Minnesota Department of Natural Resources
Investigational Report 565, May 2019

DEPARTMENT OF NATURAL RESOURCES

Compilation and Assessment of Historical Minnesota Late-Summer and Fall Walleye Electrofishing Data

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This project was funded in part by the Federal Aid in Sport Fish Restoration (Dingell-Johnson) Program.
Completion Report, Study 652, D-J Project F-26-R Minnesota.

INTRODUCTION

Walleye *Sander vitreus* management is a high priority in Minnesota and ranges from activities such as habitat protection and enhancement through more aggressive techniques including angling regulations and stocking. Population assessment is a vital component of Walleye management, either to assess the current population status or determine the effectiveness of a management effort. In Minnesota this has primarily been accomplished through gill-net assessments of older juveniles and adults (e.g., Parsons and Pereira 2001; Schupp 2002). However, sampling only these later life stages provides limited information about variability in abundance of early life stages, especially age 0. Understanding recruitment variability and year-class strength is necessary for making and evaluating management decisions (Quist 2007). Assessments at earlier life stages could allow proactive management regarding potentially weak or strong year-classes (e.g. supplemental stocking, regulation changes, or stakeholder education), allowing more time for implementation and possibly reducing the need for drastic or controversial measures.

Electrofishing for age-0 Walleyes became accepted following the work of Serns (1982), who reported a significant positive linear relationship between electrofishing catch per unit effort (CPUE) and age-0 Walleye density in northern Wisconsin lakes. Hansen et al. (2004) reexamined this relationship with additional data, and determined that due to decreasing catchability with increasing population density, among other factors, the relationship was nonlinear and affected by measurement error. They recommended that CPUE be used as a crude index of age-0 Walleye density. Most studies currently use age-0 electrofishing CPUE as an index of relative abundance (i.e., “weak” to “strong” year-classes; e.g., Lucchesi 2002).

While late-summer and fall electrofishing catch rates may provide at least a crude index of age-0 density, numerous factors may subsequently influence year-class strength and recruitment to the fishery (Santucci and Wahl 1993; Johnson et al. 1996; Beard et al. 2003; Fayram et al. 2005). This has led to contradictory results regarding whether estimates of age-0 Walleye abundance do (Busch et al. 1975; Quist 2007) or do not (Forney 1976; Kallemeyn 1987; McWilliams and Larscheid 1992; Johnson et al. 1996) reflect abundance at older ages.

Department of Natural Resources (MNDNR) and tribal fisheries staff (e.g., Fond du Lac band) in Minnesota have been conducting late-summer and fall electrofishing assessments for age-0 Walleyes since the late 1980s. Purposes of these assessments have included determining whether natural reproduction occurred in a given year, estimating relative abundance of natural or stocked year-classes, documenting size of fish entering their first winter, and deciding whether a supplemental fingerling stocking should be conducted. Ideally, long-term data collected with standardized methods are used to assess recruitment dynamics (Quist 2007); however, the large number of lakes managed for Walleyes in Minnesota limits the number of lakes for which there are consistent long-term data. Nonetheless, the quantity of electrofishing data available from the many different lakes in Minnesota over the last 25 years should give useful descriptions of electrofishing variability and inferences concerning population status, allowing more effective management decisions without a long-term data set for a given lake.

The objectives of this project were to collate all available Minnesota late-summer and fall Walleye electrofishing data; to provide statistical summaries by appropriate lake groupings (lake classes or groups of lake classes); to determine which environmental variables affect catch rates; to determine relationships with future age-specific Walleye gill-net catch rates; and to improve future sampling efforts.

METHODS

We found that our ability to query the DNR central fisheries survey database directly from a rural field office was limited due to inadequate network speeds and the huge sizes of many of the data tables (millions of records in some cases). Also, inconsistencies in data entry and the evolution of database content over time made it impossible to query the entire survey database for late-summer and fall Walleye electrofishing data and obtain reliable statewide results. After much trial and error, we ended up using limited database queries cross-referenced with information in the DNR Fisheries Survey Module and correspondence with local fisheries managers to identify potentially useable surveys up through 2014. Using the Fisheries Survey Module, we then downloaded and examined the Standard Lake Survey Report for each potential survey to determine whether it contained useable age-0 Walleye CPUE and mean length. We only used nighttime pulsed-DC electrofishing surveys initiated in August or later. In most cases age-0 Walleyes were listed as the target species, or if age-0 Walleyes were not listed as the target species it was clear that they actually were targeted. Sometimes additional species were collected, whether or not age-0 Walleyes were listed as the target species; in these cases, we generally used the Walleye data if the surveys appeared to be primarily intended for sampling Walleyes. Usually Walleyes were not aged, so age-0 and age ≥ 1 were separated based on the length frequency. It was generally impossible to reliably distinguish age 1 from age > 1, and it was unclear whether netters attempted to dip all age ≥ 1 Walleyes or if they were only incidentally recorded. In some cases, it was necessary to read the text of the report (if available) to interpret the data, and even then it was not always straightforward. If we could not interpret the data with reasonable certainty, then we excluded the survey. Some surveys before 2006 were not included in the survey database; if possible these data were obtained from fisheries managers or archived reports. In addition, some surveys in the northeast were completed by the Fond du Lac Resource Management Division and 1854 Treaty Authority; these data were obtained from Brian Borkholder (Fond du Lac fisheries biologist).

A further challenge was that stocking records were not in the survey database. We obtained a table of pre-2011 Walleye stocking records from the Minnesota DNR Data Manager. For post-2010 stocking information, we used the DNR FishPAD stocking application. Over the range of years in which we had late-summer or fall Walleye electrofishing data for a given lake, plus up to six years following the last electrofishing survey, we used these two data sources to determine whether a lake was stocked in a given year, and if so with what life stages (fry, frying [small summer fingerling], fall fingerling, yearling, or "adult"). If fry were stocked in the same year as the electrofishing survey, it was noted but did not disqualify the survey from the analysis. Frylings only were stocked in a few cases, and since stocking occurred well before electrofishing, we included fryling-stocked year-classes in the analysis. One of the main purposes of late-summer or fall Walleye electrofishing was to determine whether fall fingerling stocking was warranted, so electrofishing almost always occurred before stocking. In the rare cases when fall fingerling stocking occurred before the electrofishing survey in a given year, we excluded the survey from analysis; otherwise, fingerling-stocked year-classes were used to calculate electrofishing CPUE but were excluded from correlations with subsequent gill-net CPUE. Yearling and "adult" life stages sometimes were stocked opportunistically after fingerling rearing ponds failed to winterkill. They obviously had no effect on age-0 CPUE, but potentially confounded relationships with subsequent age-specific gill-net CPUE. In many cases these older life stages were stocked at low densities (< 1 fish per littoral acre), which presumably would have negligible effects on gill-net CPUE. Yearling-stocked year-classes were readily identified, and if stocked at densities ≥ 1 fish per littoral acre they were excluded from analyses. The "adults" were more problematic because their ages were only estimated as ≥ 2, so they might contribute to multiple year-classes that were previously sampled at age 0. Therefore, we excluded a year-class from analyses of relationships with subsequent age-specific gill-net CPUE if "adults" were ever stocked at densities ≥ 1 fish per littoral acre, or stocked more than once at densities < 1 fish per littoral acre, between two and six years after the electrofishing survey but before the gill-net survey.

We obtained results of a query by Minnesota Information Technology staff containing supplemental information on individual electrofishing surveys. We used this to compile the number of electrofishing stations, first and last sample dates, electrofisher control-box type, anode type, minimum and maximum water temperature, electrofishing visibility (Good, Moderate, or Poor), on time and/or run time, and number of netters. These were the only variables that were commonly recorded in the survey database, although additional fields were available for data entry. In the relatively rare cases when electrofisher settings or conductivity measurements were available, there were often ambiguities or obvious inaccuracies that rendered the data unusable.

Age-specific gill-net catches were obtained from Standard Lake Survey Reports for surveys from 2006-2017. Age data prior to 2006 were not in the main survey database and therefore did not appear in survey reports. We obtained a data table from the DNR Data Manager with earlier age data, but data were missing for many earlier gill-net surveys. Age data in either the survey reports or data table were expanded to the total catch via age-length keys if not all fish were aged. We calculated the age-specific gill-net CPUE as the total catch of each age from 1-6 divided by the number of nets.

Electrofishing and gill-net CPUE data were extremely positively skewed and therefore were log-transformed for analysis; however, there were many cases of zero values that could not be log-transformed. Zeroes in fisheries data are usually dealt with by adding 1 (or some other arbitrary constant) to all CPUE values to allow logarithmic transformation, but we found this would bias the back-transformed results. Instead, we used a small constant based on the limits of detection (LOD) in place of the zero observations only. This approach is common in environmental testing (Clarke 1998) and is used here under the assumption that there are low, nonzero levels of Walleye abundance, below which they are unlikely to be detected by electrofishing or gill-net surveys. We defined the LOD as the minimum nonzero CPUE in our statewide dataset for age-0 electrofishing and age-specific gill-net CPUE: 0.370/h (1 fish per 2.7 h) for age-0 electrofishing and 0.0278/net (1 fish per 36 nets) for age-specific gill-net CPUE. We then substituted LOD/2 for the zero CPUE values only.

Sample quartiles were calculated for age-0 electrofishing CPUE across all surveys within each Schupp (1992) lake class; this was straightforward, but did not account for repeated measures of individual lakes that will bias quartile estimates if sampling frequency varies among lakes in relation to their average CPUE. A linear mixed effect (LME) model was used to estimate lake class quartiles that used a random lake effect to account for among-lake differences (in average CPUE and number of surveys) in addition to a random year effect to account for large-scale, within-sample-year correlations. The fitted model was used to predict the mean and variance for the sampling distribution of $\log_e$ CPUE for a random lake within the lake class sampled in a random year, and the quartiles calculated and back-transformed from the predicted normal distribution. Similarly, this model also allowed prediction of lake-specific quartiles using the best linear unbiased predictors of the realized random lake effects. Modeled quartiles were not calculated for lake classes with < 25 surveys.

