

# *Using species distribution models to develop movement scenarios for management strategy evaluation: a Pacific sardine case study*

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**CAFA**  
Climate and Fisheries  
Adaptation

**FUTURE SEAS**

A Physics-to-Fisheries Management Strategy  
Evaluation for the California Current System

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Collaborative Program



# Acknowledgements

## **Funding:**

NOAA Climate and Fisheries Adaptation Program

## **Data Providers:**

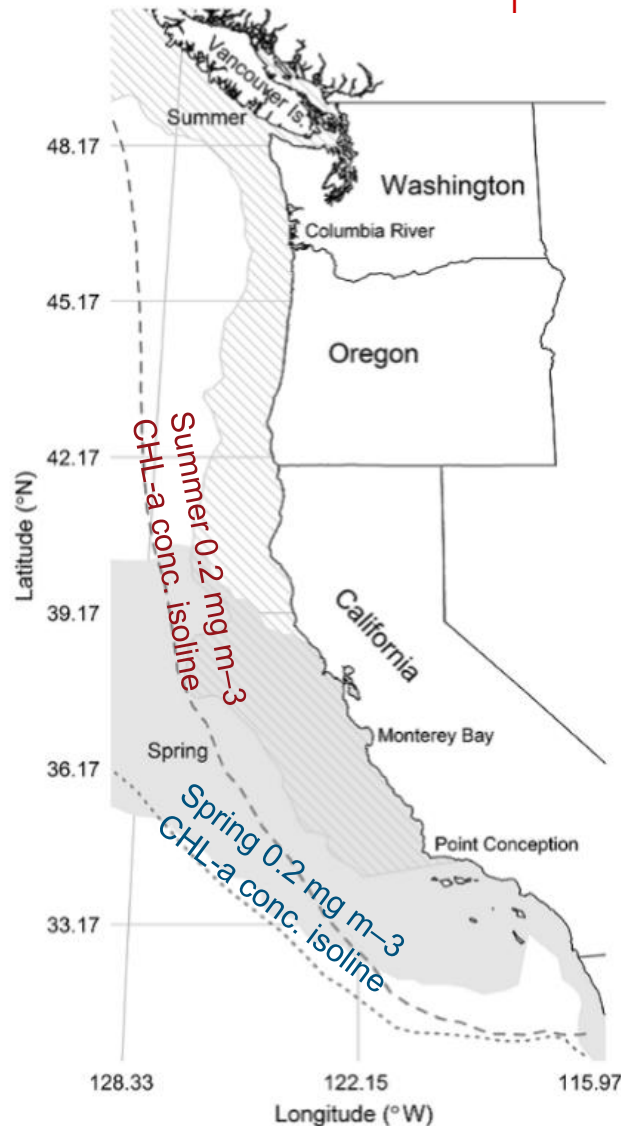
- Jennifer Boldt at DFO
- NOAA SWFSC Life History Program and Advanced Survey Technologies Program

## **Travel Grant:**

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# Pacific Sardine Stock Assessment



- In the U.S., uses a fisheries independent acoustic abundance index calibrated using trawl sampling. Conducted in Spring (2006, 2008, 2010-2016) and Summer (2008, 2012-2019, 2021-2024)
- **Northern SP** assigned using SST and CHL-a habitat suitability model, which is inherently spatial<sup>2</sup> (Post survey and pre-assessment)
- One area model, uses fleets as representation of area / space
- In Canada, a migration index is estimated based on survey observations and U.S. stock assessment abundance indices

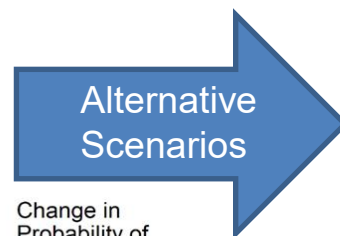
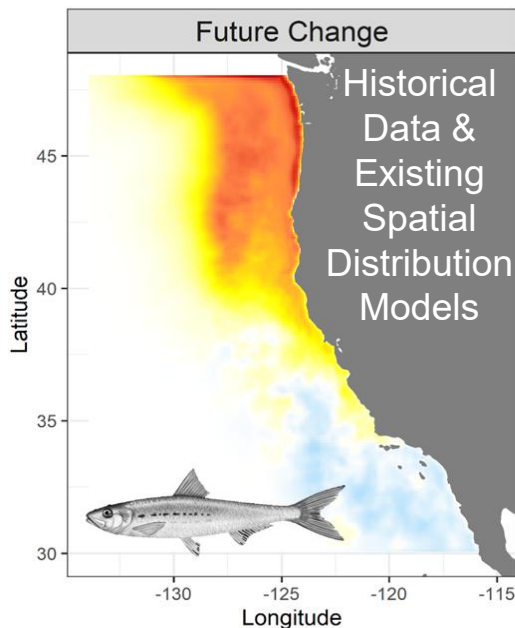


# Project Goals

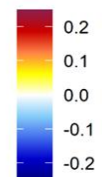
**The Big Question:** Does our current fishing rule still work if the fish move to unexpected places?

