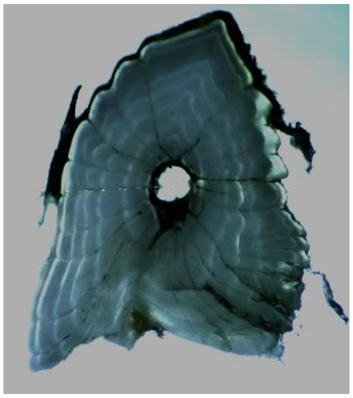

Evaluation of Channel Catfish Population Dynamics in Stocked and Unstocked Natural Lakes in Iowa with Emphasis on the Effects of Natural Recruitment

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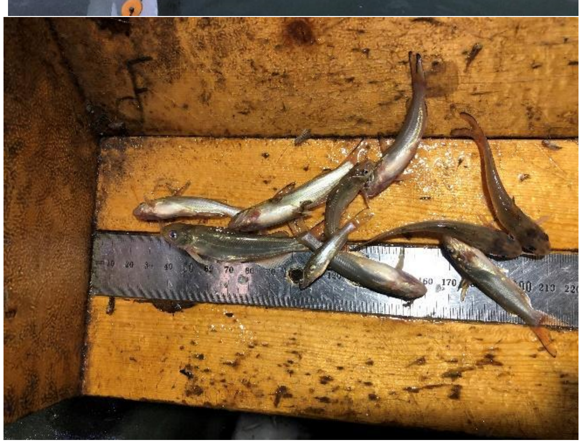

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Abstract

Many natural lakes in Iowa are managed as a multi-species fishery, and several lakes have been stocked with Channel Catfish fingerlings to provide Iowa anglers with diverse angling opportunities. These stockings are prescribed using stocking policy guidelines and the assumption that Channel Catfish natural recruitment is limited. However, robust self-sustaining populations of Channel Catfish at unmanaged natural lakes occur, and the influence of natural recruitment and agency stocking densities on Channel Catfish population dynamics is largely unknown. This study used long-term tandem hoop netting Channel Catfish population data collected at thirteen natural lakes to 1) evaluate population dynamics within stocked and unstocked natural lakes and 2) to determine the contribution of stocked fish. We also used long-term summer seine data to evaluate natural recruitment trends in eight natural lakes. Channel Catfish size structure (proportional stock density, mean total length), condition (relative weight), growth (mean total length at age-4) and density (number/acre) varied considerably among lakes, but some similarities among lakes of similar morphology and stocking rates were observed. Channel Catfish populations in larger natural lakes (>1,000 ac) were less dense and had better size, condition, and growth than smaller natural lakes, regardless of stocking rates. Small natural lakes with Channel Catfish stocking rates exceeding 4.4 fish/ac/year and adult densities exceeding 10.0 fish/ac consistently had poorer size structure, condition, and growth. Unstocked natural lakes also had highly variable population characteristics and exhibited adult densities (>30.0 fish/ac) that negatively influenced population parameters. Year-class contribution using standardized age and growth techniques were complicated by the timing of hoop netting surveys and inability to accurately determine age distribution of sampled Channel Catfish. Likewise, the ability to accurately identify the first annulus for back-calculated length-at-age-1 models made determination of Channel Catfish origin (i.e., wild or hatchery fish) difficult. Hence, natural recruitment trends via age-0 seining surveys were the best indicator of natural lakes where recruitment potential was high. These findings were used to generalize Channel Catfish population trends and develop lake-specific management strategies that could improve Channel Catfish populations across a gradient of natural lake types in Iowa.

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Introduction

Channel Catfish *Ictalurus punctatus* are an important sportfish in Iowa (Duda et al. 2019), and many populations are maintained via annual or biennial fingerling stockings. Recent Iowa research determined lakes stocked with larger (at least 8.0 in) Channel Catfish had significantly improved adult Channel Catfish density and biomass compared to lakes stocked with smaller fish (Cashatt 2012). Thus, hatchery production in Iowa consists of obtaining early-spawned Channel Catfish fingerlings (~2.0 in) from the Missouri Department of Conservation in May and rearing those fish in lined outdoor ponds for advanced fingerling production (Clouse et al. 2021). Approximately 107,000 advanced fingerlings are harvested from lined ponds annually in September and stocked into over 230 small impoundments, ponds, community fishing lakes, and natural lakes in Iowa. Channel Catfish production costs on average $72,659 per annum ($0.6919/fish; 2017-2021 average), and stocking fish requires assistance from multiple hatchery and management teams across the state to fulfill stocking quotas. Thus, rearing and stocking Channel Catfish in Iowa requires a substantial financial and workforce investment

However, many Channel Catfish stockings are necessary in Iowa since anglers' desire Channel Catfish angling opportunities (Cashatt 2012; Duda et al. 2019), but many populations are not self-sustaining (due to poor natural reproduction and high post-stocking predation, see Cashatt 2012). Consequently, managers have often prescribed stocking rates near the maximum stocking density allowed (Iowa's Fish Stocking Policy 2013) since limited fishery data were available to make informed stocking decisions across a gradient of lake types. Recently, Michaletz et al. (2011) found lakes that were overstocked (≥15 fish/acre/year) with Channel Catfish suffered from long-term poor size structure and could have unintended negative impacts on other sportfish populations (Michaletz 2006; Michaletz 2009). Studies conducted between 2008 and 2011 in Iowa found adult population density estimates of Channel Catfish at Five Island and Silver lakes between 10.8 and 14.6 adult fish/ac, despite relatively low stocking rates (≤2.4 fish/acre/year). In response to these observations and changes in production techniques that began in 2010, Channel Catfish stockings in Iowa occur on a biennial frequency and some managers have reduced stocking rates to <1.4 fish/acre/year with the intent to improve size structure and quality of the recipient Channel Catfish population. Yet, some natural lakes remain stocked at rates near the maximum allowed (2.0-5.4 fish/acre/year). It is unclear whether stocking rates in Iowa could be contributing to fishery declines as observed elsewhere. Thus, there is an overwhelming need for more information regarding lake-specific Channel Catfish stocking densities and subsequent population characteristics, angler harvest rates, and impacts of high Channel Catfish stocking densities to the existing fish community in many of Iowa's Channel Catfish-managed natural lakes.

In addition to stocking, natural recruitment of Channel Catfish in Iowa's natural lakes is not uncommon. Annual summer seining surveys have been conducted in many stocked lakes to evaluate age-0 recruitment, and natural Channel Catfish reproduction has often been documented. For example, a summer seining survey at Storm Lake (a stocked fishery) in 2019 captured 357 wild age-0 Channel Catfish (i.e., unstocked year). Ten other natural lakes commonly stocked with Channel Catfish have exhibited successful Channel Catfish natural recruitment via captures of age-0 fish during summer seining investigations. Recently, self-sustaining populations of Channel Catfish have been documented in lakes not traditionally managed for Channel Catfish. These observations have prompted additional questions regarding appropriate Channel Catfish stocking rates in natural lakes with documented natural recruitment and the need for maintenance stockings. Measuring population characteristics such as size structure, condition, year-class indices, and growth rates could be used to characterize stocked and unstocked lakes as well as be used to make inferences regarding stocking contribution and the effect of biennial stocking. Ultimately, it is unclear if reductions or elimination of Channel Catfish stocking in natural lakes would benefit the overall size structure and quality of the fishery.

Therefore, the objectives of this study were to (1) evaluate Channel Catfish population dynamics in stocked and unstocked natural lakes; (2) estimate the age of Channel Catfish in natural lakes to determine year-class fluctuations; (3) evaluate natural recruitment; (4) develop tools that can be used to estimate stocked Channel Catfish year-class contributions during stocked years; and (5) provide lake- specific stocking recommendations for natural lakes.

Methods

Study sites. - Thirteen natural lakes across ten northcentral and northwestern Iowa counties have been managed for Channel Catfish via annual or biennial stockings since at least the early 1990s (Table 1). Three natural lakes (Tuttle, Iowa, and Little Spirit Lake) have not been stocked with Channel Catfish, and wild populations exist due to natural connections to rivers or natural reproduction. It is important to note that Little Spirit Lake is part of an interconnected lake chain known as the "Iowa Great Lakes" and Channel Catfish are stocked and managed in East Okoboji Lake. However, a spillway that connects Spirit Lake to East Okoboji Lake is impassable to fish during >95% of flow events; thus Channel Catfish in Spirit Lake and Little Spirit Lake were considered wild populations. Natural lakes managed for Channel Catfish have been stocked at various frequencies and rates since 2010 (Table 2) and were broadly categorized as either those stocked at high rates (≥2.0 fish/acre/year; Black Hawk, Cornelia, Crystal, Ingham, Little Wall, and North Twin lakes) or low rates (<1.4 fish/acre/year; Center, Clear, East Okoboji, Five Island, Lost Island, Silver, and Storm lakes). Besides a few exceptions, Channel Catfish stocking rates were low in lakes exceeding 1,000 acres; whereas, smaller natural lakes have been stocked more aggressively. Physical and chemical characteristics of natural lakes managed for and with existing Channel Catfish populations varied considerably, with mean depths ranging from <4.0 ft to 12.2 ft, watershed- to-area ratios ranging from 2.1 to 46.5, mean total phosphorus ranging from 65.7-235.7 mg/L, and chlorophyll-a ranging from 15.7-104.9 µg/L (Table 1; mean water quality parameters from open water samples collected between 2000-2020).

Sampling, age and growth, and statistical analyses. - Channel Catfish were sampled in natural lakes by Iowa Department of Natural Resources (Iowa DNR) fisheries bureau staff between 2014 and 2022 via summer tandem-hoop netting surveys with standard comprehensive fishery surveys or as stand-alone trend surveys (Schultz 2009; Flammang et al. 2011). More specifically, each hoop net consisted of three baited hoop nets (2.5 ft hoop, 1 in bar mesh) connected in series and set at fixed stations. Nets were set for a 72-hr period between June and August at water temperatures ≥75˚F, and the number of net nights at each lake was pre-determined by the lake area (Schultz 2009). Net series were lifted at the end of each 72-hr period. All Channel Catfish were measured for total length (TL; either imperial [in] or metric [mm] measurements), and a representative subsample of weights (wt; 5 per ½-in group; lbs or g) were recorded. On occasion, basal pectoral spines for age-estimation were extracted from a subsample (typically 10 fish per 1-inch length group per lake) of Channel Catfish and placed in numbered coin envelopes.

Data from individual lake hoop netting surveys conducted between 2014 and 2022 were pooled across years for all length, size structure, and condition analyses to increase sample sizes (Michaletz and Sullivan 2002; Flammang et al. 2011). Channel Catfish length-weight linear regression models were developed for each lake, and studentized residuals exceeding ± 3 were reviewed for data accuracy and omitted if determined to be an outlier. Proportional size distribution (PSD) indices (i.e., quality [PSD], preferred [PSD-P], memorable [PSD-M], and trophy [PSD-T]; Guy et al. 2007) were calculated for each lake using the size categories reported by Gabelhouse (1984) for Channel Catfish (stock: 11 in; quality: 16 in; preferred: 24 in; quality: 28 in; trophy: 36 in). Length-frequency distributions for Channel Catfish >9.8 in (e.g., size of Channel Catfish vulnerable to gear; Michaletz and Sullivan 2002) were then compared among lakes using two-sample Kolmogorov-Smirnov tests (K-S test), and p-values were adjusted with a Bonferroni correction for multiple comparisons (Neumann and Allen 2007). Mean TLs of Channel Catfish (>9.8 in) sampled via hoop nets were compared among lakes using ANOVA followed by Tukey's post hoc test. Channel Catfish condition (i.e., relative weight; *Wr*) was calculated as described by Wege and Anderson (1978) using standard weight (*Ws*) values reported by Bister et al. (2000; a = -5.800 and b = -3.829). Lake-specific pooled *Wr* was summarized by the entire sample and by length categories (sub-stock, stock-quality, quality-preferred, preferred-memorable, memorable-trophy, and trophy), and ANOVA followed by Tukey's post hoc test was used to test for differences in mean *Wr* among lakes and length categories (minimum sample of 10 fish per length category). Lastly, size and condition indices were pooled by stocking rate group (no stocking, low stocking rate, high stocking rate), and PSD, total length (fish >9.8 in), and relative weight (stock to preferred length categories combined) was compared using Tukey's post hoc test.

