

Assessment of the Bone Lake Muskellunge Population, 2017-2018
Polk County, WI
MWBIC Code: (2628100)



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Executive Summary

Muskellunge (*Esox masquinongy*) were sampled in Bone Lake during 2017 and 2018 using mark and recapture methodology to estimate abundance and size structure of adult (≥ 30 in) fish. The adult population (sexes combined ≥ 30 in) was estimated to be 627 fish, or 0.35 (95% CI: 0.28-0.42) adult fish/acre. This is the lowest Bone Lake muskellunge population estimate since 1964 but is still considered a moderate density compared to other Wisconsin muskellunge populations. This density should provide good angling action while producing larger-bodied fish. As muskellunge density decreased over time, the size structure of the population increased. Size structure of the muskellunge population was the highest ever documented in Bone Lake. The improvement in size structure was the most apparent difference with the Bone Lake muskellunge population between this survey and previous surveys. The greatest size structure increases were observed in the largest size classes, which should be of interest to muskellunge anglers. It is too early to truly evaluate the 50 in minimum length limit (MLL) that was implemented in 2011. This increase in size structure could be partly attributed to the 50 in MLL, but likely was more due from the lower adult density and presumably lower levels of exploitation since the 2011-2012 survey. The muskellunge fishery should be managed at a moderate density with high size structure. The target population level of muskellunge in Bone Lake should be maintained between 0.2 to 0.4 adult fish/acre. An adult density within this range should provide a population with high size structure and a density that would offer reasonable angler catch rates. The alternate year stocking regime should be reduced from 1.5 large fingerlings/ac every other year to 1 large fingerling/ac every other year. Bone Lake is on a six-year rotation for muskellunge population estimates. We will continue to monitor the density, size structure, population demographics, and exploitation of the Bone Lake muskellunge fishery. Future surveys will also be used to monitor the response of the muskellunge population to the reduction in stocking rate.

Introduction

Bone Lake is a 1,781-acre drainage lake in central Polk County, Wisconsin. The lake has a maximum depth of 43 feet, and a mean depth of 20 feet (Figure 1). There are approximately 12.5 miles of shoreline, nearly all of which is in private ownership. The watershed is predominately forested (48%) and agriculture (20%; <http://ifrshiny.seas.umich.edu/mglp/>). There is an outflow on the southeast portion of Bone Lake that forms the headwaters of Fox Creek. Anglers have access to the lake through two public boat landings.

The Trophic State Index (TSI) for Bone Lake during the summer months indicates phosphorus and Chlorophyll A levels are in the lower eutrophic range and transparency is in the upper mesotrophic range. Overall, Bone Lake is considered eutrophic. The lake has moderately clear water early in the summer and algae blooms later in the summer.

The fish community consists of muskellunge (*Esox masquinongy*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*), northern pike (*E. lucius*), bluegill (*Lepomis macrochirus*), pumpkinseed (*L. gibbosus*), black crappie (*Pomoxis nigromaculatus*), yellow perch (*Perca flavescens*), white sucker (*Catostomus commersoni*), bullheads (*Ameiurus* spp.), and golden shiner (*Notemigonus crysoleucas*).

Bone Lake has long supported a well-known muskellunge fishery that is popular among anglers. Although muskellunge are not native to Bone Lake (Becker 1983), the lake has been managed for muskellunge since 1935, when the Wisconsin Department of Natural Resources (WDNR) initially stocked muskellunge. Muskellunge are not known to naturally reproduce in Bone Lake; therefore, the reproductive classification is Category 3 where stocking is necessary to maintain the population (WDNR 2012).

Bone Lake is currently classified and managed as an A1 muskellunge water, defined by its ability to produce large fish, but the overall abundance of muskellunge is lower compared to other muskellunge waters (WDNR 2012). It was previously managed as an A2 muskellunge water, a high-density action muskellunge fishery with low size structure. Due to the higher stocking rates during the 1980s and 1990s, more restrictive length limit regulations, and the increase in sport angler voluntary catch and release, the muskellunge density in Bone Lake became as high as 0.99 adult fish/acre in 1995 (Cornelius and Margenau 1999). The high density provided good angling action for

numbers of fish; however, the size structure and condition (Wr) of Bone Lake muskellunge declined when densities were high. This lower Wr suggested that high muskellunge densities caused certain forage fish species to decline, which prompted the WDNR to alter the Bone Lake muskellunge management plan. Since 2001, the Bone Lake muskellunge stocking was reduced to 1.5 fish/acre every other year (Table 1).

The only special fishing regulation is for muskellunge, which have a 50-inch minimum length limit (MLL) and one fish daily bag limit. The 50-inch MLL was implemented in 2011, with the objective of improving the size structure; specifically, to increase the abundance of fish 45 in and larger. Prior to the 50-inch MLL, Bone Lake muskellunge were managed with a 40-in MLL which was implemented in 1990.

In addition to the popular sport fishery, the Bone Lake muskellunge population supports winter and spring spear fisheries for the Chippewa tribes under the Voigt decision. The muskellunge spring spear fishery is closely regulated with harvest quotas set from the most recent population estimates (whether from a population survey or a regression model) so that the risk of exceeding the maximum sustainable exploitation rate of 27% for muskellunge is less than 1-in-40 (Staggs et al. 1990). In addition, Great Lakes Indian Fish and Wildlife Commission (GLIFWC) creel clerks count all speared fish and measure a sample of speared fish during the open water spearing season (Staggs et al. 1990). Typically, the annual quota has not been reached. The average number of muskellunge harvested each spring has been 10.3 (SE=1.6), and the average number allowed has been 18.9 (SE=3.2). The winter spear fishery is less regulated. Winter spearing of muskellunge is currently considered an "inefficient gear"; therefore, no safe allowable harvest quota exists. Harvest is typically not recorded during the winter spear fishery and fish are not measured by creel clerks. However, once every five years GLIFWC does conduct a creel on the winter spearfishing effort and reports tribal winter spear harvest.

