North American Journal of Fisheries Management 35:765–774, 2015

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2015.1044627

MANAGEMENT BRIEF

Muskellunge Growth Potential in Northern Wisconsin: Implications for Trophy Management

Matthew D. Faust*[1] and Daniel A. Isermann[2]
Fisheries Analysis Center, College of Natural Resources, University of Wisconsin–Stevens Point, 800 Reserve Street, Stevens Point, Wisconsin 54481, USA

Mark A. Luehring
Great Lakes Indian Fish and Wildlife Commission, Post Office Box 9, 72682 Maple Street, Odanah, Wisconsin 54861, USA

Michael J. Hansen[3]
Fisheries Analysis Center, College of Natural Resources, University of Wisconsin–Stevens Point, 800 Reserve Street, Stevens Point, Wisconsin 54481, USA

Abstract
The growth potential of Muskellunge *Esox masquinongy* was evaluated by back-calculating growth histories from cleithra removed from 305 fish collected during 1995–2011 to determine whether it was consistent with trophy management goals in northern Wisconsin. Female Muskellunge had a larger mean asymptotic length (49.8 in) than did males (43.4 in). Minimum ultimate size of female Muskellunge (45.0 in) equaled the 45.0-in minimum length limit, but was less than the 50.0-in minimum length limit used on Wisconsin's trophy waters, while the minimum ultimate size of male Muskellunge (34.0 in) was less than the statewide minimum length limit. Minimum reproductive sizes for both sexes were less than Wisconsin's trophy minimum length limits. Mean growth potential of female Muskellunge in northern Wisconsin appears to be sufficient for meeting trophy management objectives and angler expectations. Muskellunge in northern Wisconsin had similar growth potential to those in Ontario populations, but lower growth potential than Minnesota's populations, perhaps because of genetic and environmental differences.

A segment of recreational anglers is motivated to catch large (i.e., trophy) fish (Fedler and Ditton 1994), and managing for trophy fish is a common fisheries management strategy for some species (Jacobson 1996; Simonson and Hewett 1999; Arterburn et al. 2002; Chen et al. 2003). Trophy-oriented anglers generally support more restrictive harvest regulations (e.g., increased minimum length limits: Arterburn et al. 2002; Isermann et al. 2011) under the premise that these regulations will increase the availability of large fish. Whether such regulations can improve numbers of large fish within individual populations depends largely on rates of growth and mortality (Hanson 1986; Allen et al. 2002; Isermann et al. 2002). However, fisheries managers must often make management decisions in data-limited situations, especially in lake-rich regions where numerous fisheries preclude detailed stock assessments (Shuter et al. 1998), or when species, such as Muskellunge *Esox masquinongy*, naturally occur at low density and are difficult to sample (Scott and Crossman 1973; Becker 1983).

Many anglers fish for Muskellunge because of its large growth potential (Casselman et al. 1999) and a desire to catch relatively large fish (Isermann et al. 2011). Consequently, fisheries managers often use high (≥45 in) minimum length limits

*Corresponding author: matthew.faust@dnr.state.oh.us
[1]Present address: Ohio Department of Natural Resources, Sandusky Fisheries Research Station, 305 East Shoreline Drive, Sandusky, Ohio 44870, USA.
[2]Present address: U.S. Geological Survey, Wisconsin Cooperative Fishery Research Unit, College of Natural Resources, University of Wisconsin–Stevens Point, 800 Reserve Street, Stevens Point, Wisconsin 54881, USA.
[3]Present address: U.S. Geological Survey, Great Lakes Science Center, Hammond Bay Biological Station, 11188 Ray Road, Millersburg, Michigan 49759, USA.
Received October 7, 2014; accepted April 18, 2015

to manage for trophy Muskellunge (Simonson and Hewett 1999; Wingate and Younk 2007) under the premise that high minimum length limits delay harvest to ensure fish reach sexual maturity and grow to trophy size (Casselman 2007). However, Muskellunge growth potential varies widely across its range (Casselman et al. 1999), which makes setting appropriate minimum length limits difficult (Hanson 1986; Simonson and Hewett 1999). In addition, minimum length limits may not always increase the numbers of trophy fish in populations (Cornelius and Margenau 1999; Margenau and AveLallemant 2000), especially in populations with limited potential to produce fish of sizes desirable to anglers.

Estimating the growth potential of Muskellunge populations is hindered by several factors. Accurate and precise age estimates are necessary for estimating growth potential, which can be difficult to obtain for Muskellunge (Johnson 1971; Casselman 1983; Fitzgerald et al. 1997). Age information is either not obtained during routine sampling or age estimates are largely based on fin rays or scales, which do not provide accurate or precise age estimates for esocids (Johnson 1971; Casselman 1983; Fitzgerald et al. 1997). Furthermore, when sampling is specifically conducted to collect Muskellunge, few fish are usually observed (Cornelius and Margenau 1999; Margenau and AveLallemant 2000).

Cleithra provide accurate and precise age estimates for esocids (Casselman 1979; Casselman 1990; Laine et al. 1991; Faust et al. 2013), but removal of cleithra requires sacrificing the fish. Sacrificing adequate numbers of Muskellunge to describe growth and mortality rates is not reasonable in light of their life history traits (i.e., relatively long lived and low population density: Hanson 1986; Margenau and AveLallemant 2000) and would not be popular among anglers. However, previous studies have used cleithra from harvested Muskellunge to estimate age and growth (Casselman et al. 1999; Casselman 2007; Younk and Pereira 2007). Specifically, studies using back-calculation models to estimate multiple years of growth from individual Muskellunge have maximized information gained from relatively small samples (Casselman and Crossman 1986; Casselman et al. 1999; Casselman 2007).

Muskellunge are a culturally significant fish for Chippewa tribes and support a subsistence spearing fishery in northern Wisconsin's ceded territory (Erickson 2007). The Wisconsin Department of Natural Resources (WDNR) and the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) jointly manage Muskellunge fisheries in the ceded territory through harvest quotas and catch monitoring, and by adjusting daily bag and minimum length limits (Hansen et al. 1991; Beard et al. 2003). Intensive data collection and analysis began in 1987, with a representative sample of lakes being surveyed each year by means of fyke netting, electrofishing, and creel surveys to assess the abundance and stability of fish populations, along with a creel census during the tribal spring spearing season (Staggs et al. 1990). This data collection effort provided a sample of Muskellunge cleithra from across northern Wisconsin.

