Quantifying a potential mechanism between ice cover and cisco recruitment success: what role does light play in cisco embryonic development?

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**ABSTRACT:**

**INTRODUCTION:**

Freshwater whitefishes, Salmonidae Coregoninae (hereafter coregonines) have played important economic and ecological roles throughout the northern hemisphere (REFS). Over the past 35 years, coregonine populations worldwide have experienced declines due to highly variable and weak year-class strengths (Nyberg et al. 2001, Myers et al. 2015). Historical coregonine declines have been attributed to overfishing, invasive species, habitat alterations, and competition (Stockwell et al. 2009, Rosinski et al. 2020, Lucke et al. 2020). However, actual reasons for contemporary declines remain unknown, but climate-induced changes in early-life stage environments have been hypothesized, and winter ice and water temperature regimes have changed over the past 20 years or more (Austin and Colman 2007, O’Reilly et al. 2015). In the Laurentian Great Lakes, native coregonine conservation and restoration efforts are at the forefront of fisheries management efforts (REFS). Future climate change predictions show that the timing and physical characteristics of winter and ice regimes are likely to drive some of the most important biological changes (REFS).

Year-class strength in most fish species, including coregonines, is thought to be established prior to the end of the first season of growth (Hjort 1914, Cushing 1990). Unlike larvae, embryos are static, leaving this early-life stage vulnerable to predation (Stockwell et al. 2014) and unable to evade inter-annual variation in winter conditions (REFS). Most coregonines are autumn spawners whose embryos incubate under ice throughout the winter and hatch in spring (REFS). Changes in winter severity and ice cover could alter developmental rates, embryo survival, and time of hatching (REFS). Potential mechanisms by which ice cover might influence cisco development include the reduction of physical wave action (REFS), lower and more stable winter and spring water temperatures (REFS), and less sunlight reaching the lake bottom (REFS). Recent changes in ice cover coupled with poor coregoninerecruitment has led to speculation about the relationship between ice cover and embryo survival for decades with limited rectification. In Lake Superior, all known cisco spawning locations are estimated to be covered when lakewide ice cover reaches 15% (Figure 1, Goodyear 1982), and nearly all lakes with known populations of coregonines are seasonally ice-covered (REFS). Therefore, understanding how variable and declining ice regimes may impact coregonine early-life history is an important aspect of coregonine conservation and restoration efforts.

Lake ice cover can also play a critical role in physical and ecological processes (Sharma et al. 2020). The formation and breakup of ice are important to signal seasonal events (REFS), such as the onset of spring plankton (REFS). As ice thins in the spring, increasing levels of sunlight under the ice can drive plankton blooms suspended in the photic zone (REFS, Kelley 1997, Yang et al. 2020). Earlier ice-off has been shown to lead to earlier spring plankton bloom (Adrian et al. 2006, Sommer et al. 2012, Yang et al. 2016), and emphasizes the role winter and ice regimes can have on seasonal succession.

Increases in spring water temperature and ice breakup cues the onset of hatching in autumn-spawning coregonines (Häkkinen et al. 2002, Urpanen et al. 2005, Karjalainen et al. 2015). Synchronization of coregonine hatching and spring plankton blooms is critical to match optimal nursery feeding conditions (Hjort, Myers et al. 2015). Larval coregonines can withstand extended periods after hatching without feeding, but the time until exogenous feeding is relative to the amount of available maternal yolk for endogenous feeding (Lucke et al. 2020, Fuiman 2002). However, increased metabolic rates during embryogenesis can compromise the amount of yolk retained (REFS).

As ectotherms, fish metabolism and nearly all other biological rates increases exponentially with temperature (Brown et al. 2004, Gillooly et al 2002). Ontogenetic development and coregonines are no exception to this rule. However, light intensity has been shown to be an additive effect to temperature in regulating embryo development and growth rates (Kwain 1975). Ice thickness and snow impact light penetration into the water column (Hampton et al. 2015), and can reduce light transmittance from 83% in open water to 62% under ice coverage, and to ≤ 10% under snow and ice coverage (Bolsenga and Vanderploeg 1992). Consequently, increased light during winter, as a result of reduced ice and snow cover, could lead to an additional stressor during coregonine embryo development. Understanding the role ice has, given the recent high variability observed in coregoninerecruitment, can help predict what the future of these species may look like under current climate trends to inform restoration efforts.

We experimentally measured how cisco embryos responded to different ice regimes. Our objective was to identify to what extent light, as a proxy for ice, influences cisco embryo survival, incubation duration, yolk-sac volume and length at hatching. We hypothesized that exposure to elevated light intensity (low ice cover) would accelerate embryogenesis, resulting in smaller yolk-sacs and lower larval survival. Populations adapted to lower light levels are expected to experience more negative impacts from increasing light intensity.

**METHODS:**

Study Species and Locations

Cisco were collected from Lake Superior, near Bayfield, Wisconsin, and Lake Ontario, Chaumont Bay, New York, in December 2019. Lakes Superior and Ontario were chosen as they have differential spawning habitat for cisco. Lake Superior cisco spawn at deep depths, likely below the photic zone, with no known preference in habitat. Lake Ontario cisco spawn in shallow, protected bays on rocky shoals. Ice conditions over spawning grounds between the two lakes vary based on depth, with shallower and more protected spawn grounds likely to have more consistent ice coverage than deeper, open waters. Lakes Superior and Ontario provide a contrast in ice cover and subsequent light exposure to coregonine embryos.

