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MANAGEMENT BRIEF

# Hydroacoustic Surveys Underestimate Yellow Perch Population Abundance: The Importance of Considering Habitat Use

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***Abstract***
**When estimating fish population abundance, it is important to recognize that differing habitat use may cause one gear type to be more effective and less biased than another. We generated and compared population abundance estimates (PE) for adult Yellow Perch *Perca flavescens* in Crystal Lake, Wisconsin using a spring mini-fyke net mark–recapture survey and summer hydroacoustic surveys. Mean PE from the spring mark–recapture survey was 11,051 adult Yellow Perch (95% confidence limits of 9,878 and 12,541). This mean was 4.0–8.5 times greater than the range of mean summer hydroacoustic estimates (mean ± 95% CI = 1,291 ± 312 and 2,912 ± 703). Due to Yellow Perch spawning behavior, we assumed that the spring mark–recapture survey sampled the entire adult population, while summer hydroacoustics sampled the postspawn pelagic component. Using the mean of all hydroacoustic surveys (PE = 2,492; *n* = 5), we estimated that approximately 22% of adult Yellow Perch selected for pelagic habitats postspawn. Our study emphasizes the importance of evaluating gear bias and has implications for future assessments, particularly when the target species may exhibit multiple habitat preferences within a lake.**

Fisheries management relies on accurate estimates of fish population abundance. The accuracy of a population abundance estimate (PE) is a function of how well and how consistently actual fish abundances are approximated. Sampling accuracy for a variety of methods can be affected by habitat complexity (Rodgers et al. 1992; Kruse et al. 1998; Mullner et al. 1998), habitat size (Bayley and Dowling 1993; Kruse et al. 1998; Peterson et al. 2004), fish species and size (Büttiker 1992; Bayley and Dowling 1993; Dolan and Miranda 2003), fish density (Kruse et al. 1998; Rosenberger and Dunham 2005), sampling effort (Riley and Fausch 1992; Riley et al. 1993; Peterson et al. 2004), and fish behavior (Kubečka et al. 2012; DuFour et al. 2018). All methods have potential error; thus, research testing for biases and limitations of specific gears is of high management relevance.

Hydroacoustic surveys are a commonly used method to provide pelagic fish abundance estimates used to inform management (Kubečka et al. 2009; Rudstam et al. 2009). Despite frequent and widespread use, hydroacoustic data

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can be subject to error and bias before, during, and after surveys. These factors have forced careful consideration before the use of this method and a push for widespread standardization (Dillon et al. 2019, 2020; DuFour et al. 2021). For example, survey design and echosounder settings are critical first considerations known to influence abundance estimates (Guillard and Verges 2007; Godlewska et al. 2011). During a survey, error can be incorporated into abundance estimates by including backscattered returns from nontarget organisms (e.g., pelagic macroinvertebrates; Dillon et al. 2020), fish movement in and out of insonified zones (Lawson and Rose 1999; Neilson et al. 2003; DuFour et al. 2018), and vessel avoidance (Wheeland and Rose 2015; DuFour et al. 2017, 2018). After a survey, post hoc processing and analysis may introduce error depending on analytical decisions being made (e.g., target strength threshold, pulse length determination level, minimum and maximum normalized pulse lengths, maximum beam compensation, and angles of minor and major axes; Parker-Stetter et al. 2009; Rudstam et al. 2009; Dillon et al. 2019). Though a common and powerful tool for estimating pelagic fish abundance, hydroacoustic surveys are not immune to error and bias—as with all sampling methods.

Yellow Perch *Perca flavescens* support economically important, harvest-oriented recreational fisheries across North America (Gaeta et al. 2013). Adult Yellow Perch can occupy either the littoral or pelagic zones of north-temperate lakes (Krieger et al. 1983; Whiteside et al. 1985; Radabaugh et al. 2010), which may complicate accurate stock assessment. Systems with abundant littoral habitat and prey are known to support robust populations of this popular sport fish (Fish and Savitz 1983; Lyons 1987; Fullhart et al. 2002). Nevertheless, Yellow Perch are often captured in high numbers during vertical gill-net surveys (Kraft and Johnson 1992; Madenjian and Ryan 2011; Yu et al. 2011; Doll et al. 2014), indicating strong pelagic habitat use (Mills and Forney 1988; Radabaugh et al. 2010). Regardless of habitat preferences, most mature Yellow Perch are present in the littoral zone of lakes during the spawning period (characterized by water temperatures of 7–11°C; Herman et al. 1959; Johnson 1971; Krieger et al. 1983). During the spawning period, male Yellow Perch fertilize egg ribbons released by mature females that are then deposited on coarse woody habitat, macrophytes, or other structures (Becker 1983). Postspawn, adult Yellow Perch may then remain in the littoral zone or move to more pelagic habitats as both provide different types and levels of predation refuge, prey resources, and potentially reduced intraspecific competition (Whiteside et al. 1985; Radabaugh et al. 2010). Dichotomous habitat use by Yellow Perch requires managers to carefully consider what gears to use and when and where to use them in order to properly estimate population abundance.

