Life on the high seas: new insights into the marine distributions of Pacific salmon

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Motivation

Knowledge of Pacific salmon marine distributions important for assessing:

- Influence of marine conditions on growth and survival
- Species interactions
- Locations of likely IUU fishing activities

There is not yet a full, quantified understanding of marine distributions

- The “black box”

Goal: develop baseline ocean distribution models for 6 salmon species

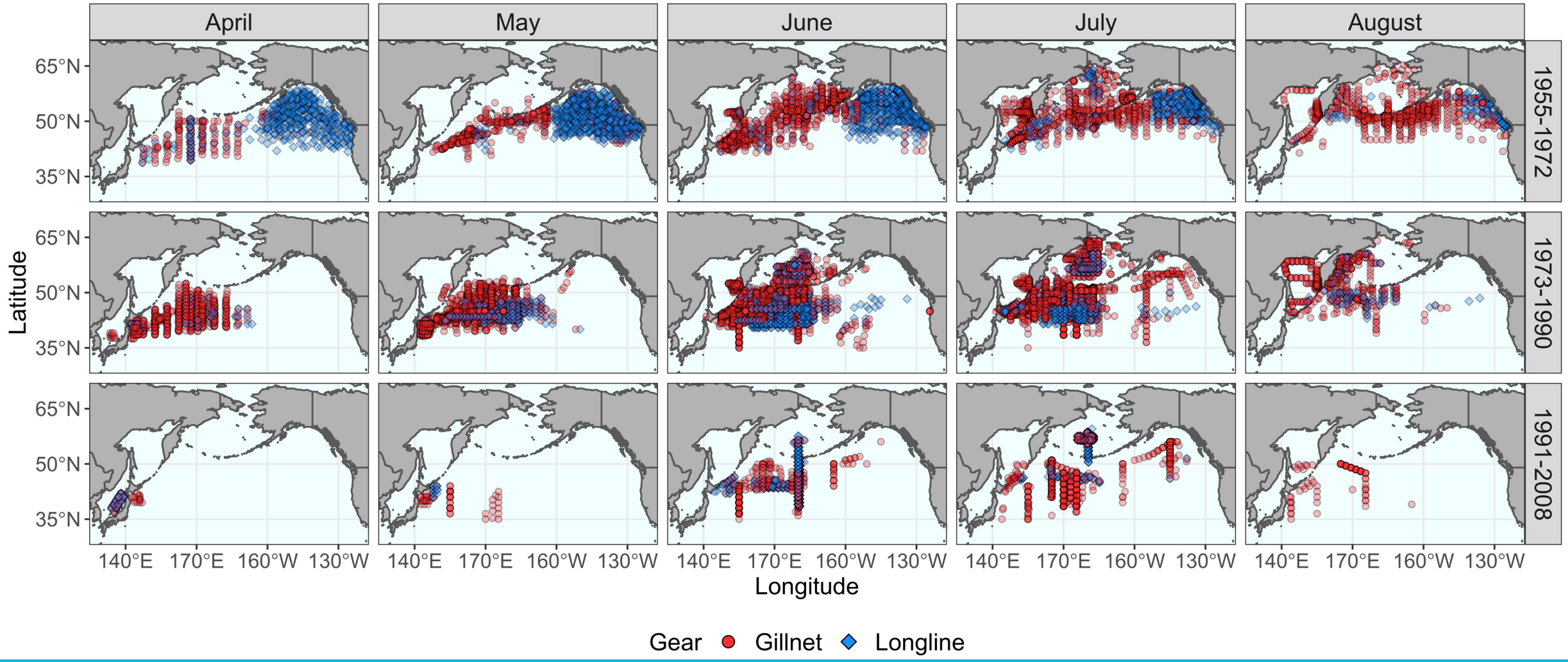
- Sockeye, chum, pink (even & odd years), coho, Chinook, steelhead

Methods

INPFC/NPAFC high seas catch data (1953-Present)

- Limited to gillnet/longline sets and April-August: **17,069 observations**
- 1955-2008

Data Distribution



Methods

INPFC/NPAFC high seas catch data (1953-Present)

- Limited to gillnet/longline sets and April-August: **17,069 observations**
- 1955-2008
- Biological data available for a subset of sets

Nested generalized additive models (GAMs)

- Response variable: Log(CPUE+1)
- Tweedie-distributed errors
- Controlled for spatially varying gear effects and abundance trends over time

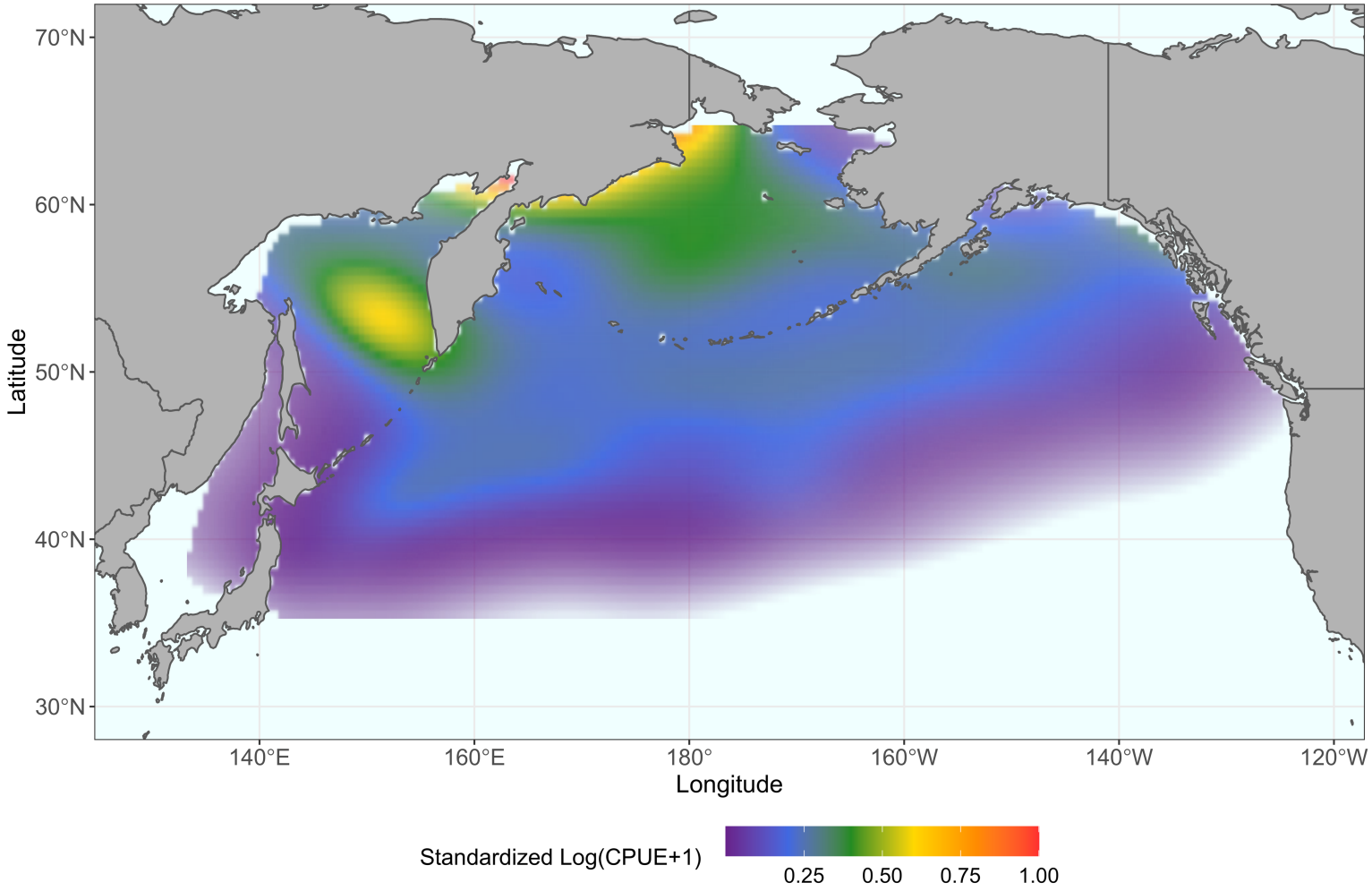
1) $\mathrm{Log(CPUE + 1) \sim Gear + f_{gear}(Lat, Lon) + f(Year) + f(Lat, Lon)}$

Nested GAMs

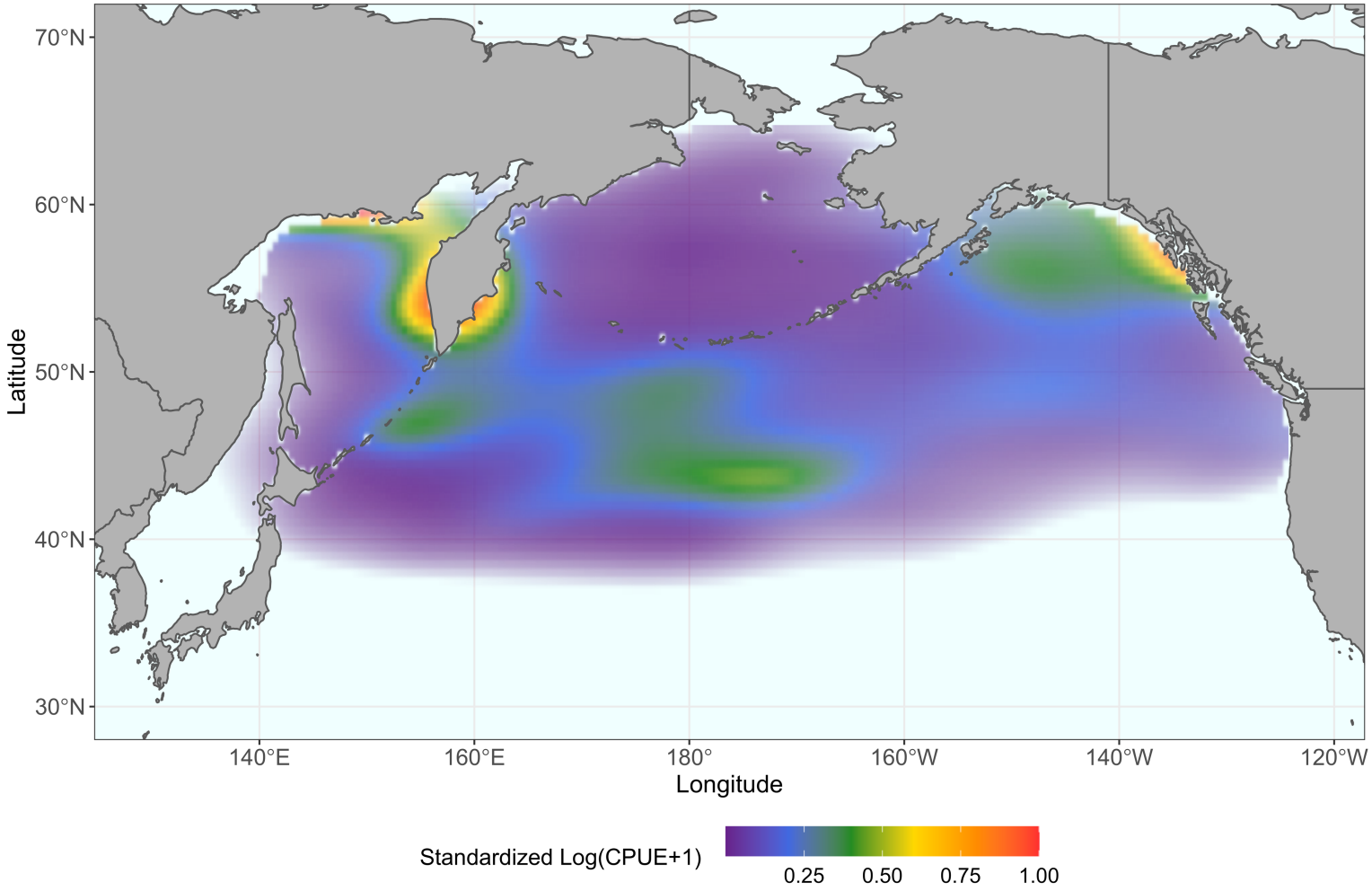
1) Control variables + average spring-summer spatial distribution (base model)
2) Add SST effect
3) Add seasonal (monthly) effect
4) Add spatially-varying SST effect

