

## MANAGEMENT BRIEF

# Limited Utility of Early Life-History Indices for Predicting Yellow Perch Year-Class Strength in Eastern South Dakota Glacial Lakes

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## Abstract

We used a long-term data set (2000–2016) of larval, age-0 (juvenile), and age-2 Yellow Perch *Perca flavescens* catches from nine glacial lakes in eastern South Dakota to track multiple cohorts through time to determine whether year-class strength (measured as gill-net CPUE of age-2 fish) could be indexed at the larval or juvenile stage. We observed a strong relationship between larval and juvenile abundance ( $r = 0.78$ ), but neither were related to abundance of the same cohort at age 2. Furthermore, categorical analyses suggested that some of the strongest age-2 year-classes corresponded with the lowest larval and juvenile catches and vice versa. Our assessment suggests that Yellow Perch year-class strength in eastern South Dakota glacial lakes may not be fixed until some point after the juvenile (i.e., fall age 0) stage and correspondingly that values for larval and juvenile CPUE are of

limited utility as early indices of year-class strength for Yellow Perch. Before using abundance estimates at early life stages as measures of recruitment, researchers and managers should confirm that these estimates provide a meaningful index of abundance at adulthood or the point of recruitment to the fishery.

Recruitment is frequently identified as an important driver of adult fish population and fishery characteristics (Ricker 1975; Carline et al. 1984; Hansen and Nate 2014). In general, recruitment failure or inconsistent recruitment with several consecutive weak or missing year-classes can lead to reduced adult abundance and subsequent lower

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angler catch rates (Mitzner 1991; Wilberg et al. 2005; Hansen et al. 2018). Alternatively, barring density-dependent growth limitations and (or) mortality, more consistent recruitment with moderate or strong year-classes can provide balanced size and age structure, an abundance of catchable-size fish, and higher angling success (Mitzner 1991; Ney 1999; Maceina and Pereira 2007). Thus, forecasting recruitment of individual year-classes into the fishery is of fundamental importance to fishery managers (Curtis et al. 1993; Shroyer and McComish 1998).

The prevailing paradigm for many fishes is that year-class strength is fixed early in life (i.e., during the egg, larval, or juvenile stages; Hjort 1914; Ricker 1975; Houde 1989). Therefore, abundance of fishes at various early life stages is often used as a measure of recruitment (e.g., Sammons and Bettoli 1998; Allen et al. 1999; Hansen et al. 2015). If year-class strength is fixed early in life and can be indexed prior to a cohort entering the fishery, fishery managers would be better able to respond to weak or missing year-classes by adjusting actions needed to achieve management objectives or to manage angler expectations. For example, contributions of Lake Whitefish *Coregonus clupeaformis* to the commercial fishery in Lake Superior were accurately indexed by using yearling catch per unit effort (CPUE) estimates 5 years before recruitment to the fishery, leaving management agencies sufficient time to adjust harvest levels to meet management objectives (Curtis et al. 1993). Similarly, Sammons and Bettoli (1998) found that larval sampling could allow early detection of weak crappie *Pomoxis* spp. and White Bass *Morone chrysops* year-classes in a Tennessee River impoundment and allow biologists sufficient time to take appropriate management actions prior to weak cohorts reaching the fishery. Although the relationship between early life stage abundance and year-class strength has been documented for some species (Sammons and Bettoli 1998), the abundance of early life stages may not always be indicative of eventual year-class strength. In Oneida Lake, New York, Walleye *Stizostedion vitreum* year-class strength was unrelated to larval and fall age-0 CPUE (Forney 1976), and Newburg and Schupp (1986) found no relationship between CPUE for late-summer age-0 Largemouth Bass *Micropterus salmoides* and abundance of the same cohort at ages 2 and 3 in a central Minnesota lake. Thus, the assumption that year-class strength is fixed early in life may not always be met, and species- and life-stage-specific assessments are needed to determine whether early life stage abundance estimates can provide a meaningful index of eventual year-class strength.