Within-system, cross-habitat (i.e., littoral versus pelagic) PE studies are infrequent for Yellow Perch. Research on Yellow Perch sampling gears have addressed size selectivity (Rudstam et al. 1984; Paradis et al. 2008; Doll et al. 2014), catch rates (Mangan et al. 2005; Rydell et al. 2010), and density or abundance differences of various gear types (Isermann et al. 2002; Paradis et al. 2008; Kocovsky et al. 2010; Dembkowski et al. 2012). However, these studies focused on one habitat type within a system (i.e., littoral or pelagic). Kraft and Johnson (1992) examined Yellow Perch between fyke nets (littoral) and gill nets (pelagic) in Green Bay, Lake Michigan, but only explored size selectivity. To our knowledge, there is no comparative study examining PE differences between habitats on the same Yellow Perch population. Further, there are very few studies comparing fyke-net and hydroacoustic surveys, and those that have were focused on riverine salmonids (Johnson et al. 1992; Ranson et al. 1996; Ploskey and Carlson 1999). In our review of the literature, no studies have summarized or quantified the proportion of a single Yellow Perch population representing either littoral or pelagic habitat use.

Differing habitat use by portions of a population may create issues by misrepresenting the "entire" adult population; PEs will be biased if a certain method or gear only targets one habitat for a species that uses multiple habitats. We hypothesized that PEs generated from a spring mark–recapture survey would best represent an adult Yellow Perch population due to their littoral spawning requirements. Conversely, summer hydroacoustic surveys would be biased towards the postspawn pelagic component of the population. To address our hypotheses, we generated PEs for adult Yellow Perch using a spring fyke-net, mark–recapture survey and summer hydroacoustic surveys. Our objectives were to (1) compare differences in PEs between surveys and (2) quantify the percentage of the adult Yellow Perch population representing a littoral or pelagic habitat preference.

## METHODS

*Study site.*— Crystal Lake (46.001°, –89.613°) is an oligotrophic, 46-ha seepage lake in Vilas County, Wisconsin with a maximum depth of 20.5 m (Lawson et al. 2015; Figure 1). Crystal Lake exhibits exceptionally clear water with Secchi depths ranging historically from 6 to >8 m; during summer 2020, mean Secchi depth was 6.25 m. Crystal Lake is circular with a littoral zone composed of a sandy substrate, few macrophytes, and little coarse woody habitat. Crystal Lake's fish assemblage is dominated by invasive Rainbow Smelt *Osmerus mordax* and Yellow Perch and supports no substantial recreational fishery.

*Spring fyke netting.*— Immediately after ice-out on May 11, 2020, six-mini fyke nets (0.6 × 1.2 m frame, 0.6 × 4.5 m lead, 6.35-mm stretched mesh) were set in Crystal Lake; nets were distributed around the littoral zone (Figure 1). Nets were never moved and were picked daily following a 24-h soak time. All adult Yellow Perch captured in the fyke nets were marked using a fin clip, and TL (mm), weight (g), and sex were recorded. Yellow Perch were defined as an adult if they were ≥75 mm TL since all individuals of that length expressed gametes. This length-at-maturity designation was held for the entire study. The marking and recapture period lasted until ≥10% of the population was recaptured, which occurred on May 28, 2020. A PE was then calculated for adult Yellow Perch using the Chapman-modified, continuous Schnabel procedure (Chapman 1951; Ricker 1975). Due to relatively large numbers of recaptures, we calculated the 95% CI for 1/PE by using *t*-values from the normal distribution of recaptures. These limits were then inverted to give a 95% CI for the PE (Ricker 1975). Normally distributed catch in our fyke nets indicated that we effectively captured the spawning period (i.e., gradual increase in captures and recaptures, peak catch during midsurvey, gradual decrease in captures and recaptures towards end of survey). Further, adult Yellow Perch sex ratios were consistent and stable over time at ~1.5 females to 1 male, suggesting a relatively equal probability of capture between sexes. Although this population estimation procedure assumes the use of multiple gears (e.g., fyke nets and an electrofishing run) to sample all available fish, we could not electrofish Crystal Lake due to low water conductivity (13 μS) that could not be overcome with our gear. Despite this, our mini-fyke nets were capable of sampling all lengths of available adult