Bone Lake has been one of the most surveyed muskellunge lakes in Wisconsin. The most recent muskellunge survey was conducted in 2011-2012, and survey data indicated the muskellunge population to be at a moderate density (0.42 adult fish/acre), but both the density and size structure declined from the 2005 survey, which appeared to be from increased exploitation (Cole 2013).

The objectives of this survey were to assess the abundance, size structure, and population demographics of adult muskellunge in Bone Lake, make comparisons to previous surveys, and assess the current muskellunge management strategy. Data from seven previous sampling periods (1964-1965, 1982-1983, 1985-1986, 1990-1991, 1995-1996, 2005-2006, 2011-2012) were available to monitor trends in muskellunge population parameters. Hereafter, sampling periods will be referred to by their first year.

Methods

The population abundance of adult (≥ 30 in) muskellunge was estimated using mark and recapture methodology. Muskellunge surveys are two-year fyke netting surveys, so 2017 served as the marking year and 2018 was the recapture year. Fyke nets had 4 X 6 ft. frames with 0.5 to 0.75-in bar mesh and lead lengths of either 75 or 100 ft. long. Nets were set shortly after ice-out, and checked every 24-h for approximately one week each year. Each muskellunge was measured to the nearest 0.1 in total length, and weighed to the nearest 0.1 lb. The sex of captured fish was determined by presence of eggs or milt or by visual inspection of the urogenital pore as described by LeBeau and Pageau (1989). Anal fin rays were taken for aging purposes and weights were taken during both years. Since this was the first survey anal fin rays were collected on Bone Lake, we also used the anal fin clip as our primary mark. Any muskellunge collected < 30 in was given a right pelvic fin clip in addition to an anal fin clip. In addition, all muskellunge collected ≥ 20 in were PIT tagged. Fish were checked for marks during the recapture event in 2018. To prevent double-counting fish, all fish handled in 2018 were marked by clipping the top corner of the caudal fin.

Abundance of adult muskellunge was estimated using Chapman's modification of the Petersen single-census method (Ricker 1975):

$$N = \frac{(M + 1)(C + 1)}{(R + 1)}$$

where N = population estimate; M = the number of fish marked in the first (marking) sample; C = the total number of fish (marked and unmarked) captured in the second (recapture) sample; and R = the number of marked fish captured in the second sample.

The number of fish collected in 2018 was adjusted for recruitment over a 1-year period. For this, all muskellunge collected in 2018 that were less than 32.0 in were excluded from the adult population estimate because they were assumed to have been less than 30 in during the 2017 marking event. These lengths were determined from recapture data; that is to say, all muskellunge recaptured with the primary mark in 2018 were greater than 32.0 in and all muskellunge recaptured with a right pelvic fin clip were less than 32.0 in.

Several independent abundance estimates were calculated: 1) adult muskellunge ≥ 30 in, 2) adult muskellunge of each sex ≥ 30 in; and 3) adult muskellunge, sexes combined and unknowns, 30.0- 33.9 in, 34.0-37.9 in, 38.0 in and greater, and 40.0 in and greater.

Proportional size distribution (PSD) indices were used to describe population size structure (Guy et al. 2007). PSD values represent the percent of fish stock length or larger that are also larger than a specified length. Stock length was set at 30 in per WDNR protocols. PSD lengths of interest were the proportion of muskellunge ≥ 34 in (PSD34), ≥ 38 in (PSD38), ≥ 40 in (PSD40), ≥ 42 in (PSD42), and ≥ 46 in (PSD46).

Relative weight (Wr) was used to describe condition of muskellunge. Relative weight is the ratio of a fish's weight at capture to the weight of a "standard" fish of the same length determined by the standard weight equation for muskellunge developed by Neumann and Willis (1994). The mean relative weight was determined.

Muskellunge anal fin rays were cut with a Dremel saw and aged under a dissecting microscope with side illumination from a fiber optic light. Mean length-at-age comparisons were made with the Barron and Polk County averages, and the

regional averages (18 counties in the WDNR Northern Region) obtained from the WDNR Fisheries and Habitat database.

The von Bertalanffy (1938) growth model was determined using mean length at age data to assess growth using the following equation. Growth equations were calculated separately for each sex due to sex-specific growth differences.

$$L_t = L_{inf} (1 - e^{-k(t-t_0)})$$

Where L_t is length at time t , L_{inf} is the maximum theoretical length (length infinity), e is the exponent for natural logarithms, k is the growth coefficient, t is age in years, and t_0 is the age when L_t is zero.

The instantaneous mortality (Z) and annual mortality ($A = 1 - e^{-Z}$) rates were determined using a catch curve regression fitted to those ages fully recruited to the gear (Miranda and Bettoli 2007).

The annual exploitation rate for Bone Lake muskellunge was estimated by adding two of the three primary sources of exploitation that Bone Lake muskellunge face: open water tribal spear harvest and winter tribal spear harvest. Tribal harvest data were available from GLIFWCs 2017 open water spear season, and the winter spear harvest estimate was obtained from the 2017-2018 GLIFWC Bone Lake winter spearing creel (Luehring 2019). A lake-specific estimate of recreational exploitation (i.e., angler harvest and delayed fishing mortality) was unknown and therefore not factored into this the analysis. As such, the exploitation estimate was considered a conservative estimate.

Results

There were up to 14 fyke nets set for eight nights in 2017, which totaled 104 net-nights of effort (Table 2). Similarly, there were up to 14 fyke nets set for seven nights in 2018, which totaled 94 net nights. The catch per effort was 1.9 muskellunge per net-night in 2017 and 3.3 muskellunge per net-night in 2018.