An early index of year-class strength would be especially useful for the management of fishes such as Yellow Perch *Perca flavescens*, which typically exhibit erratic

recruitment that often translates to an inconsistent and unpredictable fishery (e.g., Wilberg et al. 2005; Isermann et al. 2007; Rudstam et al. 2016; VanDeValk et al. 2016). Many studies have documented Yellow Perch recruitment patterns (e.g., Forney 1971; Sanderson et al. 1999; Isermann and Willis 2008), but little is known about when year-class strength can be indexed. Forney (1971) found significant relationships between CPUE for summer age-0 Yellow Perch and subsequent age-1 CPUE in Oneida Lake, New York. Similarly, Bogner et al. (2016) reported that fall age-0 CPUE for Yellow Perch was significantly related to CPUE of the same cohort at ages 1 and 2 in a Nebraska Sandhills lake. In South Dakota glacial lakes, Fisher and Willis (1997), Anderson et al. (1998), and Isermann (2003) reported significant relationships between larval Yellow Perch density and subsequent late-summer juvenile (i.e., age-0) CPUE, but whether larval catch rates could index year-class strength at older ages was not evaluated due to limited data pairings. However, continued sampling (spanning years 2000–2016) has offered the unique opportunity to track multiple cohorts through time to more fully evaluate the utility of early life stages of Yellow Perch to index year-class strength at the point of recruitment to the fishery (i.e., when they have recruited to gill-net capture at age 2). Specifically, our objective was to determine whether year-class strength (measured as gill-net CPUE of age-2 fish) could be indexed for Yellow Perch at the larval or juvenile (late-summer age-0) stage across nine glacial lakes in eastern South Dakota. Furthermore, the addition of lake-year observations to the initial data sets that were used by Anderson et al. (1998) and Isermann (2003) allowed us to reevaluate the relationships between larval and age-0 CPUE.

## METHODS

We addressed our objectives using data that were collected from 2000 to 2016 for larval, postlarval age-0, and adult Yellow Perch as part of multiple complementary research projects that examined the early life history and population dynamics of Yellow Perch in nine glacial lakes in eastern South Dakota (Isermann 2003; Ward et al. 2004; Isermann et al. 2007; Isermann and Willis 2008; Jansen 2008; Dembkowski et al. 2012, 2015, 2016; Dembkowski 2014). The lakes varied in morphometric and physiochemical characteristics, but they were generally shallow and productive systems that are typical of natural lakes in the Prairie Pothole Region of the Northern Great Plains (Table 1). Panfish, especially Yellow Perch, are important components of the recreational fishery in each lake (South Dakota Department of Game, Fish and Parks [SDGFP] creel and lake survey reports: <https://gfp.sd.gov/fish/>; accessed November 2020).

TABLE 1. Morphometric and trophic descriptors of nine lakes in eastern South Dakota where larval, postlarval age-0 (juvenile), and age-2 Yellow Perch were collected during 2000–2016. Trophic status was based on Carlson's (1977) trophic status index. The data are summarized from Stueven and Stewart (1996) and Stukel (2003). SDI = shoreline development index.

Lake	Surface area (ha)	Maximum depth (m)	SDI	Trophic status
Brant	420	4.3	2.1	Mesotrophic
Clear	473	6.1	2.7	Mesotrophic
Cochrane	148	7.3	2.4	Mesotrophic
East 81	189	4.9	2.1	Eutrophic
Enemy Swim	877	7.9	3.4	Mesotrophic
Madison	1,094	4.9	3.4	Eutrophic
Pickrel	400	12.5	3.7	Mesotrophic
Sinai	720	10.1	6.7	Eutrophic
Waubay	6,857	10.7	5.9	Eutrophic

