Thermal Limits of Salmon in the North Pacific Ocean

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KINTAMA

Introduction

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

Welch, D. W., & Ishida, Y. (1993). On the statistical distribution of salmon in the sea: Application of the negative binomial distribution, and the influence of sampling effort. *Canadian Journal of Fisheries and Aquatic Sciences, 50(5), 1029-1038.*

Welch, D. W., Chigirinsky, A. I., & Ishida, Y. (1995). Upper thermal limits on the oceanic distribution of Pacific salmon (Oncorhynchus spp.) in the spring. *Canadian Journal of Fisheries and Aquatic Sciences, 52, 489-503. doi: 10.1139/f95-050*

Welch, D. W., Ishida, Y., & Nagasawa, K. (1998). Thermal limits and ocean migrations of sockeye salmon (*Oncorhynchus nerka): Long-term consequences of global warming. Canadian Journal of Fisheries and Aquatic Sciences, 55, 937-948.*

Welch, D. W., Ishida, Y., Nagasawa, K., & Eveson, J. P. (1998). Thermal limits on the ocean distribution of steelhead trout (*Oncorhynchus mykiss). North Pacific Anadromous Fish Commission Bulletin, 1, 396-404.*

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

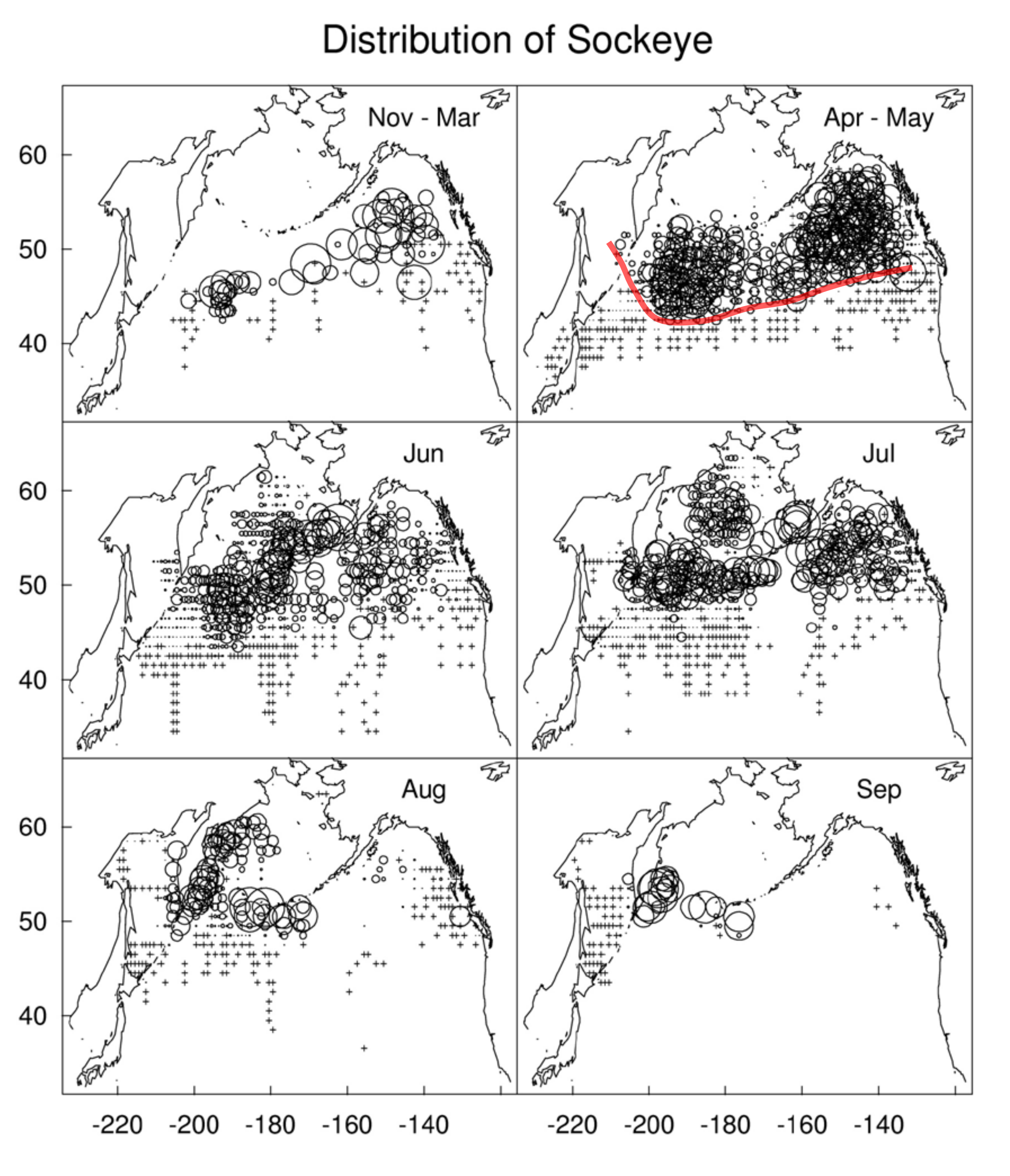
Log (CPUE+1) plotted for 1°x 1° squares

- Consistent zero catches in southern regions

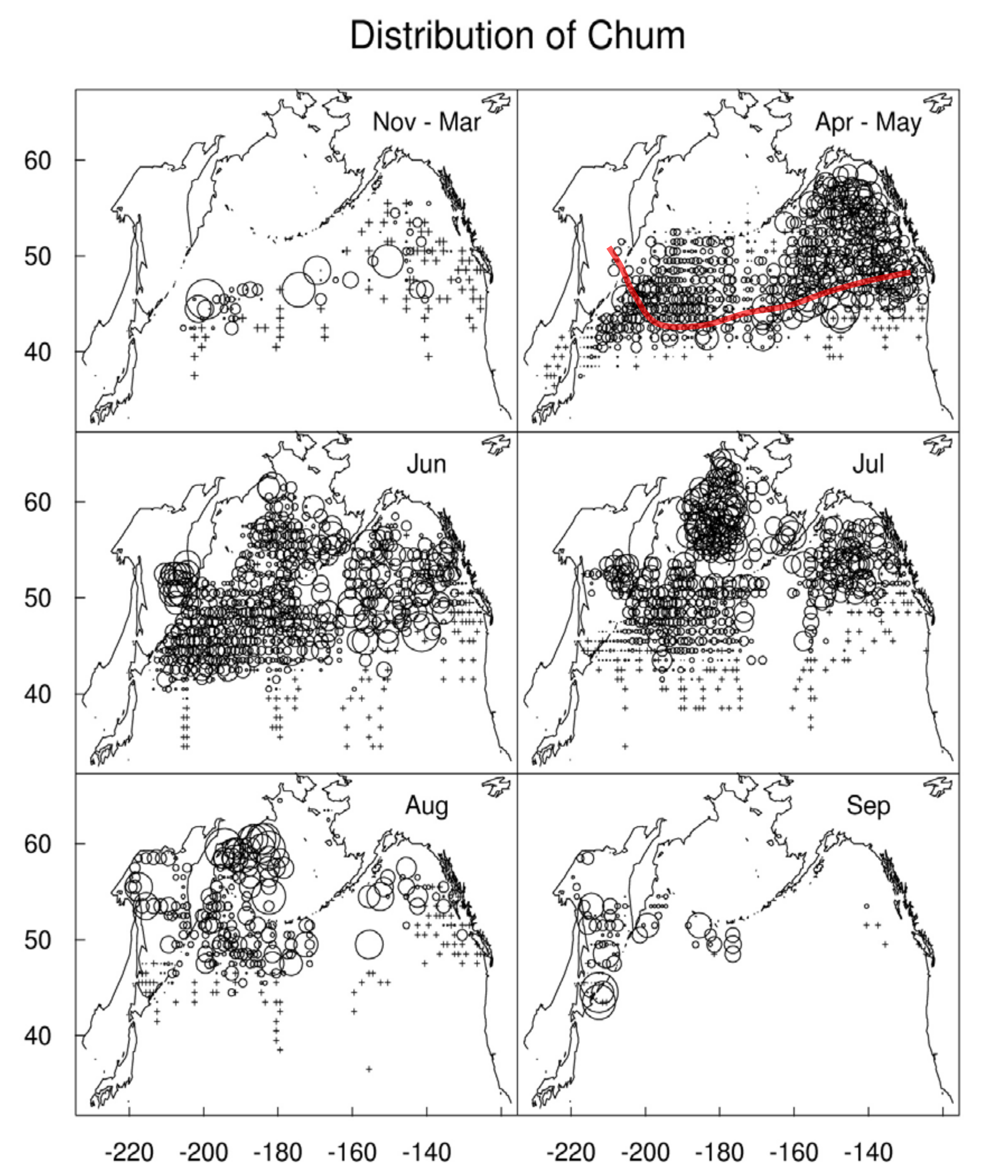
Legend (all graphs):

