Detecting single and compound marine extremes in the California Current Large Marine Ecosystem

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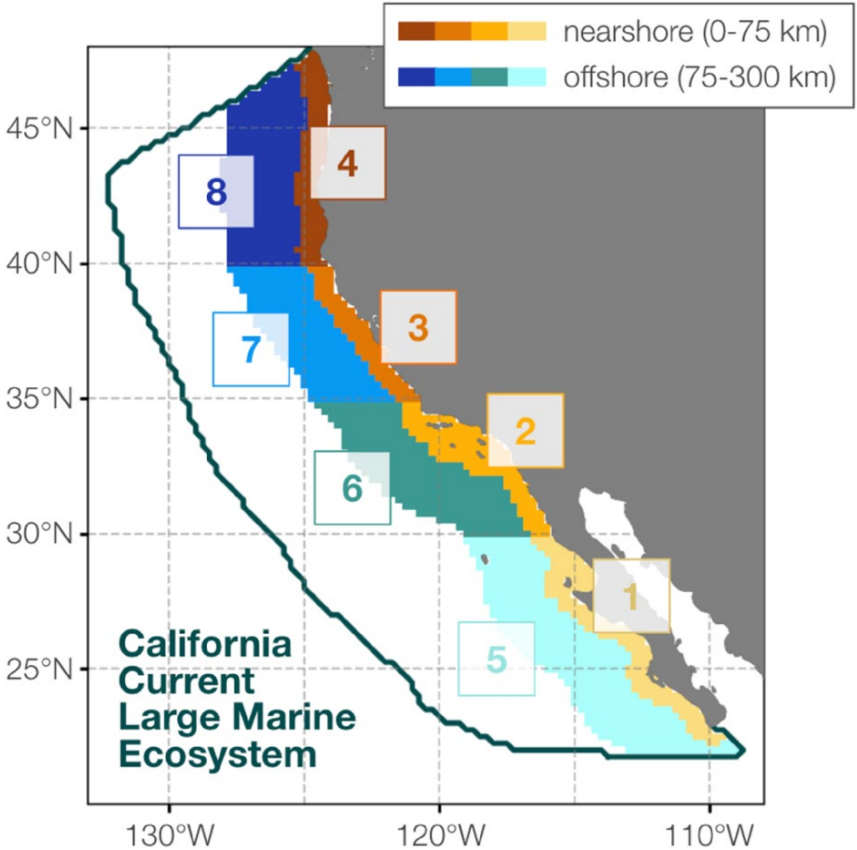
The California Current Large Marine Ecosystem (CCLME)

Section of the Northeast Pacific Ocean

Supports rich, biodiversity, and productive ecosystems

Wind-driven upwelling provides nutrients → primary production



Freeman et al. (2026)

Marine Extreme Events

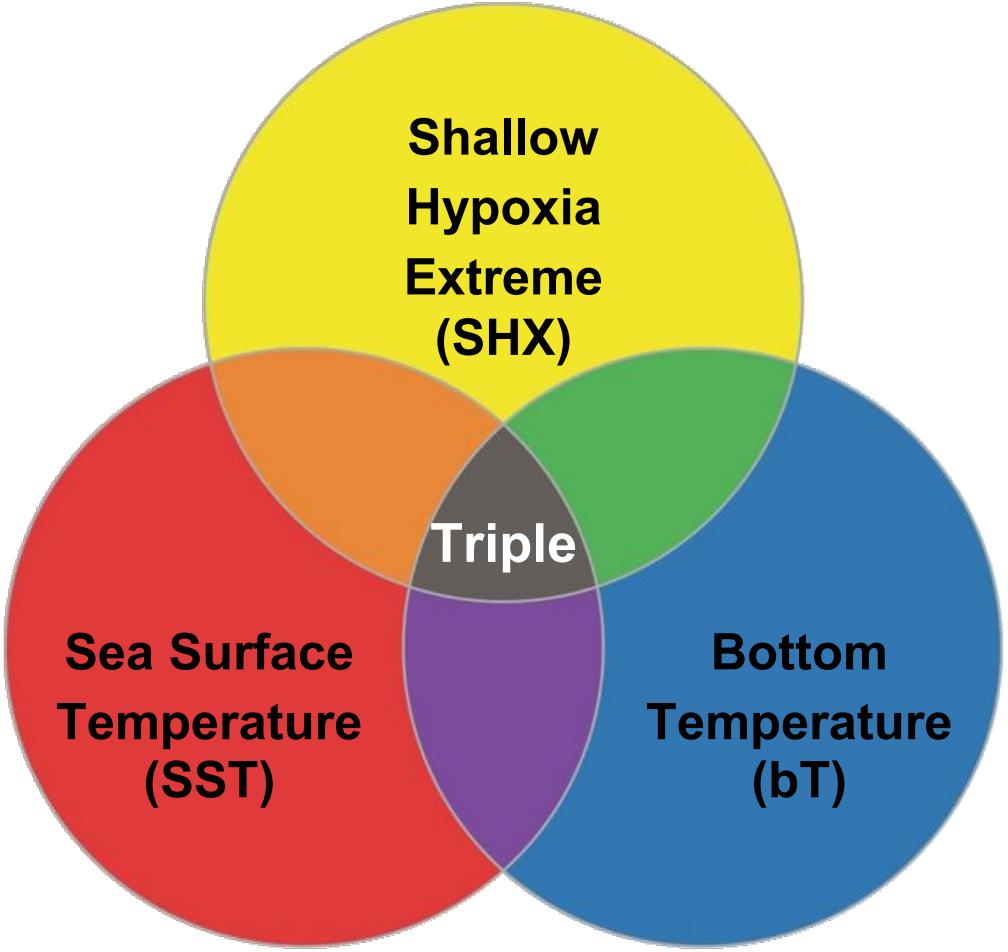
Climate intensification → increased extreme events

Marine heatwaves (MHWs)

- Well-studied

Co-occurring stressors:

- More severe than a single extreme



Objective

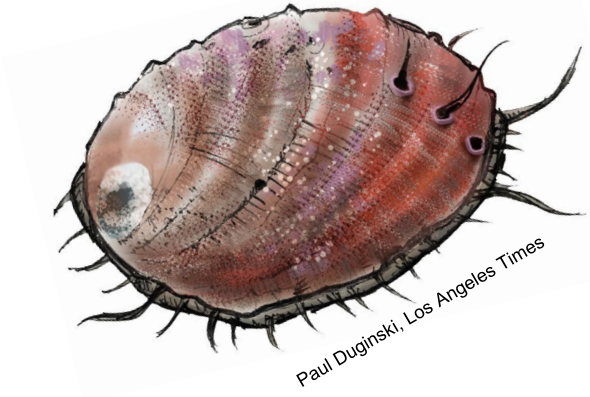
Develop a framework to detect/characterize marine extreme events across the CCLME