- This study builds on data collected coast-wide, irrespective of historical SP identity (**except where data are only for the Northern SP, e.g., the age-length key**).

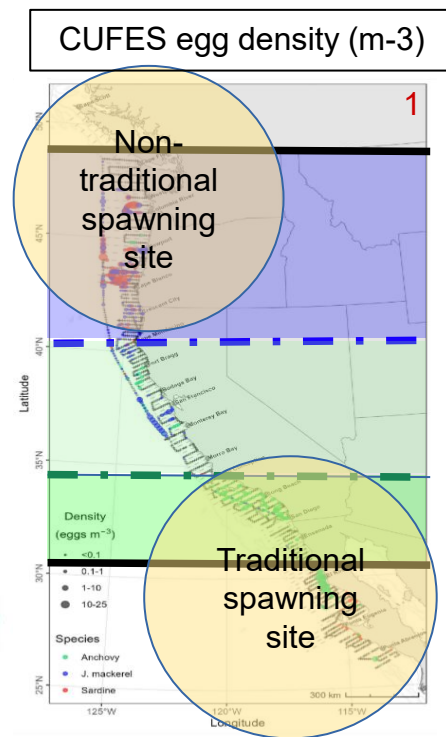
- 1. Map the Past:** Look at historical data to see where fish used to be
- 2. Track Life Stages:** Hypothesise how fish move and get caught at different lengths
- 3. Build Computer Models:** Feed hypotheses into spatial operating models (OMs)
- 4. Add the Environment:** Include ocean conditions (like temperature) that make fish move
- 5. Test the Rules:** Run simulations to see if our fishing rules still work.



