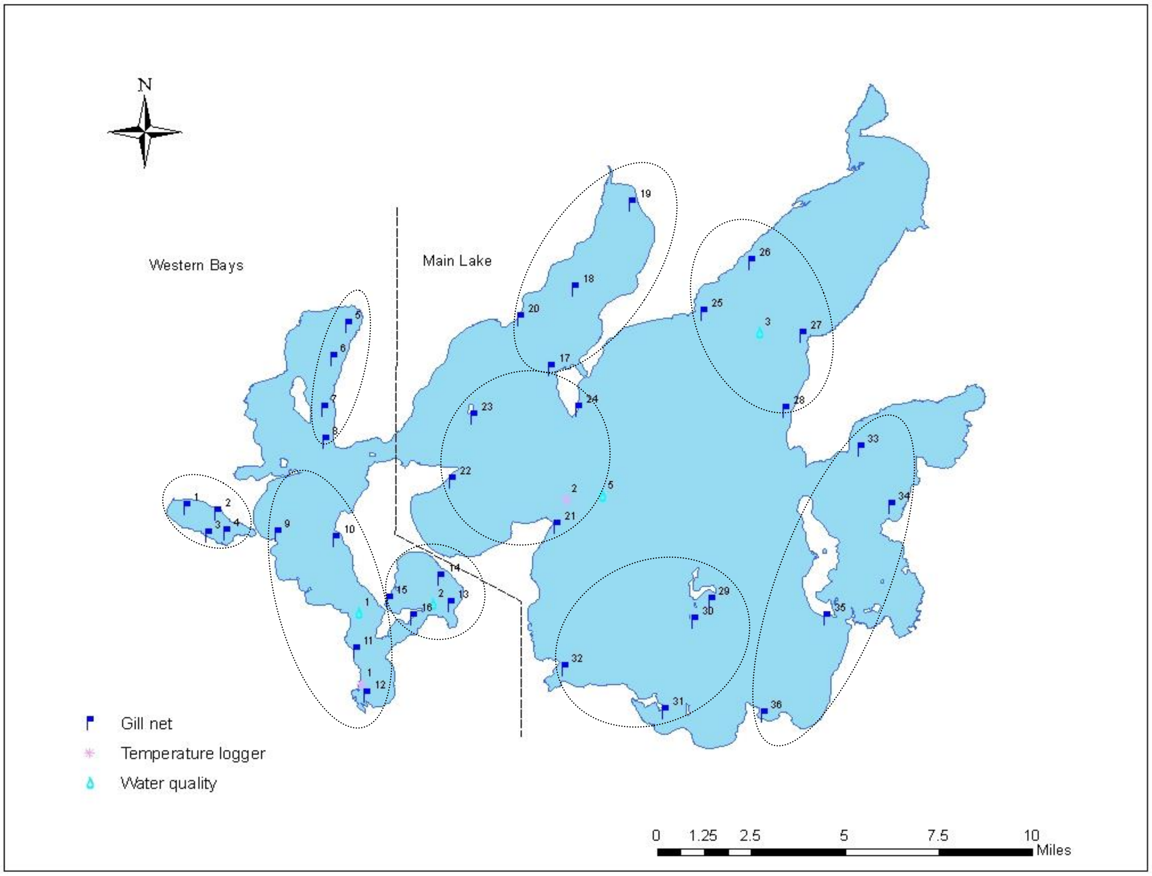


Figure 10. Gillnet (flags), temperature loggers (dots) and water quality (droplets) sampling locations on Leech Lake. Dotted circles represent gillnet sampling strata.

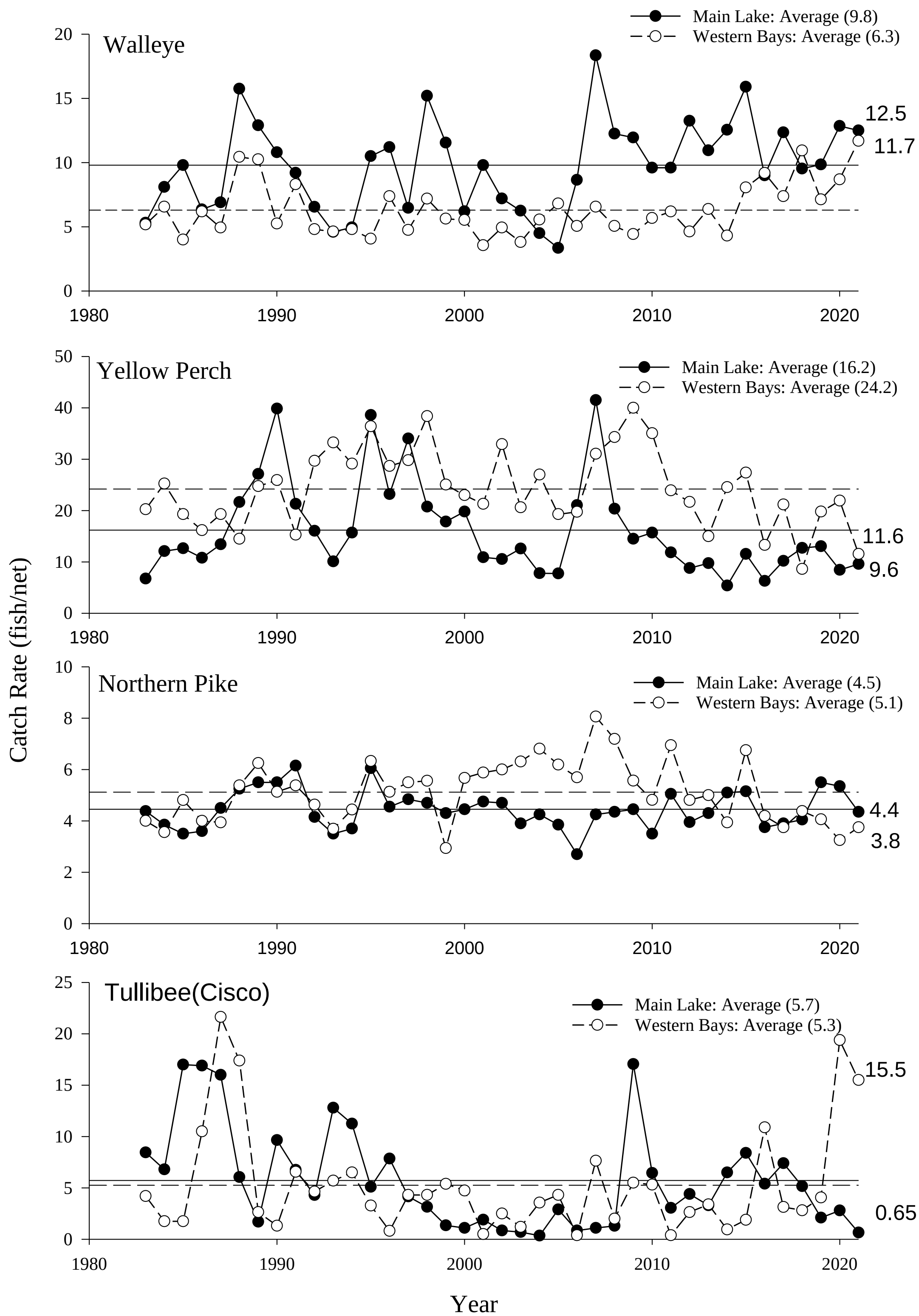


Figure 11. Basin-specific gillnet catch rates (fish/net) of selected species in Leech Lake, 1983-2021. Horizontal lines represent respective long-term averages.

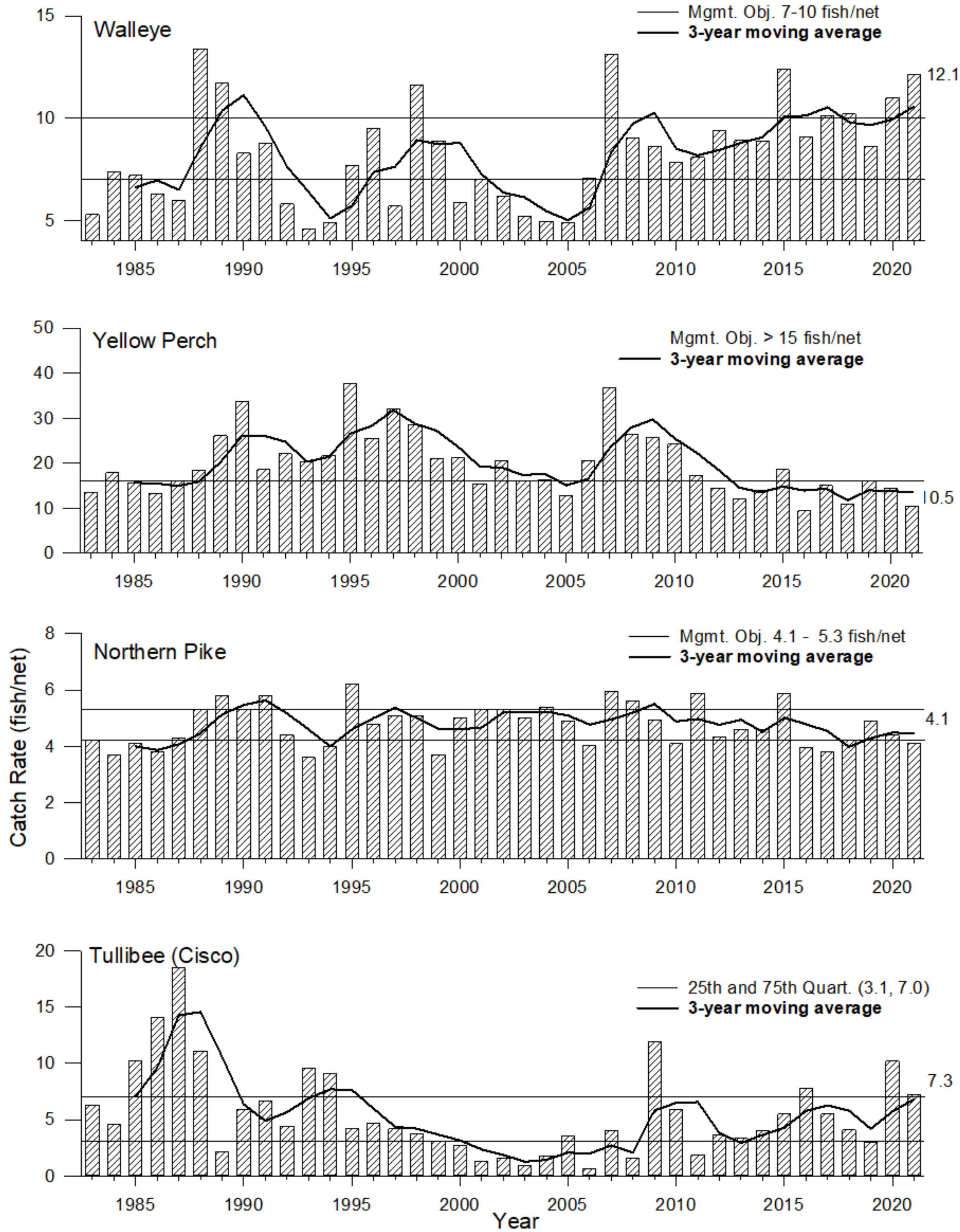


Figure 12. Gillnet catch rates (number/net) of selected species in Leech Lake, 1983-2021. Horizontal lines represent the 25th and 75th quartiles.

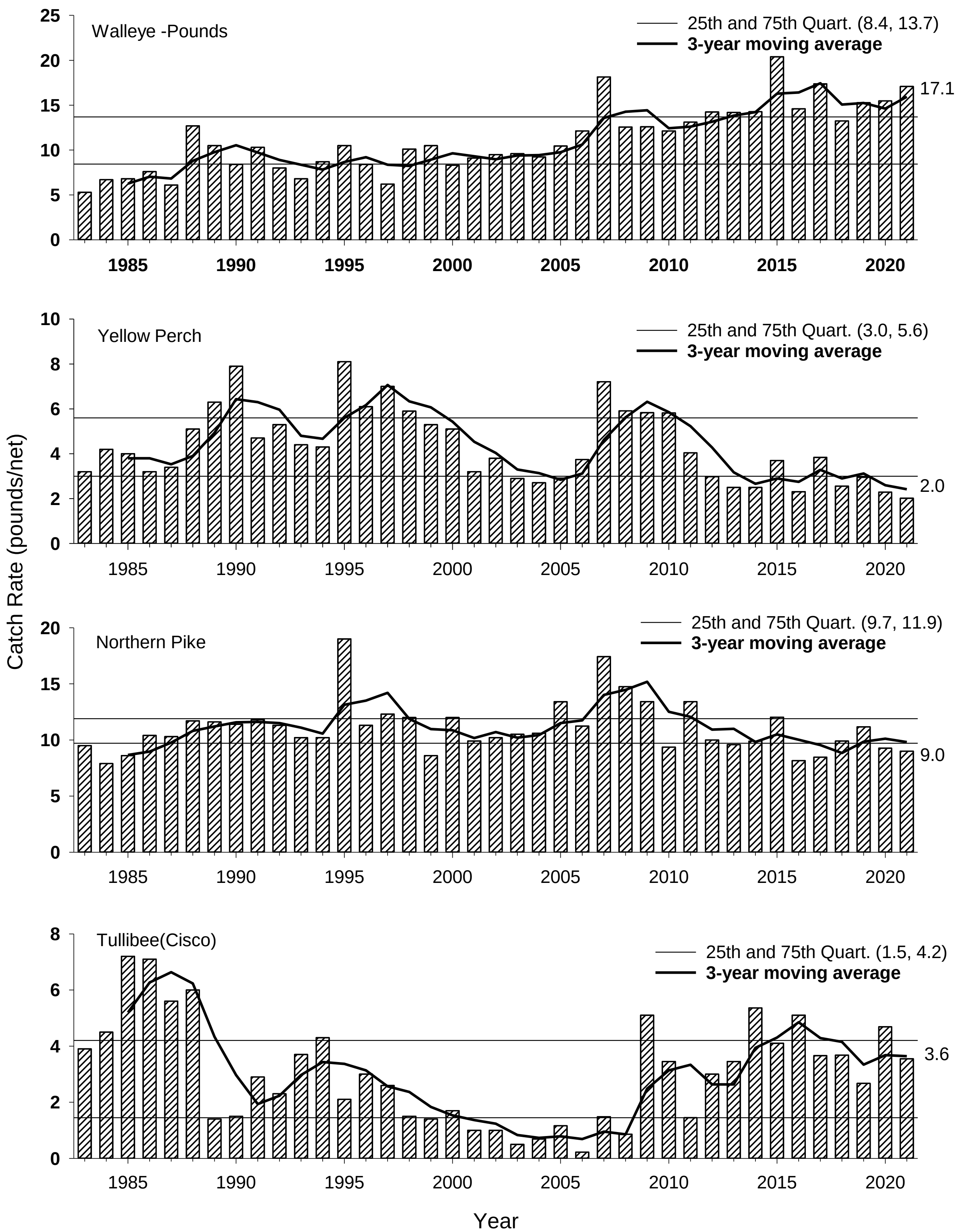


Figure 13. Gillnet catch rates (pounds/net) of selected species in Leech Lake, 1983-2021. Horizontal lines represent the 25th and 75th quartiles.