Ocean Protection Council Climate Refugia Grant

Working to develop action-oriented science

CALIFORNIA OCEAN PROTECTION COUNCIL





Data Used

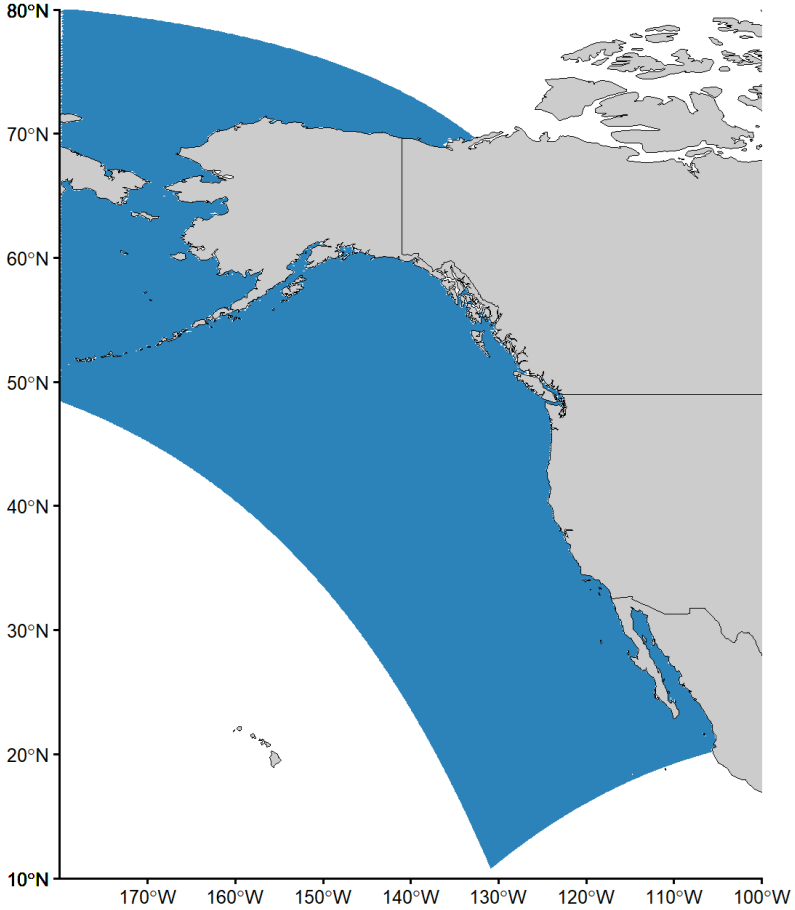
SST, bT, & 3D O2

MOM6 monthly 10km hindcasts

- **1993-2025**

In the works:

- **ROMS projections**
- **ROMS hindcasts**



Extreme Event Detection

Compute seasonal thresholds (*3 month window)*

Flag exceedances

Merge events (*1 month gap*)

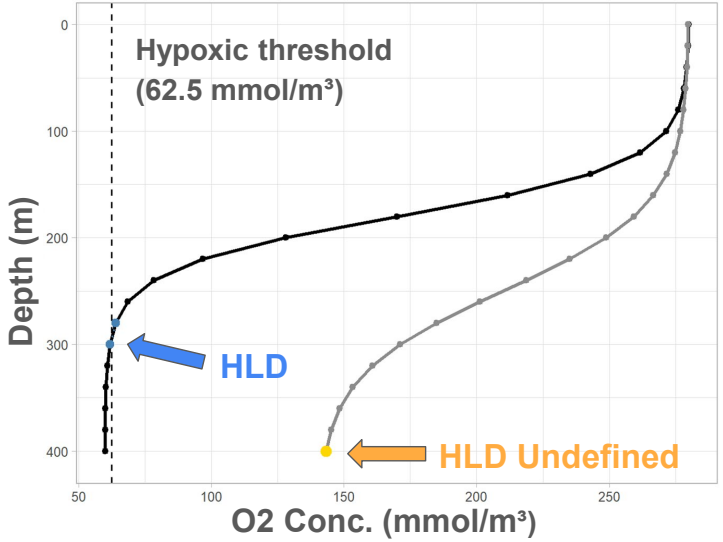
Minimum duration (*2 months*)

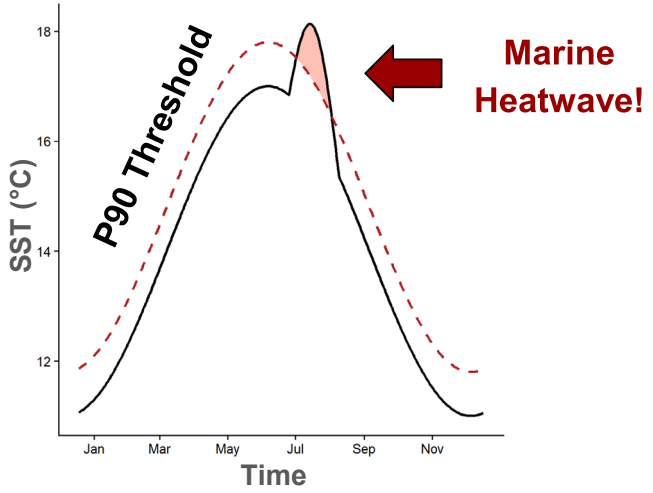
Compute anomaly z-scores

Characterize: frequency, duration, intensity

Shallow Hypoxia Extreme:

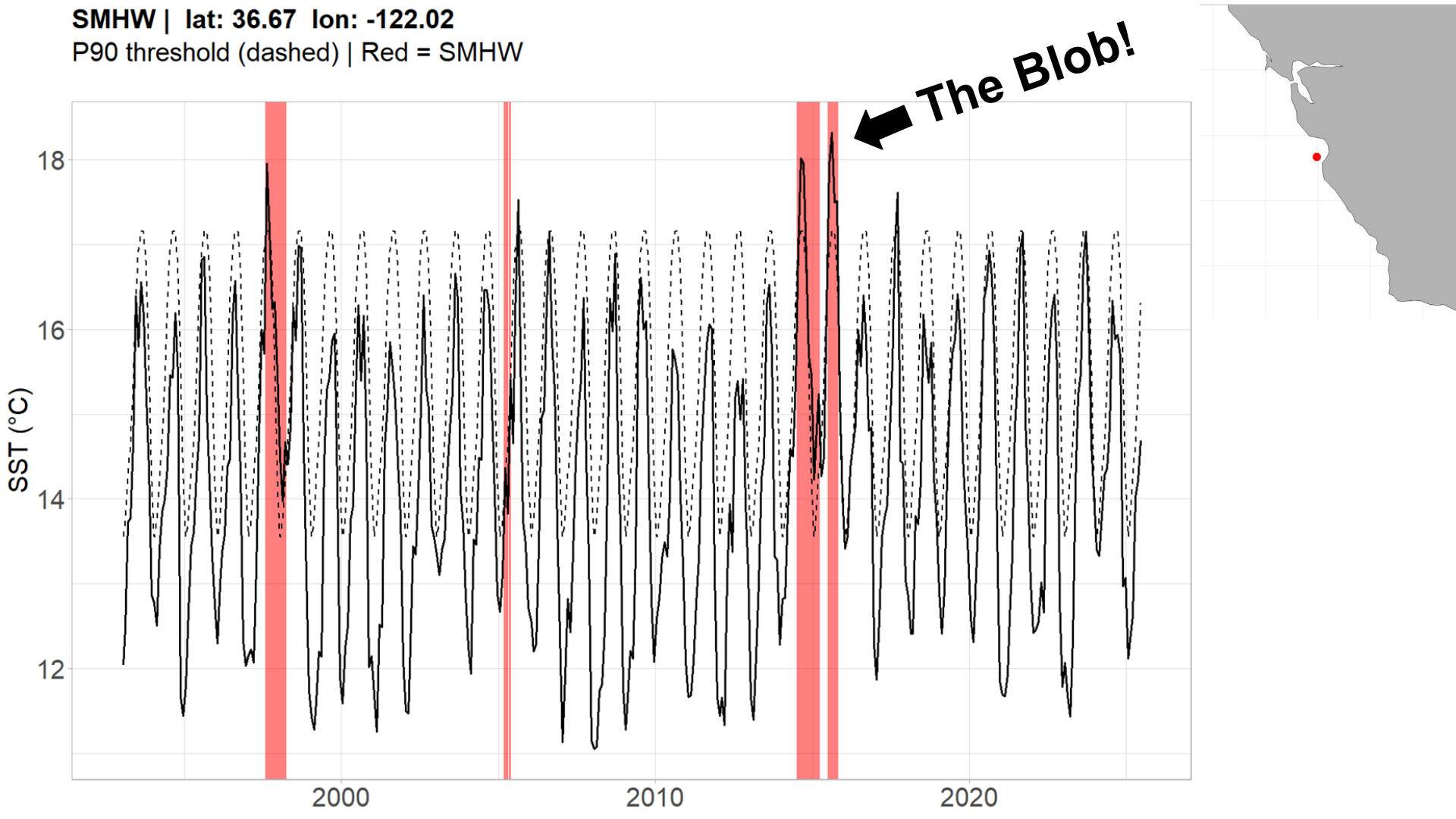
- **Lower 10% threshold**

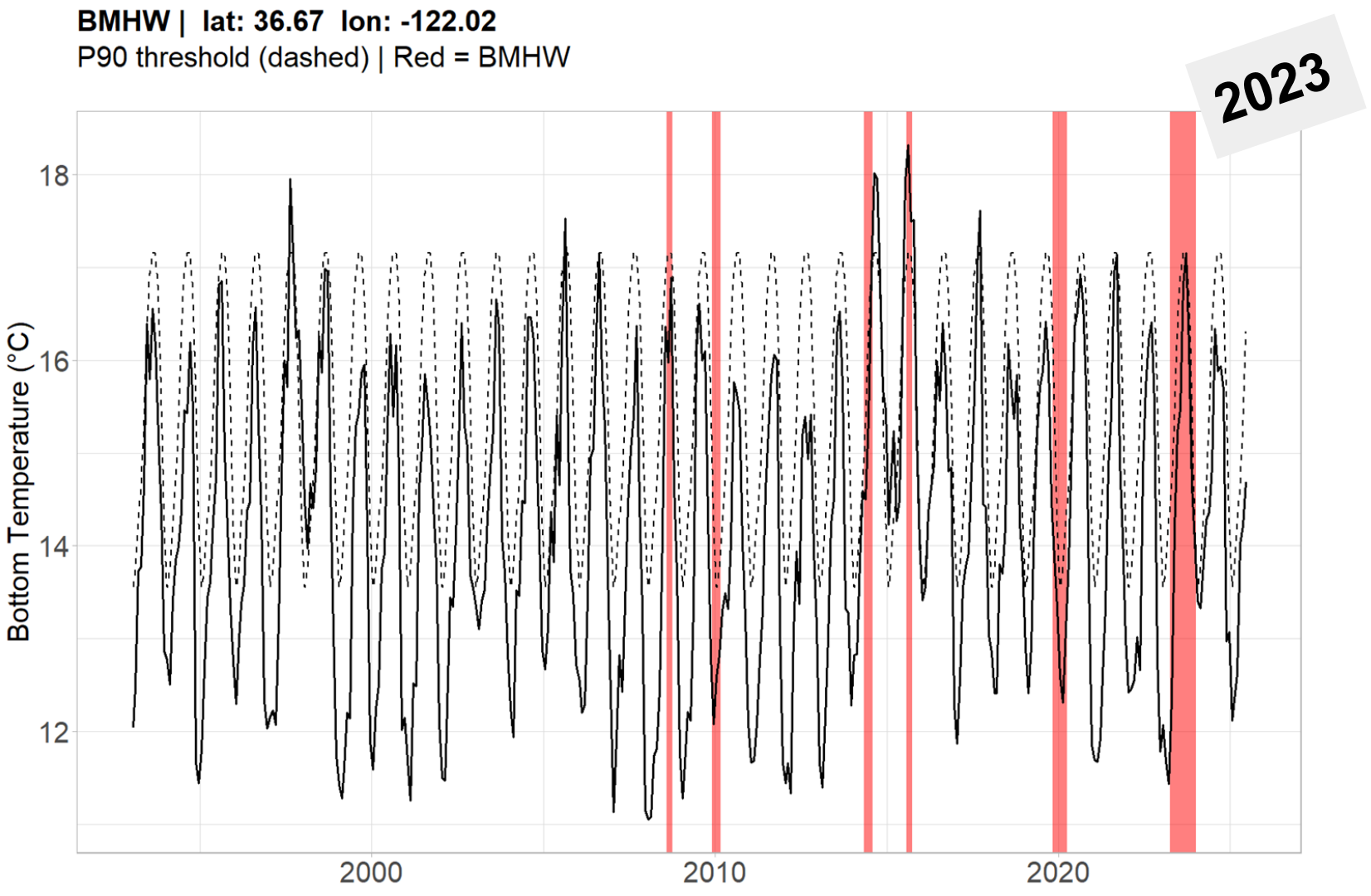


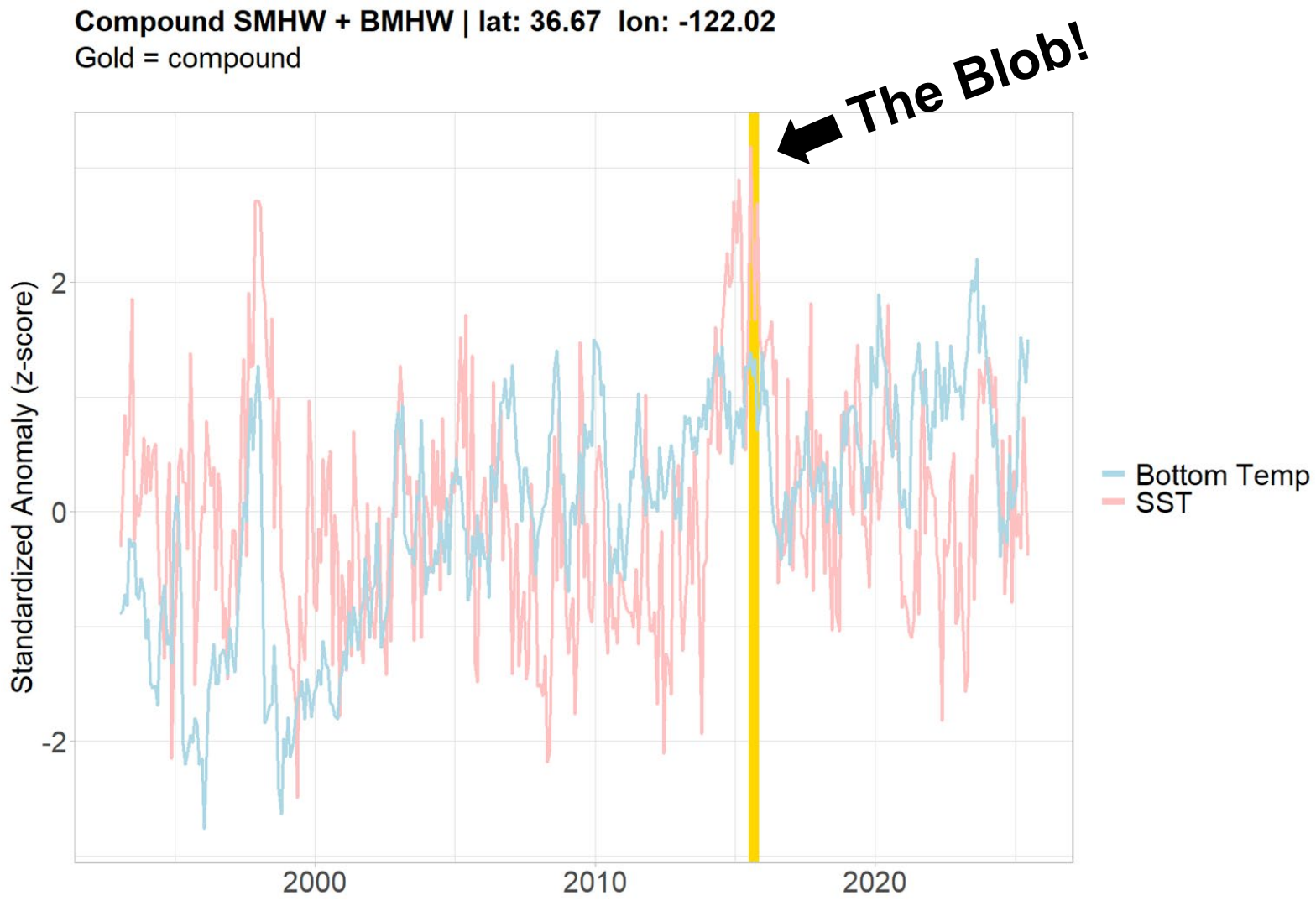


SMHW | lat: 36.67 lon: -122.02

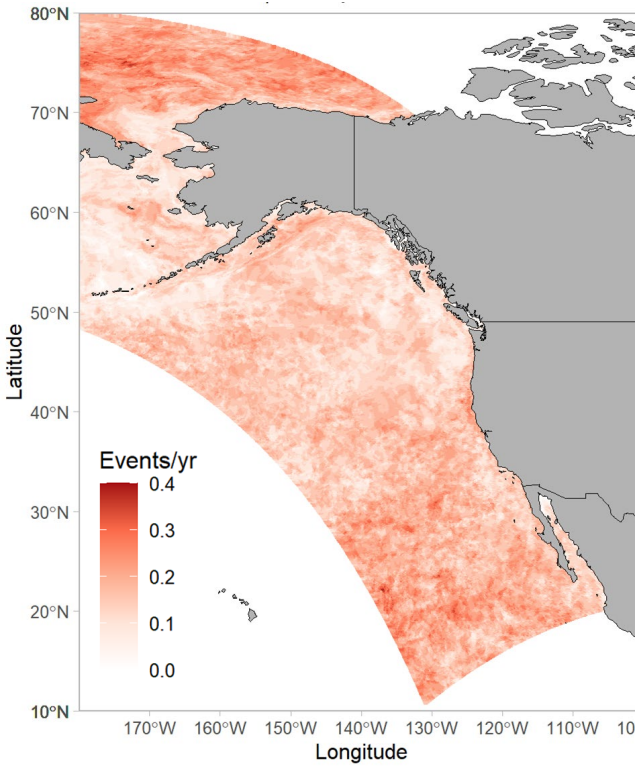
P90 threshold (dashed) | Red = SMHW



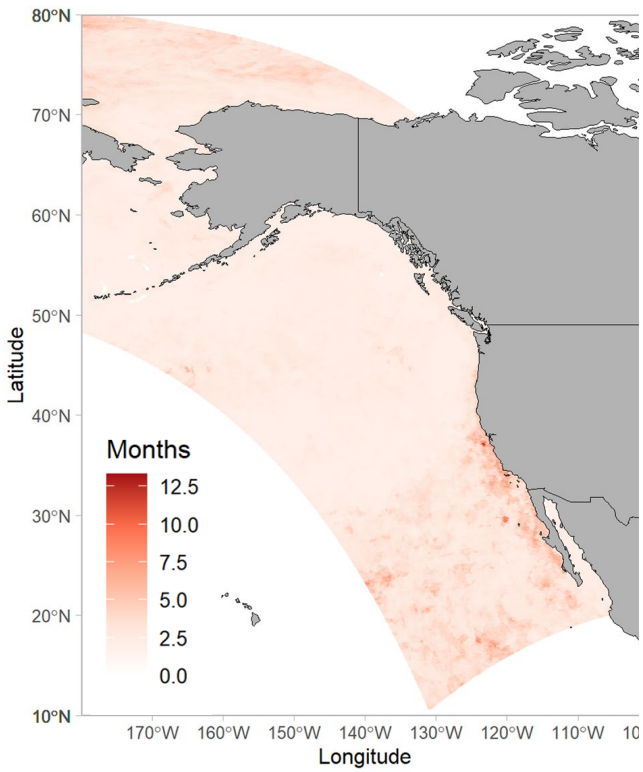

BMHW | lat: 36.67 lon: -122.02
P90 threshold (dashed) | Red = BMHW
2023
Bottom Temperature (°C)
18
16
14
12
2000
2010
2020


Compound SMHW + BMHW | lat: 36.67 lon: -122.02
Gold = compound
The Blob!
Standardized Anomaly (z-score)
2
0
-2
2000
2010
2020
Bottom Temp
SST