Larval Yellow Perch were sampled each year during 2000–2014, beginning in early May (depending on ice-out conditions and water temperatures) and continuing through mid-June at 6–12 d intervals; not all lakes were sampled during each year (Table 2). The collection gear consisted of an ichthyoplankton surface trawl with a 0.75-m (diameter) mouth, a 1.5-m conical mesh trawl with 1,000- $\mu$ m mesh (bar measure), a plastic collection jar with matching mesh, and a mouth-mounted flowmeter (General Oceanics Model 2030R, Miami, Florida). The number of trawl sites per lake varied from three to nine from 2000 to 2003 depending on the specific research objective (see Isermann 2003; Ward et al. 2004), but the number of trawl sites was standardized to three per lake beginning in 2004. Each trawl site consisted of a nearshore and

offshore sample where the trawl was towed in a circular pattern behind the boat in the upper 1 m of the water column for 3–5 min at a speed of 1–2 m/s (Isermann et al. 2002). The centroids of the circular tow patterns were approximately 50 and 150 m from shore for nearshore and offshore samples, respectively. The trawl samples were preserved in 70% ethanol, and the fish were identified to family; percids were further identified to species using the meristic and morphometric characteristics outlined in Auer (1982) and Holland-Bartels et al. (1990). Lake-, year-, and date-specific densities for larval Yellow Perch were calculated as the mean number of larvae collected per 100 m<sup>3</sup>. Annual density for larval Yellow Perch was indexed as the peak mean larval density for each lake.

Postlarval age-0 (hereafter, referred to as “juvenile”) Yellow Perch were collected during 2000–2002 from six of the nine study lakes in early to mid-August using beach seines (Table 2). Seine data are not available for later years in the time series because beach seines are not part of standard sampling that is conducted by SDGFP; the seine samples compiled for our analysis were collected to address specific research objectives that were associated with different studies (see Isermann 2003; Ward et al. 2004). The seine dimensions were 15.2  $\times$  1.8 m with 6.4-mm bar mesh, and the number of lake-specific sample sites varied by study and lake size and ranged from 12 to 20 (see Isermann 2003; Ward et al. 2004). The sagittal otoliths were removed from subsamples of Yellow Perch <120 mm total length (TL) to confirm ages. In the beach seines, CPUE for juvenile Yellow Perch was expressed as the mean number of juvenile Yellow Perch per seine haul.

Adult Yellow Perch were collected during 2002–2016 using overnight gill nets that were set during late summer;

TABLE 2. Years of data collection and associated mean and range of abundance estimates for larval, postlarval age-0 (juvenile), and age-2 Yellow Perch from nine glacial lakes in eastern South Dakota. The blanks indicate that sampling did not occur for given life stages in individual lakes.

Lake	Larval (fish/100 m <sup>3</sup> )		Juvenile (fish/seine haul)		Age-2 (fish/gill-net-night)	
	Years	Mean (range)	Years	Mean (range)	Years	Mean (range)
Brant	2001–2008	1.6 (0–6.3)			2003–2010	8.2 (0.5–41.0)
Clear	2011–2013	520.4 (8.0–1891.2)			2013–2015	8.7 (0.2–16.8)
Cochrane	2005–2006	52.4 (19.9–84.9)			2008	19.3
East 81	2000–2003; 2014	32.8 (0.1–82.9)	2000–2002	32.8 (1.5–65.3)	2002; 2004	59.1 (31.5–86.6)
Enemy Swim	2000–2014	152.1 (2.2–633.6)	2000–2002	4.9 (1.0–11.0)	2002–2016	38.1 (0.2–252.8)
Madison	2000–2014	2.0 (0–9.3)	2000–2002	9.1 (0.1–21.3)	2002–2016	39.6 (0–195.3)
Pickrel	2000–2014	86.0 (5.3–193.2)	2000–2002	25.8 (12.0–51.0)	2002–2016	8.6 (0.1–26.5)
Sinai	2000–2014	212.3 (0.1–3097.0)	2000–2002	341.3 (2.3–1019.2)	2002–2016	17.9 (0–63.0)
Waubay	2000–2014	19.1 (0–224.4)	2000–2002	75.5 (0.1–225.5)	2002–2016	4.6 (0.1–16.4)
All lakes combined	2000–2014	98.4 (0–3097.0)	2000–2002	73.1 (0.1–1019.2)	2002–2016	20.7 (0–252.8)