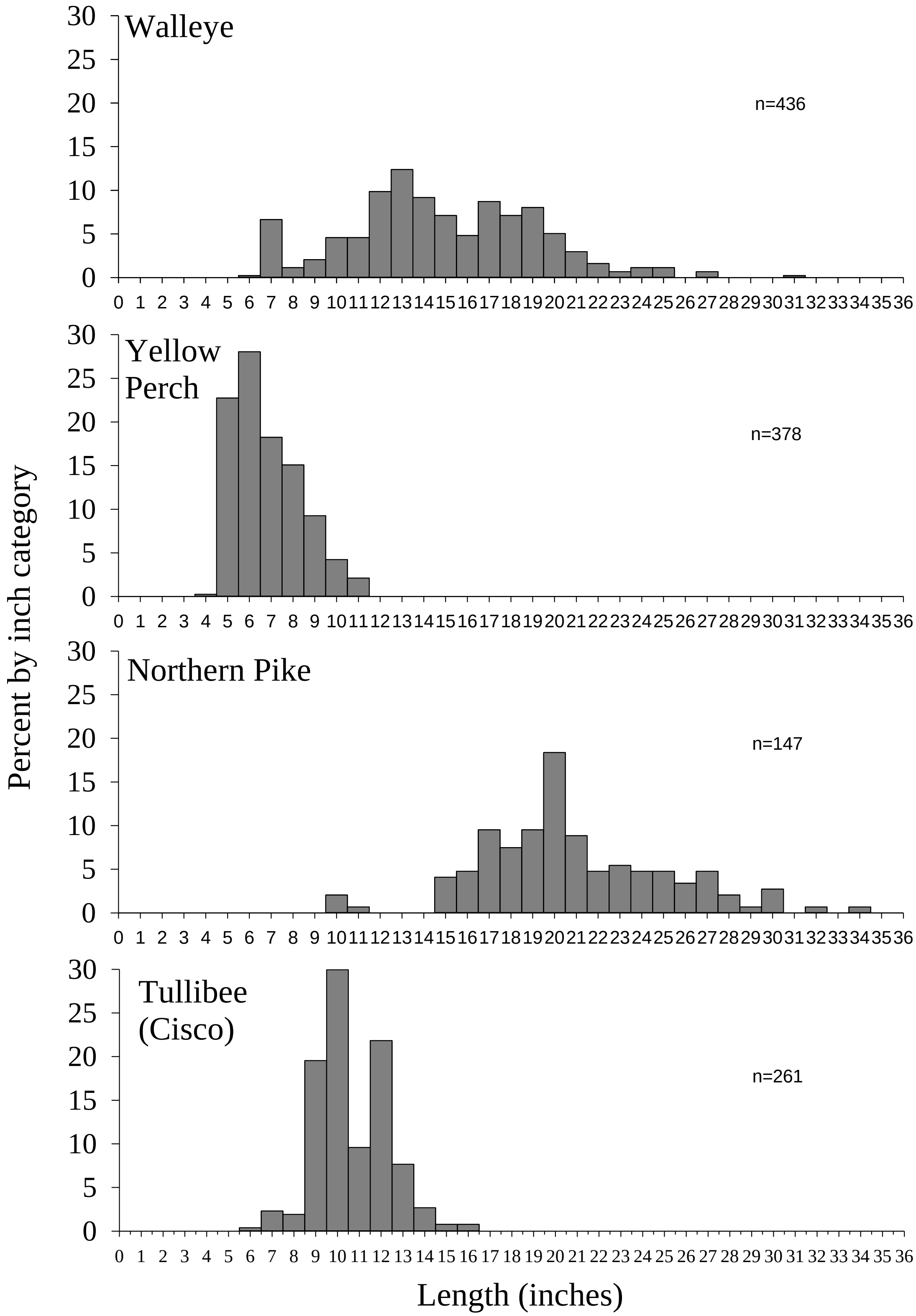


Figure 14. Length frequency distribution for Walleye, Yellow Perch, Northern Pike, and Tullibee (Cisco) sampled with gillnets in Leech Lake, 2021.

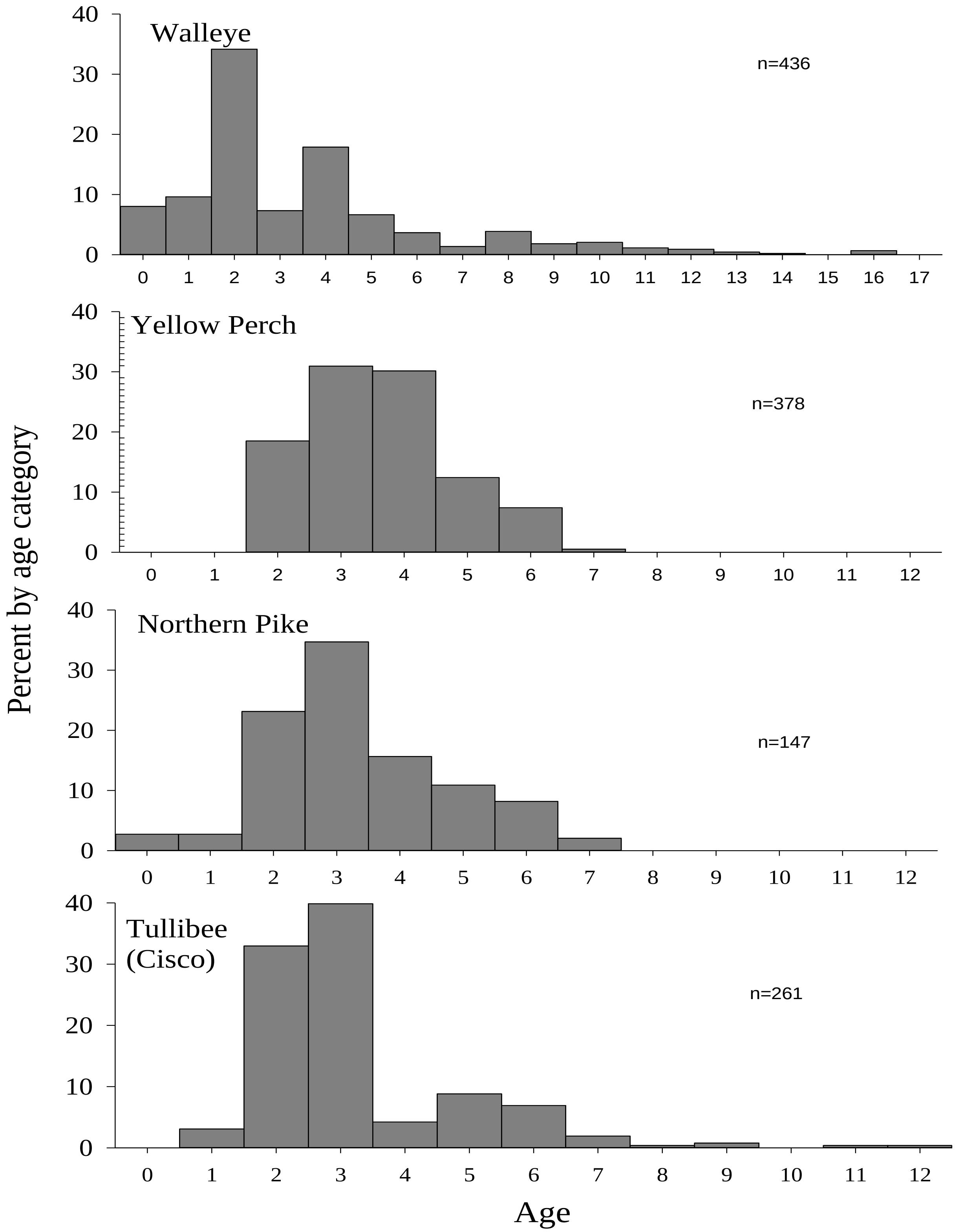


Figure 15. Age frequency distribution for Walleye, Yellow Perch, Northern Pike and Cisco sampled with gill nets in Leech Lake, 2021.

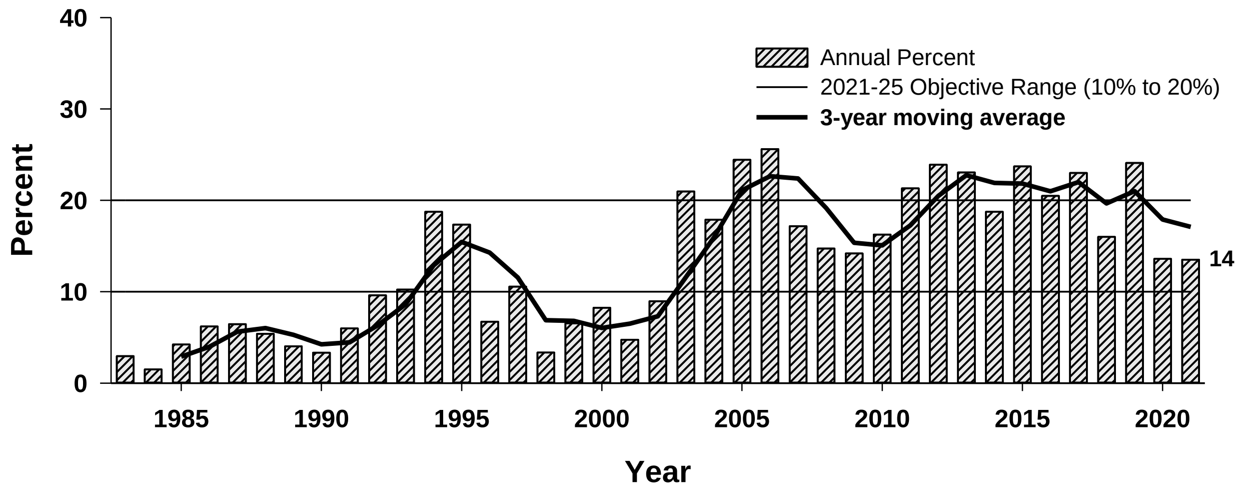


Figure 16. The percentage of Walleye in gill nets ≥20 inches in Leech Lake, 1983-2021. Horizontal lines represent the Management Plan Objective Range (39th and 70th percentiles; Pedersen 2020). The darker line represents the 3-year moving average.

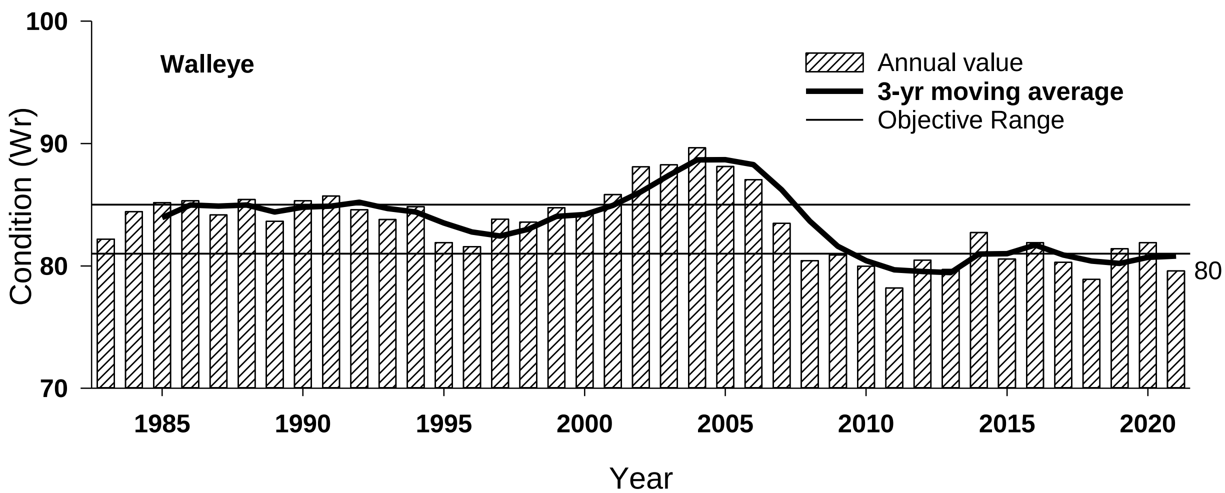


Figure 17. Annual mean condition (Wr) of Walleye in gill nets in Leech Lake, 1983-2021. Horizontal lines represent the Management Plan Objective Range (25th and 75th percentiles; Pedersen 2020). The darker line represents the 3-year moving average.

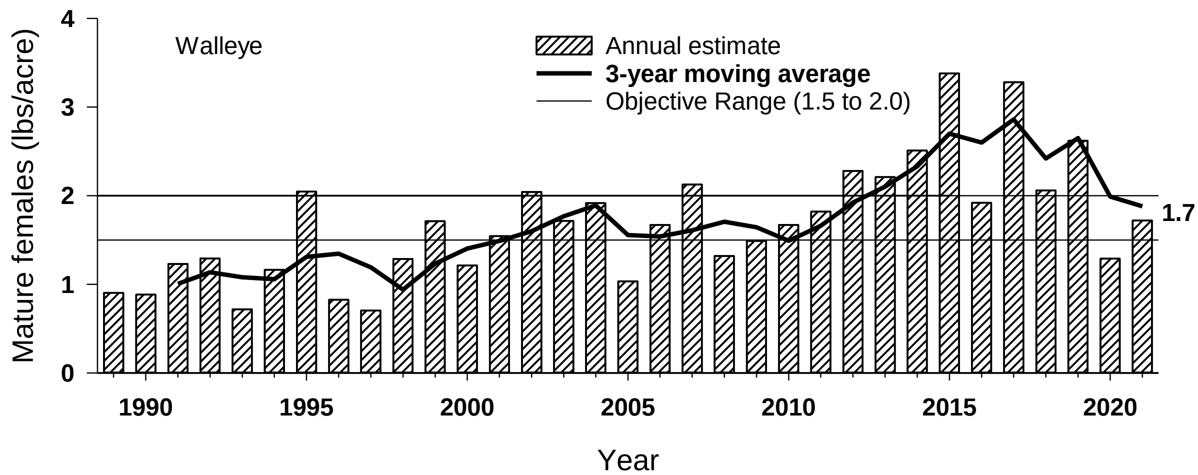
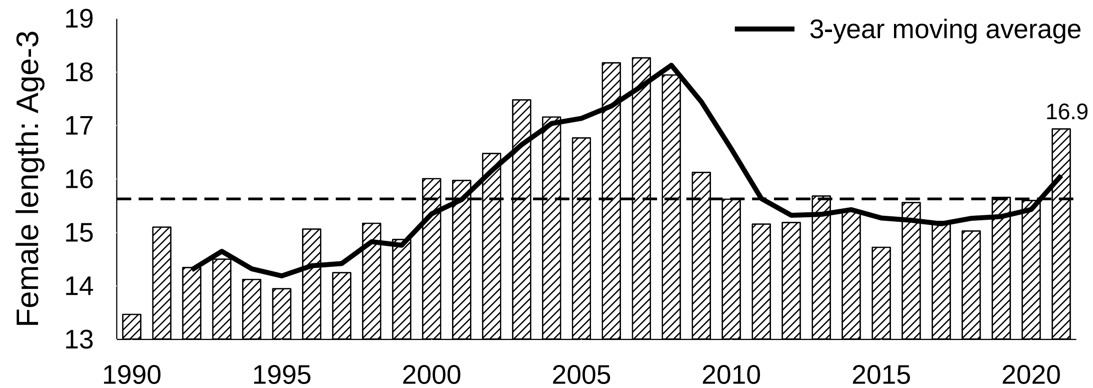
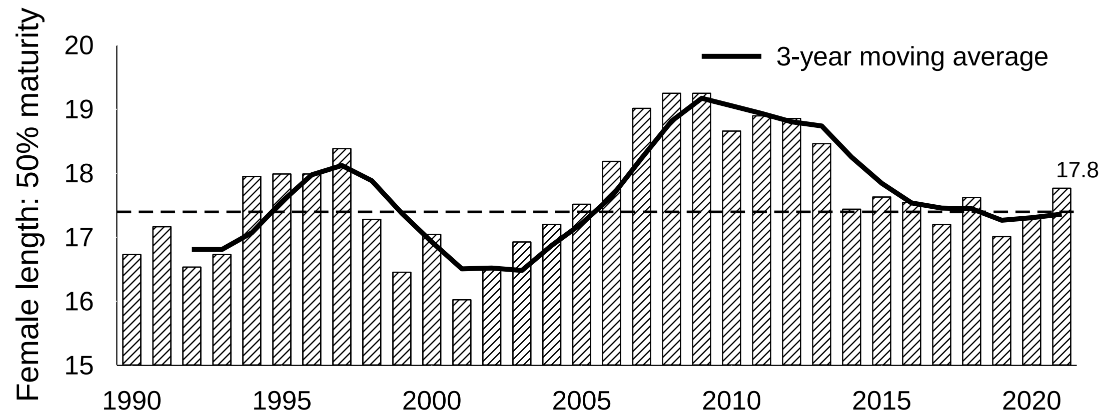


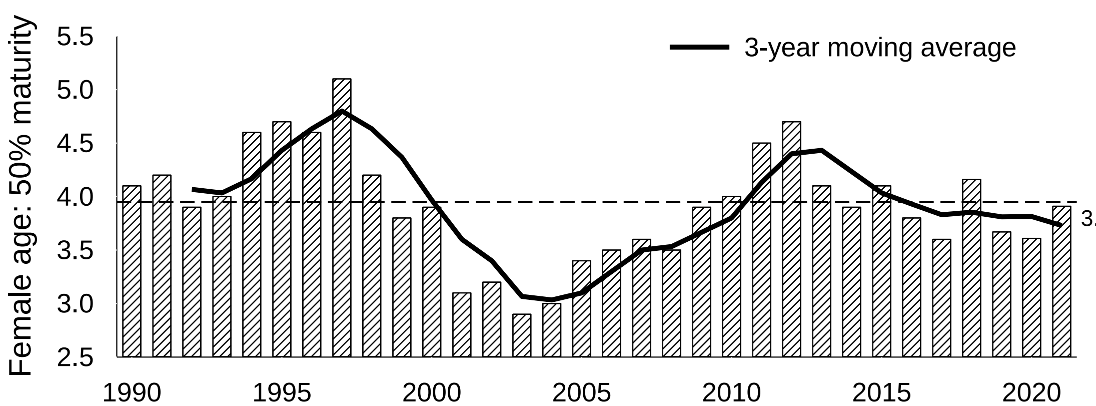
Figure 18. Estimated biomass (pounds/acre) of mature female Walleye in Leech Lake, 1989-2021. Horizontal lines represent the Management Plan Objective Range (40^{th} and 77^{th} percentiles; Pedersen 2020). The darker line represents the 3-year moving average.