The relationships between electrofishing age-0 CPUE, water temperature, and age-0 mean length were estimated with LME models with random lake effects that account for repeated measures of lakes which preclude more straightforward regression models of the raw data. Similarly, LME models were used to evaluate the ability of age-0 electrofishing CPUE to predict a cohort's gill-net CPUE at ages 1-6. All catch rate statistics were $\log_e$ transformed for analysis using the LOD/2 in place of zeroes as described above. If substantial winterkill or summerkill were known to have occurred between electrofishing and gill-net surveys of a given year-class, the post-kill surveys were excluded from analysis. Sample sizes of age-specific gill-net CPUE were reduced relative to electrofishing surveys because on most lakes gill-net surveys were sporadic rather than annual, so many electrofished year-classes caught at age 0 in electrofishing surveys did not have corresponding gill-net surveys at later ages. Additionally, many year-classes were excluded due to stocking of post-fryling life stages. The year-class strength model of Parsons and Pereira (2001) was not applicable because of the usually low number and sporadic timing of useable gill-net surveys per lake.

To estimate levels of electrofishing effort necessary to detect age-0 Walleyes, we used a generalized linear mixed effect (GLME) model with logistic link function, binomial error structure, and random lake effects in which the probability of age-0 CPUE > 0 was a function of $\log_e$ sampling effort in seconds; this model was fit with all available electrofishing data. Electrofishing CPUE can be zero due to either the true absence of a cohort or missing a present cohort because of sampling error, so modeled probabilities are the product of the probability age-0 Walleyes are truly present and the probability of detection given presence.

To evaluate if electrofishing was informative about presence/absence of a cohort in the gill nets at age 3, we used a similar GLME model with logistic link function, binomial error structure and random lake effects in which the probability of age 3 CPUE > 0 in gill nets was a function of the presence/absence or $\log_e$ catch rate of the cohort at age 0. Of the 210 lakes with both age-0 electrofishing and age-3 gill-net data, there were 165 lakes that had age 0 present in every electrofishing survey, while there were 24 lakes that had only been electrofished once and no age-0 Walleyes had been captured. Thus, to prevent confounding among-lake differences in probability of age-0 presence with the probability of detection of age-0 Walleyes, this analysis used the subset of the 21 lakes that had multiple surveys, of which at least one had detected age-0 Walleyes and at least one had failed to detect age-0 Walleyes.

RESULTS

Electrofishing surveys targeting age-0 Walleyes typically were initiated in September or early October, although they ranged from 7 August to 19 November (Figure 1). In general, non-randomly selected index stations rather than the entire shoreline were sampled, but stations were not always consistent from year to year within lakes. Presumably, stations were selected in habitats such as sandy or rocky shorelines where age-0 Walleyes were expected to be present (Lake Survey Committee 1993). Numbers of stations were usually five or fewer (median = 3; Figure 2). Effort was recorded as on-time (actual fishing time measured by the control box) and/or run-time (total time to complete the station). When both on-time and run-time were recorded for the same survey, run-time was the same as or greater than on-time. If both were available, on-time was used in the analyses, but if only run-time was available that was used instead. Effort varied widely among surveys, but was usually < 1.6 h (Figure 3). In some cases, surveys appeared to be cut short or stations omitted if initial CPUE was extremely high or extremely low.

Useable age-0 data were available for 2,975 surveys in 402 lakes from 1987-2014 (Table 1). Statewide, age-0 CPUE ranged from 0/h to 1,470/h. Sample statistics for individual lake classes varied widely, but must be interpreted with caution due to differing numbers of lakes, numbers of surveys, numbers of surveys per lake, and numbers of surveys per year. Mixed effect model predictions of lake class CPUE quartiles were generally lower than the raw sample quartiles (especially for the 75th percentiles) because lakes with higher catch rates were often sampled more frequently and dominated any raw percentile-based statistics. Model-predicted quartiles are also available for individual lakes upon request.

Surface water temperatures recorded during surveys usually were about 55-70 F, but ranged from 35-80 F (Figure 4). Over this range of water temperatures during late summer and fall, the LME estimated age-0 Walleye CPUE to increase proportionally with increasing water temperature, with expected catch rate increasing about 2% per degree F (which leads to CPUE approximately doubling between 40-80 F). Lakes with higher baseline catch rates (CPUE > 75th percentile) could show large absolute changes in catch rates associated with changes in water temperature, though observed changes would be small for most lakes relative to inherent variation in CPUE (Figure 5).

Mean length of age-0 Walleyes (Figure 6) in late-summer and fall electrofishing surveys was typically between 4.8 and 7.5 in (median 6.1 in, range 3.1-9.9 in), and tended to be larger later in the year (Figure 7). Mixed effect models showed that mean length significantly decreased with increasing age-0 CPUE (Figure 8), but for a given CPUE of age-0 Walleyes, the observed mean length did not improve the ability to predict future gill-net catch rates. However, the complex relationships in the data among electrofishing CPUE, sampling date, water temperature, mean age-0 length, and subsequent gill-net catch rates preclude straightforward conclusions about the relationship between mean length at age 0 and ultimate year-class strength.

Electrofisher control-box type was only available for 1,460 surveys, and only 169 of these were before 2006. Anode type was only available for 1,486 surveys, and only 167 of these were before 2006. Various models of Coffelt control boxes were listed for 298 surveys; various models of Smith-Root control boxes were listed for 1,126 surveys; and other control boxes were listed for 39 surveys. In a few cases more than one type of control box was used for the same survey. Types of anodes listed for Coffelt control boxes were "cable," "ring," "24-in ring," "9-12 in ring," "sphere," "sphere & ring," "spider array," "spider array/sphere," and "WI ring." Types of anodes listed for Smith-Root control boxes were "cable," "4-cable," "6-cable," "ring," "sphere," "spider array," and "umbrella." Types of anodes listed for other control boxes were "cable," "6-cable," "sphere," and "spider array." Given the scarcity of information before 2006, ambiguity and suspected errors in many of the anode descriptions, the number of combinations of control boxes and anodes, and a general lack of information on control box settings, we concluded that accounting for potential effects of different electrofishing gear or control-box settings on historical CPUE was impossible.

The reported number of netters per station was always either 1 or 2, but sometimes the number varied among stations due to different crews working on the same survey. Of the 2,263 surveys where the number of netters was available, 1,761 had one netter, 458 had two netters, and 44 had a combination. There was virtually no difference in age-0 CPUE between surveys that had one netter and those that had two netters (1 netter: median = 16.83/h, 25% = 2.40/h, 75% = 59.10/h; 2 netters: median = 16.85/h, 25% = 2.47/h, 75% = 59.16/h; Mann-Whitney Rank Sum Test, $P = 0.963$).

Electrofishing visibility (influenced by turbidity, waves, etc.) was rated as "Poor," "Moderate," or "Good" for 2,264 surveys. According to the DNR lake survey manual in use before 2017 (Lake Survey Committee 1993), Poor = "significantly affected fish catch," Moderate = "some effect on fish catch," and Good = "no perceived effect on fish catch." These subjective ratings probably were not consistent among surveys, and ratings often varied among stations in the same survey. Counterintuitively, surveys where visibility was rated as Good for all stations had significantly lower CPUE than surveys where visibility was rated as Poor or Moderate (Table 2), though this is confounded by the range in productivity across Minnesota lakes (i.e., more productive waters tend to have lower visibility).

Age-0 Walleyes were not detected in 16% (485 out of 2,975) of electrofishing surveys, and the amount of time electrofishing was significantly related to the probability of detection ($p < 0.0001$). At the lowest level of effort in the data (300 s), the GLME estimate of the average probability of detecting age-0 was approximately 0.50 (Figure 9). Probability of detection increased to 0.80 for a half-hour of electrofishing (85% of surveys had > 1800 s), and to 0.90 for 1.5 h of effort (30% had > 5400 s). Asymptotically, the probability of capturing age-0 Walleyes was approximately 0.95 (Figure 9), suggesting that age-0 Walleyes were truly absent only about once every 20 years in the average lake; however, there was significant variation in the estimated probability of detection among the 373 study lakes, likely due to among-lake differences in average age-0 abundance, sample site selection, and electrofishing effort.

For ages 1-6, there was a positive linear relationship ($p < 0.001$) between log-transformed age-0 electrofishing CPUE and subsequent log-transformed gill-net CPUE of the same cohort (Figure 10). Despite the significant correlations between electrofishing CPUE and subsequent gill-net catch, all of the models had very high residual error, making prediction intervals of future gill-net catch rates very wide in application (Figure 11). Median statewide gill-net CPUE of year-classes that were sampled by electrofishing peaked at age 3 (Table 3). Age-3 Walleyes were typically about 13-16 in TL during summer gill-net surveys; they were near the minimum quality size (Gabelhouse 1984), but had generally not yet been subjected to enough fishing mortality to substantially reduce their abundance. The proportion of gill-net surveys with CPUE = 0 was likely biased high for ages 1-2, and proportions of CPUE = 0 at ages 4-6 were also likely inflated by decreasing abundance and possibly ageing error. Therefore, like Reed and Staples (2017), we considered gill-net CPUE at age 3 as the primary statewide index of recruitment to the fishery.

In the 165 lakes with age-0 Walleyes present in every electrofishing survey, the corresponding year-class was detected at age 3 in the gill nets 98% of the time (487 of 495 surveys). For the 24 lakes in which age-0 Walleyes were not detected in an electrofishing survey, the corresponding year-class was detected at age 3 in the gill nets 58% of the time (14 of 24 surveys). For the 21 lakes that had surveys with both 0 and > 0 age-0 CPUE, age-3 Walleyes were detected for 75% (18 of 24) of the year-classes that were not caught at age-0, while age-3 Walleyes were detected for 88% (50 of 57) of cohorts that were detected at age 0. There was no relationship between the presence/absence of a cohort at age 0 and the probability of detection at age 3 in the gill nets (p = 0.266) in the overall test with the GLME model. The GLME model using $\log_e$-transformed age-0 CPUE did show a significant relationship (p = 0.024) between electrofishing catch rate and the probability of detecting a cohort at age 3, though the magnitude of the effect was small and occurred mainly for age-0 CPUE < 5 (Figure 12).