There were 183 adult (≥ 30 in) muskellunge (90 males, 92 females, and 1 unknown sex) marked in 2017 and 234 adult muskellunge (92 males, 140 females, and

2 unknown sex) collected in 2018 (Figure 2). Of the muskellunge captured in 2018, there were 68 (35 males and 33 females) recaptures from 2017. The adult population (sexes combined ≥ 30 in) was estimated to be 627 fish (95% CI: 503-750), or 0.35 adult fish/acre (Figure 3). The population decreased since the most recent survey in 2011, when abundance was estimated to be 743 fish (95% CI: 498-989), and a density estimate 0.42 adult fish/acre. The current population estimate was the lowest since the first Bone Lake muskellunge assessment in 1964.

Population estimates by sex for 2017 were 234 males (CV=0.13) and 385 females (CV=0.13; Table 3). The abundance estimates by length group for 2017 were: 133 from 30.0-33.9 in; 224 from 34.0-37.9 in; 265 ≥ 38 in; and 166 ≥ 40 in. Abundance of muskellunge ≥ 38 in and ≥ 40 in increased greatly (124% and 158%, respectively) from the 2011 survey, but were slightly less than the 2005 survey. However, the abundance of the smaller length groups (i.e., 30.0-33.9 and 34.0-37.9 in) decreased when compared to the 2011 survey. Abundance of muskellunge in the 30.0-33.9 in and 34.0-37.9 in length groups decreased by 67% and 30%, respectively, from the 2011 survey. In general, the abundance of the smaller size groups (i.e., 30.0-33.9 and 34.0-37.9 in) were the lowest documented on Bone Lake, but the abundance of ≥ 40 in muskellunge were similar to the other two highest years (i.e., 1995 and 2005).

Muskellunge ranged in length from 12.2 to 48.0 in, and the mean length of muskellunge (sexes combined) was 35.7 in (SE= 0.24); the mean length by sex was 33.3 in (SE=0.28) for males, and 38.6 in (SE=0.28) for female (Table 4). The mean length for male muskellunge was similar to the those of the last several surveys, but the length for female muskellunge was the highest ever documented in a Bone Lake survey. The mean length for sexes combined was the second highest on record.

Muskellunge PSD34 was 82, PSD38 was 42, and PSD42 was 17 and PSD46 was 2 (Table 5; Figure 4). All PSD indices were the highest ever documented Bone Lake muskellunge. The greatest improvements in size structure from recent surveys were in the PSD38 and PSD42 size groups, which had increases of 92% and 546%, respectively. In addition, this was the first time the PSD46 was over 1. There was a strong relationship between the adult density and PSD40 of muskellunge in Bone Lake, 1985-2017 ($R^2=0.74$; Figure 5). PSD40 declined with increasing adult density. The

2011 survey was excluded from the regression, due to the decline in size structure during that survey which appeared to be from increased exploitation (Cole 2013).

Adult muskellunge collected in this survey were in good condition. The mean W_r was 102, which was a slight decrease from the 2011 survey (111). There continues to be a strong relationship between mean W_r and density of adult muskellunge from Bone Lake, 1964-2017 ($R^2=0.62$; Figure 6).

Bone Lake muskellunge had good growth rates. Mean length at age of Bone Lake muskellunge closely followed the Barron and Polk County average. When compared to the northern region muskellunge mean length at age, Bone Lake muskellunge were larger at younger ages, but smaller at older ages. Bone Lake averaged 3.3 in greater than the Northern Region average for ages 2 to 9 (Table 6) but averaged 1.2 in less than the Northern Region average for ages 10 to 15.

No age and growth comparisons were made with previous surveys because this was the first Bone Lake muskellunge survey with an extensive aging dataset using anal fin rays. Mean length at age of female muskellunge were greater than male muskellunge across all ages (Figure 7). The predicted length infinity (L_{inf}) from the von Bertalanffy growth model was 44.5 in for female muskellunge, and 38.9 in for male muskellunge.

Muskellunge were fairly long-lived. Ages of muskellunge ranged from 1 to 17. The catch curve regression model (fitted to age 5 to age 17) estimated annual mortality to be 23.8% ($Z= -0.27$, $R^2 = 0.75$; Figure 8). The theoretical maximum age was 21.4.

Tribal spearers harvested 1 muskellunge speared during the 2017 open water spearing season, which was less than the declaration of 13. It was estimated that 10 muskellunge were harvested from Bone Lake by tribal spearers during the winter spearing season of 2017-2018 (Luehring 2019). A total of 11 muskellunge were estimated to be harvested from Bone Lake by tribal spearers during the 2017-2018 season. Based on the population estimate derived from the present survey (i.e., 627), the exploitation rate from tribal spearing was 1.8%.

Summary and Discussion

The Bone Lake muskellunge fishery drastically changed over the past couple decades. As recently as 1995, muskellunge abundance in Bone Lake was at all-time high (0.99 adult fish/acre). The muskellunge fishery at that time was characterized as having high density and low size structure. Due to concerns of intra-specific competition and poor condition, stocking was reduced, and the lake has been managed as a lower-density fishery since then. In addition to reduced stocking on Bone Lake since the 1990s, there was an increase in voluntary catch and release (Cornelius and Margenau 1999), more restrictive angling regulations implemented (Benike 2007), and periods of higher levels of tribal spear harvest (Cole 2013). As such, the adult muskellunge density has gradually decreased during each of the last three Bone Lake muskellunge surveys. The current density (0.35 adults/ac) is the lowest density since 1964 but is still considered a moderate density and is similar to the mean density of muskellunge (0.38 adult fish/acre) reported by Margenau and AveLallemant (2000) for 15 northern Wisconsin lakes. The current Bone Lake muskellunge density is greater than the mean density (0.22 fish/ac) for A1 muskellunge lakes across Wisconsin; however, this density should provide good angling action while producing larger-bodied fish.

