Climate Change and Evolutionary Adaptation:
The Resilience of Salmon in a Warming World


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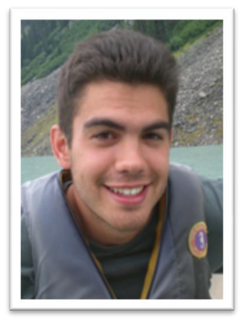
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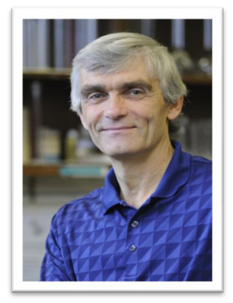
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Background

Temperature plays a fundamental role in shaping the form and function of species, driving local adaptation and eventually ecological speciation. For ectotherms, or animals that are dependent on external sources of heat, temperature has been deemed the "ecological master factor" because all aspects of physiology depend on their thermal environment. Therefore, ectotherms have thermal windows that are optimal for various activities such as swimming, feeding, and reproducing. As such, these thermal windows correspond to thermal conditions in which they evolved. Global air temperature is projected to increase by 3-5 C by the end of the century. This warming may negatively impact the viability and abundance of ectotherms that are unable to adjust their thermal tolerance in response to environmental change. Thus, it is increasingly important for biologists to understand the nature of thermal adaptation.

Salmon in hot water

- Salmon are of major economical, ecological, and cultural importance around the world


Chinook salmon in British Columbia


Print by Tony Hunt, Northwest Native Artist

- Severe decline in run sizes of both Pacific and Atlantic salmon over past 160 years
- Anomalously high river temperatures have been identified as a significant cause of mortality in recent years in both juvenile and adult salmon

	Run Size (millions)		
	Historic	Current	% of Historic
British Columbia	91	25	27%
Puget Sound	20	1.6	8%
Washington Coast	4	0.1	3%
Columbia Basin	13	0.2	7%
Oregon Coast	3	0.2	7%
California	6	0.3	5%

Figure 1. Historic and current run size of Pacific salmon. Gresh *et al. 2000*

Local adaptation: plastic or evolved?

- Response to climate change can involve either plastic or evolved mechanisms. Plastic responses are non-genetic changes in phenotype triggered by the environment, whereas an evolved response is genetically based

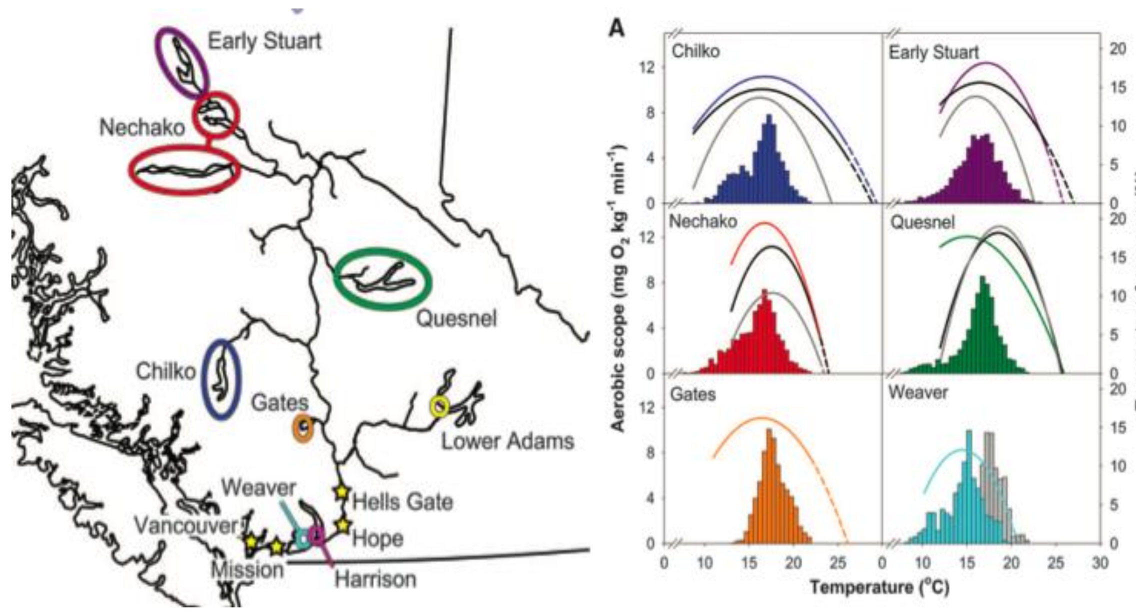
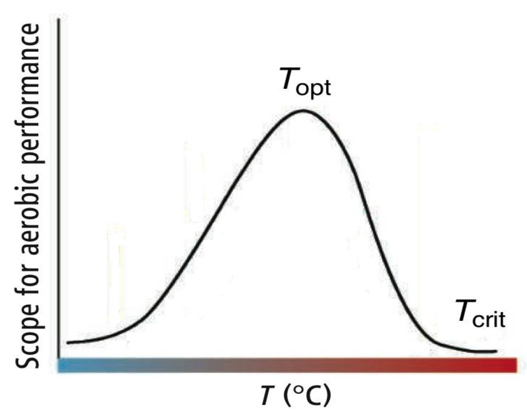


