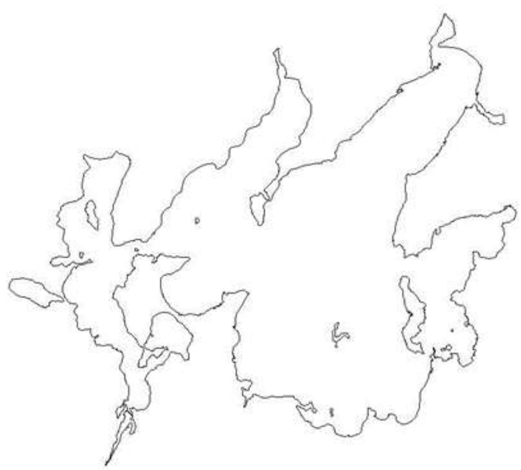
MINNESOTA DEPARTMENT OF NATURAL RESOURCES

Large Lake Sampling Program Completion Report for Leech Lake: 2015



Section of Fisheries
Division of Fish and Wildlife
500 Lafayette Road
St. Paul, MN 55155-4020

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Completion Report

Large Lake Program Assessment Report
Leech Lake
2015

Prepared by:	2-11-16	
	Date	Matt Ward, Large Lake Specialist
Approved by:	2/11/16	
	Date	Doug Schultz, Area Fisheries Supervisor
Approved by:	2/16/2016	
	Date	Henry Drewes, Regional Fisheries Manager

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INTRODUCTION

Statewide, Minnesota's ten largest Walleye *Sander vitreus* lakes account for 18% of total angler pressure (Andrew Carlson, unpublished data) and 40% of the annual Walleye harvest (MNDNR 1997).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 and harvest walleye. 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 2005a). This plan was developed with input from concerned citizens at several open house style meetings. In 2009-2010, the MNDNR convened a citizen input committee (Leech Lake Advisory Committee; LLAC) comprised of stakeholders representing local and statewide interests in Leech Lake management. The recommendations of this group were incorporated into DNR's Leech Lake Management Plan, 2011-2015 (Schultz 2010a). Management efforts throughout the life of this plan focused primarily on increasing Walleye abundance using conservative regulations, cormorant management, Walleye fry stocking, and increased habitat protection. In 2015 a citizen input group was formed (Leech Lake Fisheries Input Group, LLFIG), again comprised of stakeholders representing both local and statewide interests in Leech Lake management. The recommendations of this group were incorporated into DNR's Fisheries Management Plan for Leech Lake, 2016-2020 (Ward 2016). Due to the recovery of the Walleye population during the previous management plans, the focus of the current plan has been expanded to the entire fish community.

Aquatic invasive species currently found in Leech Lake include rusty crayfish, heterosporosis, curly-leaf pondweed, Eurasian watermilfoil, and banded mystery snail. Invasive plant species are not widely distributed within Leech Lake, but Eurasian water milfoil is expanding and beds are establishing in new areas outside of harbors. 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 its original state the lake covered about 106,000 acres. In 1884 a dam was built on the Leech River, raising the water level about two feet and increasing the surface area to its present size (Wilcox 1979). The maximum depth of the lake is near 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 many 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). 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), and numerous off-shore gravel-rock-boulder reefs are also available.

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 *Sander vitreus*, 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 eutrophic bays. Yellow Perch *Perca flavescens* are abundant throughout the lake and are the primary forage for most predators. 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 Cisco also comprise larger proportions of predator diets when large year classes are present. Other species present in the lake include: White Sucker *Catostomus commersoni*, Burbot *Lota lota*, Rock Bass *Ambloplites rupestris*, Bowfin *Amia calva*, Shorthead Redhorse *Moxostoma macrolepidotum*, Bullheads *Ameiurus spp.*, Pumpkinseed *Lepomis gibbosus*, Bluegill *L. macrochirus*, Largemouth Bass *Micropterus salmoides*, Smallmouth Bass *M. dolomieu*, and Black Crappie *Pomoxis nigromaculatus*.

YOUNG-OF-YEAR ASSESSMENT

Introduction

Recruitment variability, or the variability in the size or strength of a 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.

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. Factors limiting the frequency of strong year classes include prey abundance (Forney 1974), temporary climate shifts (Schupp 2002), or high abundances of adults (Ricker 1975). 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.

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 in the late 1990s and early 2000s (Sledge 1999, Sledge 2000), and increased harvest of larger adults (Stevens and Ward 2015). Mixed ages of Walleye were infrequently stocked at low densities in isolated locations from 1922 through1987. Stocking was discontinued from 1988-2004, and the strongest year class observed to date occurred in 1988. Higher densities of Walleye fry were stocked as part of recent efforts to rebuild the Walleye population (Table 1).

From 1983 through 1992 seining was conducted at as many as 16 stations in attempts to refine station selection and from early July through early September in attempts 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 reduced to the middle two weeks of July (Julian Weeks 28-29) in 2013, 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. Seine catch rates can be strongly influenced by several factors, including fish behavior and 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 attempts 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.

From 2005 through 2007 electrofishing was conducted at as many as 16 stations in attempts to refine station selection. Twelve of these stations are now the standardized locations to improve on year class strength estimation. Electrofishing has shown to be a useful method for predicting Walleye year class strength on some of Minnesota's other large lakes and, in time, may have the potential to more precisely estimate year class strength on Leech Lake. Electrofishing catch rates are highly dependent on water temperature, water clarity, and weather. Consequently, not all stations may be sampled during years of frequent inclement weather.

The objectives of this assessment include: 1) estimate wild fry hatch rates and compare those to other Minnesota lakes; 2) estimate wild and total fry densities; 3) index the relative abundance of YOY Walleye and Yellow Perch; 3) characterize early growth rates for both species; 4) estimate Walleye year class strength (YCS); and 5) evaluate factors effecting recruitment.

Methods

Stocking

Newly hatched Walleye fry (<24 hours post hatch) were treated by immersion in OTC, an antibiotic that leaves an indelible mark on fish bones that allows biologists to identify them as stocked fish (Lucchesi 2002, Logsdon 2006). To reduce handling stress fry were treated directly in the transport containers. Each container was five gallons and contained approximately 50,000 fry, three gallons of OTC solution, and oxygen. Fry remained in the solution for a minimum of 6 hours to ensure mark retention. Efforts to minimize mortality during marking included applying crushed ice to the containers as needed to maintain temperature and moving the vehicle hourly to reduce settling of fry into corners of the jugs. After 6 hours, fry were transported in a boat to stocking locations around the lake. For a more detailed description of methods, see Logsdon (2006). From 2005-2014, stocking rates ranged from of 129-389 fry per littoral acre (Table 2).

Hatch rates and fry densities

By stocking a known number of fry, the total number of wild fry at the time of stocking was estimated using the Chapman modification of the Peterson single census method (Ricker 1975):

$$N = (M+1)(C+1)/(R+1)$$

where M is the number of marked Walleye fry stocked, C is the number of YOY Walleye from seine, trawl, and electrofishing catches that were inspected for the presence of an OTC mark, and R is the number of inspected Walleyes with a visible mark.

This provides the ratio of marked (stocked) to unmarked (wild) YOY Walleye collected overall during seining, trawling, and electrofishing. The hatch rate of wild fry can then be estimated as a percentage of estimated eggs carried the previous fall by mature females that hatched into fry the following spring (Logsdon 2006).

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) 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 measured (TL, mm). All non-gamefish were identified and counted. Gamefish were recorded as either young-of-year (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. Up to 20 YOY Walleye and Yellow Perch per station per date were retained for individual measurement (total length (TL), mm; weight (WT), g).

Trawling

Trawling was 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 were 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 consisted of five-minute tows at a fixed speed of 3.5 mph for a total effort of 100 minutes of trawl time. Depths trawled ranged from 6-12 feet depending on transect and location. Fish were identified, measured, and enumerated as per the methods described for shoreline seining. Up to 20 YOY Walleye and Yellow Perch per station per date were retained for individual measurement (TL, mm; W, g).

Fall Electrofishing

Electrofishing was conducted using a MLS-Infinity pulsed-DC electrofishing boat (twin spider array anode) in mid-September (Julian Weeks 37-38). Standardized stations consisted of four clusters of sites, each of which contain three transects (Figure 1). Three 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 twelve 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 retained for individual measurement (TL, mm; W, g) and otolith removal. 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 was indexed by mean length sampled by week from July through September. Mean lengths were determined for Julian Weeks 28-29 for seining, 33-34 for trawling, and 37-38 for electrofishing.

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 2015 cohort we used a model of YCS as a function of age-0 gillnet and trawl catch rates fit to 1987-2015 data; model predictions give the predicted mean YCS for this cohort based on 2015 trawling and age-0 gillnet CPUE.

Values for YCS are currently estimated by two methods. Values used to establish the Walleye recruitment objective in the 2016-20 Fisheries Management Plan for Leech Lake were estimated using the Maciena and Pereira (2007) catchability corrected model of cohort strength to calculate the YCS fit to 1983-2015 gillnet data. This is a two-way ANOVA of age-specific catch rates for ages 1 through 3 as a function of age and cohort (both categorical variables); the least-squares mean of the cohort effect for each year class is the YCS measure.

As of 2015, a method for calculating YCS values became standardized among large lakes in Minnesota. This YCS model is a mixed-effects model (Kutner et al. 2004) version of the model presented in 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:

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

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, σ^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); these estimates have an expected mean of zero, and when back-transformed by exponentiation to the original scale the YCS estimates will have an expected median value of zero.

For year classes younger than age-3 (2013-2015 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 fully recruit to the fishery 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 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

Hatch rates and fry densities

From 2005 through 2014, either approximately 7.5 or 22.0 million Boy River strain Walleye fry marked with OTC were stocked throughout the lake (Table 1). Young-of-the-year Walleye were then sampled by seining in mid-July, trawling in mid-August, and electrofishing in mid-September. A subsample of individuals equally distributed between gear types and among stations within gear types were examined for the presence of an OTC mark. Of the fish examined, 47% (range 14-86%) were identified as stocked fish (Table 2). Fish held in ponds to determine mark efficacy annually demonstrated 100% mark retention. On average, wild fry hatch rate was determined to be 0.38% (range 0.12-0.89%; Table 2). The average numbers of wild, stocked, and total fry per littoral acre (acres ≤15 feet) were 317 (range 61-779), 257 (range 129-390), and 574 (range 237-908), respectively (Table 2; Figure 2).

Seine Catch Rates

Twenty seine hauls (6.2 acres) were completed from July 13-22, 2015 at five standard stations, sampling 17 species (Table 3). Overall catch rates of YOY Walleye and Yellow Perch were 81/acre and 1,093/acre, respectively (Figures 3 and 4). Catch rates for YOY Walleye and Yellow Perch both exceeded the 75^{th} percentile.

Trawl Catch Rates

Twenty trawls (100 minutes) were completed from August 17-26, 2015 at the three index stations, sampling 19 species (Table 4). Overall catch rates of YOY Walleye and Yellow Perch were 258/hour and 2,605 hour, respectively (Figures 3 and 4). Catch rates exceeded the 75th percentile for YOY Walleye, while they were below the 25th percentile for YOY Yellow Perch.

Electrofishing Catch Rates

Twelve transects (240 minutes) were electrofished from September 16-22, 2015. The overall catch rate of YOY Walleye was 97 fish/hour (Figure 3), which is similar to the long-term average of 98/hour.

Growth

Average YOY Walleye lengths were 3.3, 5.0, and 6.1 inches while seining, trawling, and electrofishing in 2015, compared to long-term averages of 3.4, 5.3, and 6.0 inches, respectively (Figure 5). Average YOY Yellow Perch lengths were 1.6 and 2.0 inches while seining and trawling in 2015, compared to the long-term averages of 1.6 and 1.8 inches (Figure 6).

Walleye Year Class Strength

Based on trawl and gill net catch rates of YOY Walleye, a year class strength index value of 1.67 is predicted for the 2015 year class (Table 5; Figure 7). This value exceeds the management plan objective threshold of 1.1 (25th percentile for the 1983-2014 time series) and approximates a year class of average strength. Caution should be used against over-interpreting the age-0 predicted value; the first true measure of year class strength occurs when this same year class will be sampled with gill nets in 2016.

Factors Affecting Recruitment

Based on OTC marking, Walleye fry densities ranging from 300-600 fry/LA have resulted in the greatest number of individuals recruiting to the fishery since 2005 (Figure 8). A higher stocking rate (20-22.5 million vs. 7.5) has not resulted in greater recruitment (Figure 9). First-year growth was negatively related to total fry density, as indicated during the mid-September electrofishing assessment (Figure 10). The average length of fish sampled in mid-September was positively associated with eventual recruitment of year classes at age-3 (Figure 11). Other than initial fry density, another factor influencing first-year growth has been the length and intensity of the growing season (Figure 12, GDD_{50}). A longer and warmer growing season has resulted in more individuals recruiting to the fishery at age-3 (Figure 13). The 2008 and 2009 year classes, which had the lowest year class strength values in recent years (Figure 7), had the two shortest growing seasons and two of the highest fry densities over this time period. There was no strong relationship between total fry density and GDD_{50}, suggesting each factor acted independently on YOY Walleye growth and survival. Higher Walleye fry densities have also been demonstrated to negatively affect recruitment of Yellow Perch surviving to age-4 (~7 inches) and the fishery (Figure 14).

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, can exert enough predation on a Walleye year class to significantly influence its outcome (Hansen et al. 1998). 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 rate 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).

Walleye hatch rates in Red Lake were estimated from 1999-2003 and serve as a benchmark for strong reproduction in a self-sustaining population (mean 0.22%, range 0.02-0.60). More recently hatch rates have also been estimated for other Minnesota lakes as part of a study evaluating fry densities in Walleye egg-take lakes (Table 2; Dale Logsdon, personal communication). These data demonstrate Walleye hatch rates observed in Leech Lake are similar to other quality Walleye populations in Minnesota. Generally, marking rates increase with stocking density because higher stocking density is the same as higher marking effort in mark-recapture studies. Higher densities of stocked fry and total fry have not translated to stronger year classes.

Young-of-year Walleye catch rates exceeded the long-term averages for seining and trawling, while catch rates were similar to the long-term average for electrofishing in 2015. Walleye lengths were below average in mid-July and mid-August, while slightly exceeding average in mid-September. Young-of year Yellow Perch catch rates were variable in 2015 and exceeded the 75th percentile in mid-July and were below the 25th percentile in mid-August. Yellow Perch lengths were similar to average in mid-July and exceeded average in mid-August.

Electrofishing in mid-September has the potential to more accurately index Walleye year class strength than trawling in mid-August. This is because a strong relationship is evident between year class strength and average length of YOY Walleye sampled electrofishing (Figure 11). A similar relationship has been observed on Lake Vermillion (D. Williams, MN DNR, personal communication). 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.

Overall, numbers of YOY Walleye sampled via trawling and gill netting in 2015 indicate a predicted YCS above the management plan objective threshold. Although the 2013-2015 year classes are not fully recruited the fishery, they are predicted to be above average in strength. The consistency within the fishery the past several years has been a reflection of the consistency in recruitment during the same time period.

While stocking efforts during 2005-2015 approximately doubled average total fry density relative to pre-2005 estimates, recruitment was been limited by natural trade-offs associated with density. Increased stocking rates did not resulted 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; however, the trade-off is slower growth rates. 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 activities that reduce first-year growth, such as stocking (i.e.

higher fry densities), will inherently reduce the likelihood for individual survival. This explains why higher stocking levels have not resulted 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. Lastly, another important consideration when contemplating appropriate fry densities is the prey population. Juvenile Walleye, whether stocked or naturally produced, 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 (Figure 14).

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 gear 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. 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 25^{th} 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 the four target species (Walleye, Yellow Perch, Northern Pike, and 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. Data collected with gillnets measure 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 gillnet 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 each of 9 different areas (Figure 15). 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 to be 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, Cisco, and Northern Pike when possible. Data were recorded separately for each of the five mesh sizes within each net. Weights and lengths were converted from metric units to English units.

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 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 observed in population metrics among basin types, particularly growth rate (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 on Leech Lake at 8 inches. Northern Pike size structure was summarized by quantifying the percentage of Northern Pike sampled in gill nets ≥22 inches. The 8 inch threshold was selected, as summer and winter anglers start harvesting Northern Pike on Leech Lake at 22 inches.

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. Age-4 Yellow Perch are a size (approximately 7 inches on Leech Lake) at which 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 Qabg (Anderson 1998). 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 indicator calculated included female length at age-3(Gangl and Pereira 2003).

Results

Standard experimental gillnet were set at 36 sites from September 6-18, 2015, sampling 16 different species. Of the four target species, catch rates for Walleye and Cisco are typically higher in the main lake sets, while catch rates for Yellow Perch and Northern Pike are typically higher in the western bays (Figure 16). Past trends held true for all four of these species in 2015. Long-term gillnet catch rates for all species are summarized in Appendix 1.

Walleye

A total of 447 Walleye were sampled in gillnets. An overall catch rate of 12.4 (fish/net) and 20.4 (pounds/net), was higher than catch rates observed in recent years (Figures 17 and 18). This is higher than the long-term averages of 7.9 (fish/net) and 9.5 (pounds/net). 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). The 2015 catch rate exceeded the 2016-2020 management objective of range of 7-10 fish/net (Figure 19); 7 and 10 are the 40th and 90th percentiles for the 1983-2014 time series. Consistent with long-term trends, catch rates were higher in the main lake (15.9 fish/net) compared to the western bays (8.1 fish/net) (Figure 16).

Total length of Walleye sampled ranged from 6 to 26 inches (Tables 7 and 8; Figure 20) and ages ranged from 0 to 13 years old (Table 9; Figure 21). Age and length frequency distributions represented a balanced population, with age-3 individuals (2012 year class) being the most frequently sampled. The percentage of Walleye sampled that were ≥20 inches was 24%, and exceeded the management objective range of 10-20% (Figure 22). The average lengths of age-1 through age-4 Walleye were 9.9, 12.2, 14.6, and 16.9 inches, respectively (Table 10).

All males were mature by 15 inches and age-4, while all females were mature by 21 inches and age-6 (Tables 8 and 9). Condition (*Wr*) in 2015 was 81, and remained below the management plan objective range of 82-86 (Figure 23). Mature female density (pounds/acre) was 3.4 and exceeded the management plan objective range (1.5 to 2.0 pounds/acre; Figure 24).

Female length at age-3 in 2015 (14.7 inches) was slightly below the threshold of 15.6 inches (Figure 25). Female length at 50% maturity in 2015 (17.6 inches) was slightly above the threshold of 17.4 inches. Female age at 50% maturity in 2015 (4.1 years) was slightly above the threshold of 4.0 years.

Yellow Perch

A total of 669 Yellow Perch were sampled in gillnets. Catch rates in 2015 were 18.6 (fish/net) and 3.7 (pounds/net; Figures 17 and 18), and lower than the long-term averages of 21.1(fish/net) and 4.9 (pounds/net). Previous catch rates ranged from 12.1 fish/net (2013) to 37.7 fish/net (1995), and 2.5 pounds/net (2013) 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 19). Consistent with long-term trends, the catch rate in 2015 was higher in the western bays (27.4 fish/net) compared to the main lake (11.6 fish/net) (Table 6, Figure 16).

Total length of Yellow Perch sampled ranged from 3 to 13 inches (Tables 7 and 8; Figure 20) and ages ranged from 1 to 9 years old (Table 9; Figure 21). The 2011, 2012, and 2013 year classes made up 83% of all Yellow Perch sampled. Of all Yellow Perch sampled, 25% were ≥8 inches, 15% were ≥9 inches, and 7% were ≥10 inches. The percentage sampled in gill nets (3-year moving average) ≥8.0 inches remained below the 30% management plan objective threshold for the second consecutive year, indicating a lower than desired abundance of larger individuals available to the fishery (Figure 26). The average lengths of age-1 through age-4 Yellow Perch were 5.7, 6.3, 6.9, and 7.8 inches, respectively (Table 10).

Length and age of female Yellow Perch at 50% sexual maturity were 6.4 inches and 2.0 years. All males sampled in 2015 were mature, while most females were mature by 7 inches and age-5 (Tables 8 and 9). Males tend to reach sexual maturity before they are effectively sampled by gillnets.

The catch rate of age-4 Yellow Perch in 2014 was 4.7 (2011 year class), which was slightly below the 1997-2011 average. The gill net catch rate (3-year moving average) of age-4 Yellow Perch increased slightly and now is on the management plan objective threshold (Figure 27). Catch rates of age-4 Yellow Perch have been below the long-term average (4.8 fish/net) for the past four year classes fully recruited to gill nets (2008-2011).

Northern Pike

A total of 211 Northern Pike were sampled in gillnets. The overall catch rate was 5.9 (fish/net) and 12.0 (pounds/net; Figures 17 and 18). Catch rates in 2015 exceeded long-term averages of 4.8 (fish/net) and 11.5 (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 2015 catch rate exceeded the 2015-2020 management objective range of 4.2-5.3 fish/net (Figure 19). Catch rates of 4.2 and 5.3 are the 25th and 75th percentiles of the 1983-2014 time series. Consistent with long-term trends, catch rates were higher in the western bays (6.8 fish/net) than the main lake (5.2 fish/net; Table 6; Figure 16).

Total length of Northern Pike sampled ranged from 12 to 34 inches (Tables 7 and 8; Figure 20) and ages ranged from 1 to 9 years old (Table 9; Figure 21). The 2011 and 2012 year classes made up 67% of all Northern Pike sampled. Of all Northern Pike sampled, 60% were 20 inches or longer, 11% were 25 inches or longer, and 2% were 30 inches or longer. The percentage of Northern Pike sampled in gill nets (3-year moving average) ≥22 inches continued to exceed the 30% management plan objective threshold (Figure 29). The average lengths of age-1 through age-4 Northern Pike were 13.8, 17.0, 19.5, and 21.9 inches, respectively (Table 10).

All males were mature by 13 inches and age-2, while all females were mature by 16 inches and age-2 (Tables 8 and 9). Although the gill net catch rate of age-3 Northern Pike increased in 2015, the 3-year moving average remained between the 25th and 75th percentiles (1.0-1.6 fish/net), indicating stable recruitment (Figure 30).

Cisco (Tullibee)

A total of 198 cisco were sampled in gillnets. The overall catch rate was 5.5 (fish/net) and 4.1 (pounds/net; Figures 17 and 18). While Cisco the number/net was higher in 2015 compared to 2014, the pounds/net was lower. The number/net and pounds/net were both higher than the long-term averages of 5.4 and 2.8, respectively. 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). Catch rates remained higher in the main lake than the western bays (Figure 16). The catch rate in the main lake was 8.4 fish/net while the catch rate in the western bays was 1.9 fish/net (Table 6, Figure 16).

Cisco sampled ranged from 5 to 18 inches (Tables 7 and 8; Figure 20) and 2 to 13 years old (Table 9, Figure 21). Eleven year classes were represented in the 2015 sample, with the 2011 and 2012 year classes most frequently sampled. Of all Cisco sampled 53% were ≥10 inches and 19% were ≥15 inches. Mean lengths of age-2 through age-5 fish were 9.2, 11.3, 12.8, and 14.0 inches, respectively.