As muskellunge density decreased, the size structure of the population increased. The improvement in size structure was the most apparent difference with the Bone Lake muskellunge population between this survey and previous surveys. Simply put, the size structure of the Bone Lake muskellunge population has never looked better. The PSD values for all common size groups (34 in, 38 in, 40 in, 42 in, 44 in, 46 in) were the highest they have ever been during a Bone Lake muskellunge survey. The greatest size structure increases were observed in the largest size classes. This increase in size structure should be of particular interest to muskellunge anglers who are especially interested in large fish and the reputation or potential of a lake to produce large muskellunge is one of the main criteria used by muskellunge anglers in selecting where to fish (Casselman 2007; Isermann et al. 2011). PSD42 was 17, which met the minimum trophy requirement for A1 water. It is still too early to truly evaluate the 50 in MLL that was implemented in 2011. The 50 in MLL replaced the 40 in MLL that was implemented in 1990. The abundance of muskellunge 45 inches and larger has increased

on Bone Lake, which was the overall goal of the 50 in MLL. This increase in size structure could be partly attributed to the 50 in MLL, but likely was more due to the reduction in adult density and presumably lower levels of exploitation since the 2011-2012 survey. Exploitation appeared to reduce abundance and size structure of the Bone Lake muskellunge population during the 2011-2012 survey (Cole 2013). If exploitation remains at low levels, the size structure of the Bone Lake muskellunge population should continue to improve over the next several years.

Bone Lake is one of few lakes in Wisconsin with numerous muskellunge population estimates over such a wide range of adult densities. Currently, Bone Lake muskellunge have good Wr and size structure. However, it is evident from the linear regression models that when density of adult muskellunge is high on Bone Lake, an inverse relationship exists with both condition (Wr) and size structure (PSD40). The general trend was the higher the density, the lower the condition and size structure. If the current density can be maintained or slightly reduced, the size structure of the Bone Lake muskellunge population should continue to improve and Wr may also experience modest improvement.

Bone Lake muskellunge had good growth rates and the mean lengths at age of Bone Lake muskellunge were on par with the Barron and Polk County averages. When compared to the northern region muskellunge mean length at age, Bone Lake muskellunge were larger at younger ages, but smaller at older ages. The reason for the size difference at older ages is unknown but could potentially be related to the small-bodied (e.g., yellow perch and centrarchids) forage base in Bone Lake, and low numbers of sucker species and absence of cisco. Otherwise, it may also be partly because northern region ages were mostly derived from scales and not anal fin rays, which would likely underestimate age. The predicted length infinity (L_{inf}) from the von Bertalanffy growth model was 44.5 in for female muskellunge, and 38.9 in for male muskellunge, which were fairly low for an A1 muskellunge lake. These are both lower than the predicted length infinity (L_{inf}) for female (47.7 in), and male (40.6 in) muskellunge in Rice Lake, an A1 muskellunge lake in Barron County (Cole 2016). Bone Lake is not a riverine system like Rice Lake and does not have a diverse forage base with abundant sucker and redhorse populations. Since this was the first muskellunge survey on Bone Lake with an

extensive aging dataset using anal fin rays. Comparisons of the mean length at age of older (\geq age 10) muskellunge and the predicted length infinity should be made during future surveys, especially when able to more accurately determine the age of recaptured fish in future surveys using PIT tag recapture data.

The muskellunge fishery should be managed at a moderate density with high size structure. The target population level of muskellunge in Bone Lake should be maintained between 0.2 to 0.4 adult fish/acre. An adult density within this range should provide a population with high size structure and a respectable density that would offer good angling action. The lower the density in this range, the higher the size structure Bone Lake muskellunge population would likely have. Past density goals (0.4-0.6 adults/ac) previously reported by Benike (2007) and Cole (2013) should be considered too high and are not congruent with managing Bone Lake as an A1 lake, where target densities typically range from 0.1-0.3 adults/ac. Since Bone Lake is considered an A1 muskellunge water, the density should be maintained at a lower level to help continue to improve the size structure. If the stocking rate would remain at 1.5 fingerlings/acre and exploitation remained low, the adult density would likely return to levels >0.5 adults/ac as documented in 2005 and prior. Such adult densities are too high for A1 lakes.

The alternate year stocking regime should be reduced from 1.5 large fingerlings/ac every other year to 1 large fingerling/ac every other year, which is the recommended maximum stocking rate for A1 lakes in the WDNR stocking protocol. This reduction in stocking is not anticipated to cause a proportionate reduction from the current population because stocking survival should increase when fewer fish are stocked. The current stocking regime of 1.5 fingerlings/ac originated back in the 1990s when stocked fish were ≥ 9 inches compared to ≥ 11 inches today. The larger size of fingerlings currently stocked in Bone Lake likely have higher survival than the smaller fingerlings that were historically stocked. Bone Lake has good survival of stocked muskellunge and has had stable recruitment over time. Reducing the stocking rate to 1 fish/ac on an alternate year basis should maintain the population within the target population density range of 0.2 to 0.4 adults/ac if exploitation is maintained at lower levels. Future surveys will be used to monitor the response of the adult density and size structure from the reduction in the stocking rate.

Bone Lake muskellunge will continue to be managed with the 50 in MLL, which will essentially allow for no angler harvest of muskellunge. The exploitation rate from tribal spear harvest (winter and open water combined) observed in this survey was 1.8%, which was considerably lower than the last exploitation rate during the 2011-2012 survey (11.7%; Cole 2013). The level of exploitation Bone Lake muskellunge experience is an important factor in the Bone Lake muskellunge fishery. If exploitation reaches high levels, managing Bone Lake as an A1 muskellunge fishery becomes impractical because muskellunge are vulnerable to the impact of even small increases in exploitation since they are a long-lived species that have low population densities (Hanson 1986; Frohnauer et al. 2007).

