Manual of Fisheries Survey Methods II: with periodic updates

Chapter 28: Muskellunge Sampling Protocol

Matthew J. Diana, Cory K. Kovacs, Neal A. Godby, and James T. Francis

Suggested citation:

Diana, M.J., C.K. Kovacs, N.A. Godby, and J.T. Francis. 2023. Muskellunge Sampling Protocol. Chapter 28 in Schneider, J. C. (ed.) 2000. Manual of fisheries survey methods II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor.

Chapter 28: Muskellunge Sampling Protocol

Matthew J. Diana, Cory K. Kovacs, Neal A. Godby, and James T. Francis

The Management Plan for Muskellunge in Michigan (Smith et al. 2016) identified as an action item adoption of a standard Muskellunge survey protocol for Michigan inland waters. In September 2019, Fisheries Division Management Team charged the Esocid Committee with establishing a standardized sampling protocol for Muskellunge as well as evaluation criteria. Data collected using this protocol will provide a path to evaluate Muskellunge populations for better management recommendations with the ability to compare populations across the region. This protocol will also be used to build a robust database of targeted Muskellunge population assessments.

Muskellunge are a long-lived primary predator with populations typically exhibiting low densities averaging around 0.5 fish per acre, and generally ranging from 0.2 to 1 adult fish per acre (Hanson 1986; Siler and Beyerle 1986; Cornelius and Margenau 1999). These low-density populations result in low catch rates in traditional fisheries survey gears. Evaluating populations can be difficult due to low capture rates and limited collection of biological data (Cornelius and Margenau 1999; Smith et al. 2016). This chapter outlines standard methods for surveys designed to target Muskellunge with the goal of assessing Muskellunge abundance, size structure, and/or growth.

28.1 Prioritization of Waters

Muskellunge surveys require extensive efforts to conduct. In addition, fish are more vulnerable to certain gears for short durations. These factors limit the number of surveys Michigan Department of Natural Resources (MDNR) management units can conduct each year. Prioritizing waters and timing of surveys is critical to ensuring a survey achieves the desired goal. The goals of MDNR Muskellunge surveys generally include evaluating stocking efforts, growth rates, size structure, establishment of a fishery, and natural recruitment. Stocking evaluations depend upon the stage of development of a fishery and should be conducted following multiple stocking events that have had enough time to establish a population. Muskellunge recruit to large-mesh entrapment gear once they reach approximately 30 inches resulting in average full age class recruitment by age-6. There should be multiple age-6 or older cohorts or 3 cohorts at a minimum of age-5 (minimum of 9 years after stocking begins) before surveys are conducted. Systems can be surveyed earlier for initial evaluation of survival of stocked fish, but full evaluations require adequate time for fish to recruit to the gear. The Esocid Committee has identified evaluation of Great Lakes strain Muskellunge stocking as a priority goal and has established statewide survey priorities for evaluating the stocking program. Lakes are identified based on the stocking history and the need for management evaluation. Lakes that meet the stocking history and age requirements for full evaluation will be included in the priority list. Lakes will be ranked based on the number of cohorts vulnerable to the gear, the length of time since the last survey evaluating Muskellunge (lakes with no recent surveys will be ranked higher), and need for management (e.g., few fish included in initial Von Bertalanffy estimate of asymptotic size [L_∞] used to assign a minimum size limit).

A secondary goal is to monitor populations supported by natural reproduction. The Esocid Committee will maintain a separate table of statewide priorities for assessing these populations. This list will be established based on past survey history and perceived management needs. Identifying priorities will rely

on Management Unit input as well as input from stakeholders. The Esocid Committee will maintain a document containing the above referenced tables of statewide priorities that will be housed in the Team Room and available to Management Units to aid in developing workplans. This list will be updated annually and reviewed by the committee every five years. Water bodies selected for sampling Muskellunge populations are at the discretion of the Management Unit.

28.2 Survey Procedures

Three survey types should be used depending on environment, available resources, and goals. In addition, growth analysis can be supplemented through collection of growth structures opportunistically using alternative methods described below.