Our objective was to determine whether Muskellunge growth potential in northern Wisconsin is compatible with the use of minimum length limits ≥ 40 in for trophy management. Ages were estimated from cleithra collected during 1995–2011 and von Bertalanffy growth models fitted to back-calculated lengths at age to estimate growth potential of male and female Muskellunge. Minimum ultimate sizes and minimum reproductive sizes were then compared with minimum length limits used to manage Muskellunge fisheries in Wisconsin.

METHODS

The ceded territory encompasses 22,400 mi^2 and all or part of 30 counties in northern Wisconsin, which includes most (>85%) of the state's Muskellunge waters (Staggs et al. 1990; Simonson 2012). Muskellunge waters within the ceded territory vary widely in size from less than 100 surface acres to more than 10,000 surface acres, Muskellunge population density (Margenau and AveLallemant 2000), and reproductive status (i.e., naturally recruiting or stocked lakes: Simonson 2012). Further, a variety of angling regulations are used on Wisconsin's Muskellunge waters (Table 1).

Cleithra were collected from 305 Muskellunge (n = 50 lakes) by the WDNR and the GLIFWC during 1995−2011 within the ceded territory. Cleithra collected by the WDNR came from Muskellunge captured in spring and autumn fyke netting and electrofishing surveys, donations from taxidermists (i.e., angler caught), or found dead. Cleithra collected by the GLIFWC were taken from Muskellunge harvested by tribal spearers during 2007−2011. Muskellunge TL was measured and sex determined by WDNR and GLIFWC personnel or by taxidermists.

Cleithra with excess tissue were cleaned either by being submersed in near-boiling water for a short period (<30 s) and scrubbed, or placed within a colony of dermestid beetles (*Dermestes* spp.) for at least 1 week prior to age estimation. Cleaned cleithra were placed in a black dish, immersed in water to improve visibility of annuli, and examined with the

TABLE 1. Percentage of Wisconsin's inland Muskellunge waters by angling harvest regulation. Numbers in parentheses correspond to actual number of waters with a given angling regulation jurisdiction. MLL = minimum length limit.

Regulation type	Percentage of inland waters
28 inch MLL	3.0 (20)
40 inch MLL	93.4 (622)
45 inch MLL	1.1 (7)
50 inch MLL	2.4 (16)
Catch-and-release only	0.2 (1)

naked eye under ambient light to estimate Muskellunge age. Annuli were identified as alternating translucent and opaque zones (Casselman 1979).

Three independent readers estimated ages of a subset of Muskellunge ($n = 122$) to detect bias and to quantify precision of age estimates. Reader 1 had no previous experience estimating fish age and was instructed how to estimate age from cleithra, while readers 2 and 3 were experienced estimating age of esocids from cleithra. Each reader examined cleithra independently of the other two readers and had no knowledge of fish length or sex when estimating age.

Precision between the age estimates from each reader were compared by calculating the CV as follows:

$$\mathrm{CV} = 100 \times \frac{\sqrt{\sum_{i=1}^{R} \frac{\left(X_{ij} - X_j\right)^2}{R-1}}}{X_j},$$

where X_{ij} is the ith age estimate of the jth fish, X_j is the mean age of the jth fish, and R is the number of times each fish has its age estimated (Campana et al. 1995). Age-bias plots were constructed for each combination of readers and visually interpreted relative to a 1:1 equivalence line (reader A = reader B), and the age estimates of reader B was presented as the mean age and 95% CI corresponding to each age-class estimated by reader A (Campana et al. 1995).

Growth increments were measured using a digital caliper (±0.001 in) along the anterior axis of the cleithrum from the origin to the outside edge of each annulus (Casselman and Crossman 1986). Individual growth histories (i.e., length at age) were back-calculated using the biological-intercept model (Campana 1990):

$$L_t = L_T + \frac{S_t - S_T}{S_T - S_0}(L_T - L_0),$$

where L_t is Muskellunge length at age t, L_T is Muskellunge length at capture, S_t is cleithrum radius at age t, S_T is cleithrum length at capture, S_0 is cleithrum length at the time of cleithrum formation, and L_0 is Muskellunge length at the time of cleithrum formation. The biological-intercept model (Campana 1990) is a linear method of back-calculation, which is superior to other commonly used back-calculation models. Campana (1990) defined the biological intercept as the fish and structure length corresponding to the initiation of proportionality between fish and structure growth, which in many species occurs at hatching. Cleithrum formation has not been defined for the Muskellunge, but cleithra are visible at a fish length of 11.6 mm for Redfin Pickerel *E. americanus americanus*, a relative of the Muskellunge (Mansueti and Hardy 1967). Redfin Pickerel are 5−6 mm long at time of hatching and grow an additional 5−6 mm before the cleithrum becomes visible (Fuiman 1982). Muskellunge have a mean length of 8.7 mm at the time of hatching, so cleithra should be visible after growing an additional 5−6 mm to ∼15 mm TL (Fuiman 1982). Cleithra grow at roughly one-tenth the rate of a Muskellunge's total body length (Casselman and Crossman 1986), which predicts that a 15-mm (L_0) Muskellunge will have cleithra with an anterior cleithral radius of approximately 1.5 mm (S_0).

The von Bertalanffy growth model was fit to each fish's back-calculated growth history:

$$L_t = L_\infty \left(1 - e^{[-K(t - t_0)]}\right),$$

where L_t is Muskellunge length at age t, L_∞ is the asymptotic length, K is the instantaneous rate at which L_t approaches L_∞, and t_0 is the hypothetical age of a Muskellunge at zero length (Ricker 1975; Quinn and Deriso 1999). We used back-calculated growth histories from individual fish, as opposed to length at capture, because parameters of the average population growth curve are unbiased when estimated with the correct statistical model (Jones 2000; Vigliola and Meekan 2009). Growth parameters for individual Muskellunge were estimated using a nonlinear mixed-effects model with a fixed population effect and random individual effects (see Box 3 in Vigliola and Meekan 2009). Muskellunge exhibit sexually dimorphic growth, with females attaining larger sizes than males (Casselman and Crossman 1986; Casselman et al. 1999), so growth parameters (L_∞, K, and t_0) were compared between sexes using a single-factor ANOVA ($\alpha = 0.05$; Zar 1999; Hansen et al. 2012). Minimum ultimate sizes (i.e., lower 99% prediction limit of mean asymptotic length: Casselman 2007) and minimum reproductive sizes (i.e., upper 99% prediction limit at age of first maturity plus 2 years: Casselman 2007) were calculated for both sexes and compared with Wisconsin's minimum length limits. Prediction limits were calculated from mean back-calculated lengths at age for each sex, which we used to fit two additional von Bertalanffy growth curves (corresponding to upper and lower 99% prediction limits) for each sex. Age of first maturity for male Muskellunge was age 5, and age 6 was used for female Muskellunge (Hanson 1986).