Compared models with % deviance explained, BIC, 10-fold cross-validation

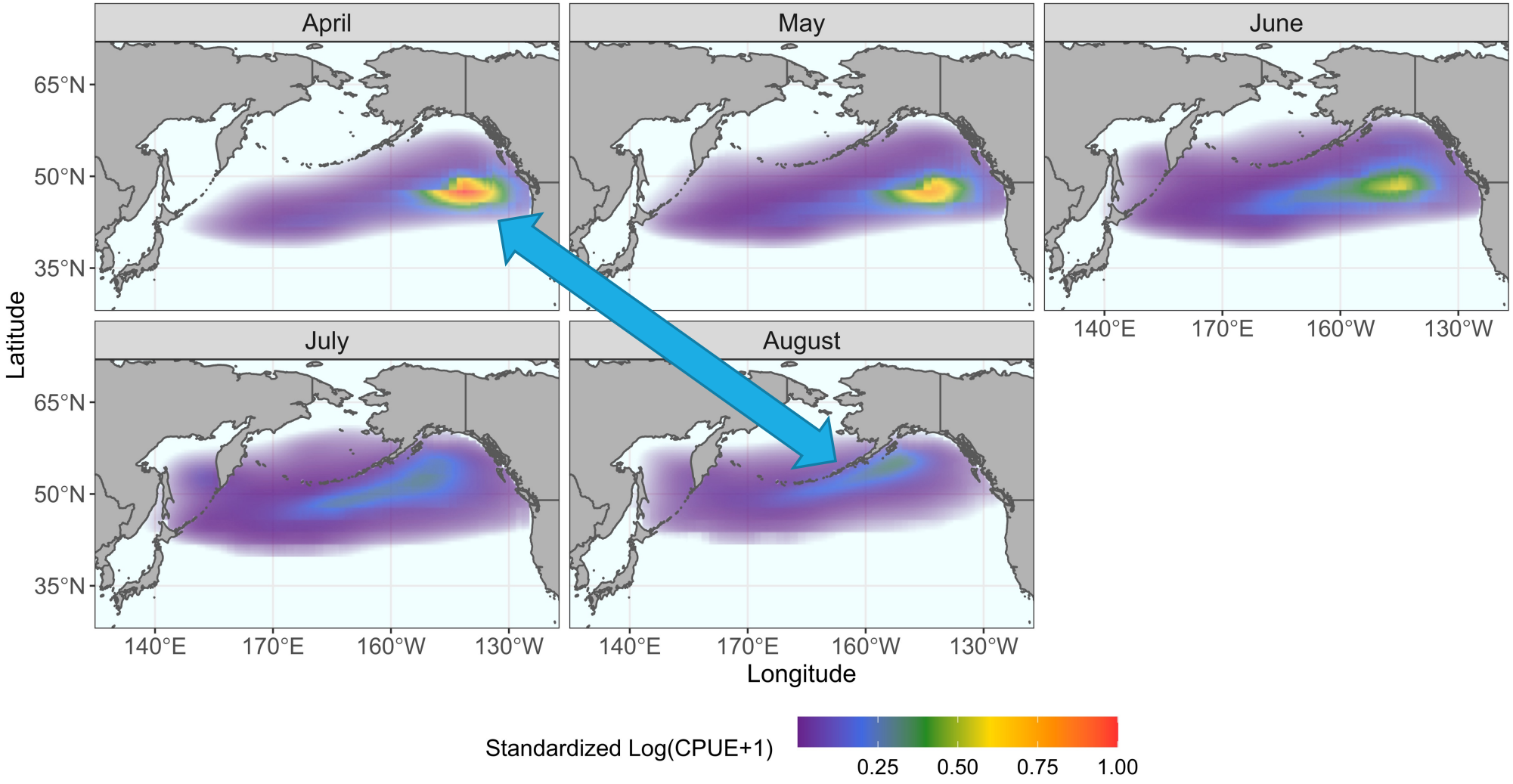
Chum Base Model



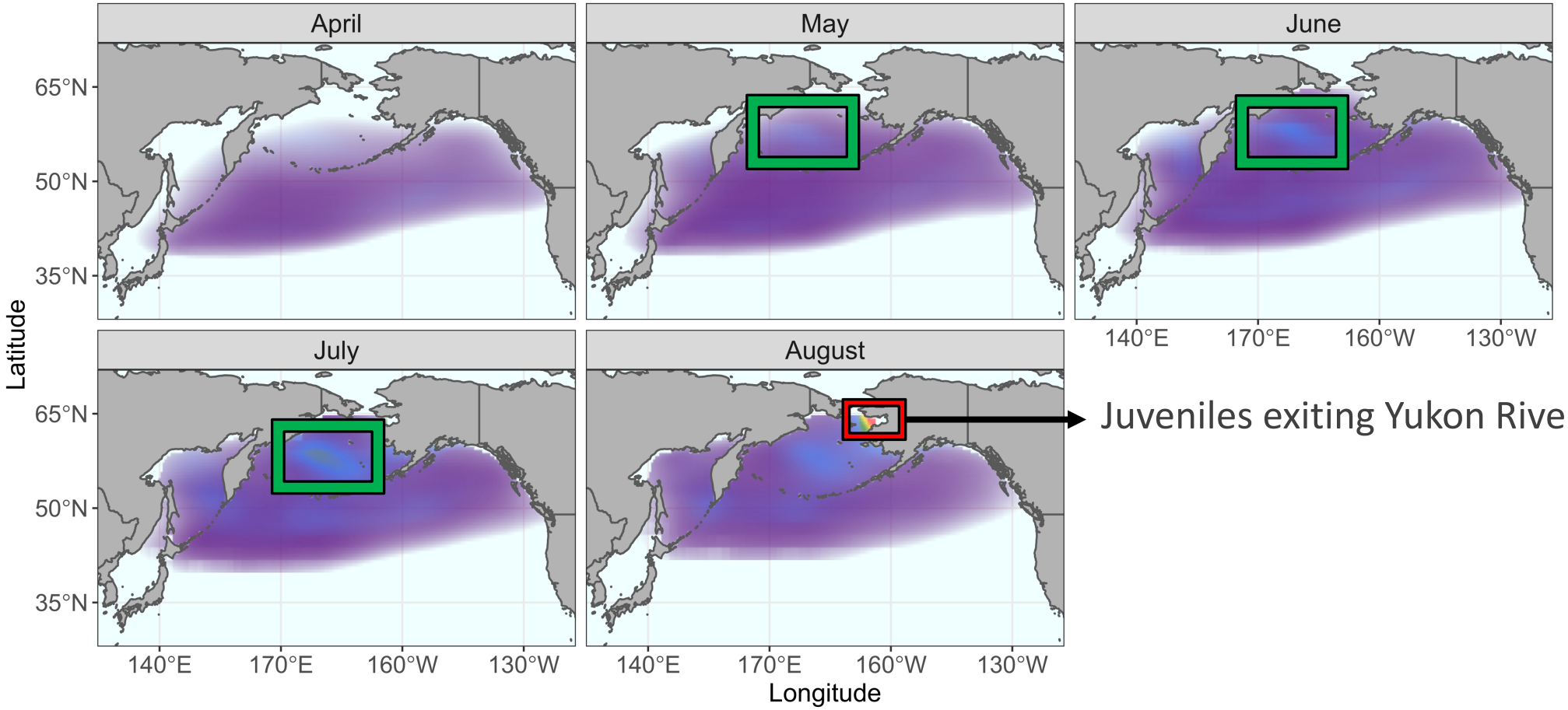
Coho Base Model



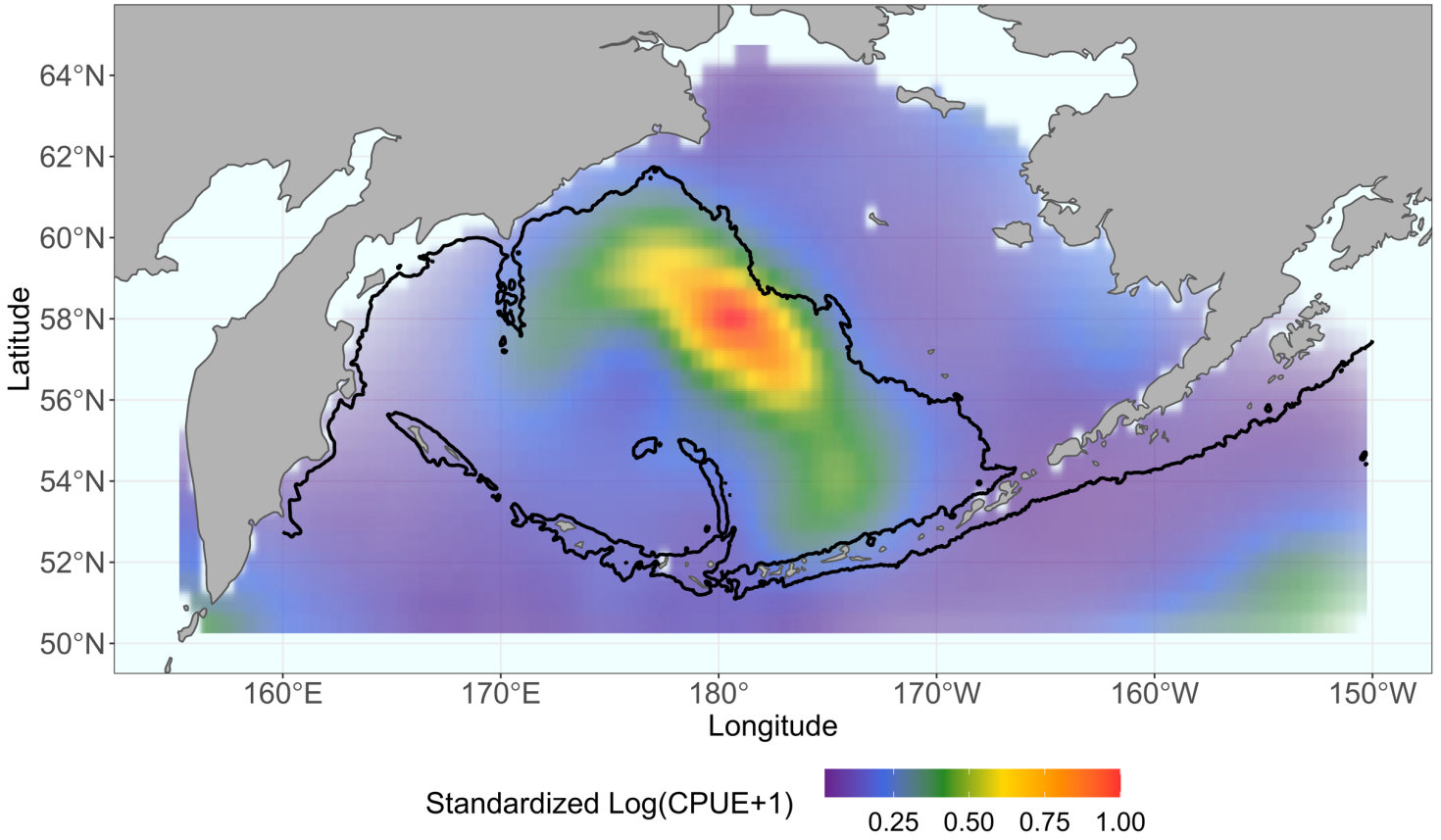
Steelhead Seasonal Distribution



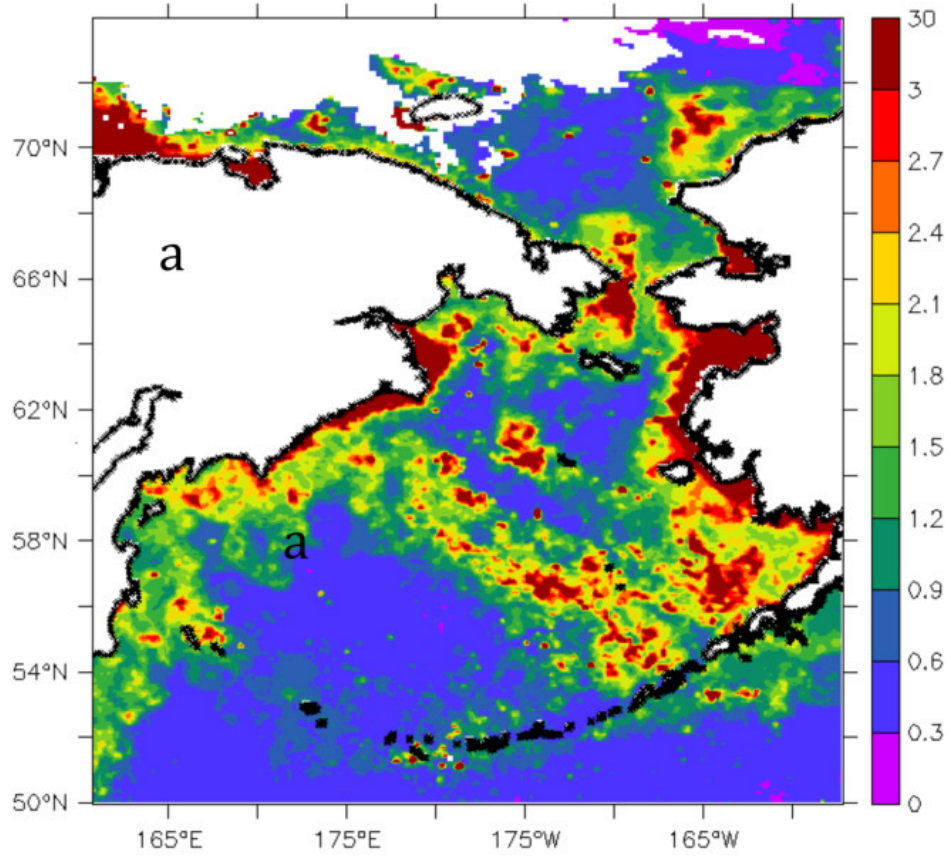
Chinook Seasonal Distribution



“Zoomed In” June-July Chinook Model



May-September 2009 Mean Chl-a



Hu et al. (2016)

SST Preferences by Species

Transparent bars: 80% HDI ≈ “Preferred Range”

