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The effect of temperature and substrate on the growth, development and survival of larval white sturgeon

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ABSTRACT

White sturgeon yolk sac larvae (YSL) were reared at 13.5 and 17.5 °C with and without gravel substrate. Larvae reared within the gravel emerged from the substrate after 11–14 days (depending on temperature), and all larvae were subsequently fed in bare tanks until 46 days post hatch (dph). Temperature and substrate significantly affected size; at 46 dph, fish reared in gravel at 17.5 °C were the largest (288 ± 19 mg), while fish reared at 13.5 °C without gravel were the smallest (107 ± 3 mg). Yolk absorption rate did not differ between substrate treatments but was greater at 17.5 °C than at 13.5 °C. In contrast, yolk absorption efficiency was independent of temperature but was significantly greater in gravel-reared larvae. YSL reared in gravel also had more lipid vacuoles in their liver. Substrate and temperature significantly affected survival. Greatest survival (84.6% ± 0.6%) was achieved when YSL were reared in gravel at 13.5 °C, and survival was lowest (46.6% ± 0.6%) when larvae were reared without gravel at 17.5 °C. Understanding factors that affect growth and survival during early life history provides insight into factors affecting wild recruitment and should improve hatchery production.

1. Introduction

White sturgeon (*Acipenser transmontanus*) are native to western North America and are found in the Sacramento, Columbia and Fraser Rivers. Within British Columbia, six populations have been recognized, four of which are listed as endangered under Canada's Species At Risk Act. The primary reason for population decline in three of these populations is recruitment failure (COSEWIC, 2013).The cause of low recruitment is not well understood, and the lack of a detailed knowledge of the behavior, ecology and habitat requirements for the early life history of these species continues to be a key limitation. Early life history mortality, prior to juvenile metamorphosis, is a major survival bottleneck for many species (Houde, 1987; May, 1974), and high larval mortality can be particularly acute during the transition between endogenous to exogenous feeding. This period is commonly viewed as critical, and survival can significantly affect recruitment (Houde, 1987). The size of fish when they begin exogenous feeding has also been cited as an important factor affecting survival and recruitment (Cushing, 1972). Based on the link between substrate changes and recruitment failure (McAdam et al., 2005), understanding the effect of environment on the growth and survival of larval sturgeon provides important information for understanding factors that affect recruitment.

Newly hatched sturgeon larvae have been described as exhibiting a swim-up and drift dispersal behavior (Conte et al., 1988; Kynard and Parker, 2005; Richmond and Kynard, 1995). Many prior studies, however, were conducted in the absence of suitable substrate or were gathered from drift net data from highly regulated rivers and may not reflect the behavior of larvae in a natural environment (McAdam, 2011). When cover has been provided, the sturgeon yolk sac larvae (YSL) of multiple species have been shown to use it. For example, Atlantic sturgeon (*Acipenser oxyrinchus*), shortnose sturgeon (*A. brevirostrum*) and white sturgeon (*A. transmontanus*) all seek cover shortly after hatch (Kynard and Horgan, 2002; McAdam, 2011). Comparison among substrates shows that both shortnose sturgeon and white sturgeon displayed drift behavior when YSL were prevented from seeking cover (McAdam, 2011; Richmond and Kynard, 1995). Gessner et al. (2009) not only found that larvae continued to swim until adequate substrate was found but also found that survival was higher when YSL were reared in gravel. Gravel substrate has also been shown to provide cover that reduces mortality due to piscine predation, including from benthic predators such as sculpin (Gadomski and Parsley, 2005; McAdam, 2011). Gravel substrates have long been known to be integral to the life histories of many riverine fish species, particularly for early life stages. Substrates have often been used in salmonid hatcheries in the culture of alevins, as this generally produces larger fry than rearing methods without substrate (Fuss and Johnson, 1982; Peterson and Martin-Robichaud,

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1995). Substrate may also play a significant role in the early life history of sturgeon, and a few studies have attempted to evaluate the potential effect of gravel rearing on sturgeon recruitment (Gadomski and Parsley, 2005; Gessner et al., 2009; McAdam, 2011; McAdam et al., 2005).

Temperature is also an important factor affecting the physiological function of ectotherms (Blaxter, 1992; Rombough, 1996), and changes in temperature will affect enzyme activity, metabolic rate, growth, development and even locomotory function (Fry, 1971). Little is known about the effects of temperature on the early life history of sturgeon, particularly larvae. Wang et al. (1987) found that egg incubation in Sacramento River white sturgeon was possible between 10 °C and 18 °C, with greatest survival to hatch between 14 °C and 16 °C. Van Eenennaam et al. (2005) found a similar thermal tolerance and optima for green sturgeon (*A. medirostris*) YSL and feeding larvae (FL). A study by Hardy and Litvak (2004) found that the survival of Atlantic and shortnose sturgeon FL was greater at lower temperatures, but growth increased with warmer temperature. As sturgeon generally hatch on a declining hydrograph after spring freshet, temperature can be expected to increase dramatically during their first month. The effect of temperature on growth and survival, therefore, may strongly influence year-class strength.

It is important to understand the effect of rearing environment on larval sturgeon development, as this information is vital for effective hatchery practices, particularly in conservation aquaculture, but also for habitat restoration to enhance natural propagation. Yet the interaction between substrate and temperature on white sturgeon YSL during incubation has not been examined previously. The objective of this study, therefore, was to determine how substrate and temperature influence growth, efficiency of endogenous energy use (rate of yolk absorption) and survival from hatch until 46 dph for the white sturgeon, a species listed as endangered in British Columbia, Canada.