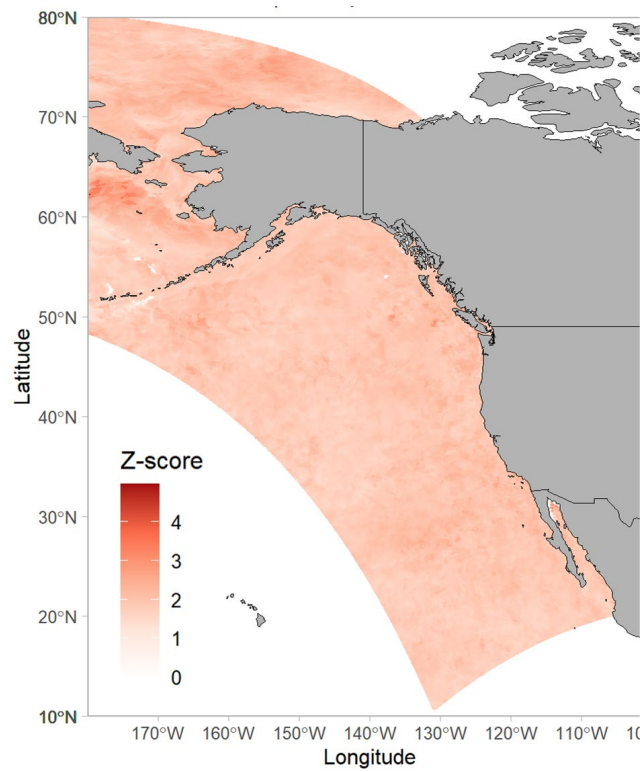
SMHW Frequency



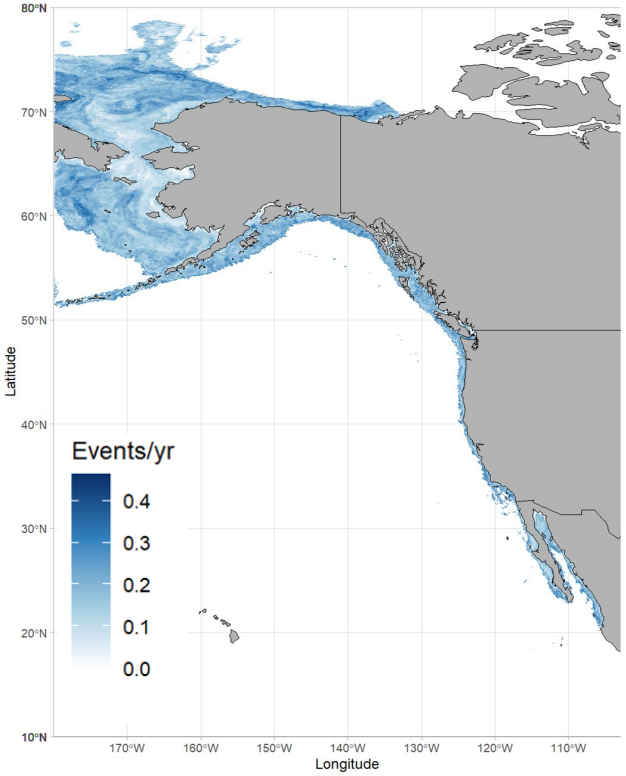
SMHW Mean Duration



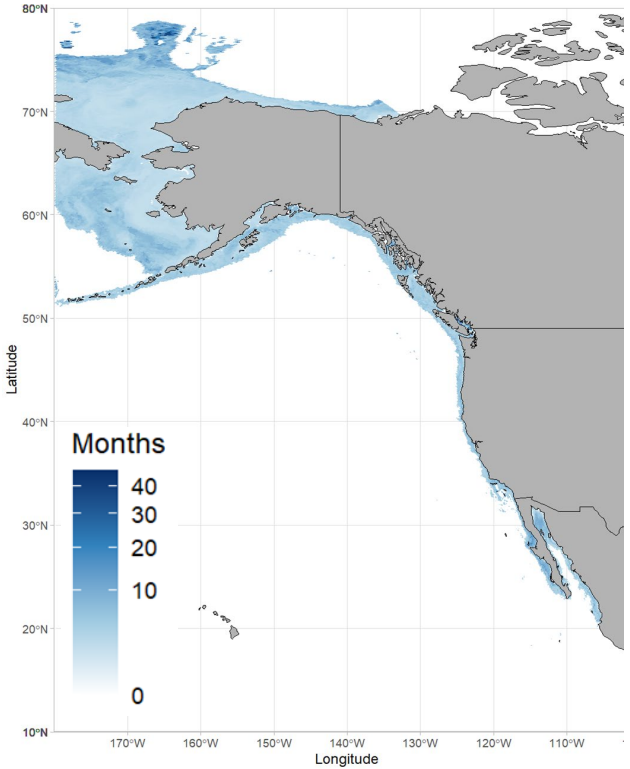
SMHW Mean Intensity



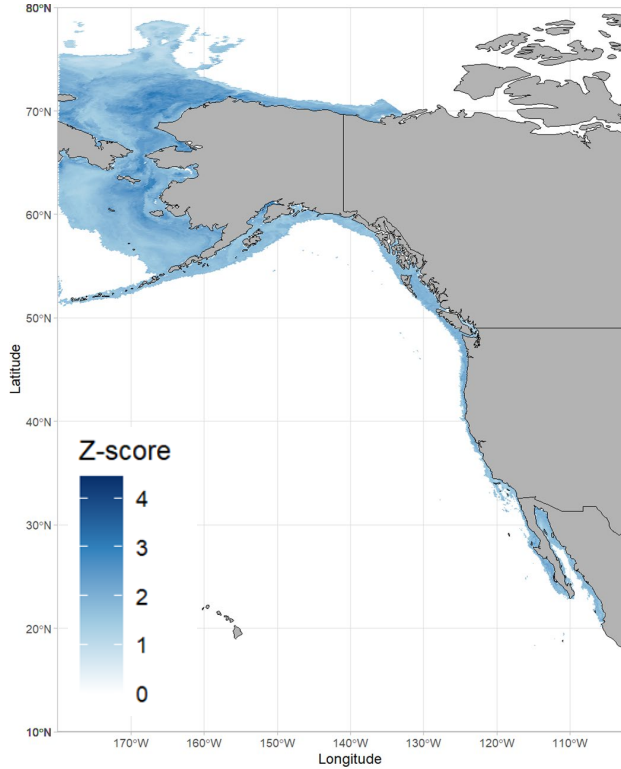
BMHW Frequency



