Overwintering ability of juvenile ocean-type Chinook salmon: effect of water temperature and food deprivation on growth, energetics and survival

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ABSTRACT

Large-scale changes in climate have been implicated in the variable early marine survival exhibited by Pacific salmon populations and recent declines in southern British Columbia Chinook salmon (*Oncorhynchus tshawytscha*) returns. Rapid shifts in temperature during the early marine phase of Pacific salmon also affect the production of lower trophic levels, thus driving variability in the prey field encountered by migrating salmon. Our objectives were to experimentally evaluate how juvenile ocean-type Chinook salmon respond to climate and food variability during early marine life. By controlling water temperature and food during winter, we simulated match/mismatch dynamics in prey abundance associated with regional winter thermal regimes, and assessed overwinter growth patterns, survival and behavior.

Survival was high throughout the study period (>85%). Overall survival was similar between temperature treatments, but within the cool water temperature treatment, continuously fed fish suffered the highest mortality (40%). Juvenile Chinook salmon in the cool water treatments were larger than fish in the warm water treatments by the end of the study period. The only treatment that experienced significant weight loss by the fourth week was the warm water/4 week food deprived treatment. The respiration rate of juvenile Chinook was higher in all warm water treatments than in the cool water tanks. Activity and aggression were also highest in salmon residing in the warm water treatments.

Under the current warming trend of regional SSTs, increased winter water temperatures could have a negative effect on the growth of juvenile ocean-type Chinook salmon during prolonged periods of poor resource availability. Further, the increased metabolic costs of inhabiting a warming ocean during winter could negatively affect juvenile ocean-type Chinook salmon if food resources are not available to meet the increased physiological obligations.

INTRODUCTION

Problem:

The North Pacific region has experienced long-term sea surface warming over the last several decades (Figure 1; Sherman et al. 2009).

Pacific salmon are cold water fishes and warming ocean temperatures could have serious implications for the early marine phase of their life cycle.

Long-term ocean surface warming has also been associated with altered phenology and variable abundance of the planktonic prey for juvenile Pacific Salmon (Mackas et al. 2007).

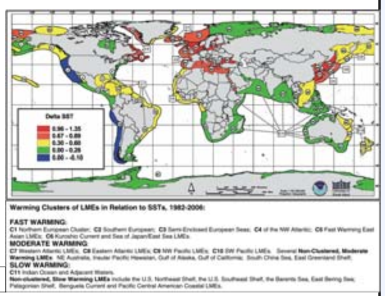
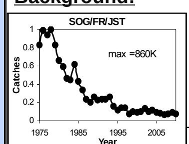


Fig 1. Changes in SSTs (1982-2006) of the World's large marine ecosystems (LMEs). Figure obtained from Sherman et al. 2009.

Background:



Chinook salmon (*Oncorhynchus tshawytscha*) stocks in southern British Columbia (BC), Canada are in serious decline despite drastic reductions in fishing (Figure 2; Tompkins et al. 2011). Unfavorable conditions during early marine life of juvenile Chinook associated with climate change such as increasing sea surface temperature and altered prey dynamics have been identified in the sustained low return rate of southern BC Chinook stocks during the last few decades (Holt 2010).

Fig 2. Long-term catches of Chinook salmon in the Strait of Georgia, Fraser River and Jonstone Strait. Figure obtained from M. Trudel (DFO). Data from Chinook Technical Committee (2012).

Some ectotherms can reduce metabolic demands by initiating periods of little or no activity during winter, but pelagic fishes must maintain some degree of activity. Thus, fishes residing in the water column must continue to consume resources during winter to fuel the metabolic demands associated with sustained activity.

Growth potential and overwinter survival of juvenile Chinook are likely maximized in years with ideal ocean conditions. Elevated metabolic costs associated with warming marine waters may increase the rate at which energy reserves are used and decrease the ability for juvenile Chinook to endure periods without food resulting in increased risk of physiological dysfunction, stunted growth, and eventually death.

Need and contribution:

Chinook salmon was selected for this study because this species is integral to the BC economy, culture, and ecology and many of the stocks are at critically low levels. Poor marine survival in a changing climate has been identified as one factor contributing to the decline. However, the mechanisms and timing associated with high marine mortality in Chinook salmon are poorly understood.

