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Overwintering Ability of Juvenile Ocean-type Chinook Salmon: Effect of Water Temperature and Food Deprivation on Growth, Energetics, and Survival

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In ectothermic animals, metabolic rates are driven by variability in the ambient temperature, and thus influence growth rates and bioenergetics. During winter, many ectothermic fishes can reduce metabolic demands considerably by initiating periods of little or no activity, but pelagic fishes continually swim to maintain position in the water column (Brodersen et al. 2011). As a result, pelagic fishes must consume resources during winter to fuel the metabolic demands associated with sustained activity. Metabolic demands typically increase with temperature and thus, warm winter water temperature, particularly those projected under the current global ocean warming regime, could negatively affect cool water fishes if food resources are not available or abundant enough to meet the increased physiological demands.

The North Pacific region has experienced long-term sea surface warming over the last several decades (Sherman et al. 2009). Long-term ocean warming has been associated with altered timing and magnitude of phytoplankton production in the Strait of Georgia (SOG), thus driving variability in the prey field encountered by migrating Pacific salmon during early marine life (Mackas et al. 2007). Large-scale changes in climate have been implicated in the variable early marine survival exhibited by Pacific salmon populations (Holt 2010) and in the recent declines of southern British Columbia Chinook salmon (*Oncorhynchus tshawytscha)* returns (Tompkins et al. 2011), but the mechanisms remain unclear. Our objectives were to experimentally evaluate how juvenile ocean-type Chinook salmon responded to climate and food variability during early marine life. By controlling water temperature and food for six weeks during the winter 2013, we simulated match/mismatch dynamics in prey abundance associated with regional winter thermal regimes and assessed overwinter survival, growth, and behavior.

Juvenile sub-yearling Chinook salmon were obtained from a local hatchery and transported in an aerated live well by a University of Victoria (UVic) aquatic transport vehicle to the UVic Aquatic Research Facility. At the beginning of the experimental period, eleven fish were transferred into one of sixteen experimental 240-L aquaria. The experimental aquaria were assigned to treatments with one of two temperatures (6.5°C and 10.5° ±0.5°C) simulating the 1940-1970 winter average (hereafter termed cool) sea surface temperature (SST) recorded from the SOG, and a 50-year projected average winter (hereafter termed warm) SST, respectively. Fish were also subjected to three feeding regimes (fed once daily to satiation continuously throughout the entire study period, food deprived for two weeks from the beginning of the experimental period, and food deprived for four weeks from the beginning of the experimental period) to create the factorial design (temperature x feeding regime) with single replicates per treatment combination. The six-week experimental period was divided into three phases consisting of two weeks per phase. During phase one, both of the experimental treatments were food deprived. During phase two, feeding was restored to the two-week food deprived treatment while food deprivation continued in the four-week food deprived treatment. During phase three, feeding was restored to the four-week food deprived treatment. The control groups were fed to satiation once daily during all three phases.

All treatment tanks were monitored at least three times per day (morning, afternoon, and evening). During each monitoring event, water quality and quantity, and treatment parameters were maintained and all tanks were checked for mortalities. Survival was examined graphically for each treatment level using cumulative survival curves. Growth was estimated from randomly sampling six fish for length (TL) and weight (g) from each tank at the beginning of each two-week study phase. Respiration rate (number of buccal cycles per minute) was recorded three times per week from direct observation of one focal fish per tank. Activity was measured three times per week as the proportion of fish in each tank that crossed the vertical and/or horizontal midlines over a one-minute direct observation period. Aggression was measured three times per week as the number of nips, charges, and chases in each tank over a one minute direct observation period.

Preliminary results showed that survival of the juvenile Chinook salmon was high throughout the study period (> 85%). Overall survival was similar between warm (89%) and cool (85%) temperature treatments irrespective of feeding regime. The warm temperature/continuously fed and cool temperature/two-week food deprived treatments experienced 100% survival (Fig. 1) throughout the experimental period. Fish in the cool water temperature/continuously fed treatment suffered the highest mortality (40%) by the end of phase three. The majority of the fish in this treatment died during the initial three weeks of the study and no mortality was observed during phase three (Fig. 1). Survival of fish in the warm water treatments declined the greatest in those deprived of food for two weeks.