RESULTS

Female Muskellunge had a larger mean TL at capture of 40.0 in (SE = 0.467) than males (34.7 in, SE = 0.432; Figure 1). No consistent bias was observed among reader age estimates (Figure 2), so age estimates from reader 1 were used for subsequent age and growth analyses. Mean CV was 8.0% (SE = 0.7) among readers and mean CV between readers ranged from 6.2% to 7.8%. Female Muskellunge had an average age of 10.1 years (SE = 0.369), and males had an average age of 9.02 years (SE = 0.306) (Figure 3). Visual inspection of residuals of the cleithrum–TL relationship confirmed that a linear back-calculation model was appropriate (Figure 4). The

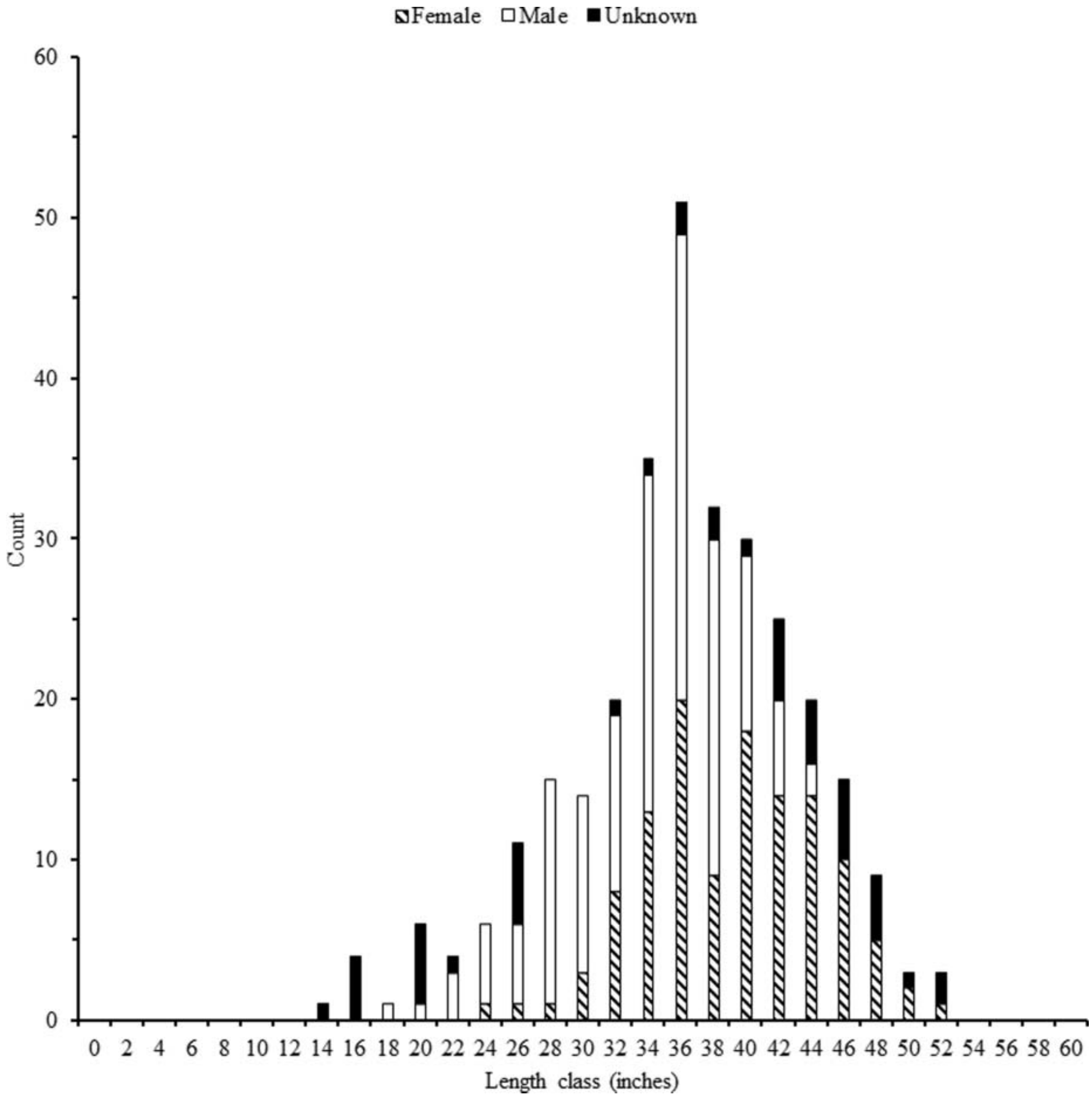

FIGURE 1. Number of Muskellunge ($n = 305$) by length class (inches) collected from northern Wisconsin during 1995–2011.

final sample used to evaluate sex-specific growth potential consisted of 305 Muskellunge, which included 141 males, 120 females, and 44 fish that were not assigned a sex.

Female Muskellunge grew to a larger average asymptotic size than male Muskellunge in northern Wisconsin. Males and females differed significantly in average L_∞ ($F_{2,\ 302} = 22.1$, $P < 0.\ 001$) and average K ($F_{2,\ 302} = 10.3$, $P < 0.001$), but not average t_0 ($F_{2,\ 302} = 1.19$, $P = 0.304$; Figure 5). The mean L_∞ of male Muskellunge was 6.4 in shorter ($L_\infty = 43.4$ in, SE = 0.659) than that of females ($L_\infty = 49.8$ in, SE = 0.714). Minimum ultimate size of male Muskellunge was 34.0 in, while the minimum ultimate size of female Muskellunge was 45.0 in. Minimum reproductive size of male Muskellunge was 39.0 in, and the minimum reproductive size of female Muskellunge was 44.0 in. The mean K of male Muskellunge was greater ($K = 0.191$ per year, SE = 0.004) than that of females ($K = 0.164$ per year, SE = 0.004). In contrast, the average t_0 of male Muskellunge ($t_0 = -0.426$ years, SE = 0.026) was similar to that of females ($t_0 = -0.468$ years, SE = 0.028). For 44 fish not assigned a sex, mean TL at capture was 35.8 in (SE = 1.82), mean age at capture was 9.80 years (SE = 0.884), mean L_∞ was 47.0 in (SE = 1.179), K was 0.172 per year (SE = 0.007), and t_0 was -0.390 years (SE = 0.047).