+ - No catch

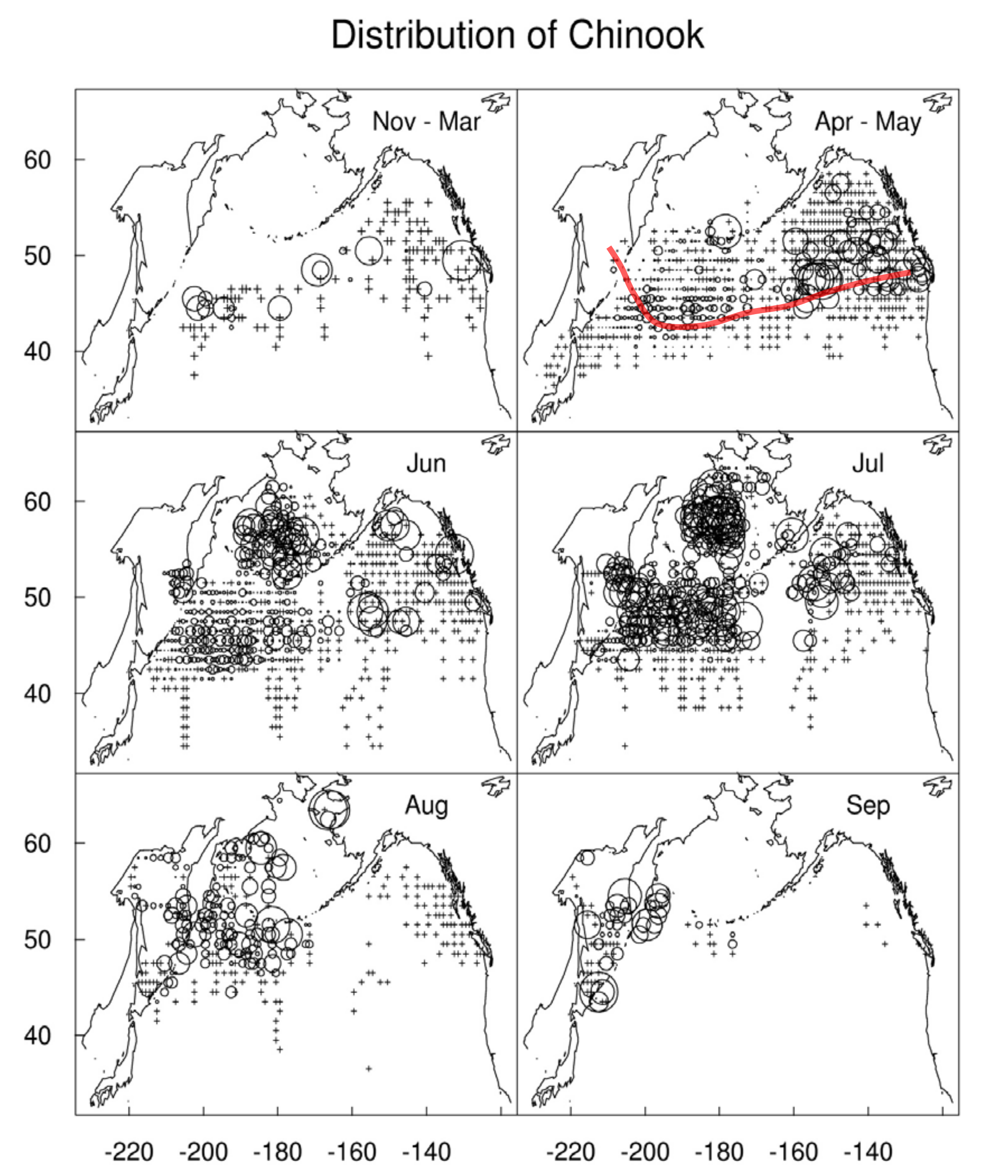
○- Circle size scaled by catch magnitude



Chum


Distribution of Chum
Nov - Mar
Apr - May
Jun
Jul
Aug
Sep
60
50
40
-220
-200
-180
-160
-140

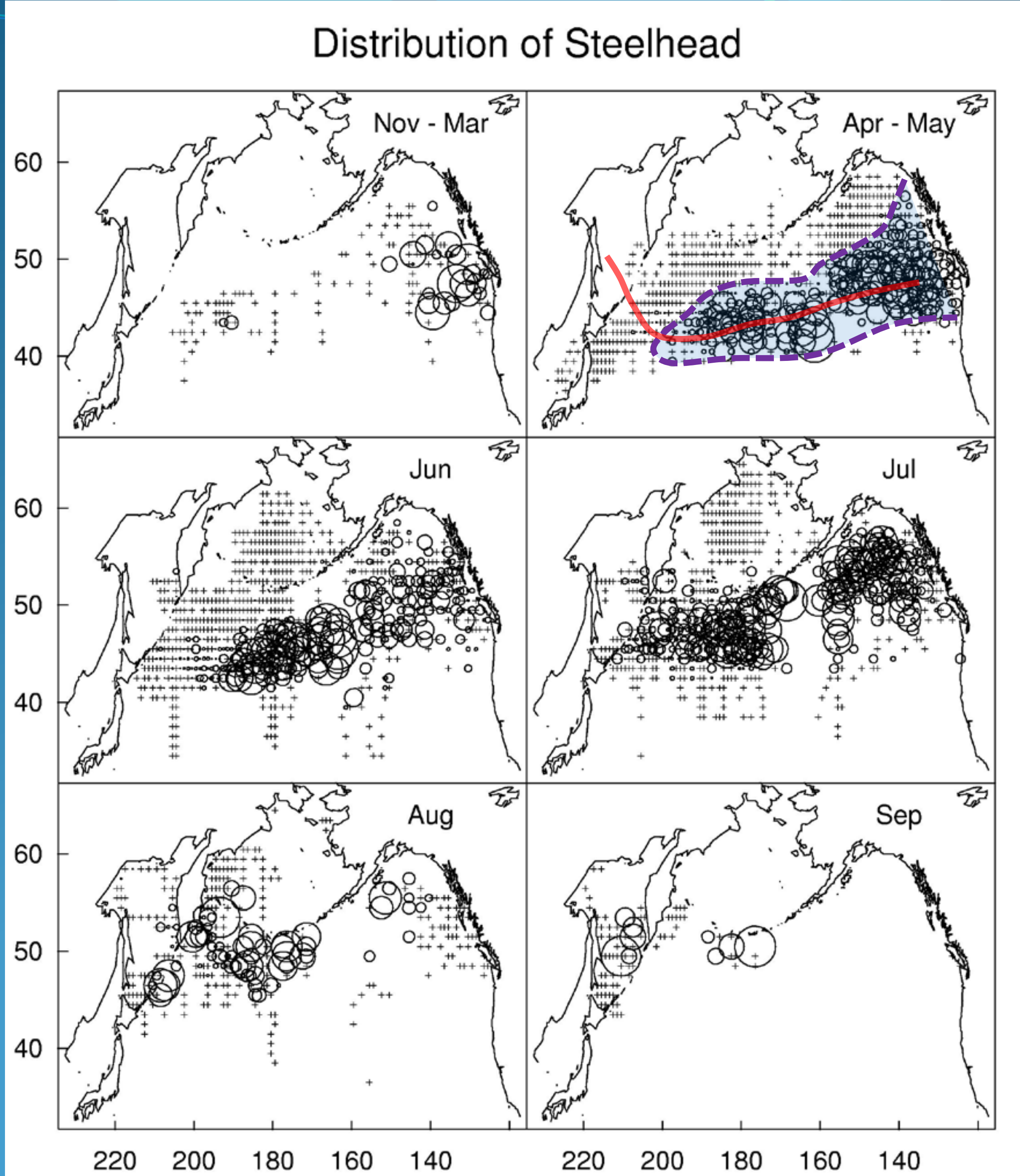
Chinook



Distribution of Chinook
Nov - Mar
Apr - May
Jun
Jul
Aug
Sep
60
50
40
-220
-200
-180
-160
-140