Therefore, research efforts which assess the response of juvenile Chinook salmon to simulated winter sea surface temperatures under different resource conditions are much needed.

HYPOTHESES / OBJECTIVES

Juvenile ocean-type Chinook salmon were subjected to a combination of winter conditions comprised of two winter water temperatures (warm and cool) and three feeding regimes (continuous feeding, 2 week food deprived and 4 week food deprived). Simulated early marine winter conditions will affect juvenile Chinook salmon such that:

Hypothesis 1: Survival will be similar between fish in continuously fed/warm vs. cool treatments, but higher in cool/food deprived than warm/food deprived.
Objective: Determine weekly survival rates and compare across treatments.

Hypothesis 2: Growth will be greatest in the warm water/continuous feeding treatment.
Objective: Calculate and compare instantaneous growth (g) over the 3 phases of the study period.

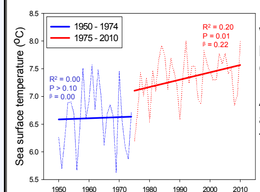
Hypothesis 3: Respiration rate of fish will be higher in warm water temperature treatments across all feeding regimes.
Objective: Estimate treatment-specific respiration rates over the 3 experimental phases of the study period.

Hypothesis 4: Fish behavior will be similar between temperature treatments, but decline with food deprivation.
Objective: Calculate weekly activity level and aggression of fish in all treatments.

METHODS

Fish collection and experimental design:

Juvenile ocean-type Chinook salmon were obtained from a local hatchery, and smolted and reared at the University of Victoria Aquatic Research Facility.



Winter SST in the Strait of Georgia (SOG) has been increasing since 1975, coinciding with Chinook declines in Southern BC (Figure 3).

At the recent rate of ocean warming, mean annual winter SST could approach 10°C over the next 50 years.

Fig 3. Winter SST recorded by the Canada Department of Fisheries and Oceans (DFO) Entrance Island Lighthouse observation station. Winter SST was divided into two general time periods corresponding to the pre-Chinook stock declines (1950-1974) in blue , and the period of stock decline (1975-2010) in red.

Experimental design:

- Total study period = 6 weeks divided into 3 phases (2 weeks per phase)
- Sample size = 11 fish per tank
- 2 temperature treatments x 3 feeding regimes x 2 replicates = 12 tanks (132 fish)
  - *Two temperature treatments:*
    - Cool ≈ 6.5 °C
    - Warm ≈ 10.5 °C
  - *Three feeding regimes:*
    - Fed daily at liberty
    - Food deprived during phase 1
    - Food deprived during phases 1 & 2
- After food deprivation phases, fish in all treatments were fed daily at liberty for 2 weeks to assess capacity for compensatory growth

Analysis:

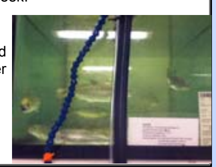
Survival – 3X daily mortality checks. Reported as cumulative weekly survival curves.

Growth – 6 fish per tank were sampled bi-weekly for length (TL) and weight (g) and compared within and among treatments across study phases.

Basic metabolism – Respiration rate (# buccal cycles per minute) from direct observation of 1 focal fish per tank 3x weekly and compared within and among treatments by week.

Behavior (3x weekly):

- Activity – proportion of fish in each tank that crossed the vertical and/or horizontal midlines over a 1 minute direct observation period.
- Aggression – number of nips, charges and chases in each tank over a 1 minute direct observation period



PRELIMINARY RESULTS

Survival

- Total survival among all treatments = 87%
- Survival was similar between the warm (89%) and cool (85%) temperature treatments.
- Warm temp/fed at liberty and cool temp/2 week food deprived treatments experienced 100% survival.
- Survival declined the greatest in the cool temperature /continuously fed treatment (Figure 4.)

Fig 4. Weekly survival of juvenile ocean-type Chinook salmon over the 6 week experimental period.