There have been two muskellunge stocking events (i.e., 2013 and 2015) where PIT-tagged large fingerling muskellunge were stocked into Bone Lake. Several of these PIT-tagged fish were recaptured in this survey and provided known-age fish that will shed insight on individual growth histories, and improve our growth, mortality, and longevity estimates. However, due to the expense of PIT tagging high numbers of large fingerling muskellunge prior to stocking, it is recommended that we focus on PIT tagging all muskellunge handled in future Bone Lake muskellunge surveys. The anal fin ray should be taken from all PIT-tagged muskellunge, which would provide an accurate age, especially for younger (<10 years) muskellunge. Crane et al. (2020) found that age estimates from fin rays were relatively accurate and precise for muskellunge up to age 15, but poorer precision and accuracy were observed for age estimates of older fish.

By PIT tagging all muskellunge handled, we will be able to obtain insight on the age, growth, mortality, longevity, and general movement patterns of muskellunge at a significantly lower cost relative to PIT tagging muskellunge prior to stocking. Accurately aging all younger PIT tagged fish will prove useful in the future when those fish become older (>15 years old) and more difficult to age. Understanding population demographics of the Bone Lake muskellunge population and comparing them to similar waterbodies is critical for proper Bone Lake muskellunge management. Having reliable age estimates or known-age fish is imperative for assessing these parameters.

In total, we were able to PIT tag 393 muskellunge ≥ 20 in during this two-year survey. The population estimate of muskellunge ≥ 20 in from this survey was 830 fish.

Based on that, we were able to PIT tag a significant portion (47.3%) of the muskellunge population in a two-year survey. We also caught 43 PIT-tagged muskellunge that were from the 2013 and 2015 year classes which were tagged prior to stocking; however, these year classes were not fully recruited to our gear this survey, so the catch of these year classes is an underrepresentation of their abundance. Between the combination of the hatchery-tagged and the field-tagged muskellunge, a significant portion (likely upwards of ~60%) of the muskellunge population (≥ 20 in) was tagged following this survey. Since muskellunge are a long-lived species, and Bone Lake is on a six-year rotation for muskellunge population estimates, we will continue to encounter many of PIT tagged fish again in future Bone Lake surveys.

Previous muskellunge tagging efforts on Bone Lake focused on Floy tags (Benike 2007). Future Bone Lake muskellunge tagging should focus on PIT tags because they have very high (99%) tag retention, whereas Floy tags have poor tag retention that decreases over time (Rude et al. 2011). We did handle one muskellunge that still had a Floy tag from the 2005-2006 survey. This fish was a 45.2 in female that was caught in 2018 and was floy tagged in 2006. This fish was 41.6 in during the 2006 survey. Although this fish was not aged in 2006, based on its length it was likely at least 10 years at the time, which would have made it at least 22 years old in 2018. We aged this fish with its anal fin ray and counted 13 definite annuli but thought there were more indistinguishable annuli. Thus, the age of this fish was grossly underrepresented. The minimum age (22) of this fish does line up with the theoretical maximum age derived from the catch curve (21.4) generated from this survey. Having an extensive PIT tag recapture database will prove to be especially valuable in assigning ages to the oldest fish captured in future surveys. In addition to PIT tag recapture data from surveys, we have been getting angler PIT tag recapture data by issuing PIT tag readers to permitted muskellunge tournaments on Bone Lake and select muskellunge anglers. The angler caught PIT tag recapture data appears to be an excellent method of supplementing our PIT tag recapture database, especially during non-survey years.

Overall, Bone Lake currently has a desirable muskellunge fishery in terms of abundance and size structure. The increase in size structure documented in this survey was encouraging and should be popular among anglers, as Bone Lake has an important

muskellunge fishery that attracts many anglers. By maintaining Bone Lake near the current density (0.2-0.4 adults/ac), the size structure of the Bone Lake population should continue to improve, especially if exploitation is maintained at lower levels.

Bone Lake is on a six-year rotation for muskellunge population estimates. We will continue to monitor the density, size structure, population demographics, and exploitation of the Bone Lake muskellunge fishery. Future surveys will also be used to monitor the response of the muskellunge population to the reduction in stocking rate. If the density is not within the targeted density range (0.2-0.4 adults/ac) and have high size structure ($PSD_{42} \geq 17$; $PSD_{46} \geq 5$) by the 2029 survey, the stocking strategy should be reevaluated. If the stocking rate would need to be further reduced to achieve density and size structure goals, angler desires and expectations for the Bone Lake muskellunge population should be considered.

Management Recommendations

1. The adult muskellunge population (≥ 30 in) should be maintained between 0.2-0.4 adult fish/acre. This density range should continue to improve size structure and provide a respectable density that would offer good angling action. PSD_{42} should be ≥ 17 , the target level for A1 muskellunge water. PSD_{46} should be ≥ 5 .
2. Reduce the stocking regime to 1 large fingerling/ac every other year, the maximum stocking rate for A1 lakes in the WDNR stocking protocol. This stocking regime should maintain the population within the target population density range.
3. Implant passive integrated transponder (PIT) tags into all muskellunge (≥ 20 in) handled in surveys. An anal fin ray should be taken from all PIT-tagged muskellunge for aging purposes. Having a robust PIT tag database would provide individual growth information and give insight on growth, mortality, longevity, and general movement patterns.
4. Encourage angler-based PIT tag recapture programs on Bone Lake, especially with permitted muskellunge tournaments. These would increase the number of recaptures, especially during non-survey years.

5. Bone Lake is on a six-year sampling rotation and will be surveyed again in 2023. Future surveys will be used to monitor the response of the muskellunge population to the reduced stocking rate. If the stocking rate would need to be further reduced at that time to achieve density and size structure goals, angler desires and expectations for the Bone Lake muskellunge population need to be considered.
6. Lakeshore property owners are encouraged to minimize disturbance to the lakeshore and littoral zone and restore shoreline to a more natural state which will protect both fish and wildlife habitat and improve water quality. During the 10-year period from 2008-2018, the percentages of natural buffers on Bone Lake shorelines has greatly increased (34% to 51%) and the percentage of lawn has decreased (62% to 44%). Additional shoreline restoration projects are encouraged, and funding is available through the Healthy Lakes program.