the lake-specific sample dates were consistent throughout the time series. During each annual gill-net sampling period, total lengths were recorded for all Yellow Perch and sagittal otoliths were removed from a maximum of 10 fish in each 25-mm length bin for age estimation. Ages were applied to entire samples using lake- and year-specific age-length keys (Ricker 1975; Isermann and Knight 2005). Previous studies (e.g., Isermann 2003; Isermann et al. 2007), in combination with the preliminary analyses conducted herein, suggest that Yellow Perch in most glacial lakes in eastern South Dakota recruit to gill-net capture at age 2. Furthermore, the Yellow Perch in our study lakes enter the fishery at approximately 140 mm TL (Isermann 2003) and length-at-capture data suggest that age-2 fish typically exceed this benchmark (SDGFP lake survey reports: <https://gfp.sd.gov/fish/>; accessed December 2021). Thus, we used mean catch per gill-net-night of age-2 Yellow Perch as a meaningful measure of year-class strength when the fish have entered the fishery and recruited to gill-net capture. The number of gill nets that was set per lake ranged from five to eight; more nets were allocated to the lakes with larger surface areas. During 2002–2015, the gill nets measured  $45.7 \times 1.8$  m, with six fixed-order panels of 13-, 19-, 25-, 32-, 38-, and 51-mm monofilament mesh (bar measure). During 2016, the gill-net dimensions were modified to align with American Fisheries Society (AFS) standard net specifications ( $24.4 \times 1.8$  m, with eight randomly ordered panels of 19-, 25-, 32-, 38-, 44-, 51-, 57-, and 64-mm monofilament mesh; Bonar et al. 2009). The gill-net CPUE values for Yellow Perch from 2016 were converted using the equation provided in Smith (2015) to make them comparable to those from the net dimensions that were used during 2002–2015.

We used Pearson correlations to determine whether year-class strength (measured as gill-net CPUE of age-2 Yellow Perch) could be indexed at earlier life stages. Specifically, we examined the relationships between age-2 CPUE and metrics representing abundance at two early life stages: peak larval density and juvenile CPUE. We also used Pearson correlations to examine the relationships between CPUE for juvenile Yellow Perch and peak larval density. The data pairings for all of the correlations were structured to be cohort specific. For example, CPUE for age-2 Yellow Perch that were sampled in 2015 was paired with the values for peak larval density and juvenile CPUE of that same cohort in 2013. Preliminary analyses evaluating potential lake-specific relationships between peak mean larval density and CPUE for age-2 Yellow Perch at a subset of lakes with available data ( $N \geq 10$  paired observations; Enemy Swim, Madison, Pickerel, Sinai, and Waubay lakes) suggested that the relationship between successive life stages was consistent among the lakes; thus, observations were pooled across lakes for subsequent analyses. Diagnostic testing with the Shapiro–Wilk test

statistic suggested that the raw density and CPUE values were not normally distributed; thus, all data were  $\log_{10}$  transformed prior to analysis to meet normality assumptions.

We also used error matrices, a categorical approach (Congalton and Mead 1983; Beyan 2014; Boehm et al. 2020), to determine whether high or low larval or juvenile abundance could be useful in predicting whether age-2 CPUE was correspondingly high or low in Yellow Perch. The CPUE values for age-2 Yellow Perch were classified as high or low based on whether individual lake-year observations were above or below the median of the untransformed distribution of age-2 CPUE estimates that were included in our study. The values for abundance of larval and juvenile Yellow Perch were classified as high or low using two different approaches: (1) whether abundance was above or below the untransformed median of the distribution of larval density or juvenile CPUE estimates included in our study, and (2) whether abundance was within the upper or lower quartiles of the untransformed distribution of peak larval density or juvenile CPUE estimates included in our study. We used the first approach simply to determine whether there was any categorical relationship between abundance at larval and juvenile stages and year-class strength in Yellow Perch. The second approach was used to determine whether extreme estimates (i.e., very high or very low) of larval or juvenile abundance could be reflective of eventual year-class strength. When constructing the error matrices, true positives occurred when larval or juvenile abundance was high and corresponding age-2 abundance was high. False positives occurred when larval or juvenile abundance was high and corresponding age-2 abundance was low. True negatives occurred when larval or juvenile abundance was low and corresponding age-2 abundance was low. False negatives occurred when larval or juvenile abundance was low and corresponding age-2 abundance was high. Accuracy (i.e., the ability of categorized early life stage abundance to correctly predict corresponding categorized year-class strength) was calculated as the ratio of true positives and true negatives to the total number of observations for a specific life stage (Congalton and Mead 1983). All of the analyses were conducted using SAS (SAS Institute 2010), and decision probability was set at  $\alpha = 0.05$ .

