Examination of Sampling Bias for Larval Yellow Perch in Southern Lake Michigan

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ABSTRACT. Evidence suggests larval yellow perch, Perca flavescens, utilize nearshore and offshore habitat during the 30–40 day period between hatch and transition from pelagic to demersal habitat. In a large, open system like Lake Michigan this represents a significant increase in available habitat and it is important to understand how this increase may impact our ability to sample larval yellow perch in an unbiased manner. We measured the vertical distribution of larval yellow perch in southern Lake Michigan as a function of size, age, and diel period. Larval yellow perch were collected from two zones (surface and epilimnion) from 1 to 32 km from shore in 2001 during the day; on four dates surface samples were also collected at night. Results indicate larval perch are more abundant at the surface at night than during the day. Larval yellow perch < 15 mm total length (TL) and younger than 18 days post hatch were found in both surface and epilimnion habitat during the day, but larvae > 15 mm TL were captured only in the epilimnion and farther than 5 km from shore, which suggests a different spatial distribution for larger, older larvae. Diel differences in larval abundance and size at the surface suggest more and larger larvae will be caught for a similar effort at night as compared to daytime sampling. Observed differences in larval distribution with size and age also suggest that sampling concentrated nearshore and/or at the surface has the potential to under-sample larger/older yellow perch larvae in Lake Michigan.

INDEX WORDS: Perca, larvae, sampling, depth, Lake Michigan, pelagic.

INTRODUCTION

Pelagic fish larvae are frequently smaller, lack parental protection, and are distributed over a larger area than other types of fish larvae (Sissenwine 1984). It is important to properly characterize the distribution and mortality rate of pelagic larvae to understand how larval dynamics impact annual recruitment (Houde 1987). Both the small size and wide dispersal patterns of pelagic larvae present a challenge for conducting field surveys in an unbiased manner. In particular, it has been demonstrated that data concerning the horizontal and vertical distribution of pelagic larvae can be critical to the development of comprehensive larvae surveys (Thayer et al. 1983) that provide unbiased measures of density, size and age distributions, and mortality (Wang and Eckmann 1994) for each annual cohort. To effectively collect the complete range of larval sizes from hatch to juvenile transition, we must know if vertical or horizontal position is correlated with size, age, or diel sampling period.

Yellow perch, Perca flavescens is a popular and commercially important sport fish throughout the Great Lakes region (Francis et al. 1996). Historically, the Lake Michigan yellow perch population has been a productive fishery, but has been in decline since the early 1990s. This decline is generally thought to be due to increased mortality during the larval period (Clapp and Makauskas 2002). Yellow perch larvae occupy the pelagic zone from
hatch until about 40 days post hatch (dph) when they make an ontogenetic transition to the juvenile stage that is characterized by a shift to demersal habitat (Post and McQueen 1988, Wang and Eckmann 1994). Early-life history of yellow perch has been studied in many lakes including Lake Michigan (Perrone et al. 1983, Jude and Tesar 1985, Pothoven et al. 2000) and Lake Erie (Trometer and Busch 1999, Ludsin 2000). However, the larval phase has been most thoroughly studied in smaller systems, such as Oneida Lake, NY (Rose et al. 1999 and citations therein), where the comparatively shallow average depth (mean depth 6.4 m) makes vertical position less important to sampling. Fisher et al. (1999) found that the distribution of age-0 yellow perch was associated with water depth in South Dakota glacial lakes. Yellow perch larvae have been found in the offshore region of Lake Michigan (Nash and Geffen 1988). Ironically, despite this evidence and evidence from smaller systems that larval yellow perch may be using more of the pelagic zone, research on larval yellow perch in the Lake Michigan has largely focused on the nearshore zone less than 20 m deep (hereafter nearshore zone; Perrone et al. 1983, Jude and Tesar 1985) where vertical position is not considered a significant factor. This habitat zone represents a small percentage of the pelagic habitat in Lake Michigan and intensive efforts to collect yellow perch larvae in Lake Michigan from 1998–2001 suggest that larval density in the nearshore zone rapidly drops to non-detectable levels after the end of the spawning period (Clapp and Makauskas 2002). Moreover, intensive sampling in Wisconsin and Illinois waters of Lake Michigan revealed a significant positive relationship between larval size and distance from shore out to 35 km (Dettmers et al. 2005, Fulford 2006). These findings suggest that larval yellow perch use more of the available habitat than previously recognized. This realization leads to the question of whether larval vertical position will affect our ability to sample larval yellow perch in an unbiased manner in Lake Michigan. The goal of this study was to describe size, age, and density patterns of yellow perch larval samples collected over a range of common sampling approaches in southern Lake Michigan (SLM). We had two specific objectives:

1) Test the hypothesis that yellow perch larval density and size at the surface are different at night than during the day.