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Table 1. Stocking history of large fingerling muskellunge stocked into Bone Lake, Polk County, WI, 2000-2017.

Stocking Year	Age Class	Number Stocked
2000	Large Fingerling	2000
2001	Large Fingerling	2500
2003	Large Fingerling	3027
2005	Large Fingerling	2494
2007	Large Fingerling	1667
2009	Large Fingerling	2494
2011	Large Fingerling	2497
2013	Large Fingerling	2500
2015	Large Fingerling	2500
2017	Large Fingerling	622

Table 2. Sampling effort for the 2017-2018 Bone Lake muskellunge survey.

Date	Gear	Survey type	Effort
April 17-25, 2017	Fyke net	Muskellunge marking	104 net-nights
May 10-17, 2018	Fyke net	Muskellunge recapture	94 net-nights

Table 3. Abundance estimates of adult muskellunge by sex and length-group for Bone Lake, Polk County, WI 1964-2017.

Year	Sex		Length-group (in)			
	Male	Female	30-33.9	34-37.9	>38.0	>40.0
1964	175	150				
1982	493	468	475	328	156	76
1985	700	799	964	461	92	58
1990	554	651	432	426	243	114
1995	927	830	427	740	576	196
2005	487	546	284	368	321	190
2011	400	343	399	320	118	64
2017	234	385	133	224	265	166

Table 4. Mean (SE) total lengths (inches) of adult muskellunge sampled with fyke nets in Bone Lake, Polk County, Wisconsin 1964-2017.

Year	Male	Female	Combined
1964	29.4 (0.23)	34.2 (0.41)	31.3 (0.24)
1982	31.5 (0.14)	36.8 (0.22)	33.4 (0.15)
1985	31.7 (0.10)	35.1 (0.15)	33.0 (0.09)
1990	33.6 (0.15)	36.7 (0.24)	34.7 (0.14)
1995	34.8 (0.12)	37.7 (0.18)	36.0 (0.11)
2005	33.2 (0.19)	38.3 (0.31)	34.9 (0.20)
2011	33.7 (0.19)	37.0 (0.25)	35.2 (0.18)
2017	33.3 (0.28)	38.6 (0.28)	35.7 (0.24)

Table 5. Proportional size distributions of muskellunge 34 in and greater (PSD34), 38 in and greater (PSD38), and 40 in and greater (PSD40), 42 in and greater (PSD42), 44 in and greater (PSD44), and 46 in and greater (PSD46) from Bone Lake, Polk County, WI, 1982-2017. Stock length was 30 in.

Year	PSD34	PSD38	PSD40	PSD42	PSD44	PSD46
1982	56	18	9	5	2	0
1985	46	9	5	3	1	0
1990	65	18	9	3	1	0
1995	75	27	10	3	1	0
2005	64	30	19	8	2	0
2011	68	22	7	3	0	0
2017	82	42	26	17	6	2

Table 6. Mean length (in) at age for muskellunge (sexes pooled) in Bone Lake, Polk County, WI 2017-2018, the Barron and Polk County average, and the northern Wisconsin (NOR) average.

Age	2017-2018	Barron & Polk	NOR
1	12.2	12.8	11.8
2	21.4	20.0	15.9
3	26.5	25.9	20.5
4	30.0	29.8	25.6
5	33.0	32.3	28.8
6	35.0	34.7	31.6
7	36.6	36.7	33.8
8	36.6	37.6	36.4
9	38.5	38.2	38.2
10	38.0	38.5	39.4
11	40.3	40.0	41.1
12	40.7	40.8	42.3
13	42.1	42.3	43.1
14	42.4	43.5	45.1
15	44.0	42.6	43.5
16	44.8	44.4	—
17	45.4	42.8	—



Figure 1. Map of Bone Lake, Polk County, WI.

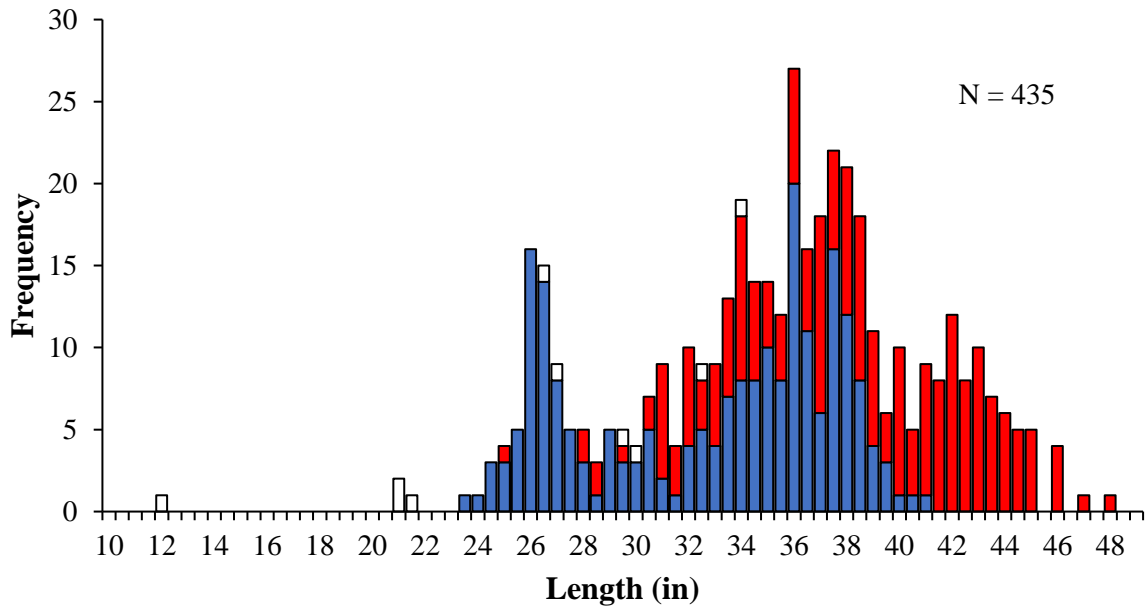


Figure 2. Length frequency histogram for muskellunge captured with fyke nets in Bone Lake, Polk County, WI 2017-2018. White bars represent muskellunge of unknown sex, blue bars represent male muskellunge, and red bars represent female muskellunge. Recaptures were excluded.

