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Effects of simulated cold fronts on the survival and behaviour of yellow perch *Perca flavescens* yolk-sac fry

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Summary

Acute reductions in water temperature (i.e. cold fronts) may influence larval fish survival directly via limits on physiological tolerance or indirectly by acting as a sublethal stressor. The primary objective was to quantify survivorship of yellow perch yolk-sac fry exposed to two different temperature declines (4 and 8°C) and compare survivorship to that of perch fry under ambient temperatures representative of natural conditions. Behaviour of yolk-sac fry following temperature declines was also qualitatively assessed. Mean survival in the control, –4, and –8 treatment tanks was 90, 91 and 97%, respectively, and no significant differences in percent survival were observed between the control and the –4 treatment ($t_s = -0.10$; $df = 7$; $P = 0.93$), the control and –8 treatment ($t_s = -1.85$; $df = 7$; $P = 0.11$) or the –4 and –8 treatments ($t_s = -1.33$; $df = 7$; $P = 0.22$). Observations of yellow perch eggs and fry behaviour following temperature declines differed among treatments. Any remaining eggs in the control treatment and –4 treatments continued to hatch during the experiment, and fry were documented swimming throughout the water column in all tanks. However, in the –8 treatment, any eggs that had not hatched remained inactive and all fry within all –8 treatment tanks ceased swimming activity and settled to the bottom of the tanks once the temperature reached 3.9°C. Fry remained at the bottom of the tanks for the entire 48 h simulated cold-front. Fry resumed swimming activity once water temperatures began to increase (by approximately 6°C). Results indicated that drops in temperature (i.e. cold fronts) similar to or greater than those found in small impoundments did not cause direct mortality of yellow perch during the yolk-sac fry (post-hatch larvae) stage. Although an acute drop in temperature may not induce sudden high mortality, it may be a sub-lethal stressor, leading to increased starvation or predation risk.

Introduction

Early life stages of *r*-selected fishes such as yellow perch (*Perca flavescens*) and Eurasian perch (*Perca fluviatilis*), which produce large numbers of small progeny with little parental investment, may be especially influenced by biotic and abiotic effects. Recruitment of yellow perch and Eurasian perch, both ecologically and economically important species, is highly variable among systems (Mills and Hurley,

1990; Lucchesi, 1991; Persson et al., 2000; Wilberg et al., 2005; Isermann et al., 2007) and years (Forney, 1971; Sanderson et al., 1999; Ward et al., 2004).

Climatic variables such as water temperature have been suggested to influence larval yellow perch recruitment (Clady, 1976; Pope et al., 1996; Ward et al., 2004; Longhenry et al., 2010), and catastrophic climatic events during early life stages have been suggested to reduce year-class strength of yellow perch (Isermann and Willis, 2008). Because water temperature has been suggested as a predominant factor influencing survival of yellow perch during critical periods (Eshenroder, 1977; Kallemeyn, 1987; Ward et al., 2004; Longhenry et al., 2010), we chose to focus our research on this factor. Jansen et al. (2009) found that decreasing water temperature did not affect hatch success of yellow perch eggs and suggested that future research should focus on the effects of acute temperature drops (i.e. simulated cold fronts) on yolk-sac fry (i.e. immediately post-hatch larvae) perch.

Acute reductions in temperature (i.e. cold fronts) are often the result of the convection of warm, moist air above a mass of cool, low-pressure air (Browning and Monk, 1982). Aside from an abrupt reduction in temperature, cold fronts are often characterized by high wind speeds and a band of precipitation at the leading edge of the low-pressure air mass (Browning and Monk, 1982). Cold fronts have previously been implicated as adversely affecting larval yellow perch survival and recruitment. In a study of yellow perch production in semi-permanent South Dakota wetlands, Longhenry (2006) attributed the lack of larval perch to a cold front that decreased water temperature from 12°C to 7°C over a period of 24 h during the time when eggs were thought to hatch. Similarly, Jolley (2009) hypothesized that a 2005 yellow perch year-class failure in Pelican Lake, Nebraska may have been caused by a cold front that decreased water temperatures from 17°C to 6°C during a period of 14 d that coincided with hatching.

Thus, our primary objective was to quantify survivorship of yellow perch yolk-sac fry exposed to two different reductions in temperature and compare survivorship to that of perch fry under ambient temperatures. We also qualitatively assessed swimming behaviour of yolk-sac fry following the temperature reductions. We hypothesized that fry survival would vary depending on magnitude of the temperature reduction. Specifically, survival was expected to be inversely related to the magnitude of temperature reduction. Moreover, fry were expected to elicit a behavioural response to acute temperature reductions (i.e. ceasing of normal swimming behaviour and settling to a static position near the

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substrate-water interface) that may induce mortality due to factors including, but not limited to, predation, starvation (reduced foraging ability), suffocation (settling to anoxic layer), or mechanical damage due to wind or wave action, emphasizing the overall importance of acute temperature reductions as a sublethal stressor.

