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Evidence of positive phototaxis in Paddlefish: Implications for larval sampling

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Paired lit and unlit quatrefoil traps were used to examine the photic response of Paddlefish *Polyodon spathula* yolk-sac larvae (YSL) and exogenous-feeding larvae (EFL) under controlled conditions in a hatchery. One lit and one unlit trap were placed in two identical circular raceways containing approximately 10,000 YSL and EFL for 20 2-min trials. Lit traps captured nearly 10x more larvae than unlit traps for each cohort and accounted for 91% and 94% of total catch for YSL and EFL, respectively. This is the first documentation of this photic response in Paddlefish. A slight increasing trend in capture with length was noted for YSL, whereas EFL demonstrated a strong decreasing trend in capture, indicating a possible behavioral shift at 15-16 mm TL. The high proportional catch of lit traps among 1-mm length classes evaluated (≥79%) suggests that Paddlefish exhibit positive phototaxis and light trapping for Paddlefish larvae <20 mm TL may have potential to substantially increase catches in the wild. More efficient capture of larval Paddlefish in the wild using lighted traps might prove useful for documenting the presence of reproduction, for initial indications of year class strength, and as a source of fish for rearing in hatcheries and repatriation to the wild. However, much remains to be evaluated in controlled and wild settings, including responses to different light emissions, lower fish density, and higher turbidities common in rivers when and where wild Paddlefish spawn.

Keywords: Paddlefish, phototaxis, ecology, recruitment, life history

Introduction

The ability to sample early life stages of North American Paddlefish *Polyodon spathula* in the wild is an important part of a stock assessment program for long-term conservation of the species (Scarnecchia, Ryckman and Lee 1997). The potential capture of larval Paddlefish can have important management implications: 1) for documenting the presence of reproduction, 2) for initial indications of year class strength, and 3) as a source of fish for rearing in hatcheries and repatriation to the wild where natural recruitment is poor or absent.

The capture of Paddlefish early life stages has proven to be a challenge from the earliest efforts (Stockard 1907; Allen 1911; Danforth 1911). Only occasionally were successful collections of age-0 Paddlefish reported in the literature during the first six decades of the twentieth century (Larimore 1949; Purkett 1961; Pasch, Hackney and Holbrook, II 1980, their Table 3). Successes in capturing Paddlefish larvae have been reported by Purkett (1961), who captured larvae in the Osage River, Missouri. Pasch, Hackney and Holbrook, II (1980) captured fewer than 50 larvae in Old Hickory Reservoir, Tennessee. Wallus (1986) sampled small numbers of larvae (1-84) in eight years from the Cumberland River and 2-24 larvae over nine years from the Tennessee River over the period 1973-1982. He used fine-meshed nets and epibenthic sleds. Gardner (1997) sampled larvae in the Yellowstone and Missouri rivers of Montana and North Dakota in the first half of the 1990s. Most larvae were caught with round or D-ring nets drifted slowly downstream near the river bottom. Personnel from Oklahoma Department of Wildlife Conservation captured 84 larvae in 19 hours of sampling with subsurface ichthyoplankton nets in the Neosho and Spring rivers in 2012, but subsequent efforts yielded even lower catch rates (Oklahoma Department of Wildlife Conservation, unpublished data). In view of the high fecundity of the Paddlefish (Russell 1986), total catches of larvae have been modest in all studies. Larvae may often be widely dispersed throughout their large-river habitats, making it difficult to catch large numbers of them at one location and time. For the larval catches to have more substantial management implications, catches must be more robust and less variable than have heretofore been achieved.

Many fishes are attracted to natural or artificial light sources. Fishing with the assistance of light for sustenance, profit, or recreation has likely been utilized since prehistoric humans discovered fire and noted the light was an attractant to fishes (Ben-Yami 1976). Use of artificial light to attract early life stages of fishes (using various methods of active and passive capture) is a common practice in management or recovery programs and is used in identifying or monitoring community assemblage (Conrow, Zale and Gregory 1990; Humphries, Serafini and King 2002; Marchesan et al. 2005), as a metric for the timing and success of spawning (Floyd, Hoyt and Timbrook 1984b), and most recently for preserving wild genetic diversity by capturing larvae for captive rearing and later repatriation (Dowling et al. 2014). Light traps in particular have been demonstrated as an effective choice for sampling larval fishes and the quatrefoil design has yielded higher species diversity and catch rates than other active gears (Floyd, Courtenay and Hoyt 1984a; Secor, Dean and Hansbarger 1992; Niles and Hartman 2007).