28.2.1 Assessing Muskellunge Density (Population Estimate)

Objective: To conduct a population estimate for adult Muskellunge using a capture, mark-recapture procedure to collect, mark, and recapture as many individuals as possible to estimate abundance.

Population estimates are the preferred method for conducting evaluations of Muskellunge densities. As a template for the development of these protocols, population estimate methods were suggested in the Management Plan for Muskellunge in Michigan (Smith et al. 2016). Population estimates are conducted through spring netting in a marking year and a recapture netting the following year. These surveys are labor intensive, require two years to complete, and rely on enough captures to conduct a proper analysis. As a result, MDNR has only conducted Muskellunge population estimate surveys on broodstock lakes where a high level of effort is warranted. These lakes include populations of Muskellunge that are all tagged with Passive Integrated Transponder (PIT) tags and are stocked at a high rate. Population estimates may be difficult in low density populations and further limit the number of systems a Management Unit can survey (see *28.2.3* and *28.2.4*). Population estimates should be reserved for high priority populations where understanding Muskellunge density is important to management and where catch rate and recapture probability is great enough that a reliable estimate can be calculated. This method is intended for closed systems to avoid violating the assumptions made when conducting population estimates, however it can be used in open systems with some limitations. Population estimates can be used in evaluating both stocked and non-stocked populations. In addition to population estimates, relative abundance or catch per unit effort (CPUE) can be calculated to compare to surveys where only catch data are available. The following are protocols for conducting a targeted Muskellunge survey to conduct a population estimate.

28.2.1.1 ***Timing***- Adult Muskellunge are vulnerable to inshore entrapment gears and electrofishing in the spring during spawning. Fish are commonly found in pairs near historic spawning locations where preferred habitat is available. Lakes should be surveyed from ice out through the conclusion of spawning when temperatures range from 40°F to 60°F. Female spawning Muskellunge have been caught in survey trap nets in Lake St. Clair during May with water temperatures ranging from 46°F to 64°F (Thomas and Haas 2012). Catch rates generally increase until peak spawning at 55 °F (depending upon system) and then catches decline. Sampling windows may vary across the state and from year-to-year because of latitudinal differences in climate, annual variability in spring warm up, and differences in lake size. Surveys that begin too early may need to extend if peak spawning is delayed. However, surveys starting too late risk missing the peak spawn resulting in low numbers of fish captured. Conservative planning should start early enough to ensure surveys are conducted during peak vulnerability for Muskellunge despite potentially requiring additional effort. Timing of spawn may vary in larger rivers such as the St. Clair and Detroit Rivers where fish appear on spawning grounds when temperature reaches 58° F. An adult Muskellunge population estimate should be conducted in two consecutive

years. The marking phase will occur during the first year and the second year will serve as the recapture phase. The marking phase should cease when most females and some males are spent. The marking phase can also end when a daily recapture rate is greater than 30 percent. The recapture phase can be conducted until 30% of the marked fish have been recaptured. In some situations, the spawning during the recapture phase may end before 30% is achieved, therefore 30% should be used as a soft target.

28.2.1.2 ***Gear***- Trap nets or large-mesh fyke nets will be set during both the mark and recapture phases. Net standards and dimensions should meet those identified in the MDNR Inland Lake Status and Trends Program Sampling Protocol (Wehrly et al. In Press). Trap nets have higher catch rates but are more labor intensive to deploy and relocate. More fyke nets can be set per night and they can be moved more readily, but they also result in reduced catch rates per net and higher frequency of empty nets. These tradeoffs should be considered when choosing the appropriate gear based on the available habitat to cover. Electrofishing can be used to supplement capture of Muskellunge for population estimates (see *28.2.3*). Fish sampled by electrofishing during population estimates should not be used for catch rate or length frequency comparisons

28.2.1.3 ***Methods***- Nets should be distributed throughout the lake focusing on Muskellunge spawning locations. The number of nets used should be determined by the amount of available Muskellunge spawning habitat in the lake. The minimum number of nets used should follow recommendations of the Status and Trends Protocol based on lake size (Wehrly et al. In Press). Addition or relocation of nets is at the discretion of the field crew. Spotlighting surveys can be conducted prior to netting to inform netting locations. Historical capture locations documented in lake files, should also be considered for sampling.