Change in Probability of Occurrence

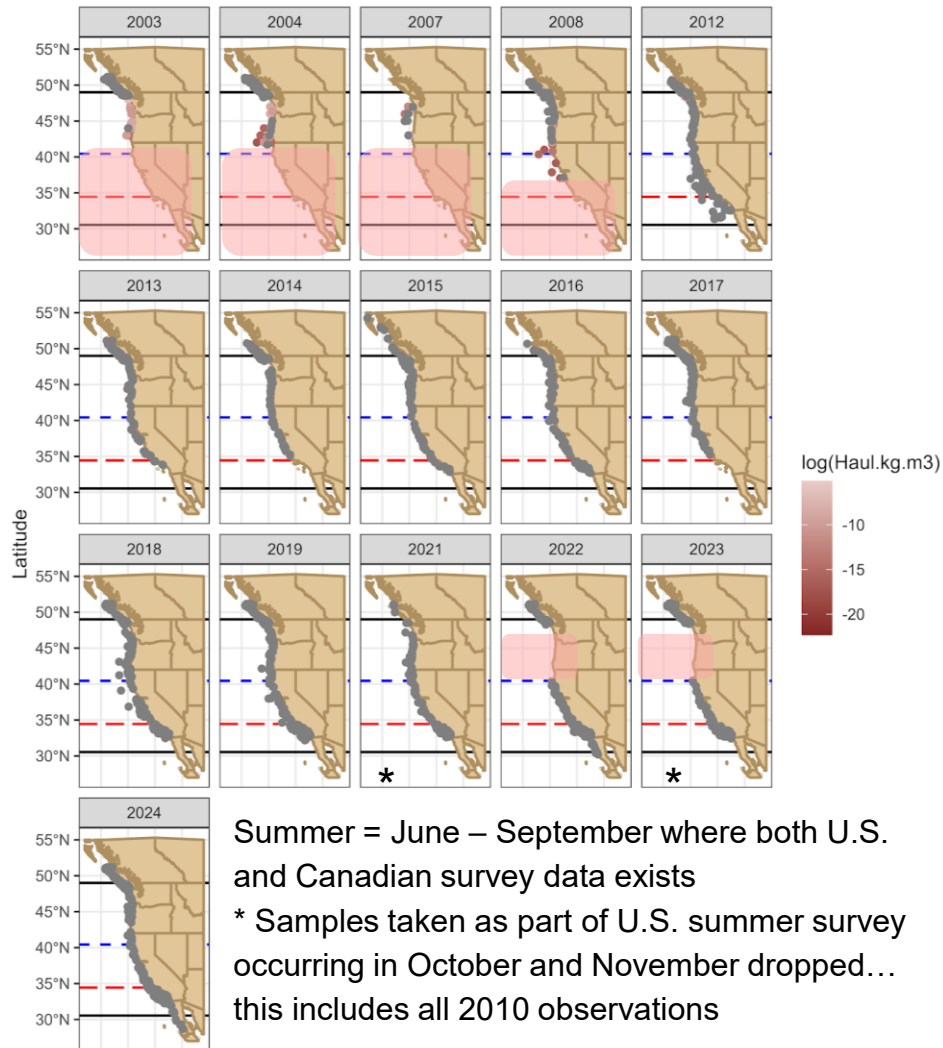


**FUTURE SEAS**  
A Physics-to-Fisheries Management Strategy Evaluation for the California Current System



<sup>1</sup>Adapted from Fig. 15b - Stierhoff et al., 2023

# Challenges

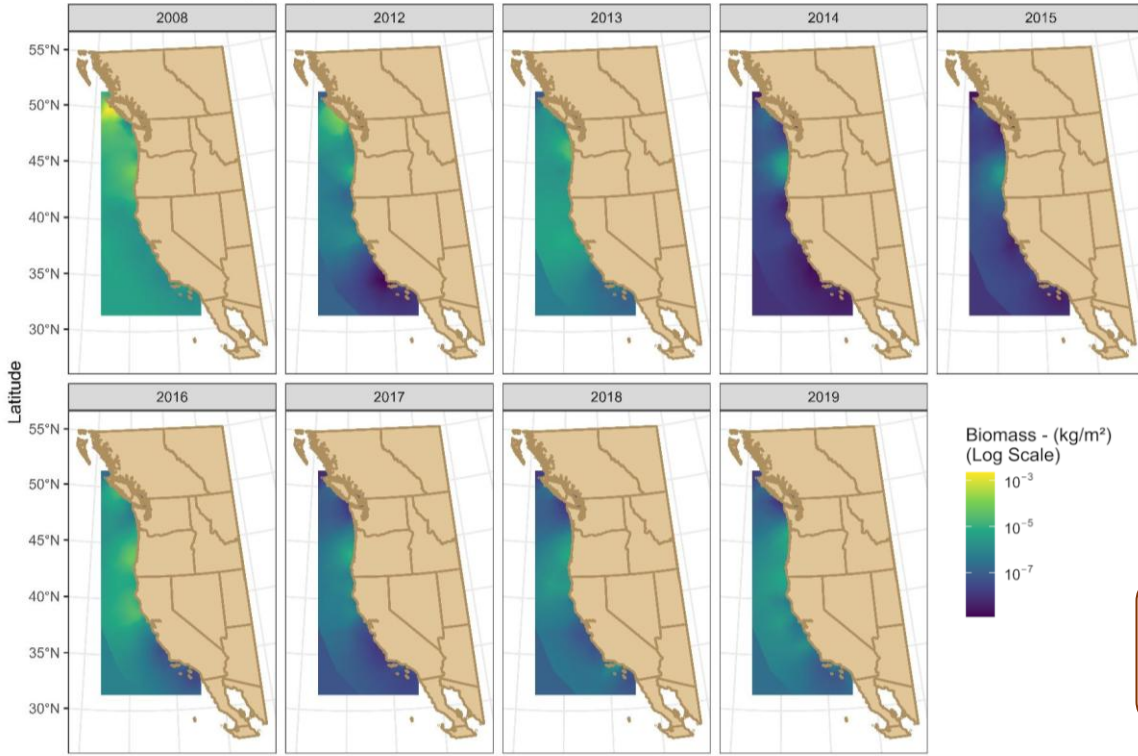


- Trawl data spatial, but imperfect estimator of patchy sardine biomass (OK for simulation study)
- Surveys had different gears, fishing efforts, sampling designs, and measurement units (corrected for in this study)
- Spring survey only run in Southern U.S. and unusable to assess distribution changes along entire west coast
- Survey data only from U.S. and Canada
- Regional Oceanographic Models (ROMS) hindcasts only up to 2020
- Not enough samples to characterize a separate 150-200mm length bin (1-3 years).

# Map the Past: Spatial Distribution of Biomass

## Preliminary Results

Summer Biomass (kg/m<sup>2</sup>) - Combined Estimate



## Standardised Abundance (kg/m<sup>2</sup>)

**Model:** Delta-lognormal spatiotemporal model (sdmTMB) fitted via REML with sweep volume ( $H*W*D$ ) offset.

**Structure:** Included land barrier mesh, year factors, and independent spatial/spatiotemporal random effects.

**Validation:** Optimal model selected via stratified 5-fold cross-validation (highest ELPD).

**Total Deviance Explained  
(Fixed + Random Effects): 49%**

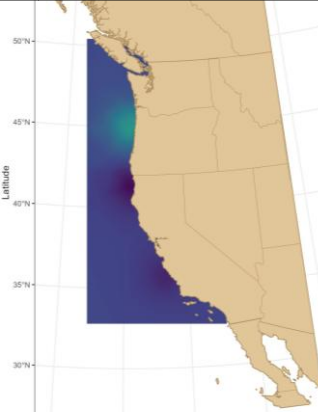
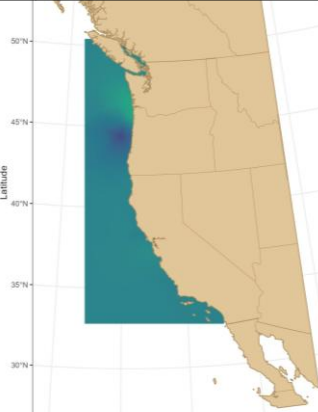
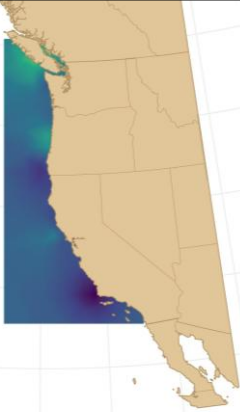
**Used to generate global and area specific abundance indices**