DISCUSSION

The quality of the historical late-summer and fall Walleye electrofishing data in the DNR Fisheries Survey database varied, but was often less than ideal. Important deficiencies included:

1. Lack of consistency of electrofishing gear, sampling dates, and sampling stations, often even within a single lake.
2. Inconsistent recording of electrofishing effort (on-time vs. run-time).
3. Lack of attention to QA/QC by field biologists and supervisors.

In addition, there was less useful auxiliary information than anticipated, which constrained our objective to determine which environmental variables affected catch rates.

Despite the high sampling variation inherent in both electrofishing and gill-net surveys, we found statistically significant relationships between electrofishing and gill-net CPUE; however, prediction intervals with the models must account for uncertainty about the estimated mean in addition to unexplained variability of individual observations about a given mean. As all models relating electrofishing CPUE to gill net CPUE had very high residual error, useful predictions with the models were not possible.

Our compilation of quartiles of age-0 electrofishing CPUE for lake classes may be useful to fisheries managers for putting results of individual surveys into perspective. When available, modeled quartiles should be used rather than overall sample quartiles of lake classes, because the modeled quartiles are unbiased by sampling frequency among lakes, and more importantly, the LME models can provide lake-specific quartile estimates for more accurate estimates of expected catch rates at an individual lake. Electrofishing CPUE greater than the lower quartile for an individual lake or lake class indicates some recruitment of the year-class to the fishery is likely, but relative year-class strength at age 3 is unpredictable.

We found that electrofishing for at least 30 min resulted in about 80% power to detect age-0 Walleyes in the average lake, and 85% of the surveys in the data set had 30 min or more of effort. Failure to detect a year-class at age 0, however, did not mean that the year-class would not appear in gill-net surveys at age 3, indicating that electrofishing surveys often missed detecting a cohort even with relatively high effort. On the other hand, if a year-class was caught by electrofishing at a rate > 5 per hour, then it was almost always detected in gill-net surveys at age 3, but the realized gill-net CPUE was extremely variable. These data suggest that for basic evaluation of a cohort, electrofishing effort should be at least 30 min, and age-0 CPUE > 5 indicates that there will likely be measurable recruitment of the year-class to the fishery; however, age-0 CPUE = 0 is not strong evidence of the absence of the year-class. As a trigger for contingency stocking, electrofishing effort should be increased to > 1.5 h to help ensure adequate probability of detection.

Age-0 electrofishing CPUE increased proportionally 2% per degree over the range of temperatures observed (40-80 F) in late summer and fall electrofishing. While this is in contrast to Borkholder and Parsons (2001), who concluded that age-0 electrofishing CPUE peaked at 18.6 C (65.5 F), their recommendation to target electrofishing temperatures between 10 and 20 C (50-68 F) is reasonable, though our analysis suggests a slightly warmer temperature range of 55-75 F (13-24 C) would lead to higher catch rates. Attempting to minimize variation in electrofishing catch rates by electrofishing at relatively consistent temperatures, however, will likely also affect observed CPUE and mean length because age-0 Walleyes are growing during the late summer and fall, and natural mortality is reducing abundance over time; this is supported by the cross-correlations among sampling date, water temperature, age-0 mean length, and electrofishing CPUE observed here, and further complicates inference based on age-0 CPUE.

Additional recommendations in the current MNDNR lake survey manual (Lake Survey Committee 2017) should be strictly followed to avoid repeating the deficiencies in the historical data set. Although age-1 electrofishing CPUE might be a better predictor of recruitment to the gill nets than age-0 CPUE (Madsen 2008), there was not enough useable information on age-1 Walleyes in the historical electrofishing data set for meaningful analysis. If there is management interest in electrofishing for age-1 Walleyes, then the entire length range of fish that might be age 1 must be netted, age-1 should be clearly noted as targeted rather than netted incidentally, and age-1 fish need to be reliably distinguished from age 0 and age >1.

Although there is room for improvement in Minnesota's age-0 and age-1 Walleye surveys, there will always be a great deal of uncertainty in using these surveys for predicting recruitment to the fishery at least two years later. With more intensive sampling methods than those typically used in Minnesota, Hansen et al. (2012) found that the estimated density of age-0 Walleyes only explained 33% of the variation in estimated age-4 density in northern Wisconsin lakes. Even if abundance of age-0 Walleyes in late summer or fall could be perfectly quantified, there would still be uncertainty in predicting future gill-net catch rates because Walleye year-class strengths may not always be determined by the time of electrofishing (Koonce et al. 1977).

Electrofishing surveys are useful for verifying Walleye natural reproduction or fry-stocking success in a given year, and high catch rates of age 0 are indicative of at least some future recruitment to the fishery; however, managers should not automatically conclude that supplemental fingerling stocking is warranted based only on age-0 CPUE in a single survey, especially if sampling effort is below 1.5 h. When allocating limited staff time, fisheries managers need to weigh the potential value of the information gained from late-summer or fall electrofishing versus the effort required to obtain meaningful data.

TABLES

TABLE 1. Statistics for Minnesota age-0 Walleye fall electrofishing CPUE from all useable surveys through 2014. Schupp (1992) lake classes were as listed in the lake survey database. Within lake classes, some lakes and years had disproportionate influence on sample quartiles (Sxx%), and survey years were not equally represented among lake classes. Modeled quartiles (Mxx%), where sample size was adequate, accounted for lake and year as random effects in a linear mixed effects model.

Schupp				Age-0 CPUE (n/h)							
lake class	Years	N lakes	N surveys	Min	S25%	M25%	S50%	M50%	S75%	M75%	Max
1	1999-2014	1	16	5.99	30.42		87.87		247.36		842.74
2	1994-2014	4	72	0.64	19.67	16.50	39.21	37.63	98.09	85.81	303.87
3	1997-2014	1	4	0.00	1.28		2.05		2.45		2.60
5	1994-2014	9	110	0.00	2.80	0.78	13.65	4.49	46.87	25.97	752.05
6	1997-2014	7	94	0.00	4.83	3.98	21.87	15.07	81.11	56.98	398.15
7	1993-2014	5	41	0.00	14.87	12.90	63.23	42.33	154.08	138.93	1091.50
8	1999, 2000, 2002	1	3	12.01	15.27		18.52		34.54		50.56
10	1996-1997	1	2	0.00	0.00		0.00		0.00		0.00
11	1995, 1998-2014	3	21	0.00	0.00		38.21		112.41		464.68
12	1997-2014	7	87	0.00	9.02	5.87	33.31	21.29	79.11	77.25	425.07
13	1997-2014	2	19	0.00	13.18		35.86		123.29		272.51
15	1998-1999	1	2	3.81	3.87		3.93		3.99		4.05
16	1995-2014	10	118	0.00	18.08	3.57	51.62	16.25	104.00	73.96	428.80
19	2009-2014	3	11	0.00	0.00		1.02		12.68		23.35
20	2007, 2009, 2012	1	3	0.00	0.00		0.00		0.38		0.75
22	1990-2014	43	455	0.00	3.20	1.74	16.29	6.93	45.88	27.60	702.18
23	1994, 1997, 1999-2003, 2005-2007, 2009-2014	12	35	0.00	0.00	0.30	2.00	1.25	16.24	5.17	107.36
24	1987-2014	45	262	0.00	0.79	0.47	7.71	2.23	28.36	10.60	541.50
25	1993-2014	29	160	0.00	2.38	1.05	8.86	4.58	52.33	20.02	311.91
26	1996-2014	3	35	8.94	48.98	38.65	104.80	73.88	184.60	141.22	356.71
27	1990-2014	56	423	0.00	2.17	0.63	9.63	2.91	40.09	13.42	604.00
28	1996, 2000, 2003-2004, 2006-2009	3	8	0.00	0.00		0.43		10.79		61.02
29	2010-2014	2	7	0.00	0.00		0.00		0.00		0.00
30	1995, 1997, 1999, 2000-2001, 2003, 2009	2	7	0.00	0.00		0.00		18.53		164.00
31	1996 , 1999-2011, 2013-2014	17	37	0.00	0.00	0.26	1.09	1.05	12.00	4.26	98.00
32	1998-2000, 2002-2004	4	10	0.00	0.00		0.00		0.00		0.92
33	2000	1	1	2.56	2.56		2.56		2.56		2.56
34	1994-2014	12	68	0.00	0.00	0.88	8.66	5.44	64.21	33.44	255.00
35	1996-1997, 1999-2000, 2006-2009, 2011, 2013	3	12	0.00	0.00		0.00		14.78		38.45
36	2001-2003, 2005, 2007, 2009, 2011, 2013	1	8	5.65	35.84		117.99		169.68		201.43
37	2002	1	1	0.00	0.00		0.00		0.00		0.00
38	1995, 1997-2014	8	34	0.00	0.00	0.54	1.84	3.42	51.75	21.65	541.50
39	1995-2002, 2004-2014	9	42	0.00	0.00	0.79	3.04	3.58	17.34	16.29	189.88
40	1998-2008	3	16	0.00	0.00		1.50		30.48		345.00
41	1987-2014	35	390	0.00	7.90	4.28	33.00	17.97	83.24	75.41	1012.27
42	1993-1996, 1998-2014	11	56	0.00	0.92	1.11	10.50	6.56	42.00	38.61	905.47
43	1987-2014	46	305	0.00	2.00	1.33	20.00	7.82	72.00	45.97	1469.97
All	1987-2014	402	2975	0.00	2.43		17.00		59.66		1469.97

TABLE 2. Sample statistics for electrofishing CPUE (n/h) of age-0 Walleyes, by subjective ratings of visibility during the surveys. Results exclude surveys where ratings varied among stations. Letters following medians indicate results of Dunn's multiple comparisons following a significant (P < 0.001) Kruskal-Wallis one-way analysis of variance on ranks; medians followed by the same letters were not significantly different at α= 0.05.