DISCUSSION

Our findings showed that female Muskellunge growth potential (minimum ultimate size and minimum reproductive

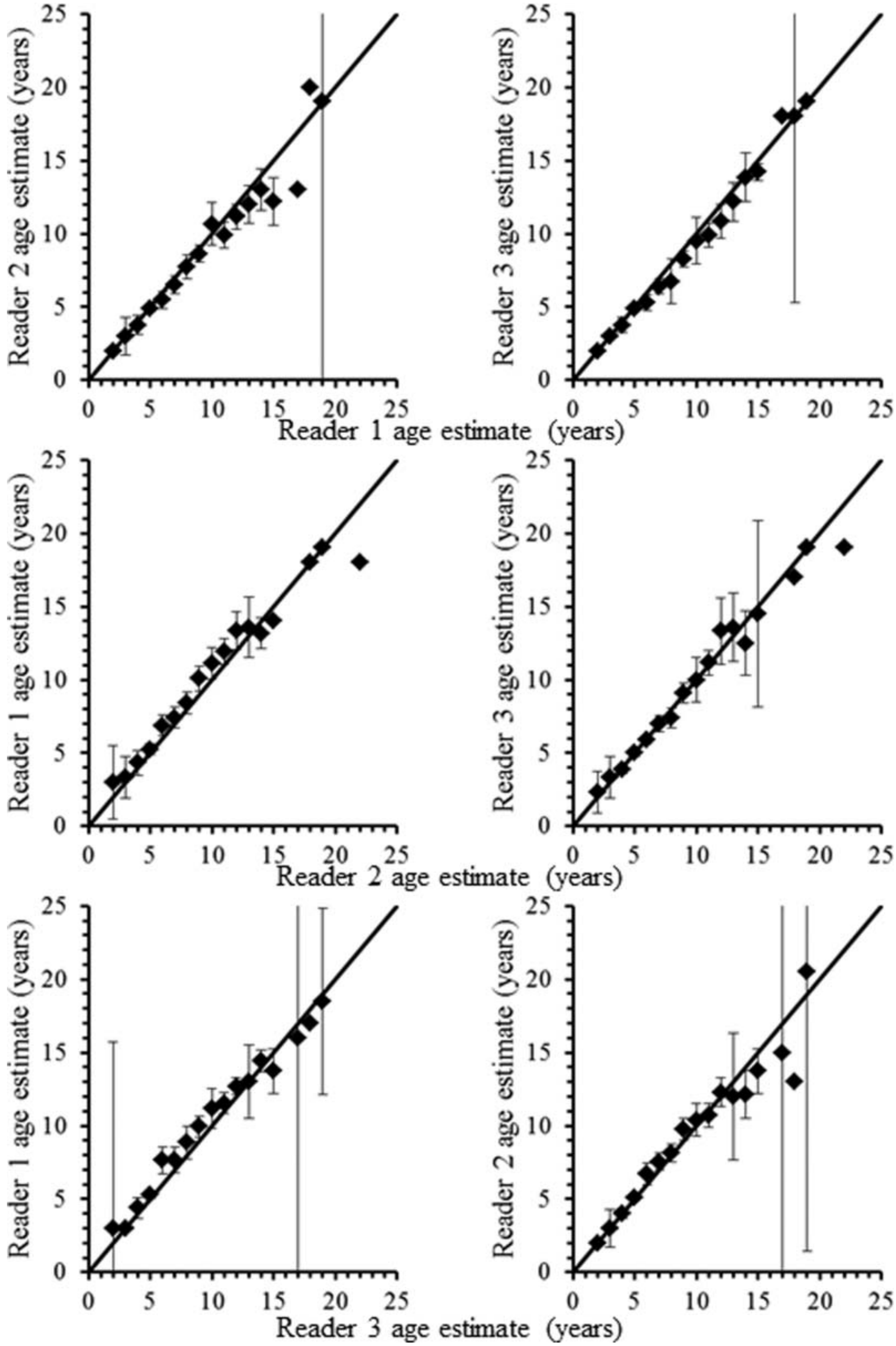

FIGURE 2. Age-bias plots comparing Muskellunge age estimates between three independent readers for fish collected from northern Wisconsin during 2007–2011. Diamond symbols represent mean values (±95% CIs). Solid line indicates 1:1 equivalence line.