Value <u>above</u> the dotted line for Female length at age-3 indicate a potential population stress response to exploitation



Value <u>below</u> the dotted line for Female length at 50% maturity indicate a potential population stress response to exploitation



Value <u>below</u> the dotted line for Female age at 50% maturity indicate a potential population stress response to exploitation

Figure 19. Biological performance indicators (BPIs), Female Walleye length at age-3 (top), length at 50% maturity (middle) and age at 50% maturity sampled with experimental gillnets in Leech Lake, 1990-2021. (Gangl and Pereira, 2003). The darker line represents the 3-year moving average**.**

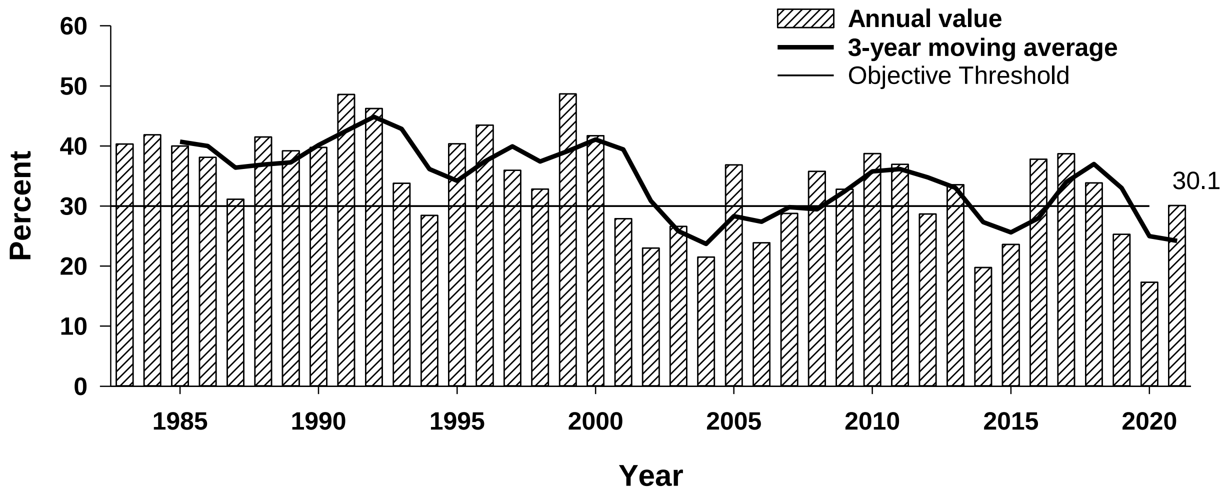


Figure 20. The percentage of Yellow Perch in gill nets ≥8 inches in Leech Lake, 1983-2021. The horizontal line represents the Management Plan Objective Threshold (25th percentile; Pedersen 2020). The darker line represents the 3-year moving average**.**

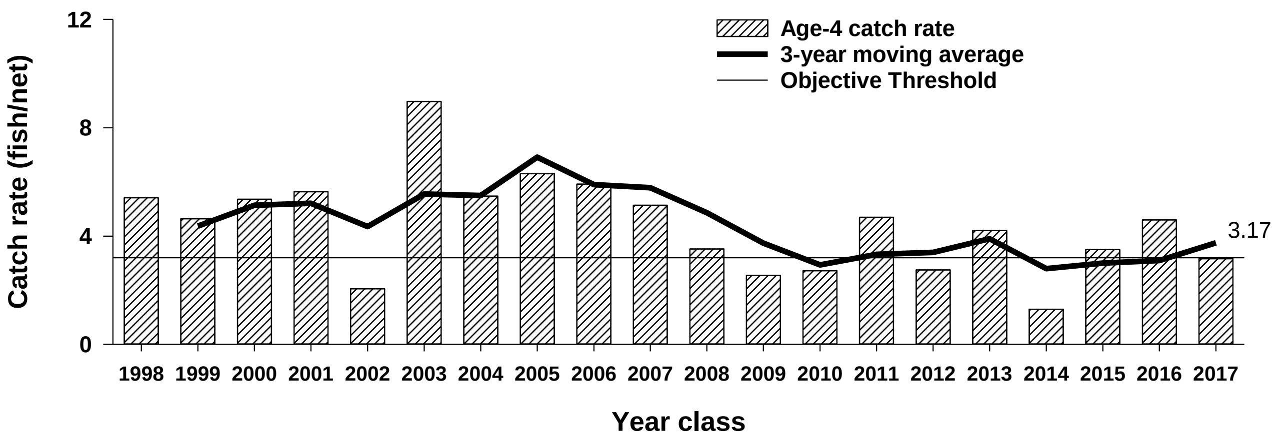


Figure 21. Gill net catch rates (fish/net) of age-4 Yellow Perch by year class in Leech Lake, 1998-2017. The horizontal line represents the Management Plan Objective Threshold (25th percentile; Pedersen 2020). The darker line represents the 3-year moving average.

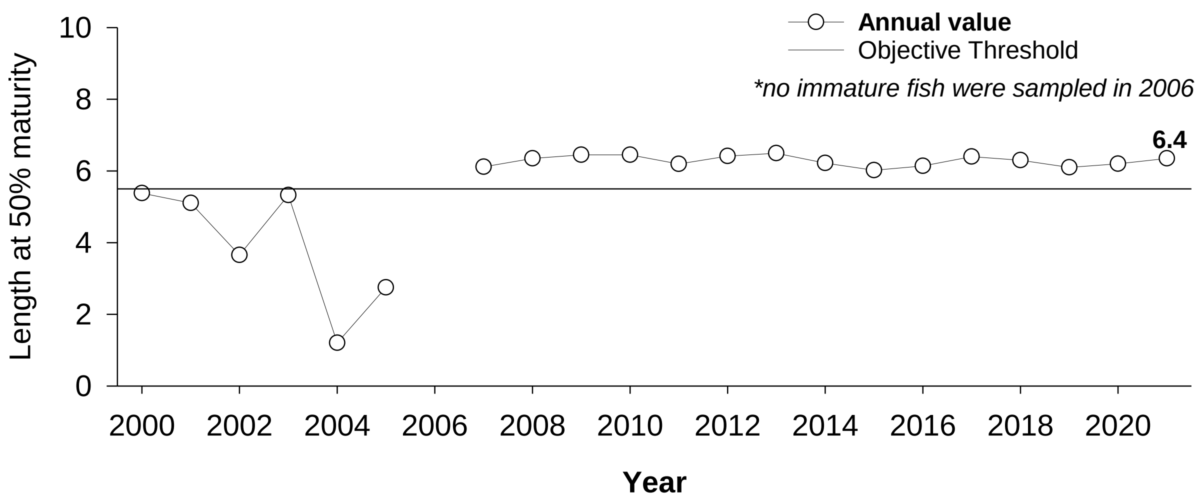


Figure 22. Total length of female Yellow Perch at 50% maturity in gill nets in Leech Lake, 2000-2021. The horizontal line represents the Management Plan Objective Threshold, below which Yellow Perch matured at shorter lengths (5.5 inches; Pedersen 2020).

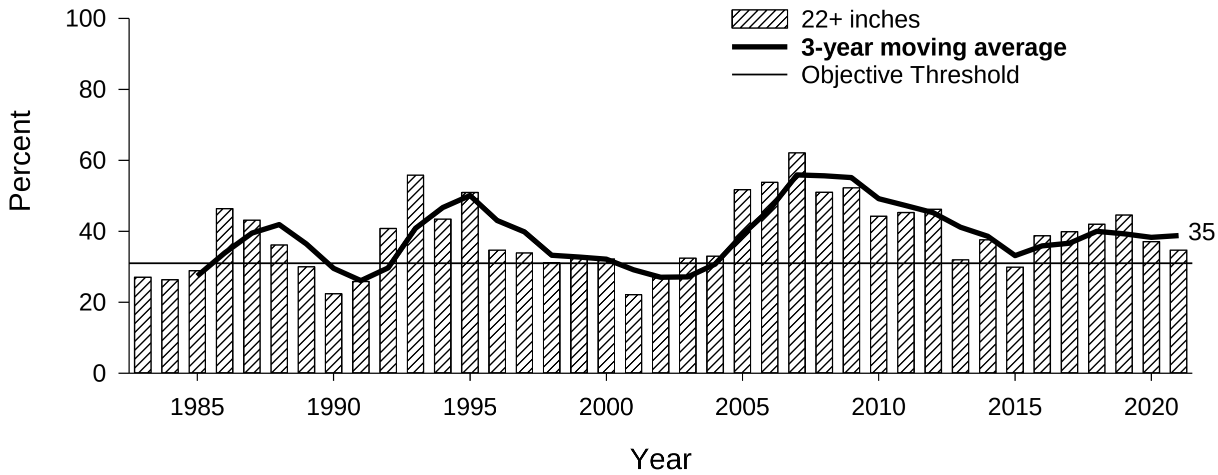


Figure 23. The percentage of Northern Pike in gill nets ≥22 inches in Leech Lake, 1983-2021. The horizontal line represents the Management Plan Objective Threshold (25th percentile; Pedersen 2020). The darker line represents the 3-year moving average**.**

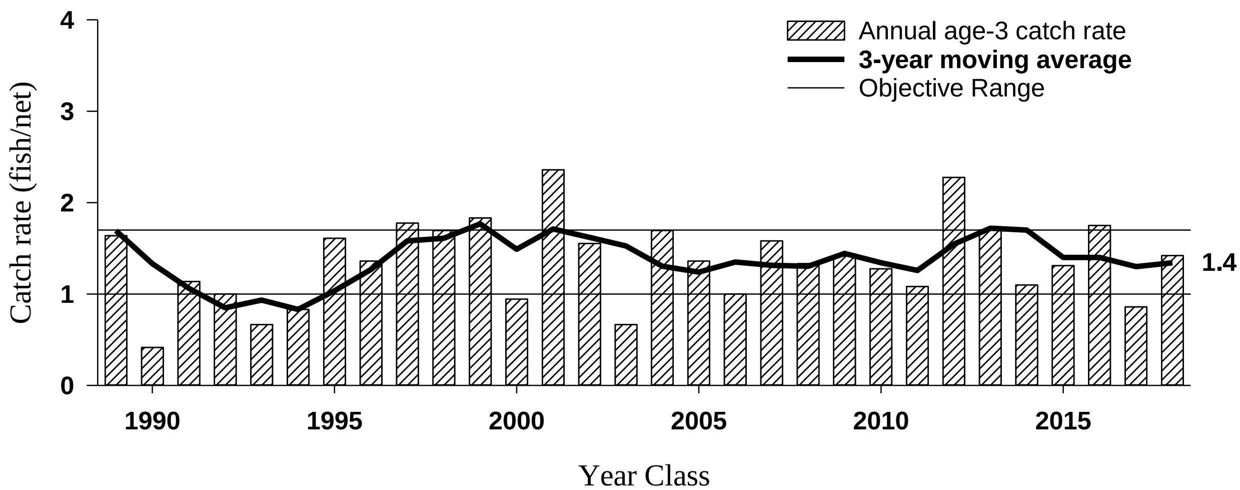


Figure 24. Gill net catch rates (fish/net) of age-3 Northern Pike by year class in Leech Lake, 1998-2018. Horizontal lines represent the Management Plan Objective Range (25th and 75th percentiles; Pedersen 2020). The darker line represents the 3-year moving average.

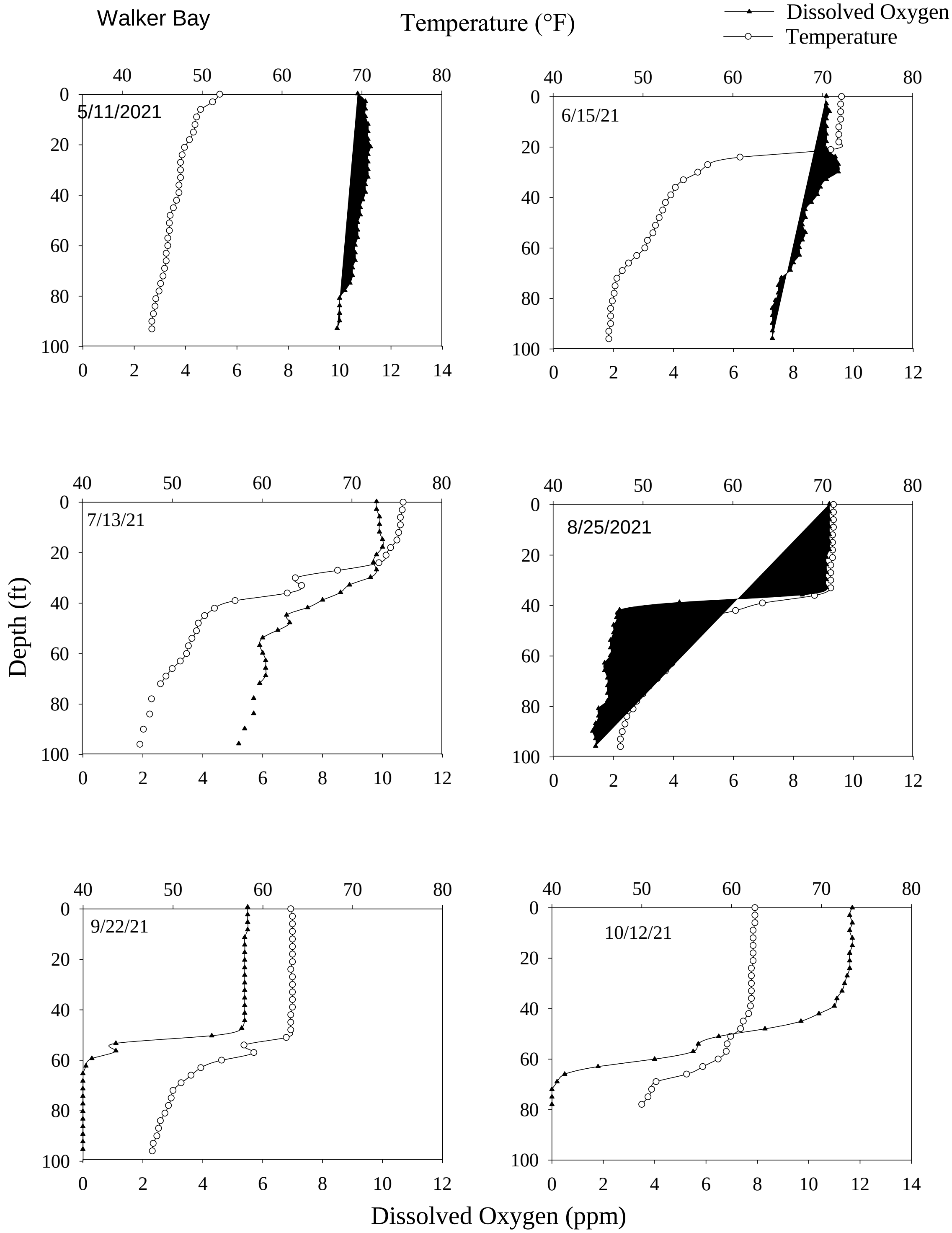


Figure 25. Monthly temperature and oxygen profiles from Walker Bay (WQ1), Leech Lake, from mid-May through mid-October 2021.