Beginning with the marking phase, <u>all</u> Muskellunge should be marked with a PIT tag and/or fin clip (dorsal fin ray removal for age and growth determination can be used as a mark). The use of PIT tags is beneficial for future assessments and long-term monitoring of the population (see *28.2.4*). Other marks or tags can also be used if adjustments are made for tag loss. Muskellunge captured during the marking period measuring less than 30 inches can be given a separate clip. This helps to differentiate fish during the recapture phase that recruit (become > 30 in) during the subsequent year of sampling (See Section 28.4.1 for further population estimate instructions). In the recapture phase, <u>all</u> Muskellunge should be marked with a secondary mark (top caudal clip to distinguish recaptured fish). To limit fish stress, fish can be held in oxygenated holding tanks and sock nets may be used to aid in handling. All fish should be released away from nets (*or electrofishing station*). Electrofishing effort should be recorded as GPS track distance (in miles) as well as generator time (in hours).

28.2.2 Assessing Relative Abundance and Growth

Objective: To assess Muskellunge populations using catch per unit effort (CPUE) as a measure for relative abundance and to collect aging structures to evaluate size structure, growth, and mortality.

Large-mesh fyke net or trap net surveys conducted during spring have become the most commonly used method for MDNR surveys to collect biological data and evaluate stocking success of Muskellunge. Using this method requires less staff time than a population estimate survey. Muskellunge management in Michigan relies heavily on size limits established by evaluating growth rates and size potential of a population. These factors can be linked to density if prey is limited but can often be evaluated without the need for density estimates. Catch rates have been used as a surrogate for density in Muskellunge populations but has not been fully validated using MDNR survey data. CPUE of Muskellunge from MDNR surveys using multiple gear types in Muskellunge waters in Michigan have demonstrated

significant correlation among gear types (Diana et al. DRAFT). The Esocid Committee will continue to corroborate this relationship as population estimate data becomes available.

28.2.2.1 ***Timing***- Adult Muskellunge are vulnerable to inshore entrapment gears and electrofishing in the spring during spawning. Fish are commonly found in pairs near historic spawning locations where preferred habitat is available. Lakes should be surveyed from ice out through the conclusion of spawning when temperatures range from 40°F to 60°F. Female spawning Muskellunge have been caught in survey trap nets in Lake St. Clair during May with water temperatures ranging from 46°F to 64°F (Thomas and Haas 2012). Catch rates generally increase until peak spawning at 55 °F (depending upon system) and then catch rates decline as the spawning period ends. Sampling windows may vary across the state and from year-to-year because of latitudinal differences in climate, annual variability in spring warm up, and differences in lake size. Surveys that begin early may need to extend if peak spawning is delayed. However, surveys starting late risk missing the spawn resulting in low numbers of fish captured. Conservative planning should start early enough to ensure surveys are conducted during peak vulnerability for Muskellunge despite potentially requiring additional effort. Timing of spawn may vary in larger rivers such as the St. Clair and Detroit Rivers where fish appear on spawning grounds when temperature reaches 58° F.

28.2.2.2 ***Gear***- Trap nets or large-mesh fyke nets should be used to target Muskellunge during the spring spawning period. Net standards and dimensions should meet those identified in the MDNR Inland Lake Status and Trends Program Sampling Protocol (Wehrly et al. In Press). Trap nets have higher catch rates but are more labor intensive to deploy and relocate. More large-mesh fyke nets can be set per night and they can be moved more readily but they also result in reduced catch rates per net and higher frequency of empty nets. These tradeoffs should be considered when choosing the appropriate gear based on the available habitat to cover.