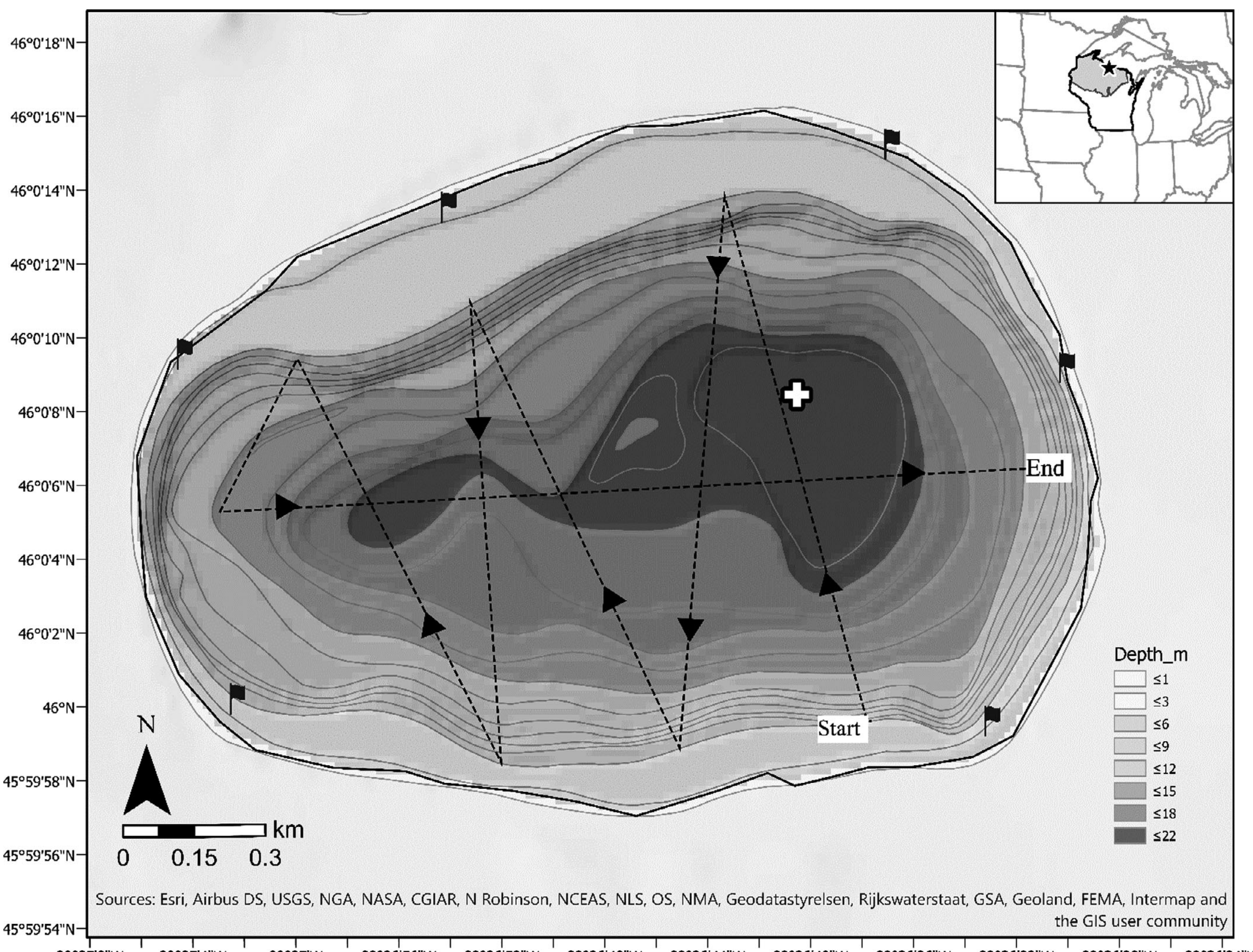


FIGURE 1. Map of Crystal Lake (Vilas County, Wisconsin) with mini-fyke-net locations (black flags) used for the spring mark–recapture survey and vertical gill-net location (white cross) and transects (dashed lines) used for summer hydroacoustic surveys to estimate adult Yellow Perch population abundance in 2020.