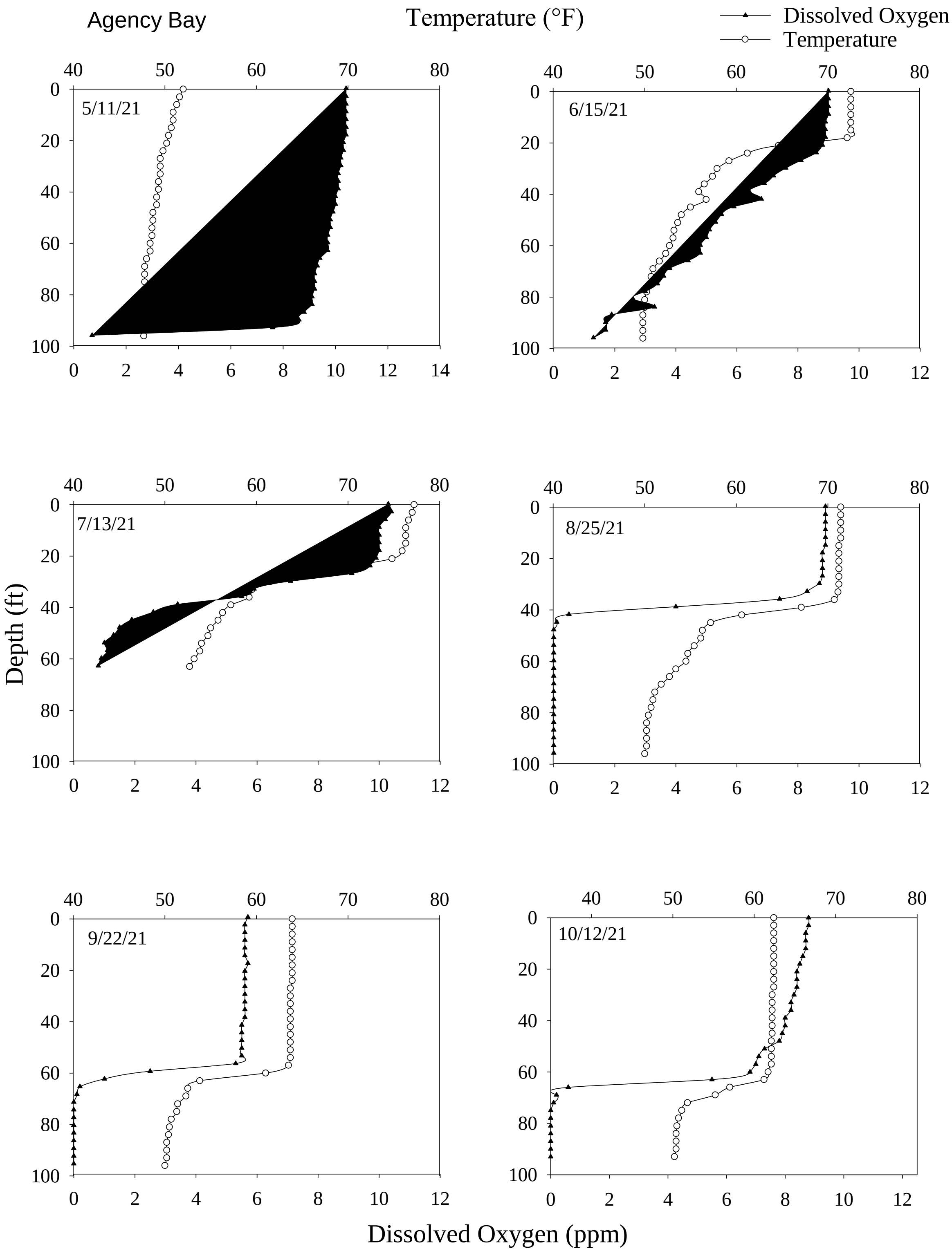


Figure 26. Monthly temperature and oxygen profiles from Agency Bay (WQ2), Leech Lake, from mid-May through mid-October 2021.

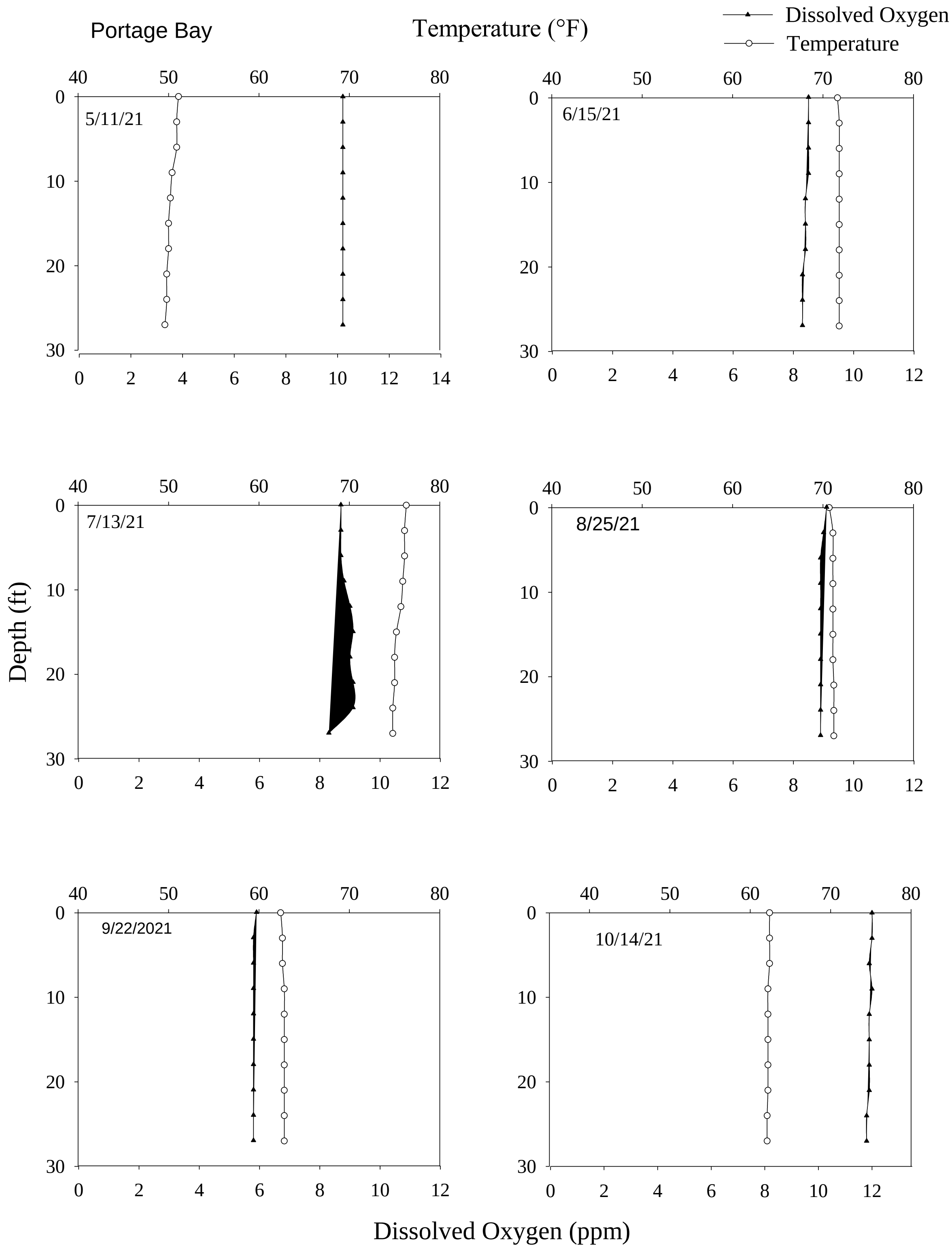


Figure 27. Monthly temperature and oxygen profiles from Portage Bay (WQ3), Leech Lake, from mid-May through mid-October 2021.

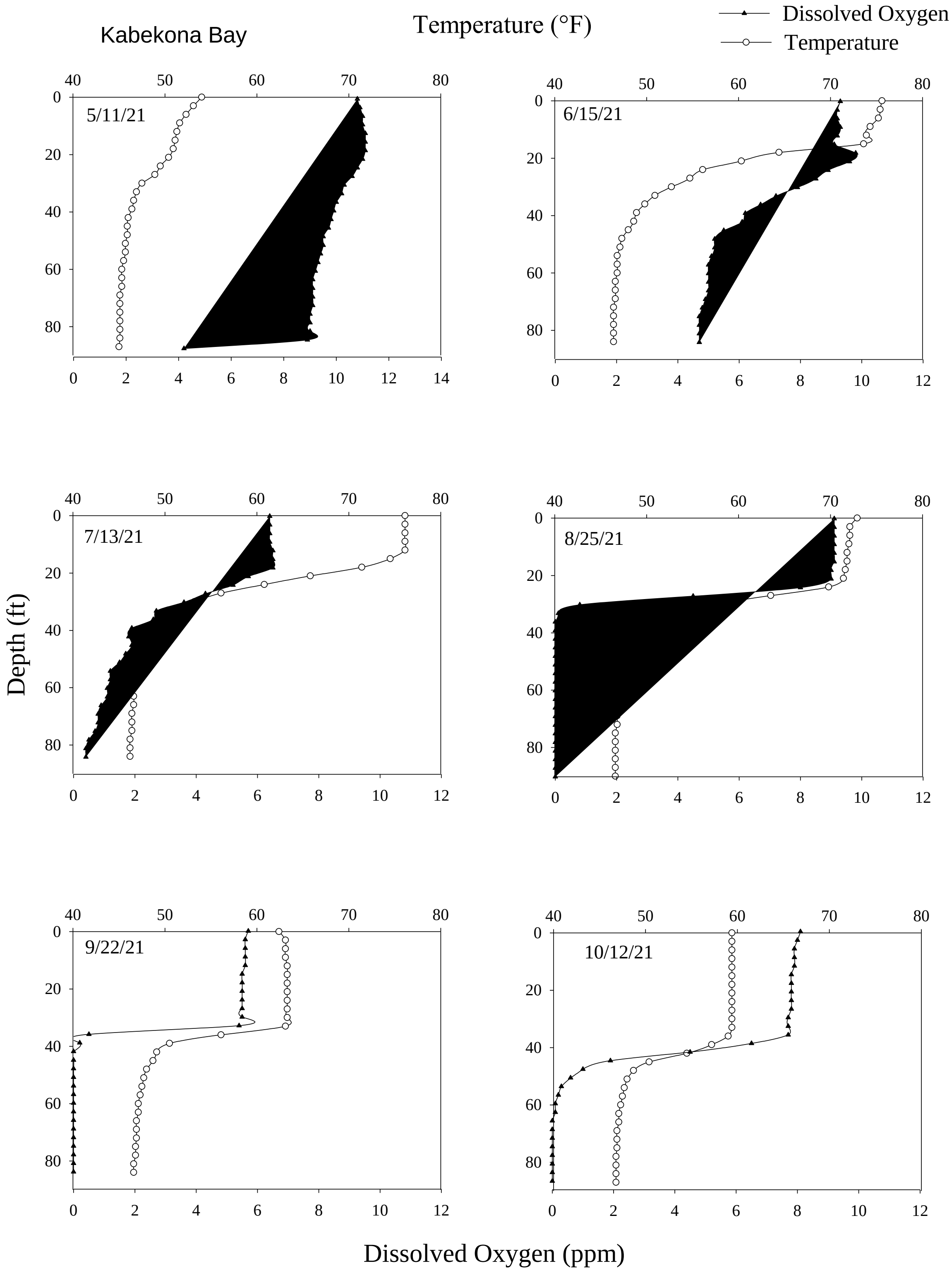


Figure 28. Monthly temperature and oxygen profiles from Kabekona Bay (WQ4), Leech Lake, from mid-May through mid-October 2021.

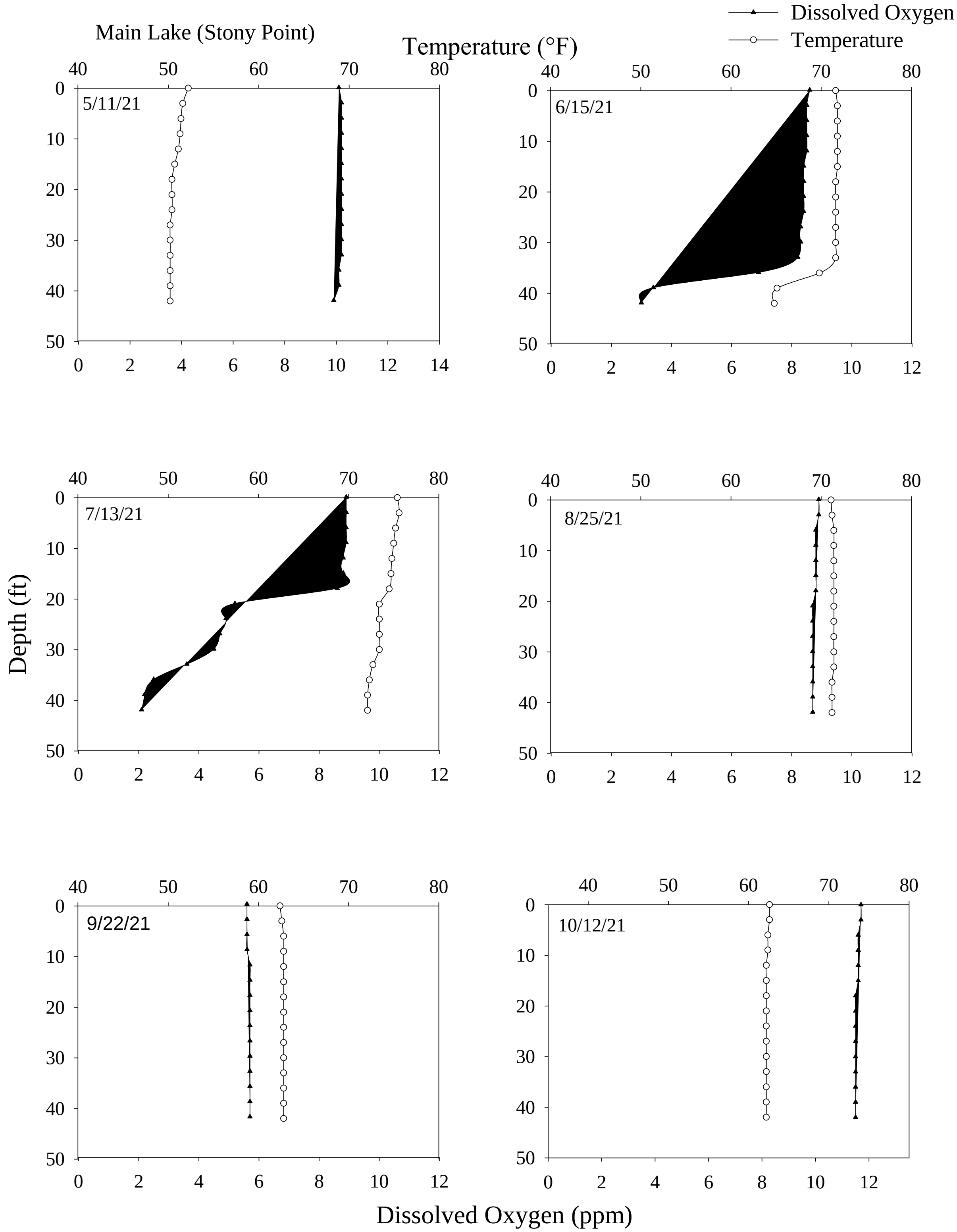


Figure 29. Monthly temperature and oxygen profiles from the Main Basin (WQ5), Leech Lake, from mid-May through mid-October 2021.

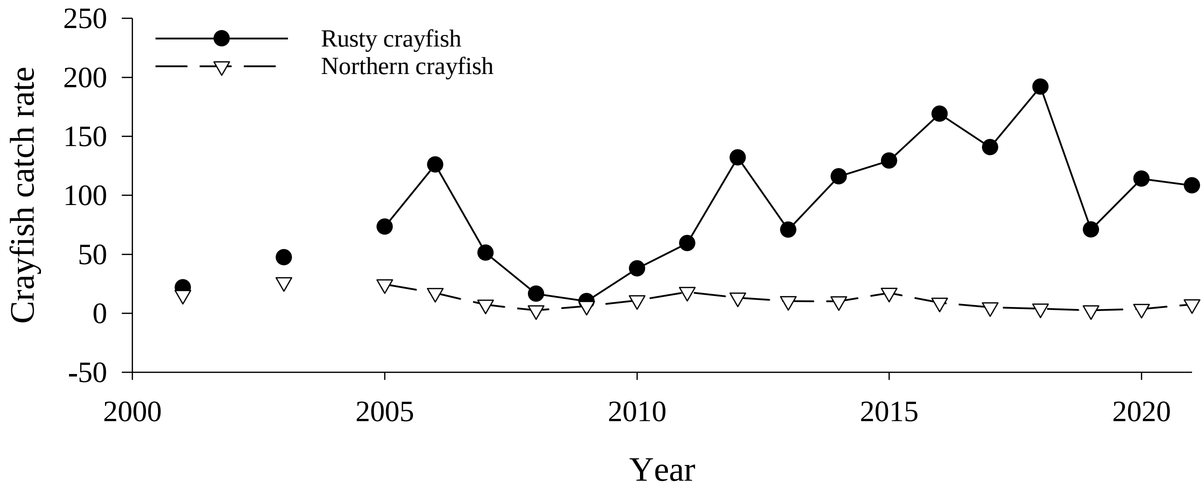


Figure 30. Crayfish entanglement rates (number/net) in gill nets, 2001-2021 as an index of relative abundance. Numbers were not recorded in 2000, 2002, or 2004.

