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The Influence of Incubation Temperature on Aerobic Swimming Performance of Juvenile Salmonids

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Project Summary

Salmonid populations in California have rapidly declined in the past century, in large part due to dams and water diversions that block critical habitat and increase water temperatures in remaining habitat. Recent work shows that salmonids exposed to high temperatures during incubation have decreased thermal tolerance later in life. Thermal tolerance has been linked to an organism's ability to deliver oxygen to its cells. Based on this, we hypothesized that fish exposed to high temperatures early in development would exhibit reduced aerobic performance later in life, as compared to fish incubated lower temperatures. We also hypothesized that this difference would be magnified when fish were swimming in high temperature waters. Aerobic performance is an ecologically relevant metric because it determines how much energy an organism can devote to activities related to survival and reproduction, such as foraging, growth, migration, and predator avoidance. To test our hypotheses, we incubated *Oncorhynchus mykiss* (Rainbow trout) eggs at three different temperatures. After hatch, we measured swimming metabolism at a range of swimming trial temperatures. We found that contrary to expectations, incubation temperature did not have a significant effect on thermal tolerance or aerobic performance of juvenile *O. mykiss* at the range of temperatures examined in this study. Student researchers are currently completing a similar study using *O. tshawytscha* (Chinook salmon), which is scheduled for completion in summer 2018.

Research Program

Background

Habitat degradation and the onset of climate change are introducing organisms to novel environmental conditions that they have not historically experienced. The ability of an organism to respond to these changes determines the persistence and success of a population in the future. In California, populations of salmonids have dramatically declined over the past century, with the greatest decrease occurring since the construction of major dams and water diversions in 20th century. These dams have blocked critical habitat for salmonids, and have led to altered water characteristics in the remaining habit, including increases in water temperature. We know that increases in water temperature are tied to mortality and reduced reproductive success in these fish, but there is still much unknown about their capacity to deal with temperature stress on both an individual level and on a population level.

Some plasticity has been documented in salmonid life histories, meaning that they can exhibit different characteristics depending on the environmental conditions that they experience. In some cases plasticity can be adaptive, allowing an organism to immediately respond to environmental conditions, unlike genetic changes that occur at the population level on a slower generational time scale. However, one recent study has indicated that while Pacific salmon do exhibit plasticity in response to high temperatures during egg incubation, this plasticity is maladaptive. Rather than inducing physical changes that increased their ability to function in high temperature environments, fish that were exposed to high temperatures early in development had lower thermal tolerances later in life. Another body of research has suggested that thermal tolerance is a function of an organism's ability to successfully deliver oxygen to its cells. Based on this, we hypothesized that the aerobic capacity be reduced in fish that were exposed to high incubation temperatures, and that this difference would be magnified if the fish were swimming in high temperature waters. Reduced aerobic performance can be harmful to an organism because it reduces the amount of energy an organism can devote to activities related to survival and reproduction, such as foraging, growth, migration, and escaping from predators.

This research examines the thermal tolerance and swimming metabolism of *Oncorhynchus mykiss* (rainbow trout) and *Oncorhynchus tshawytscha* (Chinook salmon) that were incubated at a range

of temperatures. First we tested whether the relationship between incubation temperature and thermal tolerance in our fish was similar to that observed in studies of closely related species. We then examined whether fish incubated at high temperatures had a lower aerobic scope than those incubated at low temperatures, and whether this difference was magnified when swimming at warmer temperatures. Methods and results for *O. mykiss* are reported here. Trials with *O. tshawytscha* are ongoing.

Methods

We collected fertilized *O. mykiss* eggs from the Mt Shasta hatchery and transported them to the California State University, Chico salmon facility for incubation. Eggs were incubated at 10, 12.8, and 15.6°C. After button-up, juvenile fish were transferred to 10°C holding tanks. When fish were approximately three months old, their critical thermal maximum (CTmax) was tested by slowly increasing the water temperature until the fish lost equilibrium. Oxygen consumption (MO_2) was measured on a different subset of fish using a Loligo Systems mini-swim respirometer (www.loligosystems.com). For each swimming trial, a fish was introduced to the working section of the respirometer and allowed to acclimate overnight at a low water speed. After the acclimation period, resting oxygen consumption (MO_{2rest}) was measured. Subsequently, fish were exposed to progressive incremental increases in swimming speed until they fatigued. Maximum oxygen consumption (MO_{2max}) was estimated using the highest MO_2 measured during the swimming trial. Aerobic scope of the individual was calculated as (MO_{2max} - MO_{2rest}). Each fish was tested at a range of temperatures between 10 and 15.6°C in order to examine the interaction between incubation temperature and aerobic performance across a range of temperatures after hatch.

Results

1. Survival to button-up was marginally higher in the low incubation temperature treatment (10°C = 92.4%, 12.8°C = 89.3 %, 15.6°C = 89.2%)
2. Incubation temperature did not significantly influence thermal tolerance (CTmax) after hatching (Figure 1A, one-way ANOVA: $F_{2,57} = 0.846$, $p=0.435$, $\eta 2=0.029$)
3. Fish mass had a small, but significant positive relationship with CTmax (Figure 1B, Linear Regression: $F_{1,58} = 4.158$, $p=0.046$, $R^2=0.067$)