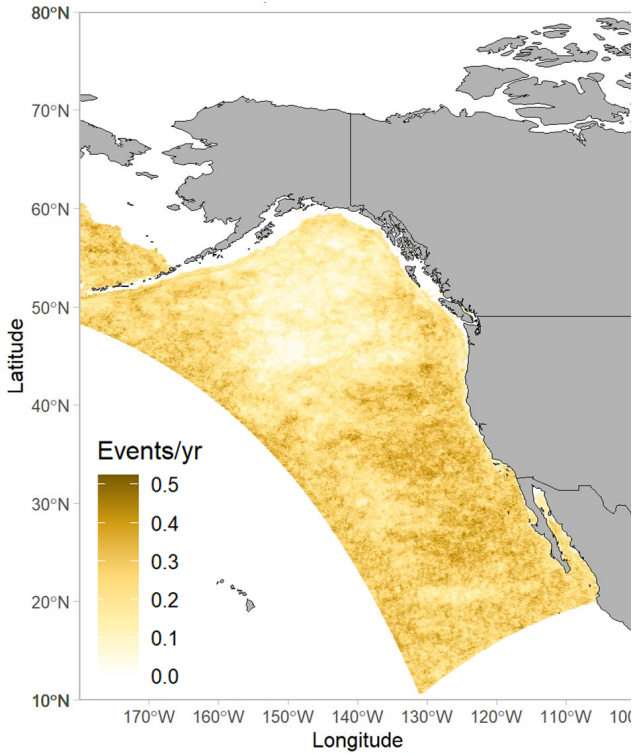
BMHW Mean Duration



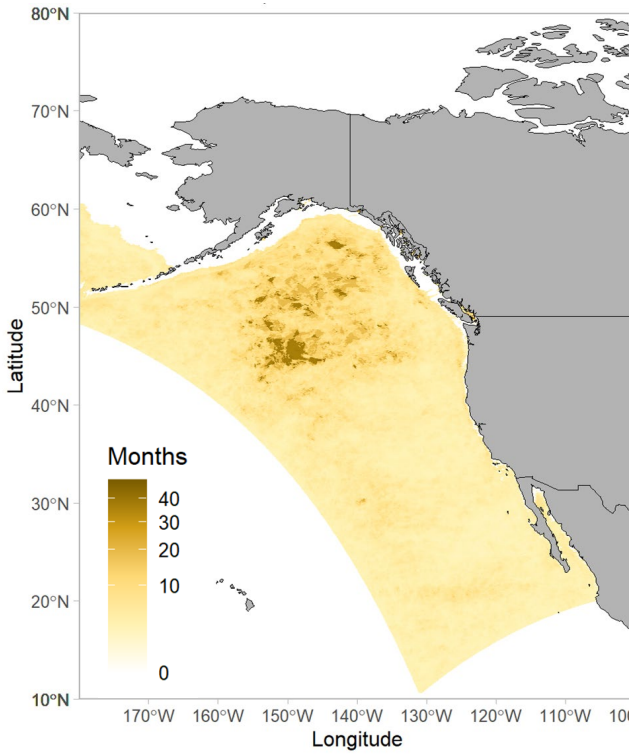
BMHW Mean Intensity



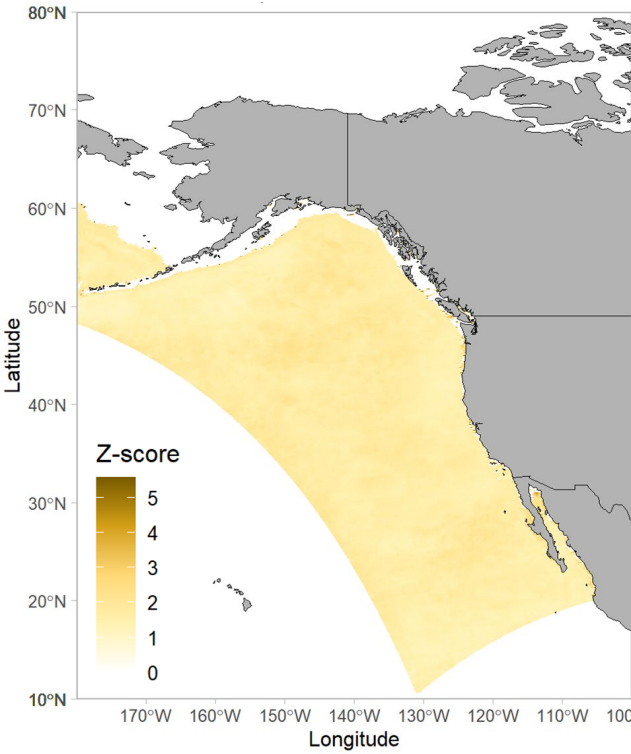
SHX Frequency

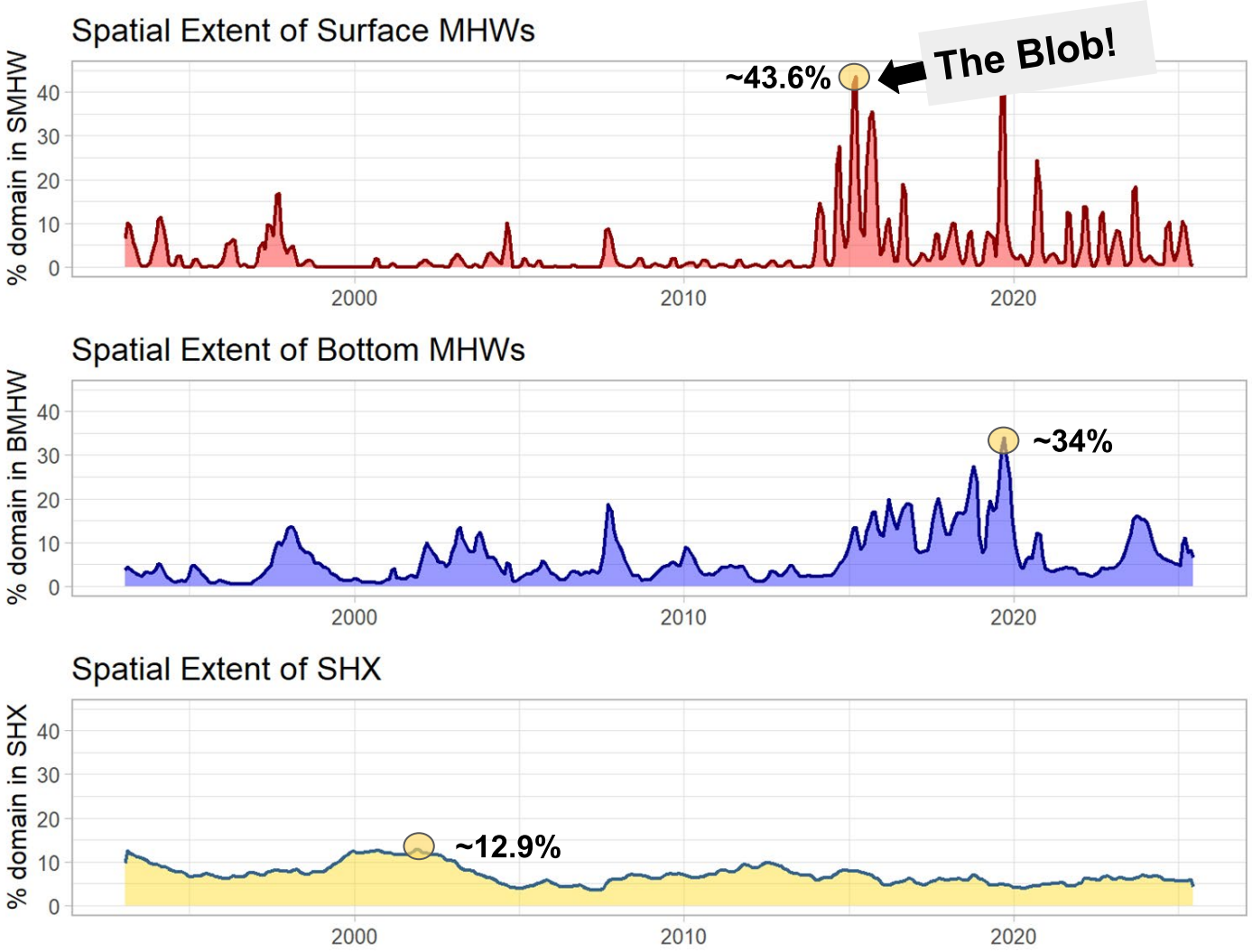


SHX Mean Duration

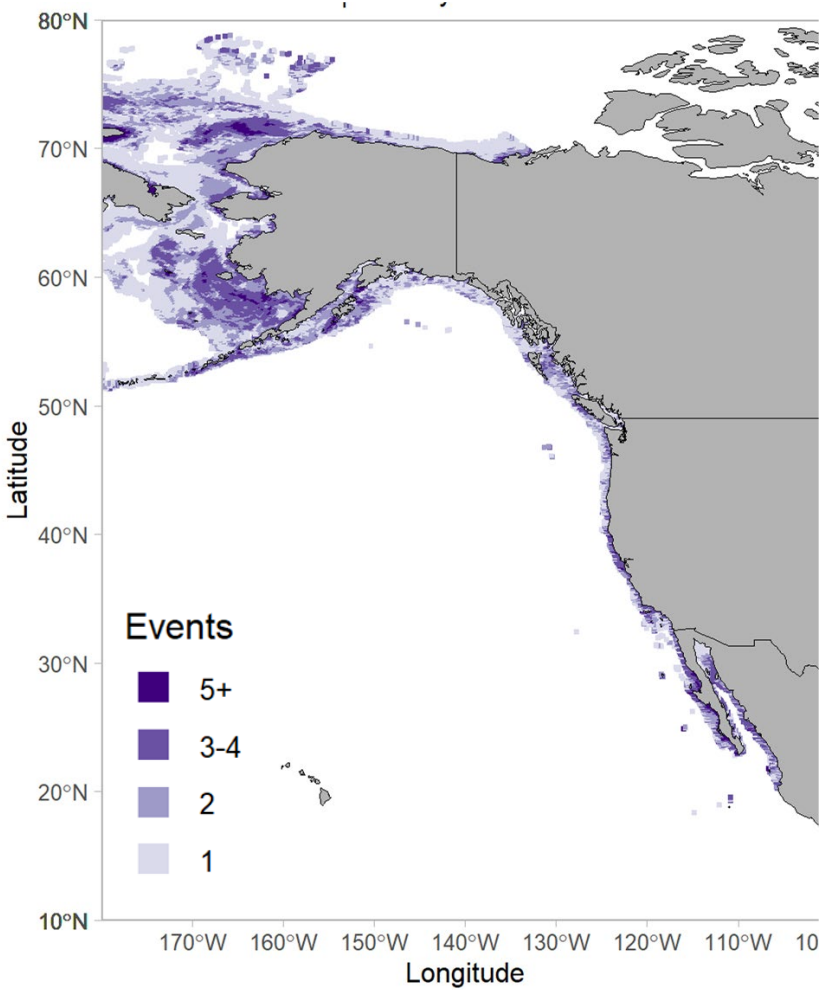