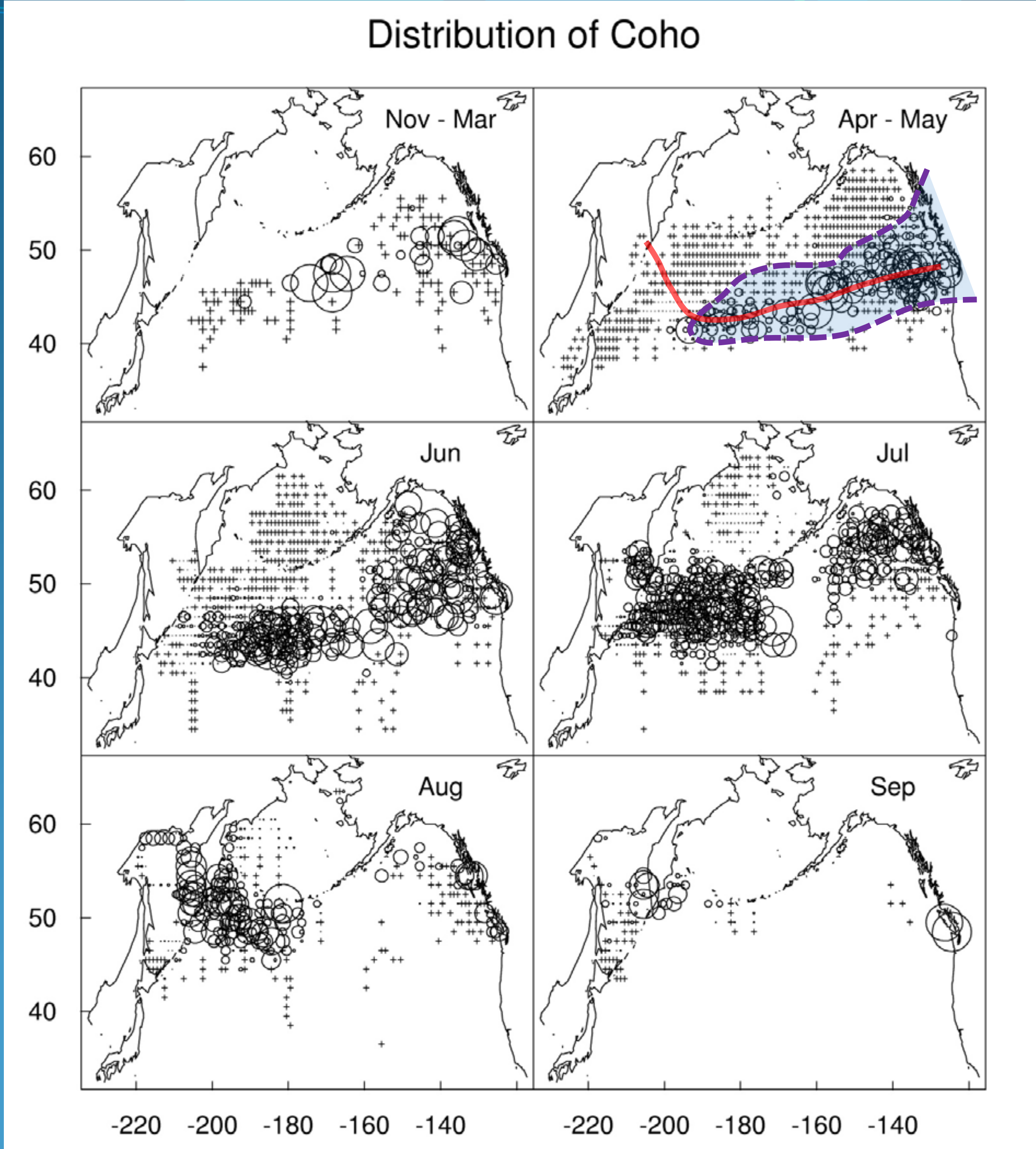
Steelhead

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

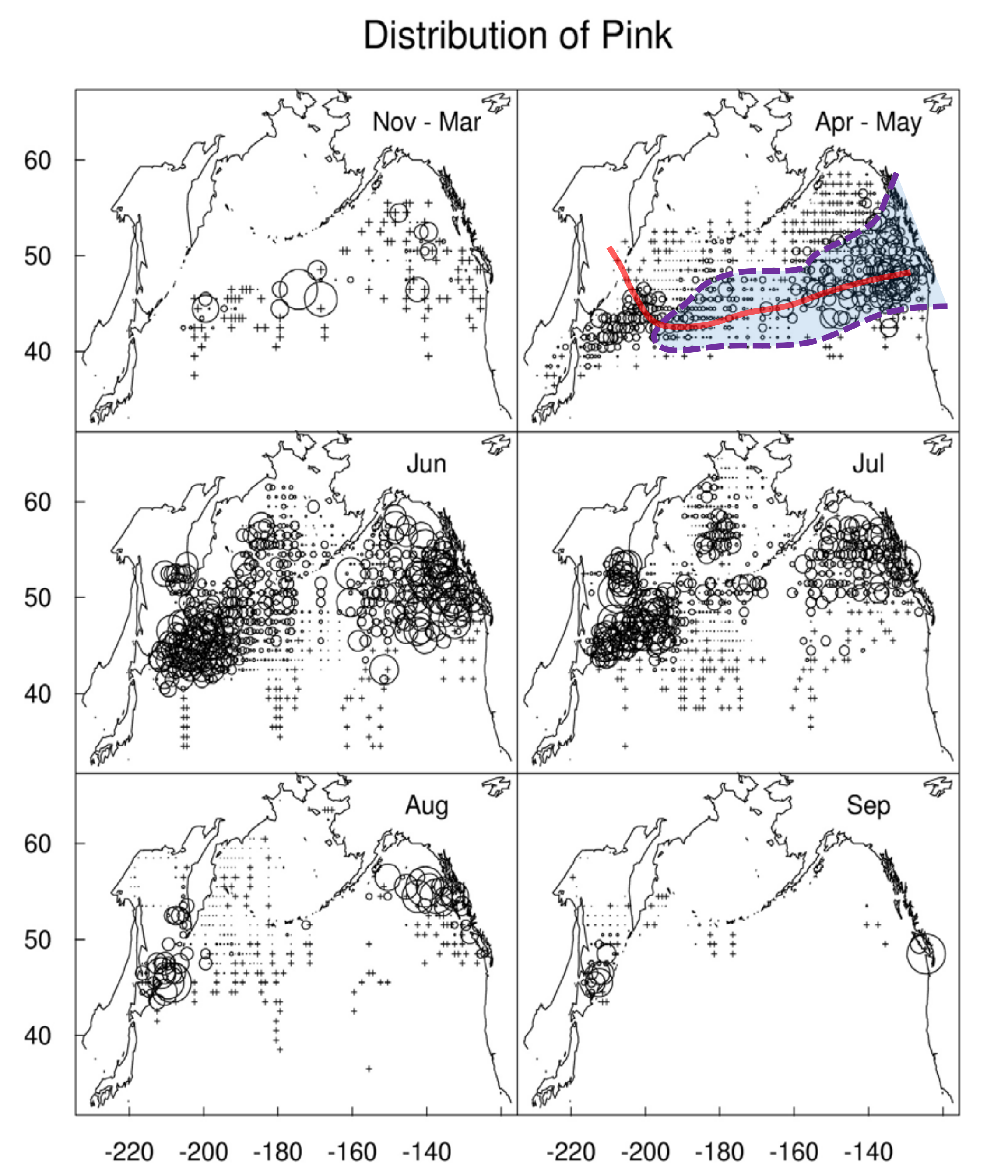


Coho

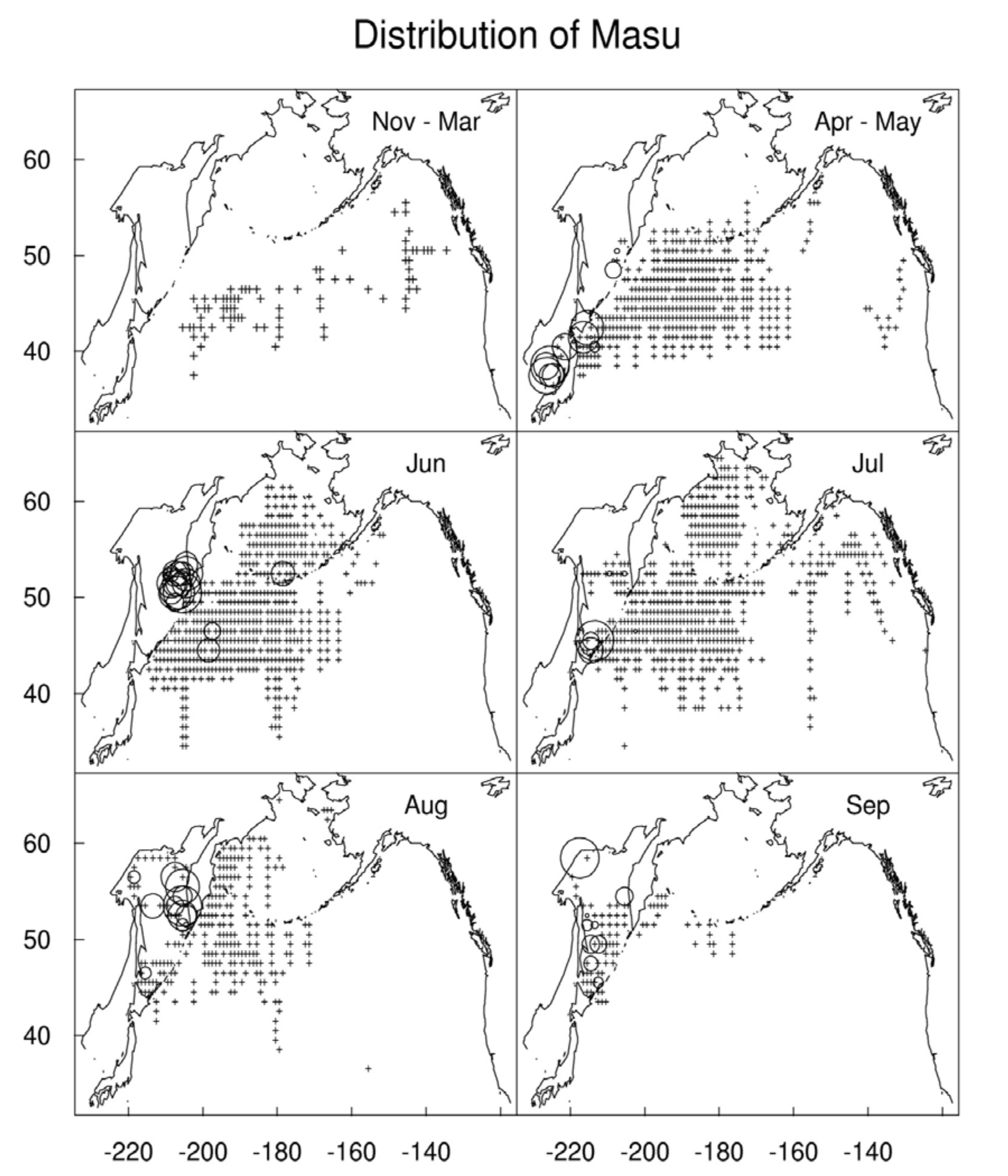
- Distribution also shows a banded structure across the North Pacific