Visibility	*n*	Median	25%	75%
Poor	448	20.50 x	2.32	63.51
Moderate	647	14.61 x	1.42	60.85
Good	776	9.83 y	1.10	40.00

TABLE 3. Summary statistics for statewide age-specific gill-net CPUE (n/net) of year-classes that were sampled at age 0 by electrofishing.

Age	n	Min	25%	50%	75%	Max
1	579	0.00	0.13	0.67	1.88	39.56
2	552	0.00	0.50	1.44	3.33	36.50
3	601	0.00	0.60	1.53	3.19	42.00
4	554	0.00	0.33	0.88	1.78	29.50
5	559	0.00	0.18	0.50	1.17	14.83
6	521	0.00	0.08	0.33	0.66	13.50

FIGURES

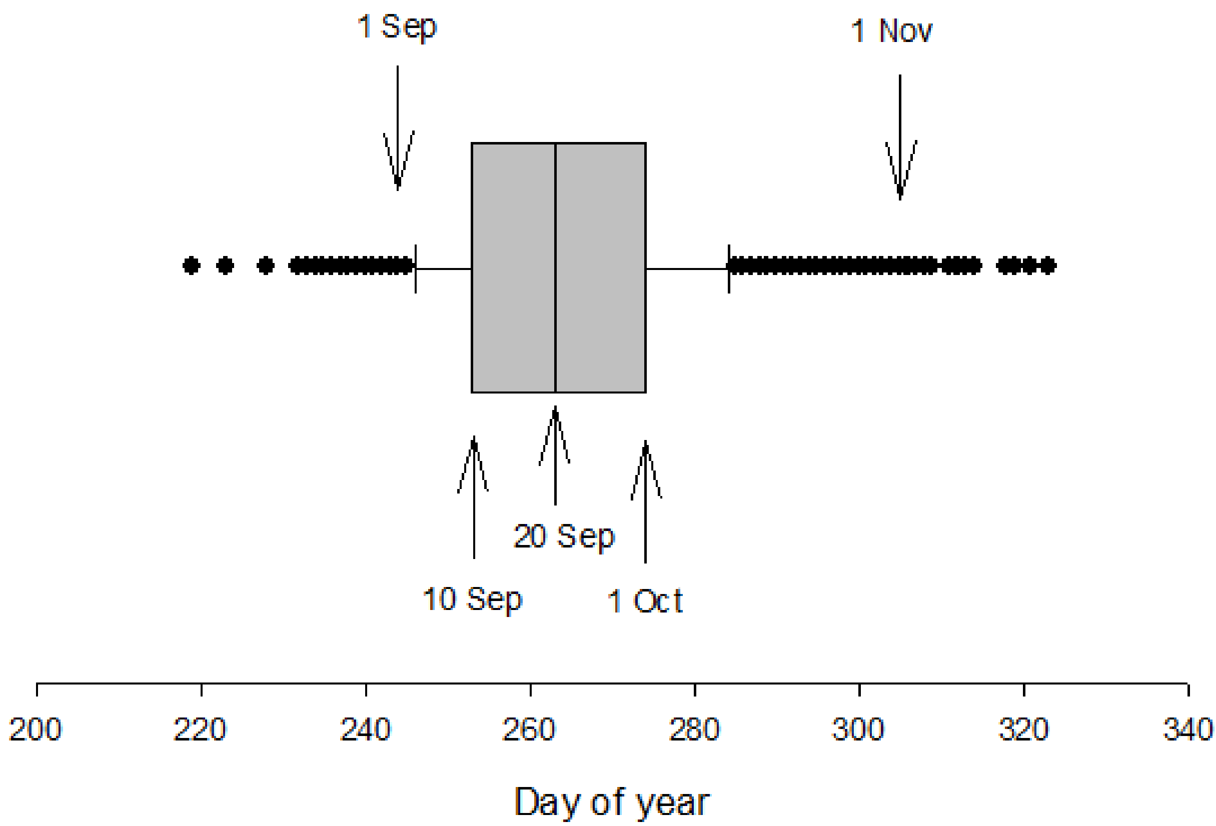

FIGURE 1. Statewide timing of initiation of electrofishing surveys targeting age-0 Walleyes; *n* = 2,827 surveys where exact dates were available. The box represents the interquartile range; the line inside the box is the median; whiskers extend to 10th and 90th percentiles; and dots are outliers. Calendar dates are for non-leap years.

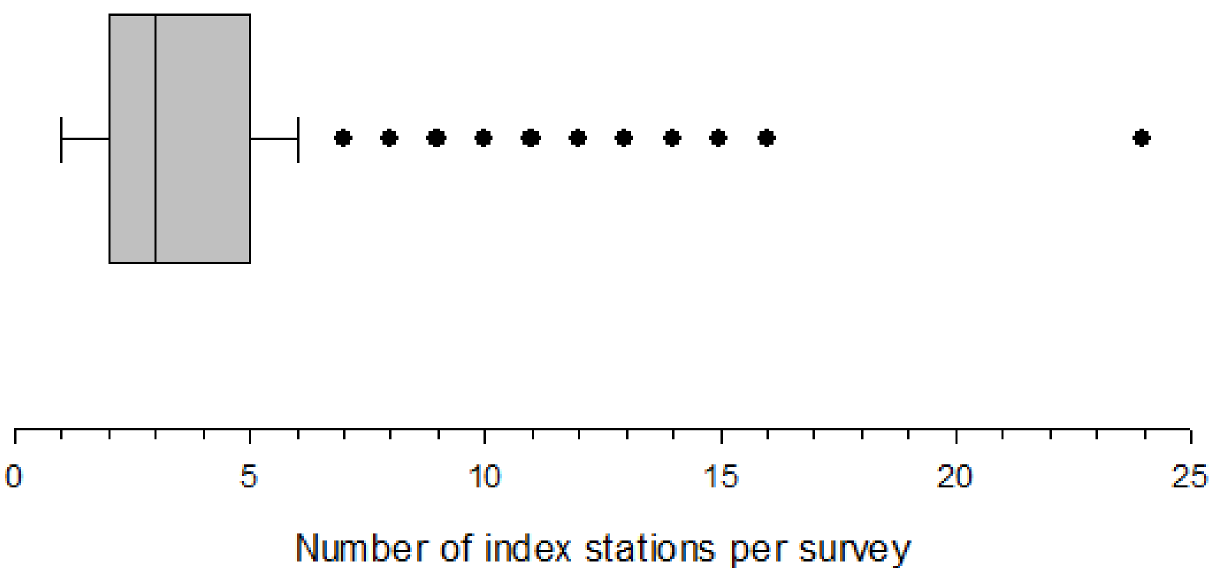

FIGURE 2. Number of index stations per electrofishing survey targeting age-0 Walleyes; *n* = 2,309 surveys where number of stations was available. The box represents the interquartile range; the line inside the box is the median; whiskers extend to 10th and 90th percentiles; and dots are outliers.

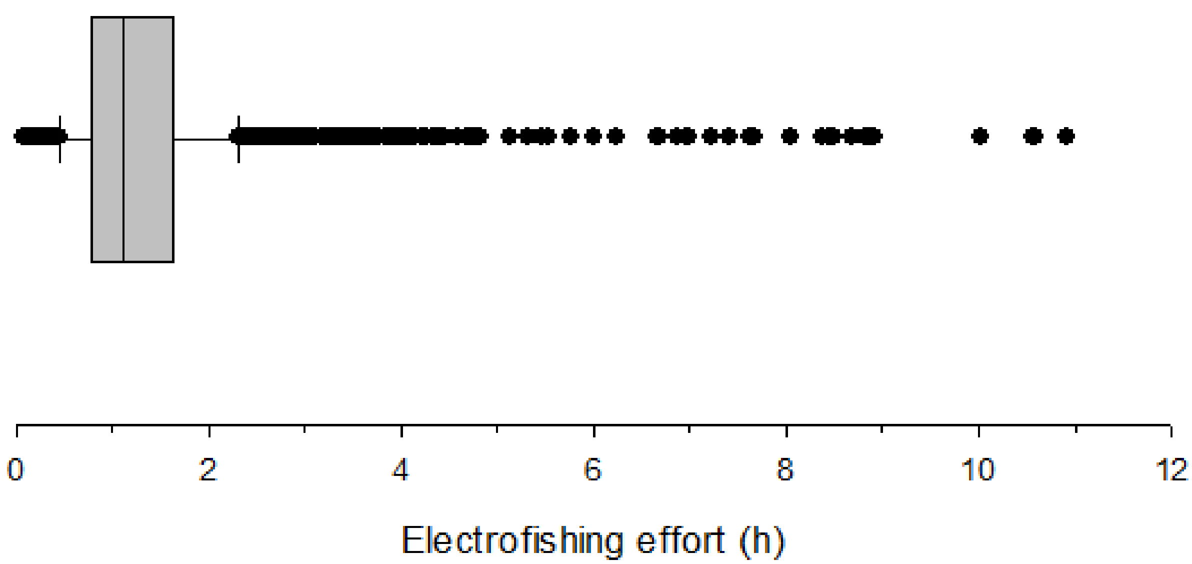

FIGURE 3. Electrofishing on-time per survey targeting age-0 Walleyes; *n* = 2,654 surveys where on-time was available. The box represents the interquartile range; the line inside the box is the median; whiskers extend to 10th and 90th percentiles; and dots are outliers.