Other Species

Other species sampled in 2015 included Black Crappie, Bluegill, Bowfin, Brown Bullhead (*Ameiurus nebulosus*), Burbot, Largemouth Bass, Muskellunge, Pumpkinseed, Rock Bass, Smallmouth Bass, White Sucker, and Yellow Bullhead (*Ictalurus natalis*), are not effectively sampled by gill nets or are present in low numbers (Table 6). Species not sampled in 2015 that have been previously sampled include Black Bullhead (*Ameiurus melas*), Lake Whitefish, Shorthead Redhorse, and Tiger Muskellunge (*Esox masquinongy x Esox lucius*; Appendix 1).

Discussion

Walleye abundance (number/net) continues to remain above the long-term average, while Walleye biomass (pounds/net) continues to have an increasing trend. Conversely, Yellow Perch abundance (number/net) and biomass (pounds/net) continues to remain around the 25th percentile. Catch rates of Northern Pike continued to remain between the 25th and 75th percentiles. Cisco catch rates were between the 25th and 75th percentiles for abundance; however, catch rates in terms of pounds/net exceeded the 75th percentile due to the high proportion of larger individuals sampled.

Biological performance indicators (BPIs), or population response metrics, were developed to monitor exploitation of Minnesota's large lake Walleye populations (Gangl and Pereira 2003). Exceedance of 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 (Figure 25). 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 these respective time periods were suggested 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). Female average length at age-3 has continued to remain below the threshold for the fourth consecutive year, indicating growth rates have returned to average. Values for female length and age at 50% maturity have returned to being above their respective thresholds, indicating no stress response by the population.

The metrics for Walleye associated with the 2016-2020 Leech Lake Management Plan (Ward 2016) exceeded management plan objective ranges and thresholds for all objectives except the condition. The consistency in the Walleye population since the late-2000s suggests a positive response to current management actions. The protected slot limit on Walleye has successfully protected mature females and has increased the reproductive capacity of the population. Walleye recruitment has also become less variable since 2007. This is similar to post-regulation recruitment patterns observed on Upper Red Lake (Kennedy 2013) and Lake Winnibigoshish (Schultz and Staples 2010a). 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 have led to considerable improvements to the recreational fishery as indicated by summer creel surveys conducted during 2008-2011, 2014 (Schultz 2009; Schultz 2010b; Vondra and Schultz 2011, Ward and Schultz 2012, Stevens and Ward 2015). Overall, Walleye metrics indicate the population has fully recovered, while some metrics indicate the population density has exceeded those levels to the detriment of the prey base.

Statewide declines in Yellow Perch have been observed and 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 recent 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 winter anglers are both suspected. Recent Walleye year classes have consistently been near or above the long-term average in terms of strength, 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 was 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 2004; Pierce et al. 2006). Recent steps taken to reduce predation pressure on Yellow Perch include specifying conditions within the 2016-2020 management plan 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.

Record Yellow Perch harvest by anglers was documented during the 2010-11 and 2014-15 winter angling seasons, with winter exceeding that of summer harvest for the first times in the creel history (Schultz and Vondra 2011; Stevens and Ward 2015). Winter creel surveys are proposed in two of the next three winters in addition to summer surveys proposed in 2016 and 2017 should quantify this further. Although many anglers continue to perceive cormorant consumption of Yellow Perch to have a significant influence on recruitment, consumption by cormorants has been reduced by 90% relative to 2004 levels and are similar to pre-2000 levels (Schultz et al. 2013).

Increases in Northern Pike density, particularly increases in ‘hammer handle’ sized pike, are currently being observed statewide (B Bethke, MN DNR, personal communication). These trends have resulted in proposals to implement new statewide regulations to address concerns by anglers. Despite statewide trends, lakewide Northern Pike catch rates have varied by less than three fish/net since 1983, indicating a stable population on Leech Lake. Catch rates of age-3 Northern Pike have also only varied between 0.4 and 2.4 (fish/net). Similar to walleye and yellow perch, northern pike in Leech Lake tend to grow slightly faster in the main lake than in the western bays.

Peaks in cisco catch rates are often highly variable, and typically are associated with strong year classes of age-1 and/or age-2 fish. 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 physiological 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. This has the potential for impacts on other species, specifically the growth rates of predatory species.

OTHER WORK

Water Quality

Water samples were collected at stations one (Walker Bay) and five (Stony Point) on July 20, 2015. The Minnesota Department of Agriculture Chemistry Laboratory in St. Paul, Minnesota analyzed the samples collected for total phosphorus, conductivity, chlorophyll a, pH, total alkalinity and total dissolved solids.

When looking at the long-term data set collected by the MNDNR, there has been no apparent change in water quality since the inception of the Large Lake Program (Table 11). Water clarity data is available from the University of Minnesota Remote Sensing and Geospatial Analysis Laboratory and Water Resources Center (2015). Water quality monitoring data is also available from the Minnesota Pollution Control Agency (2015).

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 100 feet deep and stratify annually around early to mid-July (Figures 31-35). Stratification refers to a substantial change in temperature commonly referred to as the thermocline. The location off Stony Point, similar to Portage, Sucker, Boy, and Headquarters bays, rarely exceed 30 feet and do not stratify. This means the water temperature and oxygen levels are very similar throughout the entire water column.

Aquatic Invasive Species (AIS)

A survey of Leech Lake boat harbors in 2004 found established beds of Eurasian water milfoil (EWM; *Myriophyllum spicatum*) in several harbors between Stony and Rogers points and were immediately treated with aquatic herbicide. Since 2004 harbors have typically been checked annually for EWM by DNR personnel and treated when necessary. Extensive searches have only discovered rooted EWM outside of harbors at one location, in Miller Bay on the south side of the main lake, and treatments have resulted in the eradication of EWM from some harbors. However, this invasive species continues to be discovered in new harbors throughout the lake.

The DNR Division of Ecological and Water Resources (EWR) had treatment plans for 2015 consistent with what was specified in the prior Leech Lake Management Plan. Harbor treatments planned for the 2015 season were postponed due to timing and scheduling issues. Treatment when water temperatures are too cold reduces the effect of the herbicides. Additionally, a late treatment would not produce the intended benefit of preventing the spread of the species, which should have been targeted earlier in the season when recreational boaters were more active. Because the identified harbors were not treated in 2015 as planned, EWR-AIS will organize and cover harbor treatments in the 2016 season. Inspection and treatment plans beyond 2016 will be the responsibility of the Leech Lake harbor owners. EWM is now considered widespread across the main basin boat harbors of Leech Lake, and now appears to be establishing in open areas of the main lake despite annual control efforts. Because of this distribution the initial goal of the harbor treatment program is compromised and the benefit of reducing spread of EWM into the main basin is insignificant.

While conducting EWM harbor searches during 2009 curly-leaf pondweed (CLP) (*Potamogeton crispus*) 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 (*Orconectes rusticus*) are a nonnative species of crayfish native to the Ohio River drainage basin and were first sampled by the DNR in the late 1980s. Staff began recording 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 (Figure 36). Yellow Perch appear to have a strong influence on Rusty Crayfish abundance, as an inverse relationship exists between the two species (Figure 37).

The DNR Division of Ecological and Water Resources spent 707 hours conducting 2,693 watercraft inspections at Shingobee, Federal Dam, Walker City Park, Stony Point, Erickson's Landing, Sugar Point, and Sucker Bay accesses in 2015. Preliminary 2016 plans include a similar schedule; however, new nearby infestations could result in schedule adjustments. The Cass County Soil and Water Conservation District (SWCD) also contributed significant watercraft inspection hours on area lakes.

In 2015 Cass County SWCD spent 380.5 hours conducting 1,311 watercraft inspections at Erickson's Landing (144.5 hours) and Walker City Park (236 hours) public accesses. Plans in 2016 include continuing inspections at Erickson's Landing and expanding inspections to Shingobee and Federal Dam accesses.

Double-Crested Cormorant management

The DNR will continue to support the Leech Lake Band of Ojibwe, Division of Resource Management (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 annual removal of most birds earlier in the year will continue to be supported as this reduces total fish predation and is included under the existing federal Public Resource Depredation Order. The DNR will continue to support DRM's efforts to secure funding sources and provide technical assistance for continued cormorant control and research evaluating cormorant impacts on Leech Lake sportfish populations as requested by DRM. The DNR will also continue fund cormorant management on Leech Lake as needed. The 2015 spring and fall cormorant numbers were 2,000 and 280, respectively (Figure 38). A total of 1,040 adults were removed during 2015 (Figure 39), bringing the overall total to 23,496 birds culled since work began in 2005 and making Leech Lake the largest single management site in the U.S. (S. Mortensen, LLBO Division of Resource Management, personal communication). In a study conducted from 2004-2011, Schultz et al. (2013) concluded that total feeding effort and fish consumption was reduced by nearly 90%. 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 was observed.

Modeling also determined the predation potential on juvenile walleye by cormorants was high enough during 2000-2004 to impact walleye recruitment (Schultz et al. 2013). The 2000-2005 year classes of Walleye were five of the worst seven year classes observed since 1983, and this trend was most prevalent in the main lake basin where cormorants fed almost exclusively. Statistical differences were observed in walleye recruitment, growth, and maturity rates and yellow perch growth rates among the 1992–1997, 1998–2004, and 2005–2011 time periods. These time periods represented the pre-colonization, colonization and expansion, and cormorant management eras. The differences in these metrics across these respective time periods were indicators of a population response to increased mortality (Gangl and Pereira 2003; Fielder 2008).

Zooplankton Sampling

In 2015, zooplankton were sampled monthly at five locations from mid-May through mid-October. Sampling stations included sites in Walker Bay, Kabekona Bay, Agency Bay, Stony Point (Main Lake), and Five Mile Point (Portage Bay). The sites selected were the deepest locations in each respective area. After locating each site and holding the boat with the motors with the stern into the wind, a net with a 30 cm mouth diameter and 80 μm mesh was lowered so that the bucket of the net was approximately 0.5 meters from the bottom. The net was raised at 0.5 to 1 meters per second to the surface. The sample was rinsed from the bucket into a plastic bottle and preserved with 100% reagent alcohol.

The DNR Division of Ecological and Water Resources Biology Lab processed the samples. Samples were prepared in the lab by filtering them through 80 μm mesh and rinsing specimens into a graduated beaker. Water was added to a volume that provided at least 150-200 organisms per 5 ml aliquot. The beaker was swirled to ensure thorough mixing. A 5 ml aliquot was 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).

The number and biomass of zooplankton sampled at each of the five sites throughout 2015 was variable and without discernible trends (Table 12, Figure 40). The average number of zooplankton sampled by month ranged from 28/liter in Walker Bay to 38/liter in Kabekona Bay. The biomass (micrograms per liter) of zooplankton sampled ranged from 87 (µg/liter) in Walker Bay to 113 in Portage Bay. The overall diversity of taxa sampled was high for lakes in this region, with 21 species identified (Tables 13 and 14).
No spiny waterflea (*Bythotrephes longimanus*) or zebra mussel (*Dreissena polymorpha*) veliger's were found in any of the samples. 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 two somewhat rare species have been sampled in each of the past three years. One was *Daphnia longiremis*, which is a cold/deep water daphnia which spends most of its life below the thermocline. Other regional lakes this species has been sampled include Cass, Ten Mile, and Carlos. The other rare species sampled was a large copepod *Limnocalanus macrurus*, which is a glacial relict. 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 we will closely monitor when assessing how climate change, AIS, and other influences affect the lake.

Data in 2015 indicate a similar overall density (number/liter) and biomass (μg/liter) were sampled at most stations and during most months, when compared with 2013-present data (Figures 40 and 41). Species diversity was similar between years with 20, 19, 19, and 21 species being sampled in 2012, 2013, 2014, and 2015. Over the past three years, the density sampled in Portage Bay and at Stony Point has been consistently higher than the other three sites.

Walleye Regulation Changes

Prior to 2005 Leech Lake Walleye regulations were consistent with statewide regulations. Following a formal regulation review and public input process in 2004, an 18-26" protected slot limit (PSL), bag of 4, with one fish over 26" allowed in possession, was implemented in May 2005. The objective was to protect Walleye spawning stock and promote natural reproduction. A formal review of this regulation occurred in 2010 as part of the Leech Lake Management Planning Process, which resulted in strong support for the continuation of the regulation. As an outcome of this review, criteria were established in the 2011-2015 Management Plan for relaxing the protected slot under certain predetermined conditions. Exceedance of the spawner stock biomass objective range of 1.5 – 2.0 pounds/acre for two consecutive years would initiate consideration for relaxing the 18-26" PSL to a 20-26" PSL (bag and possession limit unchanged). These criteria were met in 2012 and 2103 (Figure 24). Following a formal regulation review and public input process in the fall and winter of 2013-2014, a 20-26" PSL (bag and possession limit unchanged), was implemented in May 2014.

Criteria in the 2016-2020 Management Plan state that adjustments to the existing 20-26 inch protected slot limit will be considered if mature female biomass (pounds/acre) continues to exceed the objective range of 1.5-2.0 pounds/acre and other key population metrics (Walleye and Yellow Perch gill net catch rates, the percentage of Walleye within the protected slot, lower than anticipated fishing pressure and Walleye harvest, and Walleye density dependence) indicate signs of an unbalanced Walleye population. Signs of density dependence include maturation at longer lengths and older ages, and below average growth and condition. The DNR will review the status of these metrics annually with the Leech Lake Fisheries Input Group. Regulation 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. Summer and winter creel surveys scheduled for 2016 and 2017 will provide critical information for considering potential Walleye regulation changes.

SUMMARY

Recent management actions have allowed for improvements in the Leech Lake Walleye population. Management Plan objectives to monitor Walleye population metrics include abundance, reproductive potential, size structure, recruitment, angler catch rate (fish/hour), angler harvest (total pounds), and condition. All 2015 values exceeded management plan objective ranges or thresholds, except for condition. The Walleye gillnet catch rate was 12.4 and the 3-year moving average exceeded the objective range and was above the long-term average for the ninth consecutive year. Mature female density was 3.4 pounds per acre and the 3-year moving average exceeded the management objective range for the third consecutive year. Of the Walleye sampled in gillnets, 24% were ≥20 inches and the 3-year moving average exceeded the management objective range for the fourth consecutive year. Walleye recruitment (3-year moving average) has exceeded the objective threshold for eleven consecutive years and has exceeded the long-term average nine of the past eleven years. Although the 2012-2015 year classes are not yet fully recruited to the fishery, they are predicted to be above average in strength. Walleye condition (3-year moving average) remained below the objective range for the seventh consecutive year.

The 2011, 2012, and 2013 Walleye year classes will provide anglers harvest opportunities throughout 2016. The Walleye regulation (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. This has been reflected by overall higher Walleye catch rates in the summer creel surveys during 2008-2011 and 2014, when compared to the 2004-2005 summer creel surveys. The new Walleye regulation (PSL 20-26", bag and possession limit unchanged) resulted in about 25% of angler-caught Walleye being protected, compared to 30-35% under the previous regulation.

The strength of the 2015 Walleye year class will depend largely on winter survival. Median length of the YOY Walleye sampled during September electrofishing was 6.2 inches, indicating above average growth was accrued by greater than 50% of the cohort. Above average water temperatures in October and November extended the 2015 growing season. Of the eight complete year classes produced from 2005-2012, four exceeded the 75th percentile and were considered strong, while none fell below the 25th percentile and were considered poor. The 2013-2015 year classes are predicted to exceed the lower quartile threshold based on age-0, age-1, and age-2 catch rates thus far.

Current Walleye regulations 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 has been produced annually since 2007 has 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 contributor to population declines in the early 2000's, continued annual stockings are no longer warranted. The 2016-2020 management plan now defines how and when stocking should be used as a management tool in the future.

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 Walleye predation 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 various previously explanations.

In addition to the improvements to the Walleye population, Leech Lake continues to support numerous sportfish populations that appear relatively healthy or unchanged, and 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. Yellow Perch objectives for abundance and size structure (3-year moving averages) have remained below thresholds for multiple years, while the 3-year moving average for recruitment remained on the threshold. Yellow Perch length at maturity values have exceeded the objective threshold for nine consecutive years. The 2011 Yellow Perch year class continues to appear better than the 2012-2014 year classes; however, is still estimated to be below average in abundance. 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.

Although the monitoring and treatment of Eurasian water milfoil (EWM) has 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. Constant awareness by users and property owners alike is paramount to prevent further spread and establishment of EWM to new locations, as well as the spread of other AIS to new waters.

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 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. The vegetation study that began in 2002 was completed in 2005, and the information obtained will further our understanding of fish habitats and identify areas to focus future protection efforts on based on species presence and abundance. A future vegetation study to assess changes in species presence and abundance should be a priority. A future shoreline habitat survey, similar to Wilcox (1979), to evaluate changes in shoreline substrates and spawning areas should also be a priority.

A comprehensive list of sensitive shoreline that is prone to development was drafted to prioritize conservation action, particularly on new developments. In addition, these landowners should be contacted and made aware of options such as conservation easements. Efforts such as these provide the best opportunities to sustain the quality resources that Leech Lake provides.

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, etc.

Continued monitoring and treatment of harbors with Eurasian water milfoil is planned for 2016. Additional educational contacts should be made to those that use the harbors, with increased effort during high use periods. Cooperation of the harbor owners is critical. Similar efforts are needed to prevent the introduction of other exotic species, such as zebra mussels or spiny waterflea, 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, increased 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 and water quality analyses should continue. The next Muskellunge egg collection and put-back stocking event is scheduled for 2017. The next lakewide survey to monitor Centrarchid populations (Bluegill, Black Crappie, and Largemouth Bass) is scheduled for spring 2018. Double-Crested Cormorant management efforts should continue as prescribed by the management plan for this species. Finally, discontinuation of programmed Walleye fry stocking is necessary to completely evaluate the full capacity of Walleye reproduction and recruitment since cormorant management was implemented in 2005.

Continued summer and winter creel surveys as frequently as possible will assist in monitoring changes in pressure, catch, catch rates, harvest, and harvest rates for all species. The next summer creel surveys are scheduled for 2016 and 2017, while the next winter creel surveys are scheduled for 2015-2016 and 2016-2017.

Many of the above action items were outlined in the Fisheries Management Plan for Leech Lake, 2016-2020 (Ward 2016).

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TABLES

Table 1. The number of Walleye stocked in Leech Lake from 1922 through 2015.

Year	Adult	Yearling	Fingerling	Fryling	Fry
1922-1945	890	-	-	-	171,038,212
1946	50	-	-	-	-
1947	-	-	-	-	-
1948	-	-	87,583	-	-
1949	-	-	123,854	-	-
1950	-	66	26,464	-	-
1951	197	-	54,050	-	-
1952	-	-	62,564	-	-
1953	-	-	34,191	-	-
1954	283	-	173,483	-	-
1955	145	-	25,064	-	-
1956	6	-	9,625	-	-
1957	666	-	5,576	-	-
1958	12	-	-	-	-
1959	-	-	10,472	-	-
1960-1961	-	-	-	-	-
1962	653	1,101	15,439	-	-
1963	-	6	10,396	-	-
1964	-	-	23,148	-	-
1965	-	-	34,380	-	-
1966	-	-	11,815	-	-
1967	-	-	44,863	-	-
1968	-	-	7,387	-	-
1969	-	5	140	-	-
1970	22	-	31,603	-	-
1971	-	-	-	-	-
1972	120	-	2,660	-	-
1973	1	10	18,554	-	-
1974	50	-	2,505	-	-
1975	-	-	26,560	-	-
1976-1979	-	-	-	-	-
1980	-	-	49,650	-	-
1981	-	-	5,300	-	-
1982	270	-	34,067	-	-
1983	-	818	-	-	2,000,000
1984	-	-	12,250	-	400,000
1985	4	110	7,150	-	100,000
1986	-	-	1,790	-	2,500,000
1987	-	-	112	-	-
1988-2004	-	-	-	-	-
2005	-	-	-	-	7,562,115
2006	-	-	-	206,084	22,032,452
2007	-	-	-	-	7,523,670
2008	-	-	-	-	22,166,808
2009	-	-	-	-	22,669,368
2010	-	-	-	-	22,501,356
2011	-	-	-	-	22,021,332
2012	-	-	-	-	7,501,632
2013	-	-	-	-	7,527,478
2014	-	-	-	-	7,500,512
2015	-	-	-	-	-

Table 2. Summary of Walleye fry stocking for five Minnesota lakes, 1999-2014 and Leech Lake, 2005-2014. SSB refers to spawner stock biomass estimated from gillnet catches of mature female Walleye the previous fall. Walleye fry were not stocked in Leech Lake in 2015.

Lake		Red	Leech	Ottertail	Woman	Winnie	Vermillion
Years		1999, 2001, 2003-2005	2005-2014	2008-2014	2007-2014	2009-2014	2010-2014
Mature female density (pounds/acre)							
	Average	1.15	1.78	1.47	1.13	2.06	1.76
	Range	0.08-3.68	1.04-2.51	0.97-2.65	0.35-1.49	1.43-2.69	0.90-2.66
Stocking density (fry/littoral acre)							
	Average	302	130.39478	796	1096	603	769
	Range	49-522	129-391	153-1,728	290-2,448	133-1,038	400-1,000
Percent marked							
	Average	55	47	63	83	60	44
	Range	9-86	14-86	29-86	60-97	4-88	12-62
Hatch rate (%)							
	Average	0.22	0.38	0.41	0.42	1.45	1.04
	Range	0.02-0.60	0.10-0.89	0.12-1.11	0.02-1.01	0.10-8.16	0.27-2.85
Fry density (number/littoral acre)							
<u>Wild</u>							
	Average	377	319	407	338	3862	1669
	Range	11-1,325	61-779	146-854	21-1,014	72-22,246	474-5,533
<u>Stocked</u>							
	Average	302	255	786	1096	603	769
	Range	49-521	129-390	153-1,728	290-2,448	132-1,039	400-1,000
<u>Total</u>							
	Average	679	574	1193	1433	4465	2438
	Range	339-1,452	237-908	526-2,582	325-3,344	272-23,28	1,066-6,306

Table 3. Seine catch rates (CPUE, number/haul) of all species and ages captured, Leech Lake, 2015.

Species	Age	Total number	Number measured	Mean length (inches)	Length (inches) Min	Max	Catch rates num/haul	num/acre
Bluegill	YOY	1	1	1.8	1.8	1.8	0.05	0.16
Bluntnose Minnow	All	18	0	-	-	-	0.90	2.90
Central Mudminnow	All	58	0	-	-	-	2.90	9.35
Emerald Shiner	All	1	0	-	-	-	0.05	0.16
Golden Shiner	All	1	0	-	-	-	0.05	0.16
Iowa Darter	All	1	0	-	-	-	0.05	0.16
Johnny Darter	All	24	0	-	-	-	1.20	3.87
Largemouth Bass	YOY	94	71	1.7	1.3	2.2	4.70	15.16
Logperch	All	81	0	-	-	-	4.05	13.06
Longnose Dace	All	5	0	-	-	-	0.25	0.81
Mimic Shiner	All	4,834	0	-	-	-	241.70	779.68
Smallmouth Bass	YOY	71	61	1.4	1.1	1.9	3.55	11.45
Spotfin Shiner	All	15	0	-	-	-	0.75	2.42
Spottail Shiner	All	23	0	-	-	-	1.15	3.71
Walleye	YOY	503	225	3.3	1.9	4.5	25.15	81.13
White Sucker	All	1	0	-	-	-	0.05	0.16
Yellow Perch	YOY	6,774	426	1.6	1.1	2.2	338.70	1092.58
Yellow Perch	≥1	146	146	3.4	2.7	5.6	7.30	23.55

Table 4. Trawl catch rates (CPUE, number/hour) of all species and ages captured, Leech Lake, 2015.