Yellow Perch in Crystal Lake (due to mesh size), reducing the effect of violating this assumption.

*Hydroacoustic surveys.—* Adult Yellow Perch (i.e., ≥75 mm TL) pelagic abundance was estimated once in June and twice in both July and August of 2020 with hydroacoustic surveys. Hydroacoustic data were collected with a BioSonics DTX echosounder and downward facing 70-kHz split-beam transducer mounted 1 m below the water surface. Thresholds for data collection were set to exclude raw echoes below −100 decibel (dB) for $S_v$ data and −70 dB for target strength data. Transmitted pulse duration was set at 0.4 ms. Hydroacoustic surveys were conducted at least 30 min after nautical twilight following a standardized and replicable 2,778-m whole-lake transect (North Temperate Lakes Long-Term Ecological Research [NTL-LTER]; Magnuson et al. 2006) at a vessel speed of ~10.2 km/h. Our whole-lake transect surveyed habitat >3 m in depth (Figure 1). We calibrated our system prior to the first survey using a tungsten carbide sphere (38.1 mm in diameter) following Foote et al (1987). Observed target strength (−40.00 dB) fell within acceptable limits of the nominal target strength (−40.56 dB).

All acoustic data was analyzed using Echoview software (v5.4). We excluded the top 2 m of the water column from analysis, including the 1-m transducer depth and twice the transducer nearfield range (0.49 m). We applied a ~0.25-m bottom exclusion line to delineate returns from the benthic acoustic dead zone. Data criteria closely followed the recommendations of the Great Lakes Standard Operating Procedures (Parker-Stetter et al. 2009); target strength threshold of −55 dB, 6-dB pulse length determination level, 0.5 minimum and 1.5 maximum normalized pulse length, 6-dB maximum beam compensation, and minor- and major-axis angles at 1°.

To inform species composition from the hydroacoustic surveys, we used 24-h vertical gill-net surveys to calibrate (apportion) species-specific estimates using count and length data. For each set, we followed standardized NTL-LTER protocols (Magnuson et al. 1994, 2006) and deployed seven monofilament nets in the deep hole of the lake from surface to bottom (~20.5 m; Figure 1). Vertical gill nets were 3 × 30 m with stretched mesh sizes of 19, 25, 32, 38, 51, 64, or 89 mm. Species-specific average TL was then transformed into a target strength following the multispecies model developed by Love (1971). Species classes were assigned using average target strength and then assigned a proportion of total biomass (derived from gill-net catches). We then used single target analyses to estimate sigma values (excluding targets below−55 dB), which we then applied to $S_v$ data to estimate adult Yellow Perch pelagic density for each 200-m segment along the whole-lake transect ($n = 14$). This segment length was chosen because correlation analyses have shown that 200-m segments are generally not spatially correlated (Holbrook 2011; Heald et al. 2017). We treated each 200-m segment as a replicate such that whole-lake density and associated 95% CI could be estimated. A PE was then calculated by multiplying the mean and 95% CI density estimates by total lake surface area. Since Crystal Lake has very little surface area <3 m deep (Figure 1), we did not correct our whole-lake estimate for the noninsonified waters <3 m.

A bootstrapped ($n = 5,000$ iterations) Kolmogorov–Smirnov test was used to test for differences in the length distributions of adult Yellow Perch collected between mini-fyke nets and vertical gill nets. Our null hypothesis was that there was no difference in the length distributions between gears with $\alpha = 0.05$.

## RESULTS

### Population Characteristics and Abundance Estimates

During spring fyke netting, 886 Yellow Perch were measured for length and weight. Mean ± SD TL and weight were 156.8 ± 35.9 mm and 39.9 ± 29.9 g, respectively. For vertical gill netting, 336 Yellow Perch were captured and measured during June, July, and August. Mean ± SD TL and weight were 161.4 ± 32.4 mm and 42.6 ± 26.3 g, respectively. Total length distributions of Yellow Perch sampled with mini-fyke nets in May did not differ from those sampled during June, July, and August with vertical gill nets (Kolmogorov–Smirnov bootstrap $P > 0.05$, $D = 0.07$; Figure 2). The adult Yellow Perch PE derived from the spring fyke net mark–recapture survey was greater than all summer hydroacoustic PEs (Figure 3). The spring fyke-net survey resulted in a 4.0–8.5 times greater adult Yellow Perch PE compared to summer hydroacoustic surveys.