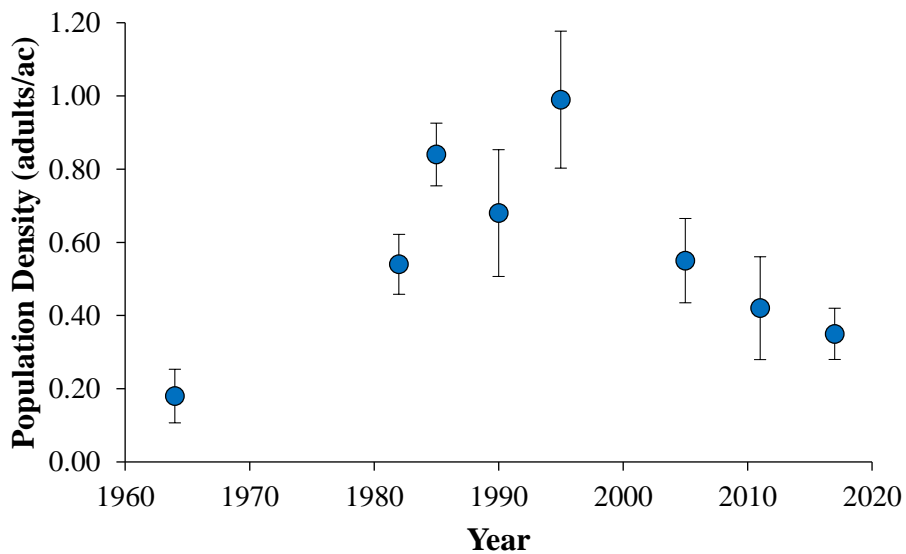


Figure 3. Population density (fish/ac) estimates of adult (≥ 30 in) muskellunge (with 95% confidence intervals) in Bone Lake, Polk County, WI 1964-2017.

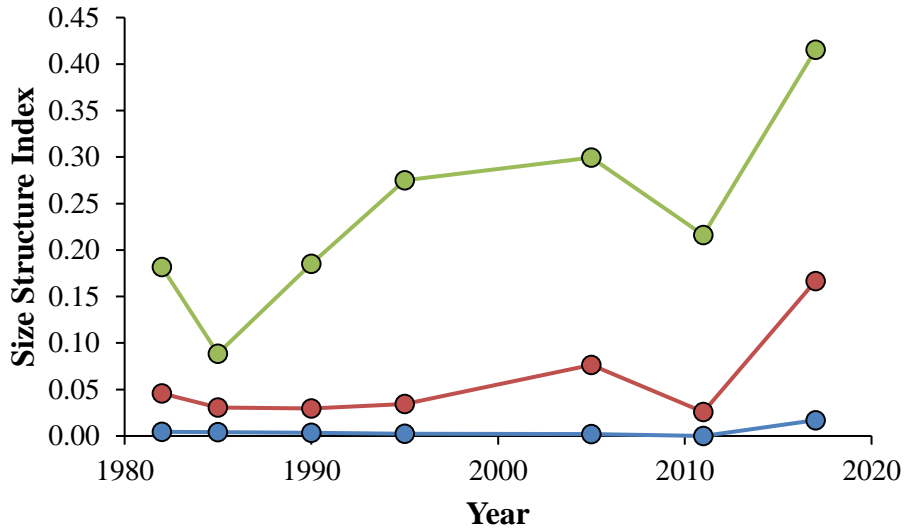


Figure 4. Proportional size distributions of fish 38 in and greater (PSD38; green circles), 42 in and greater (PSD42; red circles), and 46 in and greater (PSD46; blue circles) for muskellunge from Bone Lake, Polk County, WI, 1982-2017. Stock length was 30 in.

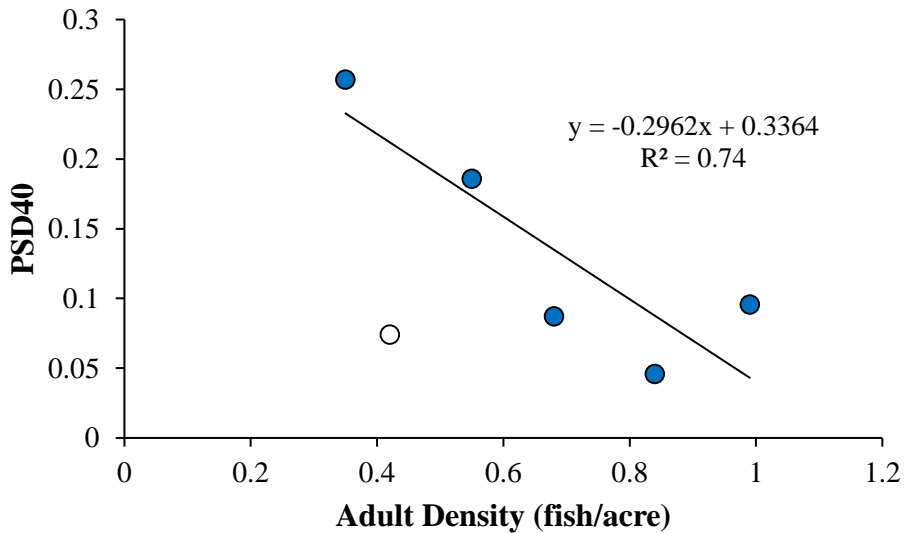


Figure 5. Proportional size distribution of fish 40 in and greater (PSD40) in relationship to adult density (fish/acre) for muskellunge from Bone Lake, Polk County, WI, 1985-2017. Stock length was 30 in. The 2011 survey (open circle) was excluded because of the high exploitation that occurred prior to that survey.