				Mean	Length range			
		Total	Number	length	(inches)		Catch rates	
Species	Age	number	measured	(inches)	Min	Max	num/haul	num/hour
Black Crappie	YOY	2	2	1.1	1.1	1.2	0.1	1.2
Bluegill	YOY	1	1	0.9	0.9	0.9	0.1	0.6
Bluntnose Minnow	All	3	0	-	-	-	0.2	1.8
Burbot	YOY	3	1	3.1	3.1	3.1	0.2	1.8
Johnny Darter	All	8	0	-	-	-	0.4	4.8
Largemouth Bass	YOY	19	19	2.9	1.8	3.7	1.0	11.4
Logperch	All	267	0	-	-	-	13.4	160.2
Mimic Shiner	All	282	0	-	-	-	14.1	169.2
Mottled Sculpin	All	1	0	-	-	-	0.1	0.6
Northern Pike	All	5	5	22.1	18.8	26.5	0.3	3.0
Rockbass	YOY	24	24	1.4	1.2	1.8	1.2	14.4
Smallmouth Bass	YOY	43	43	2.2	1.7	3.3	2.2	25.8
Spottail Shiner	All	265	0	-	-	-	13.3	159.0
Tadpole Madtom	All	1	0	-	-	-	0.1	0.1
Trout-Perch	All	88	0	-	-	-	4.4	52.8
Tullibee (Cisco)	YOY	39	37	3.4	2.9	3.8	2.0	23.4
Tullibee (Cisco)	1	6	6	8.4	8.0	9.1	0.3	3.6
Walleye	YOY	430	283	5.0	2.7	6.5	21.5	258.0
Walleye	≥1	51	51	13.4	8.2	25.3	2.6	30.6
White Sucker	All	3	0	-	-	-	0.2	1.8
Yellow Perch	YOY	4,342	373	2.0	1.5	2.6	217.1	2605.2
Yellow Perch	≥1	771	333	3.7	2.5	8.2	38.6	462.6

Table 5. 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, 1980-2015. Estimates are incomplete until Walleye are fully recruited to gill nets at age-3.

								Year Class Strength[3]			
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)	Year Class Strength[2]	Observed Year Class Strength	3-year running average	Lower 85% confidence interval	Upper 85% confidence interval
1980						1.31		1.45		0.91	2.28
1981					0.66	1.11		0.92		0.63	1.32
1982				0.81	0.61	0.92		0.80	1.05	0.58	1.08
1983			0.22	2.42	1.89	1.36	1.96	1.80	1.17	1.35	2.40
1984			0.33	0.72	0.89	0.33	1.20	0.72	1.10	0.52	0.97
1985			0.03	0.56	0.39	4.00	1.49	1.04	1.19	0.77	1.40
1986			0.08	2.39	3.39	1.83	2.18	2.29	1.35	1.72	3.04
1987	49		0.11	0.53	0.78	0.94	1.06	0.66	1.33	0.48	0.90
1988	128		1.81	4.47	4.08	3.14	2.30	3.24	2.06	2.44	4.28
1989	62		0.06	0.94	1.03	0.47	1.10	0.77	1.55	0.56	1.04
1990	72		0.03	1.47	0.78	0.69	1.20	0.98	1.66	0.72	1.32
1991	58		0.47	1.53	1.36	1.17	1.64	1.42	1.06	1.06	1.90
1992	103		0.00	0.22	0.50	0.14	0.71	0.33	0.91	0.23	0.46
1993	16		0.00	0.11	0.11	0.11	0.30	0.15	0.63	0.09	0.23
1994	493		0.08	2.89	5.00	2.06	2.29	3.09	1.19	2.33	4.10
1995	183		0.51	2.00	1.51	2.00	1.81	1.70	1.65	1.27	2.26
1996	262		0.14	0.66	2.00	1.33	1.42	1.17	1.99	0.87	1.57
1997	5		0.29	4.22	2.86	1.43	1.89	2.32	1.73	1.74	3.08
1998	139		0.47	1.08	0.89	0.94	1.11	0.96	1.48	0.71	1.30
1999	348		0.56	1.14	1.61	1.47	1.31	1.39	1.56	1.03	1.85
2000	28		0.14	0.97	0.36	0.31	0.73	0.52	0.96	0.37	0.72
2001	103		0.64	1.31	1.00	0.92	1.04	1.10	1.00	0.82	1.48
2002	38		0.31	1.08	1.31	0.94	1.04	1.16	0.93	0.86	1.55
2003	27		0.08	0.61	0.42	0.28	0.61	0.49	0.92	0.35	0.67
2004	3		0.00	0.44	0.19	0.67	0.47	0.44	0.69	0.31	0.61
2005	247	60	0.03	2.69	3.36	1.61	1.33	2.33	1.08	1.75	3.09
2006	240	35	0.69	4.67	3.50	2.94	1.88	3.23	2.00	2.43	4.28
2007	31	27	1.47	2.06	2.47	1.72	1.78	2.02	2.52	1.51	2.68
2008	508	42	0.00	0.72	1.31	1.03	1.38	1.02	2.09	0.75	1.37
2009	153	164	0.03	0.92	0.92	0.89	1.23	0.91	1.32	0.67	1.23
2010	80	56	0.03	1.47	2.14	1.69	1.66	1.69	1.21	1.26	2.25
2011	40	175	0.03	1.67	1.47	1.64	1.47	1.53	1.38	1.14	2.04
2012	148	237	0.56	1.83	1.67	2.72	1.69	1.87	1.69	1.39	2.49
2013[1]	346	88	0.06	1.58	1.78		1.60	1.46	1.62	1.02	2.06
2014[1]	356	109	0.06	1.81			1.67	1.43	1.59	0.89	2.25
2015[1]	258	97	0.28				1.67	1.63	1.63	0.67	2.60
Mean	152	99	0.29	1.58	1.58	1.34	1.39	1.38	1.38	1.01	1.87

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

[2] Year class strength estimates calculed with the Maciena and Pereira (2007) catchability corrected model. These values were used to establish the Walleye recruitment objective in the 2016-2020 Fisheries Management Plan for Leech Lake.

[3] 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.

Table 6. Gillnet catch-per-effort (fish/net) summary by species and basin for Leech Lake, 2015.

		Western Bays		Main Lake		Whole Lake	
			1983-2015		1983-2015		1983-2015
Code	Species	2015	Mean	2015	Mean	2015	Mean
BLB	Black bullhead	0.0	8.3	0.0	2.1	-	4.9
BLC	Black crappie	0.6	0.3	1.1	0.5	0.8	0.4
BLG	Bluegill	0.7	0.7	0.7	0.3	0.7	0.5
BOF	Bowfin	0.1	0.1	0.0	0.0	0.1	0.1
BRB	Brown bullhead	0.9	1.8	0.1	1.1	0.4	1.5
BUB	Burbot	0.1	0.0	0.0	0.1	0.0	0.1
HBS	Hybrid sunfish	0.0	0.0	0.0	0.0	-	0.0
LKW	Lake whitefish	0.0	0.1	0.0	0.0	-	0.0
LMB	Largemouth bass	0.1	0.1	0.0	0.1	0.1	0.1
MUE	Muskellunge	0.0	0.0	0.1	0.0	0.0	0.0
NOP	Northern pike	6.8	5.3	5.2	4.4	5.9	4.8
PMK	Pumpkinseed	0.9	1.0	0.4	0.5	0.6	0.8
RKB	Rock bass	2.3	3.0	0.5	0.3	1.3	1.5
SHR	Shorthead redhorse	0.0	0.0	0.0	0.0	-	0.0
SMB	Smallmouth bass	0.1	0.0	0.0	0.0	0.0	0.0
TME	Tiger muskellunge	0.0	0.0	0.0	0.0	-	0.0
TLC	Tulibee/cisco	1.9	4.5	8.4	6.0	5.5	5.4
WAE	Walleye	8.1	5.8	15.9	9.6	12.4	7.9
WTS	White sucker	0.8	1.3	1.1	1.6	0.9	1.5
YEB	Yellow bullhead	2.7	2.2	0.4	0.9	1.4	1.5
YEP	Yellow perch	27.4	25.7	11.6	17.3	18.6	21.1
	Total	53.3	60.5	45.2	44.9	48.8	52.0

Table 7. Length-frequency distribution of all species sampled in experimental gillnet sets, Leech Lake, 2015.

Length	Black Crappie	Bluegill	Bowfin	Brown Bullhead	Burbot	Largemouth Bas	Muskellunge	Northern Pike	Pumpkinseed	Rock Bass	Smallmouth Bas	Cisco	Walleye	White Sucker	Yellow Bullhead	Yellow Perch
3	1								2							1
4		5							4	6						
5	4	4							10	6		1				41
6	2	7							5	3		1				297
7	1	4				1			1	6		5	11	1		160
8		3							1	4		50	8	1	1	72
9		1								9		36	22		6	54
10	5			1		1				9		5	38	1	20	22
11	12			2						4		9	20	2	14	14
12	3			1				2				34	23	3	8	7
13	1			10				2				13	46	3	1	1
14	1			2				4			1	6	42	3		
15								2				2	30	3		
16								6				10	23	6		
17			1					21				19	27	9		
18					1			17				7	26	1		
19								31					25	1		
20			1					38					31			
21								22					11			
22								19					24			
23								15					16			
24								9					16			
25								7					7			
26								7					1			
27								2								
28								1								
29								1								
30								2								
31																
32								2								
33																
34								1								
35																
≥36							1									
Total	30	24	2	16	1	2	1	211	23	47	1	198	447	34	50	669
Min. length	3	4	17	11	19	7	37	13	4	4	15	6	8	8	9	4
Max. length	14	9	21	14	19	10	37	35	8	12	15	19	27	19	13	13
Mean length	10	6	19	13	19	9	37	21	6	8	15	12	16	15	11	7

Table 8. Length- frequency distribution of immature (I) and mature (M) Walleye, Yellow Perch, Northern Pike, and Cisco, by sex from gill nets in Leech Lake, 2015.

	Walleye				Yellow Perch				Northern				Cisco			
	F		M		F		M		F		M		F		M	
Length	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
0																
1																
2																
3					1											
4																
5					14	7		20							1	
6					73	112		112					1			
7	5		6		9	117		34					2		3	
8	4		4			55		17					21		29	
9	9		13			45		9					22		14	
10	18		20			19		3					3	1	1	
11	11		9			10		4						5		4
12	11		12			7					2			18		16
13	21		17	8		1						2		9		4
14	23		10	9					1			3		5		1
15	16			14					1			1		1		1
16	9	2		12						1		5		2		8
17	2	5		20						7		14		13		6
18	2	12		12						6		11		6		1
19	1	12		12						16		15				
20	3	18		10						22		16				
21		4		7						13		9				
22		20		4						11		8				
23		14		2						11		4				
24		15		1						8		1				
25		7								7						
26		1								7						
27										2						
28										1						
29										1						
30										2						
31																
32										2						
33																
34										1						
35																
≥36																
Total	135	110	91	111	97	373	0	199	2	118	2	89	49	60	48	41

Table 9. Age- frequency distribution of immature (I) and mature (M) Walleye, Yellow Perch, Northern Pike, and Cisco, by sex from gill nets in Leech Lake, 2015.

	Walleye				Yellow Perch				Northern Pike				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	5		5													
1	28		37		1			1	2		2	3				
2	30		35		42	65		40		7		12	1		1	
3	61		13	23	38	116		88		47		35	43		46	
4	7	11		26	14	111		43		34		25	5	19	1	20
5	4	24		15	2	53		11		17		10		13		4
6		16		14		16		8		7		3				1
7		3		3		6		1		4		1		6		1
8		11		6		3		4		1				5		2
9		21		9		3		3		1				12		7
10		16		8										2		6
11		4		3										1		
12		1		1										1		
13		3												1		
14																
15				1												
16																
17																
18				1												
19				2												
20																
21																
Total	135	110	90	112	97	373	0	199	2	118	2	89	49	60	48	41

Table 10. Average length at age for Walleye, Yellow Perch, Northern Pike, and Cisco, by sex from gill nets in Leech Lake, 2015. 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 5 individuals were sampled.

	Age										
	0	1	2	3	4	5	6	7	8	9	10
Walleye											
Female											
1990-present	7.3	10.5	13.1	15.6	18.1	19.4	20.3	21.5	22.6	23.4	23.8
2015	7.1	9.9	12.0	14.7	17.5	19.3	20.9	21.9	22.9	23.3	24.1
Male											
1990-present	7.2	10.4	13.0	15.2	16.7	17.9	18.6	19.1	19.5	20.1	20.5
2015	7.1	9.9	12.4	14.4	16.4	17.5	18.5	19.0	19.9	20.4	20.8
Yellow Perch											
Female											
2001-present			6.2	6.9	7.9	8.8	9.5	10.2	10.5	11.1	
2015			6.4	7.1	7.8	8.9	10.0	11.5			
Male											
2001-present			5.9	6.2	6.9	7.5	8.7	9.0	9.7	10.1	
2015			6.0	6.5	7.6	8.1	8.4				
Northern Pike											
Female											
1990-present	10.1	15.7	19.5	21.8	24.1	26.1	28.6	30.0	31.4	32.2	
2015		15.3	17.4	20.1	22.6	24.4	28.7				
Male											
1990-present	9.5	14.7	18.1	19.8	21.2	22.0	22.4	23.3	23.3	25.1	
2015		13.3	16.8	18.7	21.0	21.2	22.7				

Table 11. 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, 1984-2015.

	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	0.9	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														
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
Mean	5.3	0.022	8.2	137	171	7.2	42	3.8	0.016	8.6	135	179	11.0	41

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

Table 12. Density (number/liter) and biomass (µg/liter) of zooplankton sampled by month at the five standardized zooplankton sites on Leech Lake, 2015.

Date	Unit	Walker Bay	Agency Bay	Portage Bay	Kabekona Bay	Stony Point	Average
5/15/15	(#/L)	15	39	48	65	61	46
	(µg/L)	53	118	134	113	185	120
6/1/15	(#/L)	35	49	36	51	33	41
	(µg/L)	121	178	247	168	133	169
6/16/15	(#/L)	30	28	22	44	26	30
	(µg/L)	91	160	54	202	81	118
7/16/15	(#/L)	36	39	35	31	31	34
	(µg/L)	90	148	52	100	55	89
8/14/15	(#/L)	46	21	50	33	55	41
	(µg/L)	101	45	53	47	89	67
9/21/15	(#/L)	21	23	32	21	30	25
	(µg/L)	81	117	116	66	77	91
10/15/15	(#/L)	14	29	29	23	21	23
	(µg/L)	69	81	136	77	125	98
Average	(#/L)	28	32	36	38	37	33
	(µg/L)	87	121	113	111	106	97

Table 13. Density (number/liter) of zooplankton at each of the five sample sites, by species, Leech Lake 2015.

Taxa	Walker Bay	Agency Bay	Portage Bay	Kabekona Bay	Stony Point	Station Average
Copepods:						
Nauplii	7.7	6.3	5.1	7.8	5.9	6.5
Copepodites	4.5	4.2	4.1	5.2	4.4	4.5
Diaptomidae	4.0	7.6	4.2	3.6	3.7	4.6
Epischura lacustris	0.1	0.0	0.2	0.0	0.1	0.1
Limnocalanus macrurus	0.0	0.1	0.0	0.0	0.0	0.0
Mesocyclops edax	0.8	0.5	0.9	1.2	0.7	0.8
Diacyclops bicuspidatus thomasi	4.2	3.7	3.3	9.0	3.5	4.7
Tropocyclops prasinus mexicanus	1.2	2.4	4.3	1.1	2.9	2.3
Total	22.4	24.7	22.0	27.7	21.1	23.6
Cladocerans:						
Daphnia galeata mendotae	2.0	2.3	4.6	3.5	4.8	3.4
Daphnia longiremis	0.2	0.7	0.0	0.5	0.0	0.3
Daphnia parvula	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia pulicaria	0.2	1.0	0.2	0.2	0.1	0.3
Daphnia retrocurva	0.6	0.8	1.8	1.0	1.4	1.1
Alona sp.	0.0	0.0	0.0	0.0	0.0	0.0
Bosmina sp.	1.3	2.2	2.8	3.9	4.9	3.0
Eubosmina coregoni	0.7	0.1	2.0	0.3	1.9	1.0
Chydorus sphaericus	0.4	0.3	0.9	0.7	0.5	0.6
Holopedium gibberum	0.1	0.1	0.0	0.0	0.2	0.1
Diaphanosoma birgei	0.3	0.2	1.1	0.1	1.5	0.7
Eurycercus lamellatus	0.0	0.0	0.0	0.0	0.0	0.0
Ceriodaphnia sp.	0.0	0.1	0.4	0.3	0.1	0.2
Total	5.7	7.8	14.1	10.4	15.4	10.7
Cumulative Total	28.1	32.5	36.1	38.2	36.6	34.3

Table 14. Biomass (μg/liter) of zooplankton at each of the five sample sites, by species, Leech Lake 2015.

Taxa	Walker Bay	Agency Bay	Portage Bay	Kabekona Bay	Stony Point	Station Average
Copepods:						
Nauplii	1.2	1.0	0.9	1.2	1.0	1.0
Copepodites	4.6	4.3	4.2	5.6	4.7	4.7
Diaptomidae	29.5	49.8	24.7	22.7	21.2	29.6
Epischura lacustris	1.4	0.2	3.1	0.0	1.2	1.2
Limnocalanus macrurus	0.8	1.9	0.0	0.0	0.0	0.5
Mesocyclops edax	3.5	2.5	4.3	5.9	4.1	4.1
Diacyclops bicuspidatus thomasi	17.7	14.2	11.9	33.2	12.4	17.9
Tropocyclops prasinus mexicanus	1.3	2.6	4.4	1.1	3.0	2.5
Total	60.2	76.6	53.5	69.7	47.6	61.5
Cladocerans:						
Daphnia galeata mendotae	16.1	19.5	38.2	26.2	36.9	27.4
Daphnia longiremis	0.8	4.8	0.0	3.3	0.0	1.8
Daphnia parvula	0.1	0.0	0.0	0.0	0.0	0.0
Daphnia pulicaria	1.5	12.9	3.5	1.4	1.0	4.0
Daphnia retrocurva	1.8	2.3	3.7	2.6	3.0	2.7
Alona sp.	0.0	0.0	0.0	0.0	0.0	0.0
Bosmina sp.	1.5	3.1	3.7	5.5	6.4	4.0
Eubosmina coregoni	2.5	0.4	5.6	0.7	5.2	2.9
Chydorus sphaericus	0.3	0.2	0.9	0.6	0.4	0.5
Holopedium gibberum	0.3	0.2	0.0	0.1	0.8	0.3
Diaphanosoma birgei	1.4	0.8	3.7	0.2	5.0	2.2
Eurycercus lamellatus	0.0	0.0	0.1	0.0	0.0	0.0
Ceriodaphnia sp.	0.0	0.1	0.2	0.3	0.1	0.1
Total	26.4	44.3	59.7	40.8	58.8	46.0
Cumulative Total	86.6	120.9	113.2	110.5	106.4	107.5

FIGURES

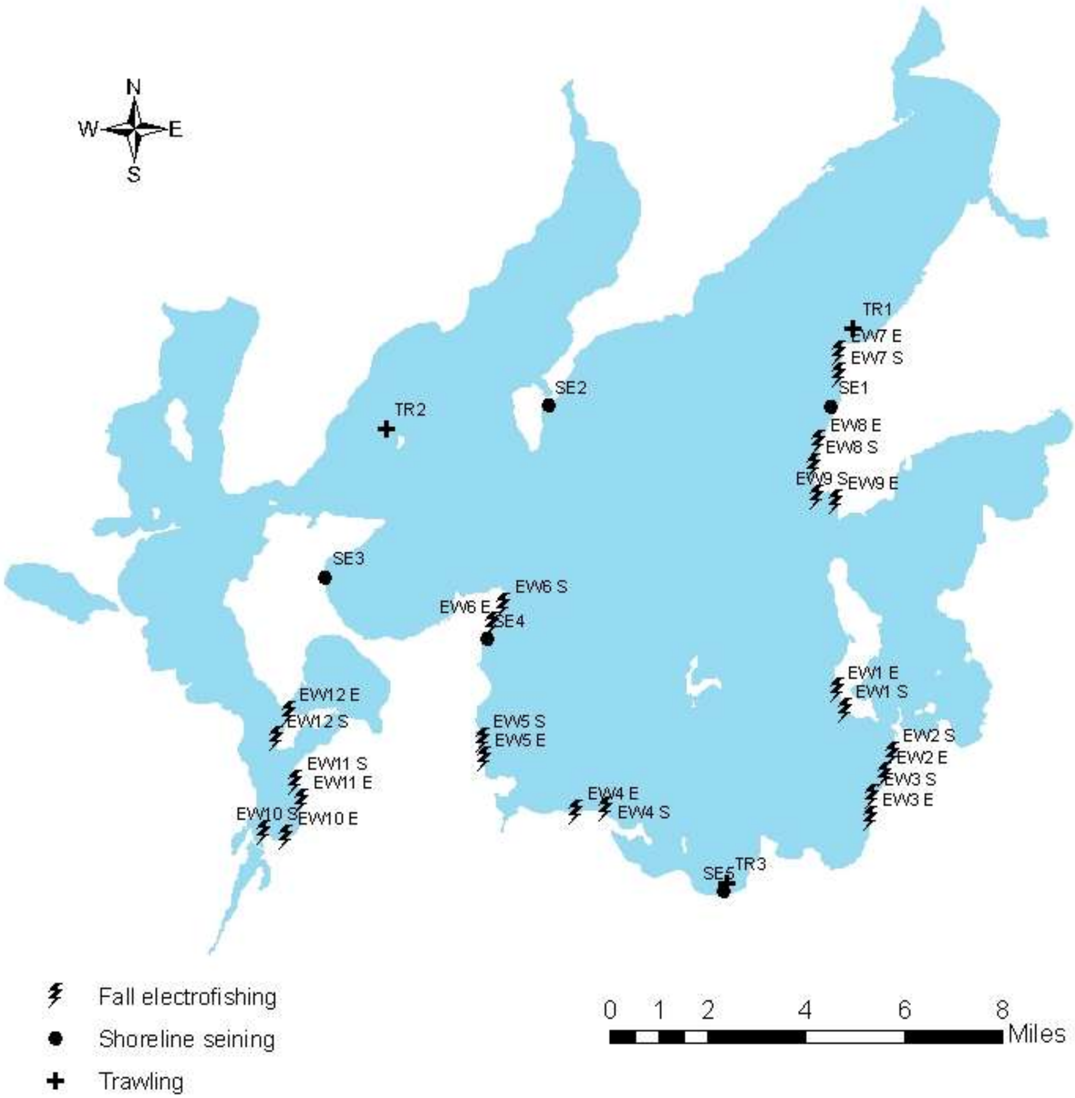

Figure 1. Long-term sampling stations targeting young-of-year Walleye and Yellow Perch in Leech Lake.