Materials and methods

Survivorship following simulated cold-fronts

We collected yellow perch egg skeins (i.e. coiled egg masses held in a gelatinous membrane) from Lake Tunkashila, a 9.2 h a private impoundment in Brookings County, South Dakota during the last week of April 2009. To ensure that all skeins were less than 24 h old, we identified spawning locations and removed all skeins from the spawning substrate. We returned less than 24 h later, collected new skeins from the spawning sites and brought them to the laboratory at South Dakota State University (SDSU). All skeins were allowed to be fertilized naturally in the lake. Water temperature in the lake at the time of egg removal was 12.8°C. Upon arrival at the laboratory, skeins were cut into sections (4.1–14.2 g) using a pair of scissors, and weighed (g). To estimate the number of eggs contained in each section of skein, we retained one to two reference sections from each skein collected in April 2009. To improve predictability in the number of eggs per mass of skein, additional skeins were collected during the last week of April 2011 from the same impoundment and using the same methods as described previously. Skein sections were weighed and placed in an individually labeled jar containing 80% ethanol. Upon fixation the total number of eggs in each section was enumerated. We then used simple linear regression to estimate the number of eggs per gram of skein.

Following weighing, skein sections were randomly assigned to tanks exposed to one of three treatments: control (initial ambient temperature; approximately 11.5°C), a 4°C decrease (–4 treatment), and an 8°C decrease (–8 treatment) to simulate moderate and severe acute temperature declines. These treatments were selected to encompass a range of temperatures similar to those documented in small lakes and impoundments in the Great Plains region, USA (Jolley and Willis, 2009; Fig. 1). Ambient water temperatures were representative of natural conditions (lake water temperature during egg skein collection was 12.8°C and experimental ambient temperatures ranged from 11.5 to 12.6°C). Seven skeins (from seven different females) were used for this experiment to minimize potential maternal and paternal effects and to encompass the potential variation in fertilization rates among males. Sections from five, six, and seven skeins were randomly assigned to the control, the –4 treatment, and the –8 treatment, respectively. To determine if mean skein weight differed among treatments we conducted *t*-tests with an alpha of 0.05. Each treatment consisted of an individual flow-through system with an independent head tank, an independent chiller unit, and eight, 38-L rectangular glass aquaria (eight replicates per treatment). Each tank contained an individual air stone, and a mesh screen egg basket where the skein sections were placed. In each tank, the egg basket was placed in a similar position relative to the air stone and water source to allow for similar incubation conditions (i.e. hydrodynamics and oxygen diffusion kinetics). Water temperature in the 38-L tanks was 11.7°C when the eggs were placed in the tanks. Additionally, a Hobo data logger (Onset Computer Corporation, Bourne, MA 02532)

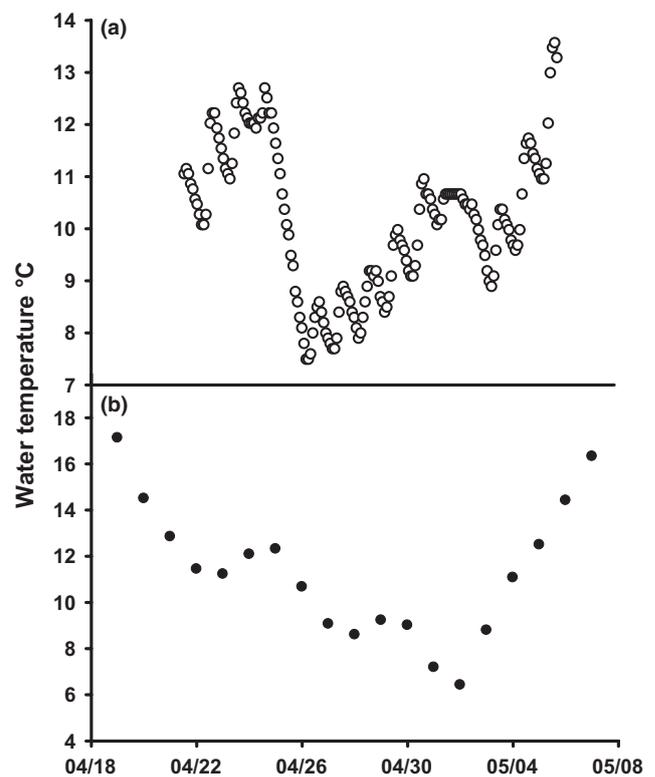


Fig. 1. Water temperature data (taken every two hours) from Lake Tunkashila, South Dakota (a), 21 April–5 May 2008 and mean daily water temperatures, Pelican Lake, Nebraska (b; Jolley and Willis, 2009), 19 April–7 May 2005

was placed in nine of the 24 tanks (i.e. three loggers per treatment). Water temperature was recorded every 15 min on all nine loggers to estimate mean hourly water temperatures for each treatment throughout the study.