28.2.2.3 ***Methods***- The number of nets used should be determined by the amount of available Muskellunge spawning habitat in the lake. The minimum number of nets used should follow recommendations of the Status and Trends Protocol based on lake size (Wehrly et al. In Press). Addition or relocation of nets is at the discretion of the field crew. Net placement should not be randomized but focus on distributing nets throughout the lake in potential muskellunge spawning habitat. Spotlighting surveys can be conducted prior to netting to inform netting locations. Historical capture locations should also be considered. Nets should remain in the water through the spawning period until catch rates decline significantly. To limit fish stress, fish can be held in oxygenated holding tanks and sock nets may be used to aid in handling.

28.2.3 Assessing Low Density Populations

Objective: To assess low density Muskellunge populations in systems where traditional netting is inefficient using CPUE as a measure for relative abundance and to continue collecting aging structures to evaluate size structure, growth, and mortality.

Boat electrofishing can be used in situations where traditional large-mesh fyke net and trap net surveys yield few fish. These include extremely low-density populations (e.g., Antrim Chain of Lakes) or rivers. Catch rates are generally low, but an active surveying technique allows for specific targeting of Muskellunge and adaptation based on success. This method is valuable for increasing the number of aging structures collected but is a poor method for evaluating adult abundance. The following methods describe targeted Muskellunge electrofishing to assess low-density, adult populations. Fall electrofishing surveys can also be conducted to provide an indication of Muskellunge recruitment (young-of-year catch rate) or survival of stocked fish (see Chapter 23).

28.2.3.1 ***Timing***- Electrofishing should be conducted in the fall when water temperatures range from 60 to 50° F. When conducting a spring survey for collecting aging structures, surveys should be conducted from ice out through the conclusion of spawning when temperatures range from 40°F to 60°F.

28.2.3.2 ***Gear***- Boat electrofishing should be conducted at night. Targeted waters depths may vary depending on habitat types, amount of habitat, and likely spawning areas. Electrofishing should be conducted at the following settings with modification as needed: Direct Current (DC)-recommended starting settings are frequency of 60 PPS and 45% duty targeting an average of 5–7 amps. These settings will be adjusted based on efficiency as conductivity, depth and success varies. Boat speed should range from 3–5 mph. Dip nets should be 36 inches diameter long-handled nets (10–12 feet) with a 36-inch-deep bag (2-inch bar mesh). Water temperature, conductivity, and generator time should be recorded as they can affect catch rates.

28.2.3.3 ***Methods***- Two boats should be used in tandem to increase probability of capture. One boat can be used in smaller lakes or rivers where tandem boat operation is difficult. Boat speed should range from 3–5 mph. The entire shoreline should be surveyed on lakes with less than 8 miles of shoreline. Lakes over 8 miles can be subsampled. Random selection of sites is achieved by dividing the shoreline into 2-mile segments and randomly selecting sites. Sites should not be targeted to ensure catch rates can be comparable to other surveys. Lakes with shorelines from 8-16 miles should survey a minimum of four, 2-mile segments (preferably 50% of shoreline surveyed). Lakes over 16 miles of shoreline should include a minimum of five, 2-mile segments. All fish should be released away from electrofishing stations. For each electrofishing station, latitude and longitude, start and end time, and habitat data should be recorded.

The goal during spring surveys should be to work the available habitat in an attempt to maximize catch rates rather than covering a shoreline distance. Spring electrofishing can be conducted using a single pass over known spawning locations. Multiple passes can be used to increase probability of capture. A meandering path can be used in wide flats to cover a greater area. Fish that are encountered may be chased to increase captures.

28.2.4 Supplement Growth Assessments

Objective: To supplement assessments of Muskellunge populations utilizing angler participation.

Management units are not always able to conduct surveys on Muskellunge waters they are actively managing. Angler information and participation can be used in a variety of formats to evaluate stocking success or growth rates. Anglers can also provide information between surveys to increase a fisheries manager's knowledge of the fishery. Ultimately, the goal of stocking is to produce a fishery and it is important to evaluate angler success and opinions on the status of a fishery. It is important to understand angler opinions and goals when managing a fishery. Surveying Muskellunge anglers can provide valuable insight on management goals and the status of a fishery for lakes where adequate sampling has not been conducted. Consultation with experts in survey question design and analysis should be conducted when launching new surveys and coordinated through the DNR Fisheries Survey Committee.