# Map the Past: Spatial Distribution by Length Bin

2012: < 200 mm

2013: < 200 mm

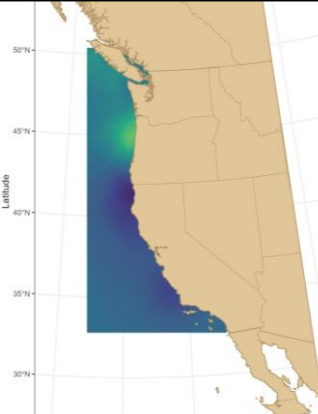
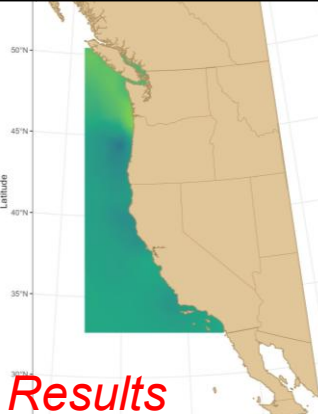
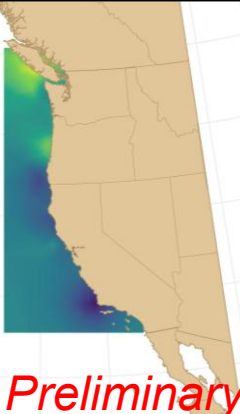
2014: < 200 mm



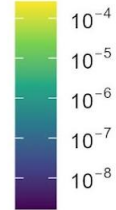
2012: 200+ mm

2013: 200+ mm

2014: 200+ mm



kg/m<sup>2</sup>  
Biomass -  $\eta$   
(Log Scale)



**Standardised Abundance (kg/m<sup>2</sup>)**

**Model:** Lognormal spatiotemporal model (sdmTMB) fitted with sweep volume ( $H*W*D$ ) \* MLD offset.

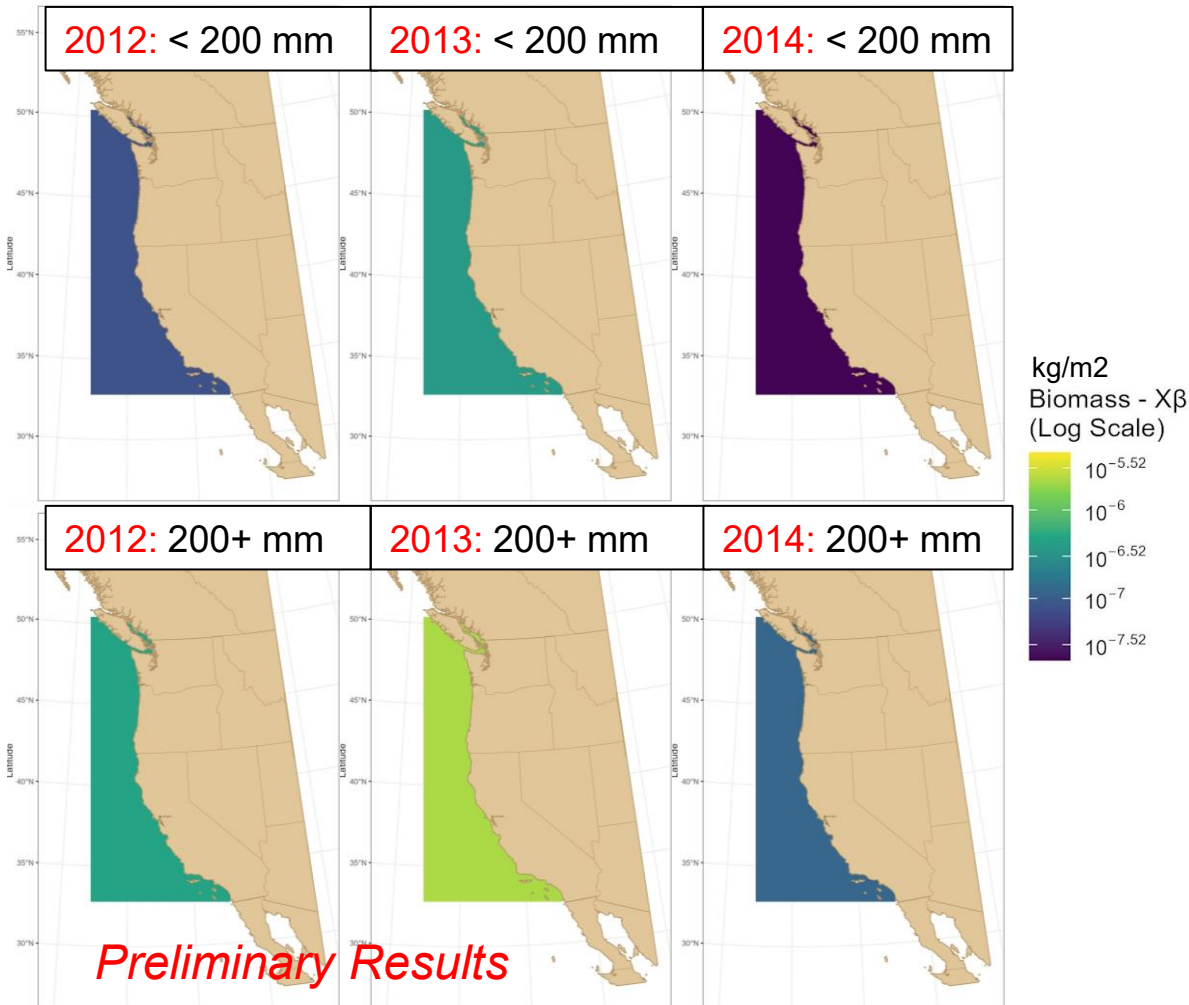
**Structure:** Land barrier mesh, fixed effects (year factors and length bin), independent spatiotemporal random effects, and spatially varying effects by length bin.