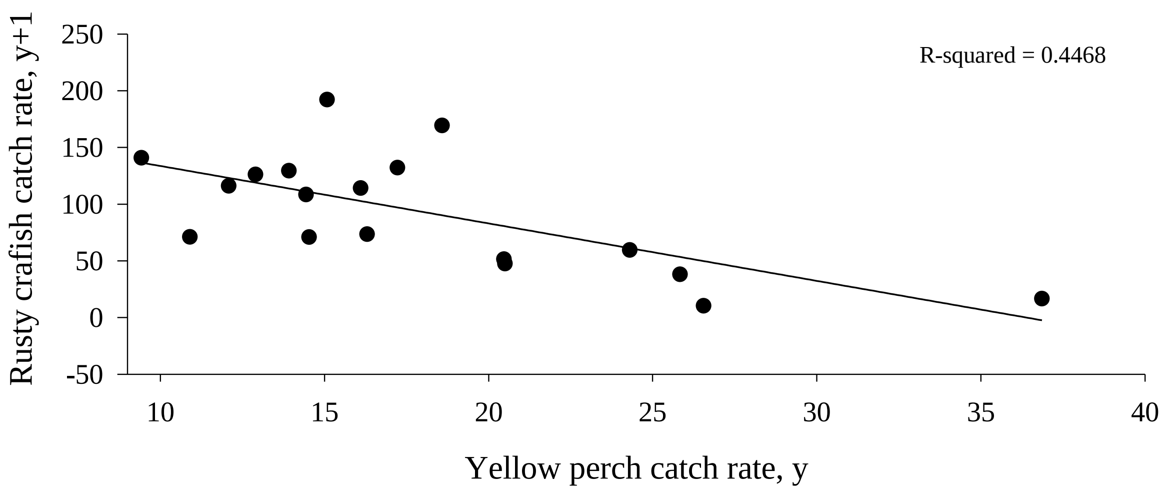


Figure 31. Yellow Perch catch rates (number/net) in year y and Rusty Crayfish entanglement rates (number/net) the following year (y+1) in Leech Lake, 2001-2021.

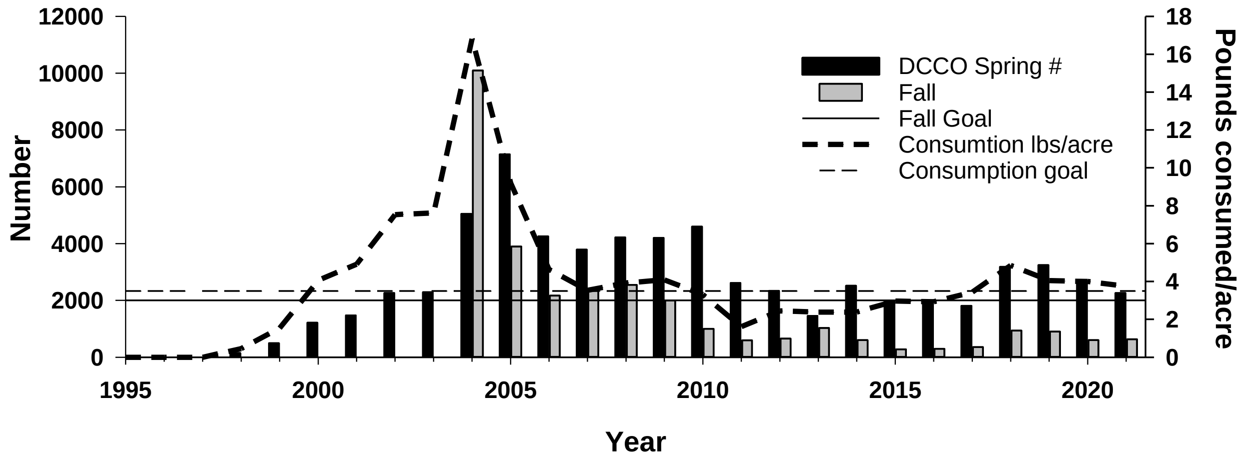


Figure 32. Spring and fall Double-Crested Cormorant numbers on Leech Lake, 1998-2021. The line depicts the current fall population goal of 2,000 birds ([500 nesting pairs x 2 adults] + 2 offspring/nest). (S. Mortensen, Division of Resource Management, Leech Lake Band of Ojibwe, personal communication).

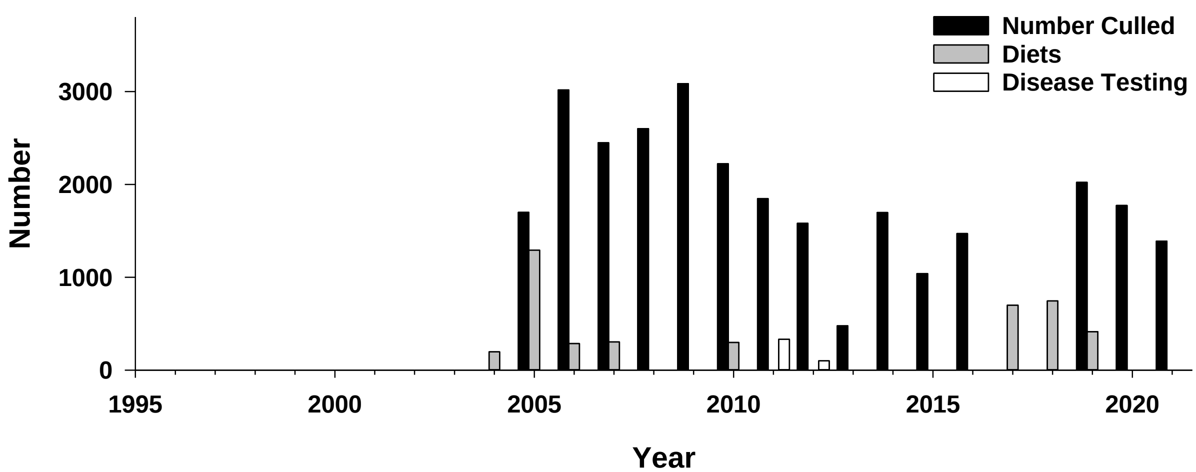


Figure 33. Double-Crested Cormorant research and management take on Leech Lake, 2004-2021. The number of additional birds collected for diet and disease testing is also indicated. (S. Mortensen, Division of Resource Management, Leech Lake Band of Ojibwe, personal communication).

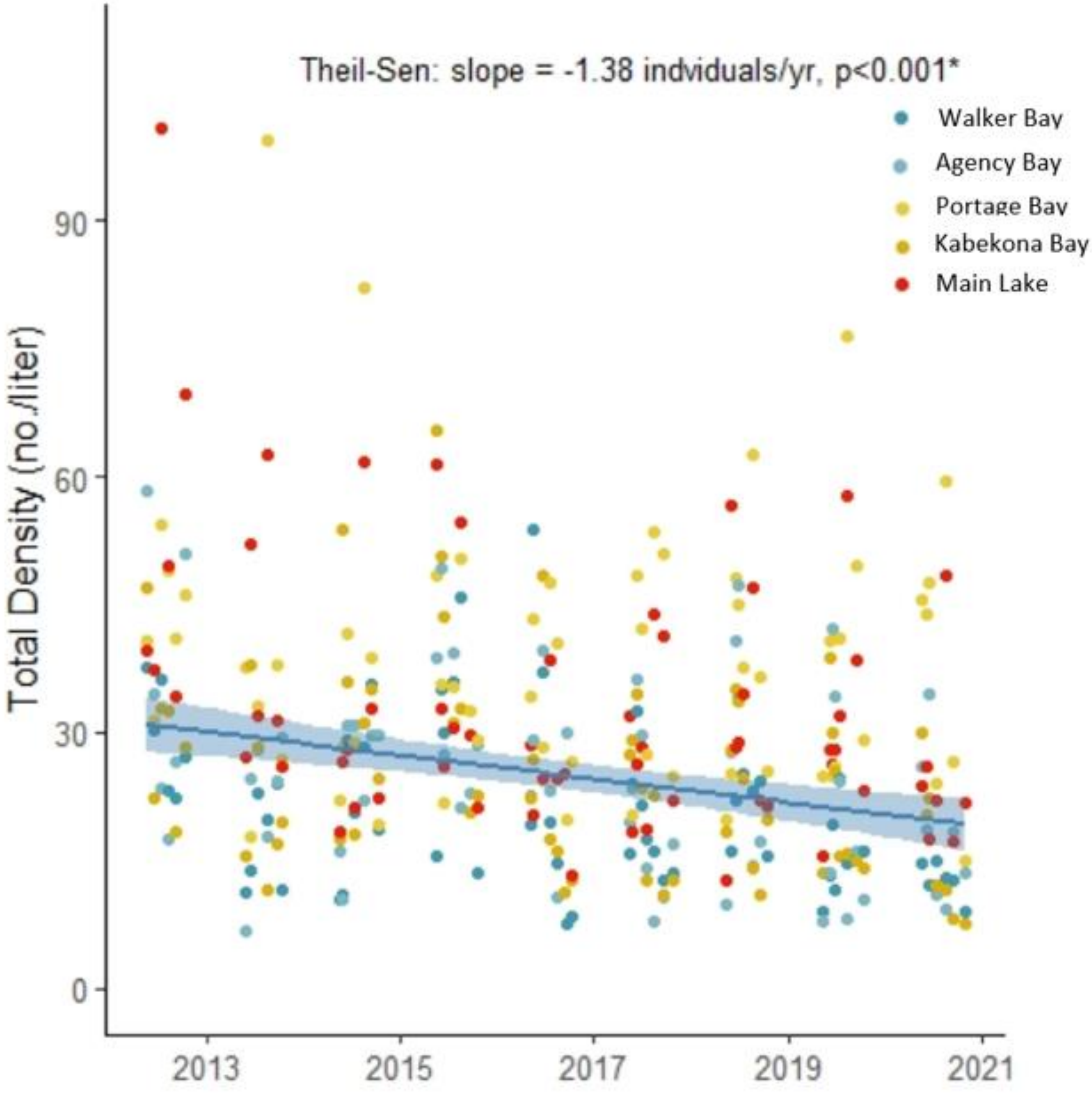


Figure 34. Average density (number/liter) of zooplankton sampled from May through October at the five standardized zooplankton sites on Leech Lake from 2012-2020.

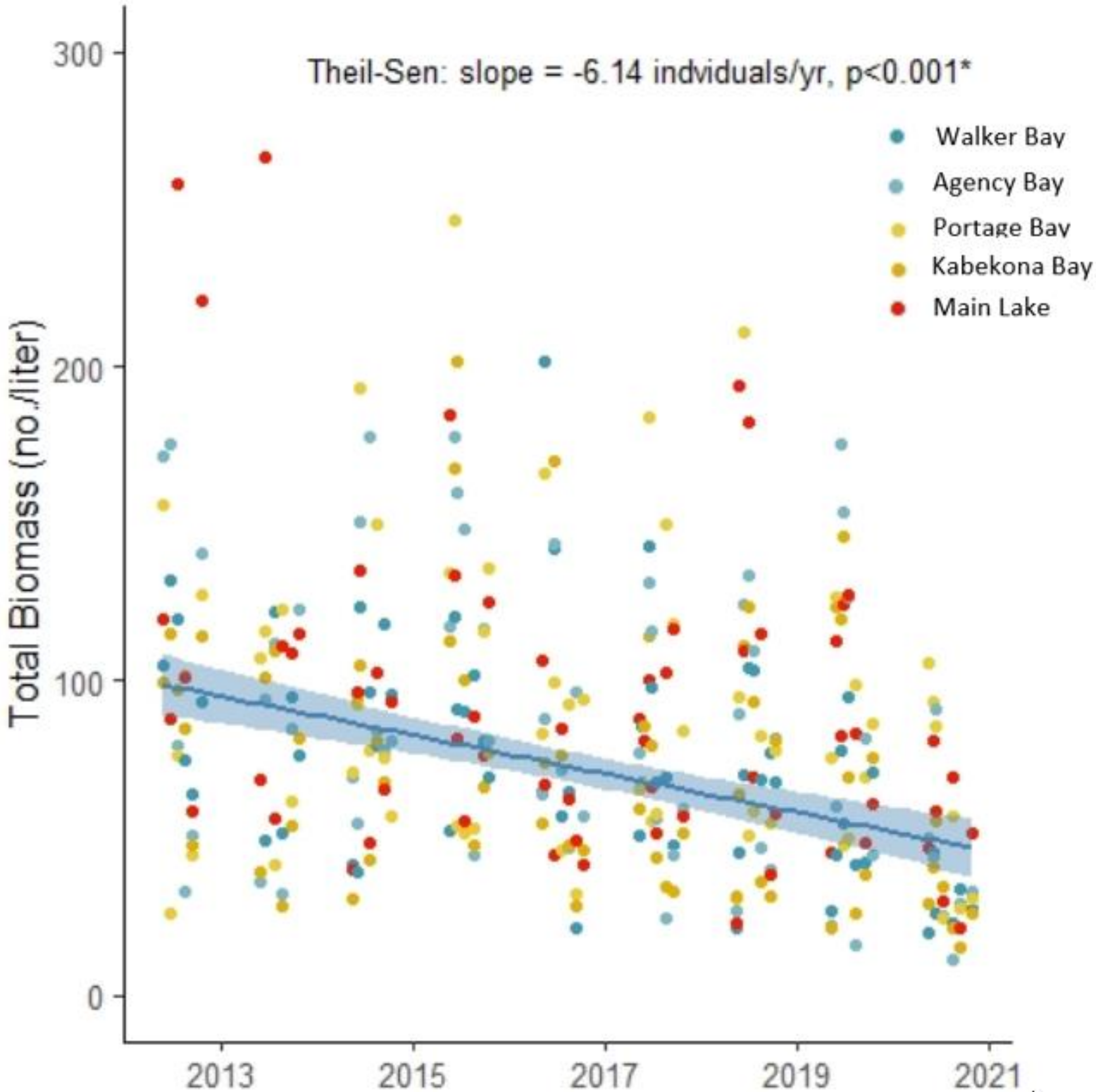


Figure 35. Density (number/liter) and biomass (µg/liter) of zooplankton sampled by bay from 2012-2020 at the five standardized zooplankton sites on Leech Lake.

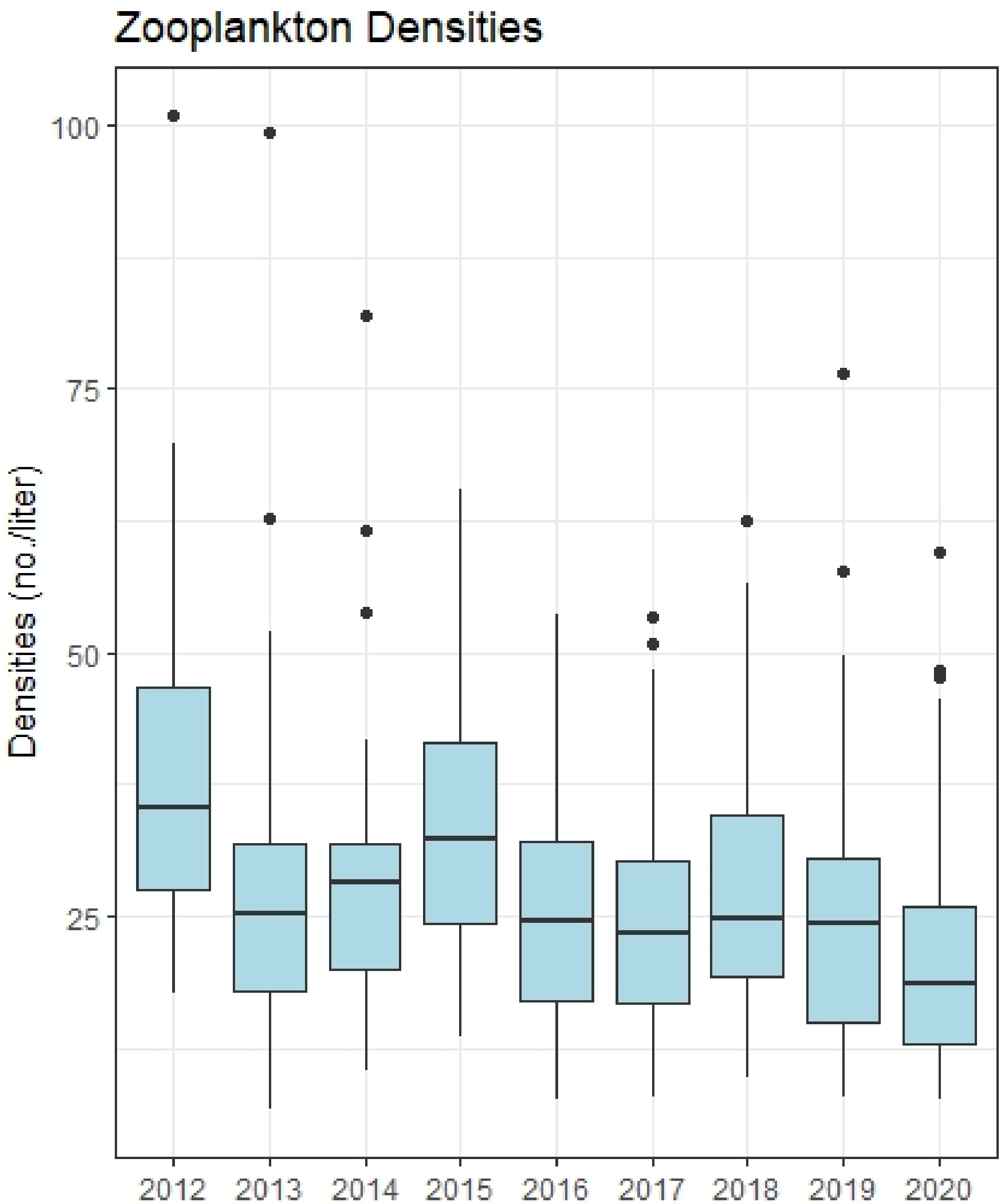


Figure 36. Density (numbers/liter) of zooplankton sampled, lake wide, Leech Lake 2012-2020.