The DNR Fisheries Division collects Muskellunge angler data through the voluntary online catch reporting tool, the mandatory harvest reporting system, and the Fishing Tournament Information System (FTIS). The Esocid Committee will continue to administer the online Muskellunge angler survey and provide results to fisheries managers. The angler survey asks for information on the number and size of Muskellunge caught, number of follows/observations, preferred angling experience, and harvest. All

anglers that harvest a Muskellunge in Michigan are required to register their harvest. The Esocid Committee keeps information from reported harvest and provides an annual summary to managers. Data is collected on the location of the harvest, size of the fish, and date of harvest. All Muskellunge Tournaments in Michigan are required to register and report to the FTIS. Tournament Directors report the species targeted, number of participants, length of tournament, number of fish captured, total weight, and largest fish. This data is summarized annually and provided to mangers. Tournament groups can also be used to collect biological data on Muskellunge populations. This could involve soliciting data from the FTIS or partnering with a tournament group to hold an event on a system where data is needed (e.g., Lake St. Clair). Catch rates can be calculated and compared to other tournaments. Biological data can be collected on the fish caught and if a marking study is ongoing, marks can be recorded, PIT tag data could be read, or tags could be injected.

This protocol stresses the importance of angler assistance in obtaining information on Muskellunge fisheries. Because MDNR survey effort is limited, information generated by anglers can greatly supplement our understanding of a fishery. Care should be used when interpreting angler derived data due to inherent biases. Managers should look for opportunities to engage with local angers utilizing the tools described in this protocol.

28.3 Data Collection

The priority in all Muskellunge surveys is the collection of biological data. Length-at-age estimates are used to estimate growth and to model ultimate size of fish in the population. For each net lift, record waterbody name, gear type, water temperature, weather conditions, and length and mark data per Muskellunge collected (record the same for electrofishing stations). For all Muskellunge label envelope with the following: sex determination, total length (tenths of inches), maturity, and presence of lesions and any abnormalities. Carefully determine sex by presence of milt or eggs, or by visual inspection of the urogenital pore using Lebeau and Pageau (1989). Fish that cannot be classified (unknowns) should be recorded separately and data should be collected in addition to known sex fish (5 categories; F, M, F?, M?, UNK). The first few dorsal fin rays (2–3) should be removed for age determination and stored in an envelope. Dry all envelopes at conclusion of each day. If an existing genetic study is being conducted, fin rays should be preserved in non-denatured ETOH or frozen for genetic analysis. Aging structures should be collected from as many fish as possible. Since low catch rates and slow growth result in overlapping of year classes, subsampling may be limited and unnecessary. Collect aging structures to meet the collection goal for the waterbody (collect a maximum of 10 aging structures by inch group stratified by sex, unless instructed otherwise by local Management Unit). See Fisheries Division's Survey Manuals for details on aging (Schneider et al. 2000).

Tagging efforts require a marking proposal approved by the Fish Marking Review Committee. If using PIT tags, fish can be scanned or injected at the time of capture if the population is part of an approved study. PIT tags may be injected in the peritoneal cavity on the ventral side just posterior of the pectoral fins. Alternatively, PIT tag locations may be selected based on project need using recommendations in Younk et al. (2010). All tags or clips observed or applied should be recorded for each fish.

Habitat information should be collected at net locations and fish capture locations within electrofishing stations to describe potential spawning habitat. These include, water depth, substrate, vegetation, water temperature, primary lake feature (e.g., cove, flat, point) and GPS coordinates. Electrofishing effort start and end locations should be recorded using a GPS, as well as track distance (in miles) and generator time (in hours).

28.4 Analysis

Data collected from targeted Muskellunge surveys will be entered into Fish Collection System using guidance from the Status and Trends Protocol (Wehrly et al. In Press). The survey type should be listed as "Species Evaluation" and the notes should include the statement referencing the use of standard protocols. The new Fisheries Information System Hub (FISH) system will have a checkbox/dropdown menu where you can specify the specific protocol used. All surveys that targeted Muskellunge using this protocol should be reported during annual requests issued by the Esocid Committee to document targeted surveys. The Esocid Committee will maintain a table of Muskellunge surveys to be used for creating updated evaluation criteria from surveys conducted according to the standardized protocol. In addition, the Esocid Committee will retain a living document that includes a table of targeted Muskellunge surveys conducted each year with associated summary data to be used for future comparisons. The following sections outline data analysis for each survey type.