2) Determine whether daytime surface vs. subsurface distribution is a function of size or age.

METHODS
Sample Sites

All samples were collected in 2001 from one of eight transects along a nearshore-offshore track from near Milwaukee, Wisconsin to a point 32 km due east of Wind Point, Wisconsin (Fig. 1). The four nearshore transects (labeled NK2-NK5; Table 1) were oriented north-south across Greencan Reef, a known yellow perch spawning area (Wisconsin Department of Natural Resources Lake Michigan Work Group, personal communication). The nearshore transects were 2, 3, 4, and 5 km from shore respectively. The four offshore transects (la-
TABLE 1. Thermocline depth (m) and schedule of sampling by date and site to illustrate nearshore to offshore coverage and amount of water column sampled. Total depth (m) is given below each site name in the first column. The mesh size of all gear types was 500 μm on 15 June and dates of mesh size increases (μm) are given in the first row. The value “X” indicates a site and date where a sample was collected but no thermocline was detected. The sites sampled on 20/6, 25/6, 2/7 and 16/7 were sampled both during the day and at night.

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beled OS1-OS4; Table 1) were oriented east-west to maximize available vessel time (i.e., moving inshore or offshore rather than parallel to shore while sampling). Offshore transects were located progressively southeast from Greencan Reef to track hypothesized southeast movement of passive particles in Lake Michigan (Mortimer 1971, Schwab and Beletsky 2003). The offshore transects were 8, 16, 24, and 32 km from shore, respectively. Transect location and spacing were chosen to provide a comprehensive nearshore to offshore sample over the pelagic larval period for yellow perch in Lake Michigan. The exact location (non-corrected GPS coordinates) of each transect was used only as a guide for location of actual sampling and did not represent fixed sites in an open system like Lake Michigan.

Samples were collected on 14 dates between 15 June and 31 July 2001. Four of the eight transects were sampled on each date with one tow completed along each transect visited on a given day. From 15 June to 25 June only nearshore transects were sampled, and from 27 June–31 July sampling was split between nearshore and offshore transects (Table 1). Sampling was conducted during daylight hours on all dates. Samples were also collected at night at all transects sampled on four dates: 20 and 25 June, 2 and 16 July. Only the day/night samples collected on the aforementioned four dates were used to address objective one. Samples collected on all dates during the day were used for addressing objective two.

**Larval Fish Collection**

The most commonly reported method for collecting larval yellow perch in Lake Michigan is surface samples collected within 5 km of shore either during the day or at night (Clapp and Makauskas 2002). Larval fish were collected for this comparison from the surface to a depth of 2 m below the surface (hereafter surface) by towing a 1 x 2-m neuston net at each site. This net size sampled water to a depth of approximately 2 m because a weight was mounted at the apex of the tow line and floats on 1-m lines were mounted on the top corners of the net frame. This float-weight adaptation guaranteed the net remained completely submerged, but it also caused the net to move through the water in a
sine-wave pattern to a maximum depth of 2 m rather than in a straight line (R.S. Fulford, personal observation). Tow duration was 1 hour and approximately 1.6 km. Total volume sampled in each net on each tow was measured with a propeller-type flow meter (General Oceanics, Inc.) located in the net mouth. Mesh size was initially 500 µm and was increased to 1,000 and 1,800 µm after the fourth and eighth sampling dates, respectively. This systematic mesh-size increase maximized capture efficiency for the largest larvae in the system and was based on historical larval growth rates in Green Bay and Lake Michigan (Brian Belonger Wisconsin Department of Natural Resources Peshtigo, Wisconsin, unpublished data).

To measure larval vertical distributions below 2 m, larval yellow perch were collected from the thermocline up to 2 m below the surface with oblique tows of a 1 x 1.2-m tucker trawl. The oblique angle of this net in the water resulted in an apparent net size of 1 m². Thermocline depth was established on each site/day by taking a vertical temperature profile (YSI International). Thermocline depth was defined as the depth at which Δtemperature/Δdepth was maximized. At the sites and/or dates where no thermocline was detected, sampling was conducted from a depth equal to ⅓ of the total depth. Where a thermocline was present, thermocline depth ranged from 9–28 m across all sites and dates (Table 1). The tucker trawl was raised ¾ of the maximum tow depth every 15 minutes for the duration of the tow. Tucker trawl samples were only collected during the day. Mesh size for the tucker trawl was always matched to that of the neuston net to maintain equivalent capture efficiency between gear types. Larval fish collected in both gears were flash frozen in dry ice-ethanol slurry and returned to the laboratory for analysis. In the lab, yellow perch larvae were identified and removed from bulk samples. The total length of each larva was measured to the nearest 0.1 mm, and otoliths were removed for age estimation.