Pink

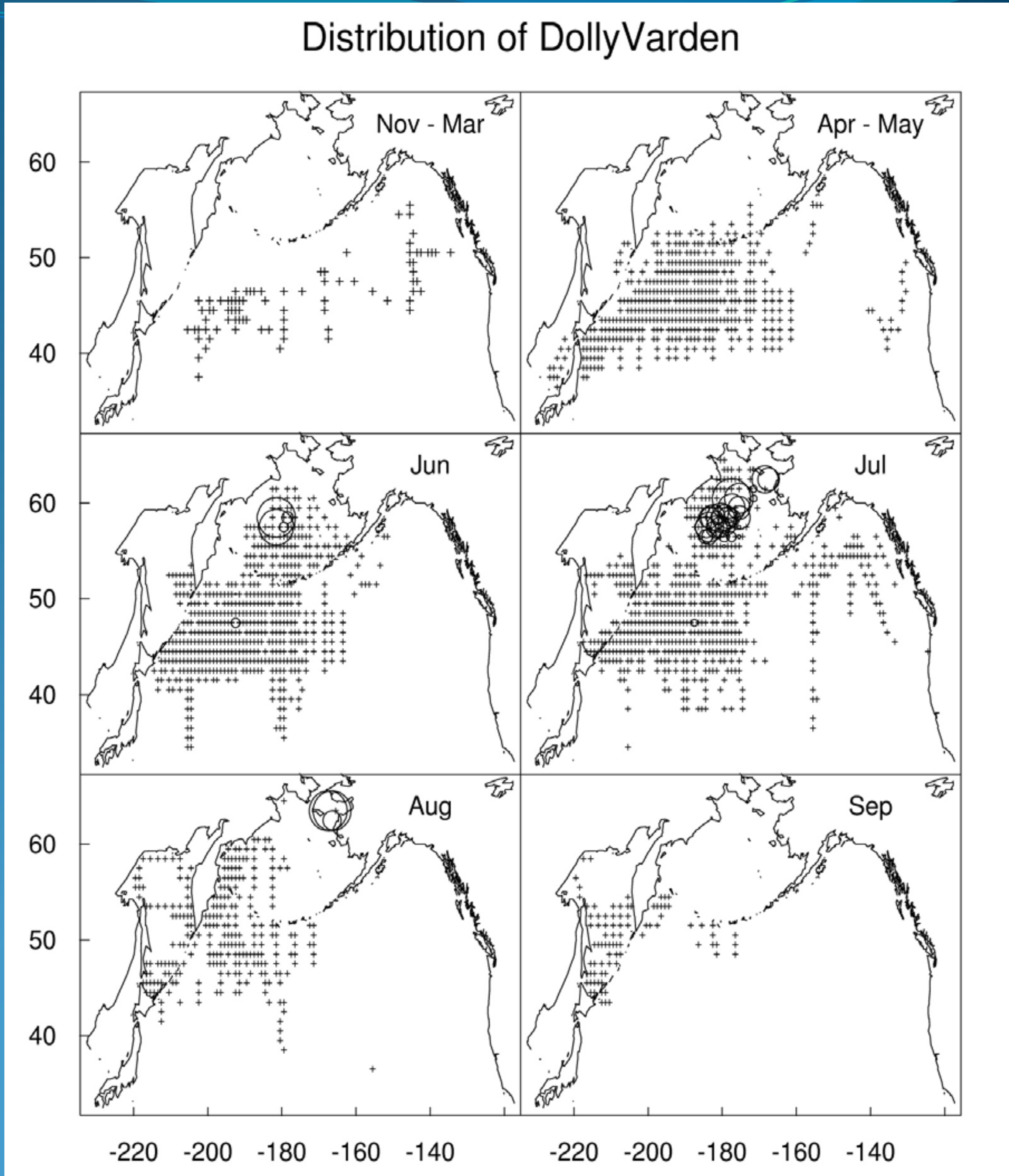

Distribution of Pink
Nov - Mar
Apr - May
Jun
Jul
Aug
Sep
60
50
40
-220
-200
-180
-160
-140

Masu



Distribution of Masu
Nov - Mar
Apr - May
Jun
Jul
Aug
Sep
60
50
40
-220
-200
-180
-160
-140