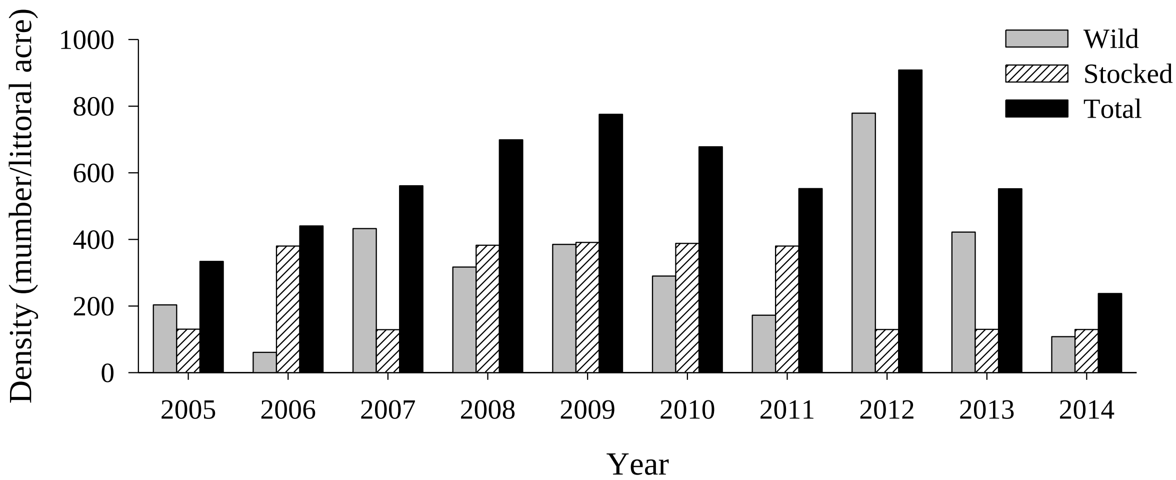

Figure 2. The Walleye fry density (fry/littoral acre) estimated with OTC marking for stocked and naturally produced Walleye fry in Leech Lake, 2005-2014.

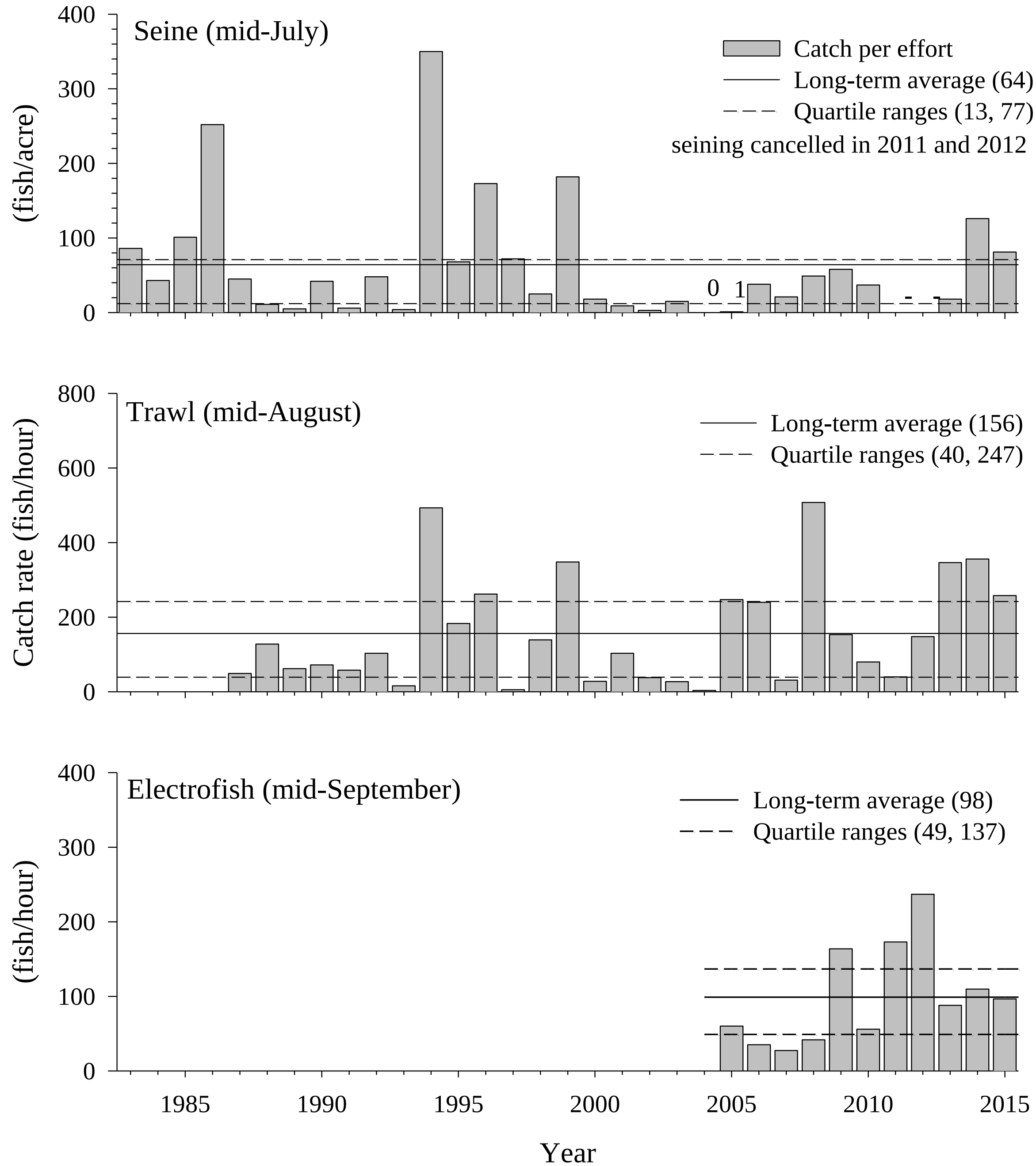

Figure 3. Catch-per-effort (bars) and long-term averages (lines) of young-of-year (YOY) Walleye sampled seining (top), trawling (middle), and electrofishing (bottom), Leech Lake, 1983-2015.

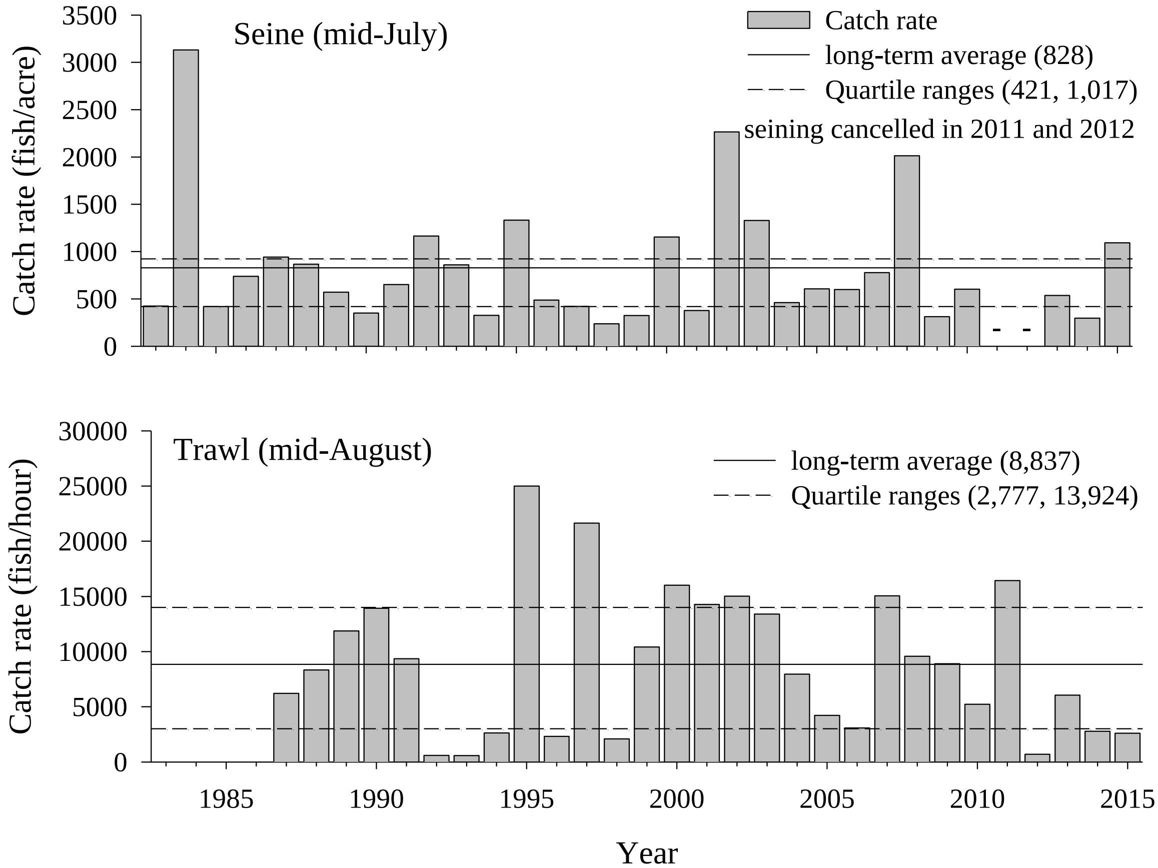

Figure 4. Catch-per-effort (bars) and long-term averages (lines) of young-of-year (YOY) Yellow Perch sampled at standardized seining and trawling locations, Leech Lake, 1983-2015.

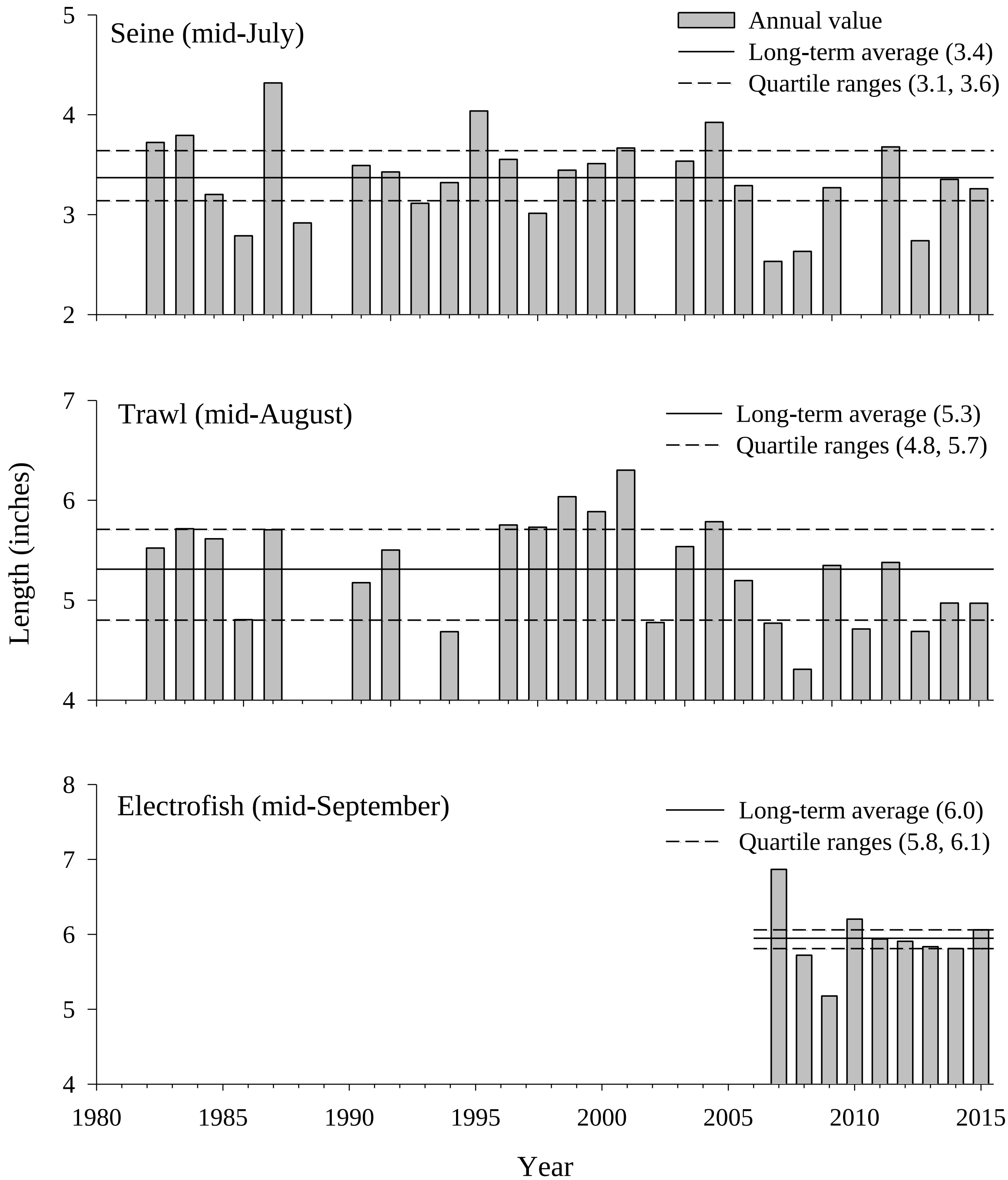

Figure 5. Average annual growth rates of young-of-year (YOY) Walleye sampled seining (top), trawling (middle), and electrofishing (bottom) in Leech Lake, 1987-2015. Growth rates are standardized by Julian Weeks 28-29 (seining), 33-34 (trawling), and 37-38 (electrofishing).

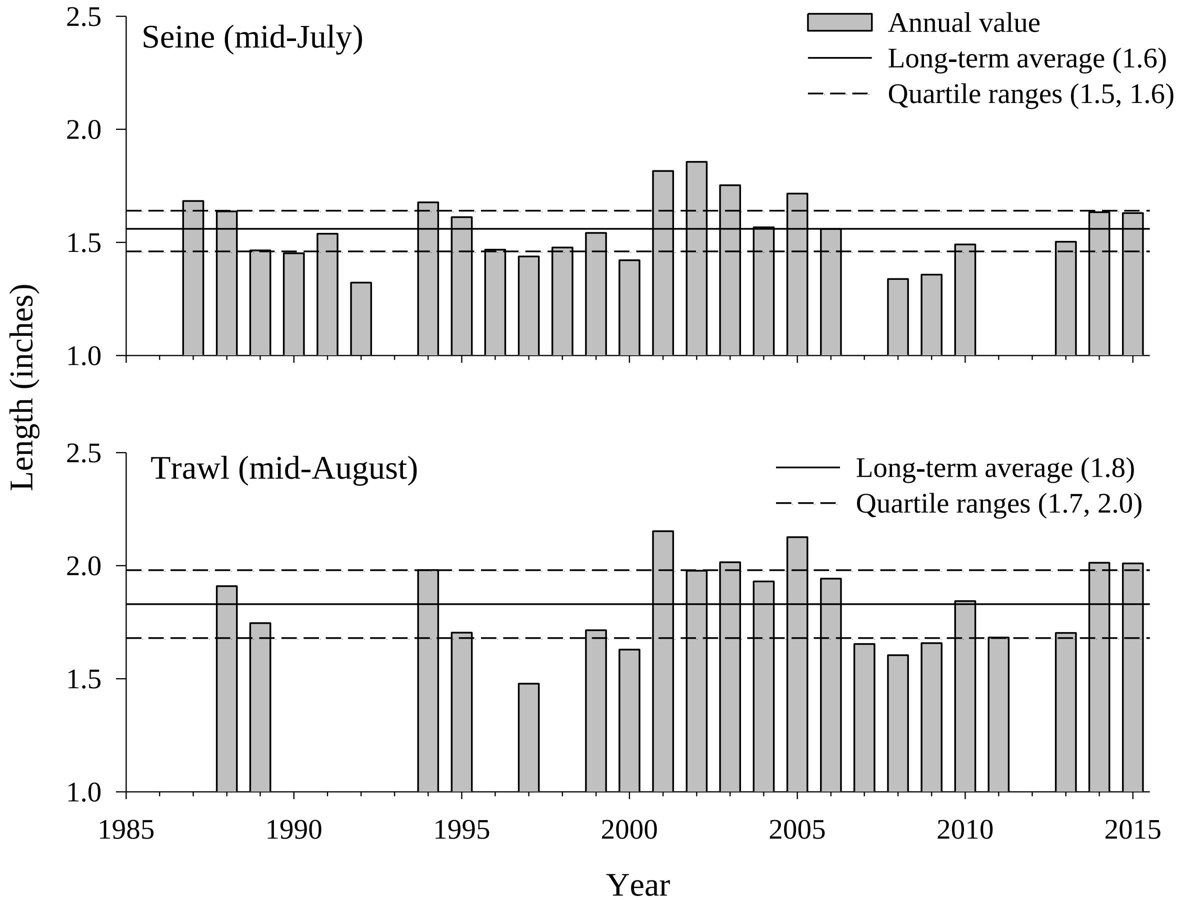

Figure 6. Average annual growth rates of young-of-year (YOY) Yellow Perch sampled seining (top) and trawling (bottom) in Leech Lake, 1987-2015. Growth rates are standardized by Julian Weeks 28-29 for seining and 33-34 for trawling.

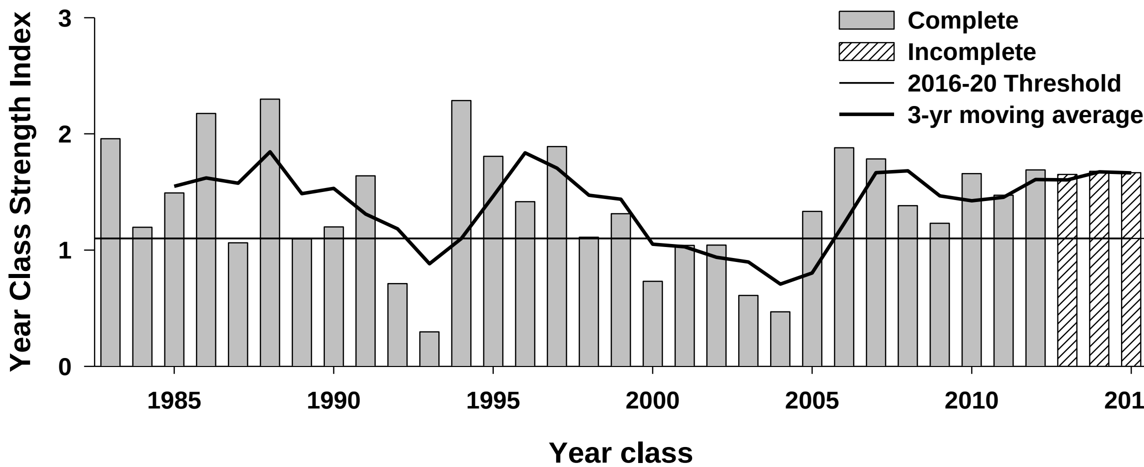

Figure 7. Year class strength index of Walleye in Leech Lake, 1983-2015. Fully recruited (shaded bars) incomplete (hatched bars) year classes are indicated. The horizontal line represents the Management Plan Objective Threshold. The darker line represents the 3-year moving average. Walleye are considered fully recruited to the fishery at age-3.

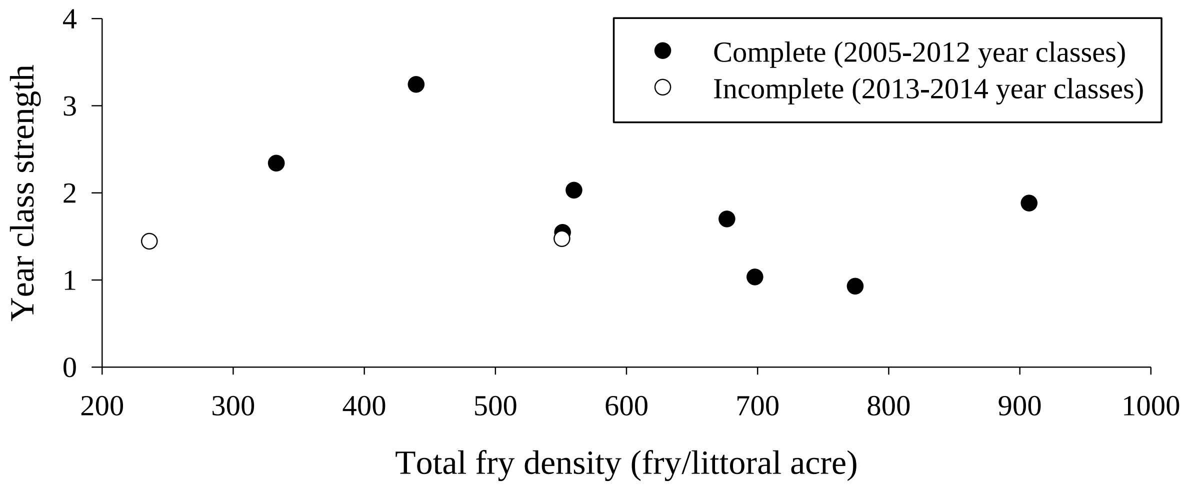

Figure 8. Total Walleye fry density (fry/littoral acre) estimated with OTC marking and the resulting year class strength index at Leech Lake, 2005-2014. The number of fry stocked for a specific year class is also indicated.

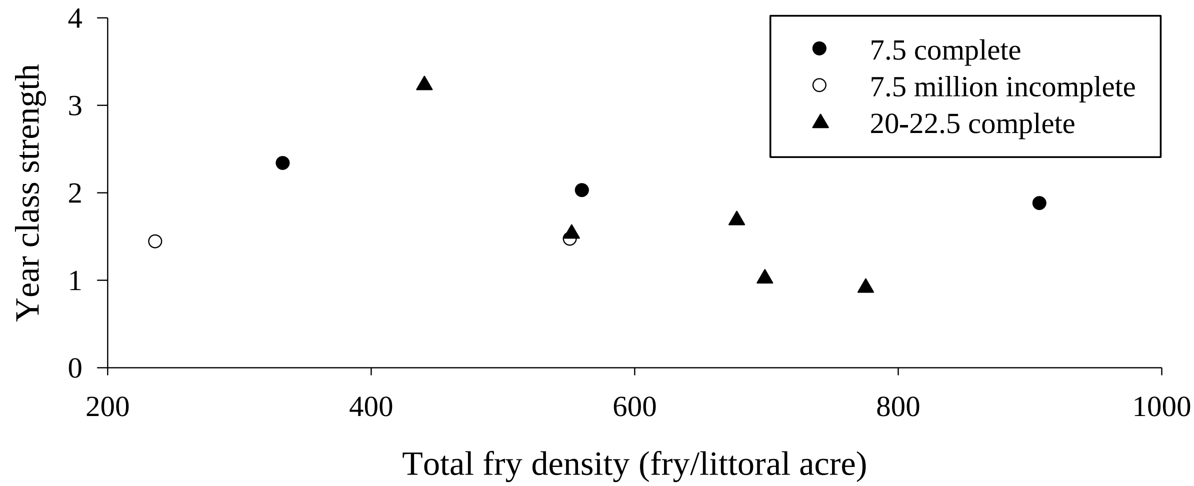

Figure 9. Total Walleye fry density (fry/littoral acre) estimated with OTC marking and the resulting year class strength index at Leech Lake, 2005-2014. The number of fry stocked for a specific year class is also indicated.