Previous work has suggested Channel Catfish catch in tandem-baited hoop nets is positively related to population density among systems (Michaletz and Sullivan 2002; Michaletz 2009; Flammang et al. 2011), however, this relationship has not been previously examined in natural lakes. To validate the assumption that hoop net catch rates could be used as a proxy for Channel Catfish population density, existing population abundance estimates (n = 9 Schnabel estimates) from six natural lakes collected from hoop netting surveys between 2006-2021 were used to examine the relationship between population abundance and the catch rate (number of Channel Catfish caught per hoop net series set for a 72 hr period [CPN]) of Channel Catfish during the first two sets via linear regression. The first two sets was used to avoid the potential to encounter "trap shy" or "trap happy" individuals within the population. A strong significant ($P < 0.05$) positive relationship that explained most of the variation in Channel Catfish population abundance was found using these data ($y = 55.381x - 122.11$; $r^2 = 0.8476$). Thus, in this study, Channel Catfish population abundance for each lake during each survey year was estimated using the linear regression model and survey specific Channel Catfish CPN. Then, the lake specific population estimate was divided by the total surface acres of the lake to estimate the Channel Catfish density (N fish/acre). For lakes with more than one hoop netting survey conducted between 2014 and 2022, Channel Catfish density was averaged among surveys. Trends in Channel Catfish density and population characteristics were examined to explain variation among systems. In addition, CPN was pooled by stocking rate group (no stocking, low stocking rate, high stocking rate) and differences among groups were compared using a t-test. Approximate t-tests and Satterthwaite's approximation for degrees of freedom were used if the folded form of the F-statistic indicated heterogeneous variances ($P < 0.05$).

In the laboratory, pectoral spines were allowed to dry and excess flesh was removed from each structure using a scalpel. Three to five cross-sections (between 0.03 and 0.05 in thick) were taken from the base of the pectoral spine with a Dremel tool fitted with a dental saw blade (Margenau 1982). The Dremel tool was fastened to a custom-built stand equipped with a sliding ruler. Cross-sections were placed on a microscope slide and viewed under a dissecting microscope with transmitted light. Digital images were captured using a camera mounted on the dissecting microscope, and cross-sections were viewed using either Image-Pro Plus® software or performed with the Iowa DNR's Structure Aging Application (Real Time Research, Bend, Oregon) which uses the RFishBC package (D. Ogle, personal communication, available at http://derekogle.com/fishR/packages) as its basis. One reader independently estimated the age of each Channel Catfish using a pectoral spine cross-section of their choice. The reader identified the focus and measured the distance from the focus to each annuli and the spine edge along the horizontal posterior or lateral transect as recommended by Michaletz et al. (2009). A second reader reviewed age estimates, and discrepancies in assigned ages were resolved via consensus.

Back-calculated lengths (BCAL) and growth increments were calculated using the Fraser-Lee (Fraser 1916; Lea 1920) method:

$$L_i = \frac{L_{c-a}}{S_c} S_i + a$$

where L_i is the back-calculated length of the fish when the *i*th increment was formed, L_c is the fish length at capture, S_c is the radius of spine at capture, S_i is the radius of the spine at the *i*th increment, and *a* is the biological intercept. Since no published biological intercept has been reported for Channel Catfish and even distribution of fish across the entire range of fish lengths was not always met, the *a*-intercept was set at 0.3 (see Michaletz et al. 2009). General patterns of fish growth were examined via comparisons of mean back-calculated TLs at age to interquartile range estimates for natural lakes reported by Meerbeek (2022). Channel Catfish mean back-calculated length-at-age-4 was compared among lakes and among stocking rate groups (no stocking, low stocking rate, high stocking rate) using analysis of variance (ANOVA) followed by Tukey's post hoc test.

Program AGEKEY was used to assign ages to unaged Channel Catfish (i.e., for surveys where aging structure was obtained) using subsampled year-specific age data obtained from each lake (Isermann and Knight 2005) to examine year-class fluctuations. More specifically, year-class proportions were calculated by dividing the number of fish caught from each year-class by the total number of fish captured during the survey. For this analysis, only fish captured and aged during the 2020 sample year were included since this was the only year where multiple lakes of varying stocking rates (controls = Iowa and Tuttle lakes; stocked = North Twin, Little Wall, and Lake Cornelia) were sampled and age-structures were collected. Growth was described via a von Bertalanffy growth model (von Bertalanffy 1938; Van den Avyle and Hayward 1999; $L_t = L_\infty(1 - e^{-K(t-t_0)})$) for each lake using Channel Catfish mean BCAL (ages 1-14) data where L_t is the mean total length (in) at age t (years), L_∞ is the theoretical maximum total length of an individual within the population, K is the growth coefficient for the population, and t_o is the theoretical age when total length is zero. Fisheries Analysis and Modeling Simulator (FAMS; Slipke and Maceina 2014) was used to perform von Bertalanffy growth simulations and a least squares model was used to determine if von Bertalanffy K or L_∞ differed between lakes. Lake specific Channel Catfish instantaneous natural mortality rates (M) and the associated conditional natural mortality rate (cm) was estimated via FAMS (Slipke and Maceina 2014). For these mortality calculations, asymptotic weight and maximum age were set to represent lake specific population characteristics observed in this study. Similarly, in instances where estimated L_∞ was unrealistic for a population, L_∞ was set to represent lake-specific Channel Catfish populations.

Several natural lakes (i.e., Black Hawk, Center, Clear, Lost Island, North Twin, Silver, Storm, and Tuttle lakes) have been annually or periodically sampled via summer (August to mid-September) seining surveys to evaluate age-0 fish recruitment patterns. Night seining surveys consisted of a minimum of two hauls (usually 3 or more) conducted at fixed sampling sites using a 50 foot ¼-in mesh seine starting at dusk at each study lake. All age-0 fish captured were identified to species and enumerated. These data were consolidated and reviewed to determine if captured age-0 Channel Catfish were known to be offspring of naturally reproducing Channel Catfish. More specifically, for each survey, the date of the survey and any stocking event was reviewed to ensure no possibility of stocked fish being present in the sample. Seining surveys where known wild age-0 Channel Catfish sampling occurred were examined for each lake to determine mean catch-per-seine haul and trends in natural recruitment for each lake over time. Regional trends in Channel Catfish natural recruitment were examined by pooling mean catch-per-seine haul each year for each lake and examining these trends among lakes. On occasion, captured wild age-0 Channel Catfish were measured for TL during seining surveys. For these surveys, age-0 Channel Catfish that were known to be of wild origin (using the process previously described) were then pooled for all lakes to evaluate seasonal length-frequency distributions. Since seining usually occurred between mid-August and mid-September, it was not practical to use TL data obtained during seining events as a proxy for expected mean BCAL age-1 TLs for determination of stocked or wild products via logistic regression models (e.g., growth of age-0 fish occurred into late fall). To account for additional growth of age-0 Channel Catfish captured via seining, growth was extrapolated for each TL measurement to provide an additional 0.066 in of growth per day (optimal daily growth in captivity; Chris Clouse, Iowa DNR, personal communication) from the time of capture to September 15. This date was chosen because all Channel Catfish stockings from 2010-2022 occurred between September 1 and October 2. A subsample of stocked Channel Catfish TLs were obtained at the Rathbun Fish Hatchery <2 days prior to stocking for the 2012-2022 stocked year-classes. Stocked Channel Catfish TLs were pooled and both stocked and extrapolated wild TLs were used to approximate the TL where the formation of the first annulus would occur for Channel Catfish entering winter (e.g., back-calculated TL at age-1). Then, logistic regression was used to determine if TLs differed and could be used to differentiate among stocked and wild Channel Catfish. For surveys with BCAL data, logistic regression coefficients were used to estimate the probability that a BCAL-estimated TL-at-age-1 was of stocked or wild origin. For each lake, probabilities were summarized and compared to stocked years to evaluate the influence of stocking on a fishery. All statistical analyses were performed using SAS Software (SAS Institute V9.4) and alpha was set at 0.05.

Results

Individual records of 14,215 Channel Catfish from sixteen natural lakes (range of 36 fish captured at Crystal to 2,790 at North Twin) spanning 36 hoop netting surveys conducted between 2014 and 2022 were consolidated into a single database to examine Channel Catfish population characteristics. A total of 9,633 unique measurements of Channel Catfish TL were recorded, and of those, 7,289 fish had associated weight measurements (Table 3). Between 34 and 1,933 Channel Catfish TL-wt measurements were obtained for each lake and mean TL and mean wt ranged from 14.3 (Crystal) to 23.0 (East Okoboji) in and 1.1 (Little Wall) to 5.4 (East Okoboji) lbs, respectively. All Channel Catfish TL-wt regressions were highly significant (linear regression; P <0.01) and r^2 values ranging from 0.9715 to 0.9893. Substantial differences in regression intercept and slope values were observed among lakes, with a values ranging from -4.1597 to -3.6745 (intercept b) and 3.1119 to 3.5622 (slope a), respectively (Table 3).

Pooled PSD was highly variable and ranged from 29 at Center Lake to 97 at East Okoboji Lake (Table 4). No Channel Catfish captured from Iowa's natural lakes were trophy size, and only six of the fourteen lakes had fish that were memorable size. In terms of PSD-P, Clear, East Okoboji, Lost Island and Little Spirit lakes had values ≥9; whereas all other lakes had PSD-P values ≤6 (Table 4). Length frequency distributions strongly reflected PSD and all but one lake comparison (Black Hawk * Iowa) was significantly different (Table 5; Ingham and Crystal lakes excluded from length frequency distribution comparisons due to low sample sizes). Likewise, significant differences in mean TLs were observed among lakes, which also strongly reflected PSD comparisons (Figure 1). More specifically, Clear, East Okoboji, and Little Spirit Lake had Channel Catfish mean TLs that were significantly larger than all other natural lakes with Channel Catfish populations. Besides Lost Island, Silver, Storm, and Tuttle lakes, mean TLs were below 18.0 in in all remaining lakes and were lowest in Center and Little Wall lakes (Figure 1). Significant differences in mean *Wr* were observed among lakes overall and by size categories (Figure 1; Table 6). Mean *Wr* above 100 was observed in Crystal, Black Hawk, Lost Island, and Silver lakes (Figure 1); these same lakes consistently had high (>100) mean *Wr* values across all size categories (Table 6). Seven of the remaining twelve lakes had mean *Wr* values between 90-99, while Little Spirit, Tuttle, Little Wall, Five Island, and Iowa lakes had mean *Wr*'s ranging from 77-88. Besides a few differences among mean sub-stock *Wr*'s, lake-specific mean *Wr* for Channel Catfish did not vary considerably by size category; however, among lake differences were often documented and followed a similar pattern to overall mean *Wr* comparisons (Figure 1; Table 6).

Channel Catfish mean density (n/ac) ranged from 0.18 fish/ac (East Okoboji) to 30.93 fish/ac (Iowa Lake; Figure 1). Seven lakes had one estimate of population density, whereas the remaining 9 lakes had 2 to 4 density estimates. Of those with multiple estimates, standard error was generally low, indicating low to moderate population fluctuation in those systems. Mean density was highest in Iowa, Little Wall, and North Twin lakes (>22.0 Channel Catfish/acre), intermediate at Cornelia, Center, Five Island, Black Hawk, Little Spirit, and Tuttle lakes (3.2-11.0 fish/ac), and low everywhere else (<1.2 fish/acre; Figure 1).