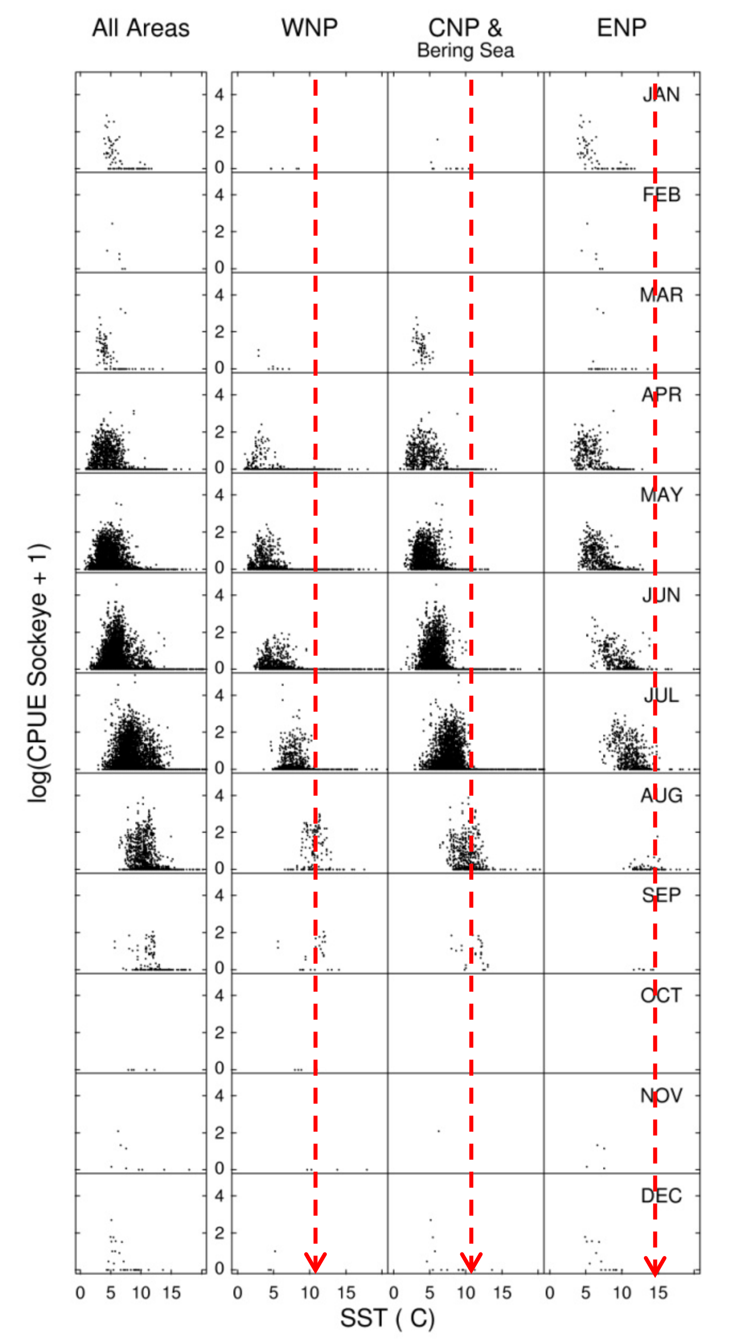
Dolly Varden



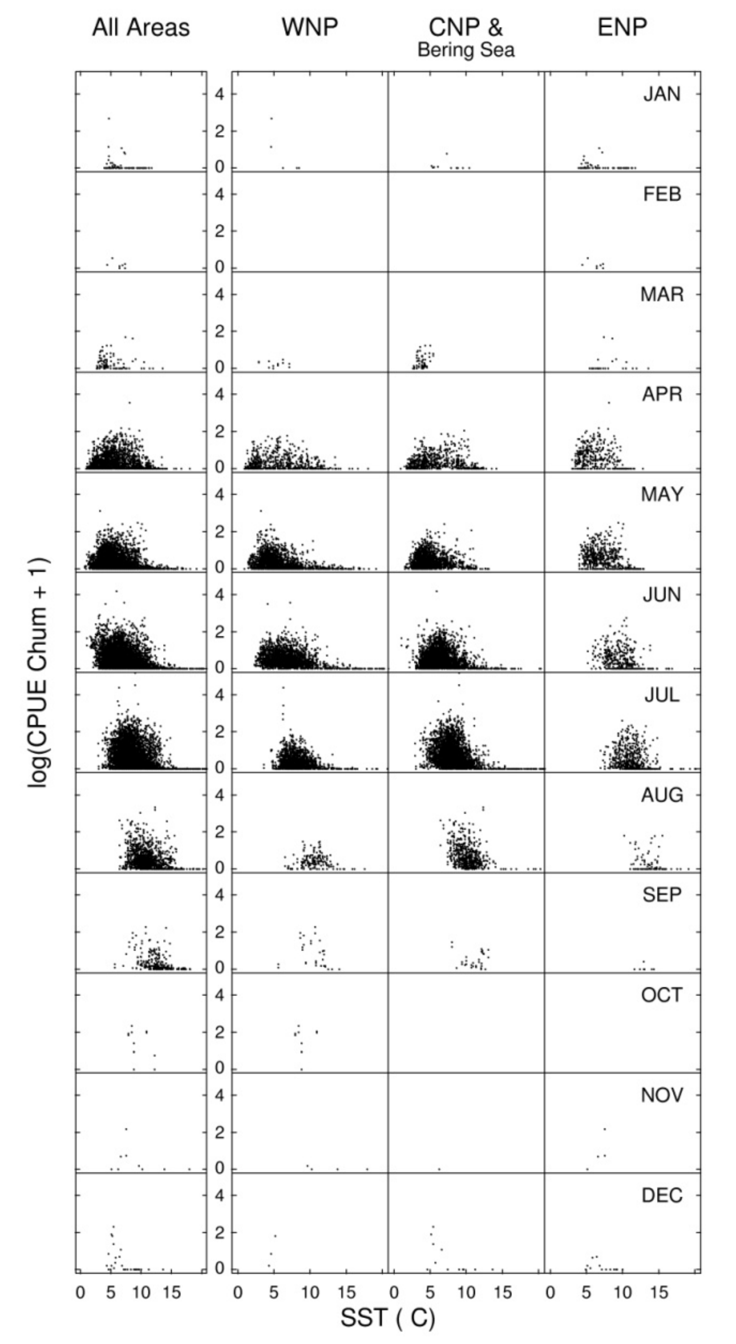
Sockeye- Log (CPUE+1) vs SST

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

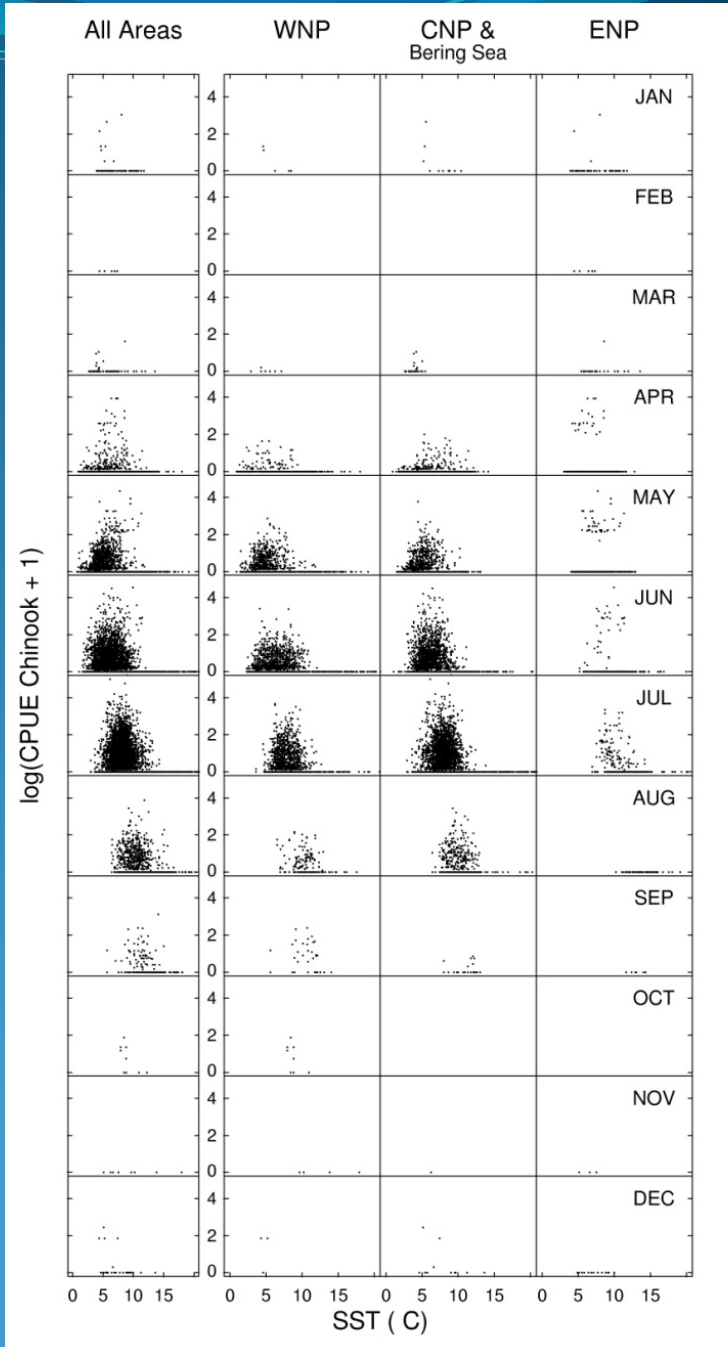
-The edge of the distribution is at colder temperatures in the spring, warmer temperatures in August.