No published evidence of the effects of light on larval Paddlefish is available. This note reports on the behavioral response and catchability of Paddlefish larvae with artificial light traps under a restricted set of controlled, hatchery conditions. Our objectives were to assess 1) if catches of larvae could be increased with the addition of light, and 2) if the response varied with size and developmental stage. An evaluation of the response of larval Paddlefish to light under controlled conditions is a potential first step in improving our ability to catch and collect this species in the wild.

Materials and Methods

Light Trapping in Circular Raceways: Adult Paddlefish broodstock were collected with nets from Grand Lake O' the Cherokees in Northeast Oklahoma, transferred to Tishomingo National Fish Hatchery in Tishomingo, Oklahoma, and spawned on March 17 and 24, 2016. Hatch occurred during March 23-25 and March 30-April 1, respectively, producing two cohorts used in light trapping trials on April 6, 2016. Both larvae cohorts (yolk-sac larvae [6-8 d], hereafter "YSL"; and exogenous-feeding larvae [13-15 d], hereafter "EFL") were separately housed in two 2,941 L circular raceways containing approximately 10,000 fish per raceway. Each raceway was identically configured, maintained at 18.6 °C, and subjected to the same ambient lighting. Flow through the raceway (approximately 15 L/min) was not observed to influence larvae position.

Light traps consisted of quatrefoil-type Aquatic Macroinvertebrate and Larval Fish Light Traps from Aquatic Research Instruments, each illuminated with one 6" Cyalume® 8-hr white snaplight. Traps were used in pairs (one lit and one unlit) within each raceway. Assignment of position within the raceway (i.e. left vs. right) was randomized.

Twenty light trapping trials were performed in darkness, consisting of lit and unlit trap deployment into each raceway for 2 min. Preliminary testing was performed to identify that the 2 min trapping duration resulted in a high catch rate. All larvae collected from each trap were preserved in 70% ethanol and later enumerated. A subsample of up to 40 larvae was measured for total length (TL) to the nearest 0.01 mm via digital calipers under a dissecting microscope. A representative control sample of 40 larvae from each cohort was also taken with a dipnet and preserved for later measurement.

Data Analyses: Distributions of capture count and fish TL were examined for normality using the Shapiro-Wilk test (SW). To investigate a possible location bias within the hatchery raceway (i.e. left versus right side), catch rates (number of larvae captured per 2 min soak) were compared within treatment/cohort combination using the Wilcoxon Rank Sum test (WRS) with Bonferroni-adjusted α = 0.0125 to account for multiple tests. Median catch rate within cohort was compared across treatments using WRS. Quartiles were calculated to create boxplots of catch rate across cohorts and treatments.

Larvae size was compared between cohorts (all fish captured in both lit and unlit traps). To investigate size catchability bias for the lit traps, median TL for both cohorts and control samples were independently, pairwise-compared using WRS with Bonferroni-adjusted α = 0.025 to account for multiple tests, when applicable. Additionally, median TL of captured larvae (lit and unlit combined) was compared to the control sample for each cohort. Quartiles were calculated to create boxplots of TL across cohorts, treatments, and controls.

Captured larvae were grouped into the nearest 1 mm length classes within cohort. To examine the potential influence of light on the catch of lit and unlit traps, proportional catch for lit traps was calculated by dividing the number of larvae captured in lit traps by the total number of larvae captured (in both lit and unlit traps) for each length class that included ten or more larvae. Trends in proportional catch as a function of TL were examined using linear regression. All data analyses were performed in R software with a significance level of α = 0.05 unless otherwise noted for corrections for multiple tests.

Table 1. Catch counts and proportional catch (in parentheses) within Paddlefish yolk-sac larvae (YSL) and exogenous-feeding larvae (EFL) cohorts for lit and unlit traps.