## RESULTS

We obtained 96 lake-year observations of peak larval density estimates for Yellow Perch that were collected from nine lakes during 2000–2014, 22 lake-year observations of juvenile Yellow Perch CPUE that were collected from six lakes during 2000–2002, and 89 lake-year observations of age-2 Yellow Perch CPUE that were collected from nine lakes during 2002–2016 (Table 2). Among lakes

and years, the peak larval density estimates for Yellow Perch ranged from 0 to 3,097 larvae/100 m<sup>3</sup> (mean = 98.4 larvae/100 m<sup>3</sup>, SD = 375.3), juvenile CPUE for Yellow Perch ranged from 0.1 to 1,019.2 fish/seine haul (mean = 73.1 fish/seine haul, SD = 216.7), and age-2 CPUE for Yellow Perch ranged from 0 to 252.8 fish/gill-net-night (mean = 20.7 fish/gill-net-night, SD = 40.7; Table 2). Collectively, 89 paired lake-year observations were available to examine the relationship between age-2 CPUE and peak larval density in Yellow Perch, 17 pairs to examine the relationship between age-2 CPUE and juvenile CPUE, and 22 pairs to examine the relationship between juvenile CPUE and peak larval density. The log-transformed values for larval and juvenile CPUE were not correlated with the corresponding log-transformed values for age-2 CPUE in Yellow Perch ( $P > 0.05$ ; Figure 1). However, the log-transformed value for larval CPUE was significantly and positively related to the log-transformed

value for juvenile CPUE measured in the same year ( $r = 0.78$ ,  $P < 0.01$ ; Figure 1).

The abundance estimates for larval and juvenile Yellow Perch, categorized as high or low based on median values (5.7/100 m<sup>3</sup> for larvae and 12.5/seine haul for juvenile perch), were only 52% and 55% accurate, respectively, in correctly predicting whether corresponding age-2 CPUE was above or below the median of the distribution of lake-year observations for age-2 CPUE estimates (6.8/gill-net-night; Table 3). Similarly, the values for larval and juvenile abundance that were categorized based on the upper (61.8/100 m<sup>3</sup> for larvae and 33.4/seine haul for juvenile Yellow Perch) and lower (0.7/100 m<sup>3</sup> for larvae and 2.3/seine haul for juvenile Yellow Perch) quartiles were only 58% and 50% accurate, respectively, in correctly predicting whether age-2 CPUE was correspondingly high or low (Table 3). The prediction errors were balanced nearly equally between false positives (high early-life-stage