## DISCUSSION

Seasonal habitat use by adult Yellow Perch can interact with inherent biases of different sampling methods to affect PEs. Our adult Yellow Perch spring fyke-net survey produced a substantially larger PE than did our summer hydroacoustic surveys. This corroborates the littoral spawning behavior of Yellow Perch (Becker 1983; Robillard and Marsden 2001), suggesting that mature individuals must be in the littoral zone for a successful spawning event to occur. Yellow Perch spawning requirements support our assumption that the spring fyke-net survey targeted the entire available adult population within Crystal Lake unless some mature fish skipped spawning. Postspawn, Yellow Perch populations may subdivide between littoral and pelagic environments as both habitats provide the species with adequate refuge and resources (Whiteside et al. 1985; Radabaugh et al. 2010). We conclude that our summer hydroacoustic surveys sampled the component of the adult Yellow Perch population that inhabited the pelagic zone. From this, it

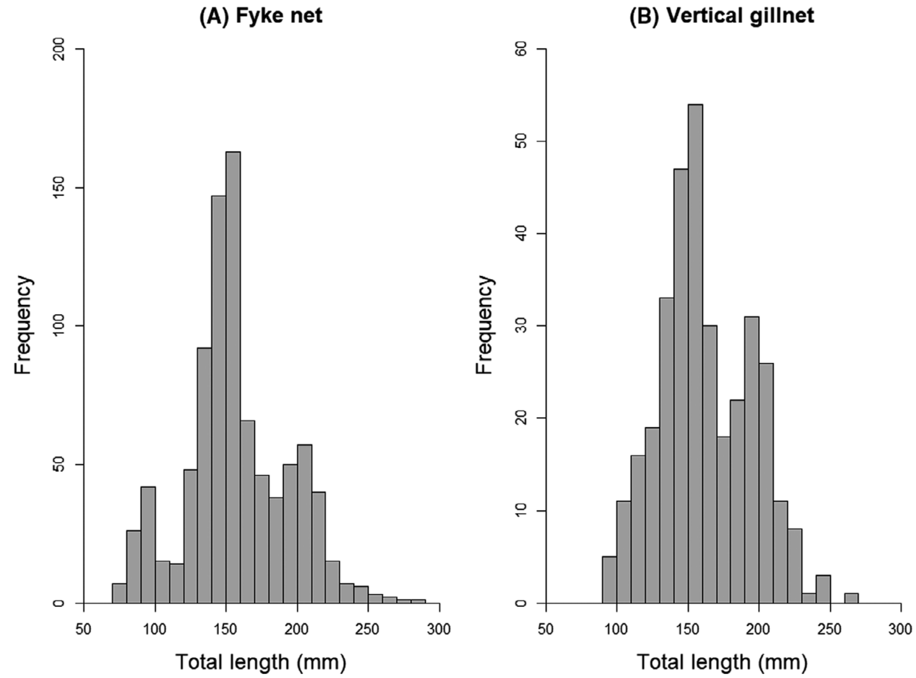


FIGURE 2. Total length (mm) frequency histograms for Yellow Perch sampled from Crystal Lake (Vilas County, Wisconsin) with **(A)** mini-fyke nets during May 2020 and **(B)** vertical gill nets during June, July, and August of 2020.