The procedure for estimating larval age in days post hatch (dph) differed based on individual larval size. For larvae smaller than 12 mm total length (TL), both sagittal otoliths were mounted on a single microscope slide with Cytoseal (Richard-Allen Scientific, Inc.); age estimates were obtained by ring counts made by two independent readers at 400× magnification. Discrepancies between independent readings were corrected with an additional joint reading. Mean ring count from all valid readings for an individual otolith was converted to an estimate of individual age with a relationship between ring count and larval age based on an inverse regression analysis of ring count data on age for known-aged larvae raised in the laboratory (Rice et al. 1987, Fulford 2003). Full details of the procedure used to age larval yellow perch including procedures used to validate daily ring counts are presented in Fulford (2003).

**Statistical Analysis**

Both larval size and density were expected to change through time and space. Our goal was not to describe biological differences between discrete locations or particular parts of the pelagic larval period. Rather, we wished to address whether samples collected in a particular way over the entire pelagic larval period differed with respect to capture density, size, or age.

We tested for diel differences in larval density at the surface with a mixed-model repeated measures ANOVA of larval density between sample dates, diel period, and date by period interaction for the four dates on which we collected diel samples (Table 1). For this comparison, sample site was a random variable and the repeated measures component allowed us to control for change through time. Only data from neuston net samples were used (N = 31 tows) in this comparison and density data were ln(x+1) transformed to reduce heteroscedasticity (Neter et al. 1990). We tested for a larval size difference between day and night samples with a paired t-test of larval mean TL (mm) between diel periods. This comparison was conducted for larvae collected on the aforementioned four dates in the neuston net only (N = 31 tows). All statistical analyses were conducted at a type I error rate of 0.05 with SAS software version 8.0 (SAS Institute, 1990). Analysis of larval size and age as a function of depth (daytime; surface vs. epilimnion) was limited to an analysis of presence/absence as a function of size and age due to declining sample return with larval size.

**RESULTS**

**Diel Comparison**

Surface density of larval yellow perch was significantly higher at night than during the day (ANOVA
FIG. 2. Comparison of mean ln(x+1) density of yellow perch larvae caught in day (white bars) and night (black bars) surface samples on four dates (four transects per date). Sites sampled at night and during the day are the same within date but differ between dates. No larvae were captured on 16/7/01. Error bars are ± 1 standard error.

F_{1,16} = 10.1 p = 0.006; Fig. 2) and declined significantly across sampling dates (ANOVA F_{3,16} = 16.3 p < 0.001). Differences in sample larval density between diel periods on particular dates were significant only on 25 June (post ANOVA tukey comparison; p_{0.20} = 0.21, p_{0.25} = 0.05, p_{7/2} = 0.94, p_{7/16} = n/a), however this result is likely due to a lack of statistical power for within-date comparisons. Sample size was small (n = 4) within sampling date, and overall low density of larvae resulted in empty samples during both periods and an inflated variance even for ln-transformed data. Mean densities for night samples were higher than mean densities for day samples on all dates (Fig. 2). There was also a significant relationship between larval size and diel period (paired t-test; d.f. = 15, p < 0.02). Larvae captured at night were significantly larger than larvae captured in comparable samples during the day. Difference in mean size between day and night samples was low from a biological standpoint (Day mean = 5.96 mm; Night mean = 6.01 mm TL), but a comparison of the size-frequency distribution between diel periods suggests this difference in not due to a few outliers in the night samples (Fig. 3).

Diurnal Depth Distribution

Larval yellow perch were present in our samples from 15 June to 30 July 2001. Yellow perch larvae were present in both surface and epilimnion samples although not on all dates or at all sites. However, larvae larger than 15 mm TL (> 18 dph) were caught only in the sub-surface samples collected more than 5 km from shore (Fig. 4). Smaller (< 10 mm TL) and younger (< 12 dph) yellow perch larvae were collected at all depths suggesting a more ubiquitous vertical distribution for early-stage yel-
larval perch larvae. However, these smaller, younger larvae were only present out to a sample distance of 20 km and at greatly reduced abundance beyond a distance of 5 km (0.04 larvae per 1,000 m$^{-3}$) in comparison to samples collected closer to shore (< 5 km, 13.3 larvae per 1,000 m$^{-3}$).