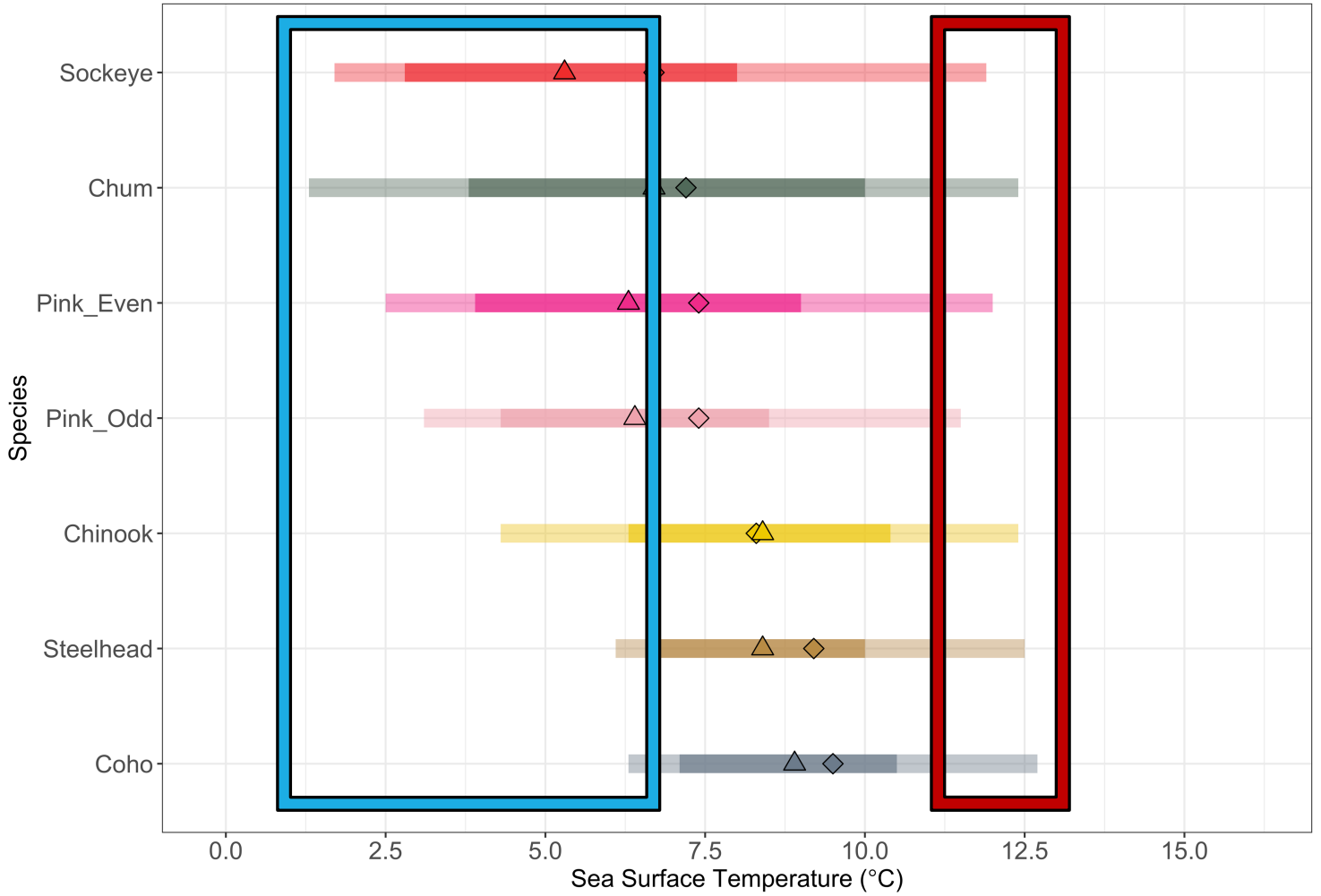
Solid bars: 50% HDI ≈ “Core Range”

Preferred upper bound: 11.5-12.7°C

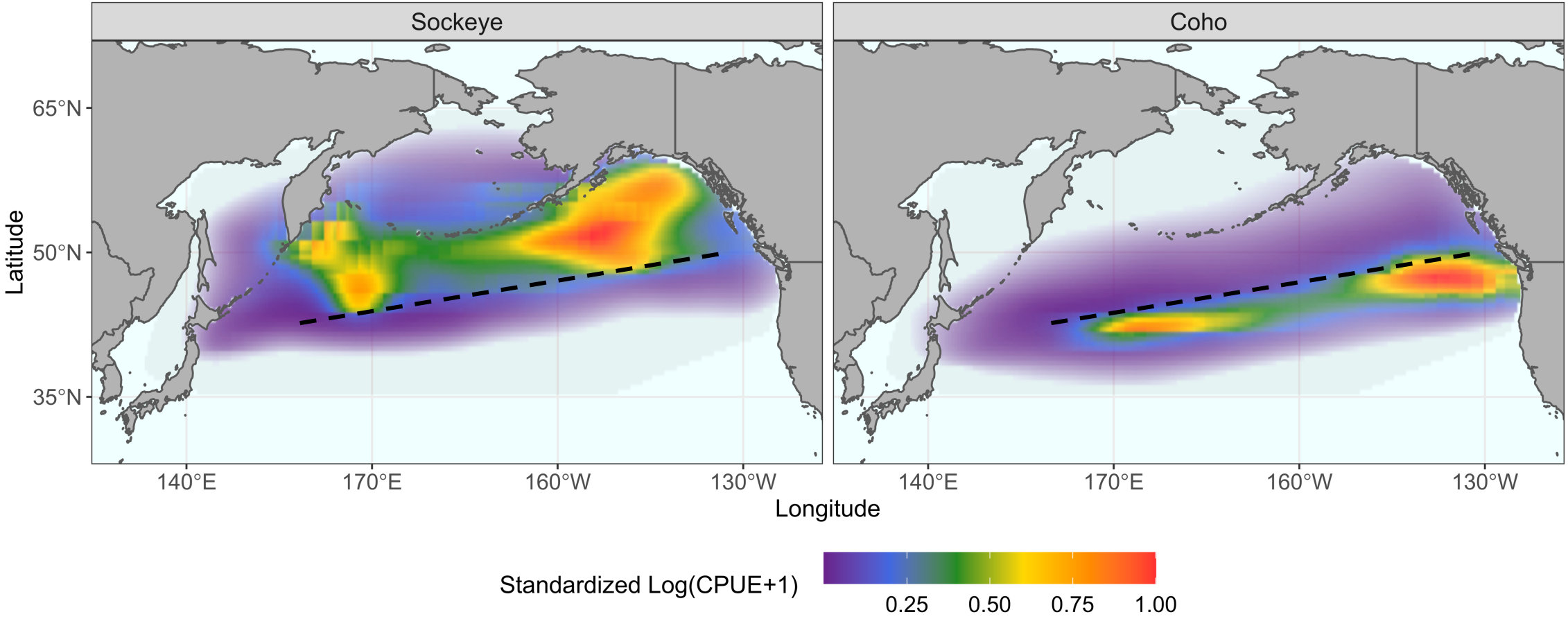
Preferred lower bound: 1.3-6.3°C

Variation primarily in cold tolerance

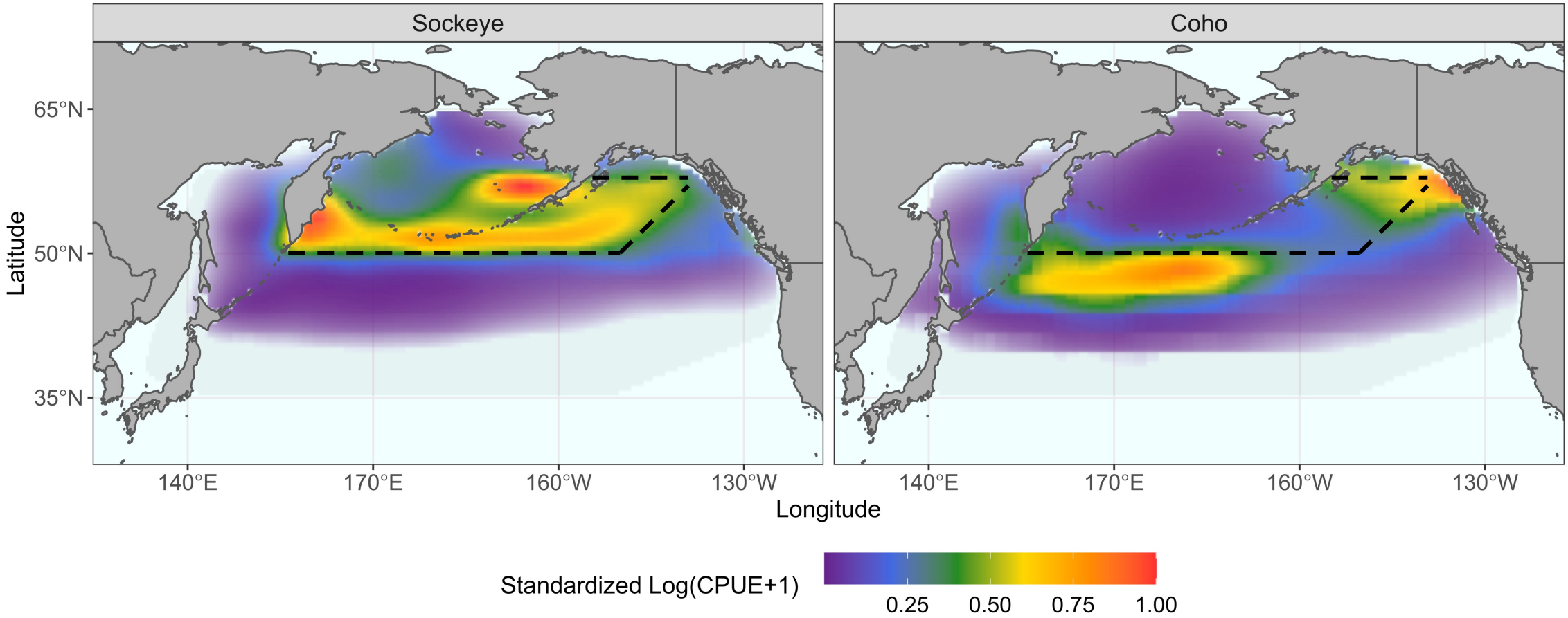
Estimated thermal niche corresponded to distribution patterns and SST sensitivity