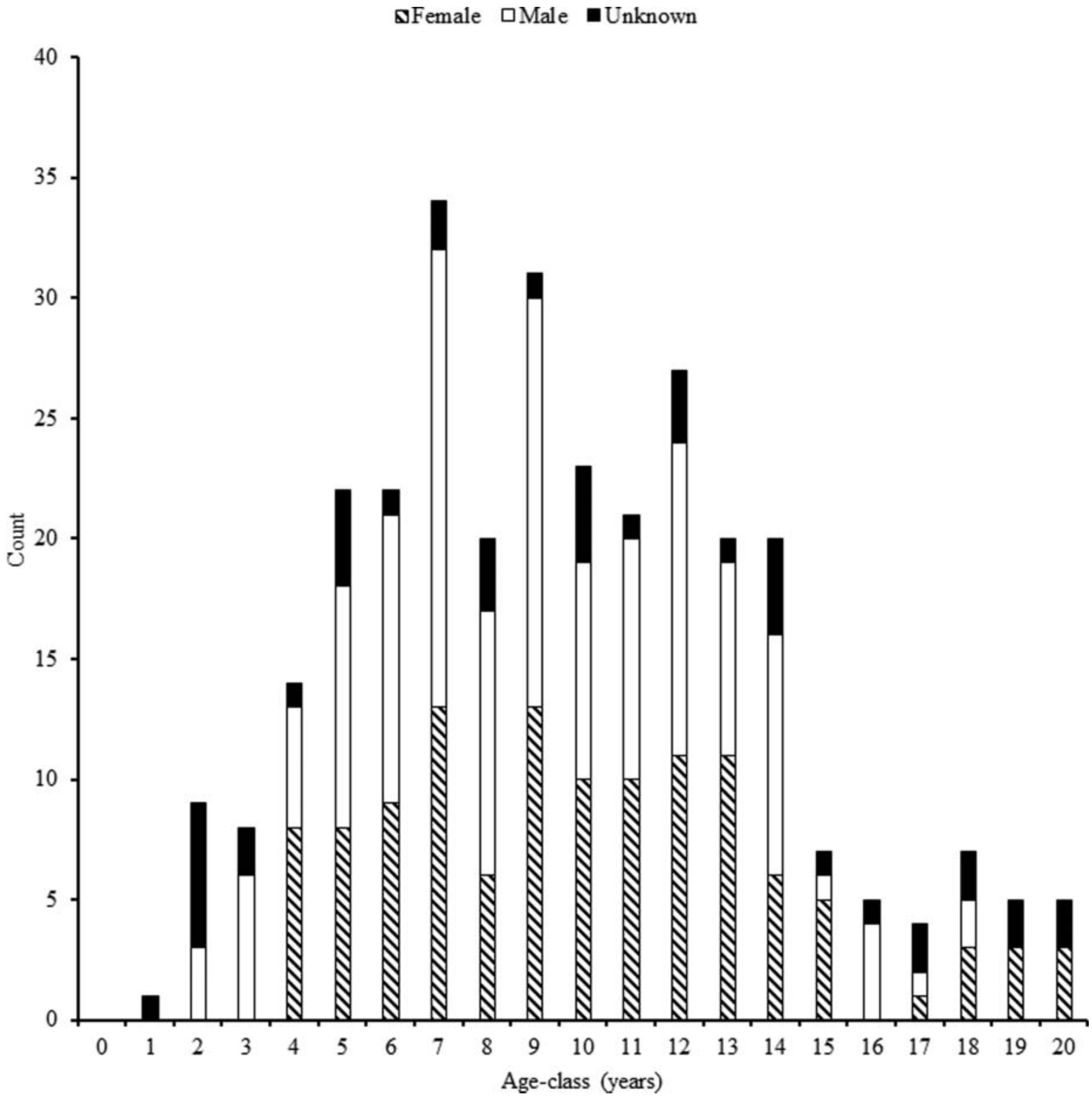

FIGURE 3. Number of Muskellunge ($n = 305$) by age-class (years) collected from northern Wisconsin during 1995–2011.

size) was consistent with trophy management objectives in northern Wisconsin. The minimum ultimate size of female Muskellunge equaled one minimum length limit (45 in), but was less than another (50 in) used on Wisconsin's trophy Muskellunge fisheries. Nearly 50% of Wisconsin's Muskellunge anglers preferred that fish be ≥50 in before considering it a trophy individual (Isermann et al. 2011), and our results demonstrate that mean L_∞ for female Muskellunge approximates this trophy-size preference. The minimum ultimate size of male Muskellunge was less than the 40-in statewide minimum length limit, and although most trophy Muskellunge fisheries are exclusively for female fish due to the lower growth potential of males (Hanson 1986), males still provide important catch opportunities for anglers (Casselman 2007). Minimum reproductive sizes of male and female Muskellunge were less than Wisconsin's trophy minimum length limits. Therefore, both sexes are generally protected from harvest by recreational anglers through at least two spawning seasons under existing trophy regulations. However, minimum reproductive size of female Muskellunge was greater than the 40-in statewide minimum length limit. Additionally, angler-caught Muskellunge are subject to some level of postrelease mortality (Margenau 2007; Landsman et al. 2011), which likely removes some individuals before becoming sexually mature or spawning in multiple years. Muskellunge may also be harvested before reaching minimum reproductive sizes by the tribal subsistence fishery, where the exploitation rate for adult Muskellunge averages 2.2% (Faust 2011).

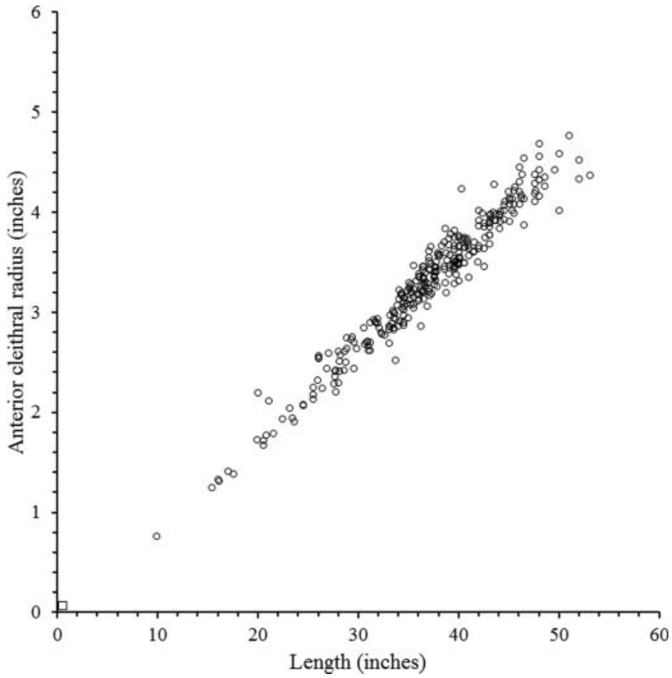

FIGURE 4. Relationship between anterior cleithral radius (inches) and body length (inches) based on 305 Muskellunge collected from northern Wisconsin during 1995–2011. The open square (where axes meet) indicates the biological intercept used in back-calculation of individual growth histories.