Collectively, significant differences were observed in size structure, condition, and density metrics among lakes with natural Channel Catfish populations and those managed with low and high stocking rates (Figure 2). Natural lakes stocked at low Channel Catfish densities had significantly higher PSDs, mean TLs, *Wr*, and significantly lower adult population densities compared to lakes that were stocked more aggressively. Lakes that were not stocked had more variability in density and PSDs than low stocking rate lakes (but lacked insufficient data for statistical comparison), but also had significantly higher mean TLs but lower *Wr*'s than lakes stocked with Channel Catfish (Figure 2).

Mean back-calculated TL at age was estimated for ten lakes, of which two (Iowa and Tuttle lakes) were not stocked, five were stocked at low rates (Center, East Okoboji, Five Island, Lost Island, and Storm lakes), and three were more aggressively stocked (Lake Cornelia, Little Wall, and North Twin lakes; Table 2; Table 7). Mean back-calculated TL varied among lakes, but some consistencies were observed. Comparing growth to the statewide standard for natural lakes (Meerbeek 2022) at Center, Five Island, and North Twin lakes, growth was fast at ages 1-2, then moderate between ages 3-8. Growth for ages 1-8 were within the interquartile range for Storm and Tuttle lakes but below the interquartile range at Iowa Lake. Growth was fastest at Lost Island and East Okoboji lakes and followed a more variable pattern at both Lake Cornelia and Little Wall Lake, with periods of growth both within and below the interquartile range (Table 7). Comparisons of TL at-age-4 found fastest growth at East Okoboji and Lost Island Lake, moderate growth at Center and Storm Lakes, and moderate to low growth at all remaining lakes. Growth was significantly lower at Little Wall and Iowa lakes compared to all other lakes where estimates of growth to age-4 were available (Table 7). Correspondingly, back-calculated mean TL at-age-4 was significantly different among lakes stocked with low and high Channel Catfish densities, as well as those that have not been stocked, with higher mean TLs at low, high, and no stocking, respectively (Figure 2).

Maximum age from the 1,388 Channel Catfish aged via pectoral spine sections was 14 (Lake Cornelia and Little Wall Lake) and all ten natural lake populations examined had fish ≥10 years old (Table 8). Lake specific von Bertalanffy growth parameters were estimated from sample sizes that ranged from 25 (Lost Island) to 309 (Tuttle) individual age records. Substantial differences in estimated L_∞, k, and t_o were observed among lakes. For example, Channel Catfish values of k ranged from 0.120 at Tuttle Lake to 0.231 at Lake Cornelia and L_∞ ranged from 21.3 (Lake Cornelia) to 36.0 (East Okoboji Lake; Table 9; Table 10). Although many significant differences among population parameters were observed, estimates of M and cm were relatively similar among lakes, with M ranging from 0.22-0.29 and cm ranging from 0.19-0.23 (Table 8).

Stocking contribution based on examination of year-class frequency from age-growth samples collected in 2020 revealed a higher proportion of the aged subsample corresponding to unstocked years (Figure 3). For example, over 30% of the fish captured in Lake Cornelia were estimated to be age-7 fish (2013), a year-class where no stocking occurred. Similarly, for both North Twin and Little Wall lakes, most of the fish collected in 2020 (>40%) were estimated to be age-5 fish, which also corresponded to a year where no fish were stocked (2015; Figure 3). At unstocked lakes (Iowa and Tuttle lakes), a large proportion of Channel Catfish sampled originated from the 2015 and 2016 year-classes, further supporting the potential for natural recruitment to contribute substantially to Channel Catfish population residing in Iowa's natural lakes.

Eight natural lakes have been surveyed for age-0 recruitment prior to any agency Channel Catfish stockings between 2000 and 2022 (Figure 4; Figure 5). At North Twin Lake, age-0 Channel Catfish (e.g., wild) catch ranged from 0.0 to 33.0 per seine haul and only three of the eighteen surveys resulted in catches of zero age-0 fish (Figure 4). Prior to the lake renovation at Black Hawk (pre-2012), age-0 Channel Catfish were observed in all seine surveys at catch rates ranging from 0.7 to 53.0 fish/haul. No age-0 Channel Catfish were captured at Black Hawk during annual surveys until 2020 (Figure 4). Similarly, prior to a renovation effort at Lost Island Lake (pre-2010), age-0 Channel Catfish were observed in all seine surveys (n = 7; 0.2-14.4 fish/seine haul) but only twice since the fishery was renovated (2013 and 2016; Figure 4). Fourteen of the nineteen seining surveys conducted at Storm Lake had sampled age-0 Channel Catfish, and several of those indicated periods of strong natural recruitment (2005, 2008, 2011, and 2019; Figure 4). At Clear Lake, age-0 Channel Catfish have been collected during 11 of 19 surveys, but at low catch rates (≤1.3 fish/seine haul; Figure 4). Other lakes, such as Center Lake (1 of 9 surveys), Lake Cornelia (3 of 9 surveys), and Silver Lake (1 of 8 surveys) infrequently documented wild age-0 Channel Catfish during seining investigations. Collectively, summer seining investigation in natural lakes indicate variable Channel Catfish natural recruitment patterns (Figure 5).

Pooled known wild age-0 Channel Catfish TLs (n = 1,273 fish) ranged from 1.2 in (August 26) to 5.0 in (September 16) and size distributions of fish captured increased at different time intervals, with mean TLs of 2.6 in, 3.0 in and 3.4 in at intervals of August 14-28, August 28-September 11, and September 13-October 4, respectively (Figure 6). Observed wild age-0 Channel Catfish TLs rarely overlapped with subsampled TLs taken from production ponds at Rathbun Fish Hatchery prior to stocking. Likewise, extrapolated growth of wild age-0 Channel Catfish to September 15 infrequently overlapped with subsampled hatchery TLs (Figure 7) and logistic regression models evaluating the relationship among the two groups were highly significant (logistic regression: df = 1; *P* = <0.001;

$$P = \frac{e^{-(-27.3884+5.266X)}}{1+e^{-(-27.3884+5.266X)}}$$

where *X* = back-calculated TL at age-1) with larger fish TLs (e.g., ≥5.3 in) having a higher probability of hatchery origination (Figure 8). Using this model and back-calculated TL at age-1, control populations (i.e., no Channel Catfish stockings) had between 86-97% of aged fish identified as wild origin (probability of hatchery ≤0.5; Table 11). At stocked fisheries, back-calculated TLs of age-1 fish were consistently identified as wild origin (70-93%) in lakes where stocking rates were highest but variable in lakes with low Channel Catfish stocking rates (15-62%; Table 11).

Discussion

Advancements in sampling techniques during the early 2000s for Channel Catfish (Michaletz and Sullivan 2002; Flammang et al. 2011) resulted in a wealth of information that has emerged across a wide range of managed resources in Iowa. Prior to the addition of baited-tandem hoop nets in comprehensive and stand-alone surveys (circa 2005), Channel Catfish were only sampled periodically during fisheries surveys that occurred in the natural lakes region which made fishery evaluations difficult. Since the inclusion of hoop netting as a tool for Channel Catfish evaluations, besides collecting information on general population dynamics and stocking contribution, managers in Iowa have used hoop netting as a means to estimate population size as well as a sampling technique for Channel Catfish removal projects (e.g., Lake Pajoha 2005). These advances have led to a greater understanding of Channel Catfish populations in Iowa, yet the evaluation of population dynamics among systems is rarely compared at a regional or system-wide scale. Cashatt (2012) was the first to evaluate Channel Catfish population characteristics at a regional scale (i.e., 32 small constructed fishing lakes) in Iowa, observing substantial variation among systems and identifying stocking and management strategies that may improve lake-specific Channel Catfish populations using hoop netting trend data. In addition, Flammang et al. (2011) provided valuable data on the ability of hoop netting to index Channel Catfish structure and growth in Iowa. Ultimately, these studies supported stocking larger Channel Catfish in Iowa's lakes and impoundments as well as the use of hoop netting as a standardized sampling technique in Iowa (Schultz 2009). Since these initial studies, lakes have continued to be stocked and sampled for Channel Catfish in Iowa, but little has been done to understand the influence of those stockings or how natural recruitment may impact Channel Catfish populations at a regional scale.

In the midwestern U.S., a paucity of information exists for population characteristics of Channel Catfish residing in natural lakes of glacial origin. Besides hoop netting surveys conducted in Iowa, I am unaware of no other state agency protocols that target Channel Catfish via hoop netting in natural lakes to monitor population status. This is not surprising since state agencies that manage natural lakes in the upper Midwest (e.g., South Dakota, Minnesota, Wisconsin) rarely, if ever, stock Channel Catfish into lakes of glacial origin. Hence, Channel Catfish management in these jurisdictions typically consists of incidental captures during routine surveys that do not target Channel Catfish, yielding sample sizes insufficient for population metric calculations. Thus, this study is the first of my knowledge that provides managers with population characteristics of Channel Catfish that reside in stocked or unstocked natural lakes. Similar to investigations at small constructed lakes (Flammang et al. 2011; Cashatt 2012), Channel Catfish populations in natural lakes of varying size, complexity, water chemistry, and stocking rates in Iowa varied considerably, yet some general trends among lakes of similar morphology and stocking practices exist. For example, larger natural lakes evaluated here typically had better Channel Catfish size structure, growth, and condition than smaller lakes, regardless of management strategy (i.e., stocking rate). Also, natural lakes stocked at the highest stocking density, generally were populations with the poorest growth, condition, and size structure. This study also documented that natural lakes with wild populations of Channel Catfish had variable population characteristics. Collectively, this study provides substantial information on Channel Catfish population characteristics in managed and unmanaged natural lakes that previously was inaccessible to managers.

As with many fish populations, Channel Catfish abundance influences population dynamics (Flammang et al. 2011; Tyszko et al. 2021), and understanding those mechanisms may alter management actions (Cashatt 2012). Here, Channel