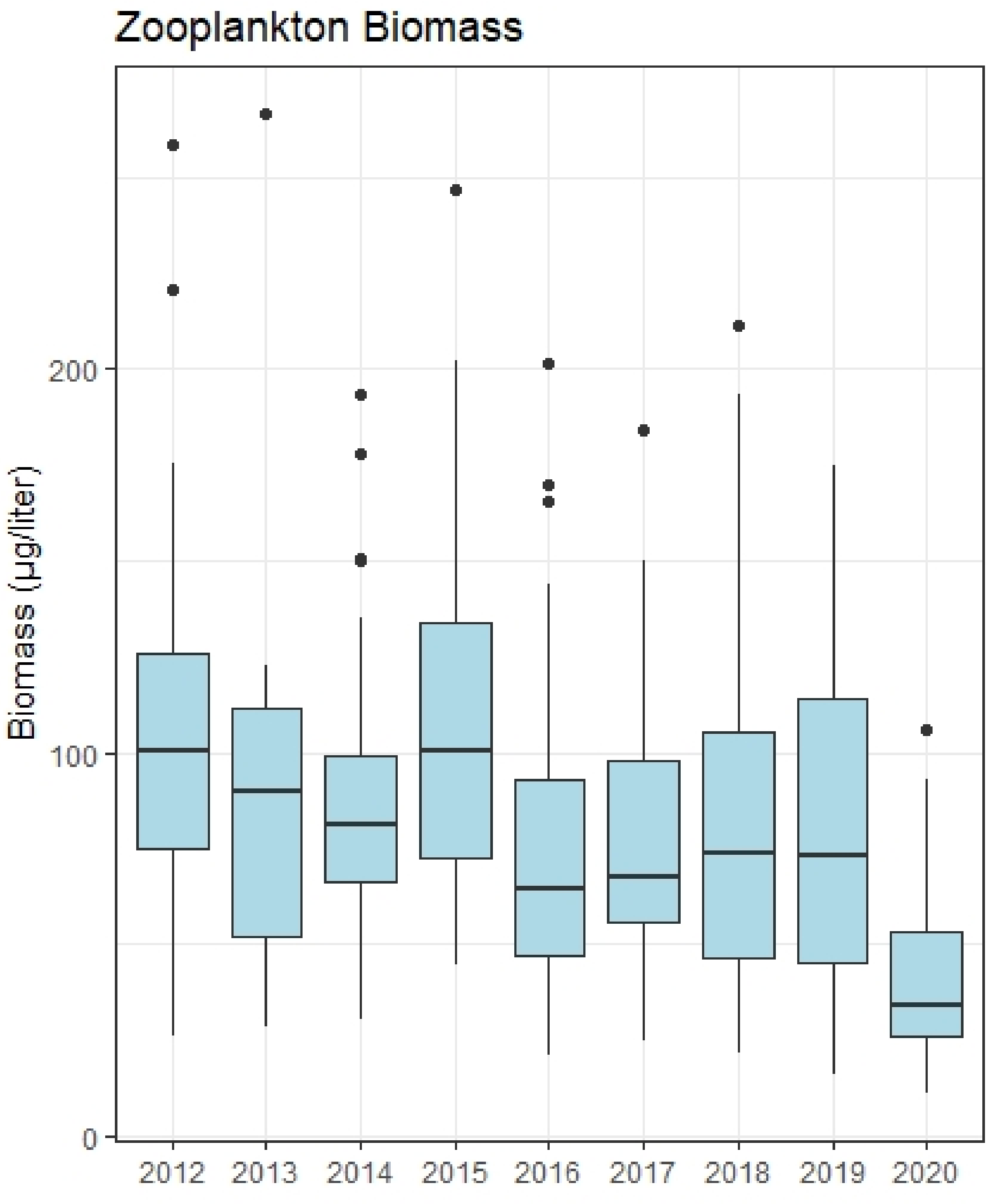


Figure 37. Biomass (µg/liter) of zooplankton sampled, lake wide, Leech Lake 2012-2020.

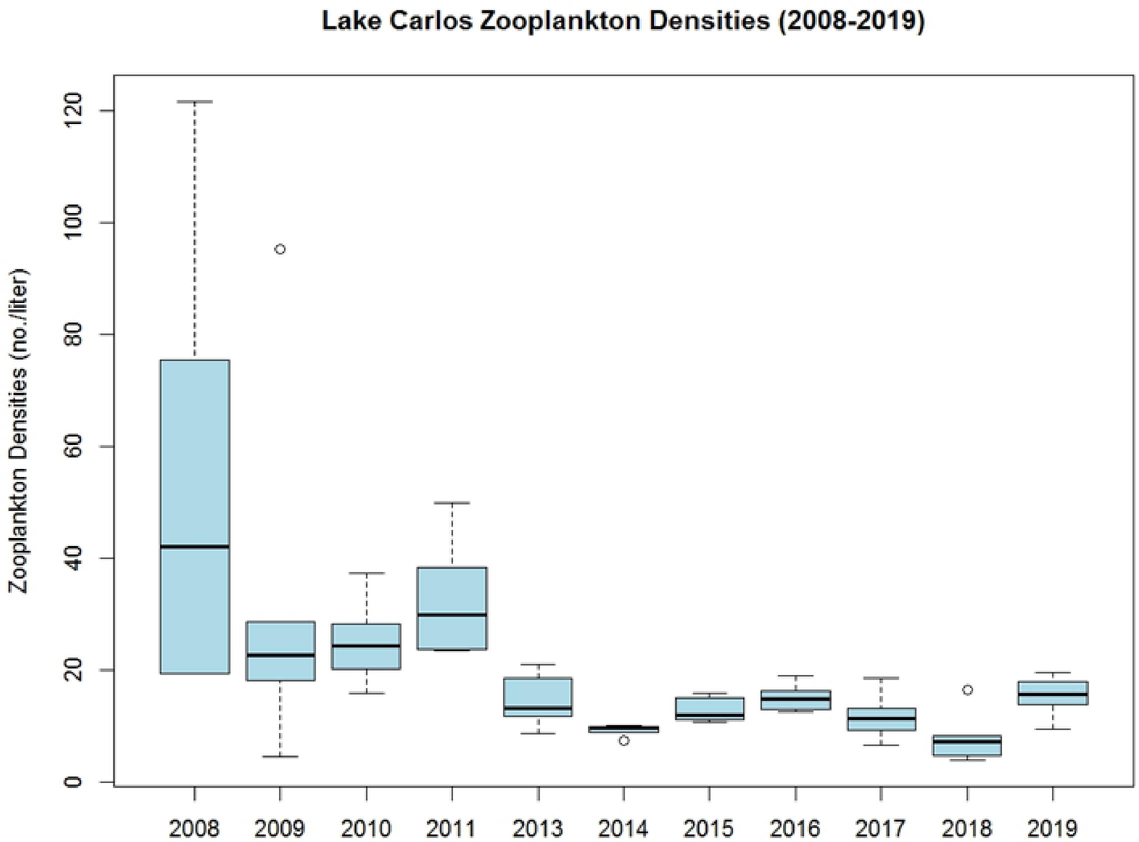


Figure 38. Densities (numbers/liter) of zooplankton sampled, lake wide, Lake Carlos 2008-2019.

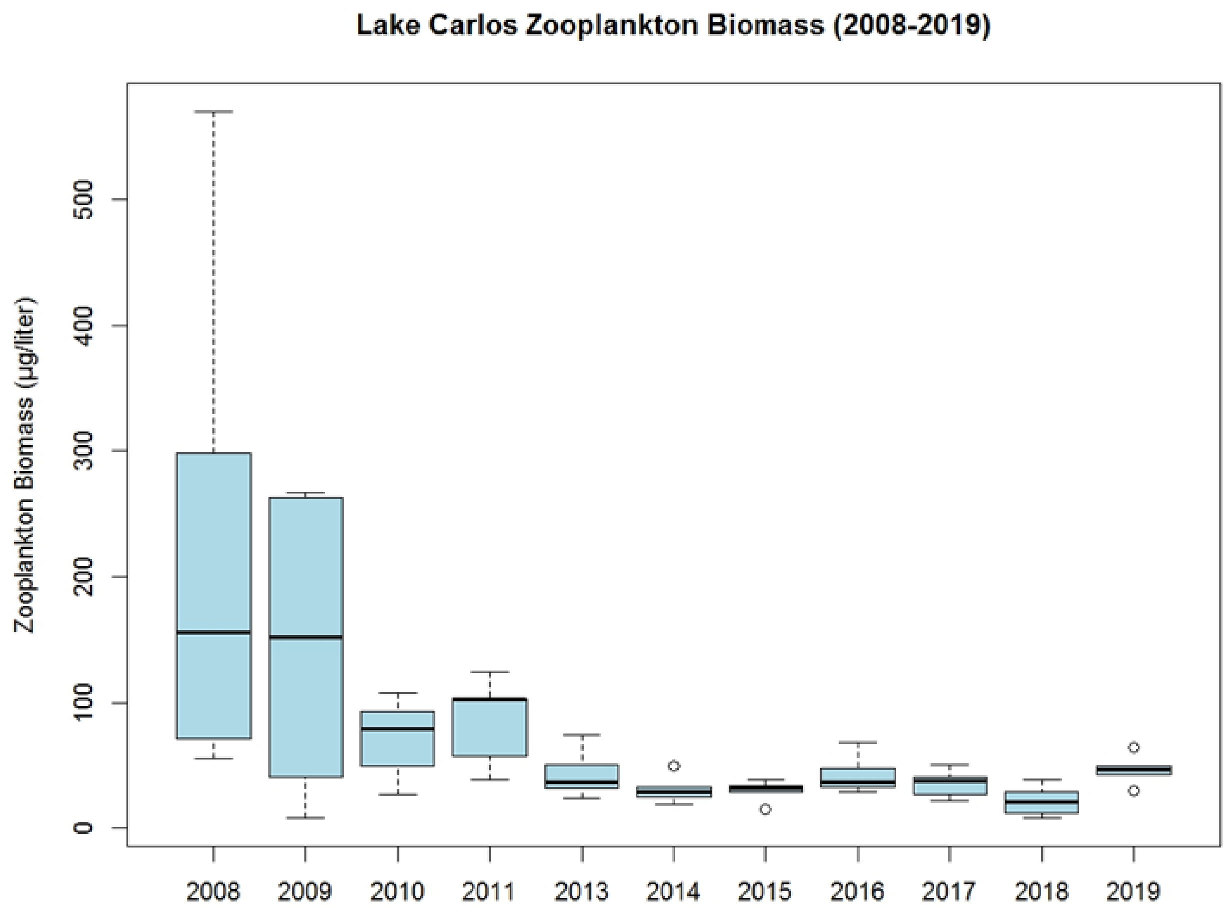


Figure 39. Biomass (µg/liter) of zooplankton sampled, lake wide, Lake Carlos 2008-2019.

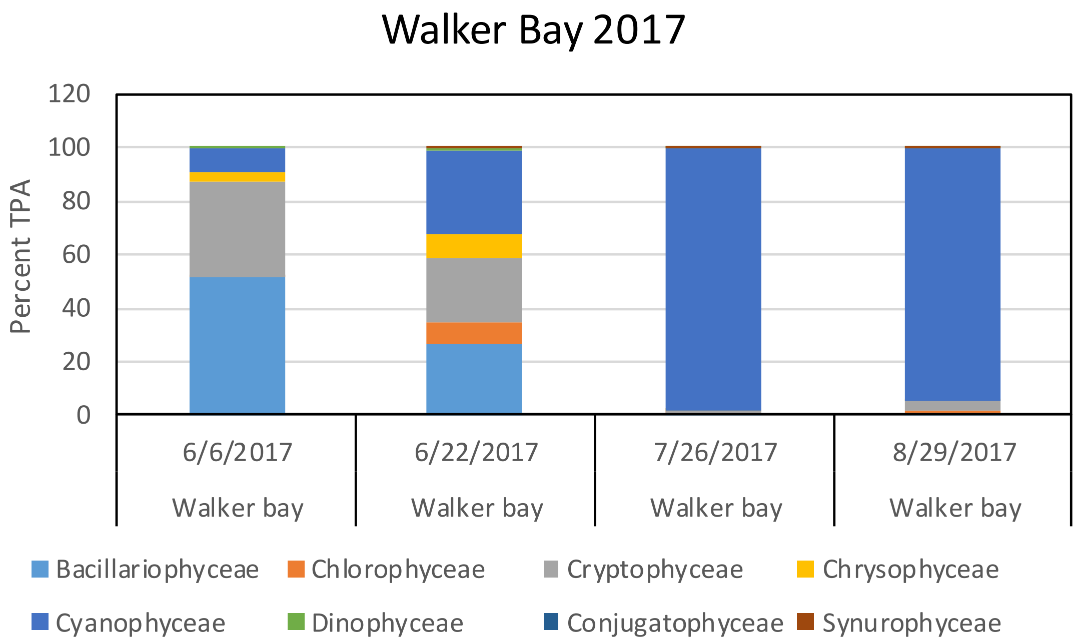


Figure 40. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Walker Bay 2017.

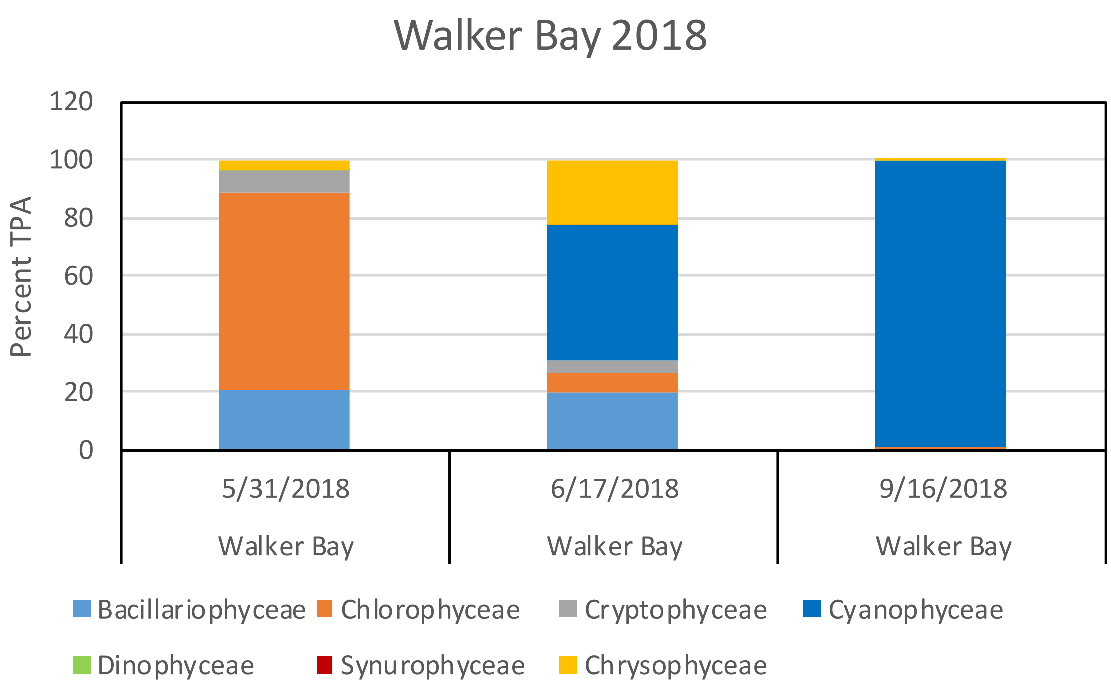


Figure 41. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Walker Bay 2018.