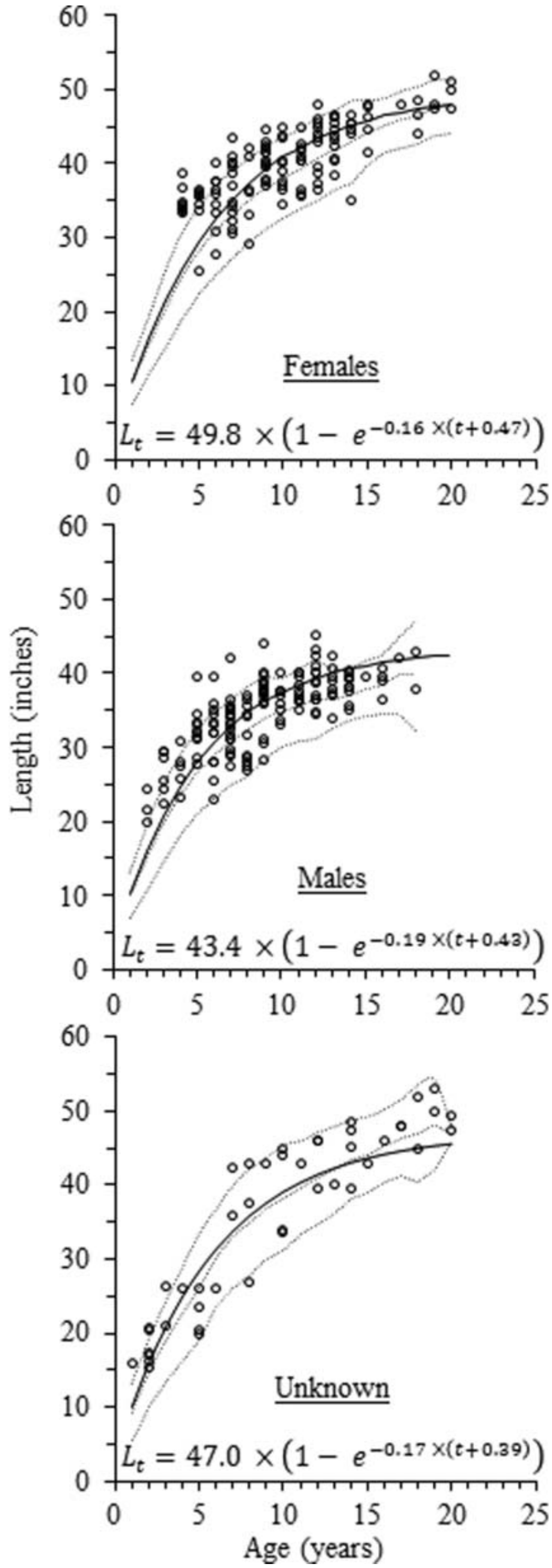

FIGURE 5. Mean back-calculated length at age (±1.96 SD; dotted lines), length at age of capture (open circles), and average von Bertalanffy growth curves (solid lines) for female (n = 120), male (n = 141), and unknown (i.e., no sex assigned; n = 44) Muskellunge collected from northern Wisconsin during 1995–2011.

The growth potential of Muskellunge in northern Wisconsin was similar to the growth potential in Ontario (Casselman et al. 1999), but lower than that in Minnesota (Younk and Pereira 2007). Female Muskellunge in Ontario had a similar mean L_∞ (49.3 in) as determined in our estimates, but males had a lower mean L_∞ (41.7 in) than our estimates (Casselman et al. 1999). In contrast, estimates of average L_∞ for female ($L_\infty = 53.0$ in) and male ($L_\infty = 47.0$ in) Muskellunge in Minnesota were higher than our estimates (Younk and Pereira 2007). Interestingly, smaller Muskellunge were caught by recreational anglers in Wisconsin than in Minnesota, but not Ontario (Vinson and Angradi 2014). These observed differences in growth potential may be due to genetic and environmental factors. Genetically distinct groups of Muskellunge exist across their native range (Koppelman and Philipp 1986; Kapuscinski et al. 2013), and genetic differences among populations may contribute to observed variation in growth across the species' range (Younk and Strand 1992; Margenau and Hanson 1996; Miller et al. 2009). For example, Muskellunge descending from Shoepack Lake, Minnesota, were stocked across Minnesota for more than 30 years, and the genetic legacy of these fish contributed to a paucity of large Muskellunge in Moose Lake, Minnesota (Miller et al. 2009). Lake size may also explain differences in growth potential among Muskellunge populations. Many of the samples used to estimate Muskellunge growth in Minnesota came from water bodies that were larger than those in Wisconsin. Lake size is positively correlated with growth potential of Lake Trout *Salvelinus namaycush* (Shuter et al. 1998) and Yellow Perch *Perca flavescens* (Purchase et al. 2005), and maximum and mean fish size within a species increase with lake size (Griffiths 2013). Large lakes have increased species richness (Eadie et al. 1986; Matuszek and Beggs 1988) and food chain length (Vander Zanden et al. 1999; Post et al. 2000), which may allow large-bodied predators like Muskellunge to reach greater sizes.

While our study aids Muskellunge management by providing improved age and growth estimates across a wide range of populations, future studies could benefit by considering the following. First, our study had a relatively large sample of cleithra considering that Muskellunge are seldom sacrificed during routine population assessments, but we often lacked lake-specific samples of sufficient size to evaluate changes in growth through time and factors underlying growth potential. While we acknowledge that sacrificing Muskellunge may not be possible or desirable in every case, lakes of greater importance may benefit from the increased knowledge that could be gained from a larger sample of fish available for routine age and growth analyses. For example, increased lake-specific sample sizes could lead to a sound biological basis for setting length limits in particular lakes, which may be the best single regulation for preventing overexploitation of Muskellunge by recreational anglers (Casselman 2007). Second, a portion of our sample came from fishery-dependent sources (i.e., either donated by anglers or taxidermists, or from tribal spearing), which is similar for other age and growth analyses conducted for Muskellunge in Minnesota and Ontario (Casselman et al. 1999; Younk and Pereira 2007). Anglers preferentially remove the largest individuals from a population (Gabelhouse and Willis 1986; Pierce et al. 1995; Miranda and Dorr 2000), and while selectivity of Wisconsin's tribal spearing fishery has not been quantified, the average size of Muskellunge harvested in the ceded territory by angling and spearing fisheries is similar (Simonson 2008; White 2013). In cases where fish are rarely sacrificed during routine assessments, as is common for Muskellunge, fishery-dependent data can provide useful information, but fisheries managers should be aware of the size-selective nature of these data. Finally, cleithra have never been validated as an age estimation structure for Muskellunge, despite being used for large-scale age and growth analyses across the species' range (Casselman and Crossman 1986; Casselman et al. 1999; Casselman 2007). Although cleithra age estimates are more precise than those from fin rays or scales (Casselman 1983; Laine et al. 1991), accuracy of these age estimates is unknown. Otoliths provide accurate and precise age estimates for other fishes, but only one study has compared esocid age estimates from cleithra and otoliths (Faust et al. 2013), which found that otoliths provided similar age estimates for Northern Pike *E. lucius* from Devils Lake, North Dakota. Future studies should strive to address these issues.