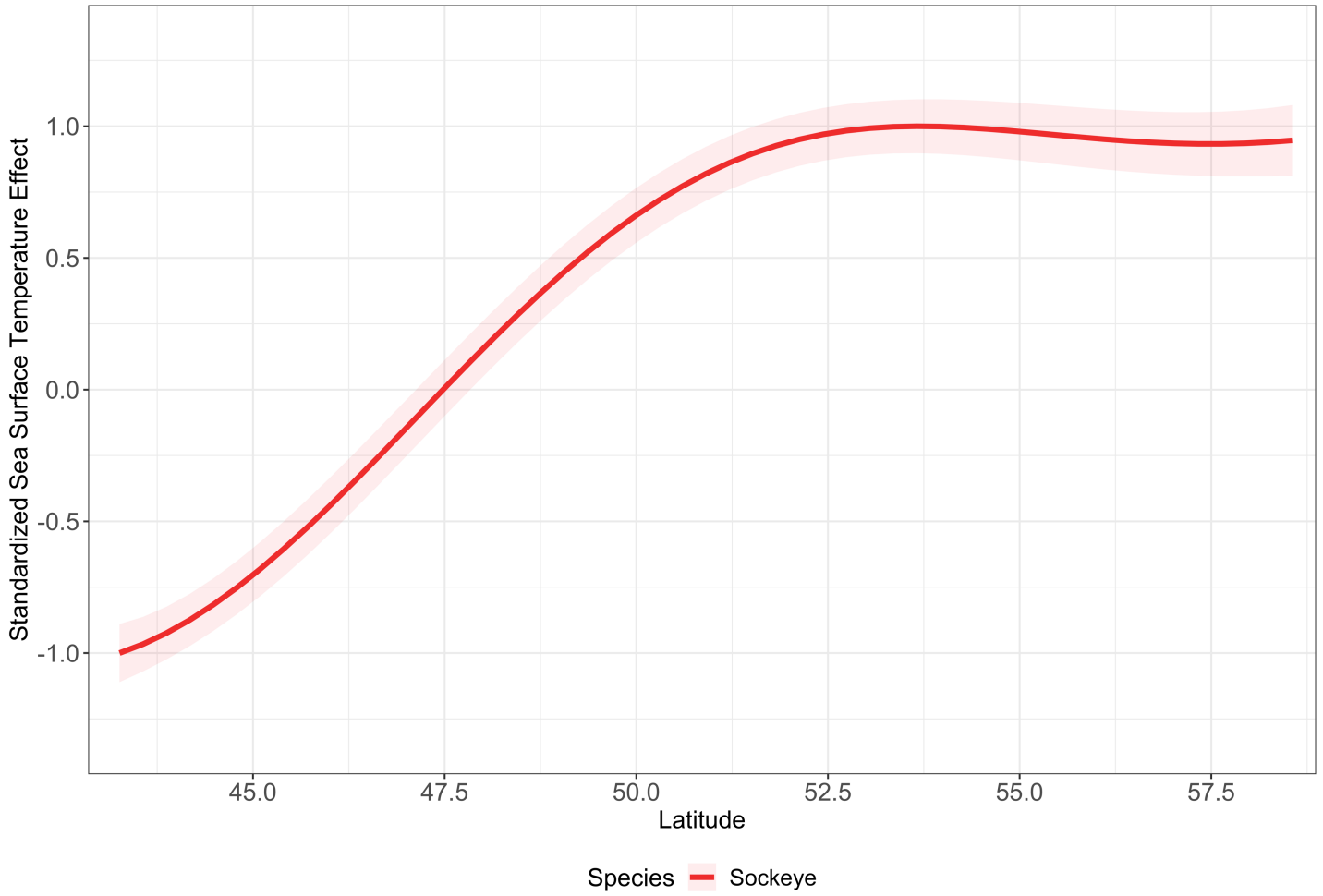
May: Sockeye vs Coho



July: Sockeye vs Coho



SST Preferences by Latitude



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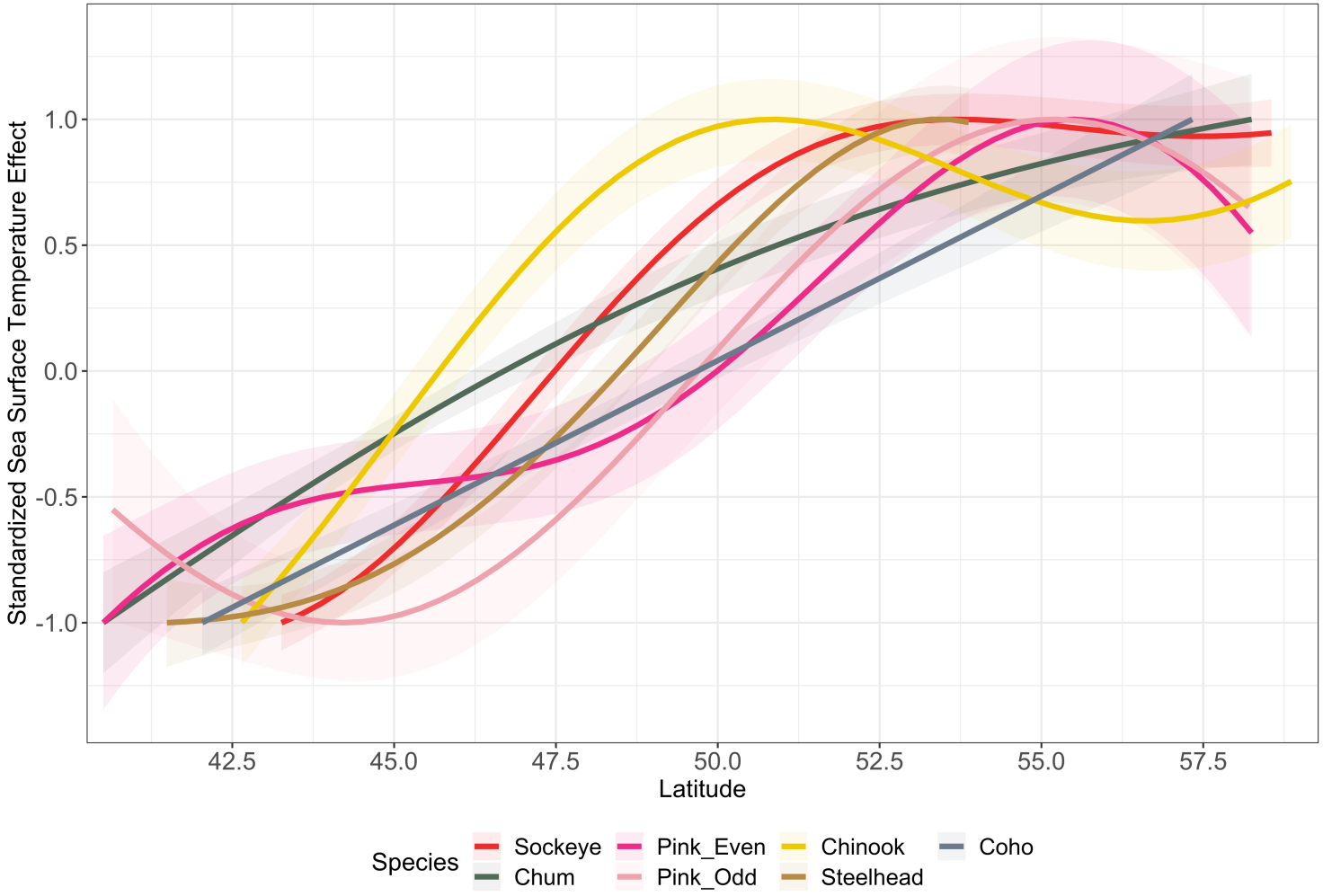
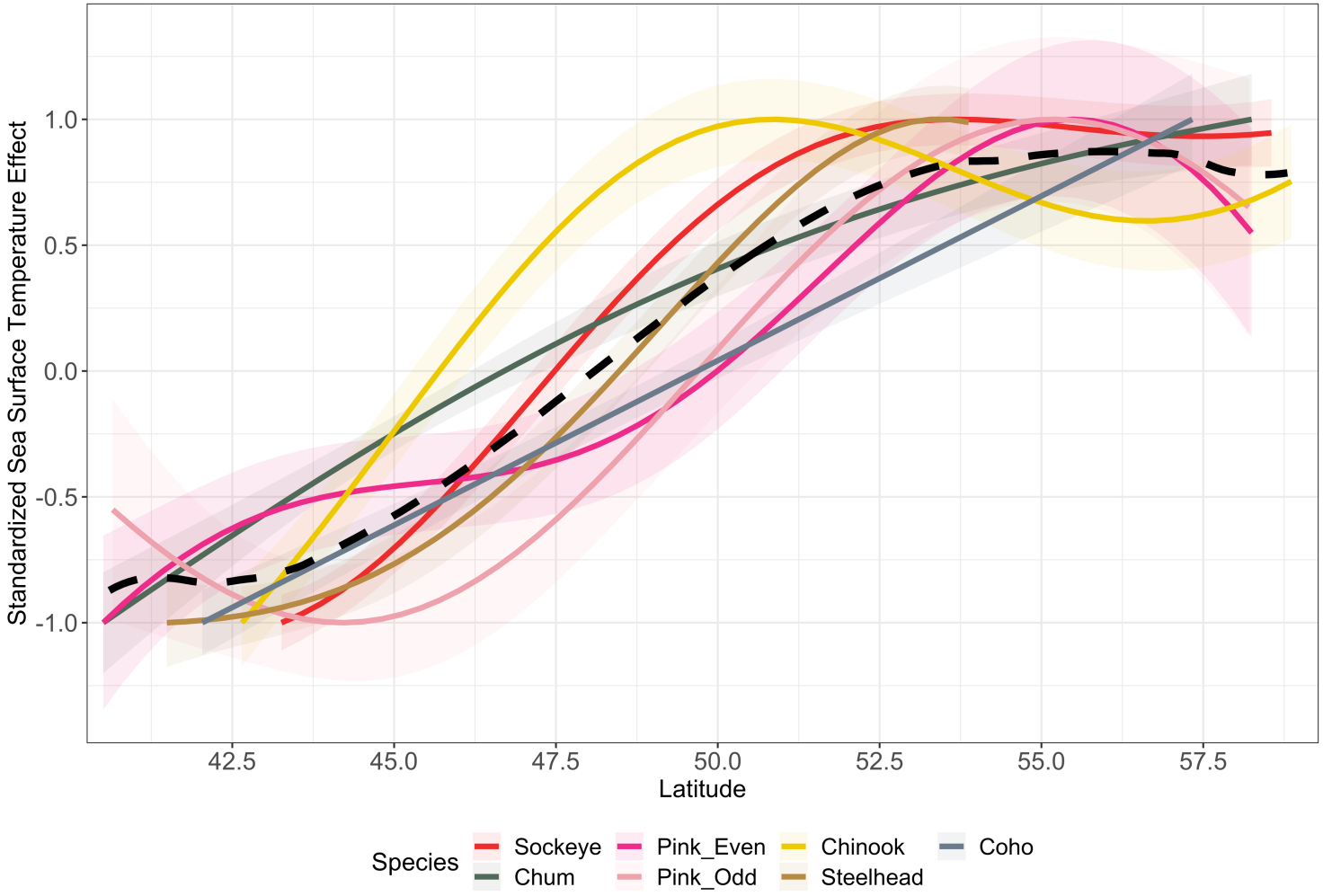


SST Preferences by Latitude

Variable, minor model improvement across species



Conclusions

Diverse species-specific distributions in the North Pacific

Ecological features contribute to distribution patterns

Large seasonal shifts in distribution
- Due in large part to temperature preferences

Species exhibit differing temperature preferences and sensitivity
- Variation primarily in cold tolerance
- Distribution sensitivity related to thermal niche breadth
- Evidence of (small) differences in temperature preference by latitude

Observed changes in temperature patterns likely impacted distributions

Next steps: machine learning approach to predict distribution patterns

Questions?

Diverse species-specific distributions in the North Pacific

Ecological features contribute to distribution patterns

Large seasonal shifts in distribution
- Due in large part to temperature preferences

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Observed changes in temperature patterns likely impacted distributions

Next steps: machine learning approach to predict distribution patterns

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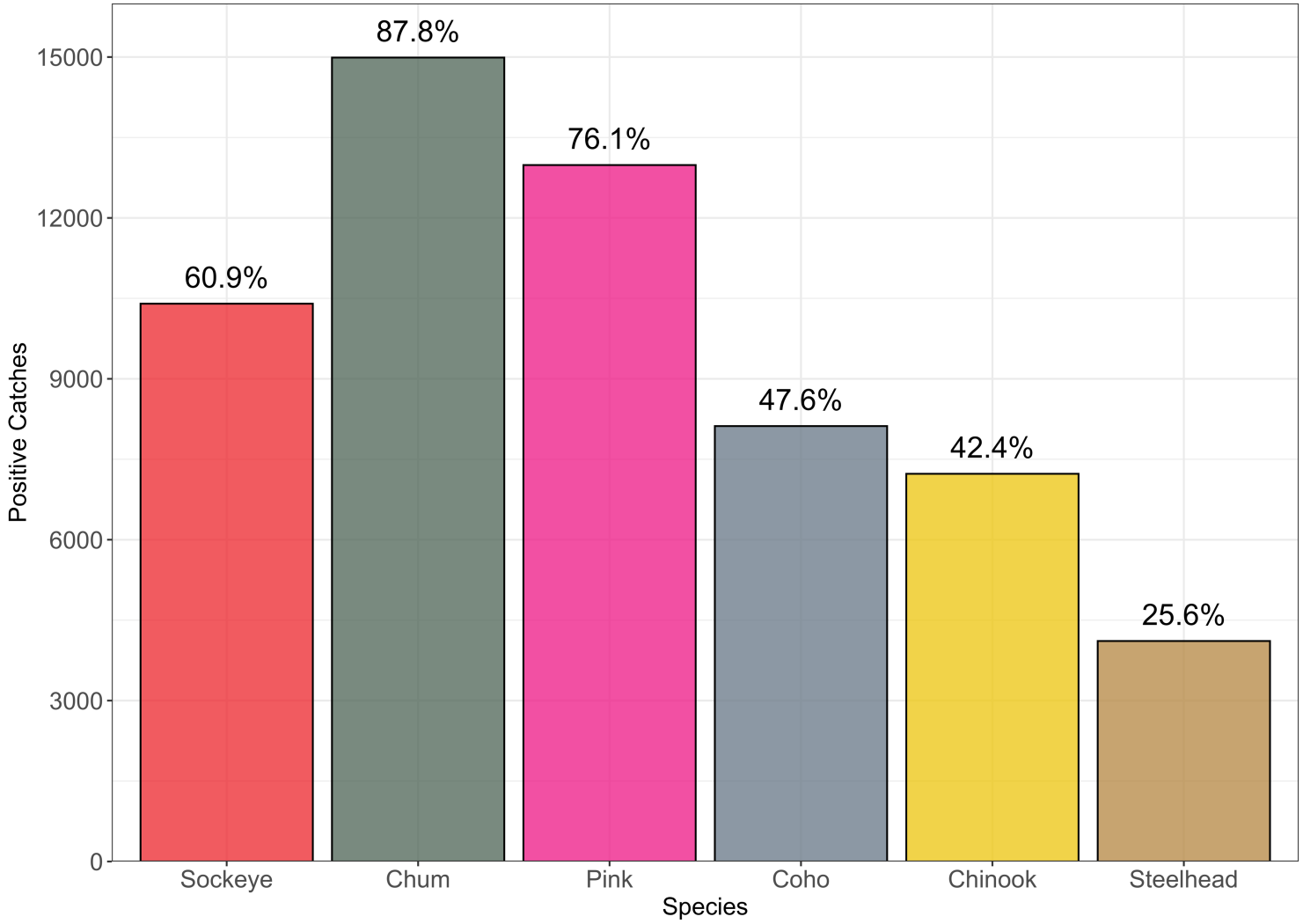
Nested GAMs

Control Variables (C*): Gear + te(Lat,Lon, by=Gear) + s(Year, k=# of years)