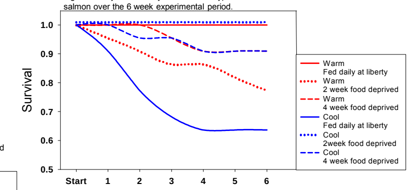
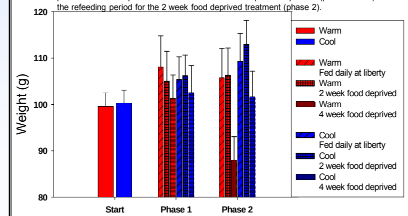


Fig 5. Weight (g) of juvenile ocean-type Chinook salmon during bi-weekly sampling periods. Phases represent the 2 and 4 week food deprivation periods (phases 1 & 2) and the refeeding period for the 2 week food deprived treatment (phase 2).



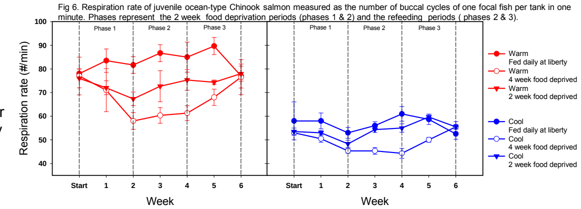
Growth

- Overall, cool water fish were modestly larger (10%) than warm water fish by the end of phase 2 (after 4 weeks).
- Within the warm water treatment, size was similar between continuously fed and 2 week food deprived fish by the end of phase 2, but fish deprived of food for 4 weeks had lost significant weight (≈1.0% bwt/d^{-1}).
- Size was similar among all cool water feeding regimes (Figure 5).

Respiration rate

- Higher in all warm water than cool water treatments.
- Greatest variability in warm water treatments.
- Within both temperature treatments, rates were similar among feeding treatments by the end of the study period (Figure 6).

Fig 6. Respiration rate of juvenile ocean-type Chinook salmon measured as the number of buccal cycles of one focal fish per tank in one minute. Phases represent the 2 week food deprivation periods (phases 1 & 2) and the refeeding periods (phases 2 & 3).



Behavior

Activity level (Figure 7):

- Overall, highest in warm water temperature treatment.
- Consistent sedentary behavior in cool/daily fed treatment.
- Activity increased in cool water/food deprived fish after feeding was restored.

Aggression (Figure 8):

- Highest in food deprived warm water treatments
- Increased in food deprived warm water fish until feeding was restored and declined thereafter.
- None observed in Cool/daily fed treatment.

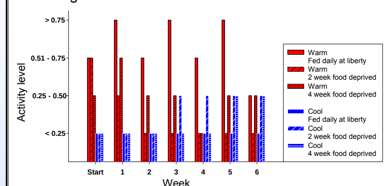


Fig 7. Weekly activity level of juvenile ocean-type Chinook salmon measured as the proportion of fish in each treatment that actively moved across the vertical or lateral midline of each tank in one minute.

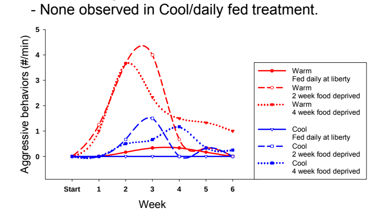


Fig 8. Weekly aggression of juvenile ocean-type Chinook salmon measured as the number of chases, charges or nips observed in one minute.

DISCUSSION / CONCLUSION

- Temperature did not appear to affect survival as overall survival was similar among temperature treatments. The mortality observed in the cool temperature/continuously fed treatment may have been the result of tank location.

- Warm winter SSTs could have a negative effect on the growth of juvenile ocean-type Chinook salmon during prolonged periods of poor resource availability. Even when food becomes available, the capacity for compensatory growth may be limited during warm winters. In our study, this phenomenon was evident only in the cool temperature/2 week food deprived treatment, but no conclusions can be drawn until the phase 3 fish measurement sampling is conducted.

- Metabolic activity was clearly higher and considerably more variable in the warm water treatments, thus winters with SSTs approaching those simulated in this study could negatively affect juvenile ocean-type Chinook salmon vital functions if food resources are not available to meet the increased physiological obligations.

- 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 potential for temperature induced erratic behavior influencing anti-predator and foraging ability warrants further investigation.

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