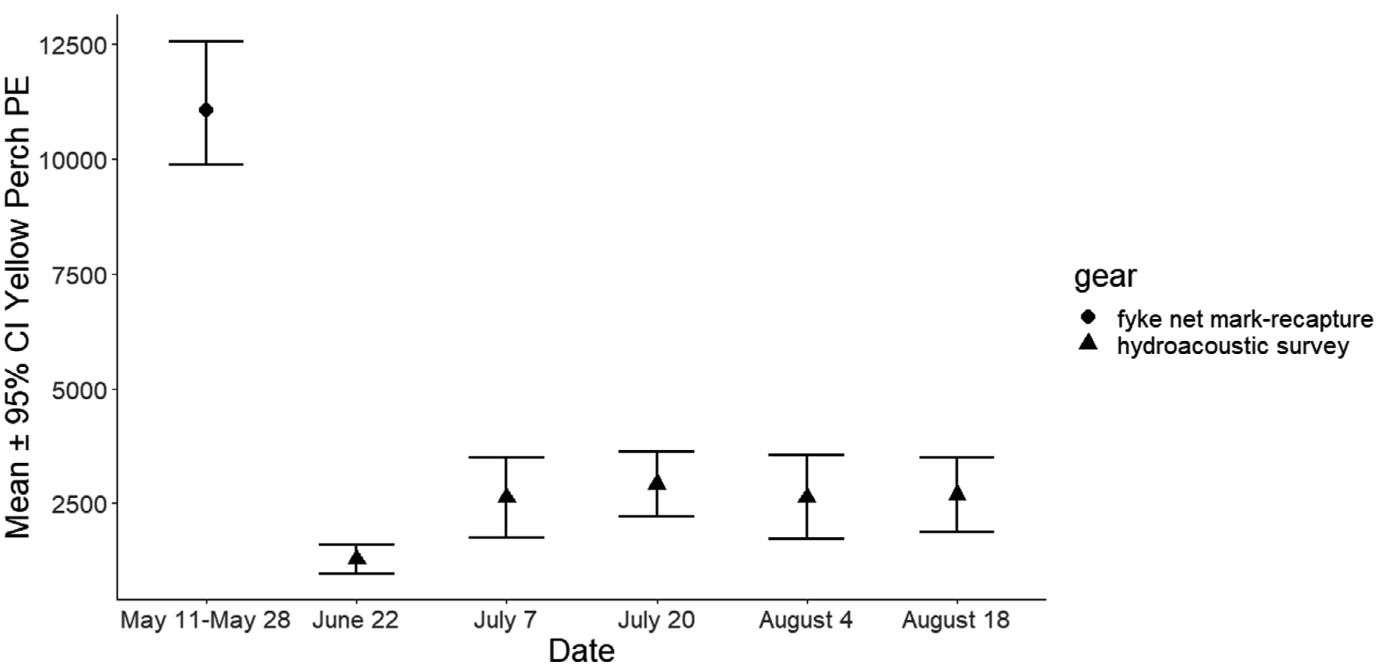


FIGURE 3. Mean ± 95% CI for Yellow Perch population estimates (PE) derived via a spring fyke-net mark–recapture survey (diamond) and hydroacoustic surveys (triangles) in Crystal Lake (Vilas County, Wisconsin) in 2020.

appears that of all adult Yellow Perch (i.e., ≥75 mm TL) in Crystal Lake (PE = 11,051), about 22% (PE = 2,492; average of all hydroacoustic estimates) exhibit pelagic habitat use during summer stratification. Inversely, of our estimated 11,051 adults, results suggest that about 78% (8,630) remained littoral (i.e., in depths <3 m) postspawn.

Although fish move and may go back and forth between habitats (Woolnough et al. 2009), limited deviation among hydroacoustic estimates implies a relatively static subpopulation with minimal immigration or emigration between littoral and pelagic habitats of Crystal Lake. This suggests a one-time movement of adult Yellow Perch from littoral to pelagic habitats postspawn as opposed to a daily exchange of individuals between littoral and pelagic environments. We reason that our lowest hydroacoustic estimate from June 22, 2020 (PE = 1,291) likely captured the transition of this pelagic component divergence, as the thermocline was just beginning to establish (NTL-LTER, unpublished data). Greater hydroacoustic survey frequency would provide more clarity on this behavioral transition (i.e., more sampling events between isothermic spring conditions and late-summer stratification). A follow-up summer (poststratification) tagging study covering both habitat types would remove uncertainty around the assumption of site fidelity. Further, contemporaneous sampling between gears, habitats, and seasons may help explain our observed differences in adult Yellow Perch PEs.