28.4.1 ***Population estimates***- Density of adult Muskellunge (≥30 inches) is estimated using the appropriate population methods. Closed populations should be estimated by using the Chapman modification of the Petersen formula (Ricker 1975). Open populations should be estimated by using the Cormack-Jolly-Seber model (Cormack 1964; Jolly 1965; Seber 1965). Because female Muskellunge do not spawn every year, populations with spatially disparate spawning habitat (e.g., river spawning population) should consider that non-spawning females may not be vulnerable to survey gear and may not be recaptured in consecutive years. Managers may consider using return time parameters to refine population estimates if this is a concern (see Pledger et al. 2013). Program Mark (or similar capture history analysis) should be considered where unique individuals are marked (e.g., PIT tags). Muskellunge captured the first survey year make up the marking run, and those in the second year compose the recapture sample. Fish that were under 30 inches and marked with an alternative mark should not be included as recaptures. Unmarked fish numbers in the recapture sample are adjusted for recruitment over a one-year period using sex-specific and lake-specific growth rates determined from dorsal fin ray interpretations to remove fish from the calculation that recruited to the over 30-inch size class after the initial mark survey occurred.

28.4.2 ***Relative Abundance***- Relative abundance will be assessed using CPUE for standardized surveys using gears outlined in this protocol. CPUE will be calculated as the total number of fish captured, divided by the total number of net nights (trap and large-mesh fyke nets) or hours of electrofishing. CPUE will be calculated separately by gear type (large-mesh fyke v trap v electrofishing).

Currently, there is no direct relationship between density and relative abundance established for Michigan Muskellunge populations due to the limited number of surveys of each type conducted on the same waters. This relationship will be further established as this protocol is used and more standardized surveys are completed. However, catch rates through time have been demonstrated to trend with density (Diana et al. DRAFT). CPUE was significantly correlated among all gear types in lakes where multiple gears were used. CPUE should be used as a measure of relative abundance of Muskellunge from standardized surveys on a broad scale, but small differences in catch rate among systems should not be interpreted as differences in density. Utilizing this standardized protocol for calculating catch rates will allow for future comparisons.

28.4.3 ***Growth***- Muskellunge growth rates can be compared temporally and across statewide Muskellunge populations using mean length-at-age. Mean length-at-age should be stratified by sex when possible to account for growth differences between sexes. Von Bertalanffy growth models should be established for each population using length at age data with support from the Esocid

Committee. Establishing updated L_∞ estimates will allow for evaluation of current minimum size limit and determine if changes are recommended. For modeling purposes growth data will be included from all Muskellunge surveys in L_∞ estimates.

28.5 Evaluation

Muskellunge population estimates and catch rates should be compared to statewide results from standardized surveys conducted using this protocol. Muskellunge density can be assessed by comparing to density goals described in the Management Plan for Muskellunge in Michigan (Smith et al. 2016). Catch rate summaries from MDNR surveys can be referenced in Diana et al. (DRAFT) and using the table below (Table 1). Population estimates and catch rates should be compared to median values for statewide Muskellunge population. Values below the 25th percentile will be considered low density and values over the 75th percentile will be considered high density. Mean length-at-age should be used to evaluate Muskellunge growth rates (Table 2). Mean length for age-6 fish was determined to be the best indicator of growth as age-6 fish are readily captured and are old enough that both male and female Muskellunge should be fully recruited to all gear types outlined in this protocol. Water bodies with mean length-at-age 6 are considered to have average growth if between the 25th and 75th percentile. Water bodies with mean length at age-6 below the 25th percentile are considered to have poor growth and above the 75th percentile are considered to have good growth. Populations should be evaluated using a combination of growth and abundance data. Populations can be managed for high density to promote increased catch rates or for low density, high growth populations with greater size potential. Ideally lakes can be managed for both, but depends upon productivity, prey populations, and carrying capacity of the system. Muskellunge populations should be managed individually with statewide catch and growth rates as a guidance for making management decisions in combination with guidance from the Muskellunge management plan. Evaluation criteria are also outlined in Diana et al. (DRAFT) based on past catch rate data providing a management matrix following the Management Plan for Muskellunge in Michigan (Smith et al. 2016). Von Bertalanffy growth models should inform minimum size limits using guidance outlined in the Management Plan for Muskellunge in Michigan (Smith et al. 2016).