**DISCUSSION**

Our analysis suggests that early-stage (< 15 mm TL, < 18 dph) pelagic yellow perch will be collected in greater numbers at the surface at night and decreased sample return during the day may be because early-stage larval yellow perch distribute themselves throughout the epilimnion during the day. Larvae were more abundant in our surface samples at night, and while it is not informative to make a direct density comparison between neuston net and tucker trawl samples, a qualitative comparison of larval number by depth of capture provides evidence larval yellow perch are using both surface and sub-surface habitat during the day (Fig. 4). The increase in larval density at the surface at night suggests at least some of the larvae found in sub-surface habitat during the day are migrating upward at night. Possible reasons for this upward movement at night include tracking migratory zooplankton or avoiding visual predators (Neilson and Perry 1990). Similar diel distribution patterns have been observed for larval herring (Wales 1984) and capelin (Fortier and Leggett 1982), as well as other populations of yellow perch (Cole and Macmillian 1984).

It is possible for increased density in night samples to be due to diel changes in the efficiency of sampling gear. Thayer et al. (1983) found differences in diel density in their larval samples and concluded that these differences were due to increased net avoidance by larger larvae during the day. We do not think this is the case in our samples for several reasons. First, unlike in the Thayer et al. (1983) study, our sampling gear mesh size was in-
increased to track larval growth and maintain constant capture efficiency with larval size. This adjustment allowed us to examine the vertical distribution of a single larval "pulse" as the larvae increased in size over time. Second, the sampling cross-sections of our gear (2 and 1 m²) were much larger than that used by Thayer et al. (1983; 0.015 m²) and this should reduce the escape potential of larger larvae. Finally, the capture frequency of all larvae between 5.5 and 15 mm TL increased in our samples at night (Fig. 3), and laboratory observations suggest that visual avoidance capacity of larval yellow perch does not develop until larvae are close to 10 mm TL (R.S. Fulford, unpublished data). So our nighttime catch also increased for larvae that are not yet capable of visual net avoidance.

Our data also provide some evidence that larger, older larvae are less likely to be captured by sampling at the surface or in nearshore waters in Lake Michigan. While our sample size for larvae larger than 15 mm TL (18 dph) was low (n = 10), it is important to note that this is likely the result of a high larval mortality rate rather than changes in capture efficiency with larval size. The procedure of increasing mesh size to track larval growth has proven effective in Green Bay for maintaining capture efficiency of larval yellow perch as they grow. It is therefore reasonable that the observed differences in depth and distance from shore of capture for larger, older larvae may be reflective of changes in larval habitat choice that will bias samples collected in a subset of the available habitat.

Overall, our data suggest that sample bias due to diel period is likely to be mixed. Estimates of density for larval yellow perch will be affected by whether they are collected during the day or at night. However, our data also suggest that samples collected during the day will not be biased with regard to size up to 15 mm TL. Night sampling of early-stage larval perch is recommended for studies that require a higher return of individuals, such as for age and growth or genetic analyses. Unbiased sampling of later-stage larvae (> 15 mm TL) may require a representative sampling effort farther offshore and below 2 m. In general, oblique sampling of the entire epilimnion, a consistent diel sampling period and a combination of inshore and offshore sampling would maximize comparability between samples and minimize size/age bias.

This level of comprehensive sampling represents a major increase in sampling effort in a large, open system such as Lake Michigan. It also represents a significant difference between sampling yellow perch larvae in smaller systems such as Oneida Lake and sampling them in Lake Michigan. In systems such as Oneida Lake (surface area 392 km²), nearshore and offshore waters can be comprehensively sampled from the surface to the bottom with similar levels of effort using the same types of gear. Due to the large amount of available pelagic habitat in Lake Michigan, an extensive effort involving coordinated multi-agency sampling (surface area 57,000 km²; four state jurisdictions) with multiple gear types (surface and sub-surface gears) will be required to obtain a comprehensive sample of the pelagic larval stage for yellow perch and unbiased data regarding yellow perch growth, mortality and distribution. However the effort will most likely result in great rewards. Unbiased information regarding the growth, distribution and survival of larval yellow perch throughout the pelagic habitat will be highly valuable for increasing our understanding of yellow perch recruitment and for improving our ability to effectively manage yellow perch in Lake Michigan.

ACKNOWLEDGMENTS

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REFERENCES


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