**Validation:** Passed spatial diagnostics; length-bin structure justified via 3-fold cross-validation via negative binomial models.

*Preliminary Results*

**Total Deviance Explained  
(Fixed + Random Effects): 66%**

# Fixed Effects (Year + Length Bin Coeff.)



**Standardised Abundance (kg/m<sup>2</sup>)**

**Model:** Lognormal spatiotemporal model (sdmTMB) fitted with sweep volume (H\*W\*D) \* MLD offset.

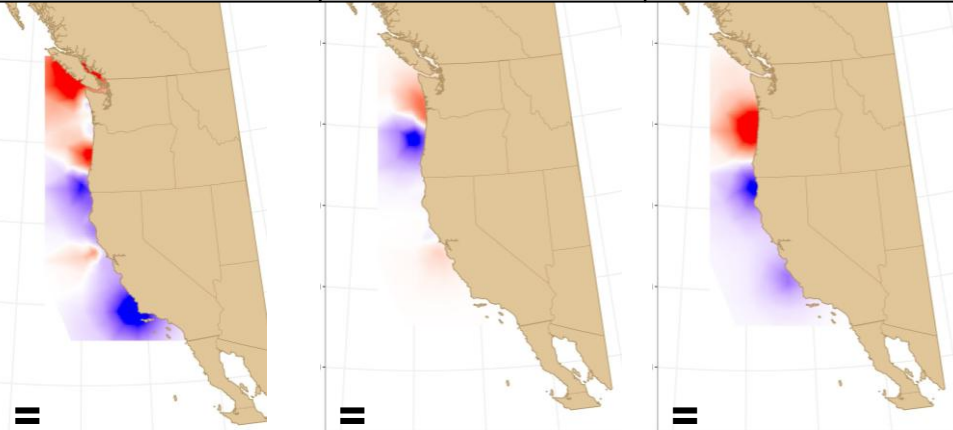
**Structure:** Land barrier mesh, **fixed effects (year factors and length bin)**, independent spatiotemporal random effects, and spatially varying effects by length bin.

**Validation:** Passed spatial diagnostics; length-bin structure justified via 3-fold cross-validation via negative binomial models.

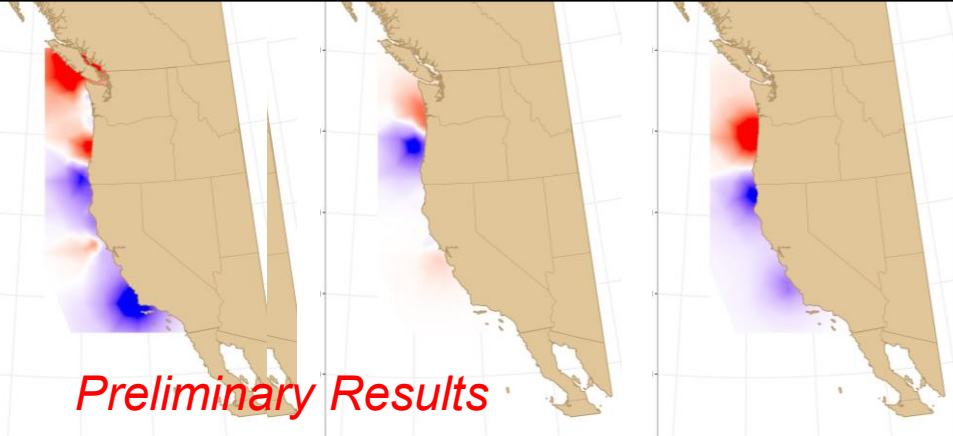
**Percent Deviance Explained (Fixed Effects): 23%**

# Spatiotemporal Random Effects

2012: < 200 mm    2013: < 200 mm    2014: < 200 mm



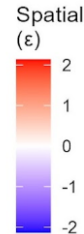
2012: 200+ mm    2013: 200+ mm    2014: 200+ mm



## Standardised Abundance (kg/m<sup>2</sup>)

**Model:** Lognormal spatiotemporal model (sdmTMB) fitted with sweep volume (H\*W\*D) \* MLD offset.

**Structure:** Land barrier mesh, fixed effects (year factors and length bin), independent **spatiotemporal random effects**, and spatially varying effects by length bin.