SHX Mean Intensity

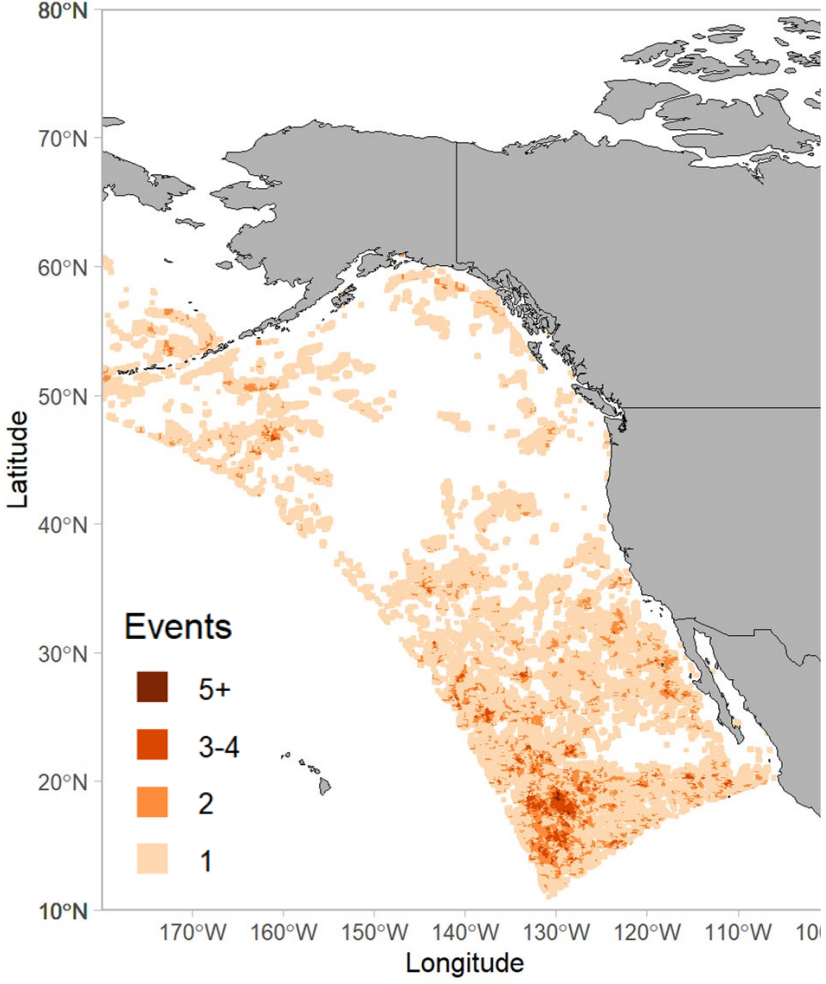



Spatial Extent of Surface MHWs
% domain in SMHW
~43.6%
The Blob!
Spatial Extent of Bottom MHWs
% domain in BMHW
~34%
Spatial Extent of SHX
% domain in SHX
~12.9%
0
10
20
30
40
2000
2010
2020