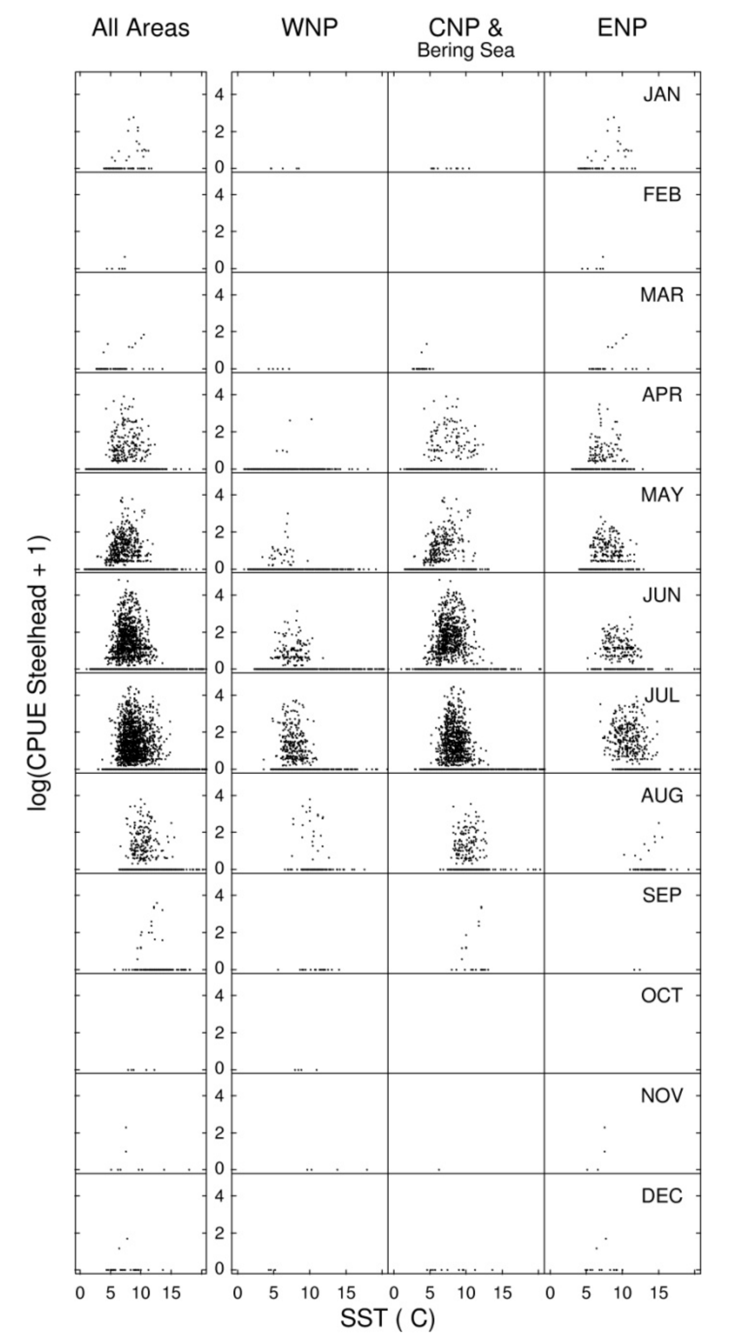
Chum- Log (CPUE+1) vs SST



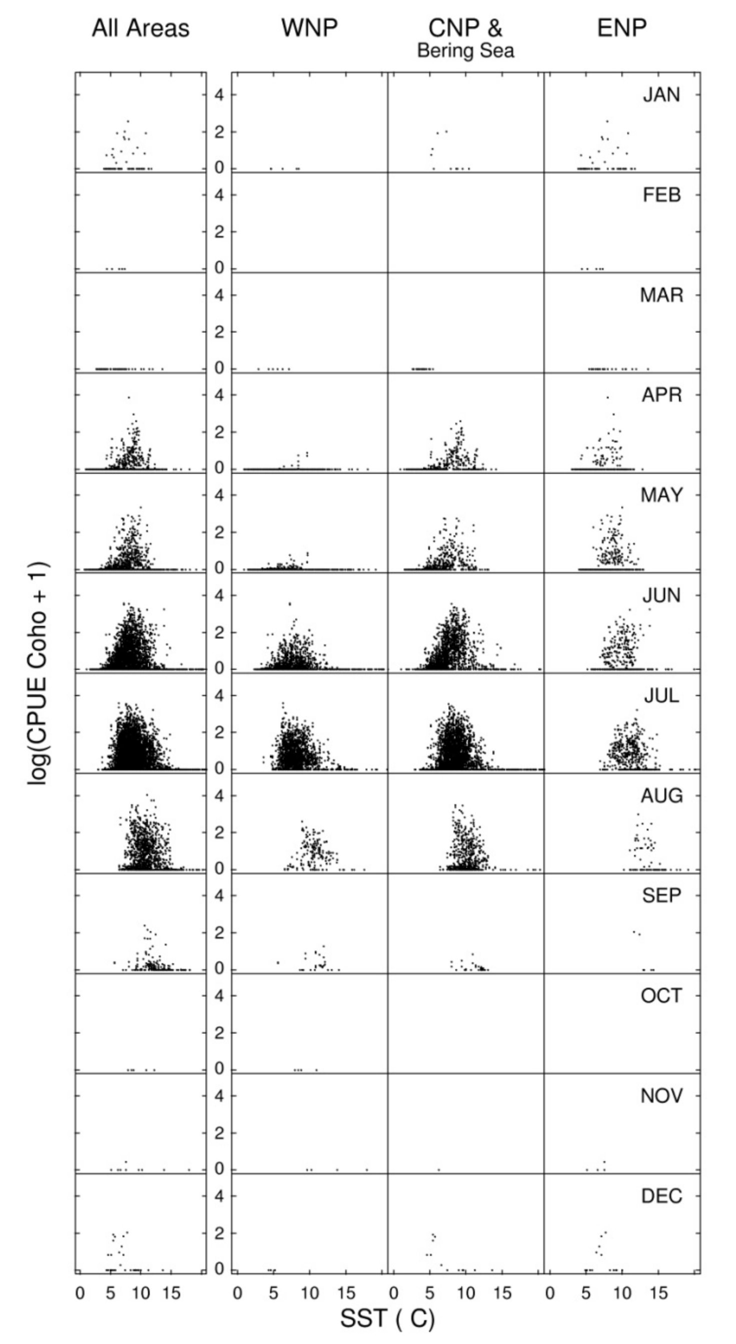
Chinook- Log (CPUE+1) vs SST



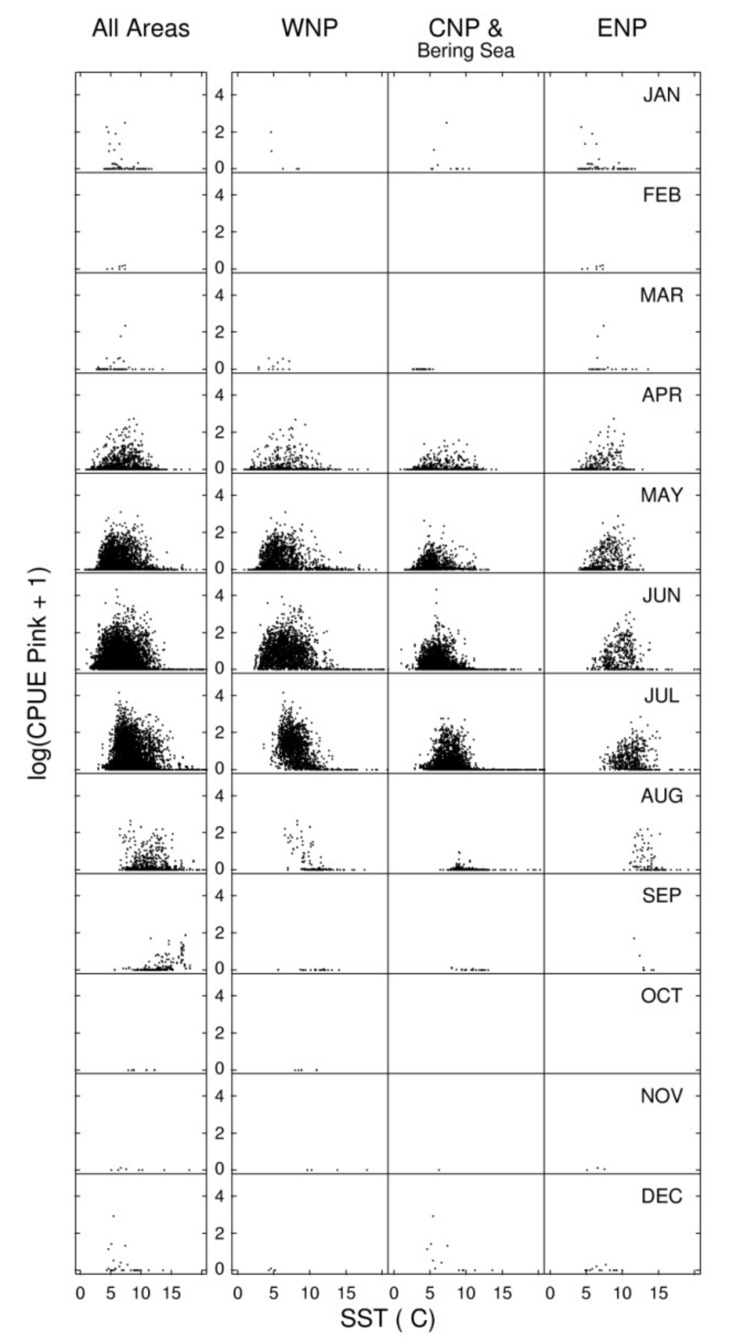
Steelhead- Log (CPUE+1) vs SST



Coho- Log (CPUE+1) vs SST



Pink- Log (CPUE+1) vs SST



Measuring the Thermal Limit

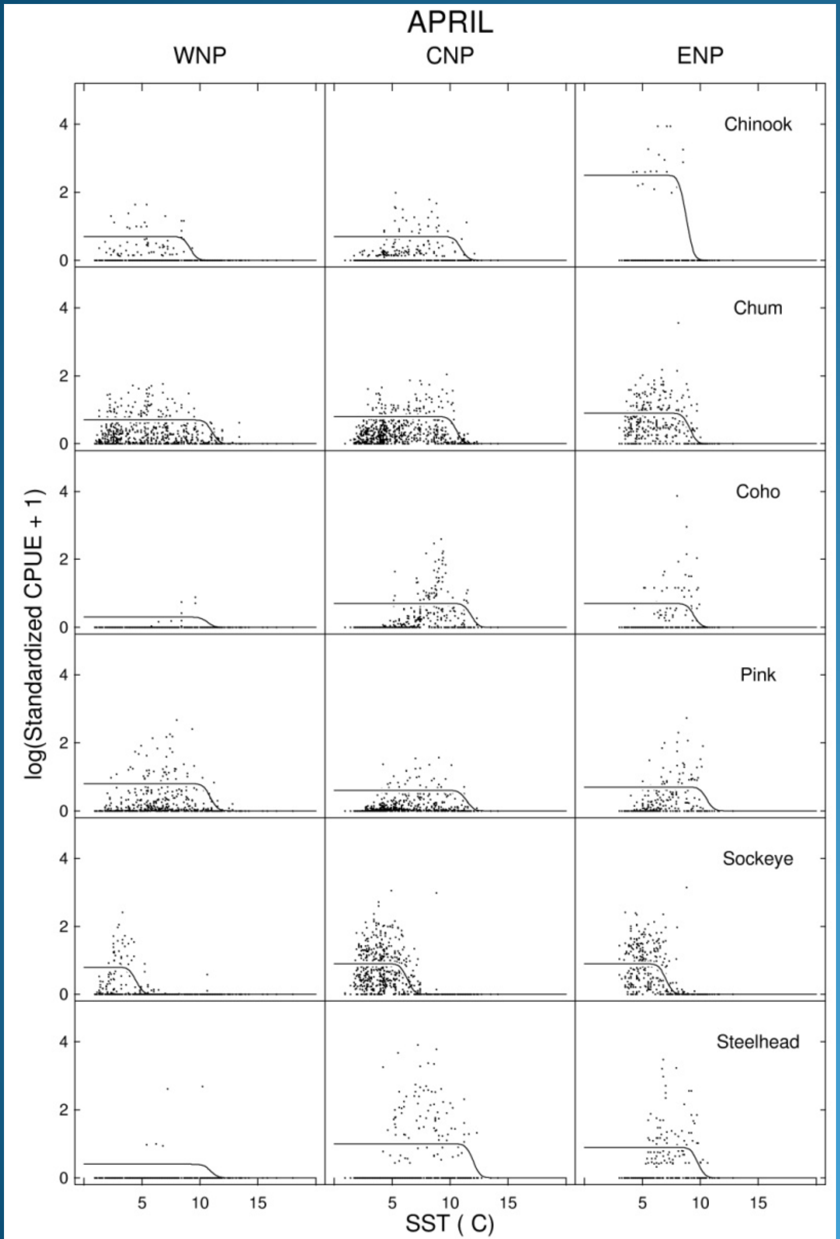
- The southern edge of the distribution can be defined by assuming an average critical temperature at which animals express avoidance behaviour, T_{crit}, and Gaussian variability between individual animals in the temperature at which this behaviour occurs, σ_T (Welch et al. 1995).