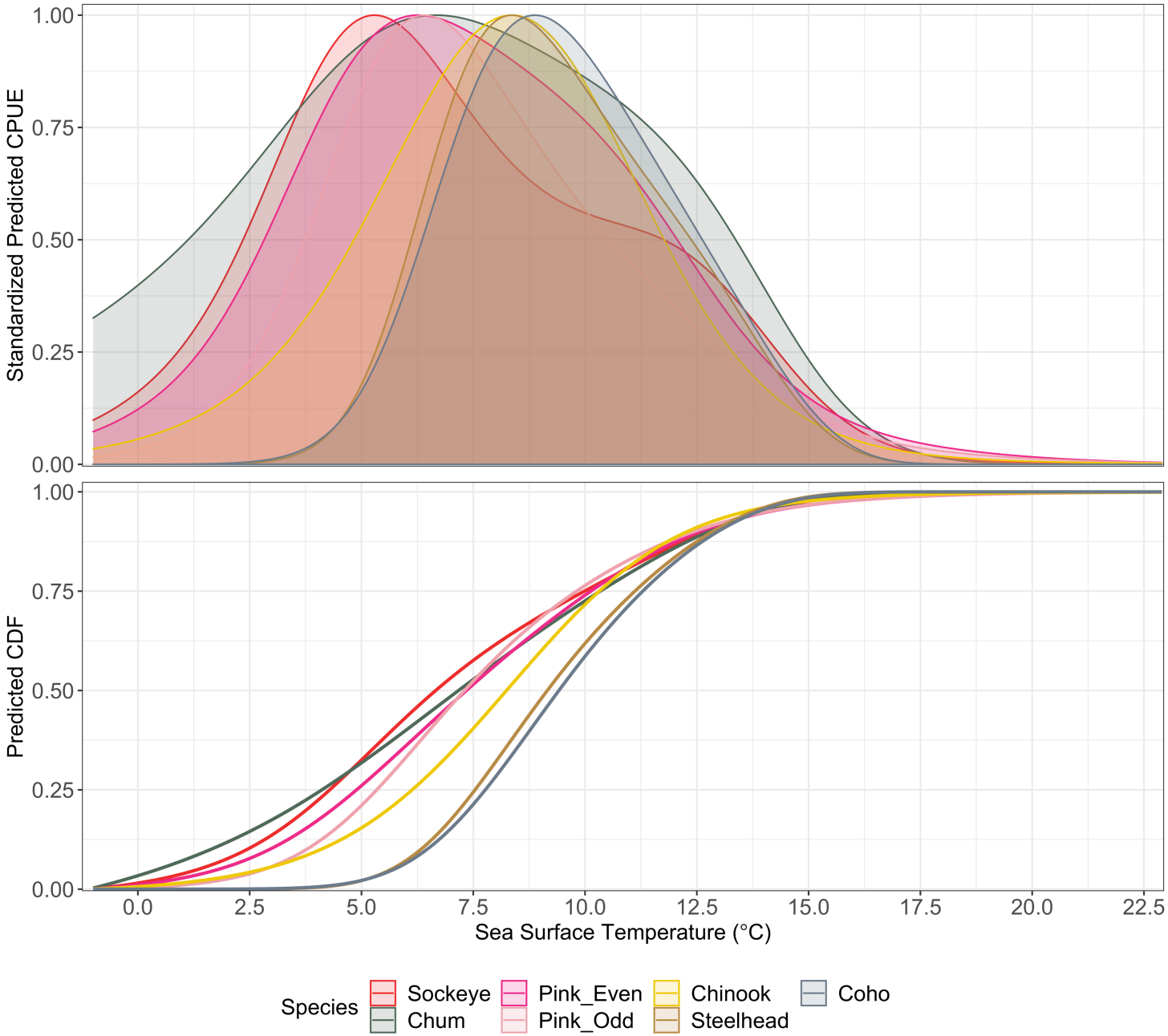
1) C* + te(Lat,Lon)
2) C* + te(Lat,Lon) + s(SST)
3) C* + te(Lat,Lon) + s(SST) + te(Lat,Lon,Month)
4) C* + te(Lat,Lon) + s(SST) + te(Lat,Lon,Month) + s(Lat, by=SST)