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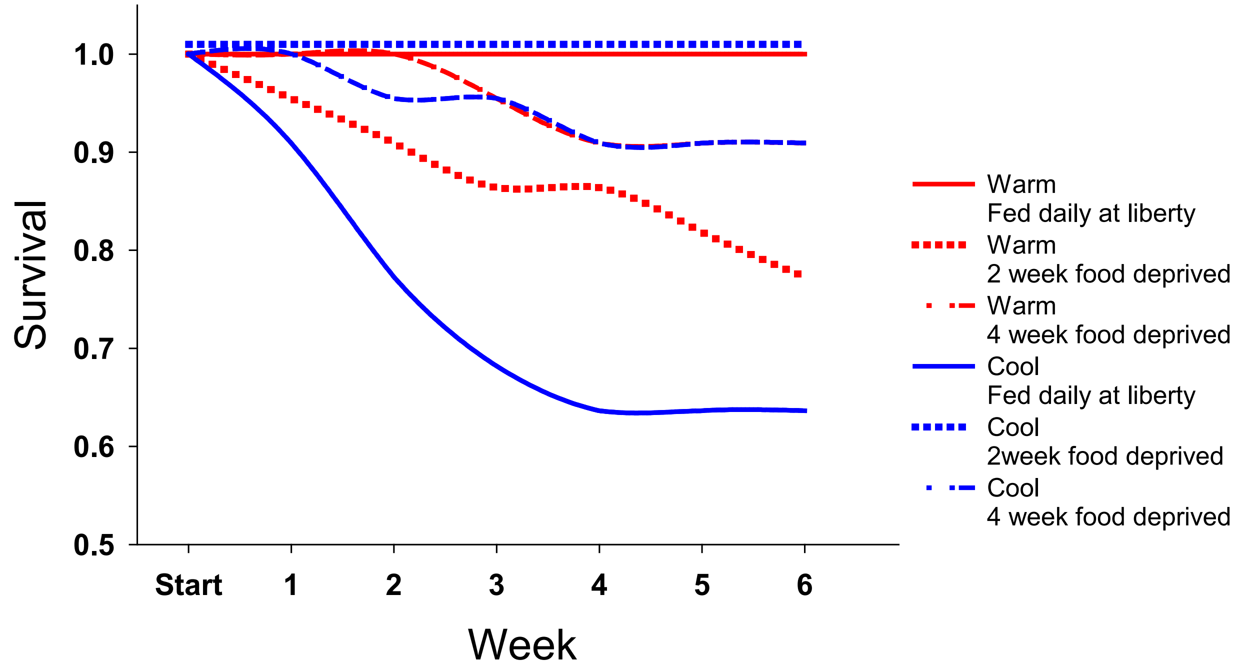

Fig. 1. Cumulative survival curves for juvenile ocean-type Chinook salmon over the six-week experimental period.

The weight of juvenile Chinook salmon was similar among all but one of the treatment combinations during phases one and two. Fish in the warm/four-week food deprived treatment (mean weight = 88 g) were smaller than fish in all other treatments (Fig. 2). The fish in the warm water/four-week food deprived treatment combination lost approximately 1% body weight per day during the two-week period of phase two. Food deprivation did not lead to significant weight loss in any of the cool water food deprived treatments. Compensatory growth was evident only in the cool water/two-week food deprived treatment as fish growth was greatest in this treatment between phase one and phase two of the experiment (Fig. 2).