ACKNOWLEDGMENTS

Funding was provided by the Wisconsin Department of Natural Resources. Christopher Cahill, Mark Vinson, Neil Kmiecik, and Tim Simonson reviewed previous versions of this manuscript. Comments from two anonymous reviewers enhanced this manuscript. The authors thank employees of the Great Lakes Indian Fish and Wildlife Commission and the Wisconsin Department of Natural Resources who collected cleithra, and the spearers, anglers, and taxidermists that cooperated during the collection process. Use of trade, product, or firm names for descriptive purposes does not imply endorsement by the U.S. Government. This article is contribution 1904 of the U.S. Geological Survey, Great Lakes Science Center.

REFERENCES

Allen, M. S., W. Sheaffer, W. F. Porak, and S. Crawford. 2002. Growth and mortality of Largemouth Bass in Florida waters: implications for use of length limits. Pages 559–566 *in* D. P. Phillip and M. S. Ridgeway, editors. Black bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

Arterburn, J. E., D. J. Kirby, and C. R. Berry Jr. 2002. A survey of angler attitudes and biologist opinions regarding trophy catfish and their management. Fisheries 25(5):10–21.

Beard, T. D. Jr., P. W. Rasmussen, S. Cox, and S. R. Carpenter. 2003. Evaluation of a management system for a mixed Walleye spearing and angling fishery in northern Wisconsin. North American Journal of Fisheries Management 23:481–491.

Becker, G. C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison.

Campana, S. E. 1990. How reliable are growth back-calculations based on otoliths? Canadian Journal of Fisheries and Aquatic Sciences 47:2219–2227.

Campana, S. E., M. C. Annand, and J. I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Transactions of the American Fisheries Society 124:131–138.

Casselman, J. M. 1979. The esocid cleithrum as an indicator calcified structure. Pages 249–272 *in* J. Dubé and Y. Gravel, editors. Proceedings of the 10th warmwater workshop. Quebec Ministere du Loisir, de la Chasse et de la Peche, Direction de la Recherche Faunique, Montreal.

Casselman, J. M. 1983. Age and growth assessment of fish from their calcified structures – techniques and tools. NOAA Technical Report NMFS 8:1–17.

Casselman, J. M. 1990. Growth and relative size of calcified structures of fish. Transactions of the American Fisheries Society 119:673–688.

Casselman, J. M. 2007. Determining minimum ultimate size, setting size limits, and developing trophy standards and indices of comparable size for maintaining quality Muskellunge (*Esox masquinongy*) populations and sports fisheries. Environmental Biology of Fishes 79:137–154.

Casselman, J. M., and E. J. Crossman. 1986. Size, age, and growth of trophy Muskellunge and Muskellunge–Northern Pike hybrids—The Cleithrum Project, 1979–1983. Pages 93–110 *in* G. E. Hall, editor. Managing muskies: a treatise on the biology and propagation of Muskellunge in North America. American Fisheries Society, Special Publication 15, Bethesda, Maryland.

Casselman, J. M., C. J. Robinson, and E. J. Crossman. 1999. Growth and ultimate length of Muskellunge from Ontario water bodies. North American Journal of Fisheries Management 19:271–290.

Chen, R. J., K. M. Hunt, and R. B. Ditton. 2003. Estimating the economic impacts of a trophy Largemouth Bass fishery: issues and applications. North American Journal of Fisheries Management 23:835–844.

Cornelius, R. R., and T. L. Margenau. 1999. Effects of length limits on Muskellunge in Bone Lake, Wisconsin. North American Journal of Fisheries Management 19:300–308.

Eadie, J. M., T. A. Hurly, R. D. Montgomerie, and K. L. Teather. 1986. Lakes and rivers as islands: species–area relationships in the fish faunas of Ontario. Environmental Biology of Fishes 15:81–89.

Erickson, S. 2007. A guide to understanding Chippewa treaty rights. Great Lakes Indian Fish and Wildlife Commission, Odanah, Wisconsin.

Faust, M. D. 2011. Effects of harvest mortality on Muskellunge size structure in Wisconsin's ceded territory. Master's thesis. University of Wisconsin–Stevens Point, Stevens Point.

Faust, M. D., J. J. Breeggemann, S. Bahr, and B. D. S. Graeb. 2013. Precision and bias of cleithra and sagittal otoliths used to estimate ages of Northern Pike. Journal of Fish and Wildlife Management 4:332–341.

Fedler, A. J., and R. B. Ditton. 1994. Understanding angler motivations in fisheries management. Fisheries 19(4):6–13.

Fitzgerald, T. J., T. L. Margenau, and F. A. Copes. 1997. Muskellunge scale interpretation: the question of aging accuracy. North American Journal of Fisheries Management 17:206–209.

Fuiman, L. A. 1982. Esocidae. Pages 155–173 *in* N. A. Auer, editor. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission, Special Publication 82-3, Ann Arbor, Michigan.

Gabelhouse, D. W., Jr., and D. W. Willis. 1986. Biases and the utility of angler catch data for assessing size structure and density of Largemouth Bass. North American Journal of Fisheries Management 6:481–489.

Griffiths, D. 2013. Body size distributions in North American freshwater fish: small-scale factors and synthesis. Ecology of Freshwater Fish 22:257–267.

Hansen, M. J., N. A. Nate, C. C. Krueger, M. S. Zimmerman, H. G. Kruckman, and W. W. Taylor. 2012. Age, growth, survival, and maturity of Lake Trout morphotypes in Lake Mistassini, Quebec. Transactions of the American Fisheries Society 141:1492–1503.

Hansen, M. J., M. D. Staggs, and M. H. Hoff. 1991. Derivation of safety factors for setting harvest quotas on adult Walleyes from past estimates of abundance. Transactions of the American Fisheries Society 120:620–628.

Hanson, D. A. 1986. Population characteristics and angler use of Muskellunge in eight northern Wisconsin lakes. Pages 238–248 *in* G. E. Hall, editor. Managing muskies: a treatise on the biology and propagation of Muskellunge in North America. American Fisheries Society, Special Publication 15, Bethesda, Maryland.

Isermann, D., K. Floress, and T. Simonson. 2011. Survey of angler attitudes and opinions regarding Muskellunge fishing and management in Wisconsin. Wisconsin Department of Natural Resources, Madison.