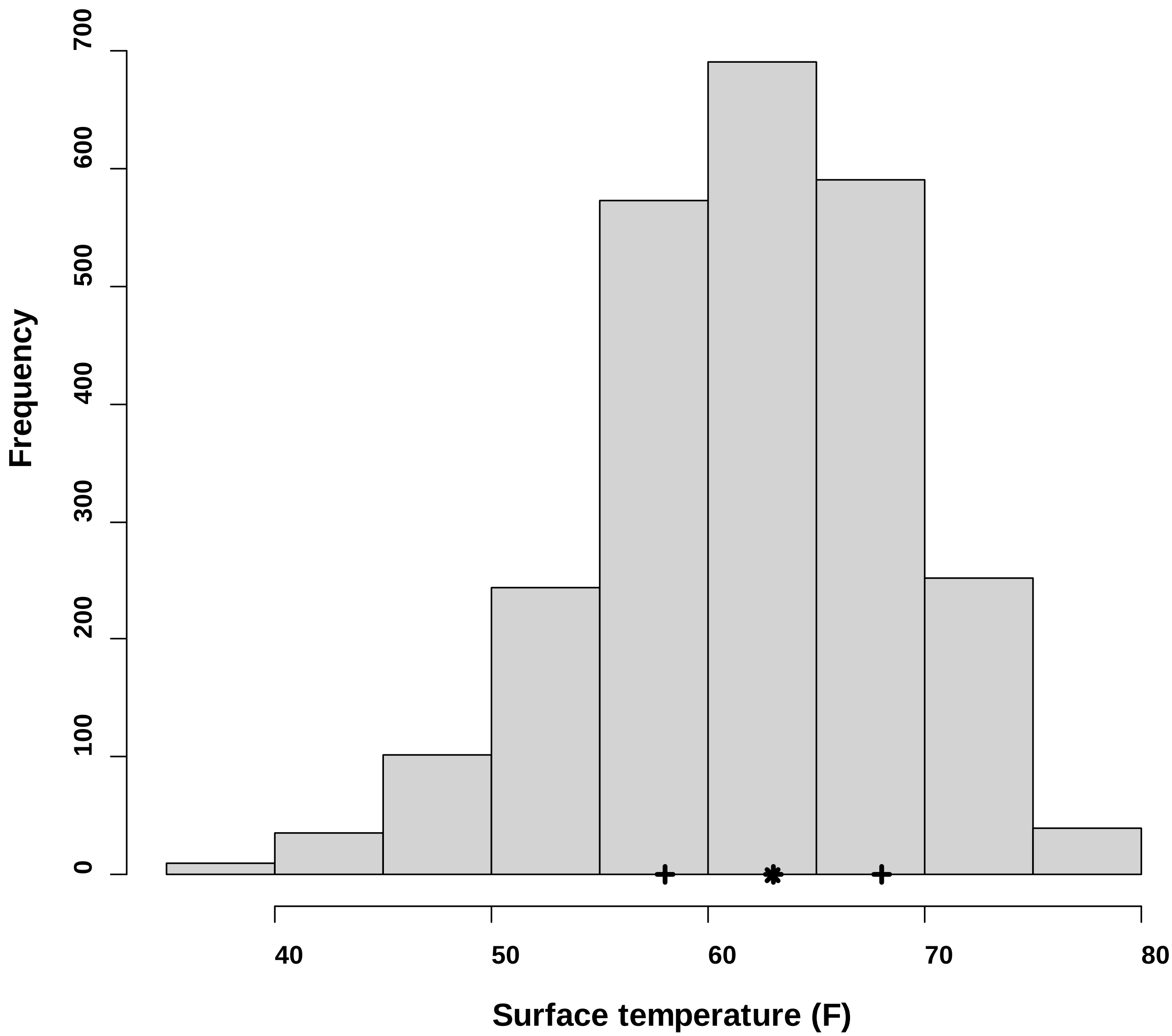

FIGURE 4. Surface water temperatures during electrofishing surveys targeting age-0 Walleyes; *n* = 2,535 surveys where temperature was available. The asterisk is the median while the + symbols represent the interquartile range.

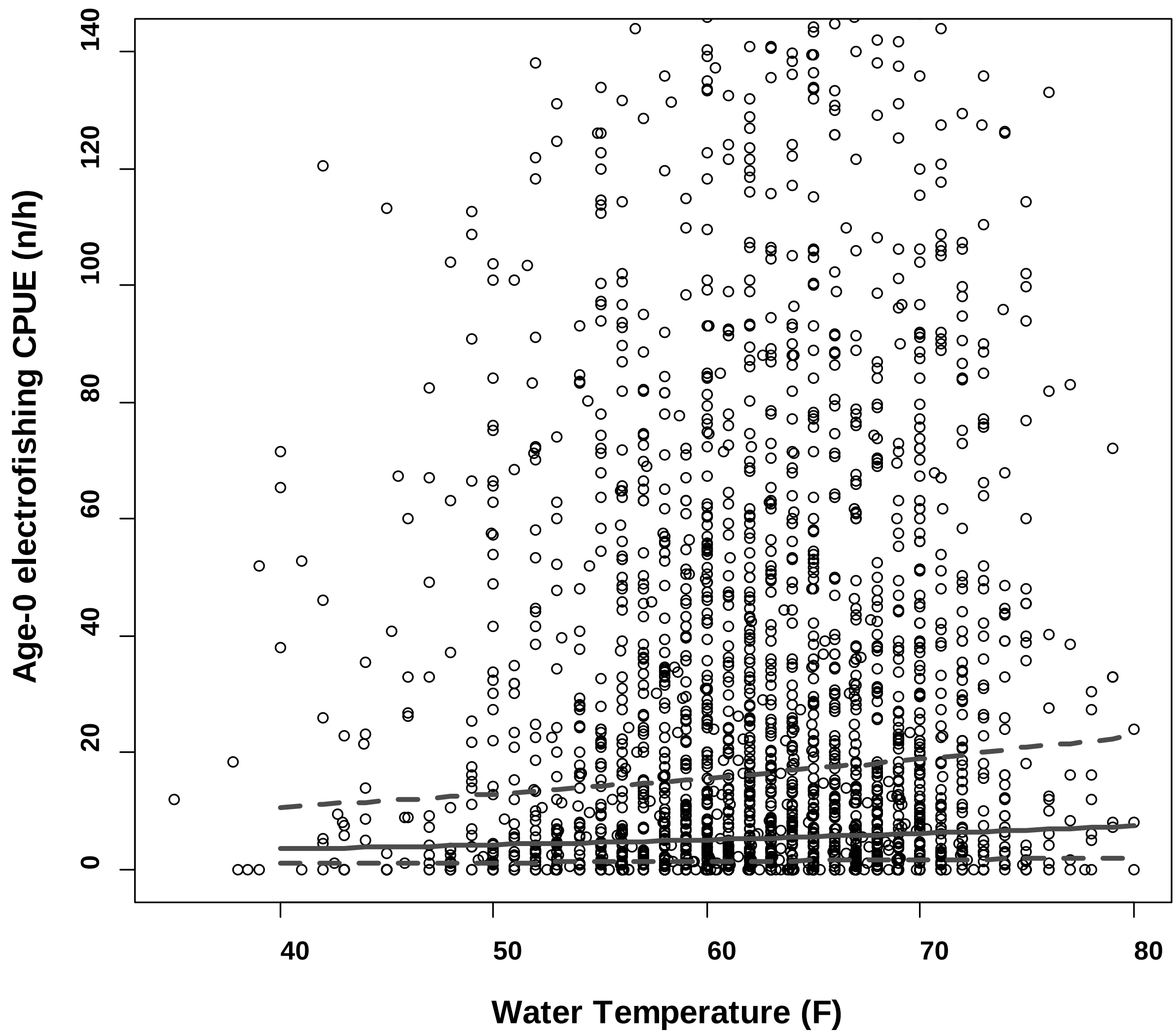

FIGURE 5. Age-0 Walleye CPUE versus surface water temperature during late-summer and fall electrofishing surveys (y-axis limited to 90th percentile of CPUE observations). Solid line is estimated change in CPUE at an average lake using a linear mixed effects model that accounts for within-lake correlations in catch rates; upper and lower dashed lines are estimated change in CPUE at lakes with CPUE respectively at the 75th and 25th percentiles of the 2,535 surveys in the analysis.