2. Methods

2.1. White sturgeon larvae and broodstock

Broodstock from the Nechako River were caught in May 2009. To induce ovulation, female sturgeon were injected intramuscularly with mammalian GnRH analogue [d-Ala^6, Pro^9, NEthylamide]-mGnRH dissolved in physiological saline to induce ovulation using an initial dose of 5 μg/kg and a resolving dose of 45 μg/kg, 24 h in advance of the anticipated time of ovulation.

Eggs were collected and de-adheased as described by Conte et al. (1988). The eggs were evenly divided into three separate bowls and individually mixed with milt from three males (one male per bowl). Fertilized eggs from each cross were incubated separately at 15 °C in McDonald jars (J30, Aquatic Eco-Systems, Apopka, FL) in a streamside hatchery at Vanderhoof, British Columbia (operated by Freshwater Fisheries Society of British Columbia). All experiments were conducted in a separate field laboratory and maintained on a simulated natural photoperiod. YSL were transferred to experimental tanks at approximately 1 day post hatch (dph), which corresponded to 8 days post fertilization and 120 accumulated thermal units (ATU). Each tank contained 450 YSL, composed of 150 from each of three half-sibling family groups. Newly hatched fish were placed in plastic bags, floated on top of the experimental tanks and allowed to acclimate for 30 minutes before introducing the fish to the tanks.

2.2. Experimental tanks

Sturgeon were reared at two temperatures referred to as cool (13.5 °C ± 0.1 °C) and warm (17.5 °C ± 0.1 °C). These temperatures are representative of those experienced by sturgeon at hatch and shortly afterward in the Nechako River at Vanderhoof. Non-chlorinated municipal water (10.5 °C to 11.5 °C) was continuously added to each temperature system (680 L) to allow for partial exchange; 6%–9% of the water was exchanged per hour. Targeted temperatures were maintained in each head tank using multiple aquarium coil heaters (Hagen, Fluval Tronic, A-770, Montreal, QC). Temperature was measured hourly (Hobo water temperature pro V2, Onset, Bourne MA). A canister filter (Hagen Fluval 405) was placed in each header tank to maintain quality of recirculated water. Water quality measurements (dissolved oxygen, pH, temperature, ammonia and nitrates/nitrites) were also monitored daily throughout the experiment.

Experimental tanks were 36 × 25 × 20 cm (L × W × H) Rubbermaid tubs (Roughneck 2213, Oakville, ON). Water was supplied to each tank from a header and manifold system and drained from the tank sides through holes covered with 750 μm Nitex screening (Sefar, Heiden, Switzerland). Each tank was placed into a larger Rubbermaid tote (Roughneck 2547), and water was allowed to overflow into the tote. Water was pumped from the totes back into the header using a submersible pump (Little Giant 4E-34NR, Bluffton, IN). Two substrate treatments were used: gravel (3 cm depth) and no substrate (bare conditions). The gravel substrate and the grain size used were based in part on the findings of a white sturgeon YSL substrate preference study by Bennett et al. (2007) and from results of our previous work (Boucher and McAdam, unpublished). A mixture of gravel was used ranging in size from 12 to 22 mm on the longest axis. A preliminary study showed that deeper substrates sometimes trapped YSL; therefore, relatively shallow substrate depths (~3 cm) were used. Four replicate tanks were used per substrate treatment per temperature.

YSL (450) were introduced into each tank just after hatch (within 24 h) and monitored until 46 dph. Sturgeon YSL exhibit negative phototaxis (Conte et al., 1988; Loew and Sillman, 1998) and to minimize disturbance, tanks were partially covered with a dark plastic lid. All dead fish were removed immediately upon detection and recorded to calculate survival rates among treatments. Sturgeon reared in tanks with substrate emerged from the gravel to initiate exogenous feeding when the yolk was absorbed (approximately 330 ATU). After that time, FL from all treatments were transferred to bare tanks and fed a combination of equal parts EWOS zero (EWOS Canada Ltd., Surrey, BC), powdered krill and Cyclop-eeze (Argent Chemical Laboratories, Redmond, WA). All larvae were fed to satiation twice daily. All sampling procedures were approved by the University of Northern British Columbia Animal Care and Use Committee.

2.3. Size, condition factor and growth

Weight (mg) and total length (mm) were determined for 8 larvae from each tank every 4 days. All fish were terminally anesthetized in 200 mg·L^{-1} tricaine methane sulfonate buffered with 400 mg·L^{-1} sodium bicarbonate. Total length was measured for each fish using digital calipers viewed under a dissecting microscope and weight determined to 0.1 mg. All fish were patted dry using paper towel prior to being weighed. After length and weight measurements, fish were preserved in 10% phosphate buffered formalin for histological analysis. Data were not collected for weight and length from warm water treatments at 43 dph (872.5 ATU). Condition factor was calculated as $K = 100(\mathrm{W}\cdot\mathrm{L}^{-3})$. The difference in growth rate for the two treatments was estimated using the temperature coefficient, Q_{10}, calculated from specific growth rate estimates using the following equation:

$$Q_{10} = \left(\frac{SGR_2}{SGR_1}\right)^{10/(T_2 - T_1)}$$

where SGR is the specific growth rate and T is the temperature. Specific growth rate was calculated using the following equation:

$$\mathrm{SGR} = 100\left(\frac{\ln W_{t_2} - \ln W_{t_1}}{t_2 - t_1}\right)$$

where W is weight at 46 dph (t_2) and initial weight at hatch (t_1).