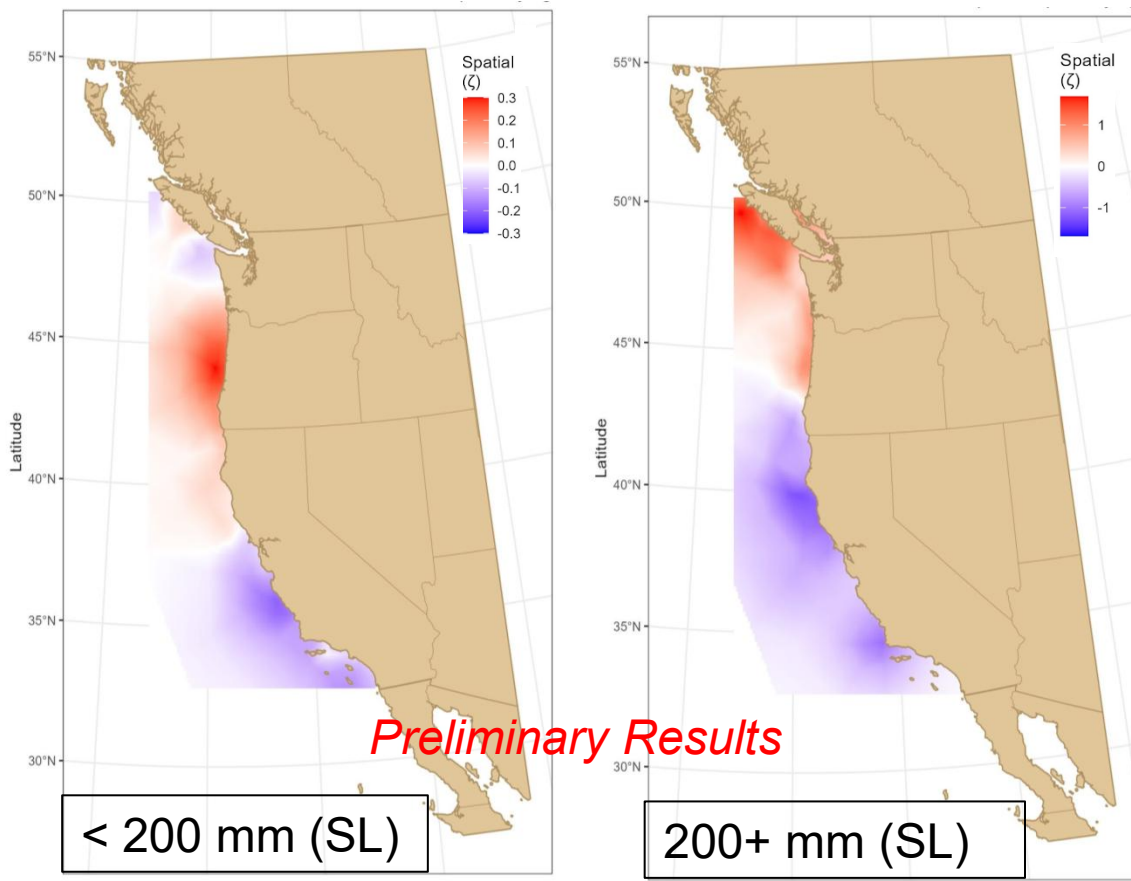


**Validation:** Passed spatial diagnostics; length-bin structure justified via 3-fold cross-validation via negative binomial models.

**Percent Deviance Explained (Spatiotemporal Random Effects): 39%**

# Track Life Stages: Spatially Varying Effects by Length Bin

Reoccurring spatial structure by length bin over time (2008, 2012-2019)