Figure 2. Population specific thermal tolerance of 6 sockeye salmon populations in Fraser River tributaries.

- Differences in thermal windows between populations that reflect natal temperatures, which may be due to phenotypic plasticity or evolutionary adaptation
- Important to understand the nature of such thermal adaptation, as responses to climate change will involve adaptive adjustments of thermal tolerance

Oxygen-limited thermal tolerance



Ectotherms reach thermal limits when they lose aerobic scope, which is their capacity to support aerobic activities i.e. swimming, growth and reproduction. The temperature which an animal preforms best at is termed T_{opt}. As Temperature increases, oxygen demand increases and eventually the animal fails to supply sufficient oxygen to tissues. This ultimately leads to a collapse of aerobic scope at the upper critical temperature (T_{crit}).

The adaptive capacity of salmon: study design

A quantitative breeding design coupled with multiple rearing environments was used to evaluate the heritability and plasticity of thermal tolerance within a wild population of Chinook salmon from the Quinsam River, British Columbia.

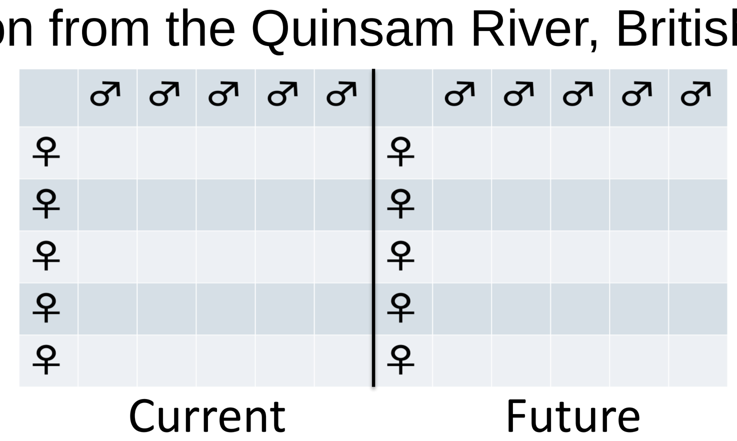


Figure 3. Quantitative breeding design: 8 females mated with 8 males in every pairwise combination in both current and future (+5 C) temperature conditions.

