

Bioenergetic Response of Coho Salmon to Climate Change

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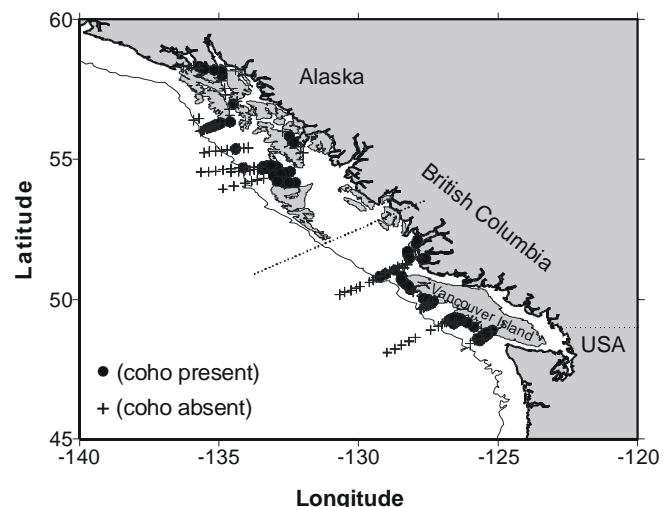
The marine survival and production of Pacific salmon and steelhead trout (*Oncorhynchus spp.*) have decreased tremendously during the last decade in British Columbia (BC), Washington, Oregon, and California (Hare et al. 1999; Beamish et al. 2000; Welch et al. 2000). Fisheries have been closed, and a number of stocks have been added to the endangered species list in the United States. This period was also the warmest on record. However, it is unclear how sea surface temperature (SST) influences the survival and production of salmon. Higher temperature may increase the metabolic rates of salmon, and hence, reduce the energy available for growth (Pyper and Peterman 1999). As mortality rates tend to be larger in small fish (Lorenzen 1996), a reduction in growth rate may thus reduce the survival of salmon. Warmer SST may also produce poorer ocean conditions for salmon growth through bottom-up processes. As warm water tends to be lighter, an increase in SST may increase the stability of the water column in the mixed layer and may prevent or reduce the upwelling of deep nutrient-rich water, and consequently, may decrease both primary and secondary productivity (Gargett 1997). Thus, in warmer years, salmon may have less food and reduced growth.

The objectives of this study were to assess how the growth rates of juvenile salmon were influenced by oceanographic and climatic conditions. We examined the effects of SST on food consumption rates of salmon. We also assessed the effects of prey quality and SST on salmon growth.

We collected juvenile coho salmon (*Oncorhynchus kisutch*) off the west coast of BC using a rope trawl and the *WE Ricker* in the spring (May–June), summer (July–August), and fall (October–November) of 1998, 1999, and 2000 (Fig. 1). For the purpose of this study, the area north of latitude 52°N was defined as Northern BC, while the area west of Vancouver Island (47–51°N) was defined as Southern BC (Fig. 1). Water temperature profiles were usually obtained before the net was deployed using a CTD. Each net tow consisted of towing the net at the surface (0–20 m) for 30 minutes at 5 knots. Up to 30 juvenile coho salmon were randomly selected from each net tow. Fork length and mass of coho were determined on board the research vessel. Otoliths and scales were removed for age determination. A skin sample was also taken from the operculum using a hole punch and preserved in 70% ethanol for DNA stock identification. Whole fish were then frozen individually at minus 20°C in pre-identified plastic bags for subsequent analyses. Energy density was determined on a subset of coho using a bomb calorimeter. Food consumption rates of juvenile coho salmon were estimated using a mass balance model of stable cesium (¹³³Cs) following the procedures presented in Rowan and Rasmussen (1996) and Trudel et al. (2000). ¹³³Cs concentration in salmon caught in the spring and fall and their food was determined by Inductively-Coupled Plasma Mass Spectroscopy.

Sea surface temperature (SST) was higher in 1998 by about 2–3°C due to a warm El Niño that was followed by a cool La Niña in 1999 and 2000.

Fig. 1. Sampling locations during the month of October 1998, 1999, and 2000.



This El Niño corresponded to one of the strongest ever recorded. Surface nutrient concentrations were also much lower in 1998 than 1999 (Whitney and Welch in press). Nitrates were actually depleted at the surface during the summer of 1998 (Whitney and Welch in press), suggesting that primary productivity was reduced during that period.

Coho salmon were half the size and also had lower energy reserves in southern BC than in Alaska in October 1998, but not in 1999–2000 (Fig. 2–3). Thus, coho salmon collected in Southern BC in 1998 were in poorer condition, and had lower growth rates than those from Northern BC, but were similar in both regions after the 1997–98 El Niño. Food consumption rates of juvenile coho salmon averaged about 10% of their body weight per day and did not vary significantly between regions or years (Fig. 4). These estimates represent about 75% of their maximum physiological capacity, and are among the highest values reported in the literature for any wild fish (Trudel unpublished data). Thus, there are no indications that coho salmon were starving, despite ocean conditions being less favourable for salmon growth in Southern BC in 1998. These results also indicates that the growth differences observed in this study were not related to feeding rate differences.

To assess the potential effects of prey quality and SST on the growth of juvenile coho salmon, we used a bioenergetic model in conjunction with the feeding rates derived in this study. We used prey with low (700 cal/g) and high (900 cal/g) quality in these simulations. These values are within the range of published energy densities for zooplankton (Davis et al. 1998). SST was modelled using the temperature cycle provided in Brett (1983). These simulations were also performed by increasing the daily temperature by 3°C to simulate the effects of increased SST on salmon. We assumed that coho smolts entered the ocean weighing 10 g on May 15 (Sandercock 1991), and calculated their growth until October 15 of the same year.