Compared with % deviance explained, BIC, 10-fold CV

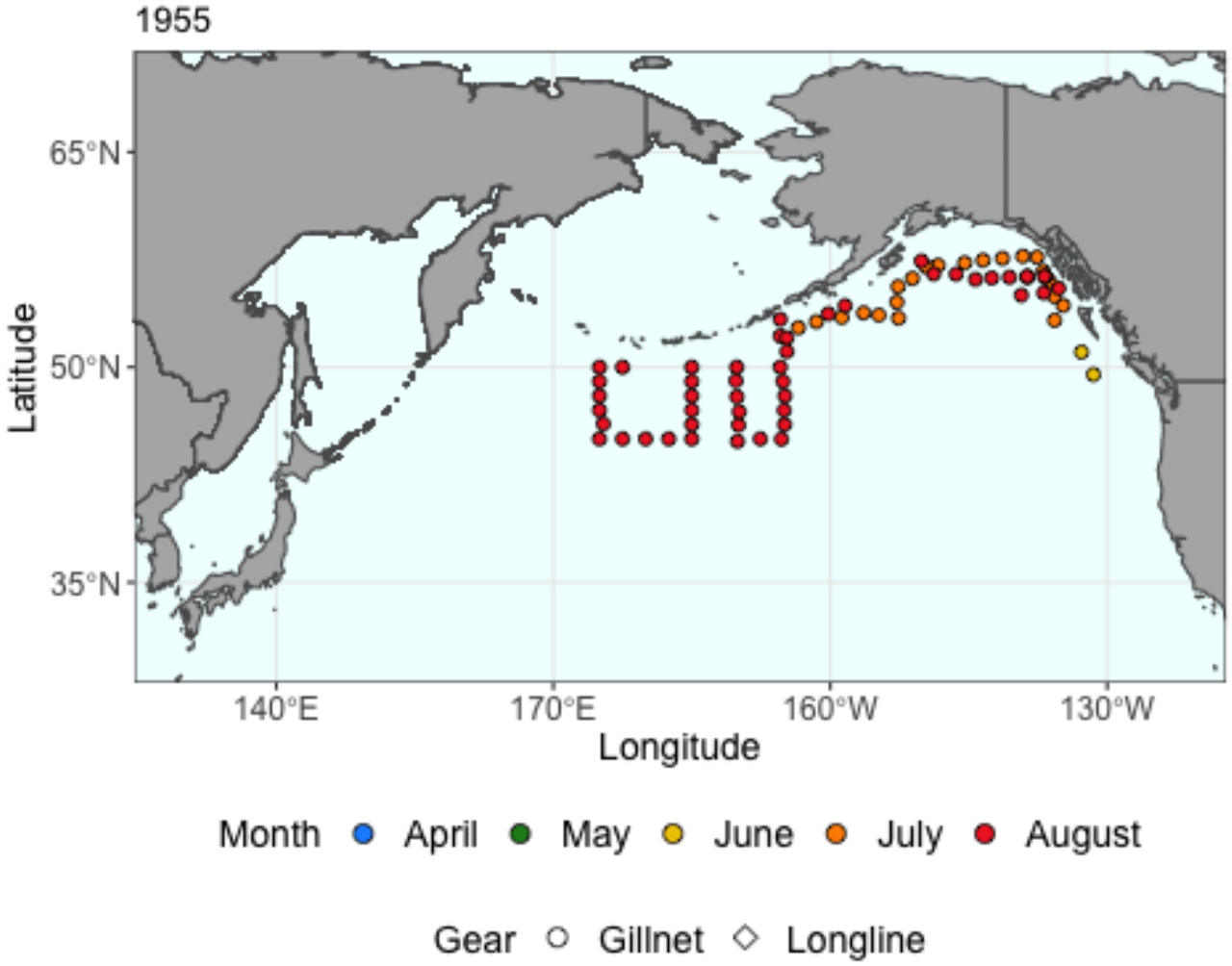
Salmon Catch Rates in NPAFC Surveys



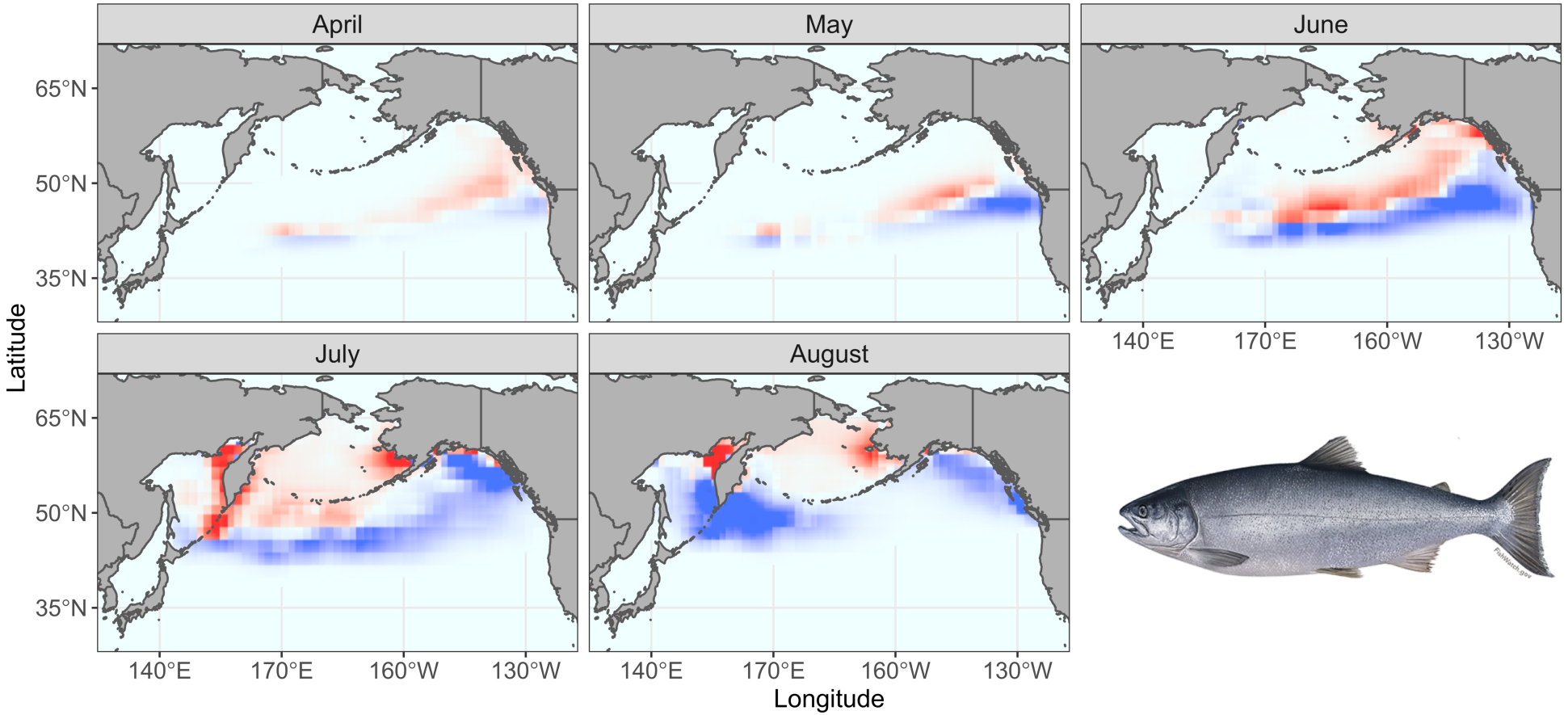
Temperature Preferences



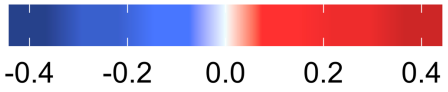
Observations By Year



Potential Distribution Shift: Coho



Scaled Log(CPUE+1) Change

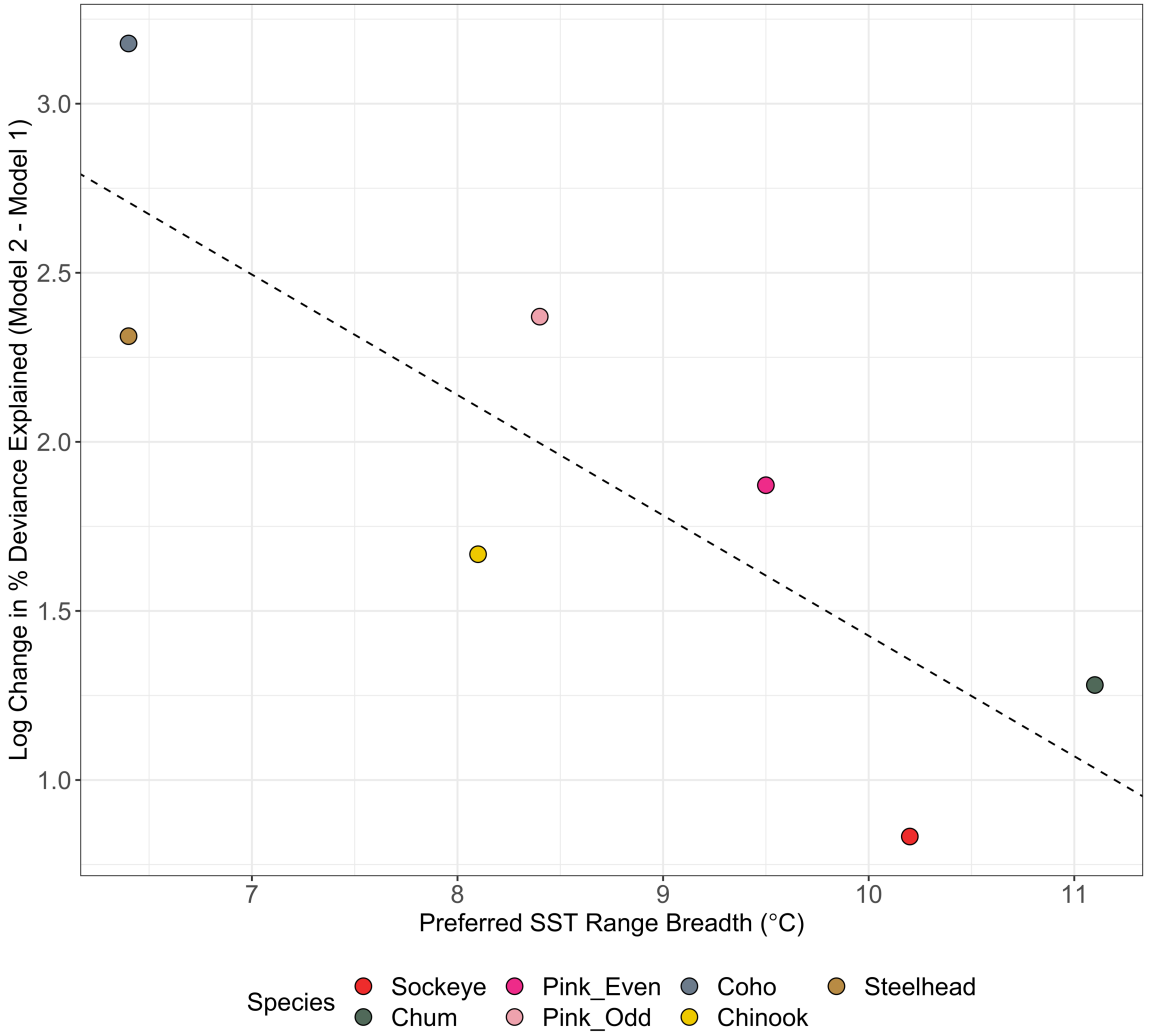