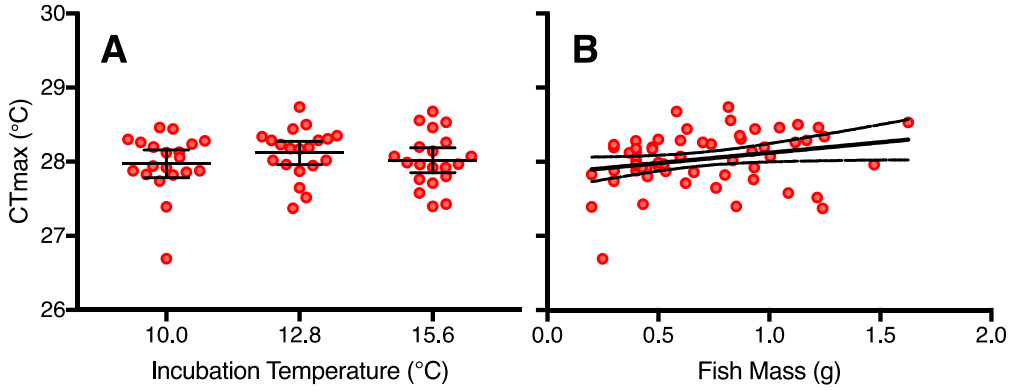

Figure 1. Thermal tolerance (CT max) was not affected by incubation temperature (A), but it did have a small, significant positive relationship with fish mass (B).

4. Within the temperatures examined in this study, incubation temperature did not significantly affect MO_{2rest} (slopes: $F_{2,16} = 0.7174$, p=0.5031; elevations/intercepts $F_{2,18} = 2.773$, p=0.0892), MO_{2max} (slopes: $F_{2,16} = 0.1847$, p=0.8331; elevations/intercepts $F_{2,18} = 1.796$, p=0.1944), or aerobic scope (slopes: $F_{2,16} = 0.04551$, p=0.9556; elevations/intercepts $F_{2,18} = 0.2907$, p=0.7512) of juvenile *O. mykiss* after hatching. Because of this, incubation temperature treatment groups were pooled to examine the effect of aerobic trial temperature.
5. Within the temperatures examined in this study, MO_{2rest} and MO_{2max} increased as aerobic trial temperature increased (Figures 2A & 2B, Linear Regressions. MO_{2rest}: $F_{1,20} = 8.565$, p=0.0083, R^2=0.2999; MO_{2max}: $F_{1,20} = 5.578$, p=0.0284, R^2=0.2181). Aerobic scope was not significantly influenced by temperature (Figure 2C, Linear Regression: $F_{1,20} = 0.9265$, p=0.3473, R^2=0.04427).

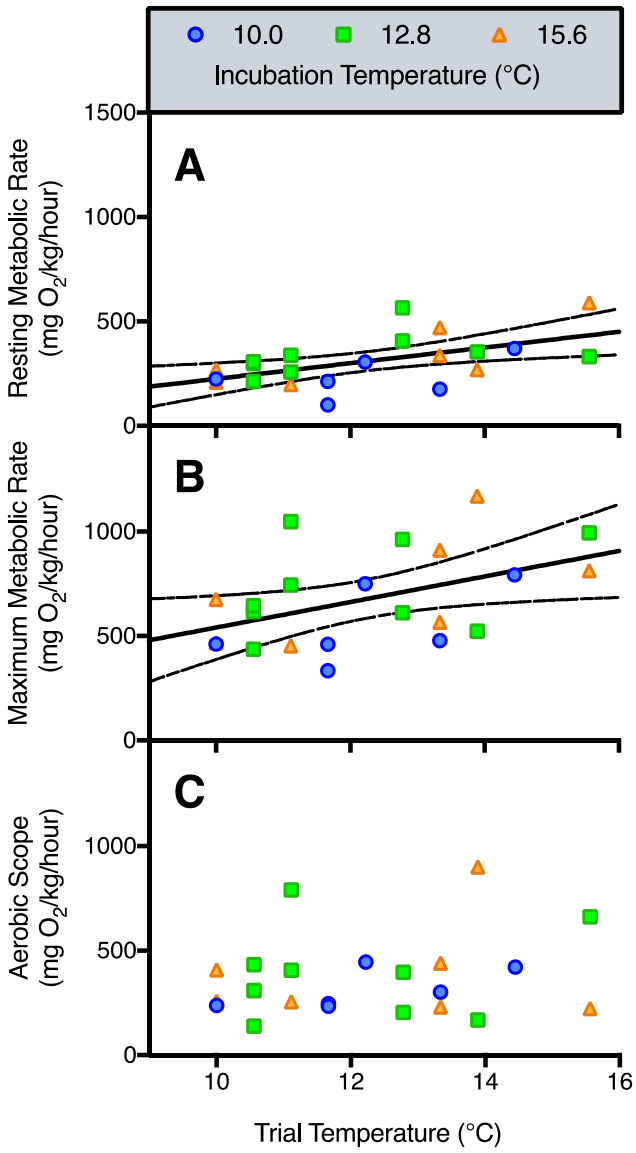

Figure 2. Resting and maximum metabolic rates increased with aerobic trial temperature (A & B), but aerobic scope was not affected by aerobic trial temperature. Incubation temperature did not have a significant effect on any aerobic performance metric.

Discussion

Contrary to expectations, incubation temperature had no effect on thermal tolerance or aerobic performance of the *O. mykiss* in our study. One possible explanation for this is that the effect of incubation temperature could vary between different salmonid species, populations, and latitudes. In addition, due to logistic constraints associated with obtaining eggs from the hatchery, our thermal treatments did not begin immediately at fertilization. Therefore, these fish may have already passed a critical point when they might be sensitive to higher temperatures. Our continuing research with *O. tshawytscha* will be able to address this, because eggs were fertilized on site and underwent four incubation treatments: high temperature, low temperature, high then low temperature, and low then high temperature. This study provides insight into the physiological effects of temperature on juvenile salmon, which can be used to help inform water management decisions.