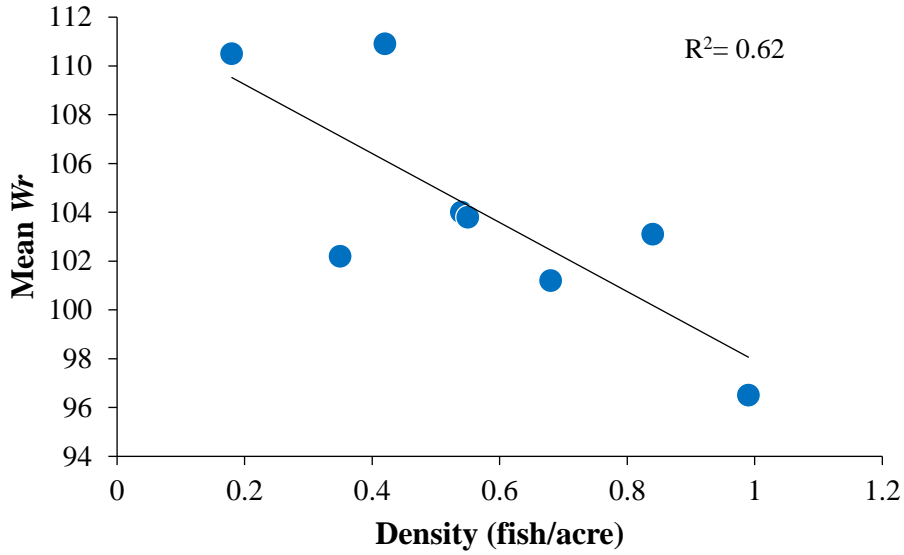


Figure 6. Mean relative weight (Wr) in relationship to density of adult muskellunge Bone Lake, Polk County, WI 1964-2017.

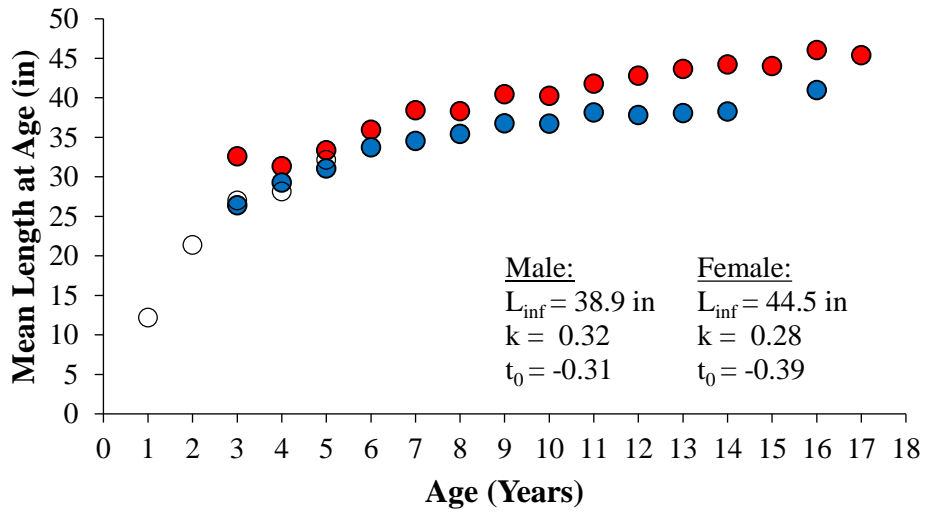


Figure 7. Mean lengths-at-age for female (red circles), male (blue circles), and unknown sex (open circles) muskellunge collected from Bone Lake, Polk County, WI 2017-2018. Mean length of age-1 and age-2 unknown sex muskellunge were included for the growth equations. L_{inf} = theoretical maximum length, k = growth coefficient, and t_0 = time at which length is zero.

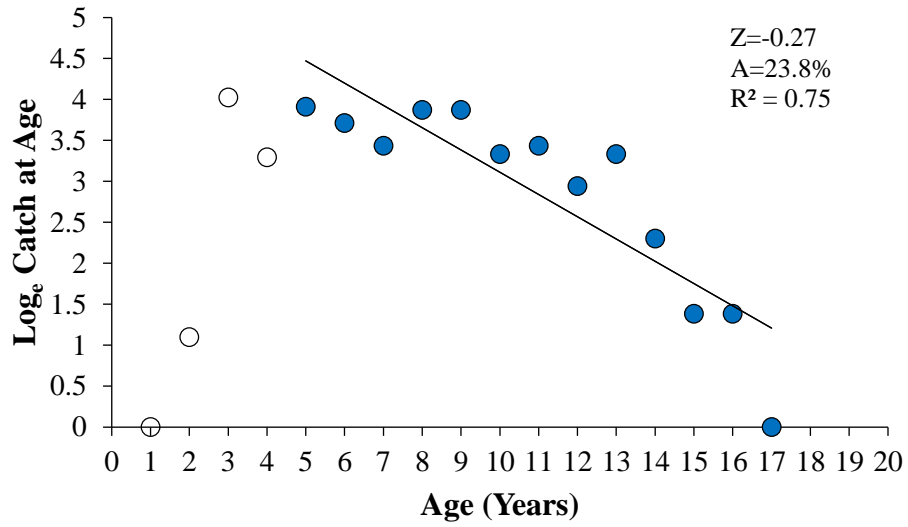


Figure 8. Number at age for muskellunge collected from Bone Lake, Polk County, WI 2017-2018. A catch-curve regression estimated instantaneous annual mortality (Z) and total annual mortality (A). Ages 1 to 4 were omitted from the regression.