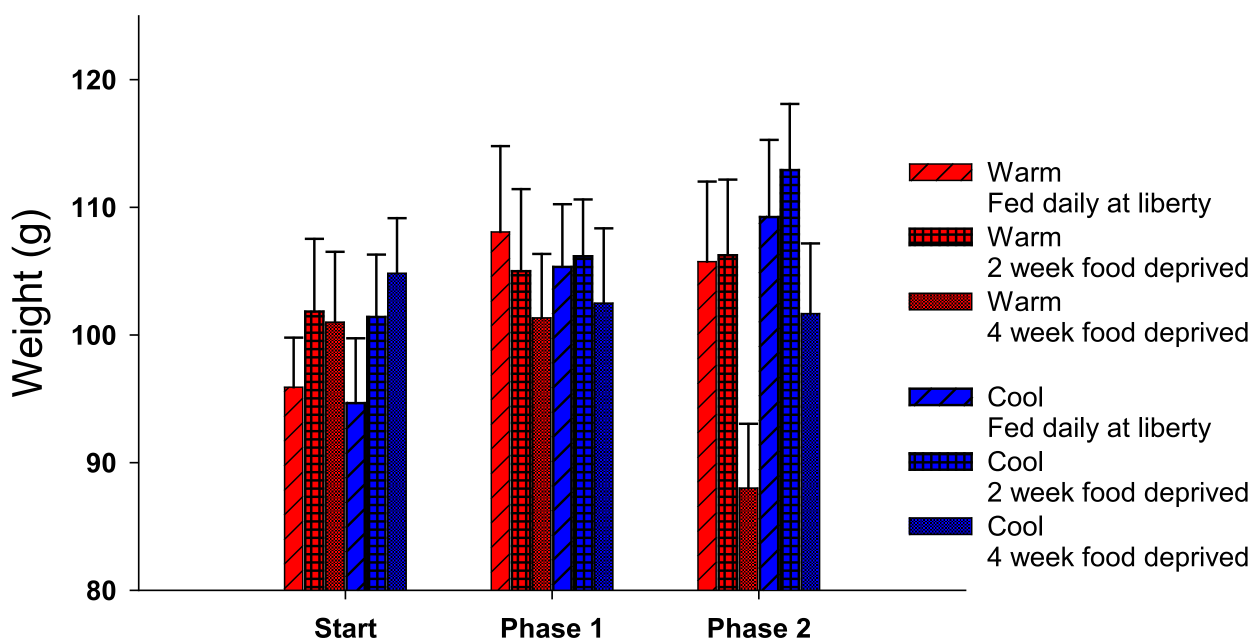

Fig. 2. Weight (g) of juvenile ocean-type Chinook salmon during bi-weekly sampling periods. Phases represent the two- and four-week food deprivation periods (phases one and two) and the re-feeding period for the two-week food deprived treatment (phase two).

The respiration rate of juvenile Chinook was consistently higher in the warm water treatments than in the cool water tanks (Fig. 3). Overall, the respiration rate of fish in the warm treatments (mean = 74 respirations/min) was 30% greater than fish in the cool treatments (mean = 53 respirations/min) combined across all combinations. Within the warm temperature treatment, the respiration rate of continuously-fed juvenile Chinook was higher than both food deprivation treatments during phases one and two, but by the end of phase three, fish in the three feeding regimes exhibited similar respiratory activity (Fig. 3). The respiration rate of juvenile Chinook salmon in both of the warm temperature food deprived treatments declined over the initial two weeks of the study, but increased in two-week food deprived fish during the subsequent re-feeding in phase two. Respiratory activity remained low in the four-week food deprived treatment during phase two, increased immediately upon re-feeding at the beginning of phase 3, and reached equivalent levels of the other warm temperature treatments by the end of the study period (Fig. 3). The respiration rate of juvenile Chinook salmon in the cool temperature feeding regimes varied less than in the warm temperature treatments over the study period, but similar trends in respiratory activity were observed among fish in the three cool water feeding regimes as in the warm temperature treatments (Fig. 3).

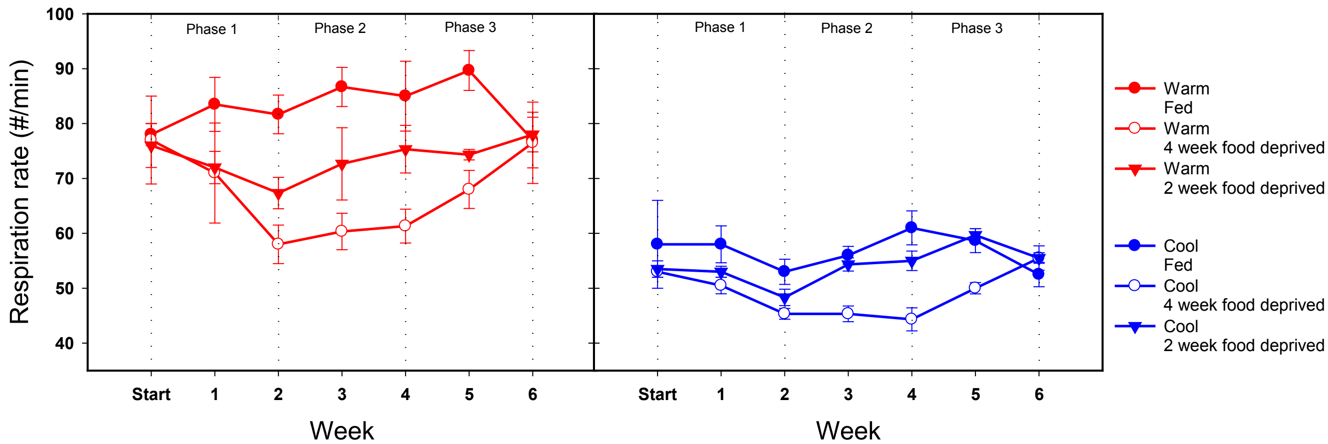

Fig. 3. Respiration rate of juvenile ocean-type Chinook salmon measured as the number of buccal cycles in one minute of one focal fish per aquarium. Phases represent the two-week food deprivation periods (phases one and two) and the re-feeding periods (phases two and three).