More Abundant in

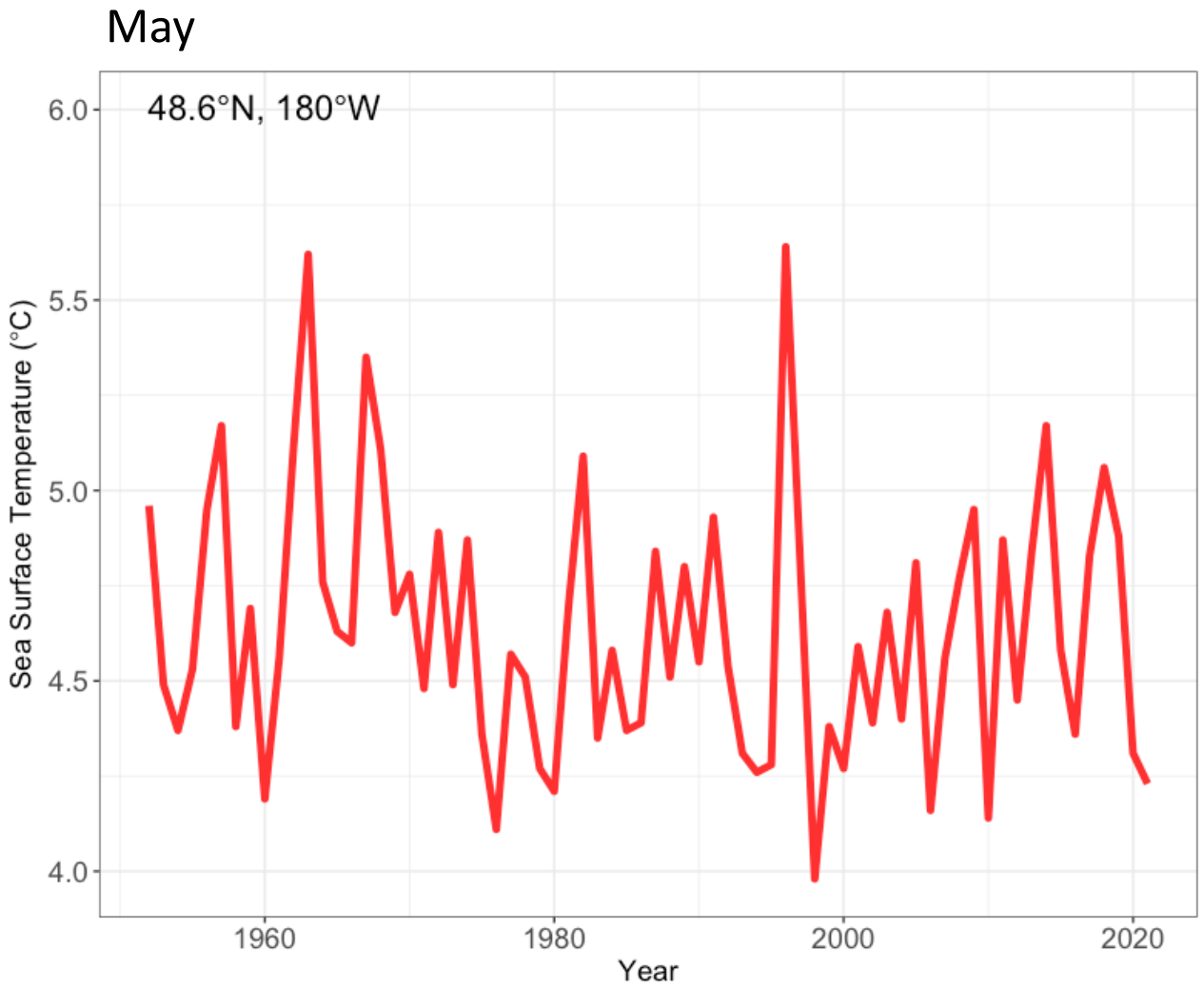
1980s: cold period

2010s: warm period

Distribution Sensitivity to SST



Why can’t we test for distribution shifts?



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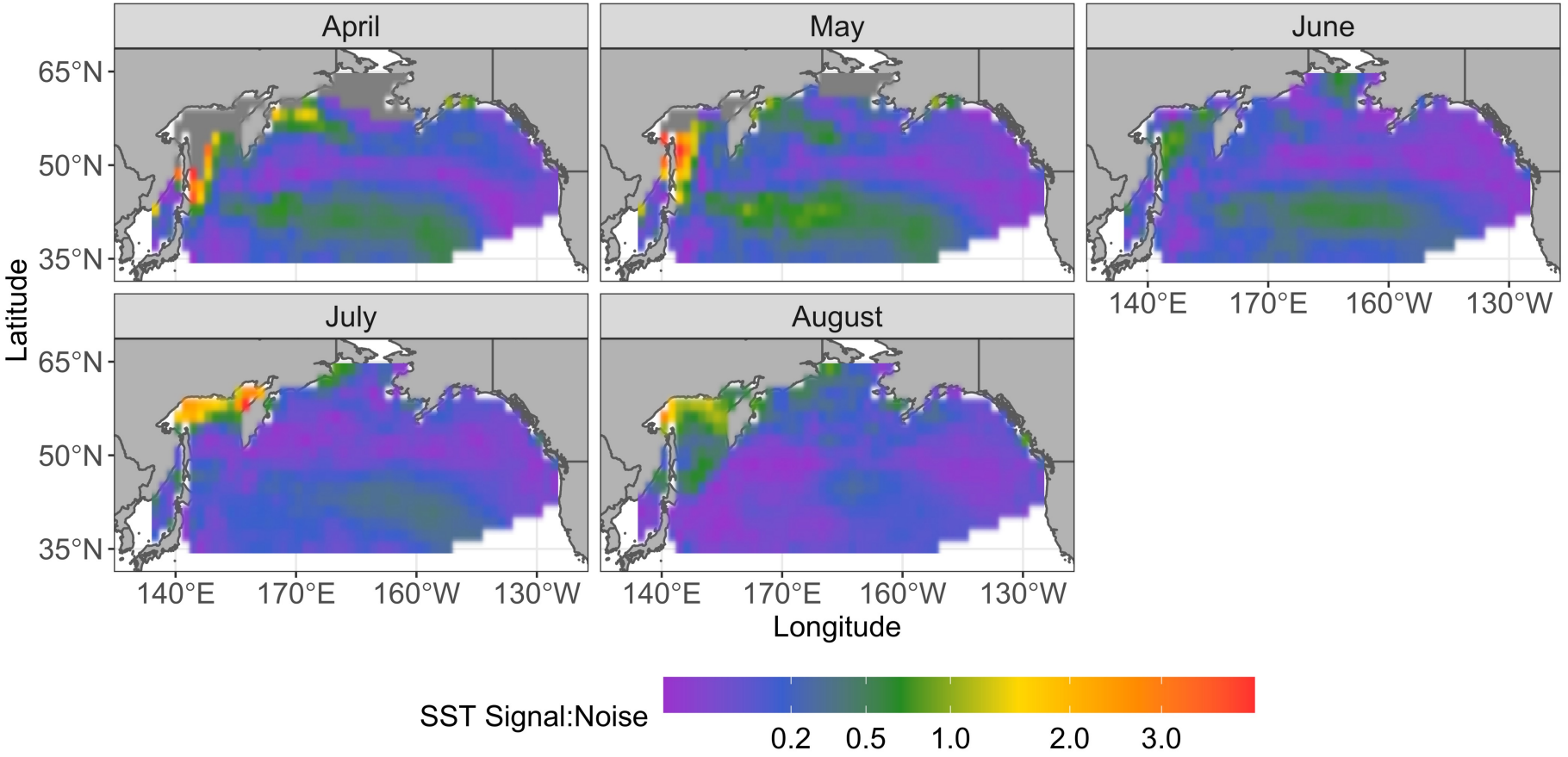
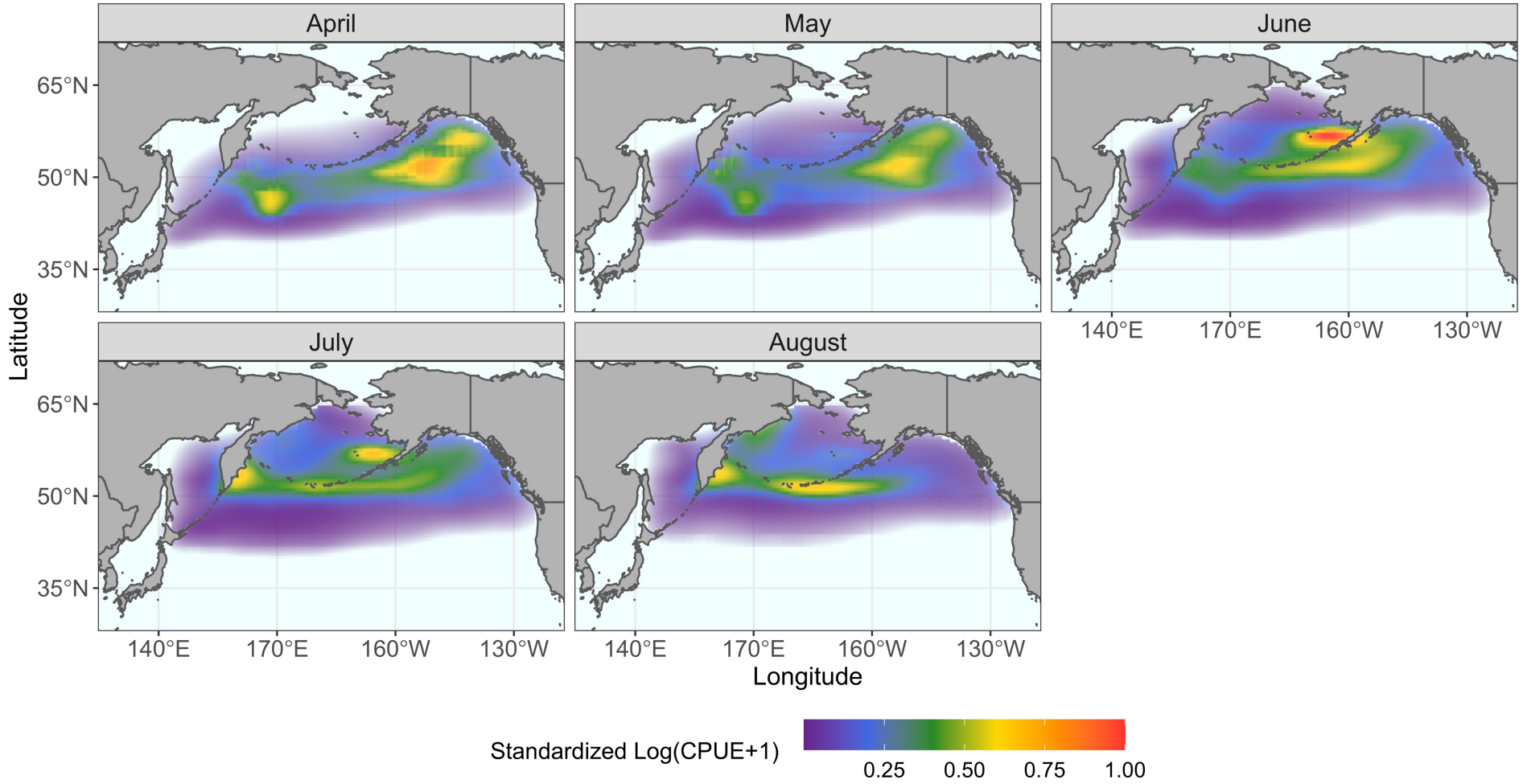
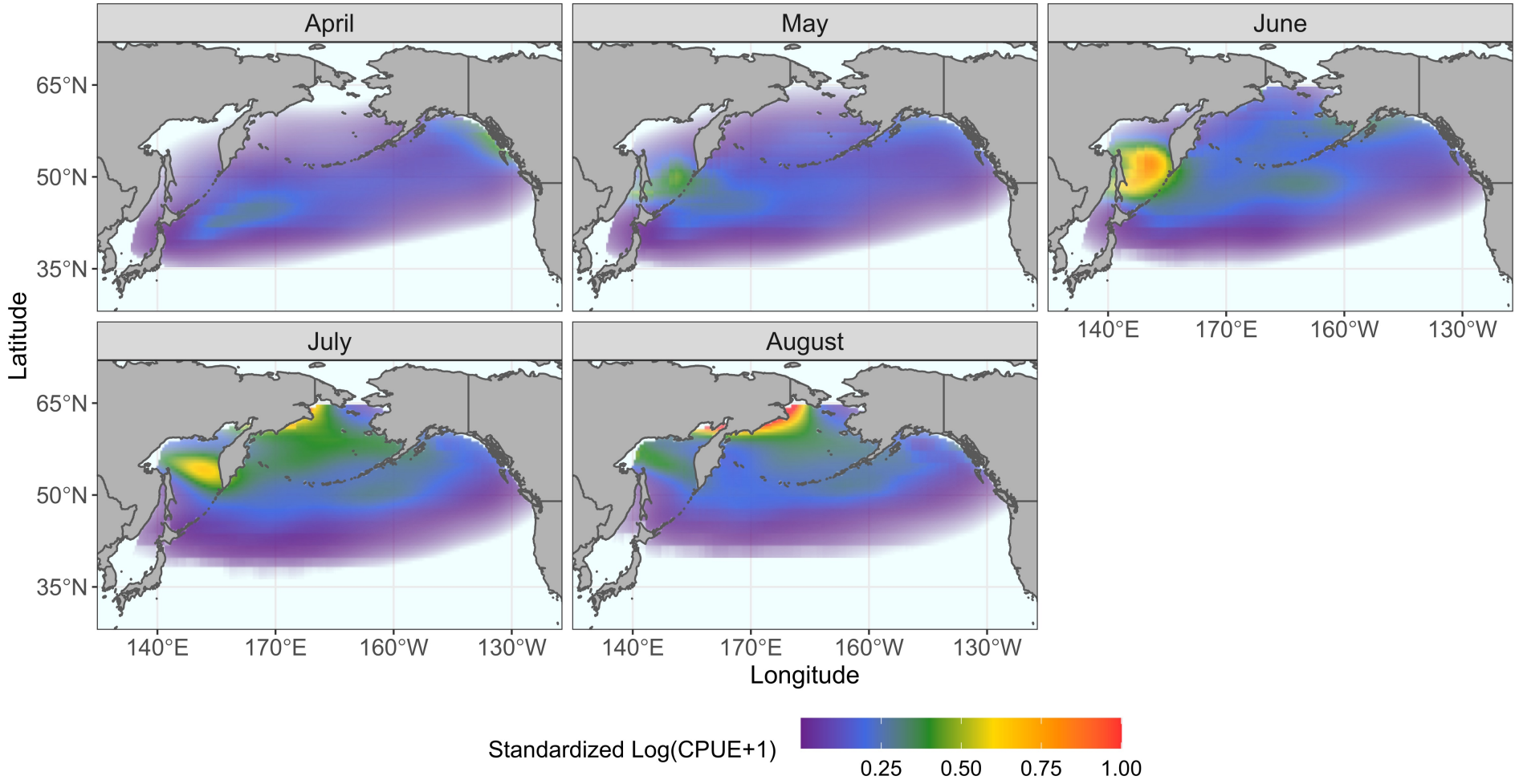