Heritability and plasticity of thermal tolerance

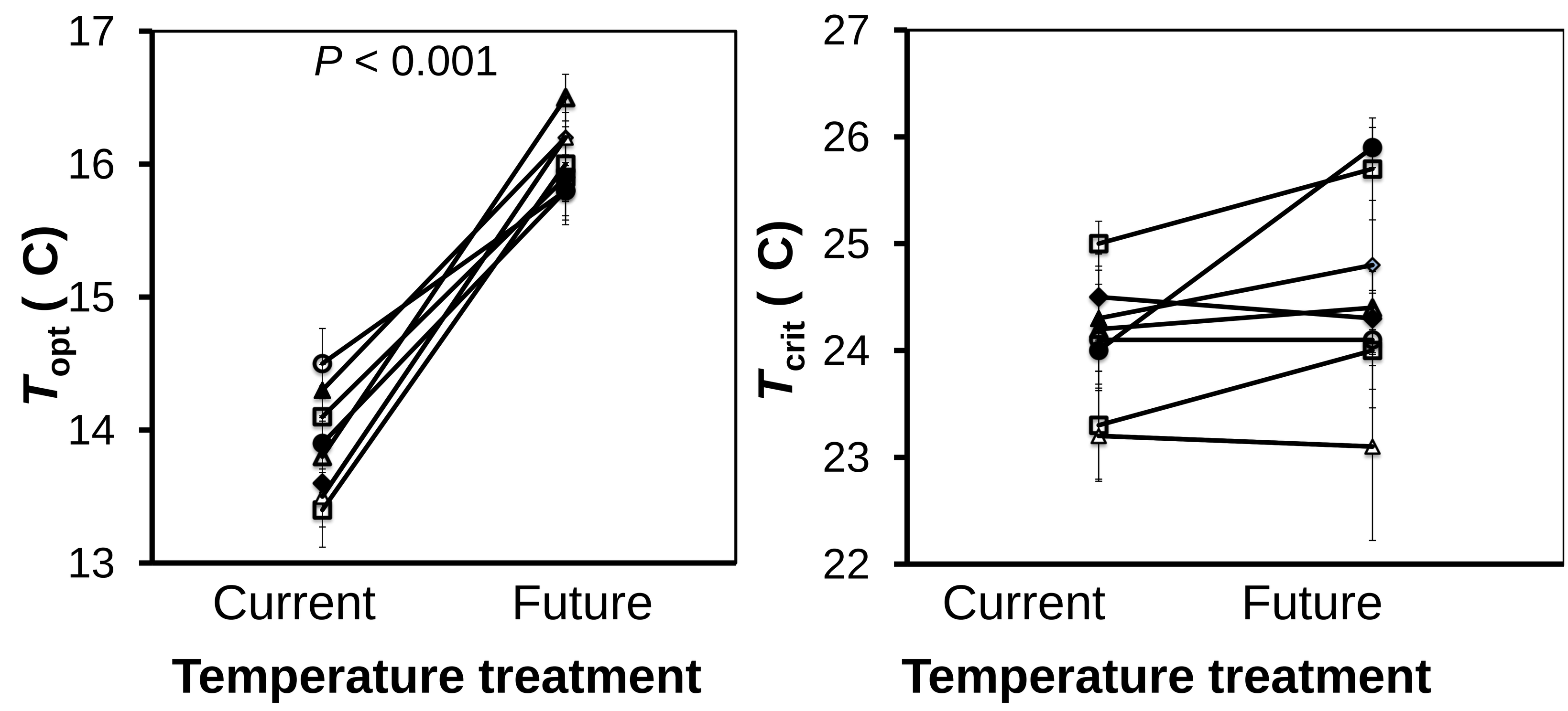


Figure 4. Variation in T_{opt} and T_{crit} among paternal families of Chinook salmon exposed to current and future temperature conditions. The mean T_{opt} across all families significantly increased from 14 0.1 C to 16.1 0.1 C in the current and future treatments, respectively, whereas the mean T_{crit} did not differ between treatments. Significant heritable variation was detected for T_{opt} in the current treatment, with additive genetic effects accounting for 22% of the phenotypic variation. Furthermore, there was a significant interaction between family ID and temperature treatment contributing to T_{opt}, indicative of a genetic basis for plasticity.

Conclusions

- The plasticity and heritability of T_{opt} represent adaptive mechanisms by which salmon populations can maintain performance in high temperatures
- The lack of plasticity and standing genetic variation for T_{crit} suggest that the upper limits of thermal tolerance cannot be readily adjusted, perhaps due to previous selection on maximum thermal tolerance
- The significant interaction between family ID and temperature treatment contributing to T_{opt} suggests that plasticity itself has a genetic basis that may increase the evolutionary potential of salmon populations faced with climate change

References

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