Throughout the course of the experiment skein sections were cleaned using aeration to prevent fungus from forming. Eggs in all treatments were held at approximately the same constant temperature (ranging from 11.5 to 12.6°C) for 12 days. Tanks were observed three to four times each day, and any mortalities of fry were removed and recorded. After 12 days, a majority of the eggs had hatched in all treatments and at that time, water temperature in the –4 treatment and –8 treatment tanks was dropped from 12.6 to 8.6°C (0.36°C h⁻¹) and from 11.9 to 3.9°C (0.73°C h⁻¹), respectively (Fig. 2). Mean (\pm SD) water temperature in the control tanks was 12.5 \pm 0.1°C throughout the duration of the experiment. Water temperature in the –4 and –8 treatment tanks was held at 8.6 and 3.9°C, respectively, for 48 h, then allowed to return naturally to 12.5°C over a period of approximately 18 h. The experiment continued for an additional 24 h, after which all living yellow perch fry were collected from each tank, removed and placed into scintillation vials containing 95% ethanol. After fixation, all fry were enumerated.

Larval survivorship after hatching was calculated by dividing the number of fry alive at the end of the experiment by the number of fry that successfully hatched during the course of the experiment. This value was multiplied by 100 to obtain the percent of survivorship. Percent fertilization of individual eggs in each skein was not known (eggs were fertilized naturally) and was assumed to be equal across all skein sections. To test for differences in survivorship among treatments we used paired *t*-tests with $\alpha = 0.05$.

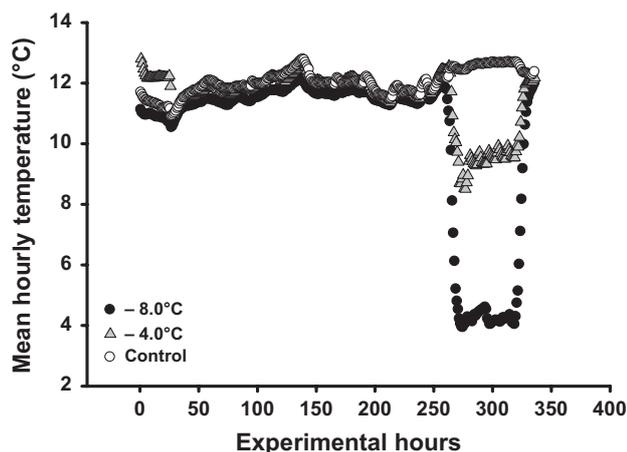


Fig. 2. Mean hourly water temperature recorded on temperature loggers placed in three tanks per treatment throughout duration of the study. Water temperature recorded every 15 min to estimate mean hourly water temperatures for each treatment throughout the study

Behavioural observations

Tanks were observed approximately every 4 h for approximately 10 min from the onset of the temperature decline to the end of the experimental period (24 h after water temperatures re-warmed to ambient room temperature, 11.5–12.6°C) to qualitatively assess the impacts of declining temperatures on the behaviour of yellow perch yolk-sac fry. We observed whether or not fry were swimming throughout the water column or whether the colder water temperatures reduced activity of the fry.

Results

We retained 12 reference skein sections in 2009 and an additional 11 skein sections in 2011 to develop our regression model. Skein sections collected during 2009 (used in the experiment) weighed between 4.1 to 14.2 g. Although there was a variation in skein size (and therefore the number of eggs) among replicates within treatments, the variation was consistent across treatments due to the random assignment of egg skein sections to each aquarium. Mean (\pm SD) weight of egg skein sections in the control, -4 , and -8 treatments was 9.8 (3.2) g, 8.5 (2.7) g, and 7.8 (2.2) g, respectively, and did not differ statistically among treatments. Skein sections collected during 2011 (only used to develop regression model) weighed between 2.7 and 15.0 g. We found a significant relationship when skein weight (g) was plotted against total number of eggs ($y = 147.7x + 146.1$, $r^2 = 0.80$, $P < 0.001$). Using the regression equation provided, we estimated that the total number of eggs per tank during the experiment ranged from 752 to 2628.

