Thermal Limits of Salmon in the North Pacific Ocean

David Welch\textsuperscript{1}, Yukimasa Ishida\textsuperscript{2}, Kazuya Nagasawa\textsuperscript{3}, & Sonia D. Batten\textsuperscript{4}

1. Kintama Research Services, Ltd., Nanaimo, Canada
2. National Research Institute of Far Seas Fisheries, Shimizu, Japan
3. School of Biosphere Science, Hiroshima University, Higashi-Hiroshima, Japan
4. Sir Alister Hardy Foundation for Ocean Science, Plymouth, UK
Introduction

- This presentation summarizes work on salmon thermal limits completed during the 1990s:


Data Sources

- All Historical Japanese, US, & Canadian Survey Data
- Directed Research Cruises, 1992-96 (January)

Temporal Coverage:
- 40 Years (1956-96)

Extent of Data
- 20,000+ Days of Sampling at Sea (29.1 yrs of Ship Time)

Geographic Coverage
- Entire N. Pacific Ocean, plus Adjacent Seas
Sockeye Log (CPUE+1) plotted for 1° x 1° squares
- Consistent zero catches in southern regions

Legend (all graphs):
+ - No catch
○ - Circle size scaled by catch magnitude
Distribution of Chum
Chinook

Distribution of Chinook

- Nov - Mar
- Apr - May
- Jun
- Jul
- Aug
- Sep
Steelhead

Unlike sockeye, distribution shows a banded structure across the North Pacific, with both southern and northern limits.
Coho

- Distribution also shows a banded structure across the North Pacific
Distribution of Pink

- Nov - Mar
- Apr - May
- Jun
- Jul
- Aug
- Sep
Distribution of Masu

Nov - Mar

Apr - May

Jun

Jul

Aug

Sep
Dolly Varden

Distribution of Dolly Varden

- Nov - Mar
- Apr - May
- Jun
- Jul
- Aug
- Sep
Sockeye- Log (CPUE+1) vs SST

-The red lines show the edge of the distribution in July.

-The edge of the distribution is at colder temperatures in the spring, warmer temperatures in August.
Chum- Log (CPUE+1) vs SST
Chinook- Log (CPUE+1) vs SST
Steelhead- Log (CPUE+1) vs SST
Coho- Log (CPUE+1) vs SST
Pink- Log (CPUE+1) vs SST
Measuring the Thermal Limit

- The southern edge of the distribution can be defined by assuming an average critical temperature at which animals express avoidance behaviour, $T_{\text{crit}}$, and Gaussian variability between individual animals in the temperature at which this behaviour occurs, $\sigma_T$ (Welch et al. 1995).

- $n(T_i) = \mu(1 - \Phi(T_i - T_{\text{Crit}}, \sigma_T))$

- This defines the cumulative Gaussian probability, $\Phi$, that have responded by some temperature $T_i$. Here, $\mu$ is abundance, $T_i$ is the temperature (SST) at the $i$-th sample location, and $\sigma_T$ is the variability between individuals.
Measuring the Thermal Limit

- Estimates of the midpoint, $T_{\text{crit}}$, and the rate of change in salmon density with temperature around this point, $\sigma_T$, define the rate at which abundance declines with increasing temperature at the thermal limit (Welch et al. 1995).
Spring (April)  Summer (June)
Upper Thermal Limits

- Strong, species-specific thermal limits bound the area of the North Pacific where salmon are found.
- Seasonal variation in the upper thermal limit is greatest in the Gulf of Alaska.
The “best guess” as to why thermal limits are so sharp is that they represent the critical point where food availability just supports temperature-determined metabolic processes.

This explanation does \textit{not} explain the existence of a northern lower temperature boundary for three species of salmon (steelhead, Coho, Pink)

\textit{Something important is missing from our understanding of the underlying processes.}
Conclusions

- Large areas of the N Pacific are projected to be lost to salmon as a result of global warming.

- The impact of climate warming is likely to be most severe for west coast North American stocks-
  - Critical upper temperature limits occur at lower temperatures in the Gulf of Alaska than the Central or Western North Pacific
  - As distributions shift into the Bering Sea in response to warming, it is unclear whether migration mechanisms can cope with the “Alaska Problem”... the Alaskan Peninsula will block straight line migration back to rivers in SE Alaska, BC, Washington, & Oregon
The “Alaska Problem”

- The details of how juvenile salmon migrate to the Bering Sea and then back to freshwater as adults may be critical to whether or not migration can be successful.
- “Map & compass” may be insufficient.
A Research Program

• **Sharp** thermal limits may be occurring because energy intake balances metabolic demand.
• This mechanism may be incorrect, because it does not explain the existence of lower thermal limits.
• A test could be developed by tagging juvenile salmon with archival tags, and determining how their migration paths interact with SST over the whole life cycle—do salmon cross thermal boundaries?
• More broadly, establishing the migration pathways of salmon over essentially the whole of the marine phase would produce huge advances from the present level of understanding.
• NPAFC & PICES are well-placed to lead this.