Cohort	Lit Traps	Unlit Traps	Total
YSL	1,801 (90.6%)	187 (9.4%)	1,988
EFL	184 (94.4%)	11 (5.6%)	195

Results

Both YSL and EFL Paddlefish larvae were captured in greater abundance in lit traps than in unlit traps (Table 1). Out of a total 1,988 YSL captured, 91% were captured in lit traps. Fewer total EFL were captured (195), but 94% were captured in lit traps. Catch per trial for YSL in lit traps was significantly greater than for unlit traps (WRS = 400, $P < 0.001$) with lit traps catching an average of 90.1 larvae in two minutes (median: 74.0) versus unlit traps, which caught an average of only 9.4 larvae (median 8.5). Similarly, for EFL, catch per trial in lit traps was significantly greater than for unlit traps (WRS = 393, $P < 0.001$) and averaged 9.2 larvae (median 6.5), whereas unlit traps averaged 0.6 larvae (median: 0) (Fig. 1). Comparison of capture rate within treatment/cohort and between raceway side (left or right) was found to be non-significant in a series of four tests (Table 2). Raceway side was thereafter not considered as a variable in catch rate.

The TL for captured fish from each cohort was found to be non-normally distributed (SW = 0.99, $P < 0.001$ for YSL and SW = 0.97, P <

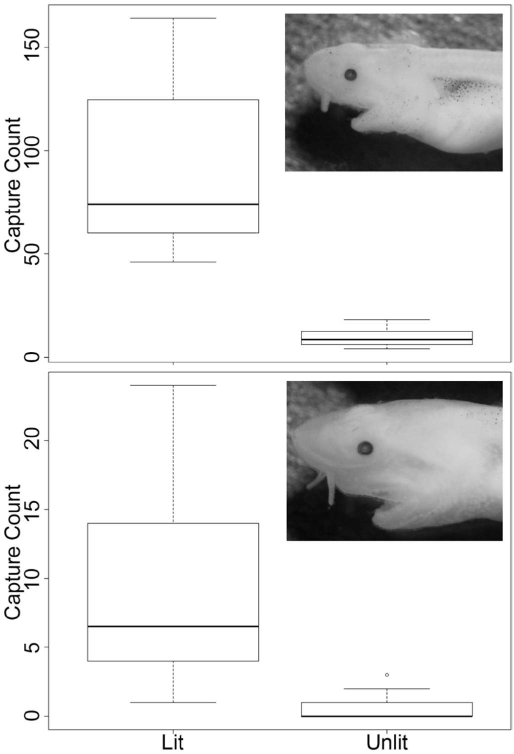

Figure 1. Box and whisker plots demonstrating difference in Paddlefish catch per 2 min trial between lit and unlit traps for yolk-sac larvae (above) and exogenous-feeding larvae (below).

0.001 for EFL). Median TLs averaged across trials within cohort (14.07 mm for YSL [range 10.68 – 16.07] and 18.75 mm for EFL [range 11.40 – 23.11]) were significantly different (WRS = 219,430, P < 0.001).

When the sizes of captured larvae from treatment groups were compared to that of the respective control samples, the results on size-catchability bias were inconsistent. Pairwise comparisons of median TL across treatment and within cohort were found to be homogeneous (Table 3, Fig. 2). Median TL for EFL captured larvae (lit and unlit) and EFL control sample were significantly different (WRS = 4,798, P < 0.001). This difference was isolated to a significant difference in median TL where EFL from lit traps were significantly smaller than the EFL from the control sample (WRS = 4,566, P < 0.001).

Table 2. Examination of raceway side (Left versus Right) on median catch rate for Lit and Unlit treatments of yolk-sac larvae (YSL) or exogenous feeding larvae (EFL). Results of Wilcoxon Rank Sum pairwise comparisons are noted. No comparisons were found to be significant with Bonferroni-adjusted α = 0.0125 to account for multiple tests.