Isermann, D. A., S. M. Sammons, P. W. Bettoli, and T. N. Churchill. 2002. Predictive evaluation of size restrictions as management strategies for Tennessee reservoir crappie fisheries. North American Journal of Fisheries Management 22:1349–1357.

Jacobson, P. C. 1996. Trophy and consumptive value-per-recruit analysis for a Walleye fishery. North American Journal of Fisheries Management 16:75–80.

Johnson, L. D. 1971. Growth of known-age Muskellunge in Wisconsin and validation of age and growth determination methods. Wisconsin Department of Natural Resources, Technical Bulletin 49.

Jones, C. M. 2000. Fitting growth curves to retrospective size-at-age data. Fisheries Research 46:123–129.

Kapuscinski, K. L, B. L. Sloss, and J. M. Farrell. 2013. Genetic population structure of Muskellunge in the Great Lakes. Transactions of the American Fisheries Society 142:1075–1089.

Koppelman, J. B., and D. P. Philipp. 1986. Genetic applications in Muskellunge management. Pages 111–121 *in* G. E. Hall. Managing muskies: a treatise on the biology and propagation of Muskellunge in North America. American Fisheries Society, Special Publication 15, Bethesda, Maryland.

Laine, A. O., W. T. Momot, and P. A. Ryan. 1991. Accuracy of using scales and cleithra for aging Northern Pike from an oligotrophic Ontario lake. North American Journal of Fisheries Management 11:220–225.

Landsman, S. J., H. J. Wachelka, C. D. Suski, and S. J. Cooke. 2011. Evaluation of the physiology, behavior, and survival of adult Muskellunge (*Esox masquinongy*) captured and released by specialized anglers. Fisheries Research 110:377–386.

Mansueti, A. J., and J. D. Hardy Jr. 1967. Development of fishes of the Chesapeake Bay region: an atlas of egg, larval, and juvenile stages. Port City Press, Baltimore, Maryland.

Margenau, T. L. 2007. Effects of angling with a single-hook and live bait on Muskellunge survival. Environmental Biology of Fishes 79:155–162.

Margenau, T. L., and S. P. AveLallemant. 2000. Effects of a 40-inch minimum length limit on Muskellunge in Wisconsin. North American Journal of Fisheries Management 20:986–993.

Margenau, T. L., and D. A. Hanson. 1996. Survival and growth of stocked Muskellunge: effects of genetic and environmental factors. Wisconsin Department of Natural Resources, Publication PUBL-RS-572 96, Madison.

Matuszek, J. E., and G. L. Beggs. 1988. Fish species richness in relation to lake area, pH, and other abiotic factors in Ontario lakes. Canadian Journal of Fisheries and Aquatic Sciences 45:1931–1941.

Miller, L. M., S. W. Mero, and J. A. Younk. 2009. The genetic legacy of stocking Muskellunge in a northern Minnesota lake. Transactions of the American Fisheries Society 138:602–615.

Miranda, L. E., and B. S. Dorr. 2000. Size selectivity of crappie angling. North American Journal of Fisheries Management 20:706–710.

Pierce, R. B., C. M. Tomcko, and D. H. Schupp. 1995. Exploitation of Northern Pike in seven small north-central Minnesota lakes. North American Journal of Fisheries Management 15:601–609.

Post, D. M., M. L. Pace, and N. G. Hairston Jr. 2000. Ecosystem size determines food-chain length in lakes. Nature 405:1047–1049.

Purchase, C. F., N. C. Collins, G. E. Morgan, and B. J. Shuter. 2005. Predicting life history traits of Yellow Perch from environmental characteristics of lakes. Transactions of the American Fisheries Society 134:1369–1381.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bulletin of the Fisheries Research Board of Canada 184.

Shuter, B. J., M. L. Jones, R. M. Korver, and N. P. Lester. 1998. A general, life history based model for regional management of fish stocks: the inland Lake Trout (*Salvelinus namaycush*) fisheries of Ontario. Canadian Journal of Fisheries and Aquatic Sciences 55:2161–2177.

Simonson, T. 2012. Wisconsin Muskellunge waters. Wisconsin Department of Natural Resources, Publication FH-515-2012, Madison.

Simonson, T. D. 2008. Muskellunge management update. Wisconsin Department of Natural Resources, Publication FH-508-2008, Madison.

Simonson, T. D., and S. W. Hewett. 1999. Trends in Wisconsin's Muskellunge fishery. North American Journal of Fisheries Management 19:291–299.

Staggs, M. D., R. C. Moody, M. J. Hansen, and M. H. Hoff. 1990. Spearing and sport angling for Walleye in Wisconsin's ceded territory. Wisconsin Department of Natural Resources, Bureau of Fisheries Management, Administrative Report 31, Madison.

Vander Zanden, M. J., B. J. Shuter, N. Lester, and J. B. Rasmussen. 1999. Patterns of food chain length in lakes: a stable isotope study. American Naturalist 154:406–416.

Vigliola, L., and M. G. Meekan. 2009. The back-calculation of fish growth from otoliths. Pages 174–211 *in* B. S. Green, B. D. Mapstone, G. Carlos, and G. A. Begg, editors. Tropical fish otoliths: information for assessment, management and ecology. Reviews: methods and technologies in fish biology and fisheries, volume 11. Springer, New York.

Vinson, M. R., and T. R. Angradi. 2014. Muskie lunacy: does the lunar cycle influence angler catch of Muskellunge (*Esox masquinongy*)? PLoS (Public Library of Science) ONE [online serial] 9:e98046.

White, K. 2013. Open water spearing in northern Wisconsin by Chippewa Indians during 2012. Great Lakes Indian Fish and Wildlife Commission Biological Services Division, Administrative Report 13-2, Odanah, Wisconsin.

Wingate, P. J., and J. A. Younk. 2007. A program for successful Muskellunge management: a Minnesota success story. Environmental Biology of Fishes 79:163–169.

Younk, J. A., and D. L. Pereira. 2007. An examination of Minnesota's Muskellunge waters. Environmental Biology of Fishes 79:125–136.

Younk, J. A., and R. F. Strand. 1992. Performance evaluation of four Muskellunge *Esox masquinongy* strains in two Minnesota lakes. Minnesota Department of Natural Resources Section of Fisheries Investigational Report 418.

Zar, J. H. 1999. Biostatistical analysis, 4th edition. Prentice-Hall, Upper Saddle River, New Jersey.