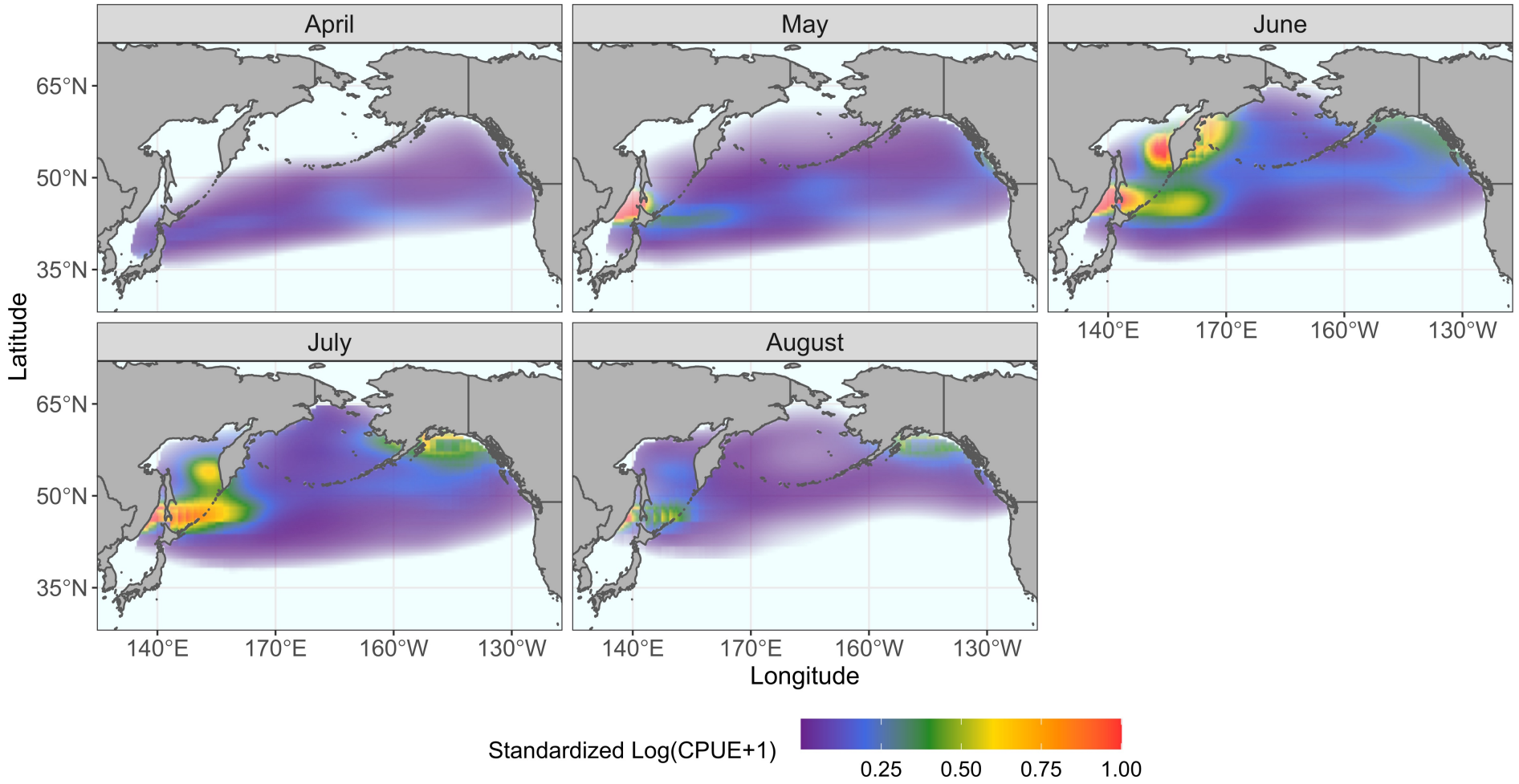
Sockeye Model Fit



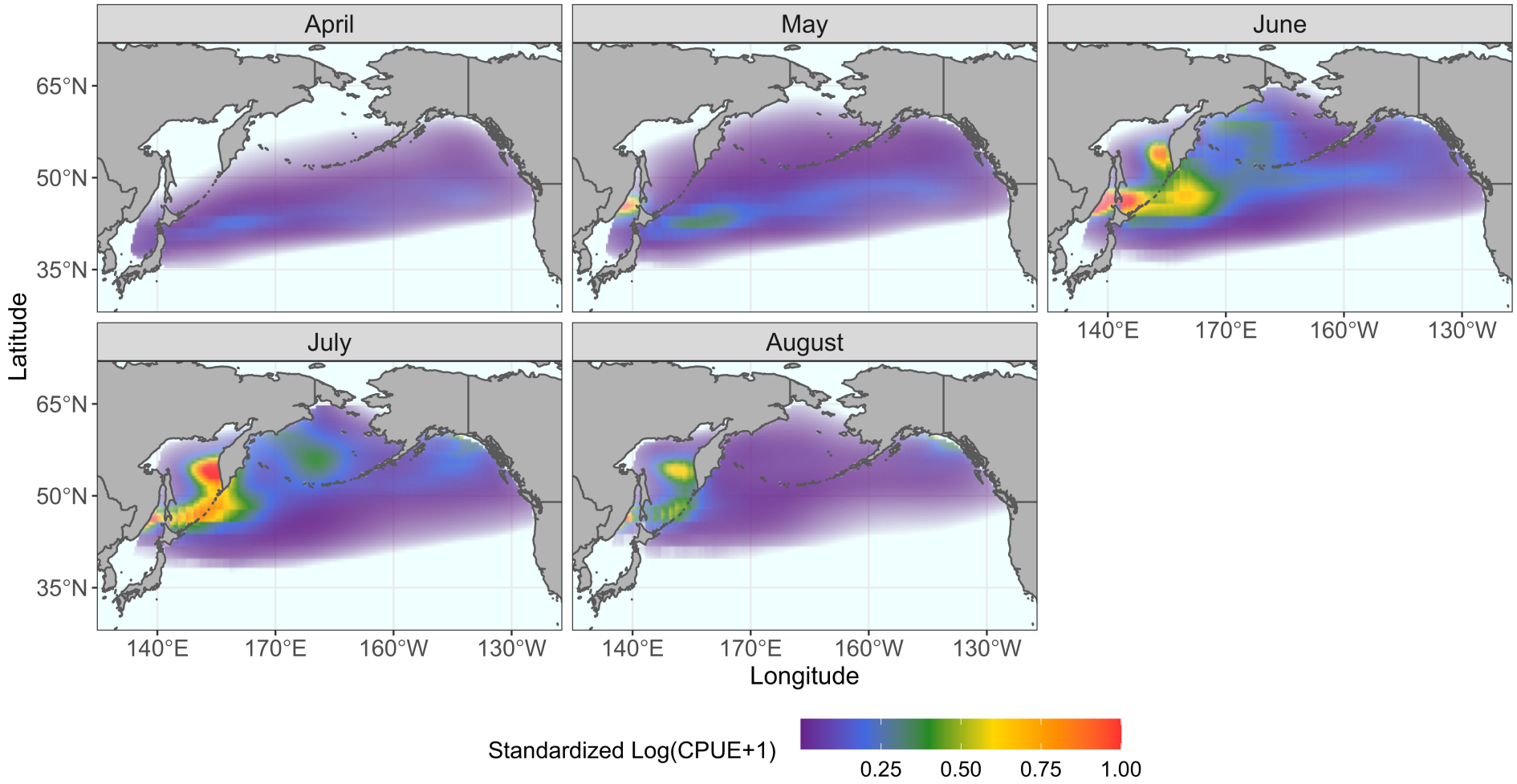
Chum Model Fit



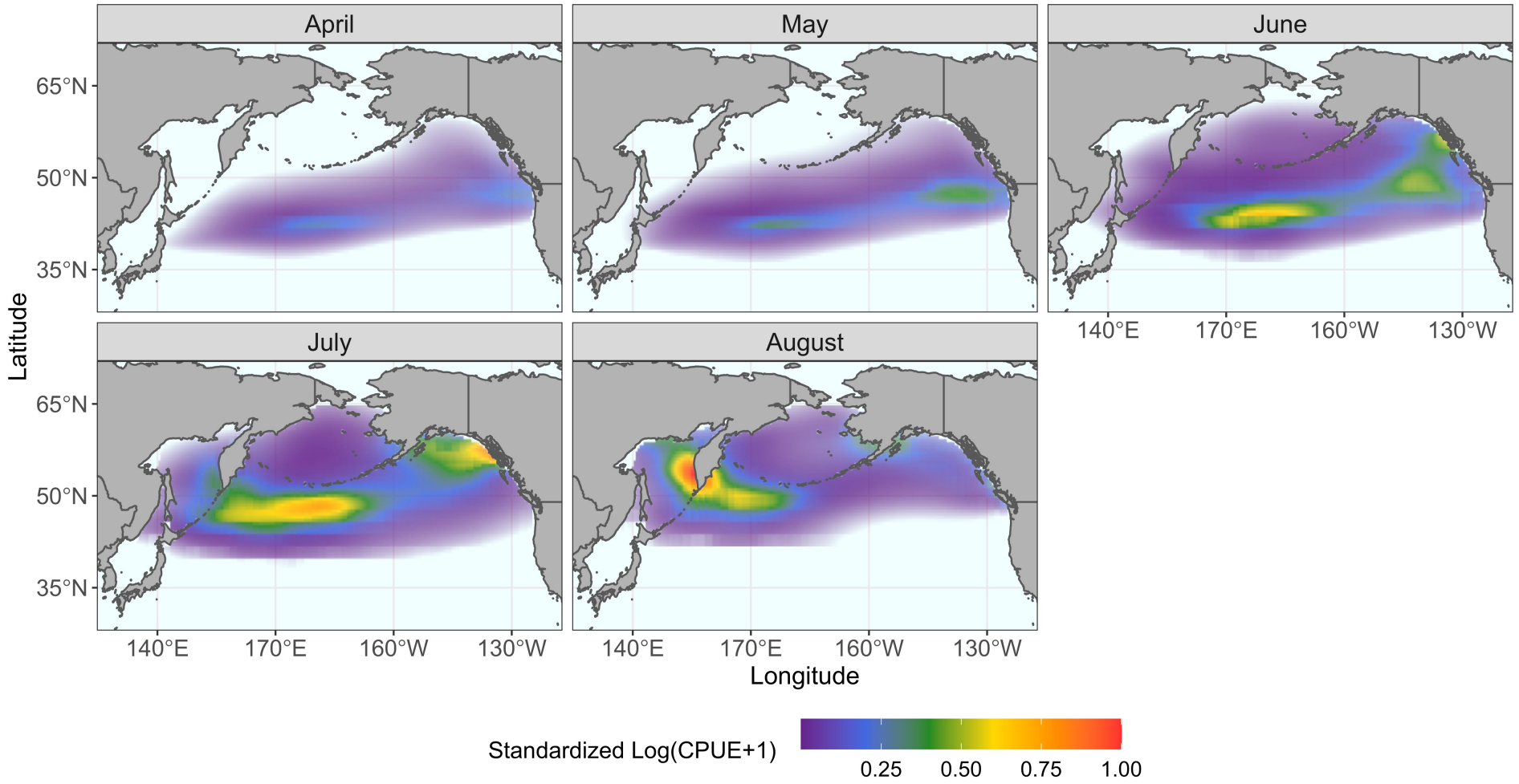
Pink-Even Year Data Model Fit



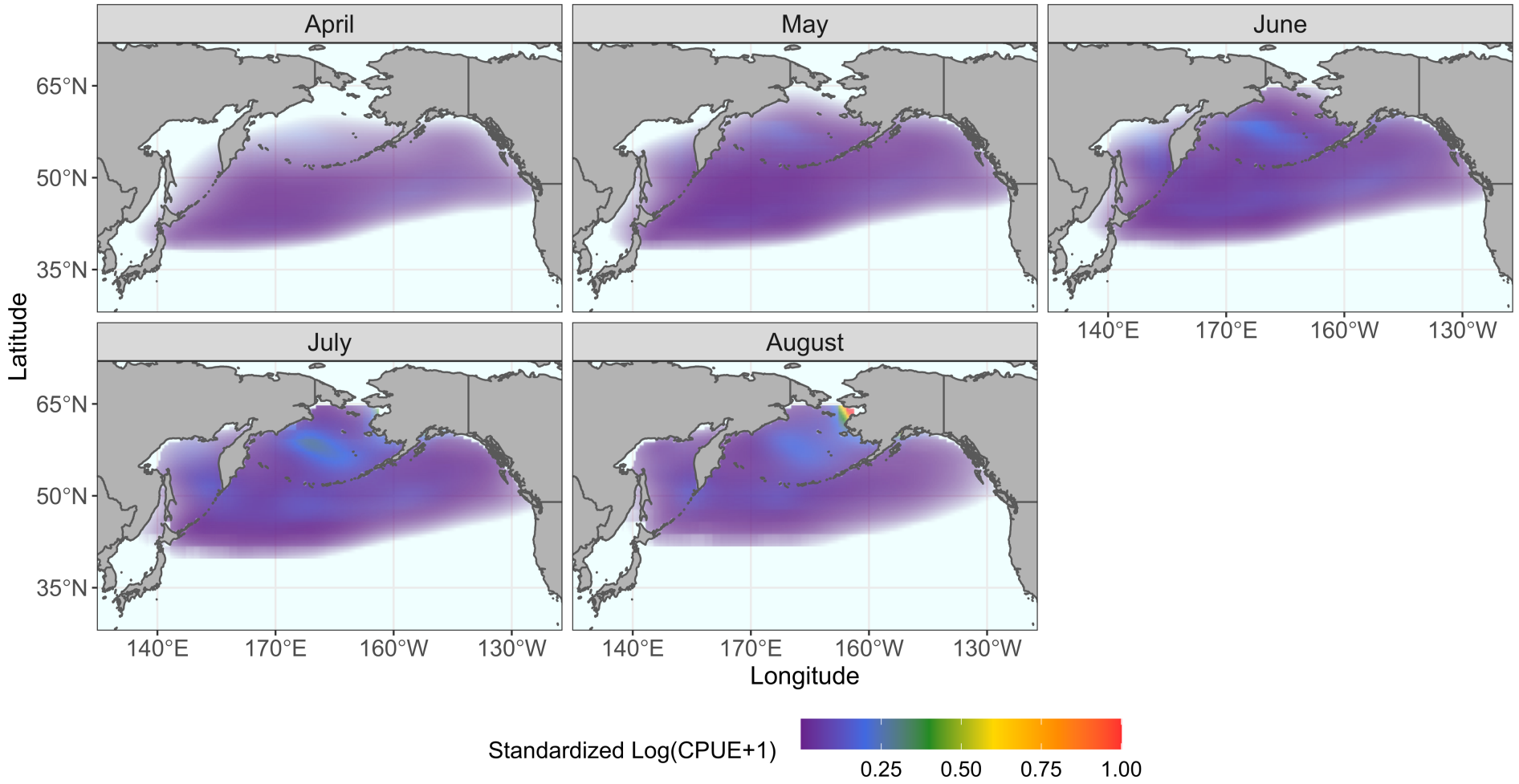
Pink-Odd Year Data Model Fit



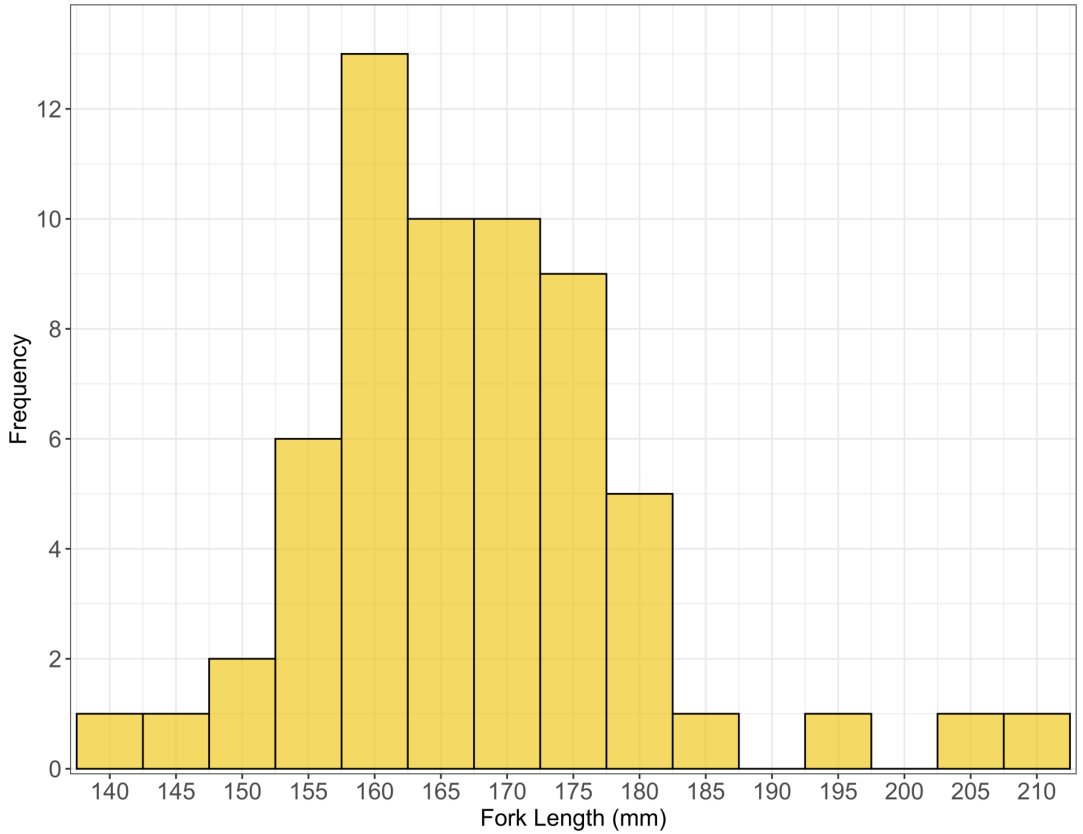
Coho Model Fit

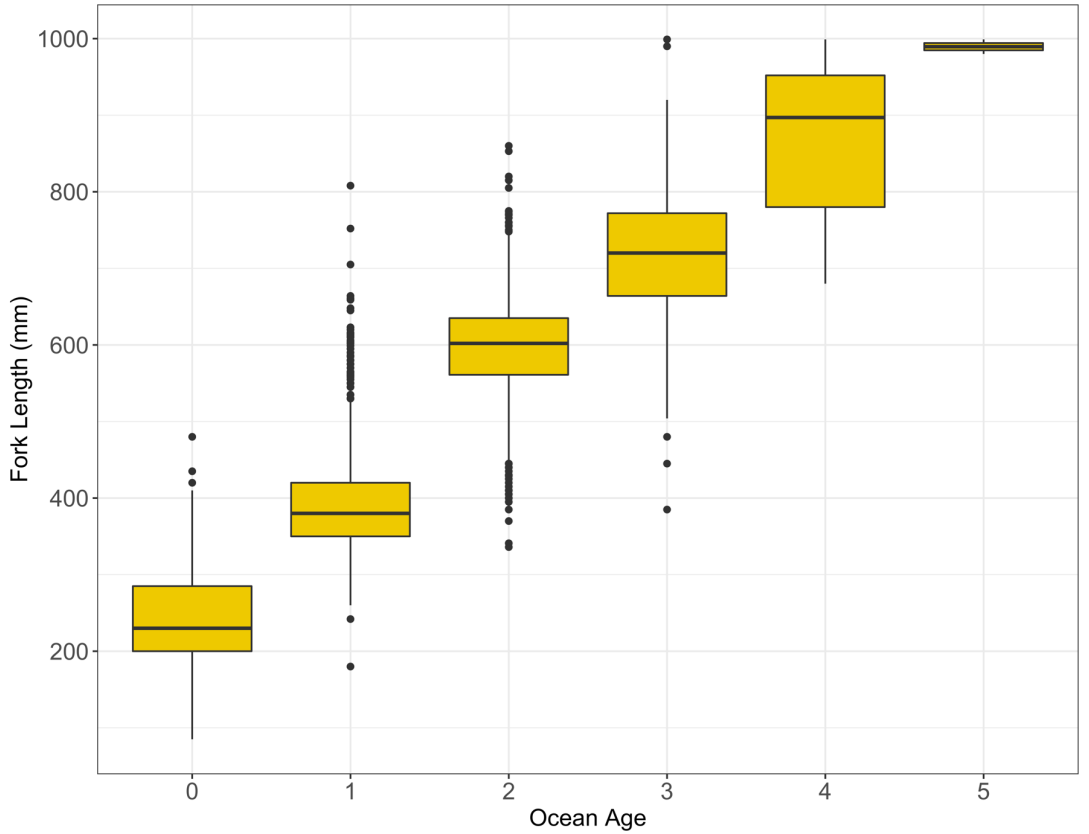


Chinook Model Fit

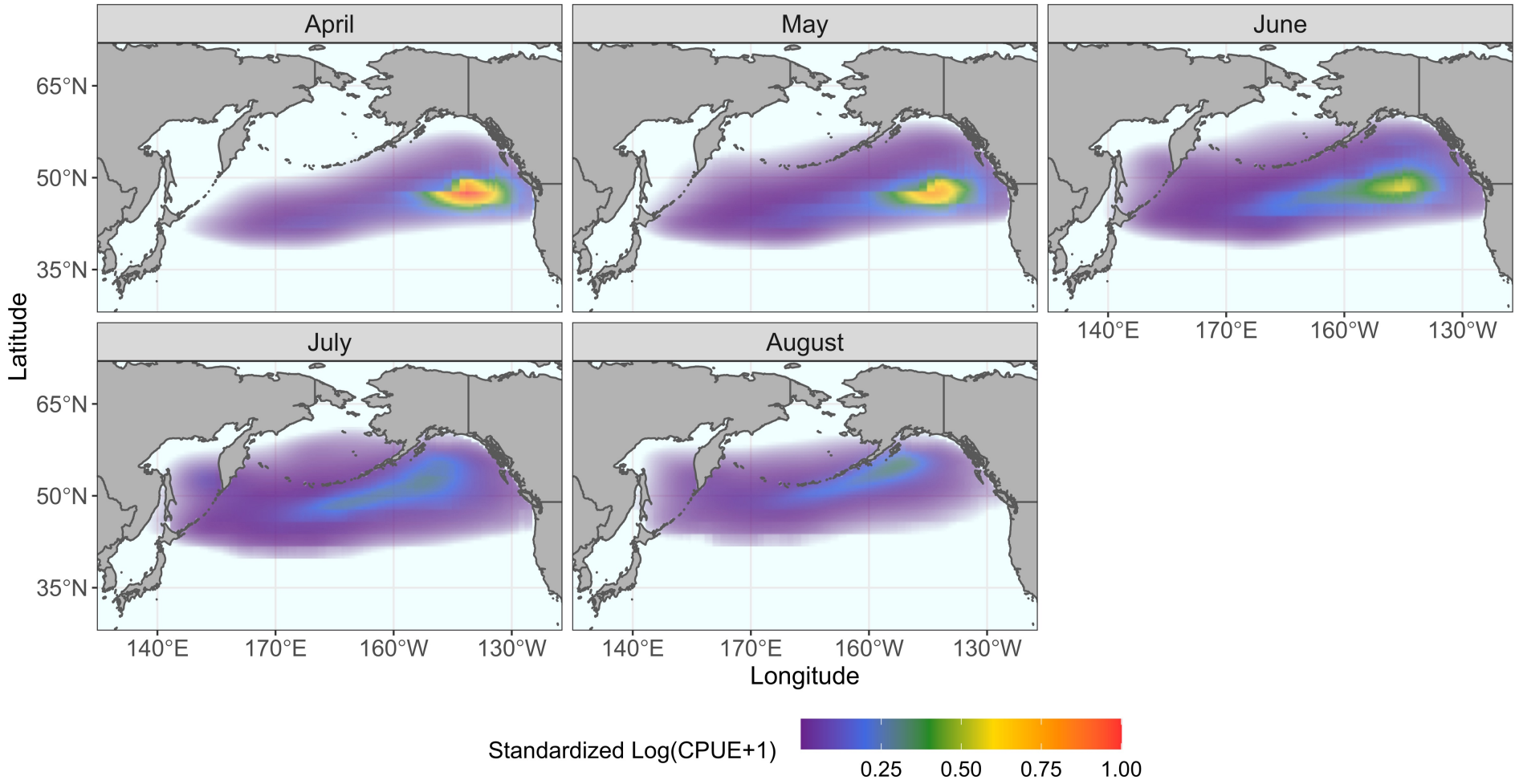


Norton Sound Chinook





Steelhead Model Fit



Local Index of Colocation