Catfish densities within each lake were estimated from hoop netting CPN data that occurred over a span of nine sampling seasons and were found to be as high as 41.5 fish/ac (342 fish/hoop net series). Channel Catfish densities of this magnitude were significantly correlated to poor size structure, condition, and growth in Iowa's constructed lakes (Flammang et al. 2011), and others have documented similar declines in Channel Catfish population metrics at high catch rates across the species' managed range (Michaletz 2009; Leonard et al. 2010; Tyszko et al. 2021). I documented that Channel Catfish densities as low as 10 fish/ac in Iowa's natural lakes can exhibit similar population characteristics as those with extremely high densities. However, larger natural lakes (>1,000 ac) often had Channel Catfish densities below ≤1.0 fish/ac and experienced better size structure, faster growth, and better condition compared to populations at smaller natural lakes. Others have also documented that Channel Catfish populations perform better in larger (>1,000 ac) reservoirs in both Texas and Ohio (Durham et al. 2005; Tyszko et al. 2021), but the mechanisms that cause these improvements are unclear. For example, lake productivity (chlorophyll-a) and forage have been associated with increased Channel Catfish growth and size structure (Shoup et al. 2007; Michaletz 2009), but no correlation among those variables and increased Channel Catfish population metrics were observed in Ohio's reservoirs (Tyszko et al. 2021). Similarly, a simple linear regression model relating Channel Catfish density to mean chlorophyll-a values observed in Iowa's natural lakes was insignificant ($P = 0.58$; $r^2 = 0.02$). Thus, it appears that a suite of biotic and abiotic characteristics within individual lakes interact and the potential for those characteristics to be maximized for Channel Catfish growth and size structure are highest in lakes of greater size and complexity. However, it is important to note that density estimates evaluated here were developed from a simple catch-density model; since catch data are inherently variable, the ability to detect trends in density and systematic variables may be difficult. For example, at Center Lake, a large catch of small fish in 2017 ($n = 545$; 24.0 fish/ac) resulted in population parameters that were not reflective of the system during other sampling events (<3.0 fish/ac; range of 51-98 total fish captured). At Crystal Lake (high stocking density), only 36 Channel Catfish were captured in two separate sampling events that may have been substantially influenced by presence of submersed aquatic vegetation. Furthermore, many of the lakes stocked via Channel Catfish since 2010 were involved in active lake restoration projects that may have had some effect of this study's findings. Most notably, a fishery renovation was conducted at Black Hawk in 2011 that eliminated the existing Channel Catfish population, but stocking there post-renovation included Channel Catfish and by 2019, several year-classes as well as natural reproduction were documented. A large Common Carp *Cyprinus carpio* reduction project beginning in 2010 significantly changed fishery composition (Meerbeek and Hawkins 2021) and may be responsible for lower Channel Catfish densities and improved growth and size structure in Lost Island Lake. Clear Lake, Storm Lake, and Five Island lakes have had extensive dredging and watershed improvements that may have changed fishery composition (Colvin 2012; Larscheid and Meerbeek 2019). Other lakes (Five Island, Center, North Twin, Silver lakes) have also had some type of active Common Carp or Bigmouth Buffalo *Ictiobus cyprinellus* management strategy since 2016 (Simonson et al. 2022) that could have influenced the Channel Catfish dynamics during the course of this study's evaluation. These events could have influenced the ability to correlate lake productivity and stocking rates at managed Channel Catfish fisheries, but care was taken to only include those data that were representative of the current population trends in an attempt to reduce this error. Regardless of these interactions, I believe the density estimates presented here provide a reasonable measure of Channel Catfish population density at a wide range of natural lakes types in Iowa. Furthermore, these data demonstrate the influence of high Channel Catfish population abundance on smaller, more simple natural lake systems and the need to reevaluate management strategies there.

This study did not evaluate the impact of Channel Catfish on other sportfish populations; however, that has been a concern among managers in Iowa interested in providing a multi-species fishery since natural lakes containing the highest CPN of Channel Catfish typically have poorer sport-fisheries. Naturally, frequent and intensive stocking of Channel Catfish have also been found to influence population densities of managed waterbodies (Michaletz 2006; Michaletz 2009), and may cause negative consequences to other sportfish populations if stocking rates and low exploitation result in high population density (Michaletz 2006; Michaletz et al. 2008; Leonard et al. 2010). However, research exploring the impacts of high Channel Catfish densities directly to species such as Bluegill *Lepomis macrochirus* and Largemouth Bass *Micropterus salmoides* were unable to correlate important population parameters to more moderate-low levels of Channel Catfish density. Thus, the impacts of high Channel Catfish density on fish population characteristics of those species commonly encountered in natural lakes are largely unknown or understudied. The effect of high Channel Catfish density on Channel Catfish population characteristics, however, has been well studied (Michaletz 2006; Michaletz et al. 2008; Michaletz 2009), and reductions in stocking rates to mitigate poor population performance may require several years before results can be achieved (Michaletz et al. 2011; Wagner et al. 2013). Management strategies of this type are especially difficult in lakes where low mortality, slow growth, and low levels of angling harvest occur. For example, at Five Island Lake, relatively high densities have continued to impact population parameters several years after Channel Catfish stocking rates were substantially reduced, likely due to longevity of the species and natural recruitment. In some instances, managers have eliminated Channel Catfish stocking altogether due to lack of angling interest and high Channel Catfish densities (Munger et al. 2016). Thus, it is important that lakes exhibiting these characteristics are identified and individual lake management plans are developed and implemented appropriately (Michaletz 2009).

Fish culture and stocking is an important management tool, but it is also important that stocking rates are periodically reviewed and decisions are made regarding the proper use of valuable hatchery products and production space. On average, about 13% (average from 2018-2021) of the total annual production of advanced fingerling Channel Catfish are stocked into thirteen of Iowa's natural lakes. Although rather insignificant in terms of total Channel Catfish annual production, it remains important that managers utilize hatchery products efficiently and effectively, regardless of production costs. Several important trends were identified using the simple approach of comparing stocking rates and resultant Channel Catfish population metrics at a gradient of natural lakes in Iowa that could improve management goals and reduce Channel Catfish production costs. Foremost, natural lakes with Channel Catfish stocking rates exceeding 4.4 fish/ac/year consistently had poorer size structure and growth. Since mortality rates at natural lakes studied here were very consistent, it is likely that additive mortality resulting from high exploitation was not occurring at any managed waterbody. Thus, high stocking rates and low exploitation may be an important consideration for managers, yet little is known regarding Channel Catfish harvest at many of Iowa's natural lakes. In a recent survey evaluating angler preferences, Channel Catfish are no longer the most preferred species for Iowa's anglers (Duda et al. 2019) and a regional shift in anglers' interest to trophy Ictalurids has occurred (Schall and Lucchesi 2021). At Clear Lake, <2.0% of anglers targeted Channel Catfish during the 2017 fishing season and harvest declined significantly ($P = <0.001$; $r^2 = 0.58$) between 2002 and 2017 to less than 275 fish harvested during the open water season (Grummer and DeKoster 2017). In addition, at Black Hawk Lake, a creel survey in 2017 found that very few anglers targeted or harvested Channel Catfish despite several strong year-classes that were available to anglers (Wallace and Mork 2017). These observations in conjunction with the data presented here provide strong evidence that managers may need to reconsider Channel Catfish stocking rates within Iowa's natural lake region. But, not only lakes of high stocking density need reconsideration. This study also documented that natural lakes with more moderate stocking rates also could have Channel Catfish population characteristics similar to those stocked at high rates (e.g., North Twin). Thus, appropriate stocking rates are needed on a lake-by-lake basis and should not be prescribed via simple guidelines or limits taken from agency stocking policies (i.e., Iowa's Fish Stocking Policy 2013).

Besides the effect of stocking, the effect of Channel Catfish natural reproduction in natural lakes on Channel Catfish population parameters may be equally important. Population demographics of three wild Channel Catfish populations were evaluated and compared to those of stocked populations in this study, and some differences were observed. However, similar to stocked populations, wild populations had extreme variability in Channel Catfish size structure, condition, and growth that appear to be inversely related to population density. For example, at Iowa Lake, Channel Catfish population densities were among the highest observed (>30 fish/ac) and fish experienced poor size structure, condition, and growth. Similar natural Channel Catfish recruitment effects may be occurring in stocked lakes, thus supplemental stocking may further exacerbate density-dependent fishery problems.

However, it is difficult to evaluate the extent stocking contributions have to existing Channel Catfish population demographics using traditional management tools. In this study, the proportion of aged fish during a 2020 evaluation at stocked and unstocked lakes revealed inconsistent patterns of year-class development and did not correlate well to stocked years. Thus, preliminary analysis suggests that stocking contribution is minimal and may be contributing to poor population performance. However, throughout this study and the study conducted by Cashatt (2012), uncertainty in Channel Catfish age estimates can occur for age-structures that are collected during summer sampling periods. For example, considerable within lake variation was observed in annulus formation in structures collected during summer and workers were often unable to decipher whether or not additional growth had occurred or if the edge of the structure was the annulus. These difficulties appear to be more common with Channel Catfish populations than many other teleost fishes as energy devoted to gamete development continues until mid-June and annulus formation may not be visible until August. Because stocking contribution was evaluated using biennial stockings, the misinterpretation of an annulus edge could substantially bias age and growth estimates. Thus, further evaluation of year-class contribution should be limited to age structures collected during either the spring or fall.

This study used back-calculation at age-1 in an attempt to evaluate stocking contribution in addition to year-class contribution via subsampled and extrapolated age estimates derived from Channel Catfish pectoral spines. Although the impetus of this work for using back-calculation to determine stocking cohort was promising based on evaluations of hatchery and wild stocked fish in Arkansas (Seigwarth 1994), several complications during our evaluation likely limited our ability to accurately determine the origin of each fish. Most notably, it was often extremely difficult to determine the first annulus on basal pectoral spine sections. It is unclear if these difficulties were the result of the expansion of the central lumen (Muncy 1959; Nash and Irwin 1999) or if over-aging occurred due to annular marks that were composed of multiple rings, as observed by Buckmeier et al. (2002) and Barada et al. (2011). Thorough examination of annual marks in unstocked populations provided some evidence as to first annulus placement, but these patterns were often inconsistent among stocked and unstocked populations. The uncertainty of the origin of the first annulus would have substantial consequences on the ability for the logistic regression model to accurately estimate the probability of fish being stocked. Although the model overall performed relatively well on the control (i.e., unstocked) lakes used in this evaluation, several instances of fish being identified as stocked origin also occurred at these lakes. Likewise, stocked natural lakes that have had little, if any, documentation of natural recruitment (Center and East Okoboji lakes) had substantial contributions from natural recruitment based on the results of the logistic regression model. Thus, the results of the work presented here are largely inconclusive and may not be an appropriate technique to evaluate Channel Catfish stocking contributions. However, the approach of using back-calculated lengths at age-1 to determine stocked fish contribution may be a useful tool for stocking evaluations where size discrepancies among same-aged fish of wild and stocked origin are substantial for species beyond Ictalurids. Considerations to improve section clarity may include the use of a low-speed saw (Barada et al. 2011), alternative spine section (Haubrock et al. 2018), or via using the articulating process to view structures. Alternatively, conventional mark-recapture studies evaluating stocking contribution may be a more useful technique for fish species where age determination is difficult.

Channel Catfish natural recruitment via observations of age-0 fish during seining investigations may be a more appropriate tool for evaluation of recruitment variability among and within populations. This study documented Channel Catfish natural recruitment via seining surveys in eight of the sixteen study lakes, but natural recruitment has been documented (via seine surveys or fish captures in unstocked populations) in at least fourteen natural lakes in Iowa when including sampling conducted beyond the scope of this project (Table 12). However, the frequency and intensity of those natural recruitment events varies considerably among lakes. Besides what was reported in this study, 500-ft daytime bag seining surveys at East Okoboji Lake found age-0 Channel Catfish in seven of twenty surveys ranging from CPN of one to six fish captured, but a similar survey at Spirit Lake captured a total of two age-0 Channel Catfish over the past 21 sampling years. Age-0 Channel Catfish were collected in four of ten summer daytime seining surveys conducted at Clear Lake between 2007 and 2017, with catch as high as 20 fish collected in 2010. Collectively, the observations of successful Channel Catfish recruitment at a gradient of natural lakes surveyed provides substantial evidence that Channel Catfish may be able to sustain viable populations without supplemental stockings from state agencies. Furthermore, the frequency and intensity of natural recruitment events that have previously been documented via seining surveys may be a useful tool for managers that are interested in reducing or eliminating agency stockings. For example, regular and sometimes intense recruitment events have been observed at several Iowa lakes, including Black Hawk, North Twin, and Storm lakes. Observations such as these could persuade managers to reevaluate stocking strategies to prevent undesired consequences resulting from high density Channel Catfish populations.

The final objective of this study was to provide lake-specific stocking recommendations for natural lakes based on the results of this work. Some researchers have suggested that stocking rates should be developed using a simple growth increment model that compares growth of individual fish to a statewide standard (Michaletz 2009; Michaletz et al. 2011). Although this approach may be appropriate for Channel Catfish populations in midwestern impoundments and reservoirs, aging structures obtained during standardized surveys in Iowa may complicate the interpretation of last increment growth, potentially biasing growth increment estimates. Growth models would require managers to collect fish during either spring or fall periods, and these surveys would often overlap with other important survey work. In addition, temperature regimes in Iowa often do not facilitate high catch rates via hoop netting surveys when conducted outside of the recommended summer sampling period. Thus, substantial effort would be required to use models relating Channel Catfish growth to statewide standards. However, the information provided in this review provides managers with trends and current Channel Catfish population dynamics commonly observed in many of Iowa's natural lakes. Specific recommendations on stocking and managing Channel Catfish for natural lakes based on Channel Catfish population characteristics, recruitment, and morphological features of lakes evaluated here are presented in Table 12. These data can be used to help guide management decisions, but it is also important that managers sample the population periodically to document changes in the fishery and adjust stocking or management goals appropriately.