**Standardised Abundance (kg/m<sup>2</sup>)**

**Model:** Lognormal spatiotemporal model (sdmTMB) fitted with sweep volume ( $H*W*D$ ) \* MLD offset.

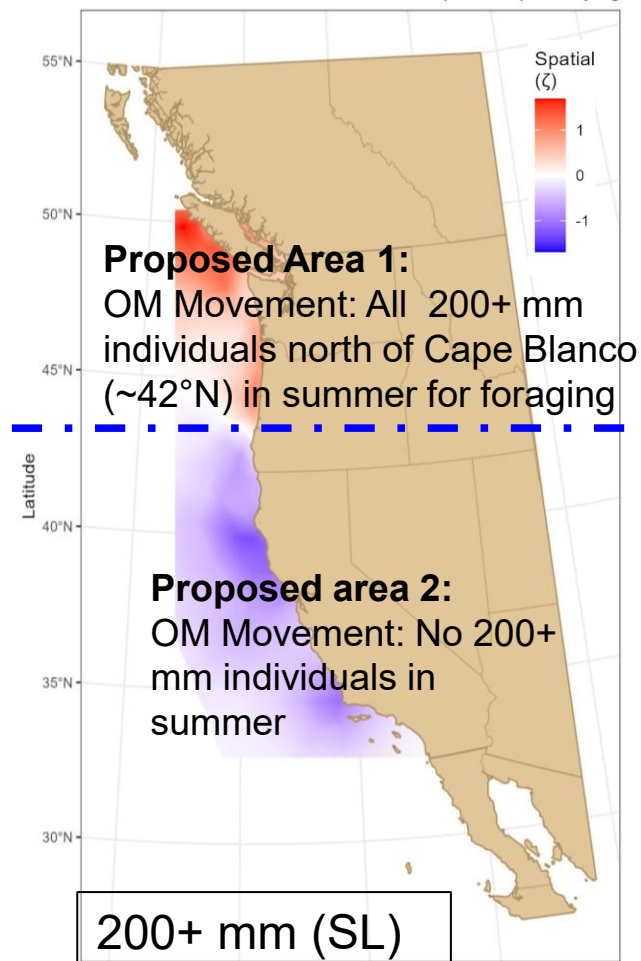
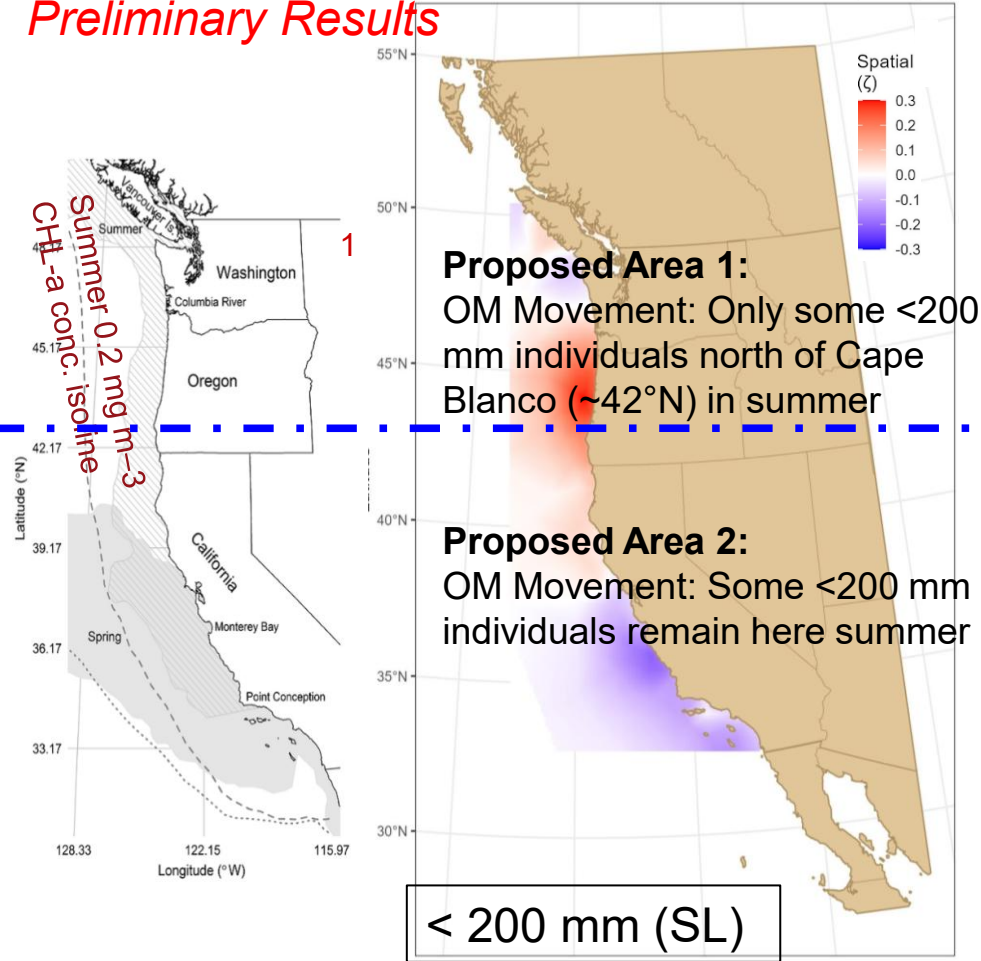
**Structure:** Land barrier mesh, fixed effects (year factors and length bin), independent spatiotemporal random effects, and **spatially varying effects by length bin.**

**Validation:** Passed spatial diagnostics; length-bin structure justified via 3-fold cross-validation via negative binomial models.