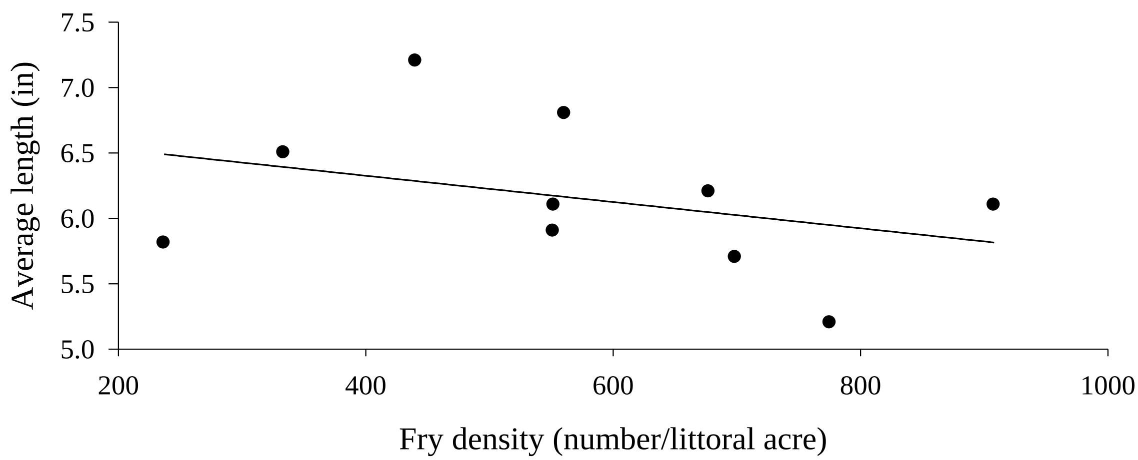

Figure 10. Total Walleye fry density (fry/littoral acre) estimated with OTC marking and the average length (in) of young-of-year Walleye sampled by electrofishing in mid-September Leech Lake, 2005-2014.

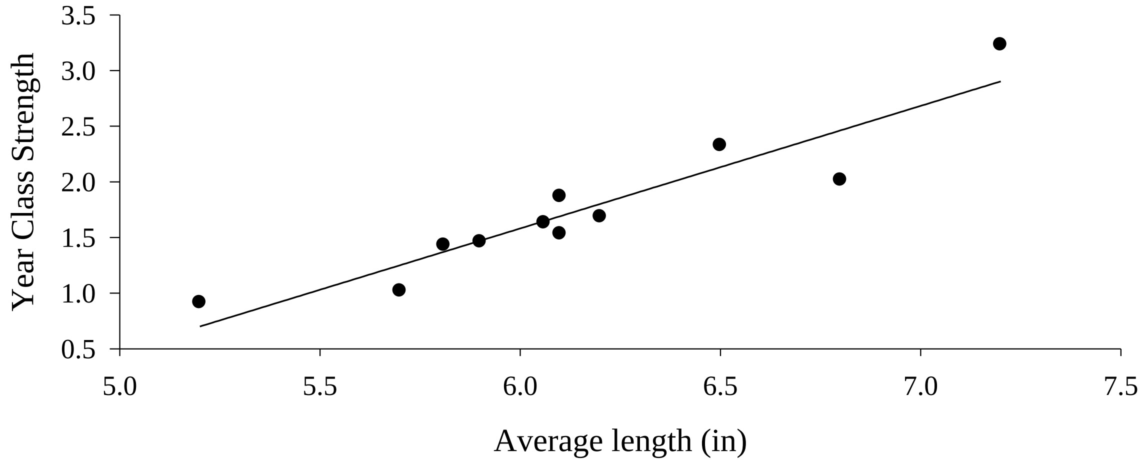

Figure 11. The average length (in) of young-of-year Walleye sampled by electrofishing in mid-September and the resulting Walleye year class strength in Leech Lake, 2005-2015.

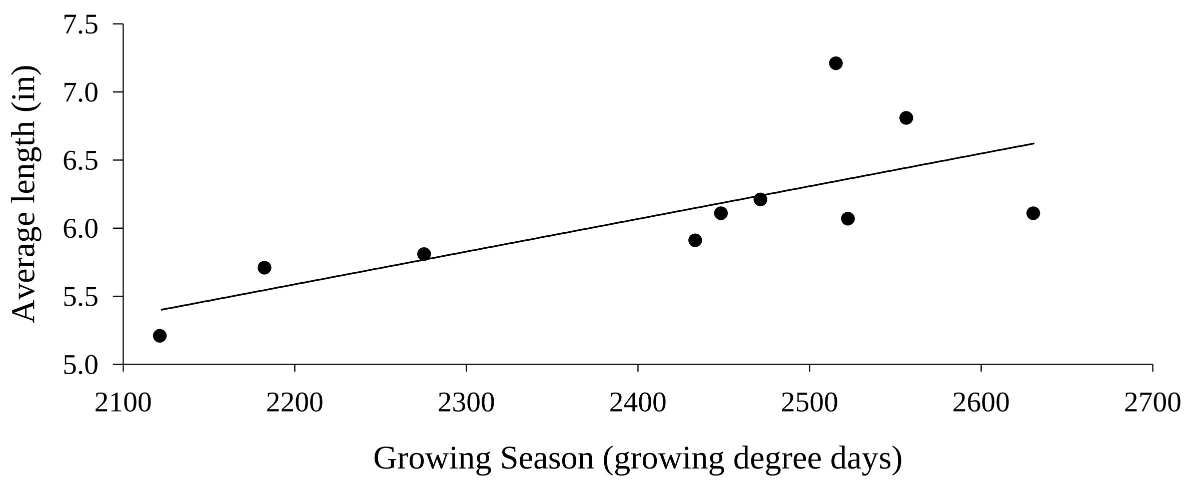

Figure 12. Growing degree days (GDD_{50}) and the average length (in) of young-of-year Walleye sampled by electrofishing in mid-September at Leech Lake, 2006-2015.

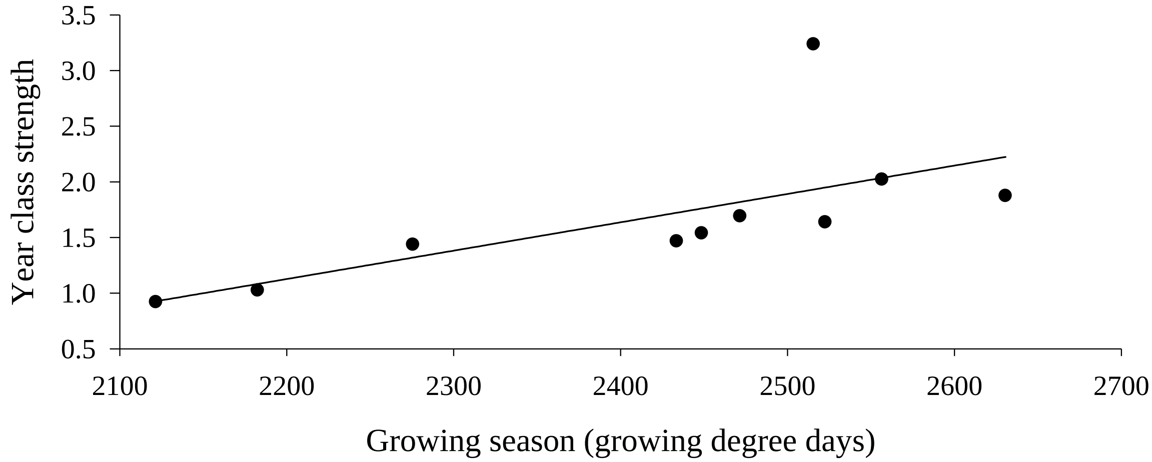

Figure 13. Growing degree days (GDD_{50}) and the resulting observed Walleye year class strength in Leech Lake, 2006-2015.

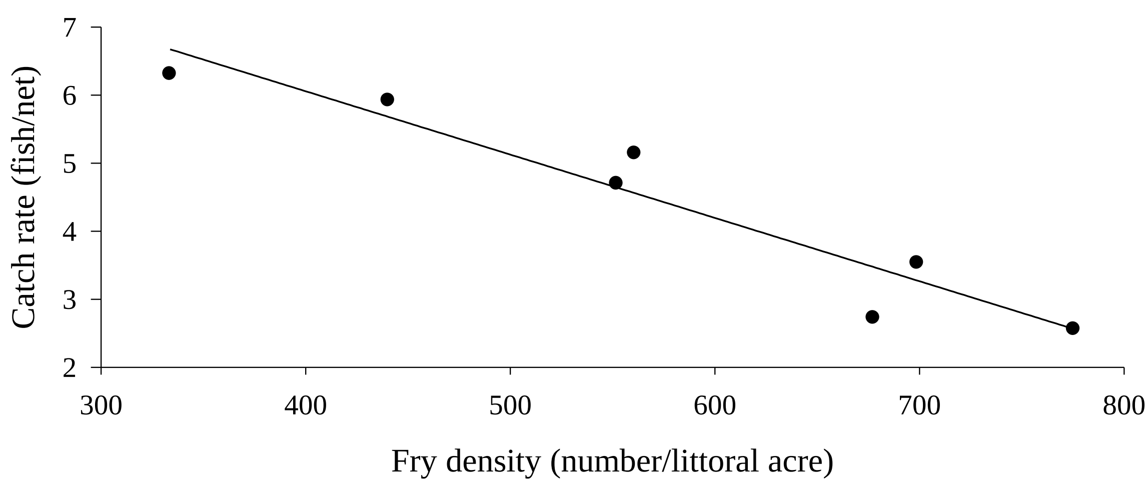

Figure 14. Estimated total Walleye fry density (fry/littoral acre, i.e. depths ≤15 feet) and the resulting strength of Yellow Perch year classes (age-4 gill net catch rate) produced in the same year.

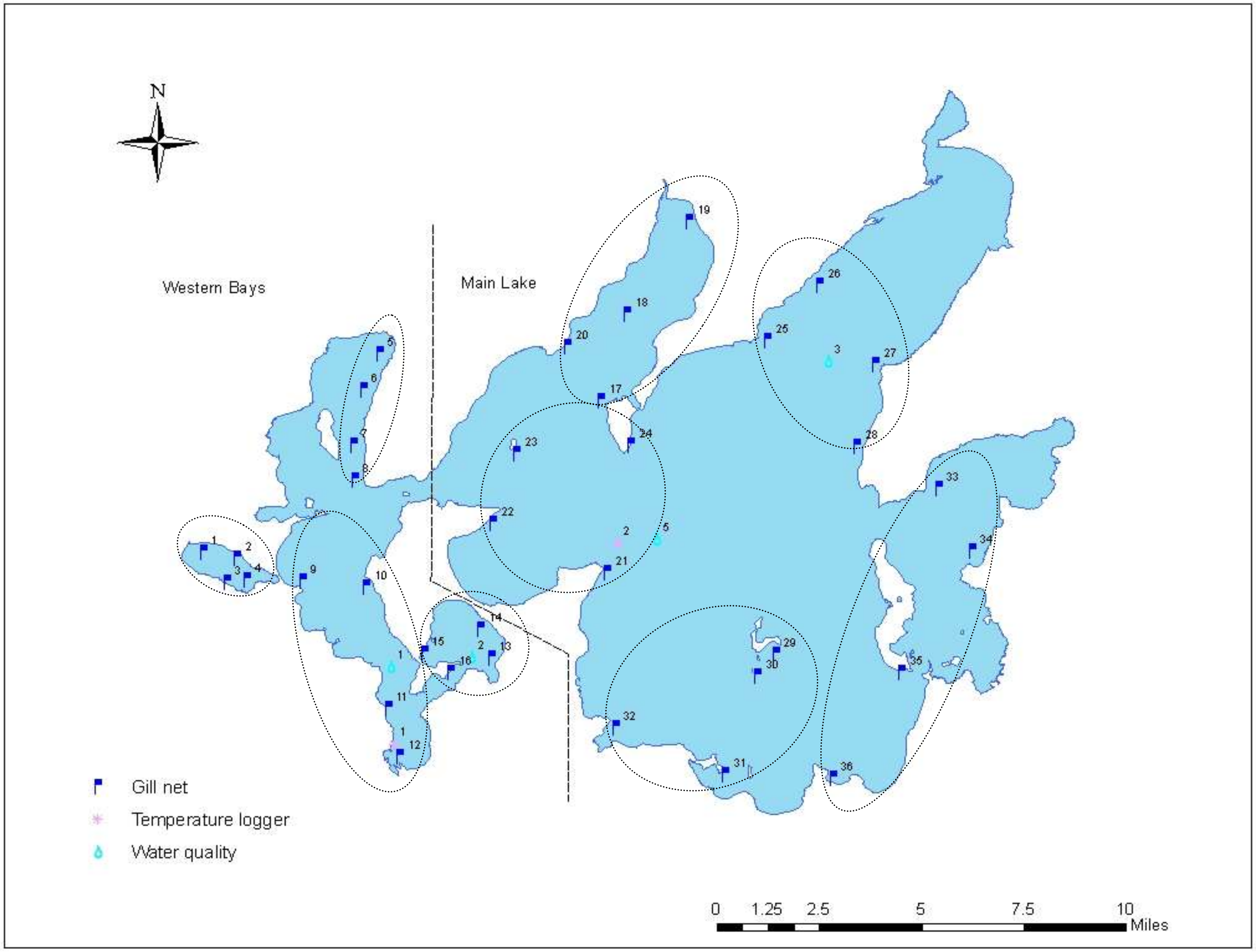

Figure 15. Gillnet (flags), temperature loggers (dots) and water quality (droplets) sampling locations on Leech Lake. Dotted circles represent gillnet sampling strata.

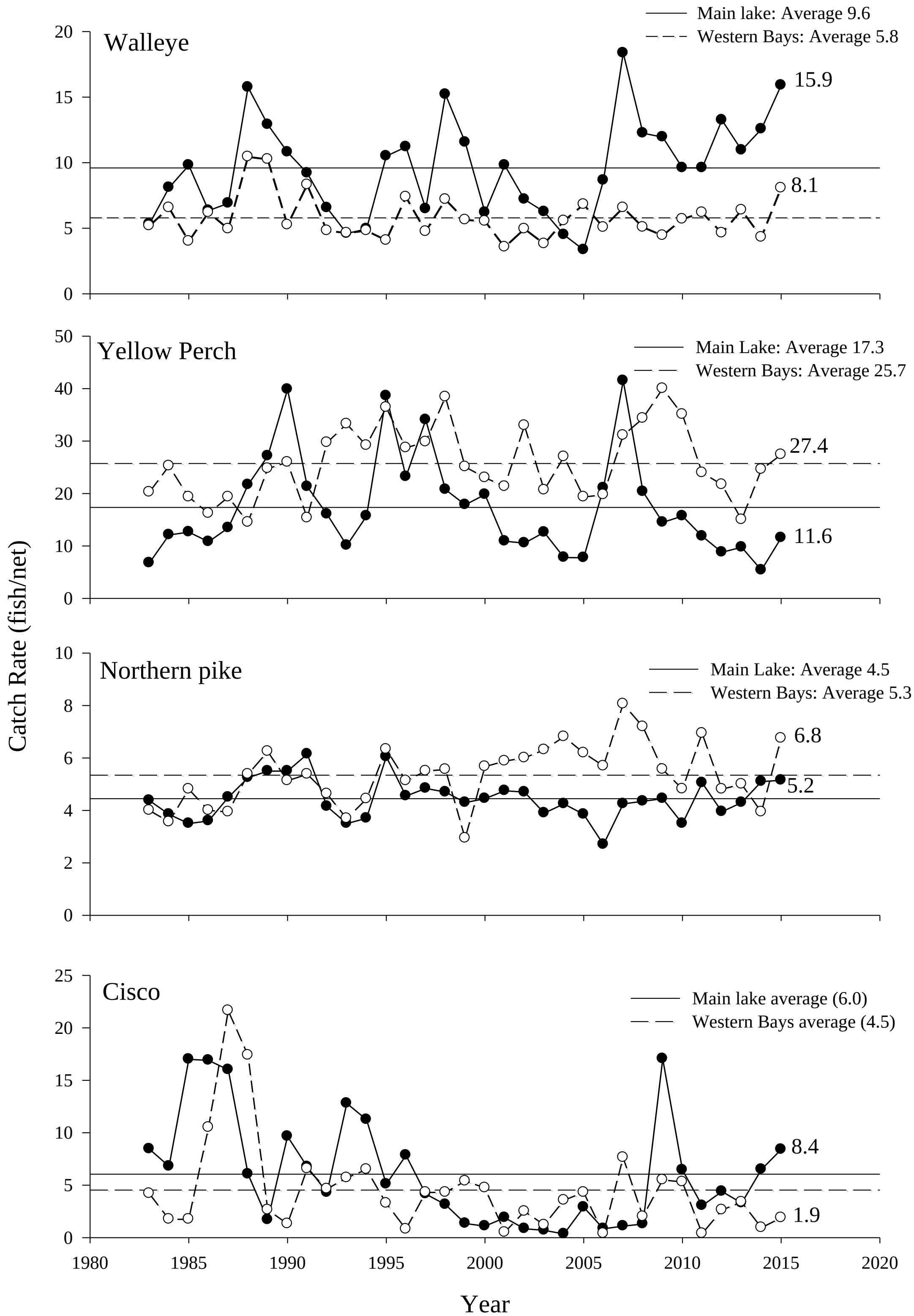

Figure 16. Basin-specific gillnet catch rates (fish/net) of selected species in Leech Lake, 1983-2015. Horizontal lines represent respective long-term averages.

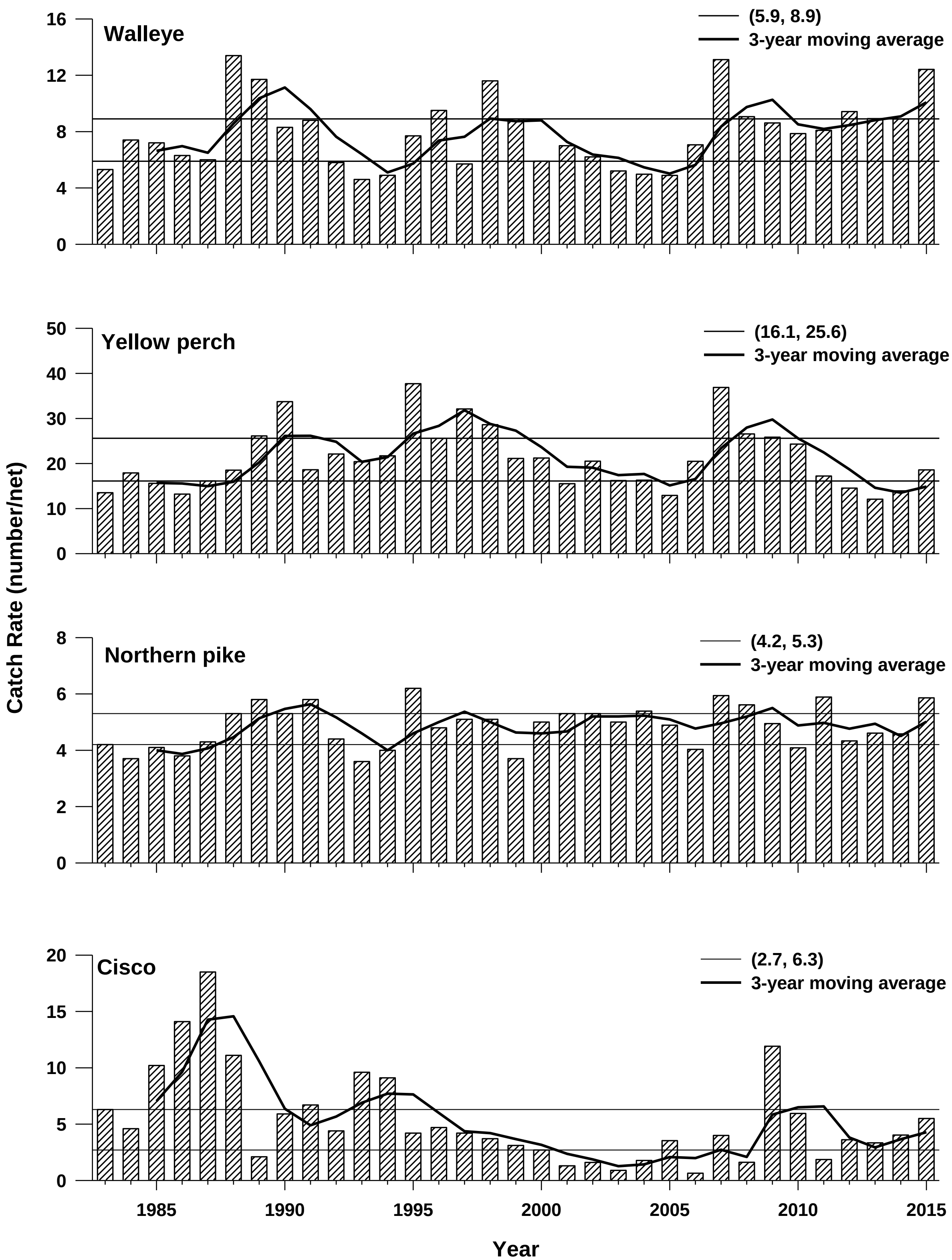

Figure 17. Gillnet catch rates (number/net) of selected species in Leech Lake, 1983-2015. Horizontal lines represent respective 25th and 75th percentiles.

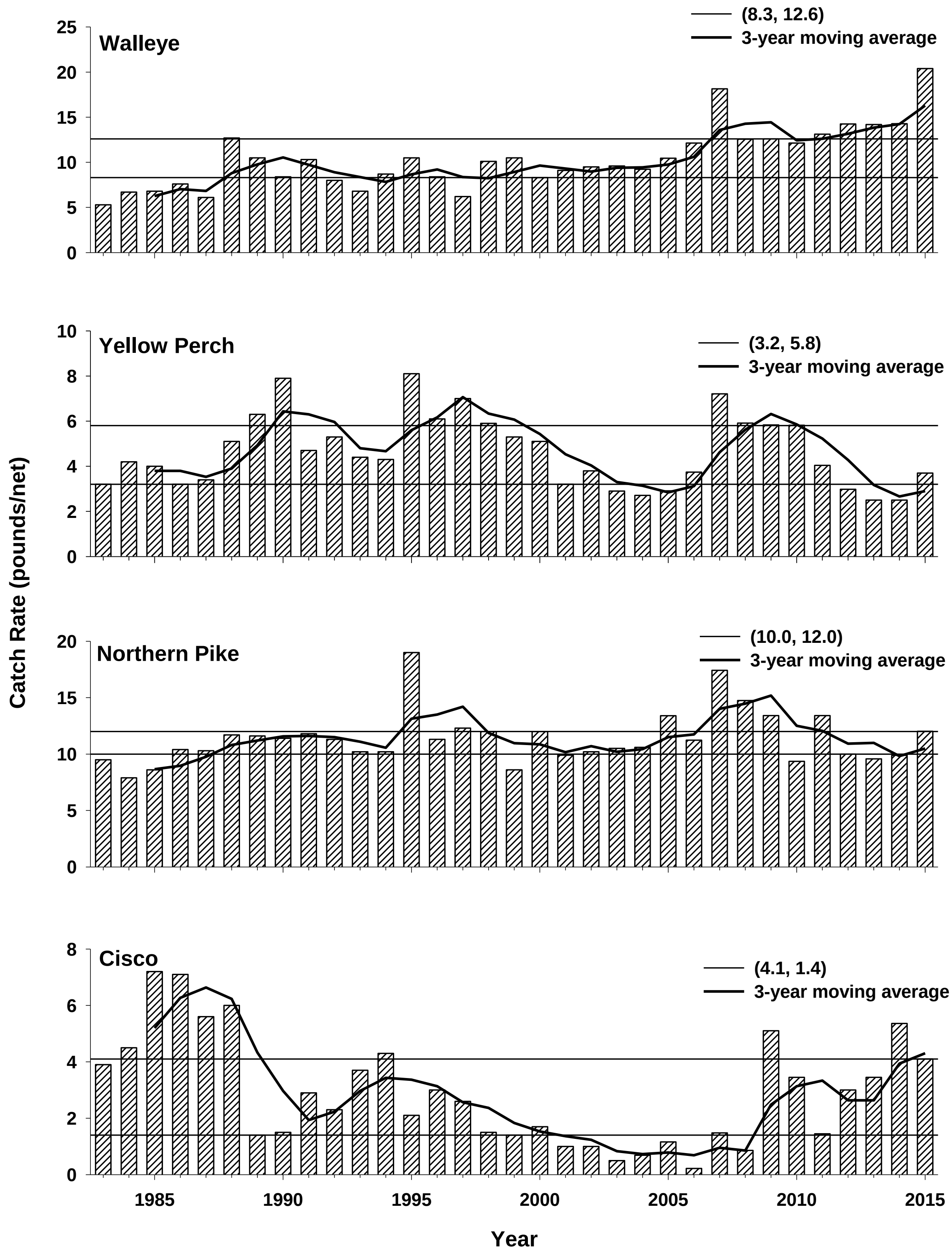

Figure 18. Gillnet catch rates (pounds/net) of selected species in Leech Lake, 1983-2015. Horizontal lines represent respective the 25th and 75th percentiles.