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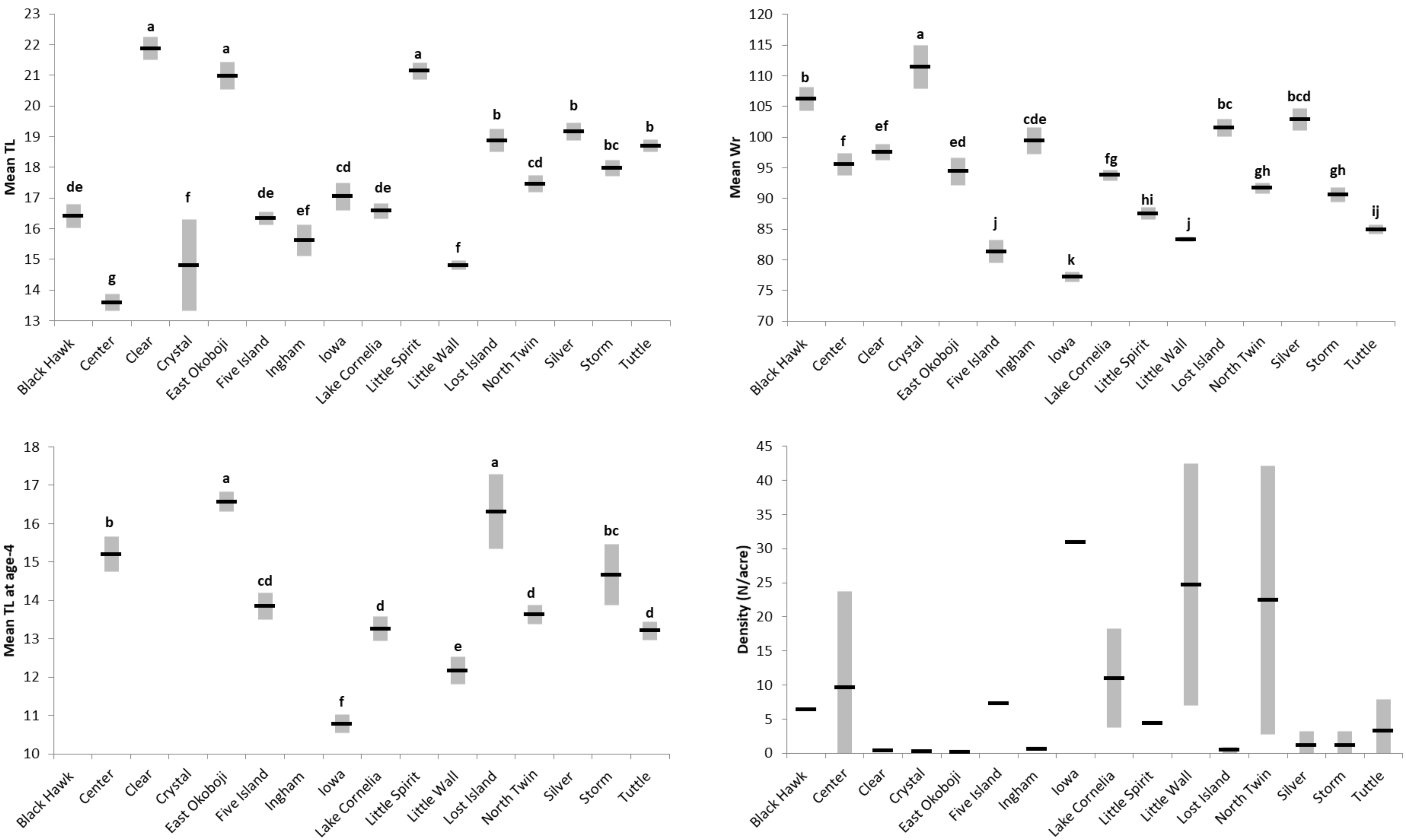

Figure 1. Pooled mean total length (TL; in), mean relative weight (*Wr*), mean TL at age-4, and estimated density (number per acre) of Channel Catfish collected via hoop nets from sixteen stocked (Black Hawk; Center; Clear; Crystal; East Okoboji; Five Island; Ingham; Lake Cornelia; Little Wall; Lost Island; North Twin; Silver; Storm) and unstocked (Iowa; Little Spirit; Tuttle) natural lakes in Iowa between 2014-2022. Ninety-five percent confidence intervals are represented in gray. Letters denote significant (P <0.05) differences among populations.

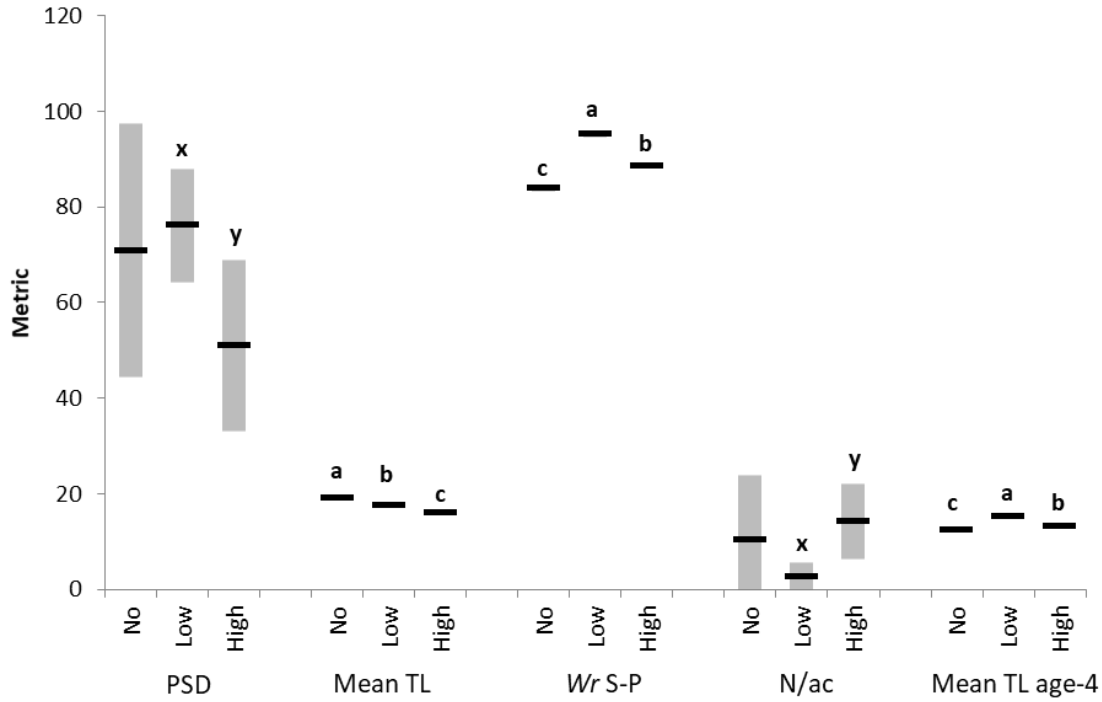

Figure 2. Mean (±95% confidence intervals; grey) pooled proportional stock density (PSD); total length (TL), relative weight (*Wr*), density (number per acre), and TL at age-4 for Channel Catfish that were sampled from natural lakes between 2014-2022 that had not been stocked (No; Iowa, Little Spirit, Tuttle) and those that had low (<1.4 fish/acre/year; Center, Clear, East Okoboji, Five Island, Lost Island, Silver, and Storm lakes) and high (≥2.0 fish/acre/year; Black Hawk, Cornelia, Crystal, Ingham, Little Wall, and North Twin lakes) stocking rates of Channel Catfish since 2010. Differences (P ≤0.05) in metrics are indicated by letter denotation (Tukey's [a,b,c]; t-test [x,y]) .

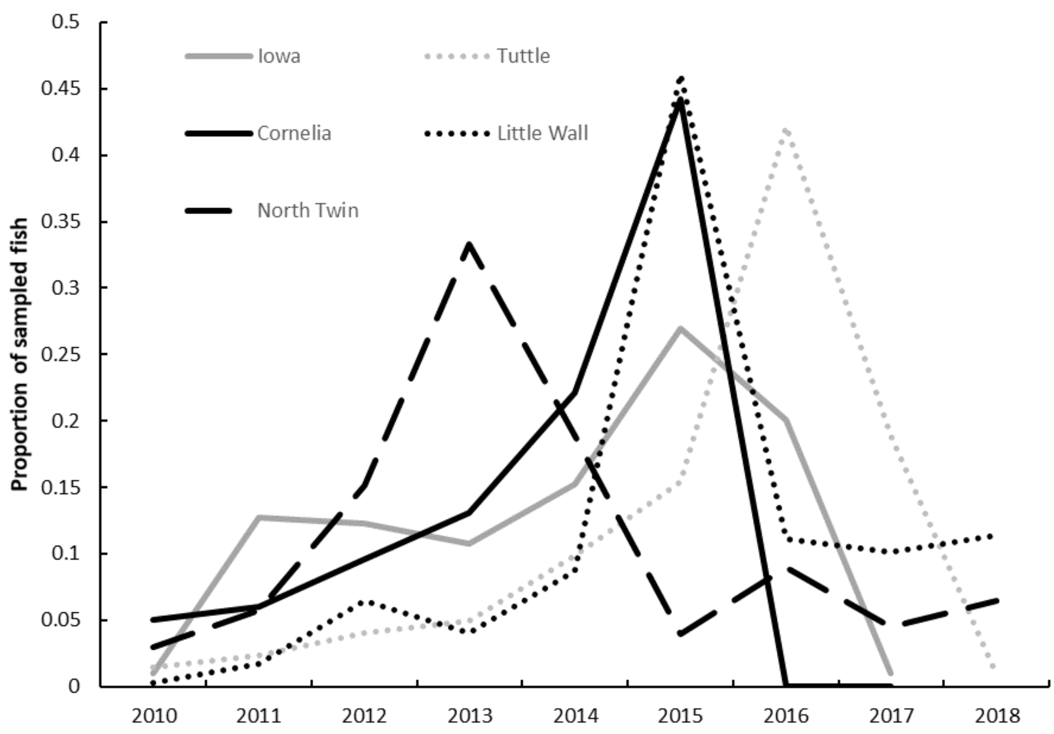

Figure 3. Proportion of Channel Catfish sampled in 2020 that were assigned an age based on pectoral spine sections (basal) from year-classes between 2010-2018 (two to ten year-old fish) at fisheries where Channel Catfish were stocked (Lake Cornelia, Little Wall, and North Twin) and those where no stocking has occurred (Iowa and Tuttle lakes).