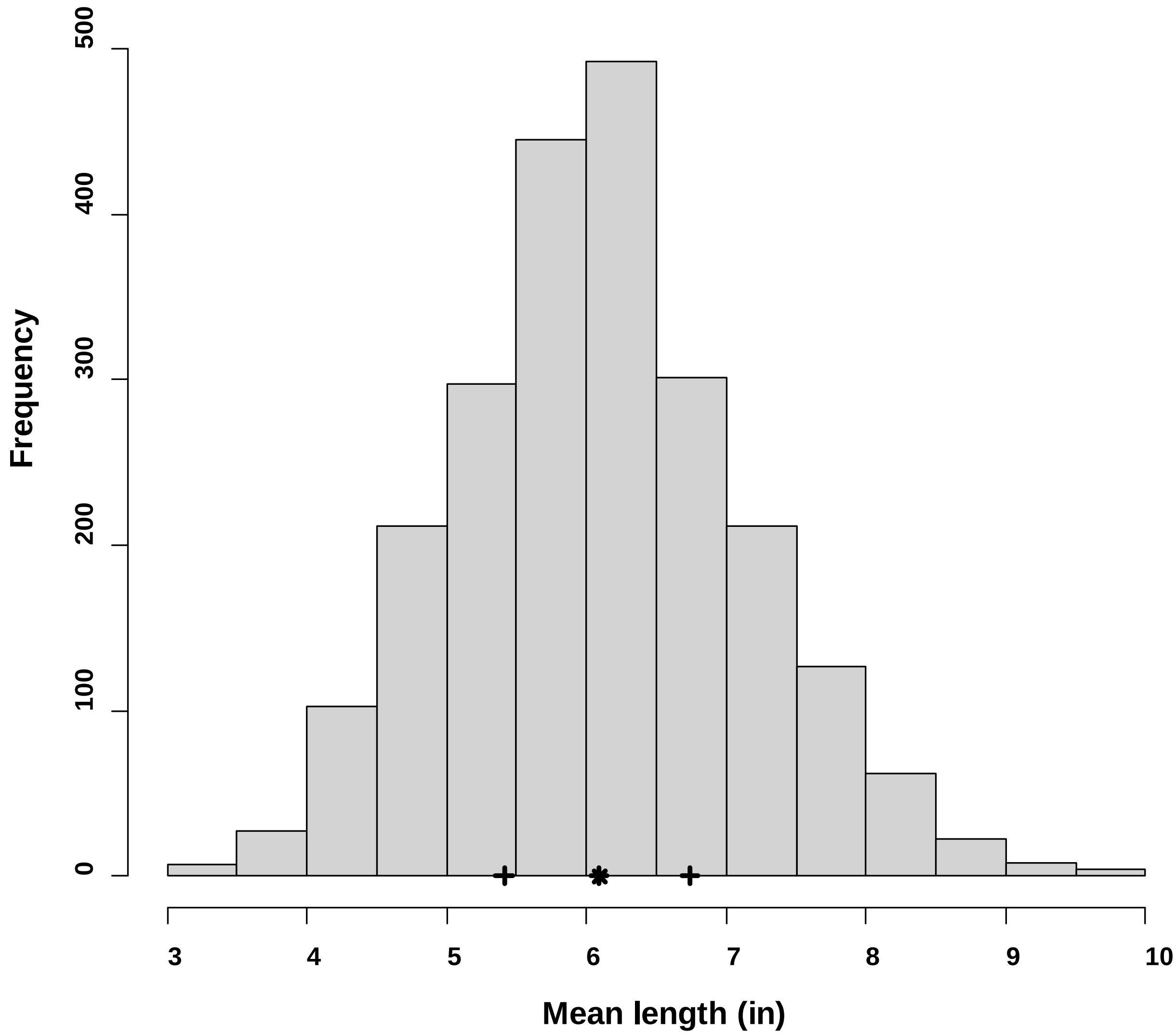

FIGURE 6. Mean length of age-0 Walleyes in late-summer and fall electrofishing surveys; *n* = 2,318 surveys where mean length was available. The asterisk is median while the + symbols represent the interquartile range.

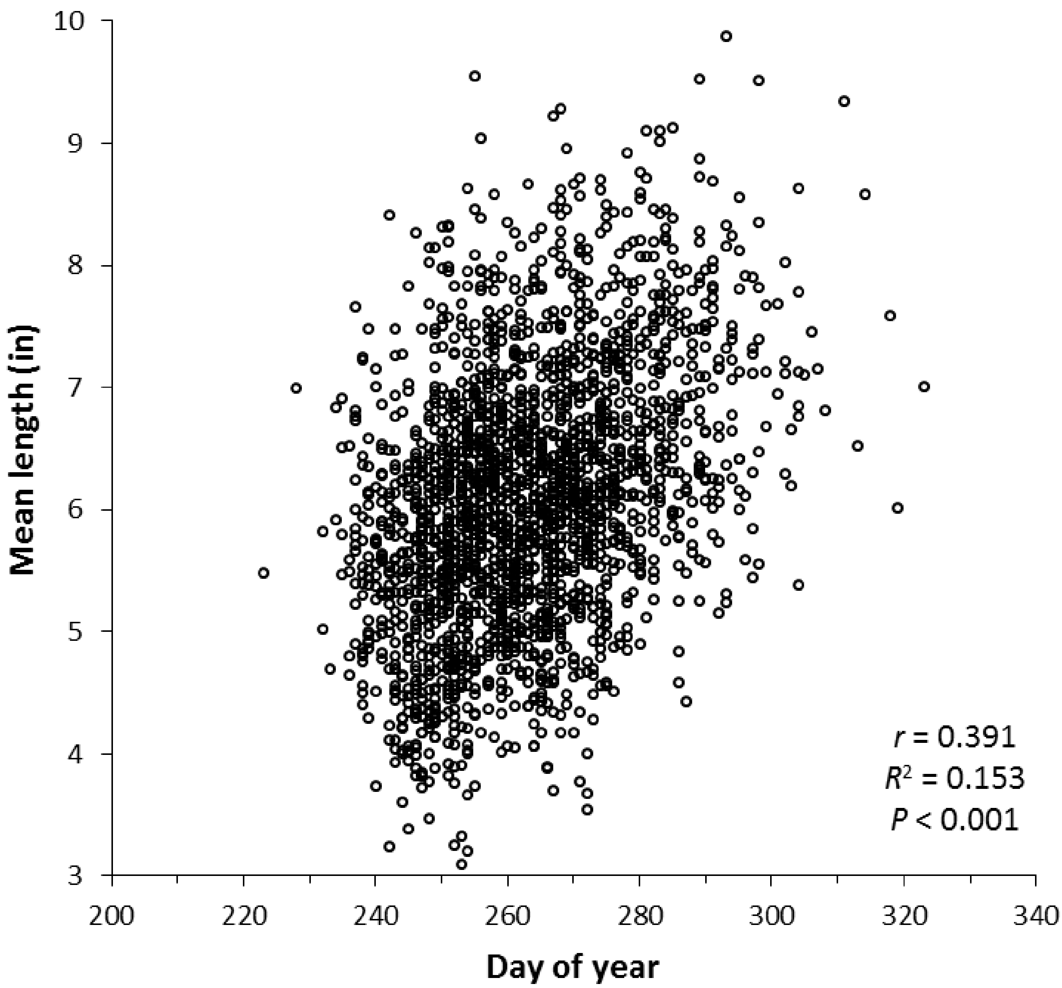

FIGURE 7. Mean length of age-0 Walleyes in late-summer and fall electrofishing surveys versus day of the year when the surveys were initiated.

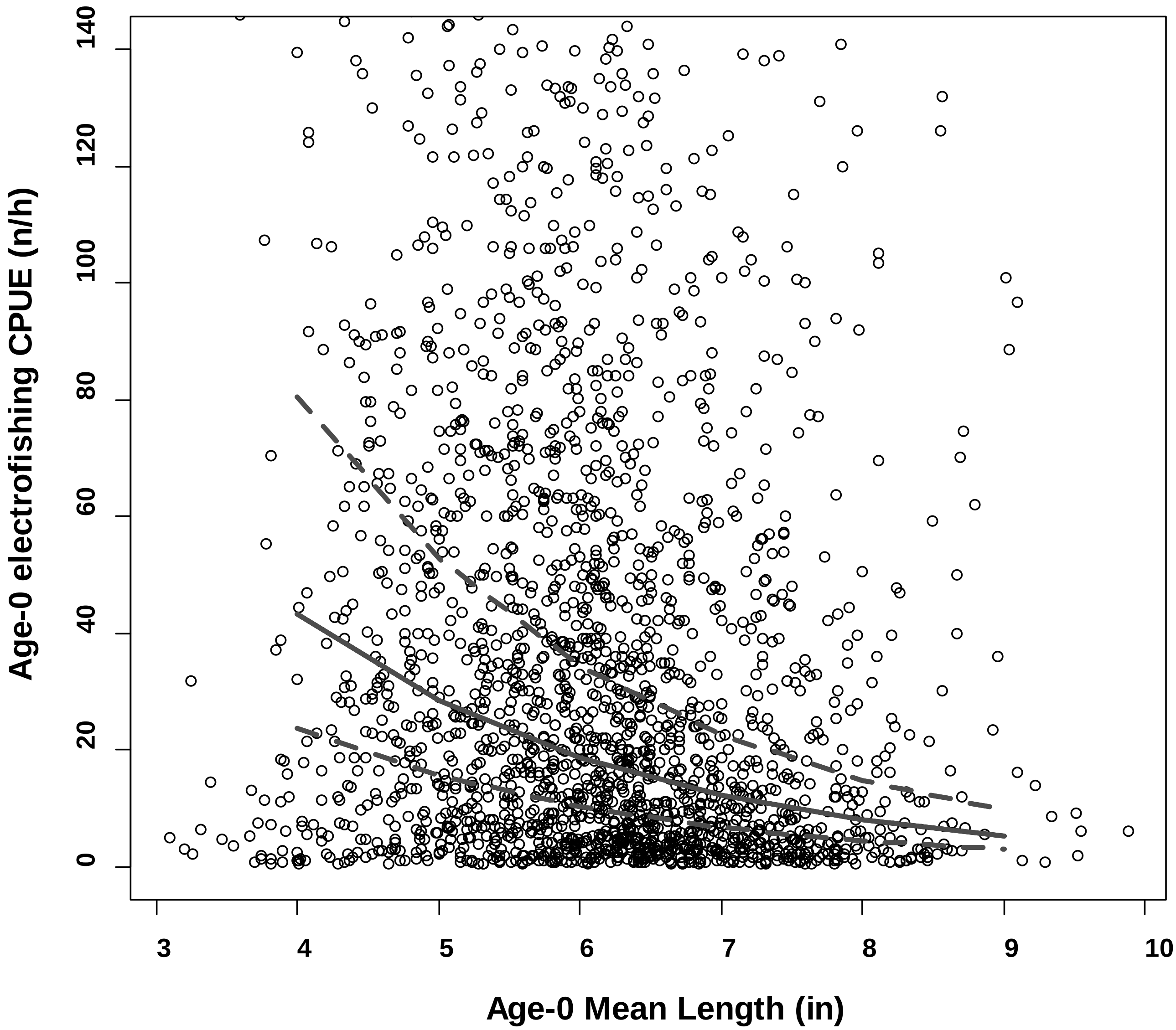

FIGURE 8. Age-0 Walleye CPUE versus mean length during late-summer and fall electrofishing surveys (y-axis limited to 90th percentile of CPUE observations). Solid line is estimated change in CPUE as a function of length for lakes with average electrofishing catch rates estimated with a linear mixed effects model; upper and lower dashed lines are estimated change in CPUE at lakes with CPUE respectively at the 75th and 25th percentiles of the 2,318 surveys in the analysis.