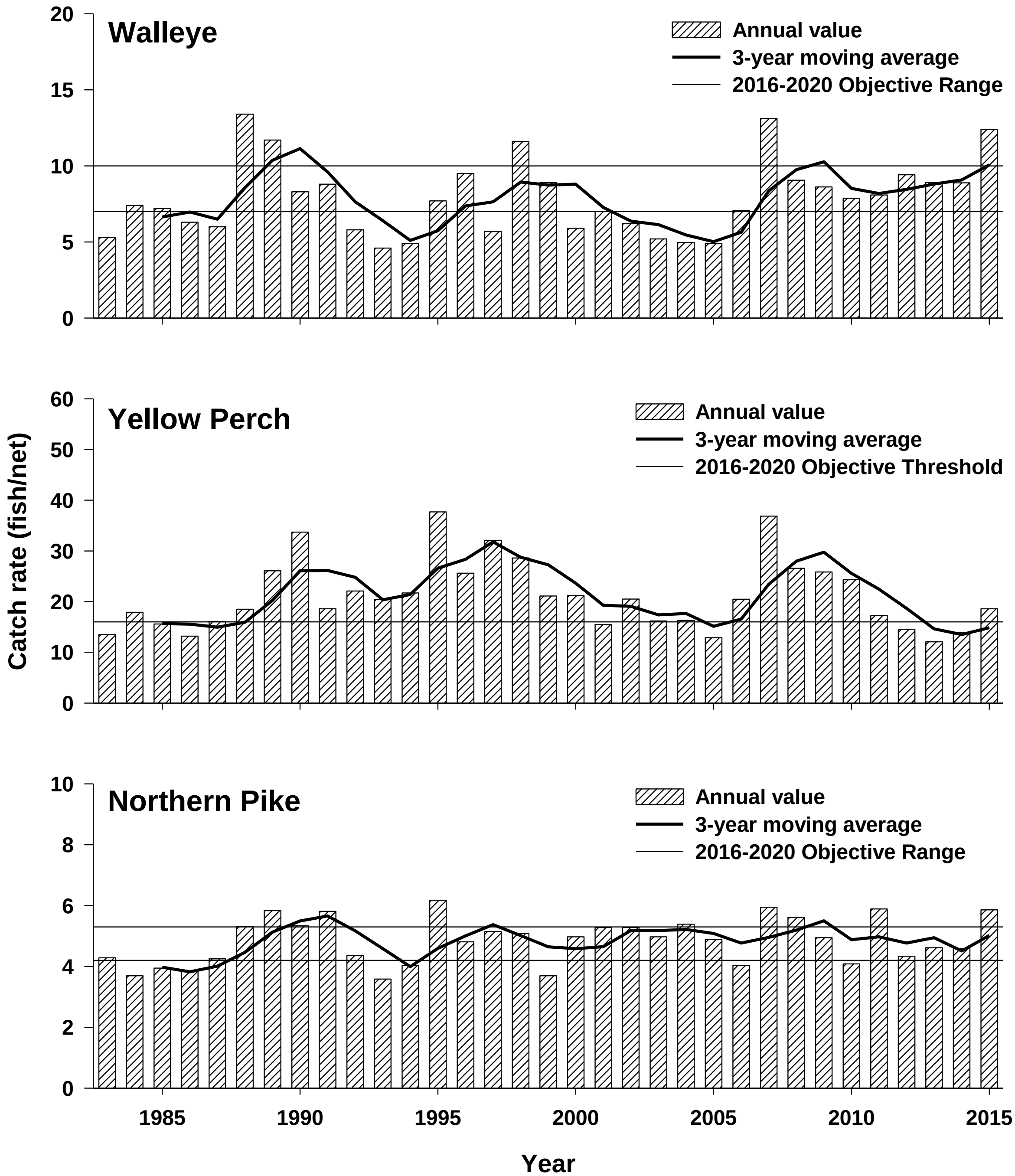

Figure 19. Gill net catch rates of Walleye, Yellow Perch, and Northern Pike from 1983-2015 compared to the 2016-2020 Fisheries Management Plan for Leech Lake objectives (Ward 2016).

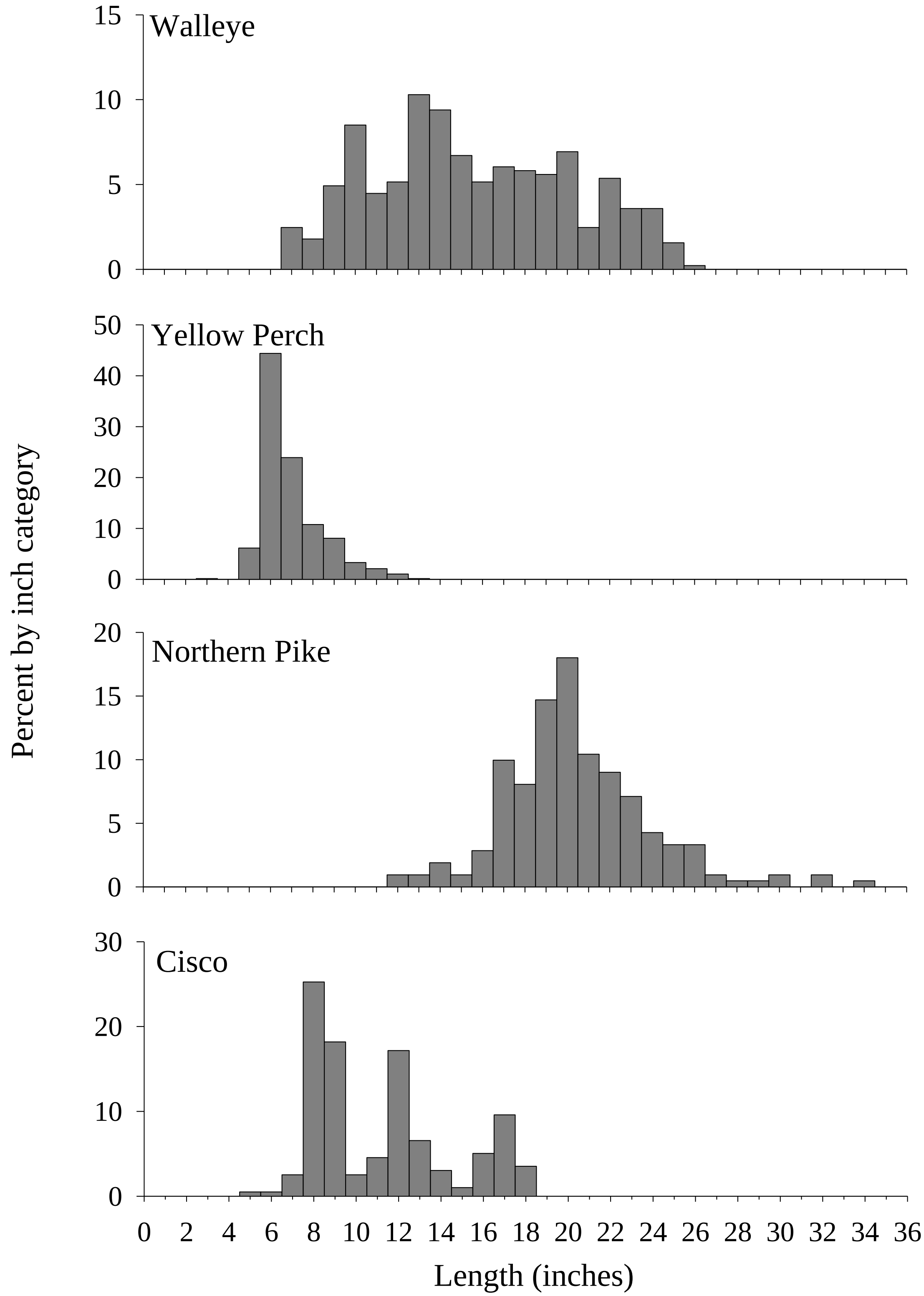

Figure 20. Length frequency distribution for Walleye, Yellow Perch, Northern Pike, and Cisco sampled with gillnets in Leech Lake, 2015.

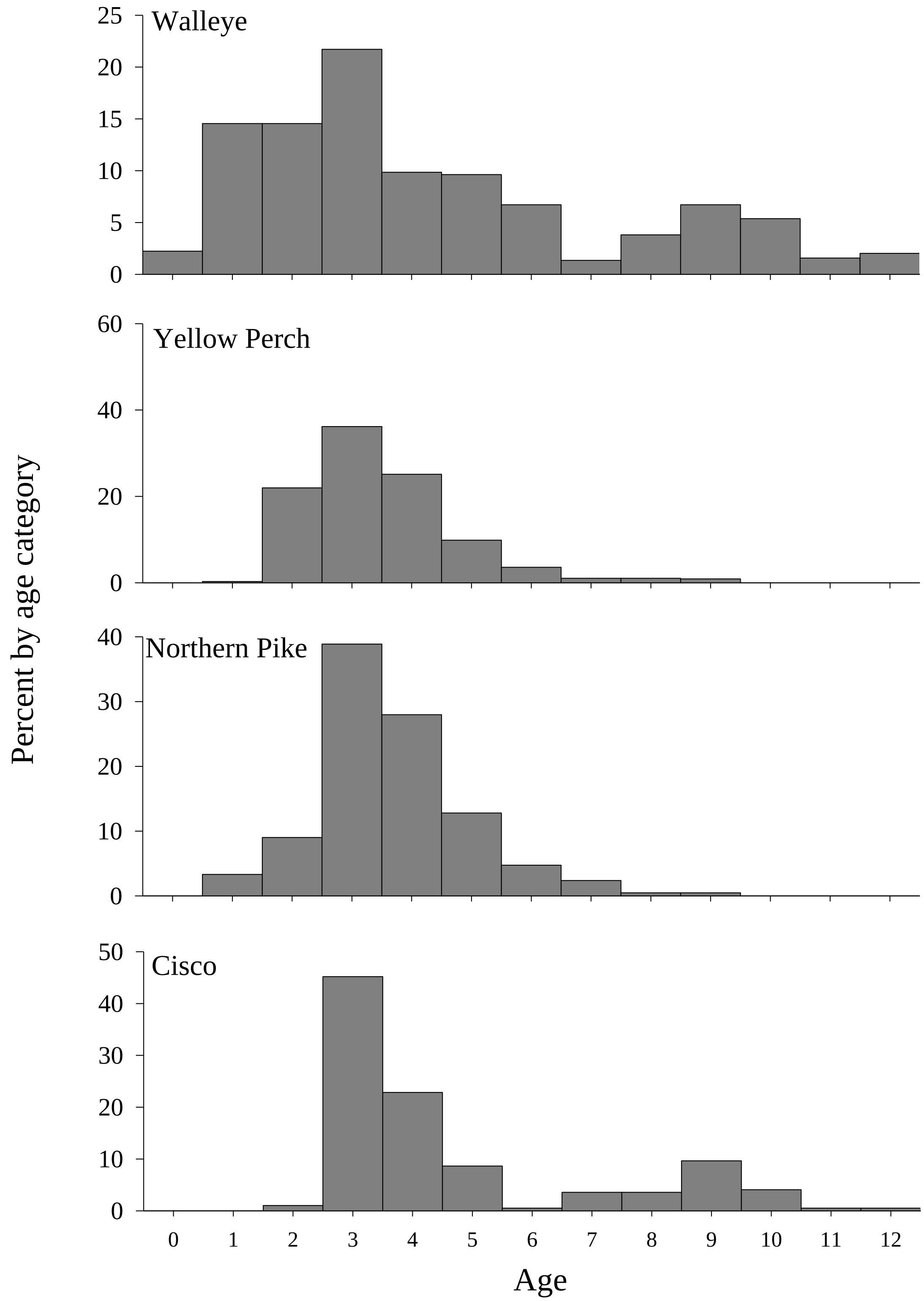

Figure 21. Age frequency distribution for Walleye, Yellow Perch, Northern Pike, and Cisco sampled with gillnets in Leech Lake, 2015. Seven Walleye with between ages 13 and 21 are included in the age 12 bar in this figure.

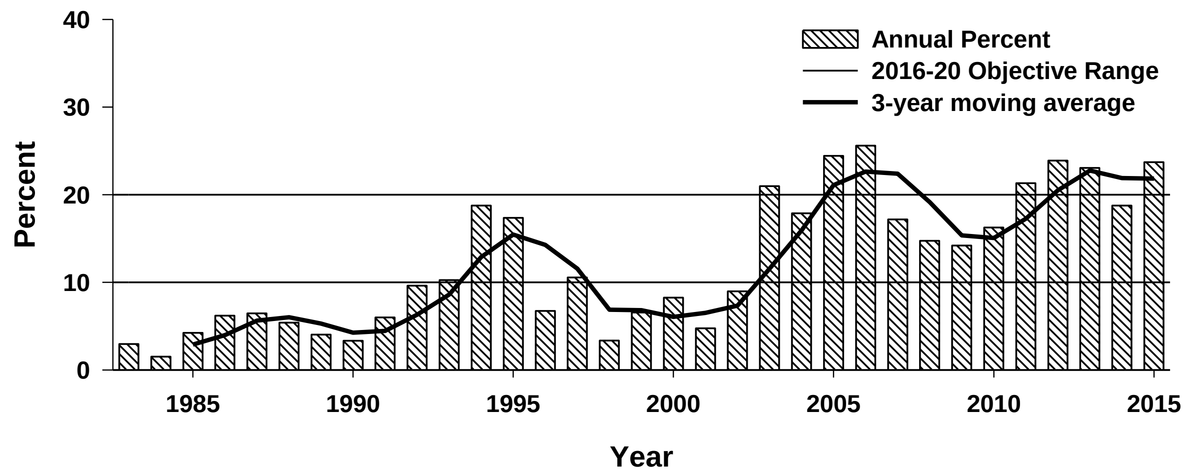

Figure 22. The percentage of Walleye in gill nets ≥20 inches in Leech Lake, 1983-2015. Horizontal lines represent the Management Plan Objective Range (50th and 80th percentiles; Ward 2016). The darker line represents the 3-year moving average.

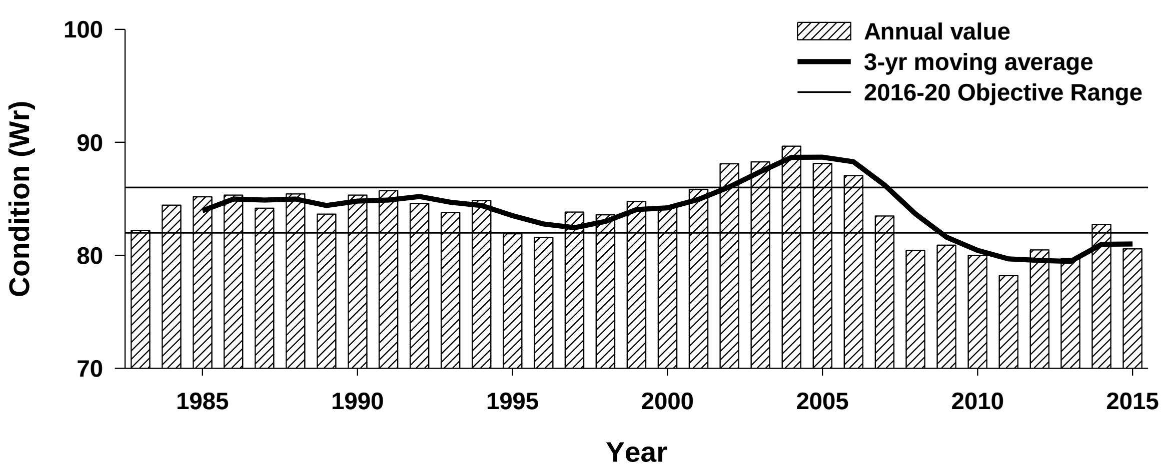

Figure 23. Annual mean condition (Wr) of Walleye in gill nets in Leech Lake, 1983-2015. Horizontal lines represent the Management Plan Objective Range (25^{th} and 75^{th} percentiles; Ward 2016). The darker line represents the 3-year moving average.

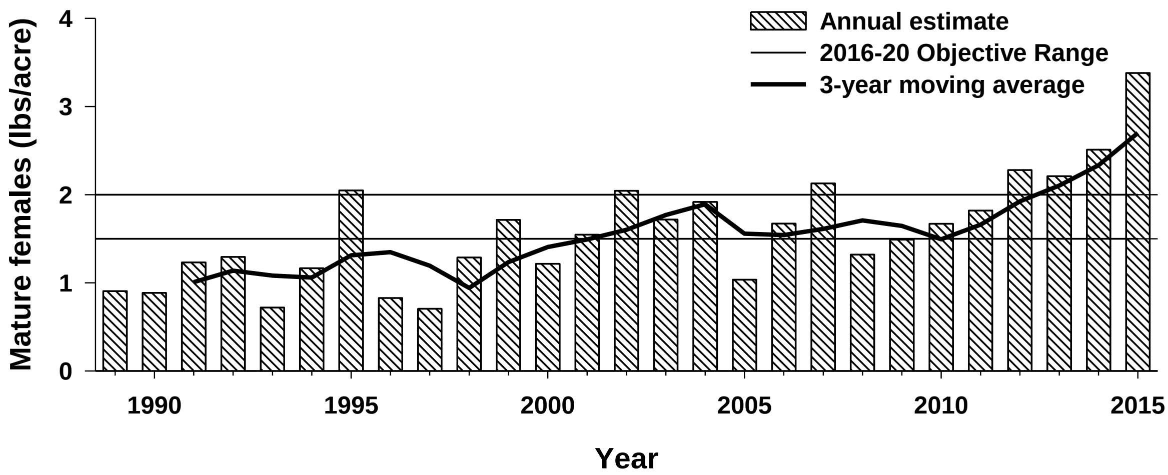

Figure 24. Estimated biomass (pounds/acre) of mature female Walleye in Leech Lake, 1989-2015. Horizontal lines represent the Management Plan Objective Range (50^{th} and 80^{th} percentiles; Ward 2016). The darker line represents the 3-year moving average.

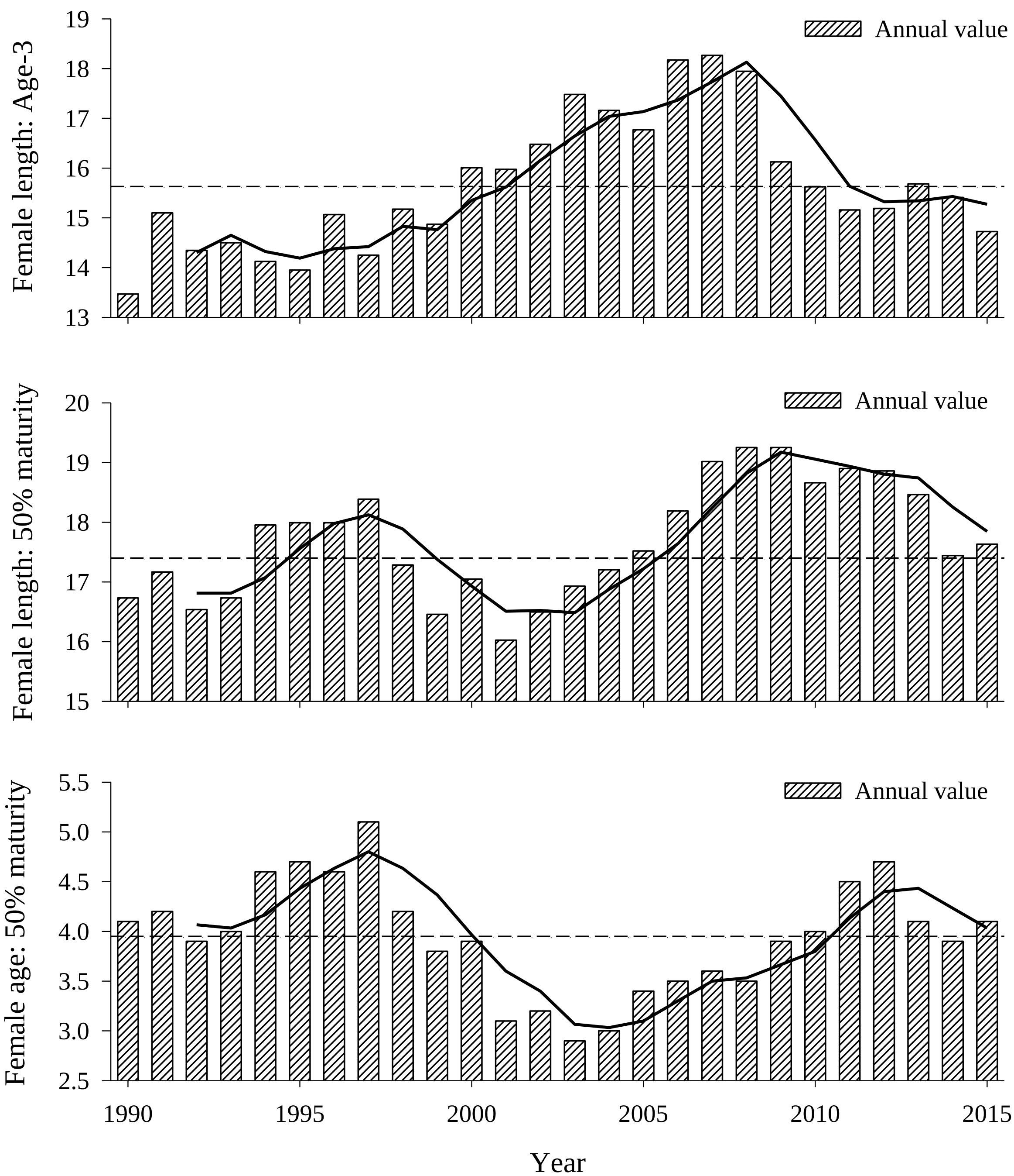

Figure 25. Female Walleye length at age-3 (top), length at 50% maturity (middle) and age at 50% maturity sampled with experimental gillnets in Leech Lake, 1990-2015. Dashed lines indicate thresholds, while the solid line indicates the 3-year moving average. Values above the threshold (dashed line) for female length at age-3 indicate a potential population stress response, while values below the thresholds for both female length and age at 50% maturity indicate a potential population stress response.