Table 1. Catch per unit effort (CPUE) from targeted Muskellunge surveys conducted by MDNR from 2000 through 2019 for electrofishing (fish/hour), large-mesh fyke nets (fish/net night), and trap nets (fish/net night).

Gear	Number of Surveys	Mean CPUE	25th Percentile	Median	75th Percentile
Electrofishing	7	3.05	0.38	1.78	5.26
Large-mesh Fyke Nets	14	0.28	0.08	0.16	0.39
Trap Nets	26	2.63	0.88	1.19	3.58

Table 2. Summary of mean length-at-age of northern strain Muskellunge captured in fish surveys conducted on lakes in Michigan from 2000 through 2019.

Age	Mean	25th Percentile	Median	75th Percentile	Number of Fish	Number of Lakes	Mean Number of Fish per Lake
3	25.1	22.2	26.1	28.0	212	25	8.5
4	31.1	28.9	31.1	33.2	439	28	15.7
5	34.0	31.6	33.8	36.0	445	39	11.4
6	35.7	33.4	35.8	38.2	379	34	11.1
7	36.5	34.7	36.1	38.2	298	34	8.8
8	38.1	36.1	37.8	40.9	249	32	7.8

28.6 References

Cormack, R. M. 1964. Estimates of Survival from the Sighting of Marked Animals. Biometrika 51: 429–38.

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.

Diana, M. J., N. A. Godby, C. K. Kovacs, and J. T Francis. DRAFT. Evaluation of Northern Pike and Muskellunge surveys conducted by Michigan Department of Natural Resources from 2000 through 2019.

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

Jolly, G. M. 1965. Explicit estimates from capture–recapture data with both death and immigration—Stochastic model. Biometrika 52, 225–247.

Lebeau, B. and Pageau, G., 1989. Comparative urogenital morphology and external sex determination in muskellunge, Esox masquinongy Mitchill. Canadian Journal of Zoology, 67: 1053–1060.

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

Schneider, J. C., P. W. Laarman, and H. Gowing. 2000. Age and growth methods and state averages. Chapter 9 *in* Schneider, James C. (ed.) 2000. Manual of fisheries survey methods II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor.

Seber, G. A. F. 1965. A note on the multiple-recapture census. Biometrika. 52: 249–259.

Siler, D. H., and G. B. Beyerle. 1986. Introduction and management of northern muskellunge in Iron Lake. Pages 257–262 in G. Hall, editor. Managing muskies: a treatise on the biology and propagation of muskellunge in North America. American Fisheries Society Special Publication 15, Bethesda.

Smith, K. M., M. V. Thomas, and P. A. Hanchin. 2016. Management plan for Muskellunge in Michigan. Michigan Department of Natural Resources, Fisheries Report 12, Lansing.

Thomas, M. V., and R. C. Haas. 2012. Status of Lake St. Clair submerged plants, fish community, and sport fishery. Michigan Department of Natural Resources, Fisheries Research Report 2099, Ann Arbor.

Wehrly, K. E., G. S. Carter, and J. E. Breck. In press. Standardized sampling methods for inland lakes status and trends program. Michigan Department of Natural Resources, Fisheries Special Report, Ann Arbor.

Younk, J. A., B. R. Herwig, and B. J. Pittman. 2010. Short- and long-term evaluation of passive integrated transponder and visible implant elastomer tag performance in Muskellunge. North American Journal of Fisheries Management 30: 281–288.