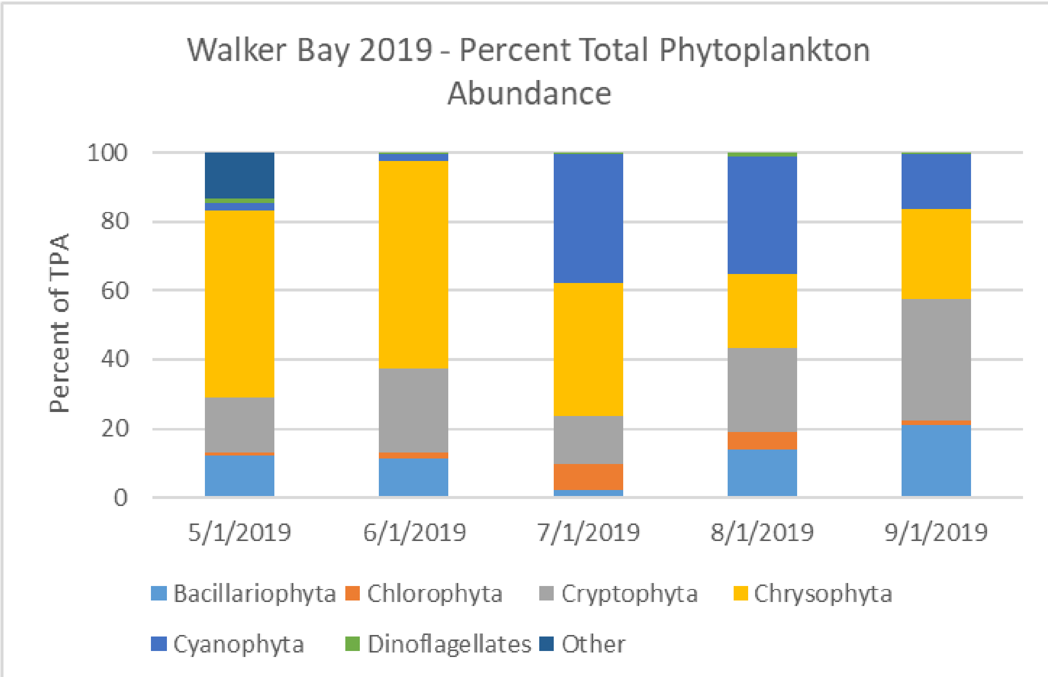


Figure 42. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Walker Bay 2019.

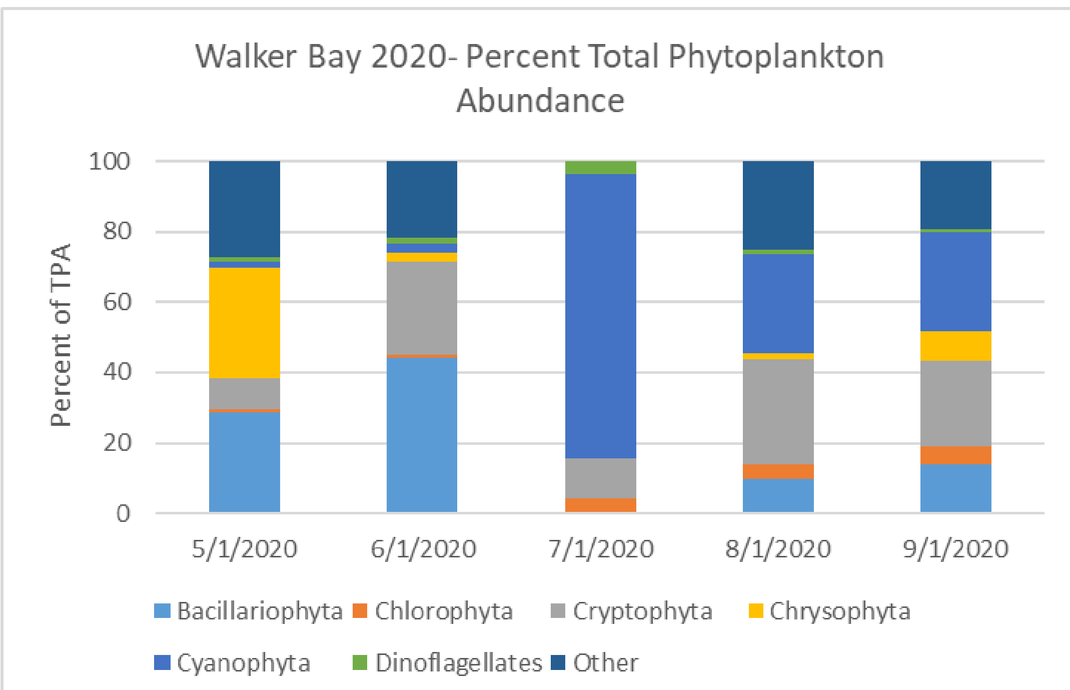


Figure 43. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Walker Bay 2020.

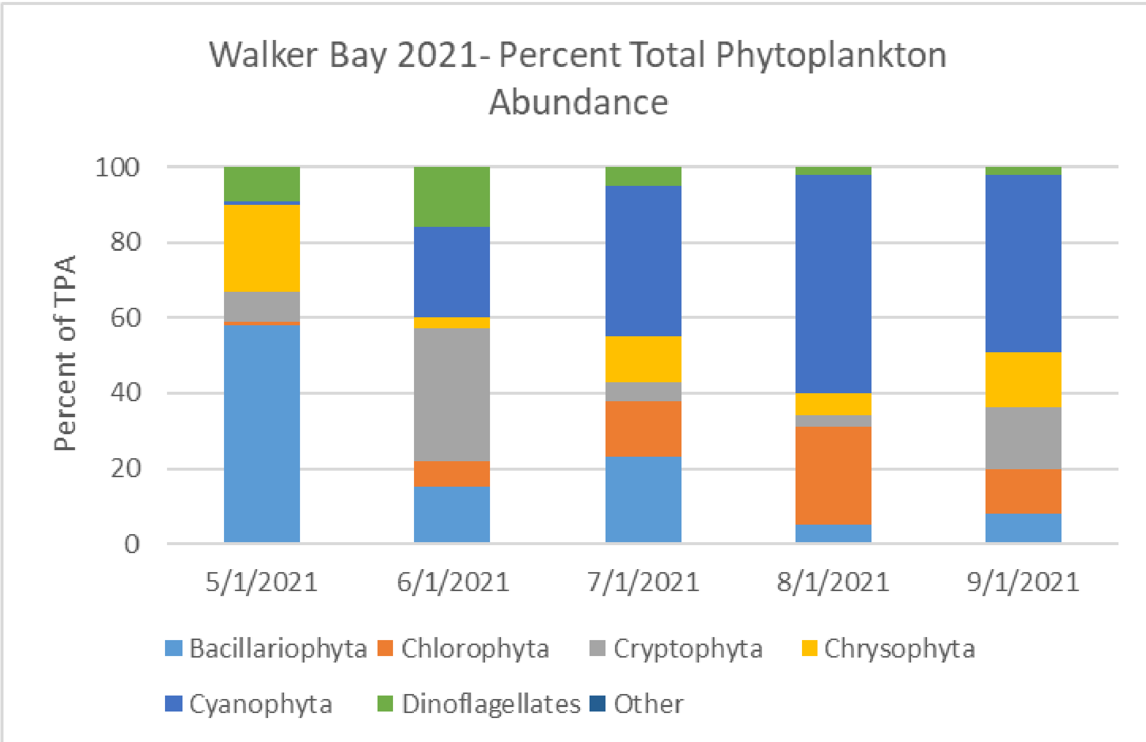


Figure 444. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Walker Bay 2021.

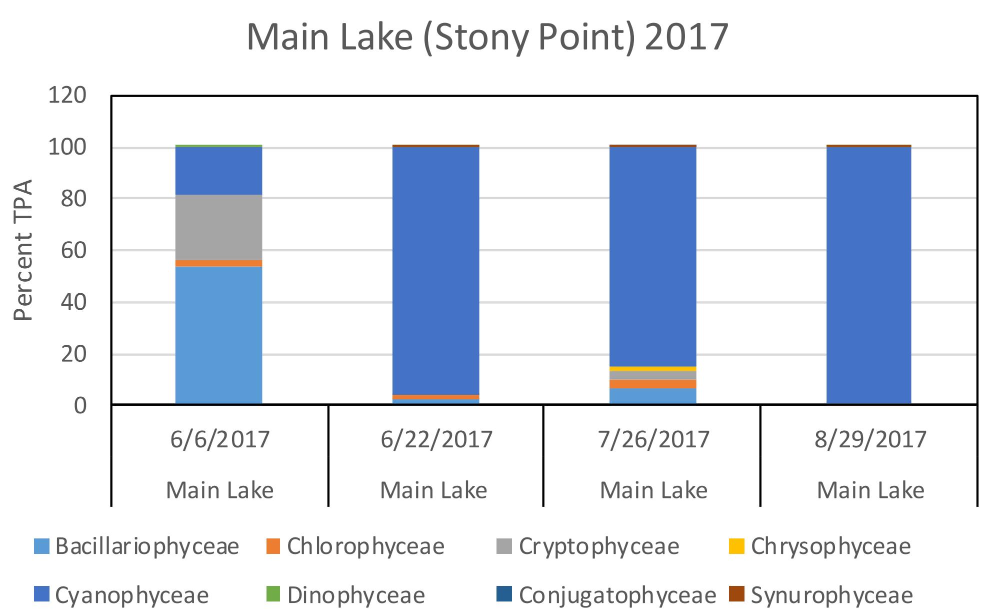


Figure 455. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Main Lake (Stony Point), 2017.

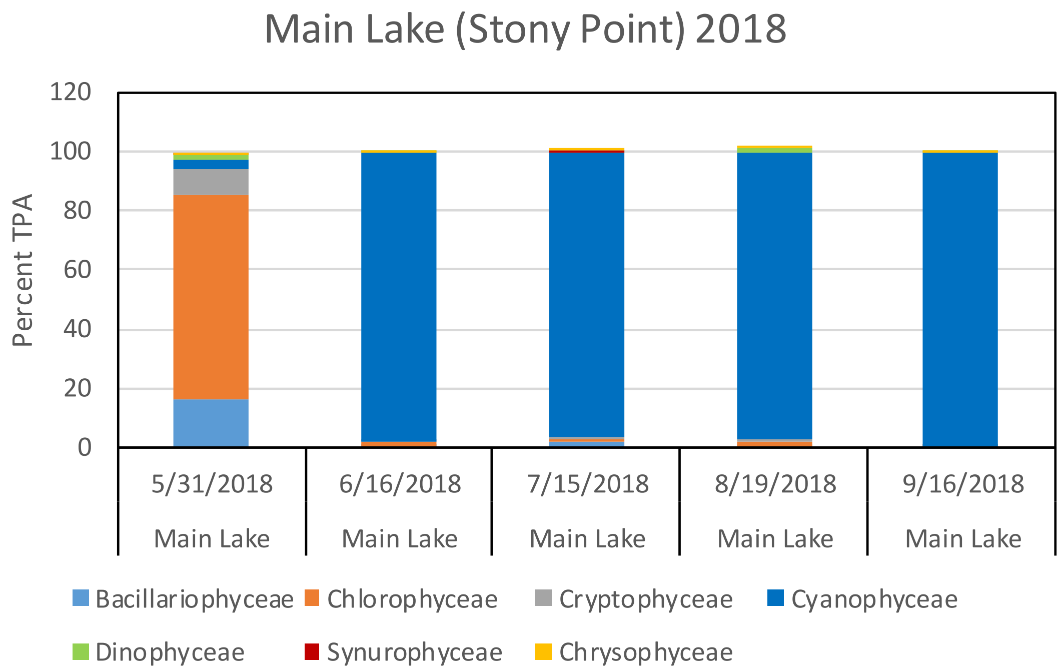


Figure 466. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Main Lake (Stony Point) 2018.

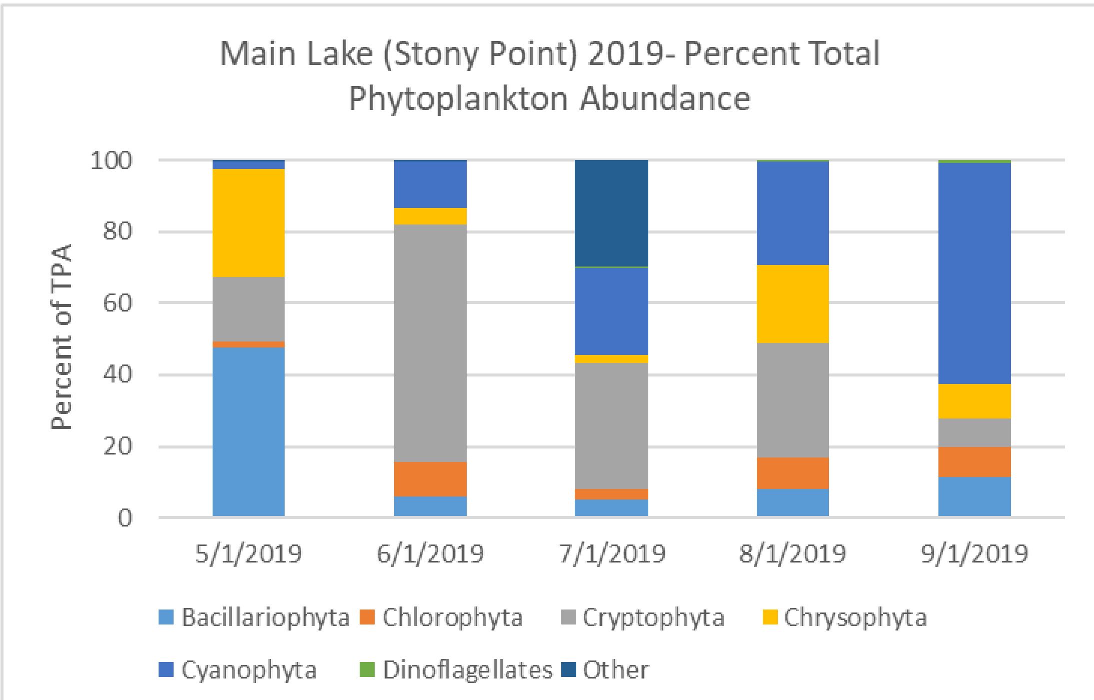


Figure 477. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Main Lake (Stony Point) 2019.

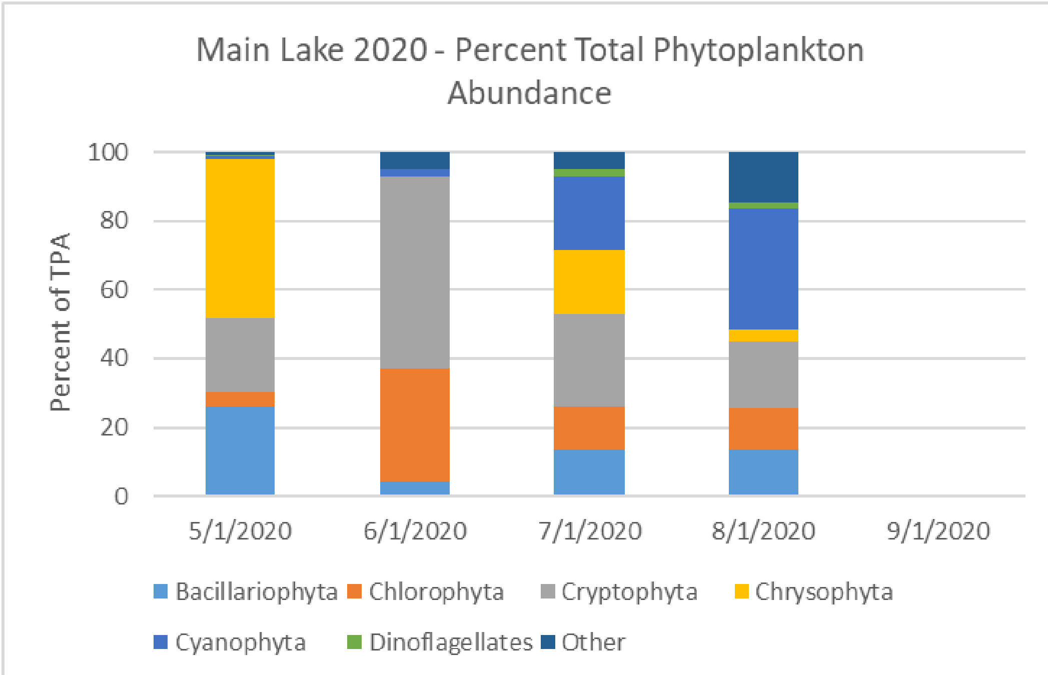


Figure 488. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Main Lake (Stony Point) 2020.