Crossing Design and Fertilization

Eggs and milt will be stripped from 12 females and 16 males and artificially inseminated to create 48 families from each lake. Fertilized eggs will be transported overnight to the University of Vermont (UVM) where all laboratory work was conducted. Fertilization success will be assessed within 48-hours post-fertilization and unsuccessful families removed. Embryos from successful families ﻿will be divided among three light treatments and individual embryos randomly distributed into three 24-well microplates. Light treatments will represent 90-100, 40-60, and 0-10% ice cover and follow daily photoperiods. Incubation light levels will be based on measured lakebed light intensity data collected by the proposal authors throughout the entirety of Lake Superior’s 2016 and 2017 ice seasons. Embryos will be incubated at a constant temperature of 4.0°C in climate-controlled chambers.

Newly-hatched larvae will be photographed, and the images then used to measure total length-at-hatch (mm) and yolk-sac volume (mm3). The relationship between embryonic life history traits (incubation period, length-at-hatch, yolk-sac volume) and incubation light treatments between lakes will be analyzed using linear mixed models and ANOVAs. A sib analysis (Falconer and Mackay 1996) will be used to assess the relative role heritability (variation within sibling families) and the common environment (light) played in effecting the measured life history traits.

Rearing Conditions

Larvae will be moved from microplates to rearing tanks by lake and incubation light treatment and exposed to the same photoperiod cycle (*i.e.,*12-hr light, 12-hr dark) with gradual sunrise and sunset transitions. Larvae will be reared in 150-L oval recirculating tanks at 10°C and provided dry feed *ad libitum*. At three months post-hatch, total length and weight of all larvae will be measured. Mean daily growth increment will be calculated as (mean final length – mean length-at-hatch)/duration of the larval experiment to assess how incubation light intensity impacted subsequent larval growth.

**RESULTS:**

**DISCUSSION:**

**LITERATURE CITED:**

**TABLES:**

Table X. Likelihood ratio test output for each model selected for embryo survival (%), incubation period (number of days post-fertilization; DPF), incubation period (accumulated degree-days; ADD), length-at-hatch (mm), and yolk-sac volume (mm3) from Lakes Superior and Ontario cisco (*Coregonus artedi*). pop indicates population. The full model that was selected is bolded for each trait.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trait | Model | Effect Tested | df | χ2 | p-value |
| Embryo Survival | **light+ pop** |  |  |  |  |
| pop | light | 2 | 181.92 | < 0.001 |
|  | light | pop | 1 | 95.00 | < 0.001 |
| Incubation Period (DPF) | **light + pop + light:pop + dam:sire + dam + sire** |  |  |  |  |
| pop + dam:sire + dam + sire | light | 2 | 11.12 | 0.004 |
| light + dam:sire + dam + sire | pop | 1 | 2974.54 | < 0.001 |
|  | light + pop + dam:sire + dam + sire | light:pop | 2 | 10.75 | 0.005 |
|  | light + pop + light:pop + dam + sire | dam:sire | 1 | 84.36 | < 0.001 |
|  | light + pop + light:pop + dam:sire + sire | dam | 1 | 25.07 | < 0.001 |
|  | light + pop + light:pop + dam:sire + dam | sire | 1 | 10.78 | 0.001 |
| Incubation Period (ADD) | **light + pop + light:pop + dam:sire + dam + sire** |  |  |  |  |
| pop + dam:sire + dam + sire | light | 2 | 56.01 | < 0.001 |
| light + dam:sire + dam + sire | pop | 1 | 3,041.75 | < 0.001 |
|  | light + pop + dam:sire + dam + sire | light:pop | 2 | 17.39 | < 0.001 |
|  | light + pop + light:pop + dam + sire | dam:sire | 1 | 84.44 | < 0.001 |
|  | light + pop + light:pop + dam:sire + sire | dam | 1 | 10.76 | 0.001 |
|  | light + pop + light:pop + dam:sire + dam | sire | 1 | 25.03 | < 0.001 |
| Length-at-Hatch | **pop + dam + sire** |  |  |  |  |
| dam + sire | pop | 1 | 334.33 | < 0.001 |
|  | pop + sire | dam | 1 | 74.32 | < 0.001 |
|  | pop + dam | sire | 1 | 6.80 | 0.009 |
| Yolk-sac Volume | **light + pop + light:pop + dam + sire** |  |  |  |  |
| pop + dam + sire | light | 2 | 7.18 | 0.028 |
| light + dam + sire | pop | 1 | 712.29 | < 0.001 |
|  | light + pop + dam + sire | light:pop | 2 | 26.84 | < 0.001 |
|  | light + pop + light:pop + sire | dam | 1 | 130.50 | < 0.001 |
|  | light + pop + light:pop + dam | sire | 1 | 2.87 | 0.090 |

**FIGURES:**