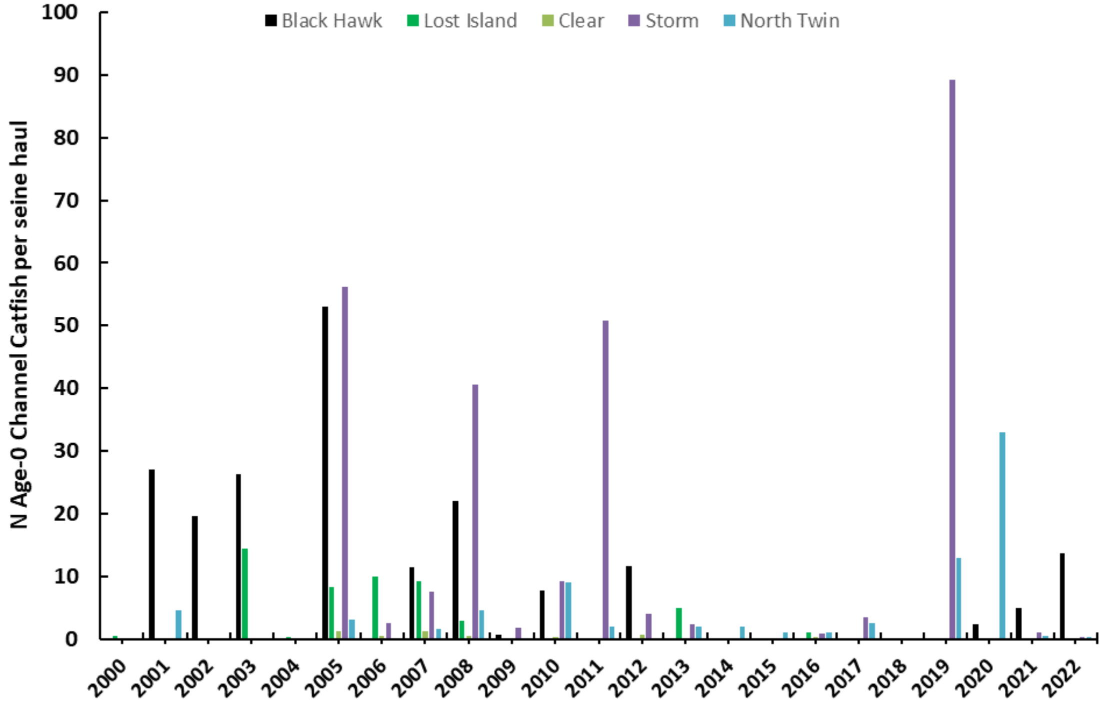

Figure 4. Number (N) of wild age-0 Channel Catfish captured per seine haul during night seining investigations conducted at five stocked natural lakes (Black Hawk, Lost Island, Clear, Storm and North Twin) between 2000-2022.

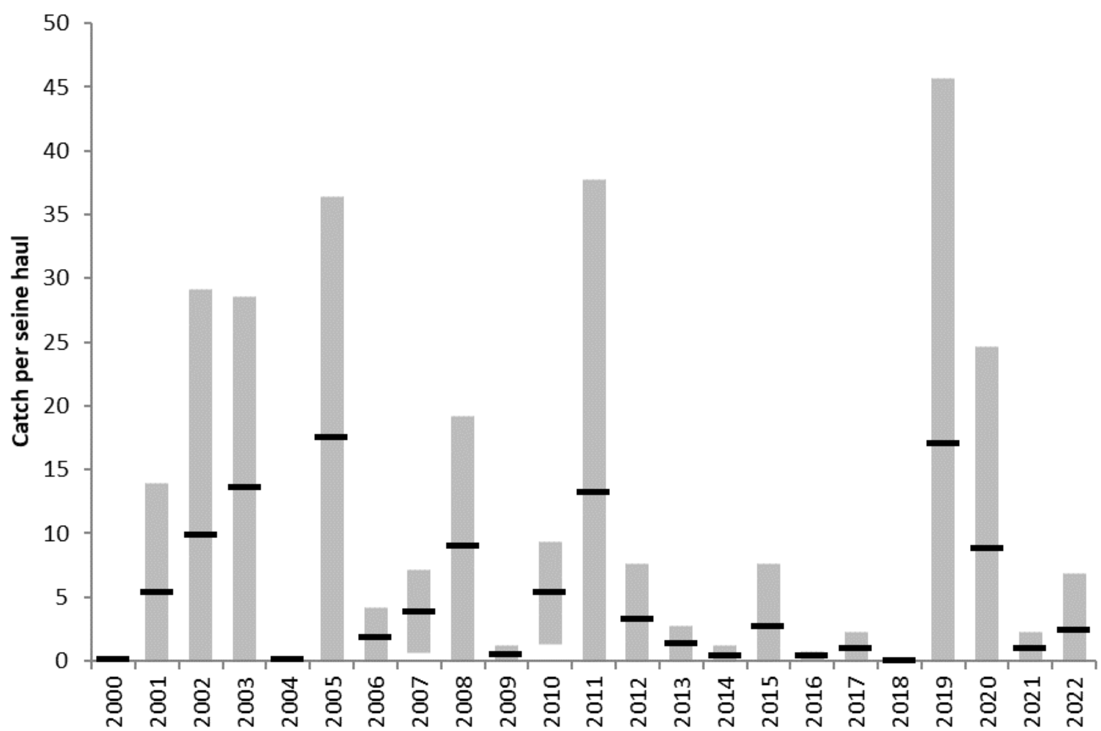

Figure 5. Mean (±95% confidence intervals; grey) wild age-0 Channel Catfish catch per seine haul from eight stocked natural lakes, 2000-2022.

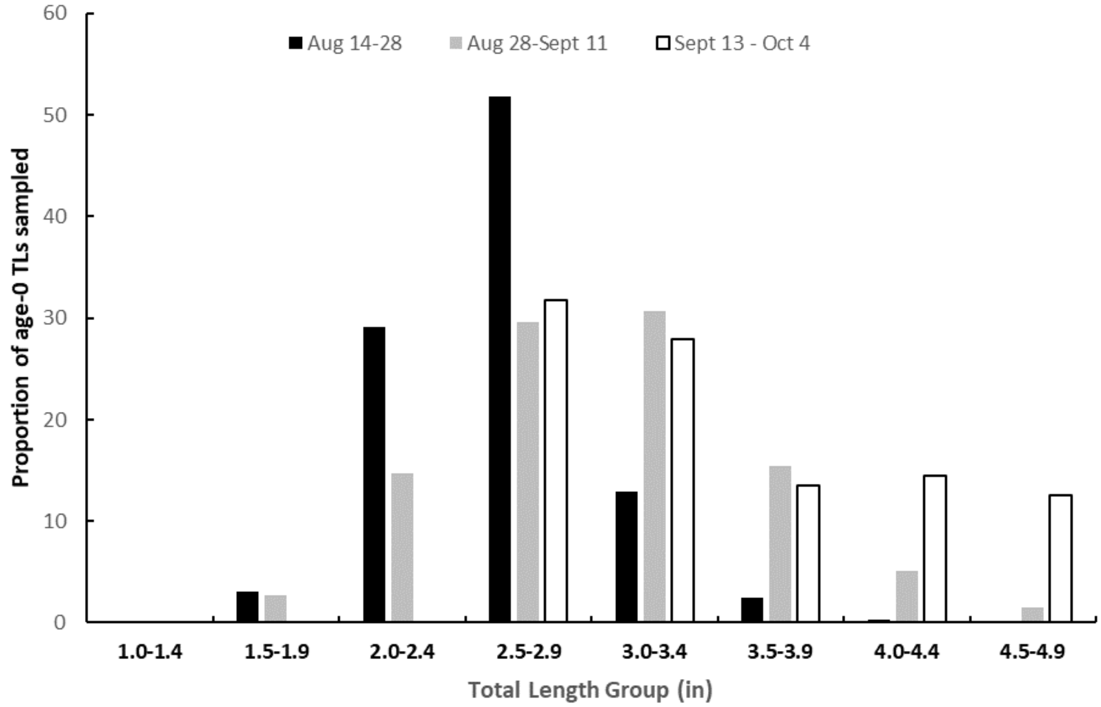

Figure 6. Total length (TL; in) distribution of wild caught age-0 Channel Catfish collected via night seining surveys at eight natural lakes during late August (black bars), early September (grey bars), and late September (white bars).

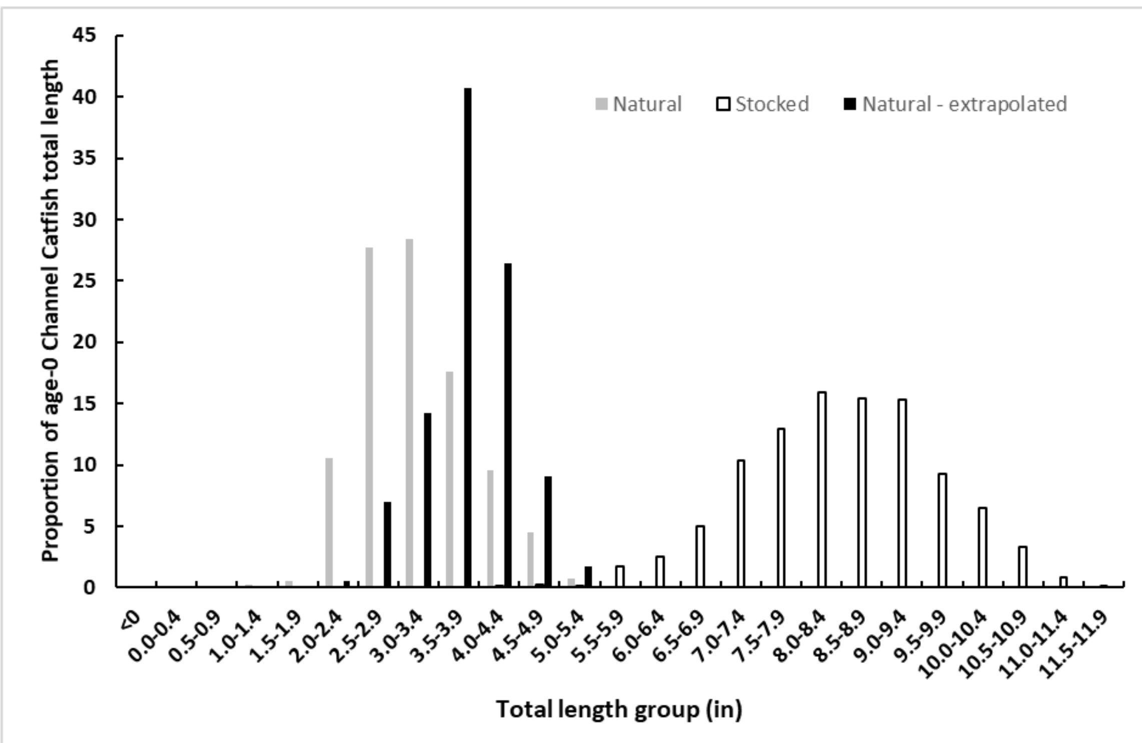

Figure 7. Proportion of length frequency distribution of subsampled age-0 hatchery reared Channel Catfish prior to being stocked in September-October in Iowa's natural lakes (white bars), September known wild age-0 total lengths (TL; in; grey bars), and known wild age-0 Channel Catfish sampled via night seine investigations and TLs extrapolated to September 15 at ½ intervals between 0.0 and 12.0 in. A growth rate of 0.066 in/day was applied to known wild captured age-0 Channel Catfish to provide a representative sample of wild age-0 TLs residing in lakes where Channel Catfish are stocked in fall.