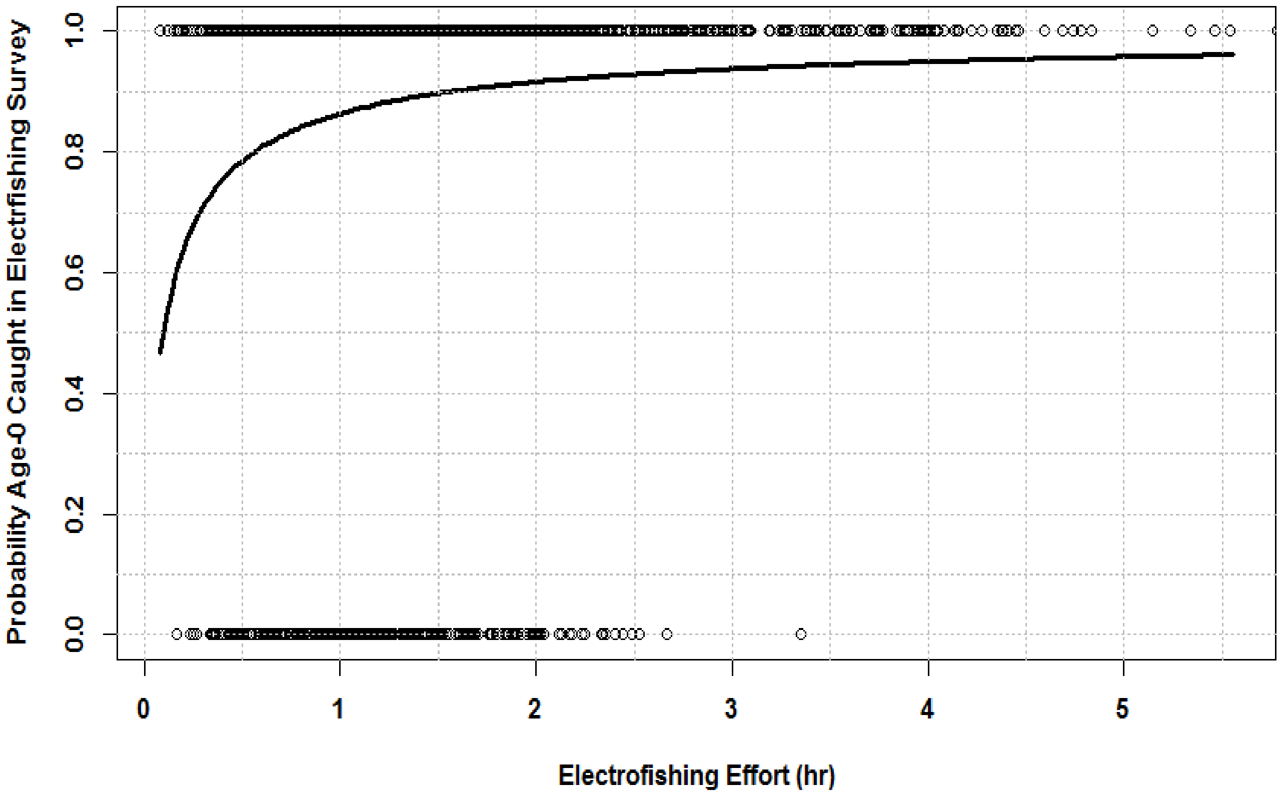

FIGURE 9. GLME predictions of the probability of detecting age-0 Walleye as a function of electrofishing effort. Black line is detection-effort relationship averaged across all lakes; open circles are presence/absence of age-0 in electrofishing surveys.

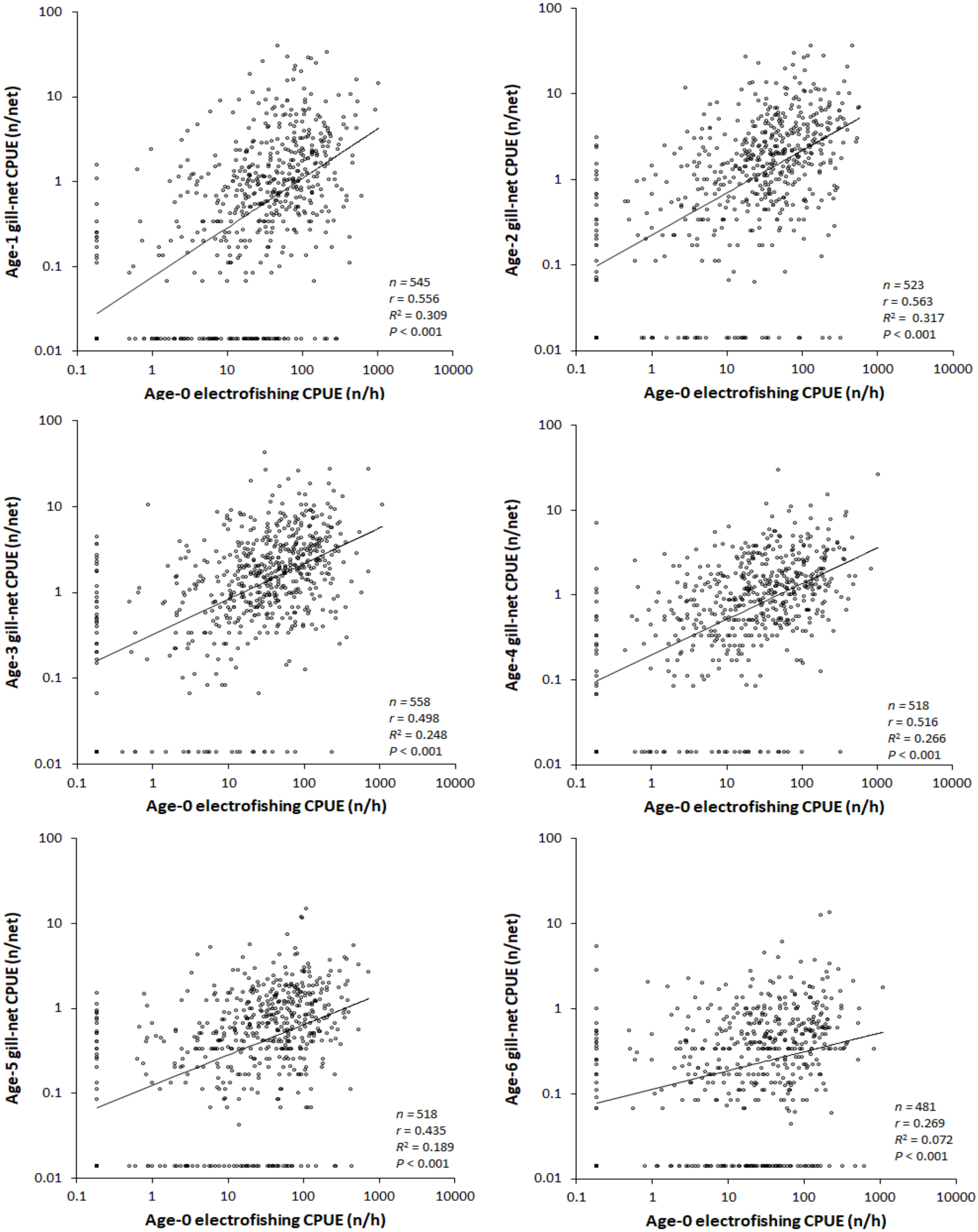

FIGURE 10. Statewide age-specific Walleye gill-net CPUE versus age-0 electrofishing CPUE of corresponding year-classes. Panels represent gill-net age-classes 1-6. Lines of points along the horizontal and vertical axes represent gill-net and/or electrofishing CPUE values below the limits of detection.