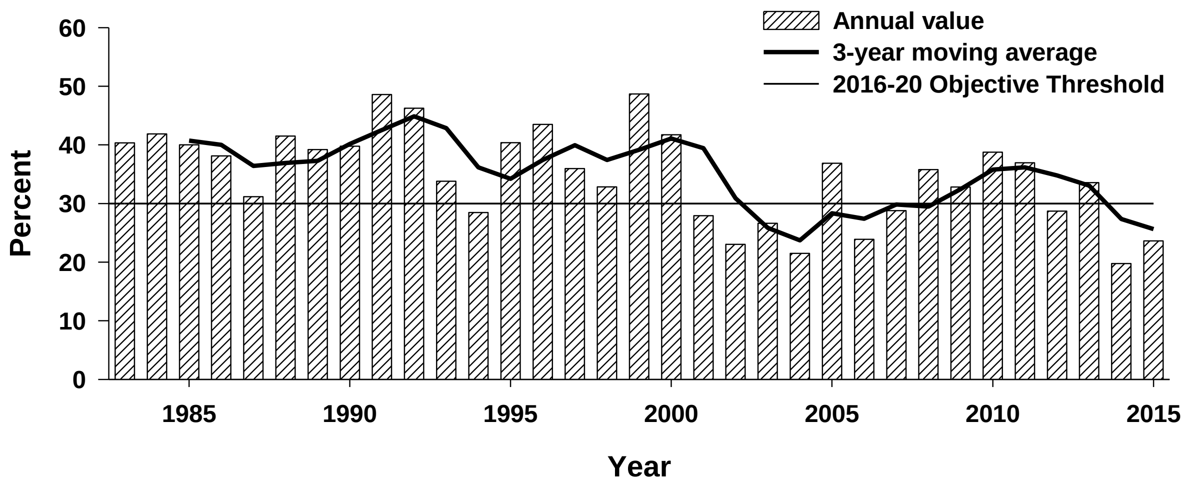

Figure 26. The percentage of Yellow Perch in gill nets ≥8 inches in Leech Lake, 1983-2015. The horizontal line represents the Management Plan Objective Threshold (25th percentile; Ward 2016). The darker line represents the 3-year moving average.

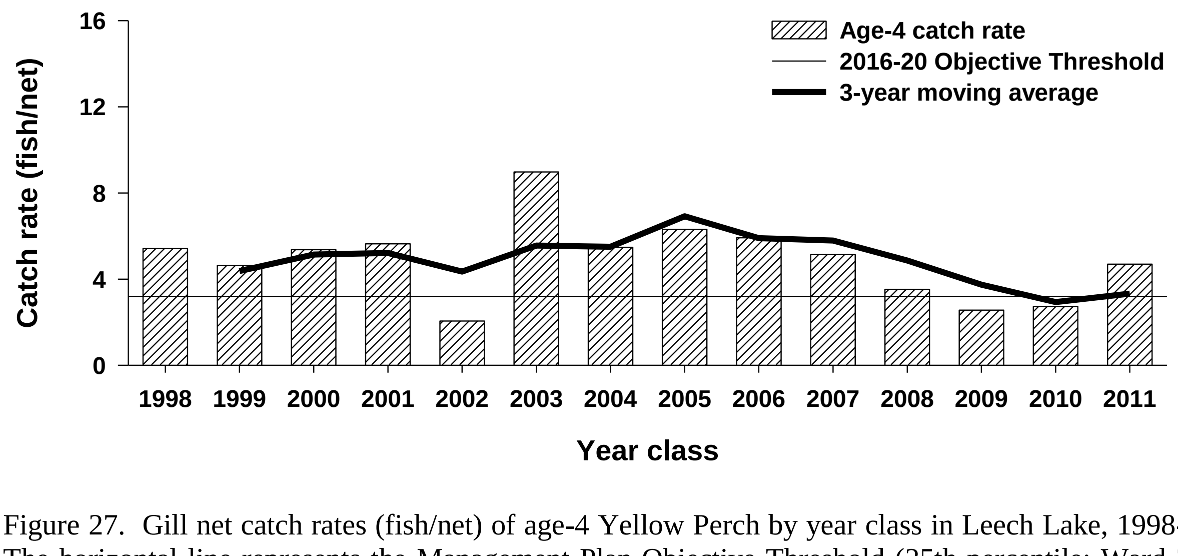

Figure 27. Gill net catch rates (fish/net) of age-4 Yellow Perch by year class in Leech Lake, 1998-2011. The horizontal line represents the Management Plan Objective Threshold (25th percentile; Ward 2016). The darker line represents the 3-year moving average.

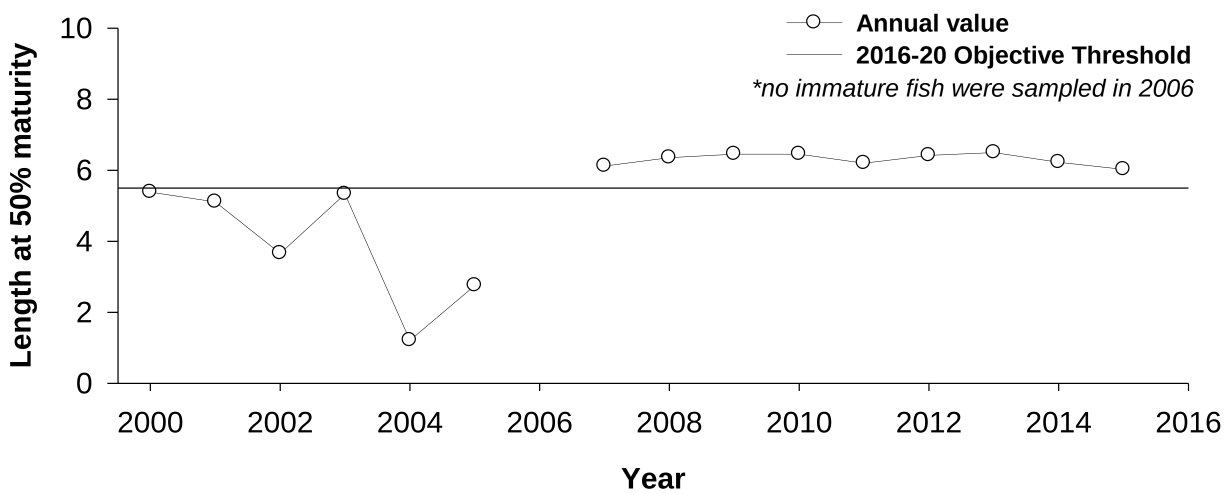

Figure 28. Total length of female Yellow Perch at 50% maturity in gill nets in Leech Lake, 2000-2015. The horizontal line represents the Management Plan Objective Threshold, below which Yellow Perch matured at shorter lengths (5.5 inches; Ward 2016).

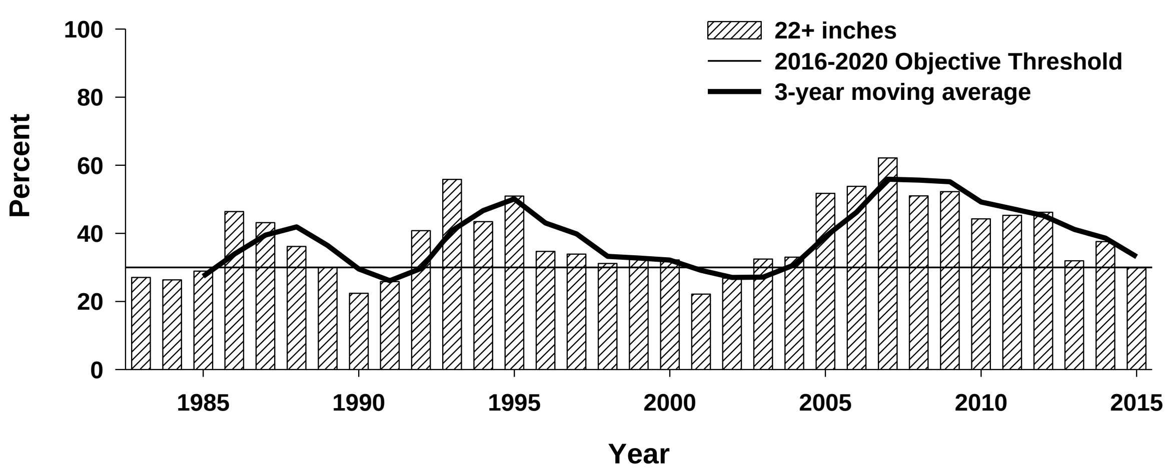

Figure 29. The percentage of Northern Pike in gill nets ≥22 inches in Leech Lake, 1983-2015. The horizontal line represents the Management Plan Objective Threshold (25th percentile; Ward 2016). The darker line represents the 3-year moving average.

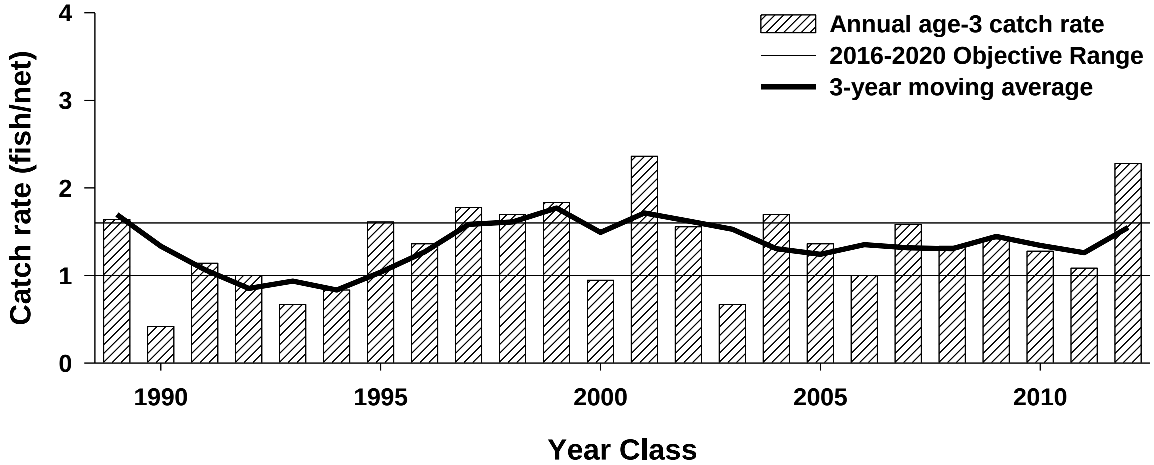

Figure 30. Gill net catch rates (fish/net) of age-3 Northern Pike by year class in Leech Lake, 1998-2012. Horizontal lines represent the Management Plan Objective Range (25th and 75th percentiles; Ward 2016). The darker line represents the 3-year moving average.

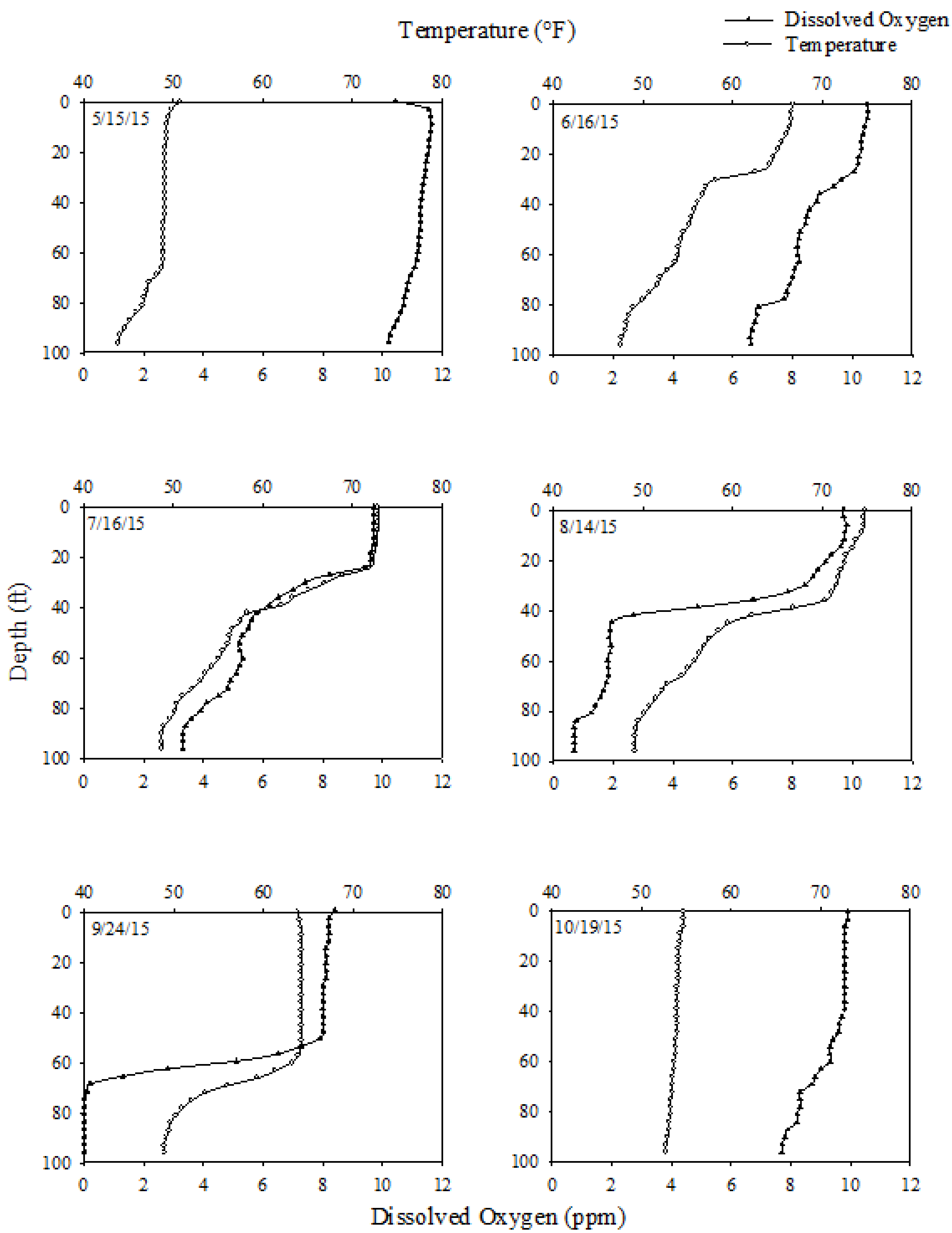

Figure 31. Monthly temperature and oxygen profiles from Walker Bay (WQ1), Leech Lake, from mid-May through mid-October, 2015.

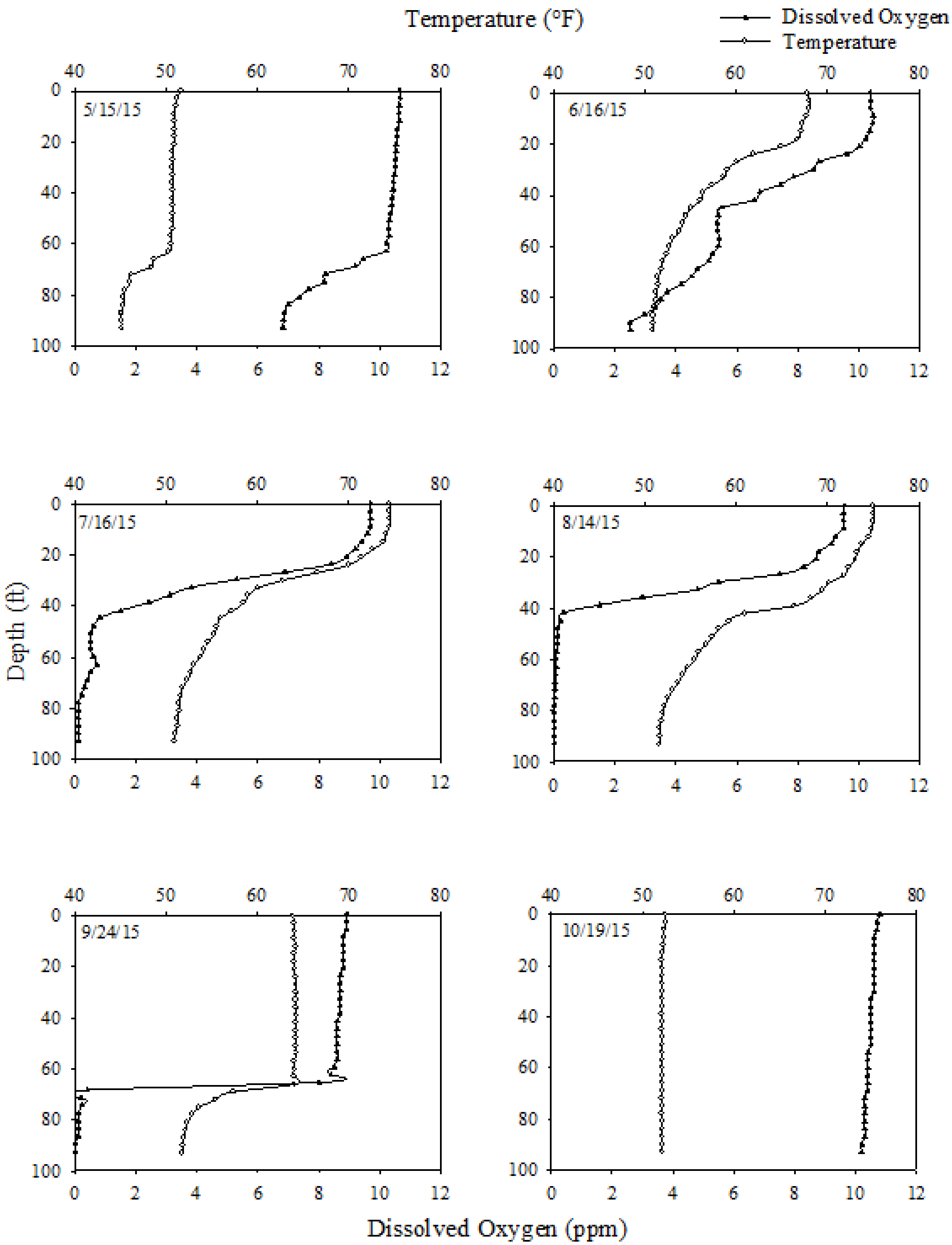

Figure 32. Monthly temperature and oxygen profiles from Agency Bay (WQ2), Leech Lake, from mid-May through mid-October, 2015.

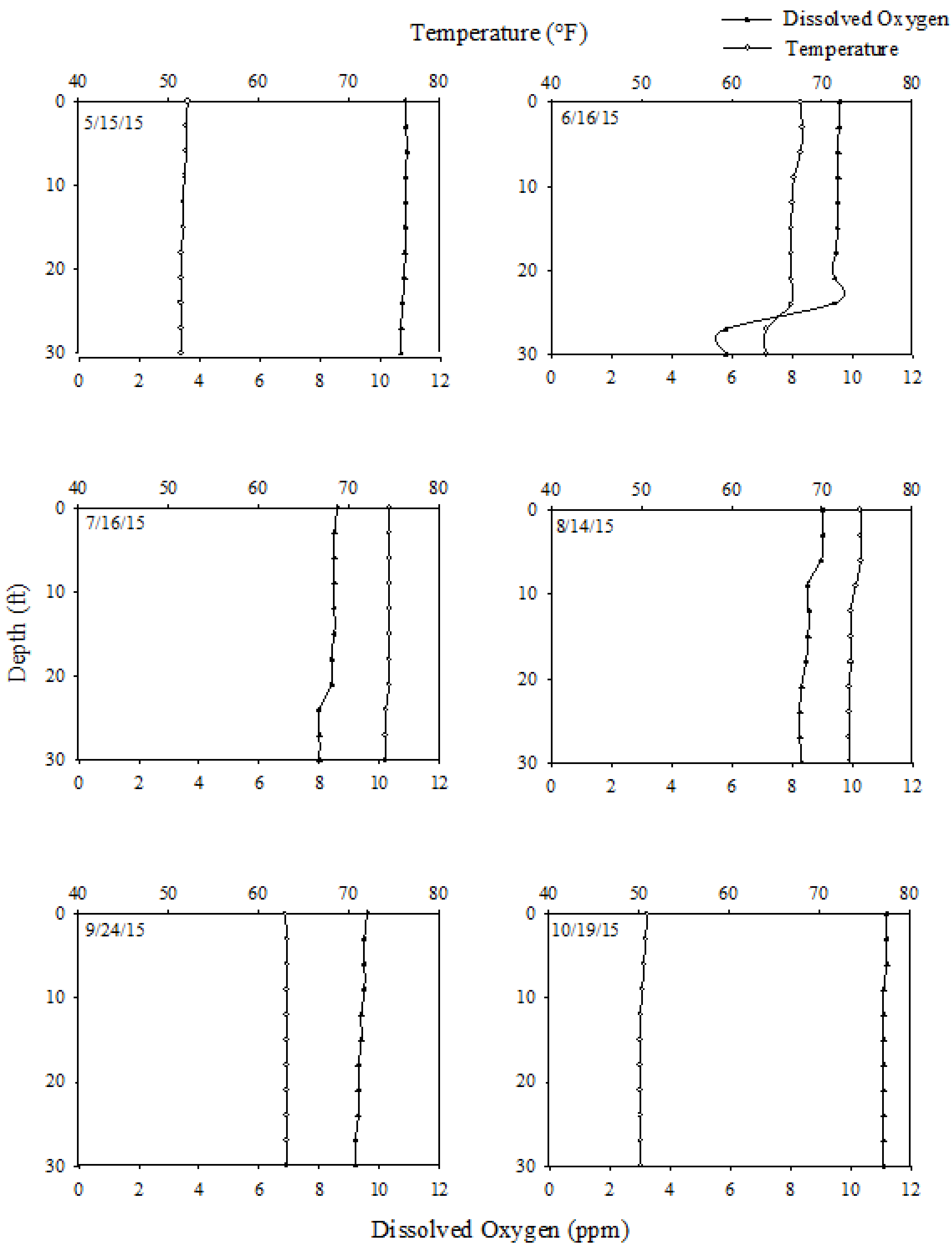

Figure 33. Monthly temperature and oxygen profiles from Portage Bay (WQ3), Leech Lake, from mid-May through mid-October, 2015.