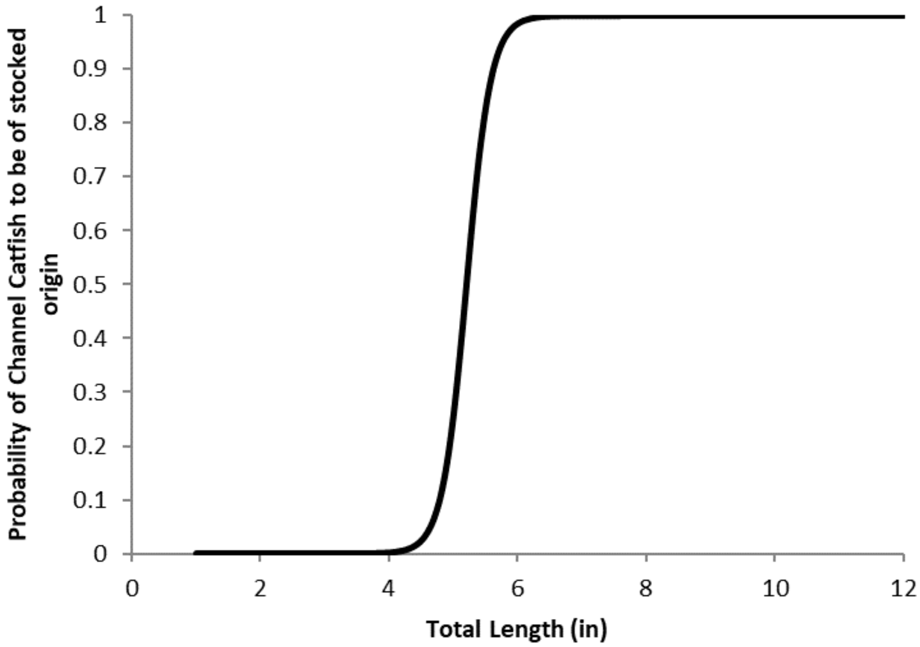

Figure 8. Probability of age-0 Channel Catfish to be of wild or hatchery origin from total length measurements in fall.

Table 1. Physical and chemical characteristics of thirteen natural lakes stocked with Channel Catfish and those with wild (n = 3; denoted by *) Channel Catfish fisheries in Iowa. Parameters were averaged between 2000-2020 from data collected via Iowa Department of Natural Resources (DNR) water quality monitoring program, citizens lake monitoring programs, and independent Iowa DNR field surveys. Ft = feet; SDI = shoreline development index.

Lake	County	Acres	Maximum Depth (ft)	Mean Depth (ft)	SDI	Watershed Area Ratio	Total Phosphorus	Turbidity	Chlorophyll a	Secchi (ft)
Storm	Buena Vista	3,097	20.4	8.2	1.7	4.4	88.0	46.1	15.7	1.6
North Twin	Calhoun	453	12.0	8.7	1.9	4.6	79.9	27.4	49.1	2.3
Clear	Cerro Gordo	3,684	19.2	9.6	1.6	2.3	72.5	N/A	31.5	N/A
Center	Dickinson	220	17.9	12.2	1.7	2.7	93.2	27.1	60.2	3.5
East Okoboji	Dickinson	1,835	22.0	10.0	2.8	6.7	81.6	16.9	41.4	3.2
Little Spirit*	Dickinson	604	10.0	6.0	3.1	2.0	204.8	61.3	75.0	2.1
Silver	Dickinson	1,041	10.6	7.4	1.8	10.7	159.9	33.7	71.8	2.7
Ingham	Emmet	357	12.0	6.0	1.6	12.1	147.9	44.3	104.9	1.2
Tuttle*	Emmet	2,268	7.7	3.8	1.8	46.5	198.9	102.5	79.8	1.0
Little Wall	Hamilton	249	13.2	6.5	3.9	0.9	106.7	33.7	46.0	1.2
Crystal	Hancock	264	18.4	7.5	1.2	6.8	235.7	52.8	80.0	2.5
Iowa*	Osceola	116	4.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Five Island	Palo Alto	973	24.9	5.6	3.6	8.9	99.7	33.6	45.4	2.0
Lost Island	Palo Alto	1,162	15.7	11.3	1.5	4.0	73.9	24.6	25.2	2.8
Black Hawk	Sac	729	15.1	6.0	2.0	13.3	200.0	57.3	48.8	1.9
Cornelia	Wright	243	20.6	9.4	1.1	2.1	65.7	18.5	24.4	2.1

*lakes not stocked with Channel Catfish

Table 2. Channel Catfish stocking rate (number of fish per acre) and mean total length (in) of stocked fish (denoted in parentheses) at thirteen natural lakes in Iowa from 2010-2022.

Lake	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Black Hawk	5.3(8.9)	0	0	7.0(9.0)	6.3(7.6)	0	6.3(9.5)	0	6.3(8.5)	0	6.7(9.4)	0	0
Center	0	0	7.4(8.7)	0	0	0	7.2(9.1)	0	0	0	0	0	0
Clear	2.4(9.1)	0	1.9(8.5)	0	2.6(8.0)	0	2.0(9.1)	0	2.7(8.5)	0	3.2(8.3)	0	3.3(9.1)
Crystal	4.8(9.2)	0	6.0(8.5)	0	6.2(8.0)	8.7(8.0)	6.0(9.3)	0	6.0(8.4)	0	6.3(8.0)	0	9.9(8.6)
East Okoboji	2.4(9.5)	0	0	0	2.4(8.0)	0	0	0	0.5(8.3)	0	0.5(8.1)	0	0.5(8.6)
Five Island	4.7(9.5)	0	0	0	0	0	5.9(9.1)	0	0	0	0	0	0
Ingham	0	0	6.3(8.8)	0	0	0	6.1(9.1)	0	6.3(8.7)	0	6.0(8.1)	0	4.2(8.6)
Lake Cornelia	0	20.4(7.3)	0	0	9.9(7.9)	0	9.9(9.5)	0	9.9(8.4)	0	9.9(8.0)	0	9.9(9.4)
Little Spirit	0	0	0	0	0	0	0	0	0	0	0	0	0
Little Wall	5.0(9.4)	0	6.3(8.6)	0	6.2(7.8)	0	10.0(8.9)	0	10.0(8.5)	0	10.0(8.1)	0	10.1(9.4)
Lost Island	0	0	3.3(8.4)	0	0	0	3.0(9.1)	0	1.2(8.3)	0	0	0	0
North Twin	4.8(8.9)	0	3.0(8.6)	0	3.0(7.6)	0	0	0	5.0(8.2)	0	5.0(8.3)	0	5.0(9.1)
Storm	2.3(8.9)	0	2.9(8.3)	0	1.0(7.5)	0	1.0(9.0)	0	1.0(8.2)	0	1.0(8.0)	0	1.0(9.3)

Table 3. Total length (TL; in) and weight (wt; lb) statistics and associated length-weight linear relationship of Channel Catfish sampled in sixteen natural lakes during summer hoop netting investigations between 2014 and 2022.

Lake	n	Length-Weight Statistics				Length-Weight Relationship		P-value	r^2
		Range TL	Mean TL	Range wt	Mean wt	Intercept	Slope		
Black Hawk	187	6.8-27.6	15.8	0.08-8.86	1.8	-3.9460	3.4094	0.0001	0.9893
Center	429	8.3-30.0	17.9	0.18-12.11	2.8	-3.7730	3.2504	0.0001	0.9886
Clear	623	8.3-29.0	19.5	0.17-9.50	3.1	-3.7560	3.2255	0.0001	0.9830
Crystal	34	10.4-25.3	14.3	0.47-6.75	1.4	-3.6745	3.2000	0.0001	0.9859
East Okoboji	161	11.6-34.4	23.0	0.46-19.55	5.4	-4.1597	3.5333	0.0001	0.9768
Five Island	320	8.2-26.7	16.6	0.18-6.34	1.6	-3.6883	3.1119	0.0001	0.9832
Ingham	54	12.1-22.6	15.6	0.44-5.33	1.4	-4.1528	3.5622	0.0001	0.9715
Iowa (Osceola)	163	11.1-28.9	17.4	0.32-10.14	1.7	-4.1281	3.4473	0.0001	0.9882
Lake Cornelia	758	8.8-25.6	15.1	0.18-7.31	1.3	-3.8740	3.2953	0.0001	0.9823
Little Spirit	208	9.6-33.4	21.3	0.25-17.19	3.5	-3.8540	3.2708	0.0001	0.9813
Little Wall	1,993	8.2-26.4	14.8	0.15-6.27	1.1	-3.7816	3.1884	0.0001	0.9835
Lost Island	737	8.8-30.8	19.4	0.18-13.72	3.2	-3.9027	3.3561	0.0001	0.9835
North Twin	446	7.4-26.9	17.6	0.13-7.30	2.1	-3.8030	3.2407	0.0001	0.9882
Silver	423	8.8-35.6	19.4	0.20-17.64	3.0	-3.8670	3.3123	0.0001	0.9837
Storm	372	8.3-29.4	18.2	0.17-10.29	2.3	-3.7092	3.1636	0.0001	0.9831
Tuttle	381	9.8-28.1	17.9	0.25-7.96	2.0	-3.8131	3.2247	0.0001	0.9887

Table 4. Channel Catfish pooled proportional stock density (PSD), PSD-preferred (PSD-P), PSD-memorable (PSD-M), and PSD-trophy (PSD-T) for sixteen natural lake populations in Iowa collected via summer hoop netting investigations, 2014-2022. An asterisk indicates lakes where Channel Catfish sample sizes were <100 fish.

Lake	PSD	PSD-P	PSD-M	PSD-T
Black Hawk	40	2	0	0
Center	29	6	1	0
Clear	91	23	1	0
Crystal*	23	11	0	0
East Okoboji	97	24	9	0
Five Island	58	1	0	0
Ingham*	33	0	0	0
Iowa	43	3	0	0
Lake Cornelia	65	0	0	0
Little Spirit	96	9	3	0
Little Wall	38	1	0	0
Lost Island	70	19	2	0
North Twin	62	4	0	0
Silver	89	6	0	0
Storm	71	6	1	0
Tuttle	78	3	0	0

Table 5. Pooled (2014-2022) length frequency comparisons among fourteen natural lakes with stocked or wild (Iowa, Little Spirit and Tuttle lakes) Channel Catfish populations using P-values (upper half) and D statistic (bottom half) obtained from independent two-sample Kolmogorov-Smirnov tests are provided.

	Black Hawk	Center	Clear	East Okoboji	Five Island	Iowa	Lake Cornelia	Little Spirit	Little Wall	Lost Island	North Twin	Silver	Storm	Tuttle
Black Hawk	*	<0.0001	<0.0001	<0.0001	<0.0001	0.1989	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Center	0.698	*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Clear	0.694	0.759	*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
East Okoboji	0.651	0.775	0.485	*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Five Island	0.197	0.591	0.728	0.600	*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Iowa	0.103	0.749	0.643	0.592	0.202	*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Lake Cornelia	0.252	0.614	0.736	0.528	0.130	0.213	*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Little Spirit	0.634	0.753	0.265	0.425	0.675	0.613	0.692	*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Little Wall	0.315	0.386	0.779	0.732	0.310	0.367	0.323	0.756	*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Lost Island	0.321	0.695	0.520	0.485	0.295	0.292	0.302	0.508	0.378	*	<0.0001	<0.0001	<0.0001	<0.0001
North Twin	0.281	0.498	0.461	0.395	0.295	0.285	0.308	0.394	0.384	0.258	*	<0.0001	<0.0001	<0.0001
Silver	0.514	0.680	0.500	0.189	0.443	0.463	0.406	0.387	0.585	0.324	0.298	*	<0.0001	<0.0001
Storm	0.327	0.648	0.629	0.336	0.280	0.283	0.216	0.557	0.404	0.200	0.209	0.241	*	<0.0001
Tuttle	0.426	0.670	0.519	0.249	0.388	0.361	0.379	0.382	0.523	0.298	0.231	0.125	0.236	*

Table 6. Mean relative weight (*Wr*) for five Channel Catfish size categories (substock [SS]; stock-quality [S-Q]; quality-preferred [Q-P]; preferred-memorable [P-M]; memorable-trophy [M-T]; sample sizes provided in parentheses) collected via summer hoop netting surveys from sixteen natural lakes in Iowa between 2014-2022. Differences (P ≤0.05) between lakes and size categories are denoted by differences in letters (no letter is provided for those with inadequate sample sizes for comparisons).