Left	Right	WRS	P-value
YSL-Lit	YSL-Lit	63	0.263
YSL-Unlit	YSL-Unlit	60	0.391
EFL-Lit	EFL-Lit	71	0.104
EFL-Unlit	EFL-Unlit	25	0.105

When YSL and EFL cohorts were placed into 1 mm length classes (ranging 12 – 15 and 16 – 20 mm, respectively), discrete trends in proportional catch were evident, and all size classes examined were more likely to be captured in a lit trap than an unlit trap (range 79 – 100%). Exogenous feeding larvae 16-20 mm demonstrated a strong and significant decline in lit trap proportional catch with increasing size (R2 = 0.88, F = 22.31, P = 0.018; Fig. 3). After demonstrating a non-significant increasing trend in lit trap proportional catch for YSL 12-15 mm (R2 = 0.79, F = 7.67, P = 0.109), a substantial and abrupt increase was observed between larvae 15-16 mm. Lit trap proportional catch abruptly increased from 85% at 15 mm to a peak of 100% at 16 mm followed by a steady decline to 86% at 20 mm (Fig. 3).

Discussion

Within these hatchery conditions, quatrefoil traps affixed with artificial light sticks captured significantly more Paddlefish larvae than did unlit traps. From this evidence, we can infer that the larvae exhibited a positive phototactic response, the first such documentation for Paddlefish. Several published studies on other acipenseriform fishes (i.e., sturgeons) present mixed conclusions on photo-response. While some sturgeons are reported as photopositive in early larval stages (Gisbert and Ruban 2003;

Table 3. Results from pairwise comparisons of median total length for combinations of treatment (Lit, Unlit, Lit and Unlit traps pooled [All Traps], or Control [C]) and cohort (yolk-sac larvae [YSL] or exogenous feeding larvae [EFL]) using Wilcoxon Rank Sum test. Significantly different comparisons are identified with an asterisk (*) and Bonferroni-adjusted α is noted where used.

Group 1	Group 2	WRS	P-value	Bonferroni-adj. α
EFL-C	EFL-All traps	4,798	<0.001*	NA
EFL-C	EFL-Lit	4,566	<0.001*	0.025
EFL-C	EFL-Unlit	232	0.792	
EFL-Lit	EFL-Unlit	661	0.132	NA
YSL- C	YSL-All Traps	22,217	0.170	NA
YSL-C	YSL-Lit	17,910	0.202	0.025
YSL-C	YSL-Unlit	4,308	0.104	
YSL-Lit	YSL-Unlit	77,348	0.337	NA

Kynard et al. 2003; Zhuang et al. 2002, 2003), including the Pallid *Scaphirhynchus albus* and Shovelnose sturgeons *S. platorynchus* (Kynard, Henyey and Horgan 2002), whose Mississippi River ranges largely overlap with the Paddlefish, other species such as White Sturgeon *Acipenser transmontanus* and Amur Sturgeon *A. schrenckii* are reported as photonegative, particularly in the yolk-absorption phase (Parsley et al. 2002; Loew and Sillman 1998; Zhuang et al. 2003). Yet, some studies suggest that an abrupt shift in photo-response during early development

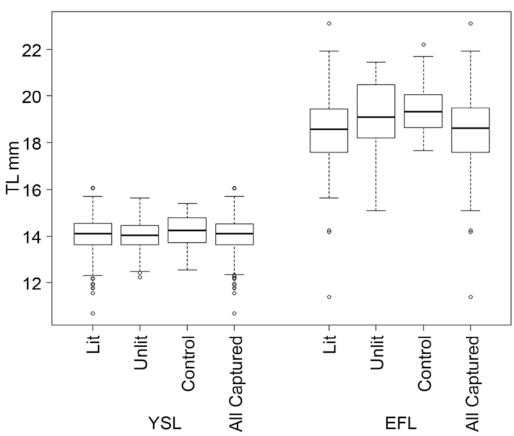

Figure 2. Box and whisker plot demonstrating similarities in Paddlefish larvae total length (TL) from lit traps, unlit traps, control samples, and all captured larvae (combined lit and unlit) for yolk-sac larvae (YSL) and exogenous-feeding larvae (EFL).

may be more prevalent than realized. Gisbert, Williot and Castello-Orvay (1999) found that Siberian Sturgeon *A. baeri* demonstrated positive phototaxis at 13d with a preference for lighter colored substrates and a denial of cover before shifting at 20d to a preference for concealment and darker colored substrates.