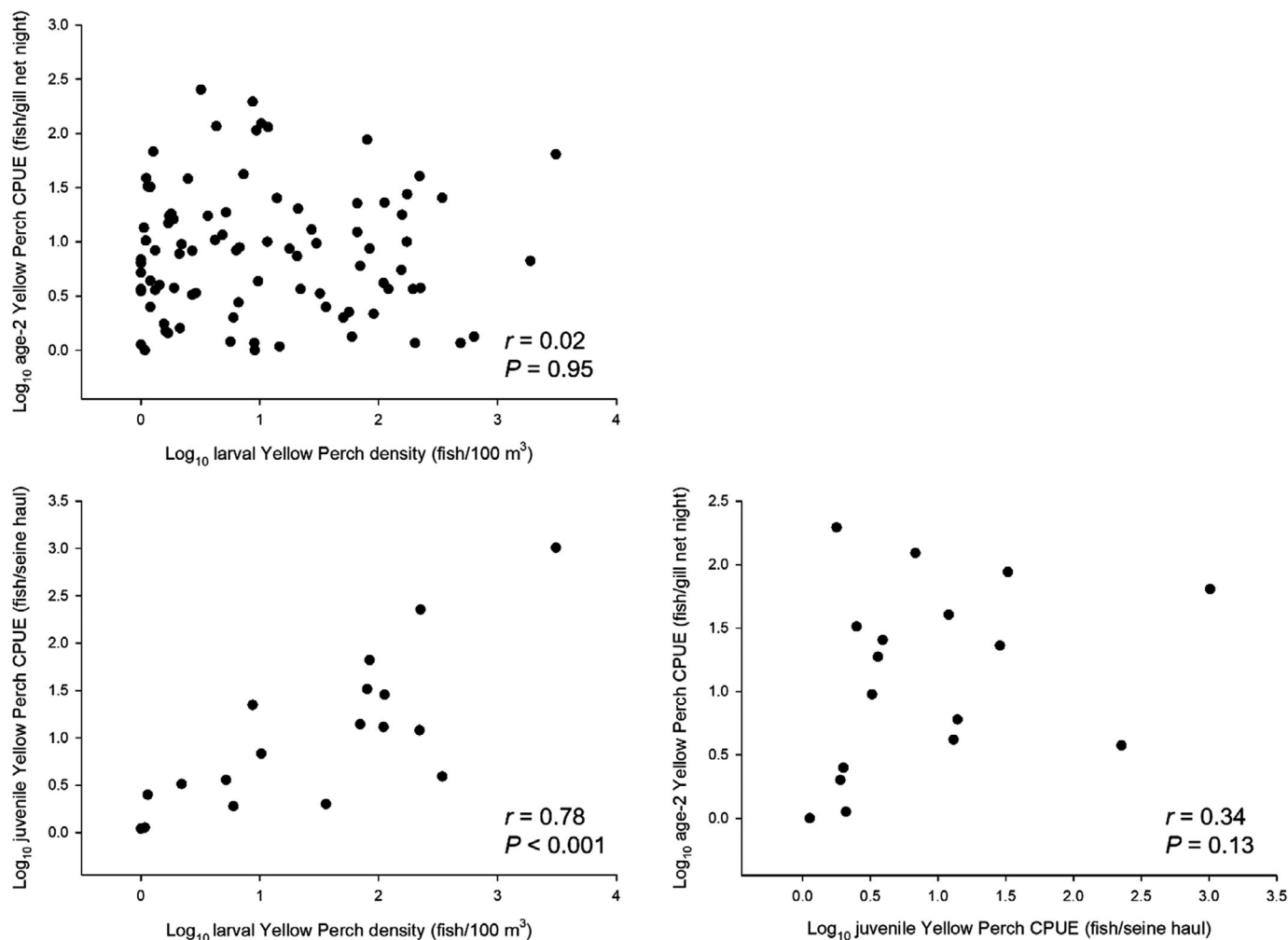


FIGURE 1. Cohort-specific relationships for abundance of Yellow Perch measured at the larval stage, postlarval age 0 (juvenile), and age 2.

TABLE 3. Error matrices demonstrating whether high or low larval or postlarval age-0 (juvenile) abundance for Yellow Perch in ichthyoplankton trawls and beach seines, respectively, could correctly predict whether corresponding age-2 CPUE for Yellow Perch in gill nets was high ( $\geq$ median) or low ( $<$ median). The median CPUE for age-2 Yellow Perch (6.8/gill-net-night) was based on the distribution of 89 lake-year observations among nine glacial lakes in eastern South Dakota during 2000–2016. Abundance for larval and juvenile Yellow Perch was classified as high or low using two different approaches: (1) whether abundance was above or below the median larval Yellow Perch density or juvenile Yellow Perch CPUE, and (2) whether abundance was within the upper or lower quartiles of the distribution of larval Yellow Perch density or juvenile Yellow Perch CPUE.