**Percent Deviance Explained (Spatial Varying Effects): 4%**

# Transitioning from SDM Outputs to OM Development

## Preliminary Results



## Recap:

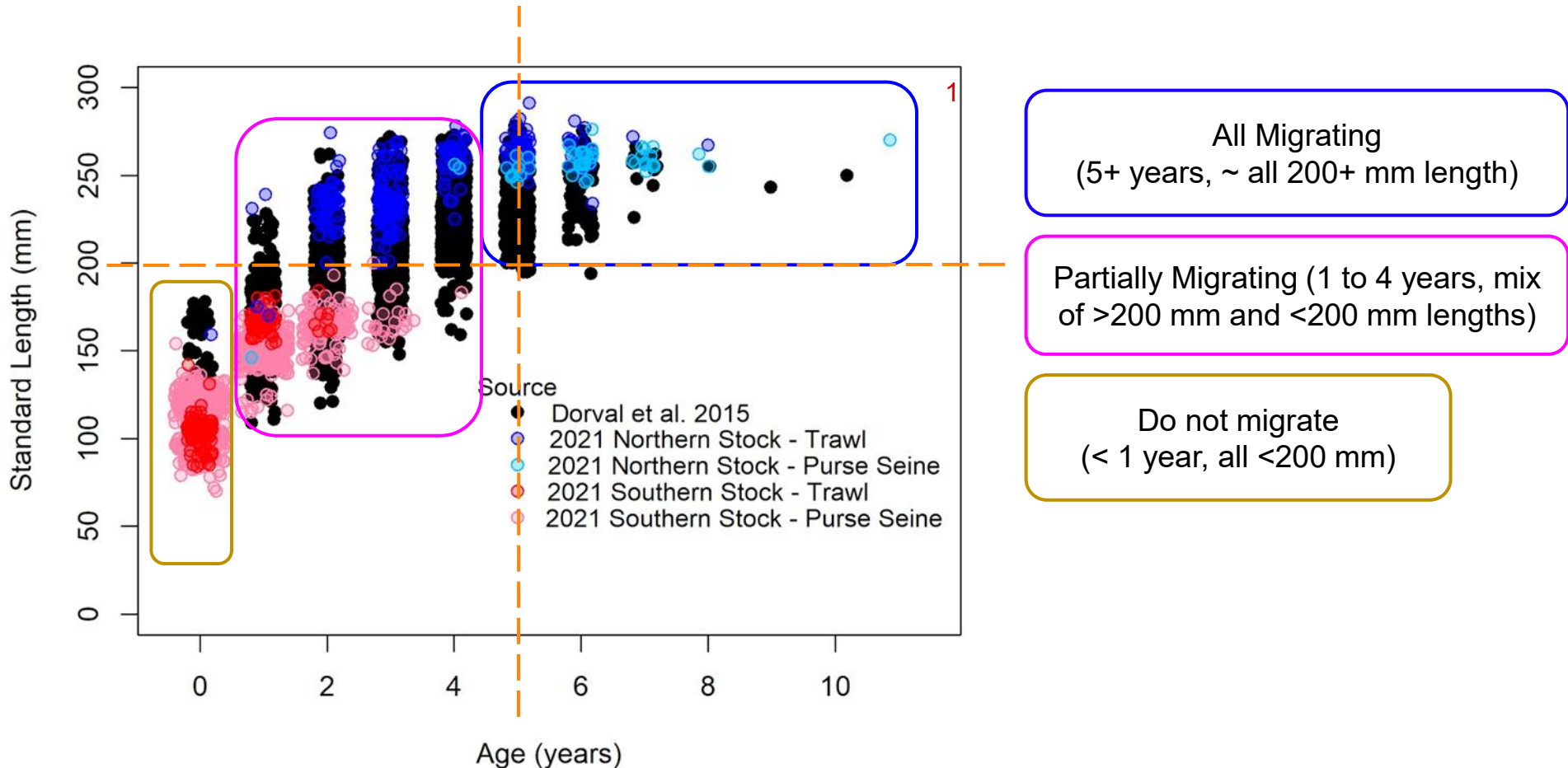
Adult individuals move north in the summer/fall to forage

## Selected Novel Results:

- Historical summer spatial distribution differs by size
- Larger individuals further north
- Some mixing signals off coast of Vancouver Island

<sup>1</sup>Adapted from Stierhoff et al., 2023

# Going from Length to Age-based Movement Assumptions



# Preliminary Summary Results / Next Steps

- Ready (***Build computer models***)  
Base Operating Models (OMs) with:
  - 1) Area Definitions,
  - 2) Regional Abundance Indices, and
  - 3) Age-based Movement
  - 4) Justified use of further climate variables given large contribution of spatiotemporal random effects to the model
- Next Steps (***Add the Environment***)
  - 1) Variance Inflation Factor Analysis of potential environmental covariates
  - 2) Assessment of SDM model performance with environmental covariates
  - 3) alternative OM scenario development
- Next Steps (***Test the Rules***)  
Simulation Analyses
- Other Studies
  - 1) Analogous Operating Models in Atlantis (an end-to-end ecosystem model)
  - 2) Simulation analyses in Atlantis

*Thank you*  
*Contact: [shopkin1@ucsc.edu](mailto:shopkin1@ucsc.edu)*



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