Mean survival in the control, -4 , and -8 treatment tanks was 90, 91 and 97%, respectively (Fig. 3). No significant differences in percent survival were observed between the control and the -4 treatment ($t_s = -0.10$; $df = 7$; $P = 0.93$), the control and -8 treatment ($t_s = -1.85$; $df = 7$; $P = 0.11$) or the -4 and -8 treatments ($t_s = -1.33$; $df = 7$; $P = 0.22$).

Qualitative observations of yellow perch fry following temperature declines differed between treatments. Any remaining eggs in the control treatment and -4 treatments continued to hatch during the experiment and yellow perch fry were documented swimming throughout the water column in all

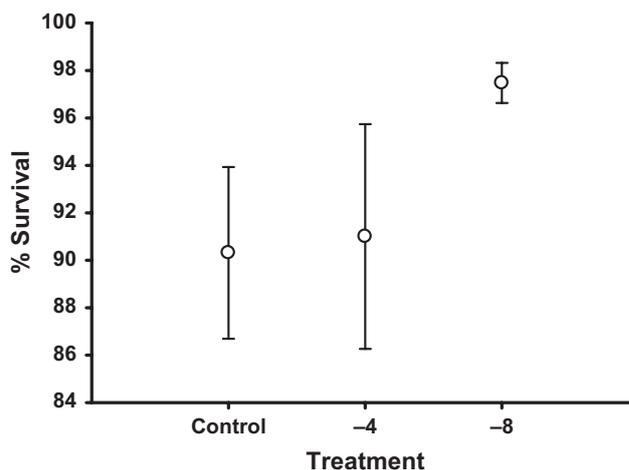


Fig. 3. Mean (\pm SD) survival of yellow perch yolk-sac fry from three different temperature regimes (control, -4°C treatment, and -8°C treatment) over the course of 16 d. Temperature drops occurred on day 12 of the experiment; means computed from 8 replicates per treatment

tanks. However, in the -8 treatment, any eggs that had not hatched remained inactive. Additionally, all fry within all the -8 treatment tanks ceased swimming activity and settled to the bottom of the tanks once the temperature reached 3.9°C . Fry remained at the bottom of the tanks for the entire 48 h simulated cold-front. However, once water temperatures began to increase (by approximately 6°C), fry began to resume swimming activity.

Discussion

Our results indicated that drops in temperature (i.e. cold fronts) similar to or greater than those found in small Great Plains USA impoundments did not cause direct mortality of yellow perch during the yolk-sac fry (post-hatch larvae) stage. Cold temperatures during early life stages have been suggested to negatively influence year class strength in yellow perch in both small wetlands (Longhenry et al., 2010) and in natural glacial lakes (Clady, 1976; Ward et al., 2004). However the mechanisms causing year-class failures and recruitment variability remain obscure (Isermann and Willis, 2008). In contrast, Jansen et al. (2009) found that similar levels of temperature drops used in this study did not significantly affect hatching success in yellow perch eggs. Their results, coupled with results presented herein, suggest that yellow perch have potentially evolved to withstand substantial changes in water temperatures during their early life history.

While temperature declines may not have significantly increased mortality, it was interesting to note the qualitative differences in behaviour that existed among treatments. The fact that eggs continued to hatch in both the control and -4 treatments suggests that drops in temperature of less than 4°C likely will not negatively impact yellow perch hatch success (Jansen et al., 2009). Additionally, while the simulated cold-front was occurring, fry remained active and were found throughout the water column in both the control and -4 treatments. However, during the simulated cold-front no eggs in the -8 treatment were documented as hatching and all yolk-sac fry in the -8 treatment tanks observed during the cold-fronts became inactive and settled to the bottom of the glass tanks for the duration of the cold-front. Following the cold-front, when water temperatures in the tanks

rose, the fry began swimming again. Because our analysis was qualitative, inferences based on the behavioural responses of larval yellow perch to temperature reductions are limited, and an obvious research directive would be to quantify patterns in larval activity with decreasing temperatures. Nonetheless, these results indicate that while temperature drops may not be the mechanism causing mortality in juvenile fishes, it may be a sub-lethal stressor.

Decreased temperatures during larval development have been shown to reduce swimming ability of larval herring (*Clupea harengus*) and plaice (*Pleuronectes platessa*; Batty and Blaxter, 1992), potentially making them more susceptible to predation. Further, cold temperatures have been shown to slow development and cause phenotypic change in larval fish, likely making them susceptible to predation over a longer time period (Betsill and Van Den Avyle, 1997; Galloway et al., 1998; Benoît and Pepin, 1999; Mischke et al., 2001; Kamiński et al., 2006). Furthermore, cold-fronts could induce larval mortality by means of mechanical damage from wind or wave action, and settling to anoxic sediment layers may result in mortality for wild populations. Further research is needed to elucidate potential mechanisms of larval fish mortality stemming from cold-fronts and other climatic phenomena.

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