Life stage	Categorized abundance	N	True positive	False positive	True negative	False negative	Accuracy (%)
<b>Median</b>							
Larval	High ( $\geq 5.7/100 \text{ m}^3$ )	44	23	21			
Larval	Low ( $< 5.7/100 \text{ m}^3$ )	45			23	22	52
Juvenile	High ( $\geq 12.5/\text{seine haul}$ )	10	5	5			
Juvenile	Low ( $< 12.5/\text{seine haul}$ )	12			5	7	55
<b>Upper/lower quartiles</b>							
Larval	High ( $\geq 61.8/100 \text{ m}^3$ )	22	11	11			
Larval	Low ( $\leq 0.7/100 \text{ m}^3$ )	23			15	8	58
Juvenile	High ( $\geq 33.4/\text{seine haul}$ )	6	2	4			
Juvenile	Low ( $\leq 2.3/\text{seine haul}$ )	6			4	2	50

abundance and low age-2 CPUE) and false negatives (low early-life-stage abundance and high age-2 CPUE) for both categorical approaches (using the median and upper and lower quartiles) and early life stages (larval and juvenile Yellow Perch; Table 3).

## DISCUSSION

An effective early index of year-class strength would ideally occur at a life stage after the critical periods of high early natural mortality (e.g., the switch from endogenous to exogenous feeding; Hjort 1914; Houde 2008) have stabilized and before a cohort enters a fishery. We observed a strong relationship between larval and juvenile CPUE in Yellow Perch, yet neither were related to year-class strength (age-2 CPUE). In fact, some of the strongest age-2 year-classes corresponded with the lowest larval and juvenile catches and vice versa. Our results confirm findings that were reported by Fisher and Willis (1997), Anderson et al. (1998), and Isermann (2003) in that larval abundance was a strong indicator of late-summer age-0 abundance among Yellow Perch in eastern South Dakota glacial lakes. Additionally, the inability of either of these two early life stages to index year-class strength is consistent with observations of Nielsen (1980), who reported substantial changes in ranked abundance of Yellow Perch year-classes between ages 0 and 2 in Oneida Lake, New York. Furthermore, Rudstam et al. (2016) reported that larval and late-summer age-0 abundance estimates for Yellow Perch were unrelated to year-class strength (measured as age-3 CPUE) at Oneida Lake during 1957–2010. Collectively, these findings suggest that year-class strength may not be fixed (and thus cannot be accurately indexed) in Yellow Perch until some point after the fall age-0

period. However, the timing of when year-class strength is fixed may vary among systems and depend on local or regional factors (e.g., latitude), as Bogner et al. (2016) reported strong relationships between fall age-0 CPUE and CPUE of the same cohort at ages 1 and 2 in Yellow Perch in a Nebraska Sandhills lake but no relationship between larval abundance and abundance measured at later life stages.

The lack of relationships between larval and juvenile CPUE and year-class strength in Yellow Perch may be related to periods of high mortality between the juvenile stage and when we measured year-class strength at age 2. The first overwinter period is often considered a critical period of high mortality for juvenile fishes (Wootton 1998; Hurst 2007), especially at northern latitudes (Post and Evans 1989). Previous studies have reported overwinter mortality rates ranging from 44% to 99% for Yellow Perch (Nielsen 1980; Post and Evans 1989; Fitzgerald et al. 2006), and an evaluation of 40 consecutive age-0 Yellow Perch cohorts in Oneida Lake, New York, during 1962–2002, demonstrated that 25 of 40 cohorts experienced overwinter mortality rates  $>75\%$  (Fitzgerald et al. 2006). If there is substantial mortality of the age-0 cohort during the first overwinter period, year-class strength may not be fixed (and potentially cannot be indexed) until later in life. For example, Johnson et al. (1996) suggested that year-class strength of Walleyes stocked into Lake Mendota, Wisconsin, could not be indexed until age 1 because of the substantial mortality of stocked fingerlings during the first overwinter period. Later indices of year-class strength (e.g., measured after the first overwinter period) may still be useful in slower-growing and longer-lived populations where there may still be sufficient reactionary time between when year-class strength is measured and

the point of recruitment to the fishery. However, these indices may have limited utility in fast-growing or short-lived populations where fish may recruit to the fishery at a younger age because of reduced management agency response time.