Fig. 2. Size frequency distribution of coho salmon caught in Southern BC (gray bars) and Northern BC (black bars) in October 1998, 1999, 2000. Here, frequency is expressed as a percent of the total catch in a given area.

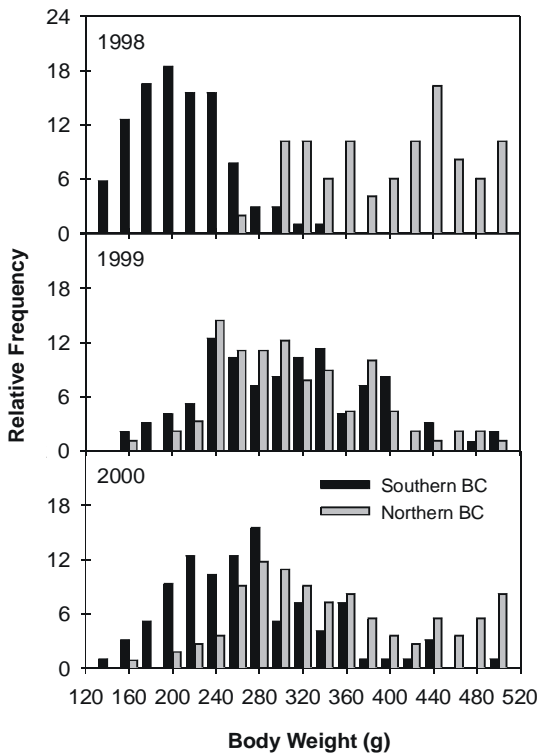


Fig. 3. Caloric contents (1 cal = 4.186 J) in coho salmon collected Southern BC (gray bars) and Northern BC (black bars) in October 1998, 1999, 2000. The error bars represent the 95% CI.

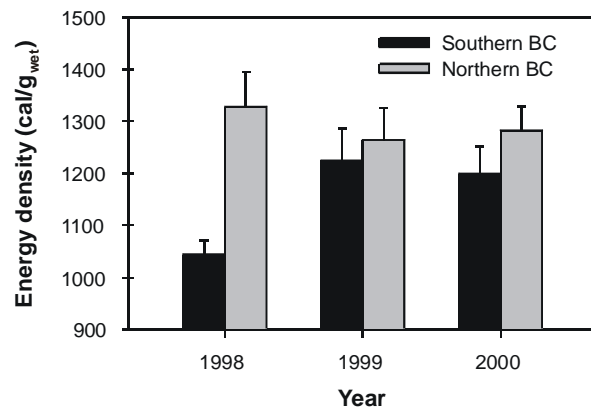


Fig. 4. Food consumption rates of juvenile coho during their first summer (May–October) in the ocean in 1998, 1999, 2000. The error bars represent the 95% CI and were determined using Monte Carlo simulations.

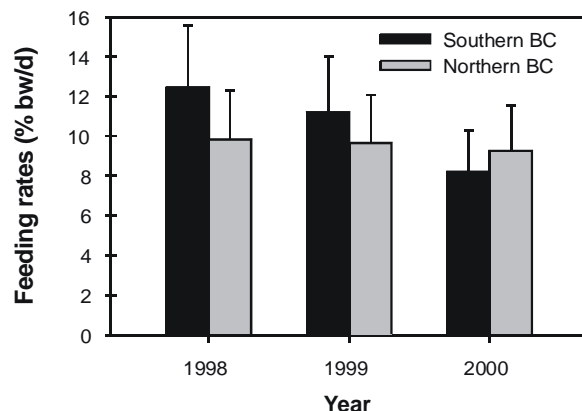
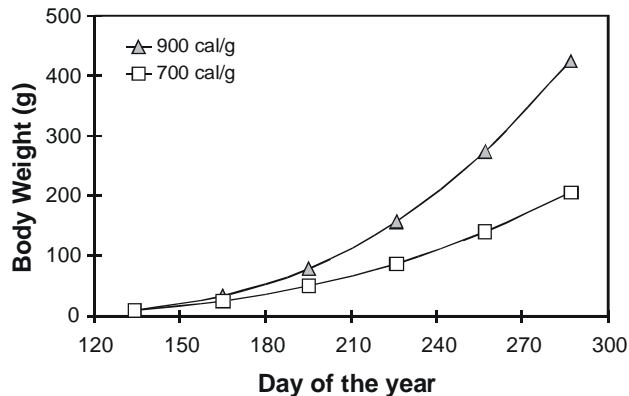


Fig. 5. Growth rates of coho salmon predicted using prey of low (700 cal/g_{wet}) and high quality (900 cal/g_{wet}).



Coho salmon reached a size of about 200 g and 400 g when they were feeding on prey of low and high quality, respectively (Fig. 5). This corresponds quite well to the mean size of coho salmon collected of Southern and Northern BC in 1998. Increasing SST by 3°C decreased the final size by only 10 g, suggesting that the direct effects of SST on salmon growth were negligible. Our analyses thus indicate that the effects of SST on salmon growth is mediated by changes in prey community structure and quality rather than by changes in food consumption and metabolic rates. These results also illustrate the importance of measuring bioenergetic parameters *in situ* for better understanding the effects of climate change on fish populations.

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