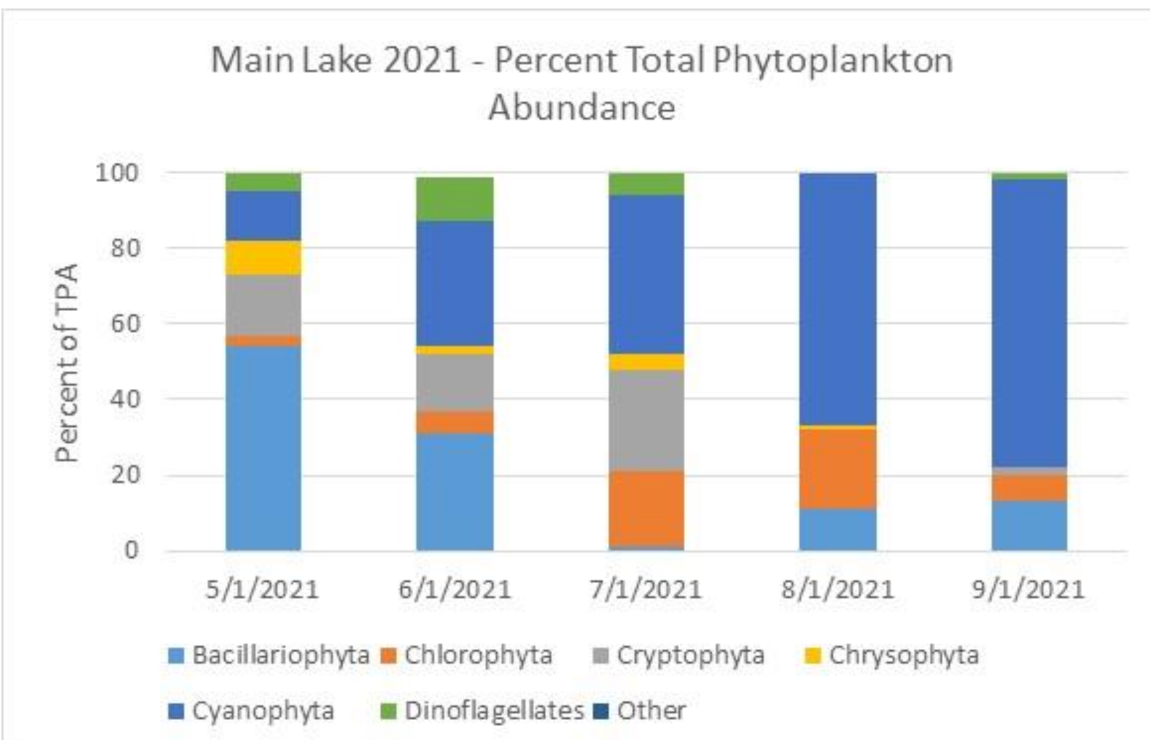


Figure 499. Algae community sampling results, major groups by percent (%) Total Phytoplankton Abundance (TPA) Main Lake (Stony Point) 2021

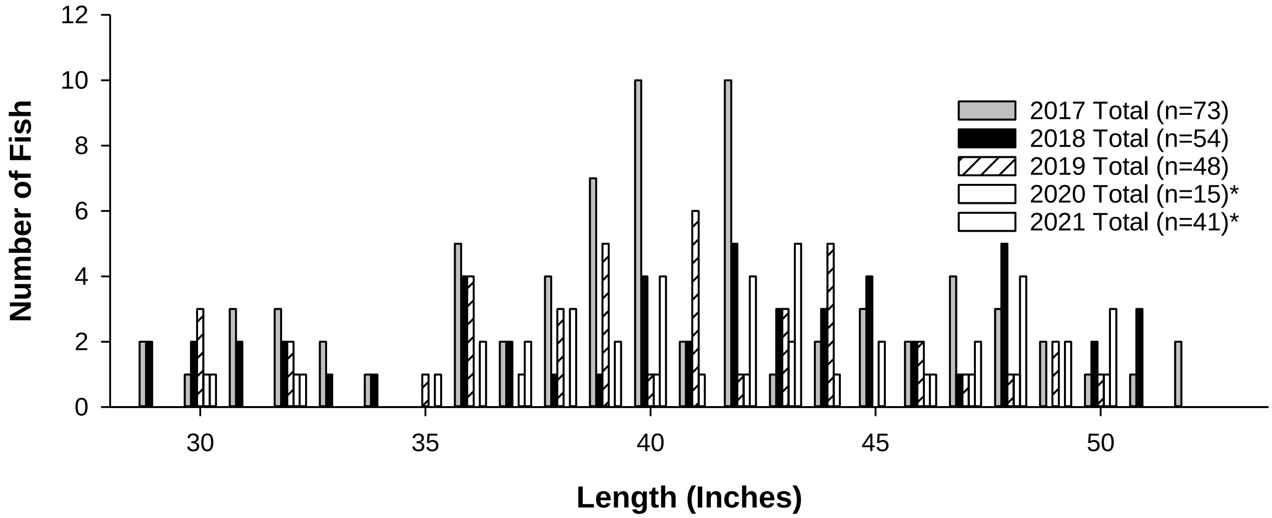


Figure 5050. The length frequency distribution of Muskellunge caught in three Muskellunge tournaments on Leech Lake, 2017 and 2021. *Data included for only 1 tournament in 2020 and 2 in 2021.

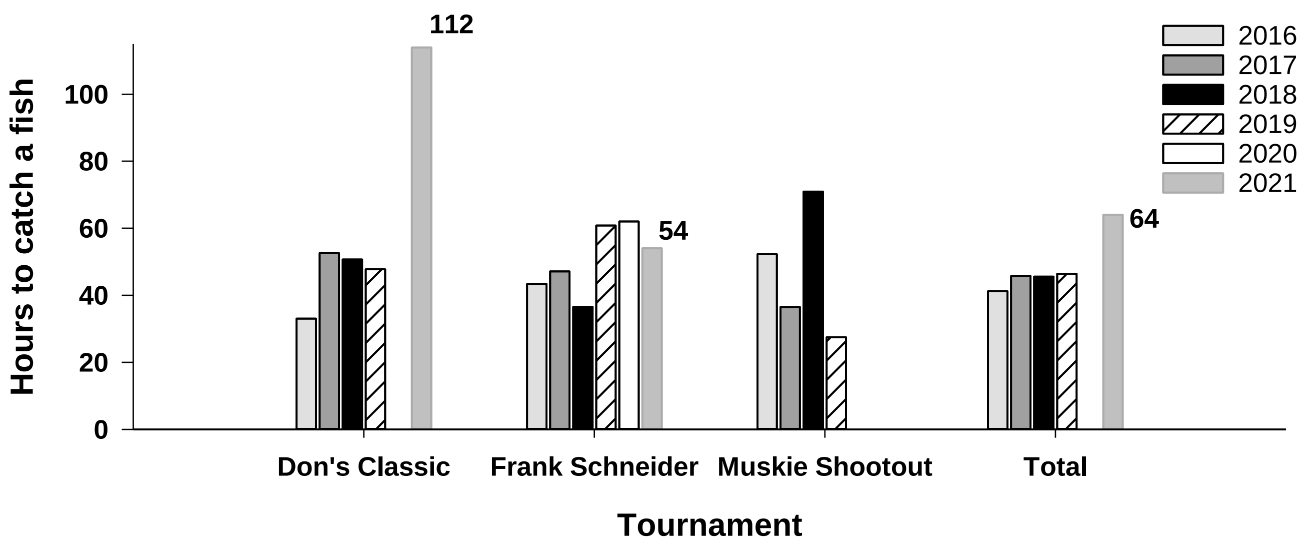


Figure 5151. The average number of hours it took anglers to catch a Muskellunge during three tournaments on Leech Lake, 2016 to 2021.

APPENDIX

Table A 1. Gillnet catch-per-effort (fish/net) by species for Leech Lake, 1983-1994.

	Year											
Species	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Black Bullhead	11.3	9.7	13.8	8.0	11.2	15.1	21.3	11.6	16.5	9.8	4.3	3.9
Black Crappie	0.1	0.5	0.2	0.3	0.3	0.4	0.3	0.3	0.5	0.2	0.2	0.2
Bluegill	0.0	0.1	0.0	0.2	0.1	0.1	0.6	0.3	0.1	0.4	0.3	0.2
Bowfin	0.0	0.0	0.1	0.0	0.1	0.2	0.0	0.0	0.0	0.1	0.0	0.0
Brown Bullhead	2.5	1.1	0.6	0.8	1.1	0.9	1.8	0.9	3.1	1.5	1.7	2.2
Burbot	0.1	0.1	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1
Hybrid Sunfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lake Whitefish	0.2	0.2	0.0	0.0	0.1	0.2	0.0	0.0	0.4	0.0	0.0	0.1
Largemouth Bass	0.1	0.0	0.0	0.0	0.1	0.1	0.4	0.0	0.1	0.0	0.0	0.0
Muskellunge	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.0
Northern Pike	4.2	3.7	4.1	3.8	4.3	5.3	5.8	5.3	5.8	4.4	3.6	4.0
Pumpkinseed	0.1	0.3	0.3	0.2	0.3	0.7	1.1	1.6	1.0	1.1	0.5	0.4
Rock Bass	0.5	1.3	2.1	1.1	0.4	0.9	2.3	2.7	2.1	1.1	2.1	1.2
Shorthead Redhorse	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Smallmouth Bass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tiger Muskellunge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tullibee/Cisco	6.3	4.6	10.2	14.1	18.5	11.1	2.1	5.9	6.7	4.4	9.6	9.1
Walleye	5.3	7.4	7.2	6.3	6.0	13.4	11.7	8.3	8.8	5.8	4.6	4.9
White Sucker	1.3	1.8	1.8	1.1	2.4	2.6	2.1	2.1	1.8	2.0	1.6	1.9
Yellow Bullhead	1.1	0.4	1.4	1.0	1.3	2.2	1.9	0.9	3.4	1.4	1.7	2.7
Yellow Perch	13.5	17.9	15.6	13.2	16.1	18.5	26.1	33.7	18.6	22.1	20.4	21.7
Total fish/set	46.6	49.1	57.3	50.2	62.1	71.5	78.0	73.9	69.1	54.4	50.8	52.6
Total sets	32	36	36	36	36	36	36	36	36	36	36	36

Table A 2. Gillnet catch-per-effort (fish/net) by species for Leech Lake, 1995-2006.

	Year											
Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Black Bullhead	0.9	0.7	1.5	2.5	1.8	0.5	0.7	1.2	1.3	4.3	3.5	1.4
Black Crappie	0.1	0.1	0.1	0.2	0.3	0.2	0.4	0.3	0.6	0.3	0.4	0.6
Bluegill	0.1	0.1	0.1	0.2	0.1	0.6	0.6	1.0	0.5	0.8	2.1	1.1
Bowfin	0.0	0.0	0.0	0.1	0.3	0.2	0.1	0.1	0.0	0.1	0.0	0.0
Brown Bullhead	0.9	0.6	0.7	1.3	3.3	2.1	2.1	0.9	0.9	1.6	4.1	2.0
Burbot	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Hybrid Sunfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lake Whitefish	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Largemouth Bass	0.0	0.1	0.0	0.2	0.1	0.0	0.1	0.3	0.3	0.1	0.0	0.1
Muskellunge	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Northern Pike	6.2	4.8	5.1	5.1	3.7	5.0	5.3	5.3	5.0	5.4	4.9	4.0
Pumpkinseed	0.2	0.5	1.1	0.7	0.4	0.4	1.1	1.1	1.6	0.8	2.1	0.6
Rock Bass	2.7	2.9	2.0	2.3	1.8	0.9	1.9	1.2	1.3	2.0	0.6	0.5
Shorthead Redhorse	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Smallmouth Bass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tiger Muskellunge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tullibee/Cisco	4.2	4.7	4.2	3.7	3.1	2.7	1.3	1.6	0.9	1.8	3.5	0.6
Walleye	7.7	9.5	5.7	11.6	8.9	5.9	7.0	6.2	5.2	5.0	4.9	7.1
White Sucker	3.1	2.0	1.2	2.0	1.2	0.9	1.2	1.3	1.4	0.8	0.9	1.9
Yellow Bullhead	0.4	0.3	0.9	0.8	0.9	0.4	0.5	1.6	1.3	2.7	2.6	1.7
Yellow Perch	37.7	25.6	32.1	28.6	21.1	21.2	15.5	20.5	16.2	16.3	12.9	20.5
Total fish/set	64.6	52.0	55.1	59.3	47.0	41.1	37.7	42.6	36.3	41.9	42.4	42.3
Total sets	35	36	35	36	36	35	36	36	36	36	36	36

Table A 3. Gillnet catch-per-effort (fish/net) by species for Leech Lake, 2007-2016.

	Year									
Species	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Black Bullhead	1.9	1.1	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0
Black Crappie	1.7	0.9	1.1	0.6	0.5	0.2	0.9	0.4	0.8	0.3
Bluegill	1.1	1.2	1.1	0.6	0.7	0.3	1.2	0.1	0.7	0.6
Bowfin	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Brown Bullhead	4.3	2.0	0.6	1.9	0.6	0.3	0.2	0.1	0.4	0.1
Burbot	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Hybrid Sunfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lake Whitefish	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1
Largemouth Bass	0.2	0.1	0.1	0.1	0.1	0.4	0.1	0.0	0.1	0.1
Muskellunge	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0
Northern Pike	5.9	5.6	4.9	4.1	5.9	4.3	4.6	4.6	5.9	3.9
Pumpkinseed	1.3	1.5	0.7	0.3	0.3	0.4	1.4	0.3	0.6	0.8
Rock Bass	1.3	2.4	2.2	1.0	1.3	0.8	1.4	0.8	1.3	1.3
Shorthead Redhorse	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Smallmouth Bass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tiger Muskellunge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tullibee/Cisco	4.0	1.6	11.9	5.9	1.9	3.6	3.3	4.0	5.5	7.8
Walleye	13.1	9.1	8.6	7.9	8.1	9.4	8.9	8.9	12.4	9.1
White Sucker	0.7	0.6	1.1	0.6	1.1	1.5	0.9	1.1	0.9	1.0
Yellow Bullhead	4.2	2.6	1.4	2.8	1.0	0.6	0.4	0.4	1.4	1.0
Yellow Perch	36.9	26.6	25.8	24.3	17.2	14.5	12.1	13.9	18.6	9.4
Total fish/set	77.0	55.3	60.1	50.6	39.1	36.4	35.6	34.7	48.8	35.8
Total sets	36	36	36	36	36	36	36	36	36	36

Table A 4. Gillnet catch-per-effort (fish/net) by species for Leech Lake, 2017-2021.

	Year									Quartiles	
Species	2017	2018	2019	2020	2021	Min	Max	Median	Mean	25th	75th
Black Bullhead	0.0	0.0	0.0	0.0	0.0	0.0	21.3	1.3	4.1	0.1	6.2
Black Crappie	0.6	0.3	0.3	0.5	0.9	0.1	1.7	0.3	0.4	0.2	0.5
Bluegill	1.0	0.7	0.1	0.3	0.8	0.0	2.1	0.4	0.5	0.1	0.7
Bowfin	0.1	0.1	0.0	0.1	0.1	0.0	0.3	0.1	0.1	0.0	0.1
Brown Bullhead	0.0	0.0	0.3	0.1	0.2	0.0	4.3	0.9	1.3	0.5	1.9
Burbot	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.1
Hybrid Sunfish	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Lake Whitefish	0.2	0.0	0.1	0.2	0.1	0.0	0.4	0.0	0.1	0.0	0.1
Largemouth Bass	0.1	0.1	0.0	0.1	0.3	0.0	0.4	0.1	0.1	0.0	0.1
Muskellunge	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.1
Northern Pike	3.8	4.2	4.9	4.4	4.1	3.6	6.2	4.8	4.7	4.1	5.3
Pumpkinseed	0.7	0.7	0.1	0.4	0.8	0.1	2.1	0.7	0.7	0.4	1.1
Rock Bass	2.1	0.7	0.8	0.7	0.8	0.4	2.9	1.3	1.4	0.8	2.1
Shorthead Redhorse	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Smallmouth Bass	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0
Tiger Muskellunge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tullibee/Cisco	5.5	4.1	3.0	10.2	7.3	0.6	18.5	4.2	5.5	3.1	7.0
Walleye	10.1	10.2	8.6	11.0	12.1	4.6	13.4	8.3	8.3	6.1	9.5
White Sucker	1.3	1.4	1.1	1.2	1.1	0.6	3.1	1.3	1.4	1.1	1.8
Yellow Bullhead	0.6	0.6	0.6	1.1	1.5	0.3	4.2	1.1	1.4	0.6	1.7
Yellow Perch	15.1	10.9	16.1	14.4	10.5	9.4	37.7	18.5	19.8	14.8	23.2
Total fish/set	41.3	34.1	35.9	44.8	40.4	34.1	78.0	48.9	50.2	41.1	56.8
Total sets	36	35	36	36	36						