Lake	SS	S-Q	Q-P	P-M	M-T
Black Hawk	101(33)^{ab}	100(68)^{bc}	111(82)^{a}	106(4)	
Center	106(39)^{a}	96(60)^{cde}	95(121)^{cd}	102(38)^{ab}	96(4)
Clear		98(30)^{bcd}	97(237)^{c}	97(77)^{bc}	92(3)
Crystal	142(1)	112(27)^{a}	108(3)	109(3)	
East Okoboji		96(11)^{cde}	94(77)^{cd}	106(45)^{a}	103(28)^{ab}
Five Island	91(26)^{cd}	88(48)^{fg}	77(75)^{i}	83(4)	
Ingham		98(36)^{bcd}	103(18)^{b}		
Iowa		76(88)^{h}	78(68)^{hi}	92(6)	105(1)
Lake Cornelia	99(23)^{ab}	98(171)^{bcd}	92(321)^{de}	113(1)	
Little Spirit	103(4)	91(11)^{efg}	87(167)^{cd}	90(16)^{b}	96(10)
Little Wall	88(312)^{d}	84(893)^{g}	82(574)^{gh}	87(14)^{d}	
Lost Island	99(5)	100(104)^{bc}	102(138)^{ab}	103(65)^{a}	107(13)^{bc}
North Twin	97(33)	92(139)^{def}	92(245)^{de}	88(29)^{cd}	
Silver	89(5)	104(29)^{b}	103(103)^{b}	103(28)^{ab}	103(2)
Storm Lake	100(24)^{ab}	96(91)^{cde}	88(221)^{e}	92(33)^{cd}	96(3)
Tuttle	97(10)^{bc}	87(128)^{fg}	83(214)^{fg}	89(28)^{cd}	90(1)

Table 7. Mean back-calculated total length (TL) at-age for Channel Catfish collected from ten natural lakes in Iowa using pectoral spine sections (basal), 2014-2022. Interquartile range for Channel Catfish from natural lakes is also provided (Meerbeek 2022). Significant differences in mean TL at age-4 are denoted by letters (P ≤0.05).

Lake	Mean Back-Calculated Length													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Black Hawk														
Center	6.1	9.5	12.4	15.2^{b}	17.0	18.5	19.2	21.2	22.9	23.8				
Clear														
Crystal														
East Okoboji	4.4	9.0	13.4	16.6^{a}	19.0	21.2	23.2	24.9	26.9	29.4	32.3	34.4		
Five Island	6.0	9.2	11.8	13.9^{cd}	15.4	17.1	18.6	19.7	20.6	21.6	22.5			
Ingham														
Iowa	3.9	6.4	8.8	10.8^{f}	12.6	14.4	16.8	19.3	21.4	24.6	25.7			
Lake Cornelia	4.7	7.4	11.0	13.3^{d}	15.0	16.0	16.8	17.7	18.5	19.2	19.6	20.0	20.0	21.0
Little Spirit														
Little Wall	3.9	7.6	9.9	12.3^{e}	14.6	16.8	17.9	18.6	19.8	19.8	20.9	22.3	23.9	25.0
Lost Island	5.6	9.4	13.4	16.3^{a}	18.7	20.7	21.3	23.2	25.1	26.0	26.7	27.2	24.2	
North Twin	4.8	8.6	11.5	13.6^{d}	15.6	17.8	19.8	21.2	22.2	22.2	22.7	23.4		
Silver														
Storm	4.2	8.1	11.4	14.7^{bc}	16.5	18.4	20.6	22.3	23.9	25.2				
Tuttle	4.2	7.3	10.5	13.2^{d}	15.8	18.1	20.3	22.0	23.6	25.2	25.2	26.7	28.1	
25th percentile	3.3	6.5	10.4	13.0	14.4	16.5	17.9	19.5						
75th percentile	4.7	8.4	12.9	16.0	18.2	20.3	21.8	23.4						

Table 8. Number (n) of Channel Catfish aged, age range, and von Bertalanffy growth parameters (L∞ = Length infinity; k = growth coefficient; To = theoretical age when length is 0) based on mean back-calculated total length at age with the associated instantaneous natural (M) and the conditional natural (cm) mortality rates of ten natural lakes in Iowa. An asterisks indicates where length infinity was set to a lake specific parameter.

Lake	n	Age range	von Bertalanffy growth parameters			Mortality	
			L∞	k	To	M	cm
Black Hawk							
Center	159	1-10	29.4	0.151	-0.581	0.23	0.21
Clear							
Crystal							
East Okoboji*	98	1-12	36.0	0.170	0.334	0.25	0.22
Five Island	139	1-11	26.8	0.152	-0.705	0.23	0.21
Ingham							
Iowa*	110	1-11	30.0	0.139	0.391	0.23	0.21
Lake Cornelia	105	1-14	21.3	0.231	-0.041	0.29	0.25
Little Spirit							
Little Wall	125	1-14	27.9	0.137	-0.221	0.23	0.20
Lost Island	25	1-12	30.7	0.180	-0.117	0.25	0.22
North Twin	284	1-12	26.4	0.187	-0.043	0.26	0.23
Silver							
Storm	34	1-10	33.6	0.136	-0.007	0.23	0.20
Tuttle	309	1-13	35.4	0.120	0.007	0.22	0.19

Table 9. Comparison of Channel Catfish von Bertalanffy growth coefficient (K) among ten natural lake populations sampled in Iowa between 2014 and 2022.

	Center	East Okoboji	Five Island	Iowa	Lake Cornelia	Little Wall	Lost Island	North Twin	Storm	Tuttle
Center	-	0.1727	0.2524	<0.001	0.0045	0.3648	0.6560	0.1431	0.1376	<0.001
East Okoboji	0.1727	-	0.9345	<0.001	<0.001	0.6564	0.0612	0.9899	0.5901	<0.001
Five Island	0.2524	0.9345	-	<0.001	<0.001	0.7600	0.1089	0.9210	0.5824	<0.001
Iowa	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	0.0010
Lake Cornelia	0.0045	<0.001	<0.001	<0.001	-	<0.001	0.0186	<0.001	<0.001	<0.001
Little Wall	0.3648	0.6564	0.7600	<0.001	<0.001	-	0.1662	0.6180	0.4160	<0.001
Lost Island	0.6560	0.0612	0.1089	<0.001	0.0186	0.1662	-	0.0453	0.0612	<0.001
North Twin	0.1431	0.9899	0.9210	<0.001	<0.001	0.6180	0.0453	-	0.5769	<0.001
Storm	0.1376	0.5901	0.5824	<0.001	<0.001	0.4160	0.0612	0.5769	-	0.0008
Tuttle	<0.001	<0.001	<0.001	0.0010	<0.001	<0.001	<0.001	<0.001	0.0008	-

Table 10. Comparison of Channel Catfish von Bertalanffy length infinity (L∞) among ten populations sampled in Iowa between 2014 and 2022.

	Center	East Okoboji	Five Island	Iowa	Lake Cornelia	Little Wall	Lost Island	North Twin	Storm	Tuttle
Center	-	<0.001	0.6837	<0.001	<0.001	0.3920	0.0392	0.1639	0.0250	<0.001
East Okoboji	<0.001	-	<0.001	0.0007	<0.001	<0.001	0.0001	<0.001	0.1585	0.0024
Five Island	0.6837	<0.001	-	<0.001	<0.001	0.6546	0.0119	0.0538	0.0121	<0.001
Iowa	<0.001	0.0007	<0.001	-	<0.001	<0.001	<0.001	<0.001	0.0002	0.0869
Lake Cornelia	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001
Little Wall	0.3920	<0.001	0.6546	<0.001	<0.001	-	0.0025	0.0110	0.0051	<0.001
Lost Island	0.0392	0.0001	0.0119	<0.001	<0.001	0.0025	-	0.2697	0.3258	<0.001
North Twin	0.1639	<0.001	0.0538	<0.001	<0.001	0.0110	0.2697	-	0.1022	<0.001
Storm	0.0250	0.1585	0.0121	0.0002	<0.001	0.0051	0.3258	0.1022	-	0.0004
Tuttle	<0.001	0.0024	<0.001	0.0869	<0.001	<0.001	<0.001	<0.001	0.0004	-

Table 11. Probability that aged Channel Catfish were of stocking origin at ten natural lakes using age-1 back-calculated lengths from pectoral fin sections and the logistic regression models developed via fall stocked and wild caught total lengths. Lakes where no stocking occurred (Iowa and Tuttle), and lakes where either low (Center, East Okoboji, Five Island, Lost Island, Storm) or high (Lake Cornelia, Little Wall, North Twin) stocking rates are provided.

Stocked origin probability	No Stocking		Low Stocking Rate					High Stocking Rate		
	Iowa	Tuttle	Center	East Okoboji	Five Island	Lost Island	Storm	Lake Cornelia	Little Wall	North Twin
0-0.1	98	218	69	43	56	7	23	70	105	167
0.1-0.2	3	24	1	5		1	2		2	10
0.2-0.3		10			1		2	1	6	5
0.3-0.4	1	4	1		1		1	1	2	9
0.4-0.5	2	7	1	1			1	1		3
0.5-0.6		13		1		2	1		2	5
0.6-0.7	3	5		1		2	1			7
0.7-0.8		6	4	1						3
0.8-0.9		3		2	1	1	1	1		7
0.9-1		17	77	7	59	8	2	29	6	61

Table 12. Current stocking rate (number [N] per acre [ac] per year), observed natural recruitment patterns, size structure, condition, growth, density, and recommendations for stocking and managing Channel Catfish in Iowa's natural lakes.

Lake	Current Stock Rate (N/ac/year)	Natural Recruitment - Intensity	Size Structure	Condition	Growth	Density	Recommendations
Black Hawk	2.9	Yes - regular	Poor	Good	NA	Moderate	Discontinue stocking, monitor recruitment and population size and age structure
Center	1.1	Yes - infrequent	Poor	Moderate	Good	Moderate	Continue stocking at low stocking rates <1.0 fish/ac/year, evaluate angler preferences
Clear	1.4	Yes - low	Good	Moderate	NA	Low	Continue stocking at low stocking rates <1.0 fish/ac/year, evaluate angler preferences
Crystal	4.1	Unknown	NA	Good	NA	Low	Reduce stocking rates to ≤1.0 fish/acre/year; evaluate recruitment and size structure
East Okoboji	0.5	Yes - low	Good	Moderate	Good	Low	Continue stocking at low stocking rate
Five Island	0.8	Unknown	Moderate	Poor	Moderate	Moderate	Reduced rates to 0.5 fish/ac/year. Evaluate natural recruitment
Ingham	2.2	Yes - Unknown	NA	Moderate	NA	Low	Reduce rate to ≤1.0 fish/ac/year. Evaluate natural recruitment
Iowa		Yes - Unknown	Moderate	Poor	Poor	High	Monitor recruitment, population size and age structure
Lake Cornelia	5.4	Yes - infrequent	Moderate	Moderate	Moderate	High	Reduce stocking rates to ≤1.0 fish/acre/year, monitor population and angler preferences
Little Spirit		Yes - Unknown	Good	Poor	NA	Moderate	Monitor recruitment, population size and age structure
Little Wall	4.4	Unknown	Poor	Poor	Poor	High	Discontinue stocking, monitor natural recruitment annually, evaluate population in 5 years
Lost Island	0.6	Yes - decreasing	Good	Good	Good	Low	Continue stocking at current rate
North Twin	2.0	Yes - regular	Moderate	Moderate	Moderate	High	Reduce stocking rates to ≤1.0 fish/acre/year, monitor population and angler preferences
Silver	0.6	Yes - infrequent	Good	Good	NA	Low	Continue stocking at ≤1.0 fish/acre/year, monitor population and angler preferences
Storm	0.8	Yes - regular	Good	Moderate	Good	Low	Discontinue stocking, monitor recruitment and population size and age structure
Tuttle		Yes - regular	Good	Poor	Moderate	Moderate	Monitor recruitment, population size and age structure