Juvenile Chinook salmon were most active in the warm water treatments across all feeding regimes. Within the warm temperature treatment, 50-75% of warm/continuously fed fish were active throughout the study period. However, activity declined in both warm temperature/food deprived treatments during the food deprivation phases and remained at or below 50% during the re-feeding phases. An opposite trend was exhibited by juvenile Chinook in cool water treatments whereby fish in all cool temperature feeding regimes were sedentary (< 25% active) during phase one, while activity increased in two-week food deprived fish (25-50% active) during phase two and in four-week food deprived fish (25-50%) during phase three. Aggression was also higher in fish residing in all warm temperature treatments except for the warm/continuously fed treatment where aggressive behaviors were consistently below one behavior/min throughout the study period. Aggressive behaviors increased within two days after food was withheld from fish in warm/food deprived treatments, declined after feeding was resumed in two-week food deprived fish and just prior to re-feeding in the four-week food deprived treatment. No aggressive behaviors were observed in juvenile Chinook in the cool/continuously fed treatment, and aggression in the cool/food deprived treatments was consistently less than 30% of aggressive behaviors observed in the warm temperature counterparts.

The water temperatures and feeding regimes simulated in this study were likely neither extreme nor extensive enough to reveal a treatment effect on the survival of juvenile ocean-type Chinook salmon. Overall, survival was similar between temperature treatments and among feeding regimes. The mortality observed in the cool temperature/continuously fed treatment is difficult to explain, but may have been the result of the location of the aquaria. All of the fish that died in this treatment had external symptoms of disease. These replicate aquaria were located nearest to the entryway of the building and routine ingress and egress by animal care staff could have induced increased stress on the fish in these treatments. It is still noteworthy that the simulated warm winter water temperature used in the present investigation did not have a direct positive or negative effect on the survival of juvenile Chinook deprived of food for up to one month. Future efforts should take advantage of a longer time scale than conducted here to evaluate whether an increase in water temperatures during an entire winter in the range predicted due to climate change may have consequences for juvenile Chinook early marine survival.

Our results show that temperature is only of minor importance to growth when food availability is not taken into account. The effect of food deprivation for one month on juvenile Chinook was a significant reduction in weight of fish inhabiting only the warm water aquaria. Thus, winter SSTs approaching those simulated in the warm temperature treatments of this study could have a negative impact on the growth of juvenile ocean-type Chinook salmon during prolonged periods of poor resource availability. Further, warmer water temperature did not confer a growth advantage to juvenile Chinook in a simulated environment of abundant food, as the weight of continuously fed fish was similar between the warm and cool temperature treatments. Compensatory growth following the recommencement of feeding was evident only in the cool/two-week food deprived fish. So, even when food becomes available, the capacity for compensatory growth may be limited during winters with the elevated water temperatures predicted over the next several decades. Phase three results of this study have not yet been summarized so we cannot draw conclusions concerning the capacity for compensatory growth in the fish deprived of food for one month.

Metabolic activity was clearly higher and considerably more variable in juvenile Chinook salmon inhabiting the warm water treatments across feeding regimes. The respiration rate of fish deprived of food for four weeks held at 10.5°C was greater than continually fed fish in 6.5°C water. Consequently, even the complete removal of food could not reduce the basic metabolic rate of juvenile Chinook salmon in warm water to that of fish fed daily to satiation in cool water. This finding coupled with the dramatic reduction in weight of phase-two fish in the warm/four-week food deprived treatment suggest that temperature plays a critical role in mediating the bioenergetics of juvenile Chinook salmon during times when food is scarce. In addition, the behavior of juvenile Chinook salmon was altered by water temperature such that fish were more active and aggressive in the warm water treatments than in cool water, and the possibility of temperature-induced abnormal behavior influencing anti-predator and foraging ability warrants further investigation. Together, these results indicate that the potential risks from increased winter ocean temperature may be greater than the potential benefits.

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