Predation is an important factor in structuring some Yellow Perch populations (e.g., Forney 1971; Forney 1974) and has been previously implicated as a factor that influences when year-class strength can be indexed. Specifically, Nielsen (1980) suggested that predation of age-1 and age-2 Yellow Perch by Walleye was the primary factor influencing changes in ranked abundance of year-classes and that year-class strength was likely not fixed until after age-2 during 1962–1974 in Oneida Lake, New York. Predation of Yellow Perch ages 0–2 by predators including Smallmouth Bass *Micropterus dolomieu* and Northern Pike *Esox lucius* has also been documented and, in glacial lakes of South Dakota that are similar to those that were included in our study, age-0 Yellow Perch comprised 27–42% of Smallmouth Bass diets by weight (Bacula 2009; Dembkowski et al. 2015) and Yellow Perch of unspecified ages comprised 30% and 50% of Walleye and Northern Pike diets by weight, respectively (Blackwell et al. 1999). If predation results in substantial losses of Yellow Perch at multiple life stages before recruitment to the fishery, relationships between consecutive ages of individual cohorts may become obscured and year-class strength may not be fixed until after the fish exceed the gape limitations of predators (e.g., Nielsen 1980). In some instances, this may not occur until the fish have already entered the fishery, rendering early indices of year-class strength ineffective.

Differences in catchability or selectivity could also confound relationships between and among abundance measured at multiple life stages with multiple gears (in our case, larval trawls, beach seines, and gill nets). Evaluating the relationships between CPUE estimates at various life stages with various gears assumes that CPUE estimates are proportional to actual abundance (Quinn and Deriso 1999; Hubert and Fabrizio 2007). However, factors such as larval trawl fouling or clogging due to dense plankton populations (e.g., Anderson et al. 1998; Isermann et al. 2002), variable efficiency of seines due to littoral habitat complexity (e.g., Lyons 1986; Bayley and Herendeen 2000), or nonconstant gill-net catchability due to fish behavior or basin characteristics (e.g., Blackwell and Brown 2000) could affect the representativeness of abundance estimates at different life stages. Despite these potential issues, different gears are needed to target different fish life stages (Bonar et al. 2009) and evaluating relationships between and among abundance estimates that are obtained with different gears is common for these types of assessments (e.g., Forney 1971; Sammons and Bettoli 1998; Bogner et al. 2016). Furthermore, all of the

gears that were used herein represent standard gears for estimating abundance at each respective life stage (Bonar et al. 2009; Kelso et al. 2012). We assume that potential gear biases did not have an undue influence on our findings because the results of our categorical analysis, which was less reliant on numerical estimates of abundance, were consistent with those of our correlation analysis.

## MANAGEMENT IMPLICATIONS

Our assessment suggests that year-class strength among Yellow Perch in glacial lakes in eastern South Dakota may not be fixed until some point after the juvenile (i.e., fall age-0) stage and that CPUE values for larval and juvenile perch were not related to year-class strength measured as age-2 gill-net CPUE. Although not directly related to year-class strength, larval and juvenile abundance estimates may still be important predictors when they are combined with other biotic and abiotic variables that are known to influence year-class strength in Yellow Perch (reviewed by Koonce et al. 1977), as the number of individuals recruiting to an adult population depends in part on the number of prerecruits (Houde 1989). For example, Hansen et al. (2012) used fall age-0 CPUE as a predictor variable in combination with lake physiochemical variables in nonlinear models explaining variation in Walleye year-class strength (measured as age-4 CPUE) in northern Wisconsin lakes. Alternatively, managers may consider use of a size-based (rather than age-based) early index of year-class strength. For example, Shroyer and McComish (1998) demonstrated that CPUE of stock-size (>130 mm TL) Yellow Perch was strongly related to CPUE of quality-size (>200 mm TL) Yellow Perch 2 years later in the Indiana waters of Lake Michigan. Although a size-based index would not aid in determining when year-class strength is fixed, the ability to predict relative abundance of harvestable-size fish could still be valuable in terms of providing managers with time to take appropriate management action and anglers with realistic expectations of catch or harvest potential. Last, our findings challenge the assumption that year-class strength is fixed early in life (Hjort 1914; Houde 2008). Abundance estimates at early life stages are used extensively as measures of fish recruitment (e.g., Sammons and Bettoli 1998; Allen et al. 1999; Hansen et al. 2015). If making inferences from these estimates about dynamics of the adult population, researchers and managers should confirm whether they provide a meaningful indication of abundance at adulthood or the point of recruitment to the fishery.

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