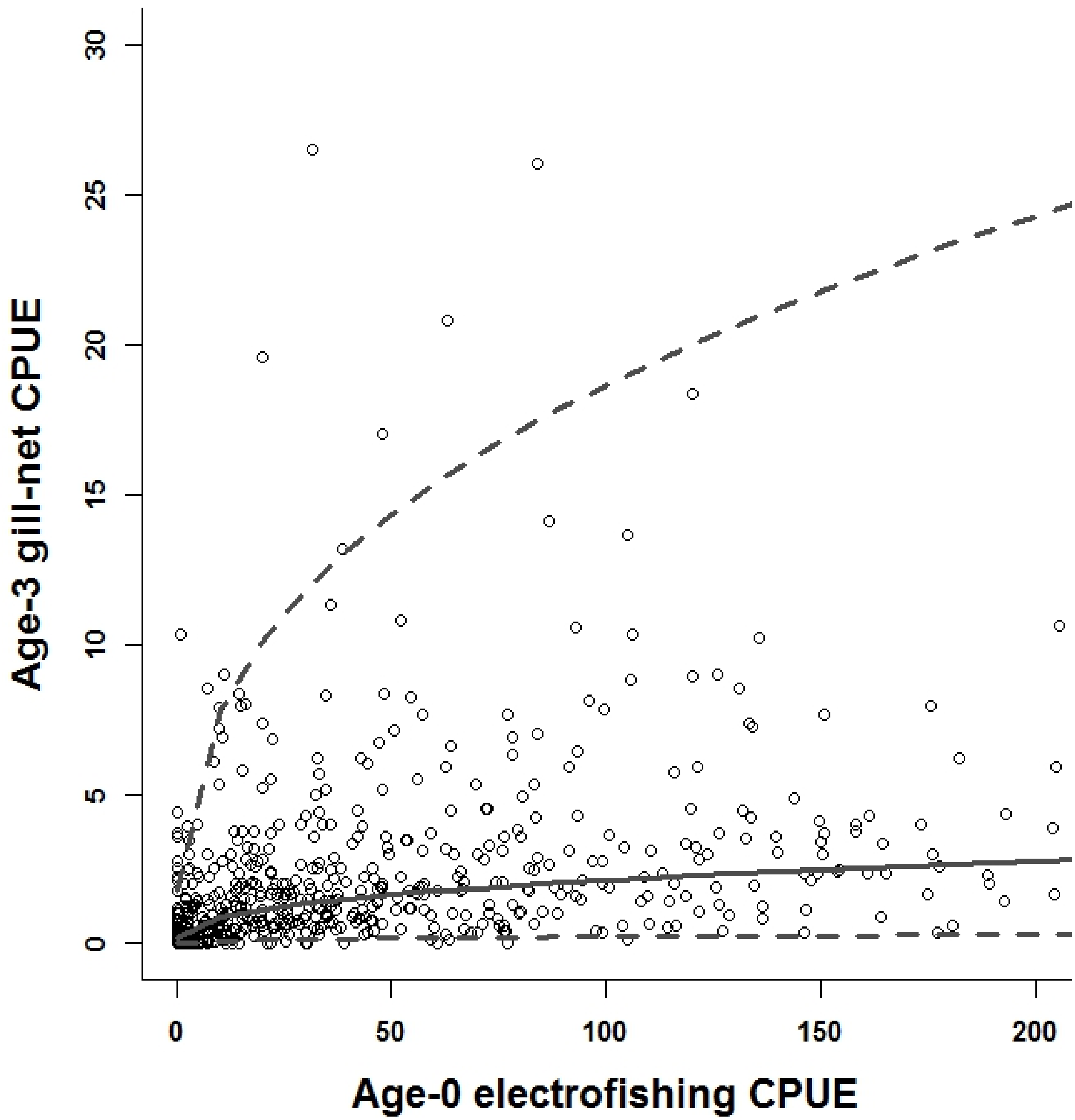

FIGURE 11. Prediction intervals for Age-3 gill-net CPUE based on Age-0 electrofishing CPUE, calculated with the linear mixed effects model based on residual error only (i.e., uncertainty about the estimated lake-specific mean is ignored, so that intervals would be wider in application). Solid line is predicted median gill-net CPUE, while dashed lines are 95% prediction interval bounds.

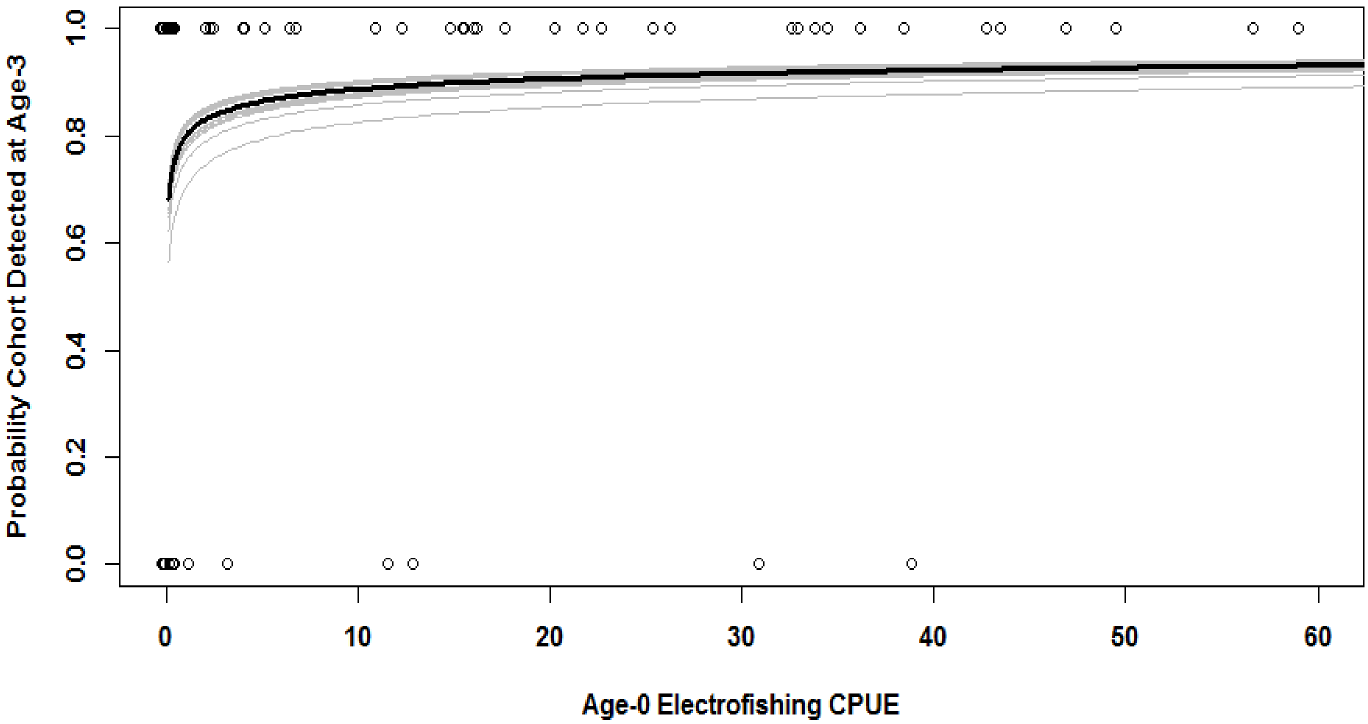

FIGURE 12. Generalized linear mixed model estimate of relationship between age-0 electrofishing CPUE and the probability of detecting the corresponding cohort at age-3 in gill net survey. Dark line is average relationship among the 21 lakes with both zero/non-zero age-0 CPUE, gray lines are individual lake predictions, open circles are observed presence/absence of age 3 in gill net surveys. X-axis is limited to better show modeled relationship; all cohorts with EF CPUE > 40 were detected in gill nets at age 3.

REFERENCES

Beard, T. D., Jr., M. J. Hansen, and S. R. Carpenter. 2003. Development of a regional stock-recruitment model for understanding factors affecting Walleye recruitment in northern Wisconsin lakes. Transactions of the American Fisheries Society 132:382-391.

Borkholder, B. D., and B. G. Parsons. 2001. Relationship between electrofishing catch rates of age-0 Walleyes and water temperature in Minnesota lakes. North American Journal of Fisheries Management 21:318-325.

Busch, W. N., R. L. Scholl, and W. L. Hartman. 1975. Environmental factors affecting the strength of Walleye (*Stizostedion vitreum vitreum*) year-classes in western Lake Erie, 1960-70. Journal of the Fisheries Research Board of Canada 32:1733-1743.

Clarke, J. U. 1998. Evaluation of censored data methods to allow statistical comparisons among very small samples with below detection limit observations. Environmental Science & Technology 32:177-183.

Fayram, A. H., M. J. Hansen, and N. A. Nate. 2005. Determining optimal stocking rates using a stock-recruitment model: an example using Walleye in northern Wisconsin. North American Journal of Fisheries Management 25:1215-1225.

Forney, J. L. 1976. Year-class formation in the Walleye (*Stizostedion vitreum vitreum*) population of Oneida Lake, New York, 1966-73. Journal of the Fisheries Research Board of Canada 33:783-792.

Gabelhouse, D. W., Jr. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.

Hansen, J. F., A. H. Fayram, and J. M. Hennessy. 2012. The relationship between age-0 Walleye density and adult year-class strength across northern Wisconsin. North American Journal of Fisheries Management 32:663-670.

Hansen, M. J., S. P. Newman, and C. J. Edwards. 2004. A reexamination of the relationship between electrofishing catch rate and age-0 Walleye density in northern Wisconsin lakes. North American Journal of Fisheries Management 24:429-439.

Johnson, B. M., M. Vogelsand, and R. S. Stewart. 1996. Enhancing a Walleye population by stocking: effectiveness and constraints on recruitment. Annales Zoologici Fennici 33:577-588.

Kallemeyn, L. W. 1987. Correlations of regulated lake levels and climatic factors with abundance of young-of-the-year Walleye and Yellow Perch in four lakes in Voyageurs National Park. North American Journal of Fisheries Management 7:513-521.

Koonce, J. F., T. B. Bagenal, R. F. Carline, K. E. F. Hokanson, and M. Nagięć. 1977. Factors influencing year-class strength of percids: a summary and a model of temperature effects. Journal of the Fisheries Research Board of Canada 34:1900-1909.

Lake Survey Committee. 1993. Manual of instructions for lake survey. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Special Publication 147, St. Paul.

Lake Survey Committee. 2017. Manual of instructions for lake survey. Minnesota Department of Natural Resources, Fish and Wildlife Division, Section of Fisheries, Special Publication 180, St. Paul.

Lucchesi, D. O. 2002. Evaluating the contribution of stocked Walleye fry and fingerlings to South Dakota Walleye populations through mass marking with oxytetracycline. North American Journal of Fisheries Management 22:985-994.

Madsen, E. R. 2008. Forecasting Walleye abundance in northern Wisconsin Lakes. North American Journal of Fisheries Management 28:481-499.

McWilliams, R. H., and J. G. Larscheid. 1992. Assessment of Walleye fry and fingerling stocking in the Okoboji Lakes, Iowa. North American Journal of Fisheries Management 12:329-335.

Parsons, B. G., and D. L. Pereira. 2001. Relationship between Walleye stocking and year-class strength in three Minnesota lakes. North American Journal of Fisheries Management 21:801-808.

Quist, M. C. 2007. An evaluation of techniques used to index recruitment variation and year-class strength. North American Journal of Fisheries Management 27:30-42.

Reed, J. R., and D. F. Staples. 2017. Evaluation of two different stocking rates of small Walleye fingerlings in Minnesota lakes. North American Journal of Fisheries Management 37:1243-1248.

Santucci, V. J., and D. H. Wahl. 1993. Factors influencing survival and growth of stocked Walleye (*Stizostedion vitreum*) in a centrarchid-dominated impoundment. Canadian Journal of Fisheries and Aquatic Sciences 50:1548-1558.

Schupp, D. H. 1992. An ecological classification of Minnesota lakes with associated fish communities. Minnesota Department of Natural Resources, Section of Fisheries, Investigational Report 417, St. Paul.

Schupp, D. H. 2002. What does Mt. Pinatubo have to do with Walleyes? North American Journal of Fisheries Management 22:1014-1020.

Serns, S. L. 1982. Relationship of Walleye fingerling density and electrofishing catch per effort in northern Wisconsin lakes. North American Journal of Fisheries Management 2:38-44.