Similarly, Kynard, Henyey and Horgan (2002) found that Shovelnose Sturgeon in aquaria shifted from a photopositive behavioral response to photonegative at approximately 10d post-hatch. Zhuang et al. (2002) described a similar photic behavioral shift for Chinese Sturgeon *A. sinensis* in a laboratory, noting that free embryos (YSL) may benefit from avoiding benthic predators in the wild by swimming far above the substrate. Much remains to be

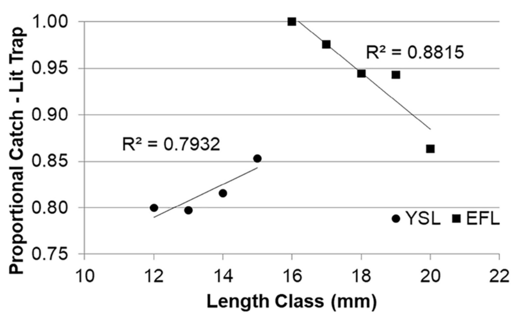

Figure 3. Lit trap proportional catch for Paddlefish yolk-sac larvae (YSL) and exogenous-feeding larvae (EFL) by 1-mm length groups with linear regression for each cohort.

learned about how these observed responses may differ with changes in light emissions, water temperature, turbidity, and current, as well as a host of other unidentified factors. Even more factors will influence the response in the wild (Marchesan et al. 2005).

The inconsistency in the strength of positive phototaxis observed among 1 mm length classes (Fig. 4) was similar to other studies with sturgeons (Kynard, Henyey and Horgan 2002; Zhuang et al. 2002). These data suggest that Paddlefish may exhibit a shift in photo-response. However, it is unknown if these inconsistencies by length indicate another type of behavioral shift or a developmental increase in swimming ability. The smaller size of the trapped EFL, compared to the control sample, suggests the possibility of a catchability bias for the light traps, where larger larvae may be less likely to enter the trap than smaller larvae due to physical constraints, rather than phototactic behavior. Additional, controlled investigations with larger, older EFL may provide evidence needed to thoroughly evaluate changes in catchability and photo-response for early life stages of Paddlefish.

The photic responses of larvae at different lengths as reported here for preserved larvae may have differed somewhat, had the measurements been taken for live fish. Shrinkage in TL by as much as 3.2% has been reported for White Sturgeon YSL preserved in 95% ethanol for 95 days (Bayer and Counihan 2001), however other studies using different species, preservatives, concentrations, and duration have provided mixed results of shrinkage and expansion of larvae specimens (Leslie and Moore 1986; Radtke 1986; Fey 1999) or geometric shape variations (Martinez, Berbel-Filho and Jacobina 2013). Though Bayer and Counihan (2001) advocate a length correction factor for White Sturgeon, no such study exists for Paddlefish. Therefore, speculation on the direction and magnitude of preservative bias on TL was improper and preserved lengths reported here are uncorrected.

The high incidence of phototaxis among all length classes evaluated here (≥79%) suggests that light trapping for Paddlefish larvae <20 mm TL has potential to increase catches in the wild. Before attempting to collect larvae in the wild, where low densities of larvae and high turbidities are typical (Russell 1986), additional, controlled examination in the hatchery of positive phototaxis in conditions of higher turbidity and lower larval density may better mimic natural conditions. Similarly, although YSL showed strong phototaxis in the controlled hatchery setting, obtaining a strong phototactic response of YSL in the wild may not be possible because of the limited directional swimming capabilities of this life stage (Jennings and Zigler 2009).

Targeting EFL (mean TL= 18.75 mm) may be more effective, especially considering their higher probability of capture in lit traps (94%) combined with greater swimming capabilities. Combining light-trapping efforts with consideration of ecological cues, life history requirements, and timing of spawning, hatching, and early development (Purkett 1961; Yeager and Wallus 1982; Jennings and Zigler 2009) may enhance capture success of Paddlefish larvae in wild conditions.

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