- $$n(T_i) = \mu(1 - \Phi(T_i - T_{Crit}, \sigma_T))$$
- This defines the cumulative Gaussian probability, Φ, that have responded by some temperature T_i. Here, μ is abundance, T_i, is the temperature (SST) at the i-th sample location, and σ_T is the variability between individuals

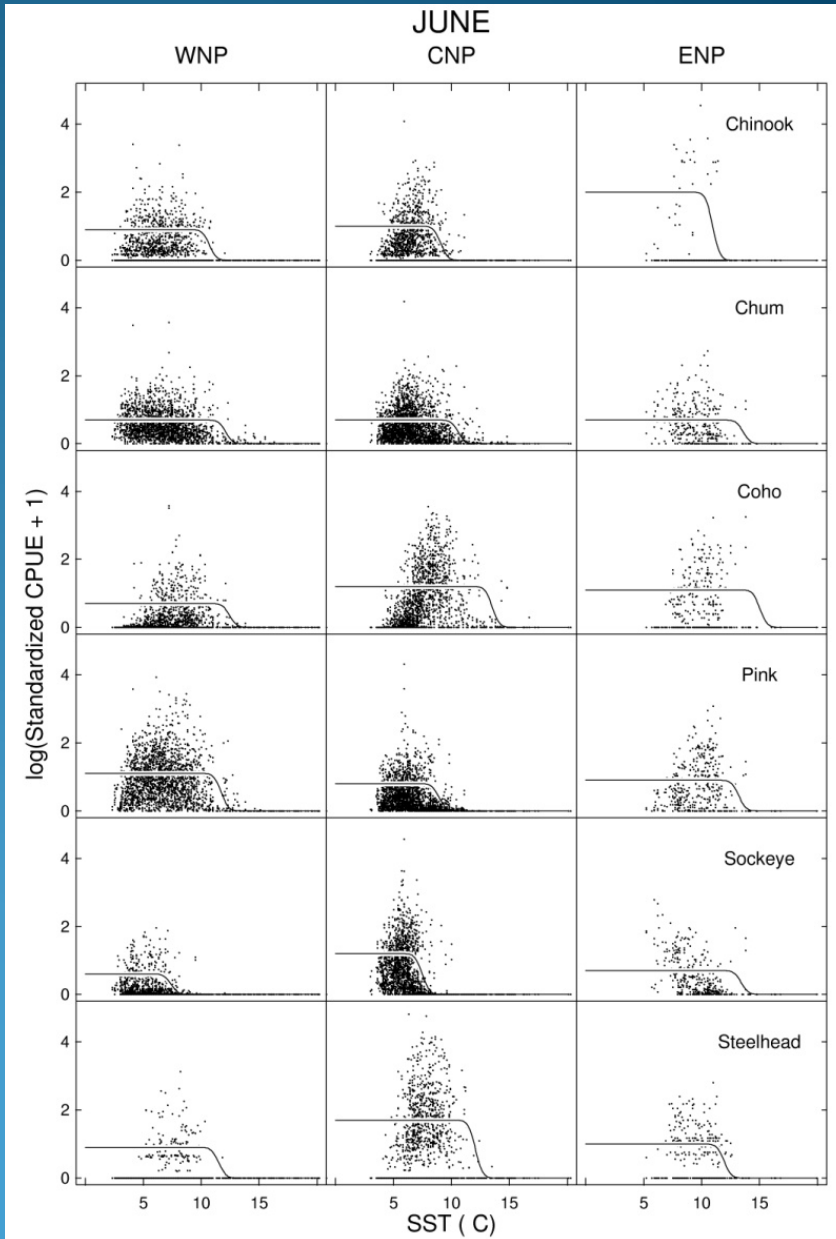
Measuring the Thermal Limit

- Estimates of the midpoint, T_{crit}, and the rate of change in salmon density with temperature around this point, σ_T, define the rate at which abundance declines with increasing temperature at the thermal limit (Welch et al. 1995).

Spring (April)

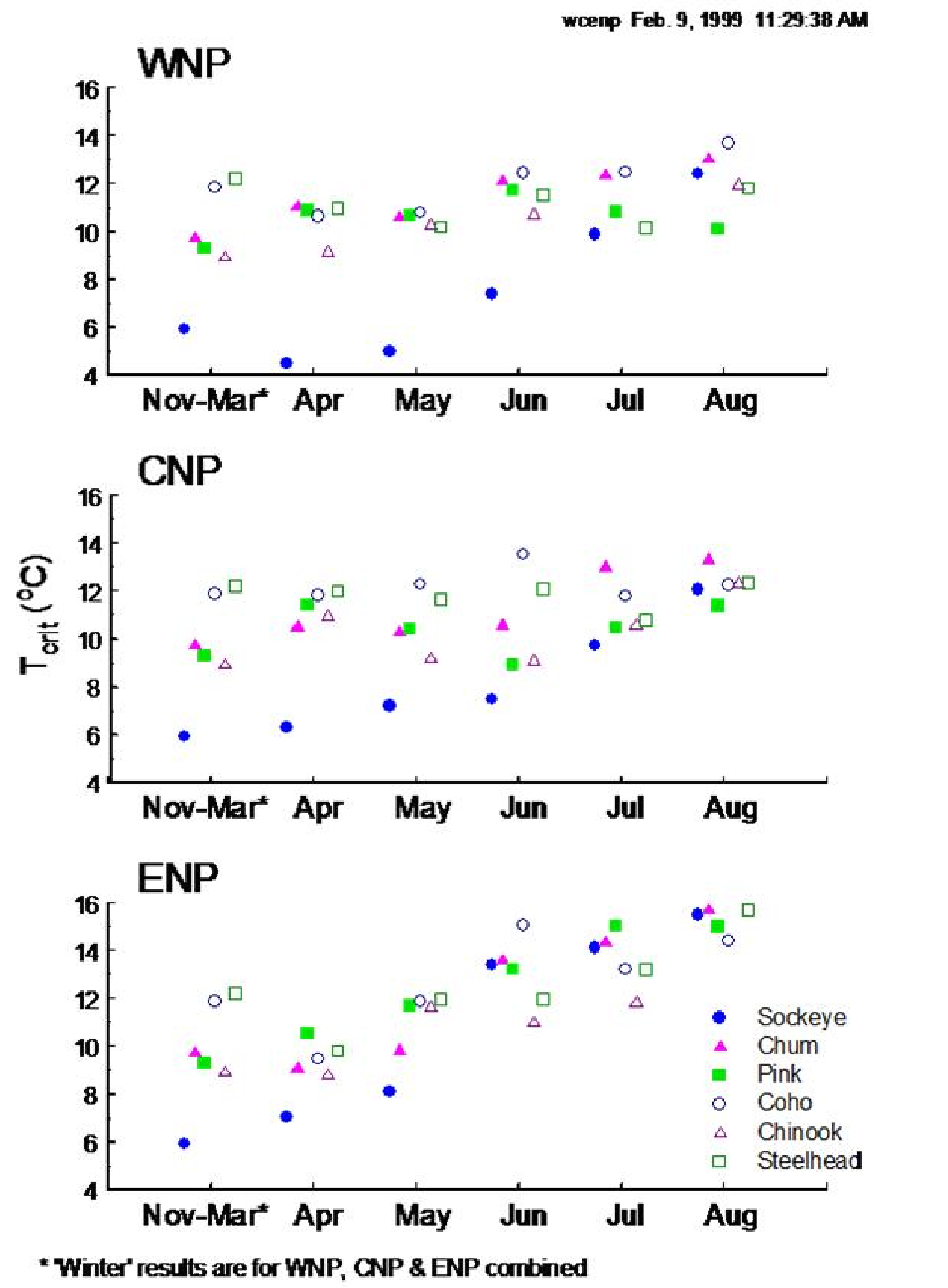
Summer (June)