Sampling gears used in fishery assessments have inherent biases that can lead to inaccurate quantification of population abundances (e.g., Bonar et al. 2009; Pine et al. 2012), which may result in inappropriate management decisions. The mark–recapture fyke-net survey used in our study is only applicable to the adult Yellow Perch population during the spawning period. Outside of the spawning period, reduced littoral movement (and thus recapture rates) likely reduces the effectiveness and power of this survey. Given the amount of effort (time) needed to produce an informative mark–recapture PE (i.e., reaching ≥10% recaptures), we recommend starting a survey following ice-out. Further, fyke nets can be biased by mesh size, net location, lead length, and frame dimensions (Hubert et al. 2012). These factors should all be considered with the survey objective prior to deployment. Nevertheless, when the species of interest is an obligate littoral spawner and coolwater fish (e.g., Yellow Perch, Walleye *Sander vitreus*, Muskellunge *Esox masquinongy*), a spring fyke-net mark–recapture survey is recommended to estimate adult population abundance. This survey design is ideal for some littoral spawners (e.g., Yellow Perch) because the species will be most aggregated during the spawn (Treasure 1981; Fago 1998). Similarly, hydroacoustic surveys can become biased under a plethora of scenarios (DuFour et al. 2017, 2018, 2021; Dillon et al. 2019, 2020), even for an ideal study system like Crystal Lake (i.e., deep and clear, no pelagic macroinvertebrates, simple fish community). For many oligotrophic north-temperate lakes, bias likely occurs when the species of interest exhibits or has the potential to exhibit multiple habitat preferences (e.g., littoral versus pelagic), such as Yellow Perch. Here, the species is not always restricted to the survey area and may avoid detection. For example, 78% of the Yellow Perch that appeared to remain in littoral habitat postspawn could have been in the noninsonified pelagic (i.e., top 2 m of water column, bottom 0.25 m of water column) or littoral (depth of <3 m) zones of Crystal Lake. Moreover, vessel avoidance by Yellow Perch could have played a role in our observed PE differences. When the species of interest is an obligate coldwater or deepwater fish, such as invasive Rainbow Smelt or native Cisco *Coregonus artedi*, habitat preferences (i.e., oxythermal requirements) could require the species to stay within the survey area, making detection avoidance less likely (i.e., Rainbow Smelt and Cisco rarely use the epilimnion). Conversely, if the Crystal Lake water level were to decrease by 1 m, the vast majority of littoral coarse woody habitat would be above the water line (NTL-LTER, unpublished data). This could potentially force the littoral component of the Yellow Perch population into more pelagic habitats, thus restricting their distribution within our survey area. Overall, understanding the seasonal behavior and ecology of a target species is critical to accurate fisheries PEs and assessments.

## Management Implications

The status of Yellow Perch populations largely remains a "black box" for some state agencies (including the Wisconsin Department of Natural Resources) and researchers due to a lack of standardized sampling protocols, management focus, and resources. Outside of Yellow Perch relative abundance indices derived from creel surveys and electrofishing CPUE estimates from general fish surveys (Hansen et al. 1998; Beard et al. 2003; Rypel et al. 2016; Feiner et al. 2020), relatively little is known about Yellow Perch population dynamics and abundance in many north-temperate lakes. Yet, Yellow Perch can be a keystone species, whereby declines in population abundance may foreshadow or cause negative cascading effects on recruitment and production of fishes at upper trophic levels (Forney, 1974; Hansen et al. 1998; Beard et al. 2003; Sass et al. 2006; Gaeta et al. 2014). Our results suggest that postspawn, adult Yellow Perch may exhibit variable habitat use within populations and ecosystems. In north-temperate lakes, we recommend that accurately quantifying Yellow Perch populations will require littoral (e.g., fyke netting) sampling gears used during the spring spawning period and the use of pelagic gears (e.g., vertical gill netting, hydroacoustics) to test whether a pelagic component exists. However, we urge caution in the use of hydroacoustic surveys to represent the "entire" adult population when the species of interest can exhibit multiple habitat preferences or occupy noninsonified zones of a lake. Finally, it is worth noting that our objective during these surveys was to produce an informative PE. Thus, we dedicated substantial time and effort to meet that objective. For example, we conducted the spring mark–recapture survey for 17 d before reaching ≥10% recaptures. It is unlikely that a management agency with many lakes on their annual sampling rotation could expend this amount of effort. If effort expended in our spring mark–recapture survey is similar to what would be required or used by others, we suggest conducting the spring mark–recapture PE on a less frequent basis (e.g., every 3–5 years). During the nonspring PE years, hydroacoustic surveys could be conducted as they require much less effort (time). Hydroacoustic PEs could then be applied to estimate the littoral component of the adult Yellow Perch population.

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