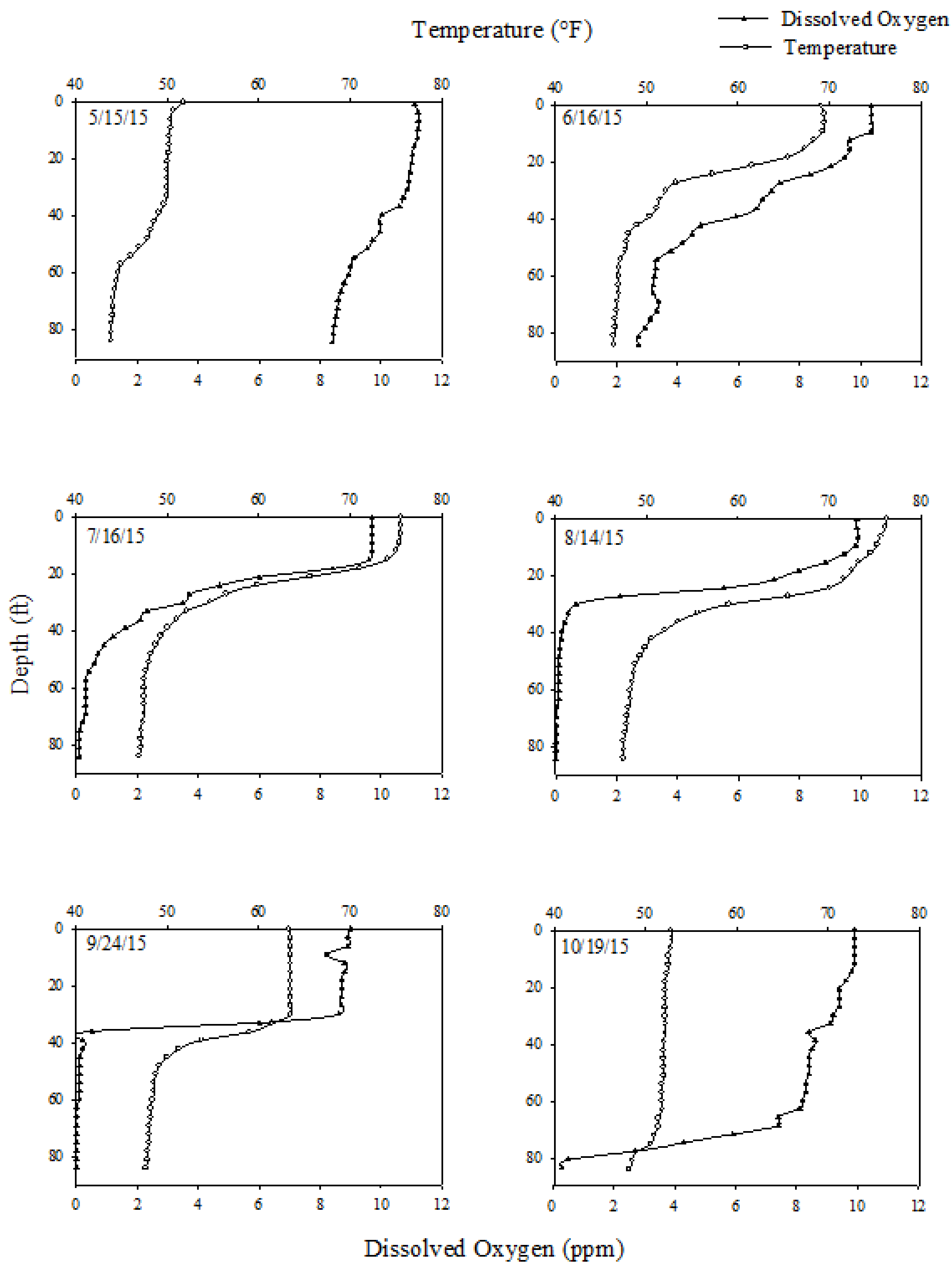

Figure 34. Monthly temperature and oxygen profiles from Kabekona Bay (WQ4), Leech Lake, in Leech Lake from mid-May through mid-October, 2015.

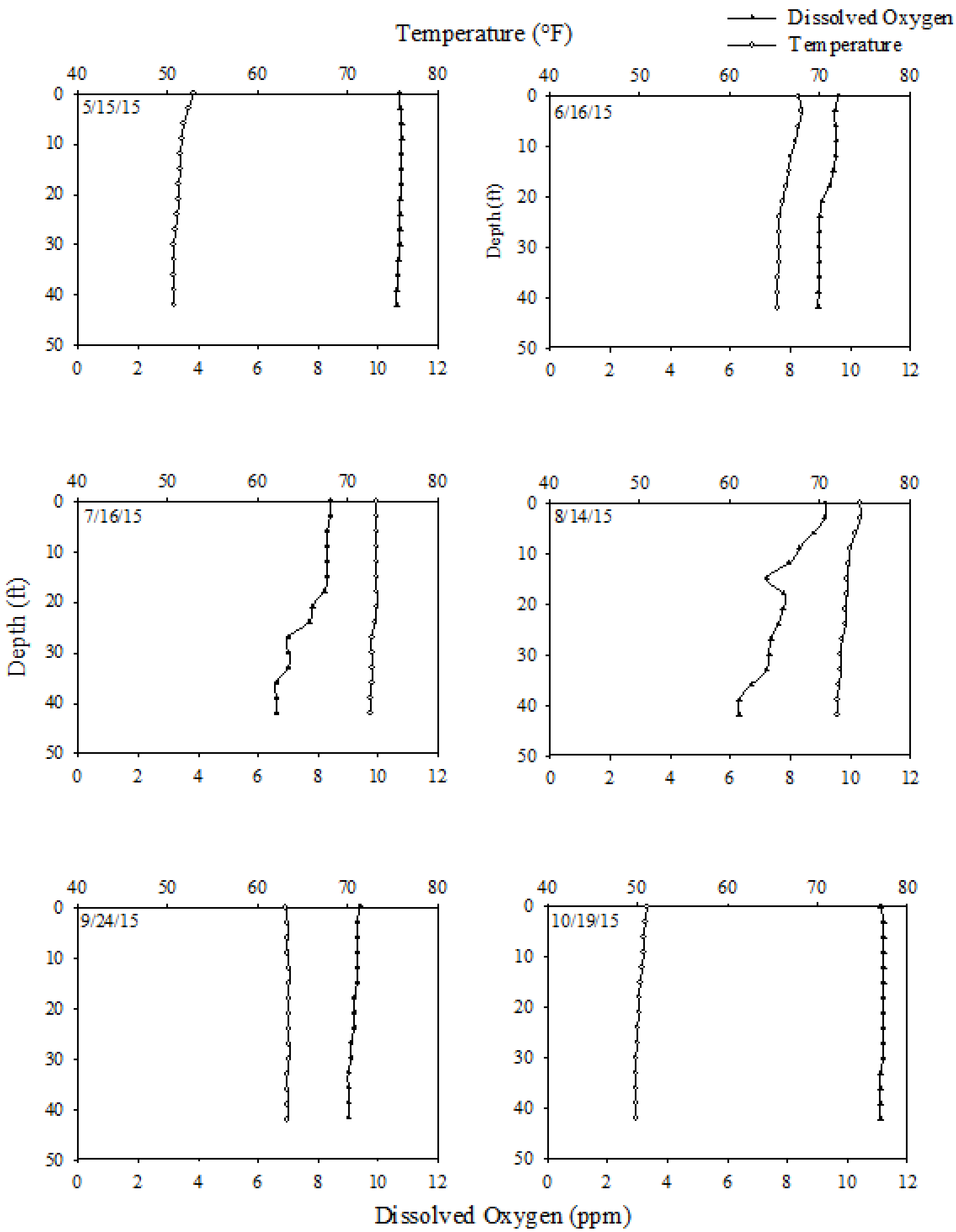

Figure 35. Monthly temperature and oxygen profiles from the Main Basin (WQ5), Leech Lake, from mid-June through mid-October, 2015.

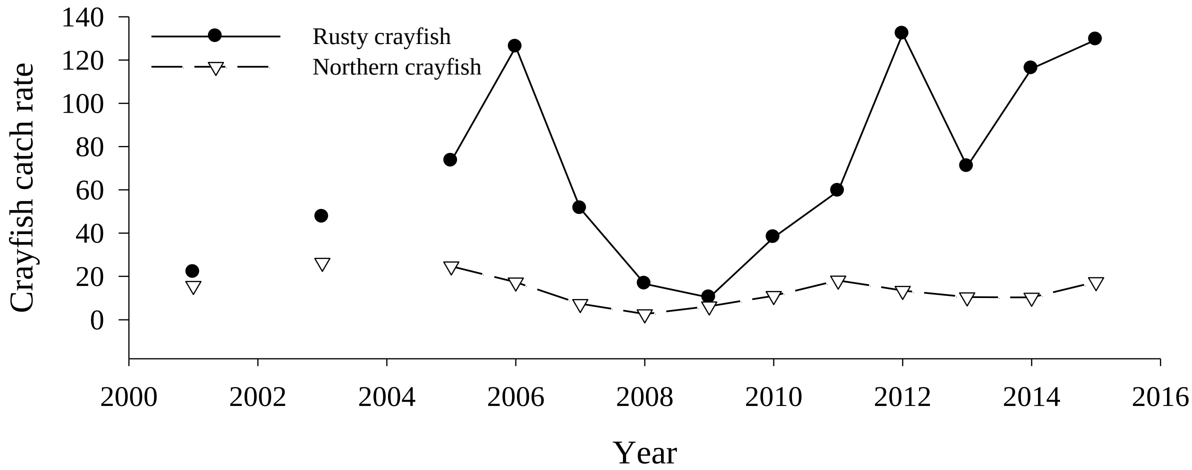

Figure 36. Crayfish entanglement rates (number/net) in gill nets, 2001-2015 as an index of relative abundance. Numbers were not recorded in 2000, 2002, or 2004.

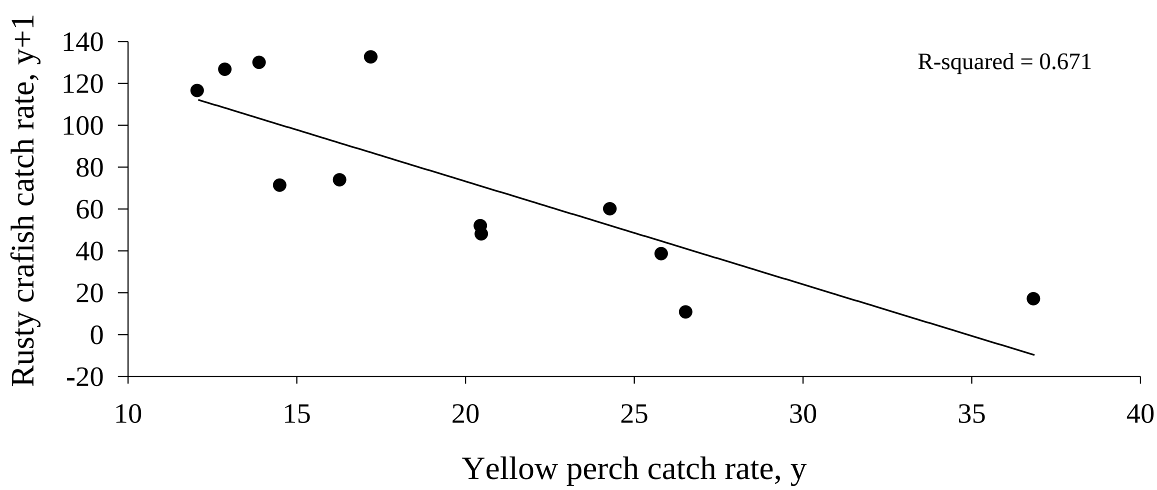

Figure 37. Yellow Perch catch rates (number/net) in year *y* and rusty crayfish entanglement rates (number/net) the following year (*y+1*) in Leech Lake, 2001-2014.

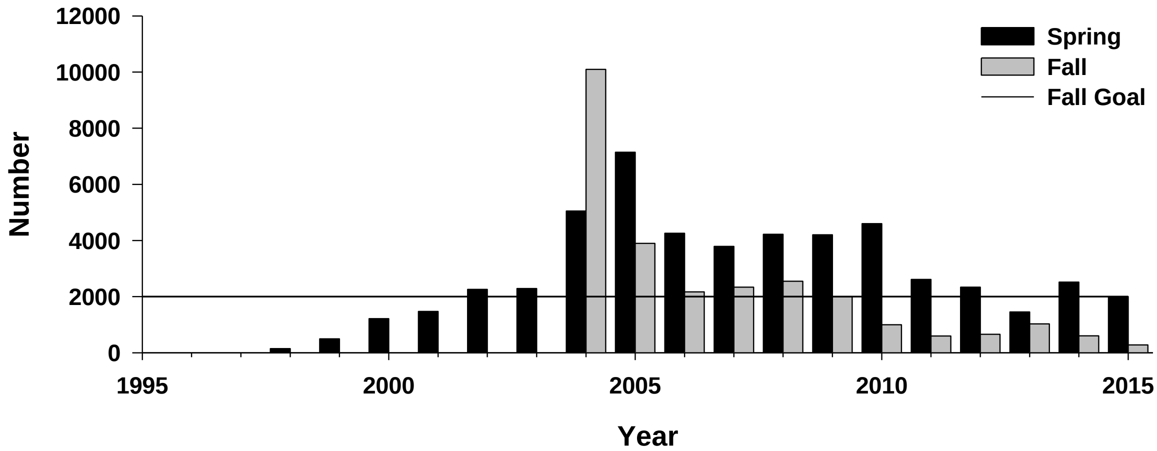

Figure 38. Spring and fall Double-Crested Cormorant numbers on Leech Lake, 1998-2015. The line depicts the current fall population goal of 2,000 birds ([500 nesting pairs x 2 adults] + 2 offspring/nest). (S. Mortensen, Division of Resource Management, Leech Lake Band of Ojibwe, personal communication).

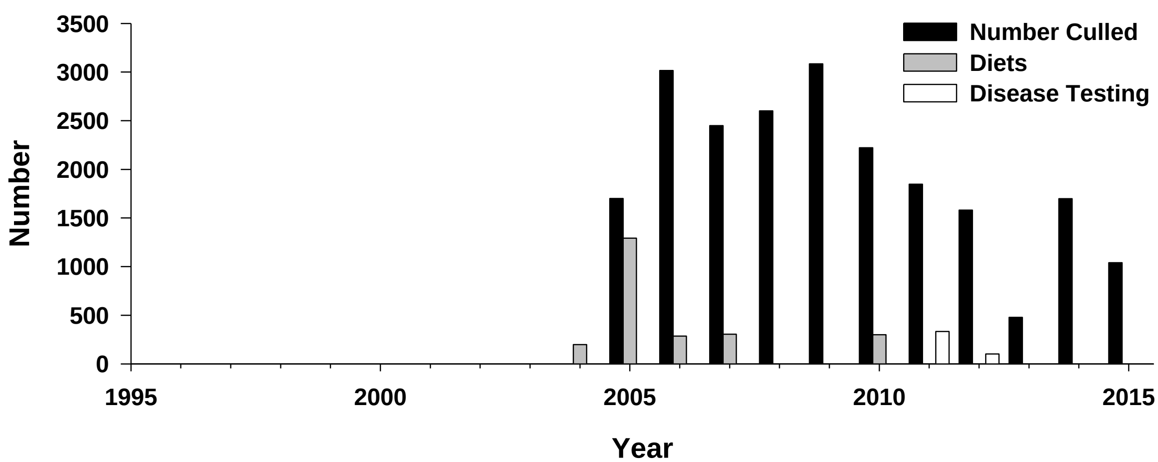

Figure 39. The number of Double-Crested Cormorants culled on Leech Lake, 2000-2015. The number of additional birds culled for diet and disease testing is also indicated. (S. Mortensen, Division of Resource Management, Leech Lake Band of Ojibwe, personal communication).

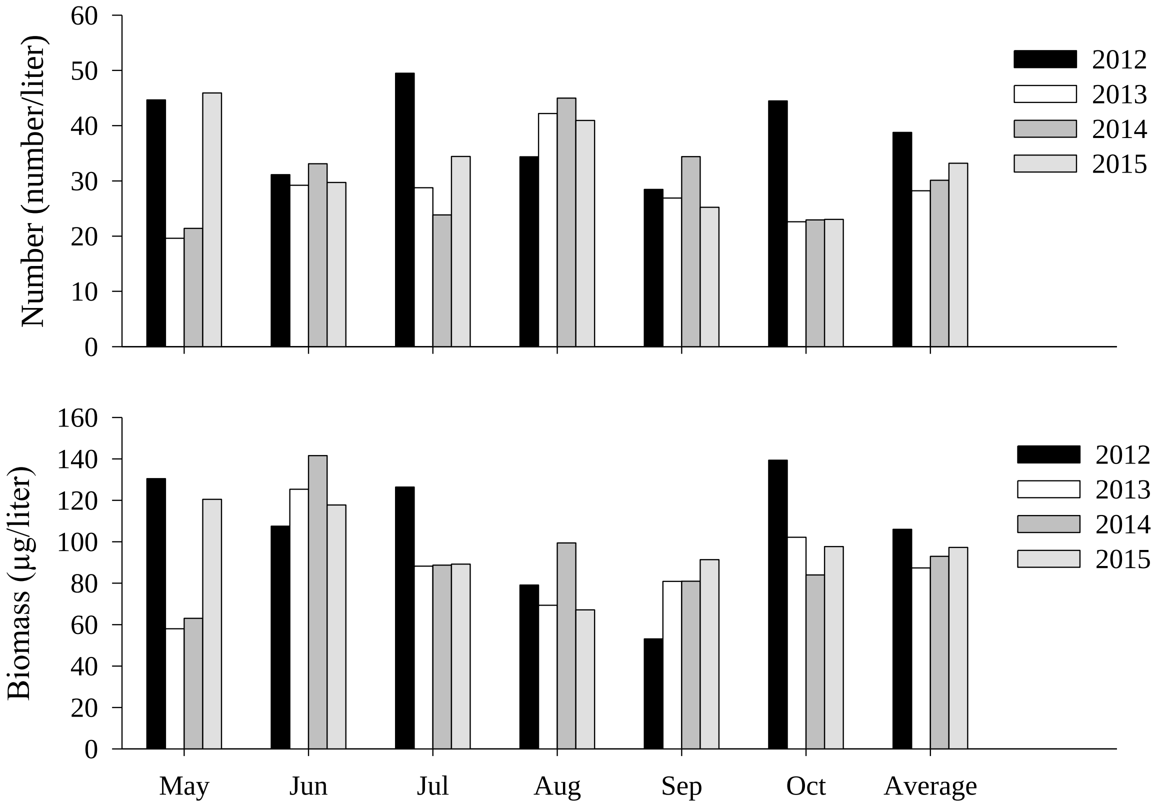

Figure 40. Density (number/liter) and biomass (µg/liter) of zooplankton sampled from May through October at the five standardized zooplankton sites on Leech Lake from 2012-2015.

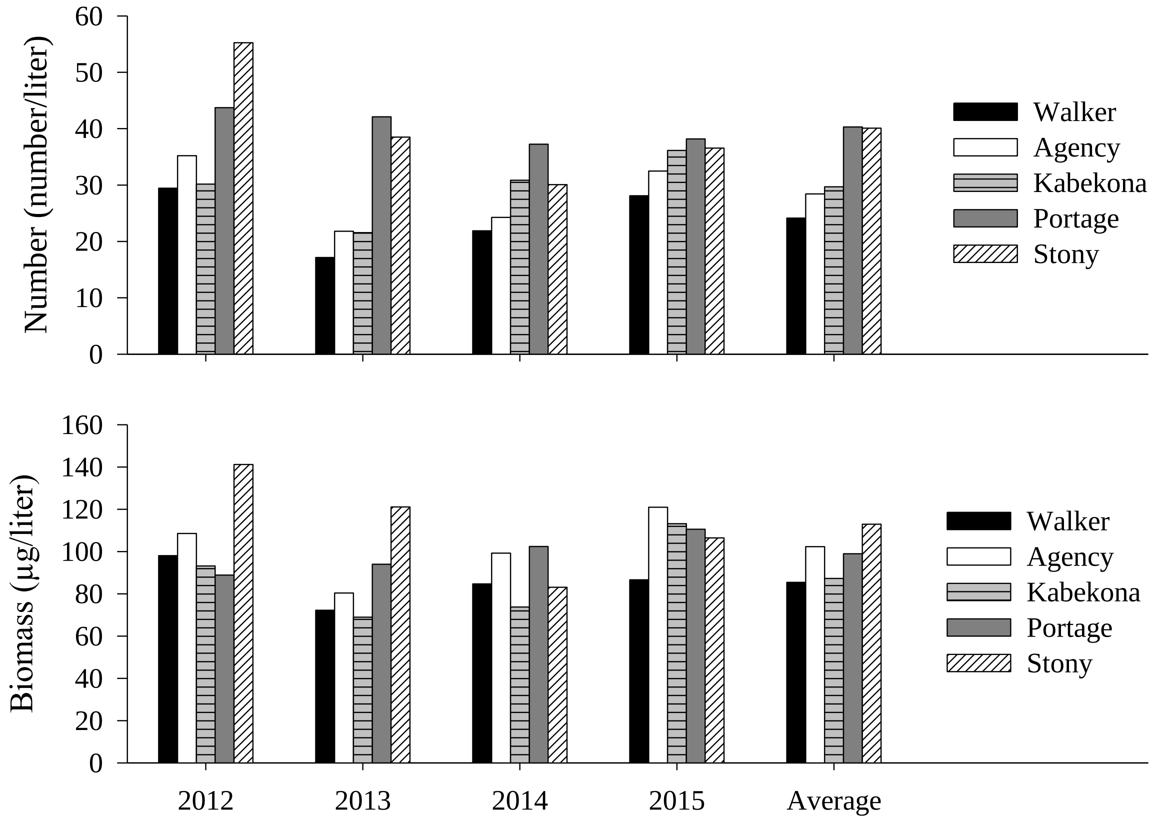

Figure 41. Density (number/liter) and biomass (µg/liter) of zooplankton sampled by bay from 2012-2015 at the five standardized zooplankton sites on Leech Lake.

APPENDIX

Table A1. Gillnet catch-per-effort (fish/net) by species for Leech Lake, 1983-2015.

	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 A1 continued. Gillnet catch-per-effort (fish/net) by species for Leech Lake, 1983-2015.

	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 A1 continued. Gillnet catch-per-effort (fish/net) by species for Leech Lake, 1983-2015.

	Year													Percentiles	
Species	2007	2008	2009	2010	2011	2012	2013	2014	2015	Min	Max	Median	Mean	25th	75th
Black bullhead	1.9	1.1	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	21.3	1.8	4.9	0.7	9.7
Black crappie	1.7	0.9	1.1	0.6	0.5	0.2	0.9	0.4	0.8	0.1	1.7	0.3	0.4	0.2	0.5
Bluegill	1.1	1.2	1.1	0.6	0.7	0.3	1.2	0.1	0.7	0.0	2.1	0.3	0.5	0.1	0.7
Bowfin	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.3	0.1	0.1	0.0	0.1
Brown bullhead	4.3	2.0	0.6	1.9	0.6	0.3	0.2	0.1	0.4	0.1	4.3	1.1	1.5	0.7	2.0
Burbot	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.1	0.1	0.0	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	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	0.0	0.4	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	0.0	0.4	0.1	0.1	0.0	0.1
Muskellunge	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.1
Northern pike	5.9	5.6	4.9	4.1	5.9	4.3	4.6	4.6	5.9	3.6	6.2	4.9	4.8	4.2	5.3
Pumpkinseed	1.3	1.5	0.7	0.3	0.3	0.4	1.4	0.3	0.6	0.1	2.1	0.6	0.8	0.3	1.1
Rock bass	1.3	2.4	2.2	1.0	1.3	0.8	1.4	0.8	1.3	0.4	2.9	1.3	1.5	1.0	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	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	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	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	0.6	18.5	4.2	5.4	2.7	6.3
Walleye	13.1	9.1	8.6	7.9	8.1	9.4	8.9	8.9	12.4	4.6	13.4	7.7	7.9	5.9	8.9
White sucker	0.7	0.6	1.1	0.6	1.1	1.5	0.9	1.1	0.9	0.6	3.1	1.3	1.5	1.1	1.9
Yellow bullhead	4.2	2.6	1.4	2.8	1.0	0.6	0.4	0.4	1.4	0.3	4.2	1.3	1.5	0.8	1.9
Yellow perch	36.9	26.6	25.8	24.3	17.2	14.5	12.1	13.9	18.6	12.1	37.7	20.4	21.1	16.1	25.6
Total fish/set	77.0	55.3	60.1	50.6	39.1	36.4	35.6	34.7	48.8	34.7	78.0	50.6	52.0	42.3	59.3
Total sets	36	36	36	36	36	36	36	36	36						