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

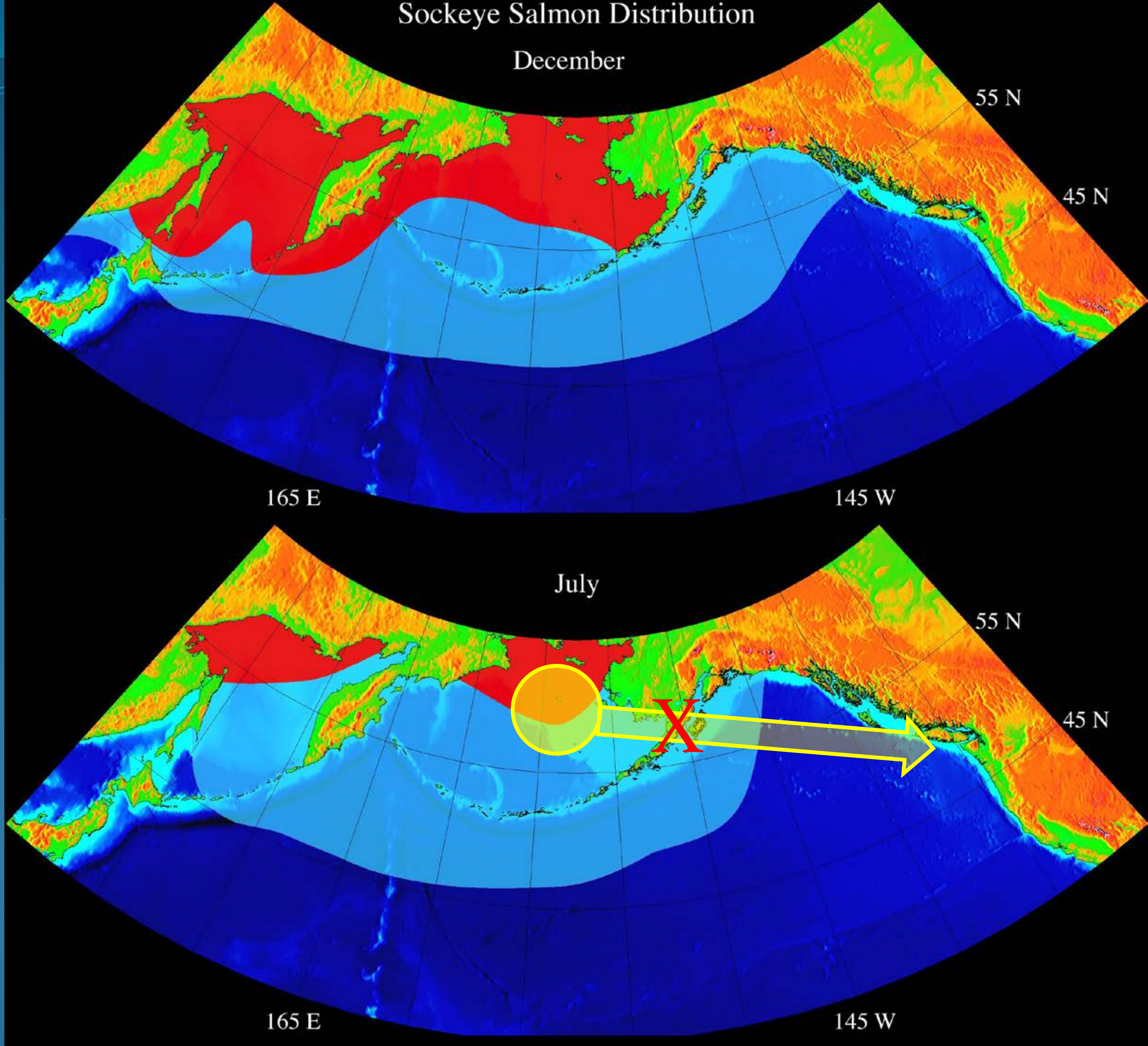


- The “best guess” as to why thermal limits are so sharp is that they represent the critical point where food availability just supports temperature-determined metabolic processes.
- This explanation does ***not*** explain the existence of a northern lower temperature boundary for three species of salmon (steelhead, Coho, Pink)

- *Something important is missing from our understanding of the underlying processes.*

Conclusions

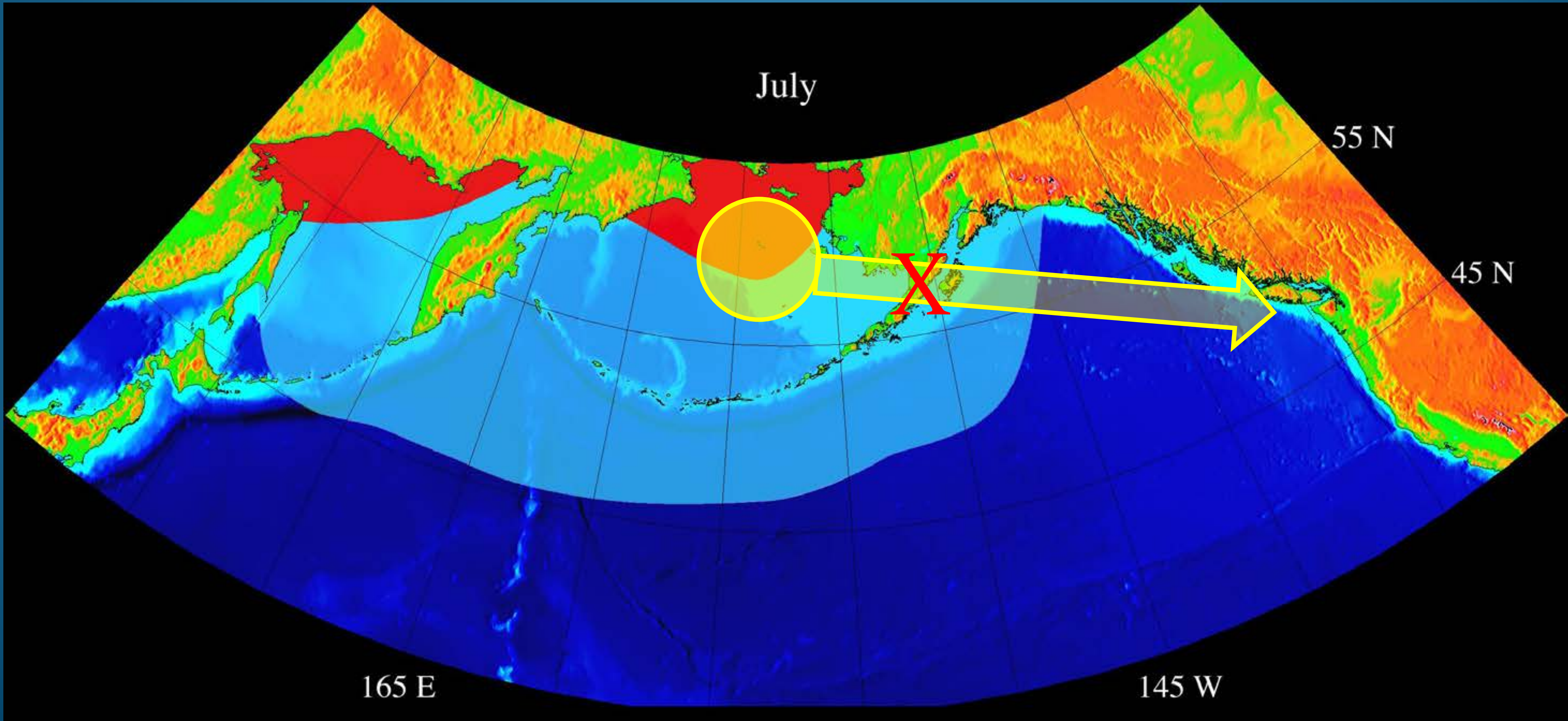
- Large areas of the N Pacific are projected to be lost to salmon as a result of global warming.
- The impact of climate warming is likely to be most severe for west coast North American stocks-
  - Critical upper temperature limits occur at lower temperatures in the Gulf of Alaska than the Central or 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



Sockeye Salmon Distribution
December
55 N
45 N
165 E
145 W
July
55 N
45 N
X
165 E
145 W

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.