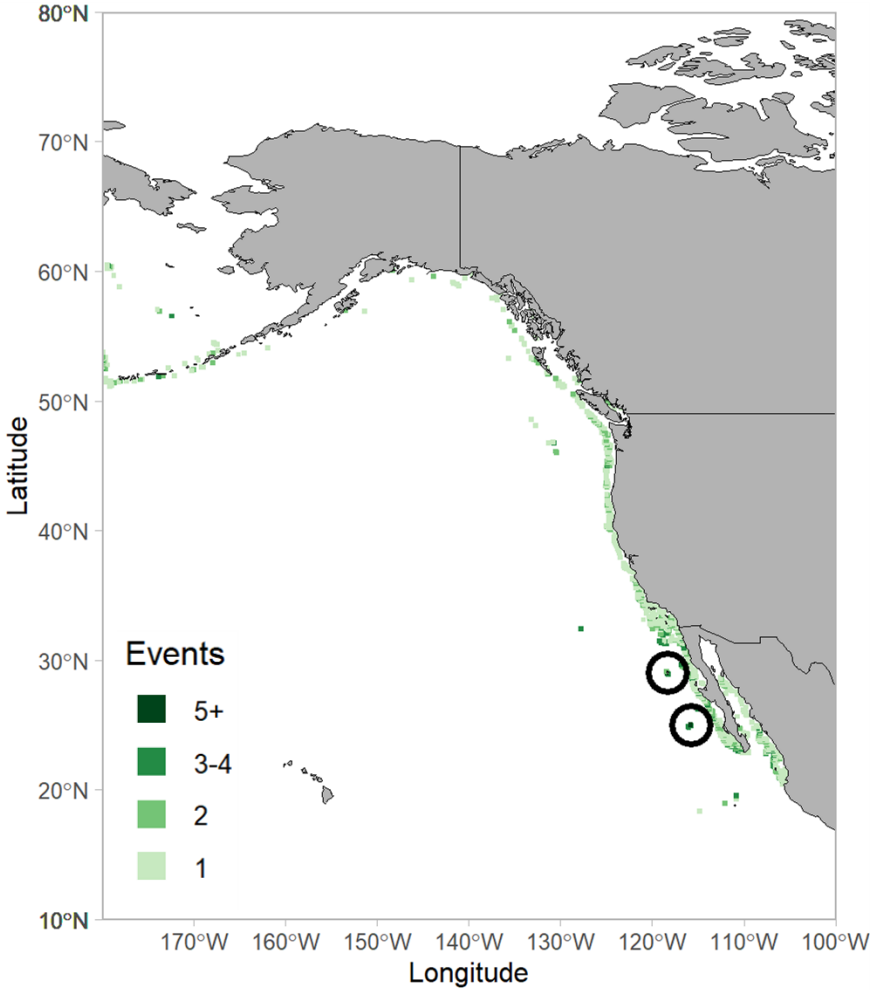
SMHW x BMHW Number of Events



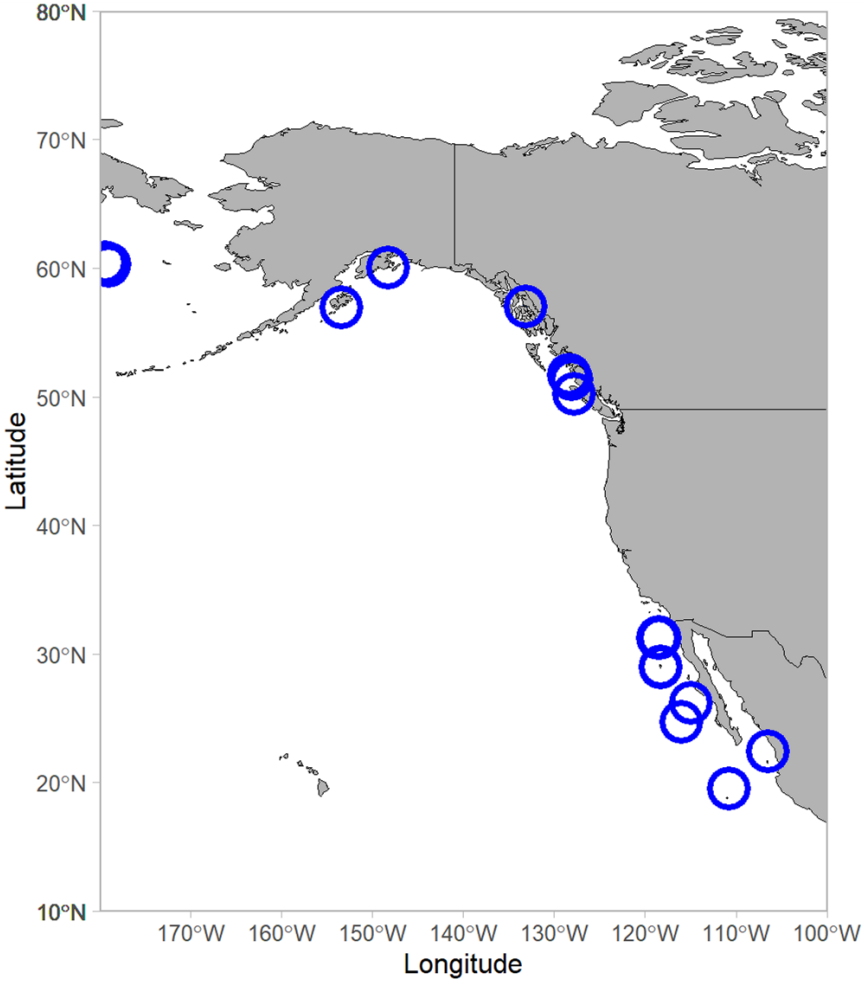
SMHW x SHX Number of Events



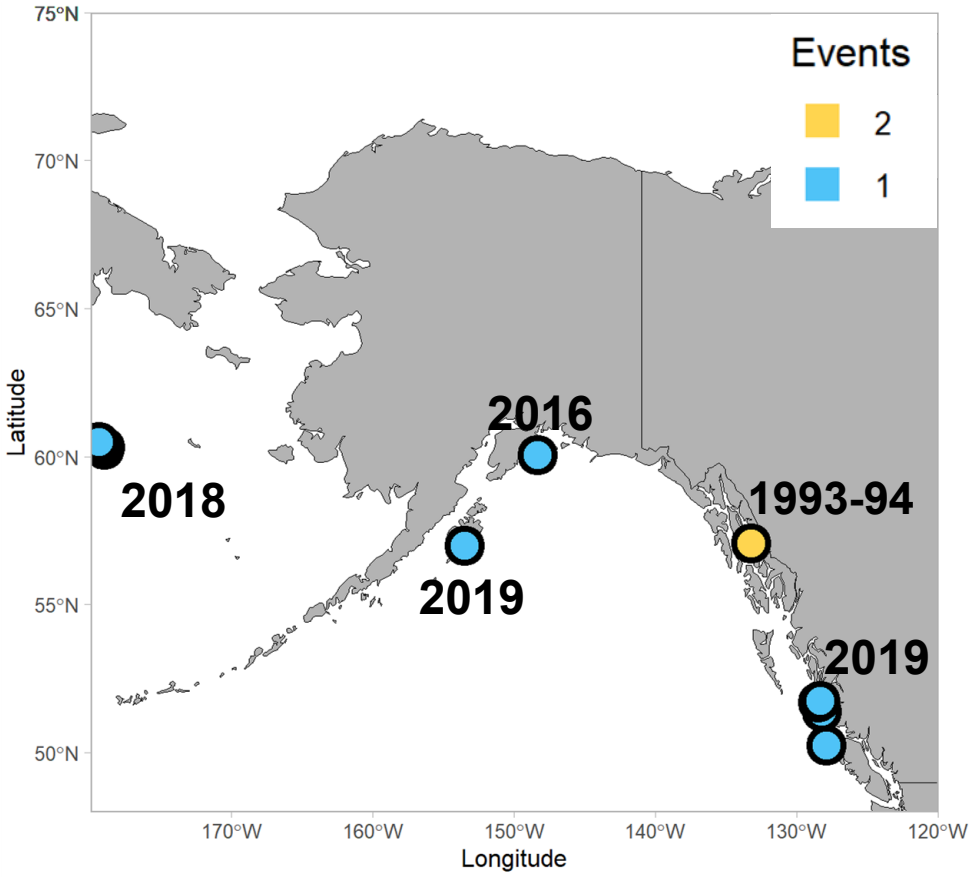
BMHW x SHX Number of Events



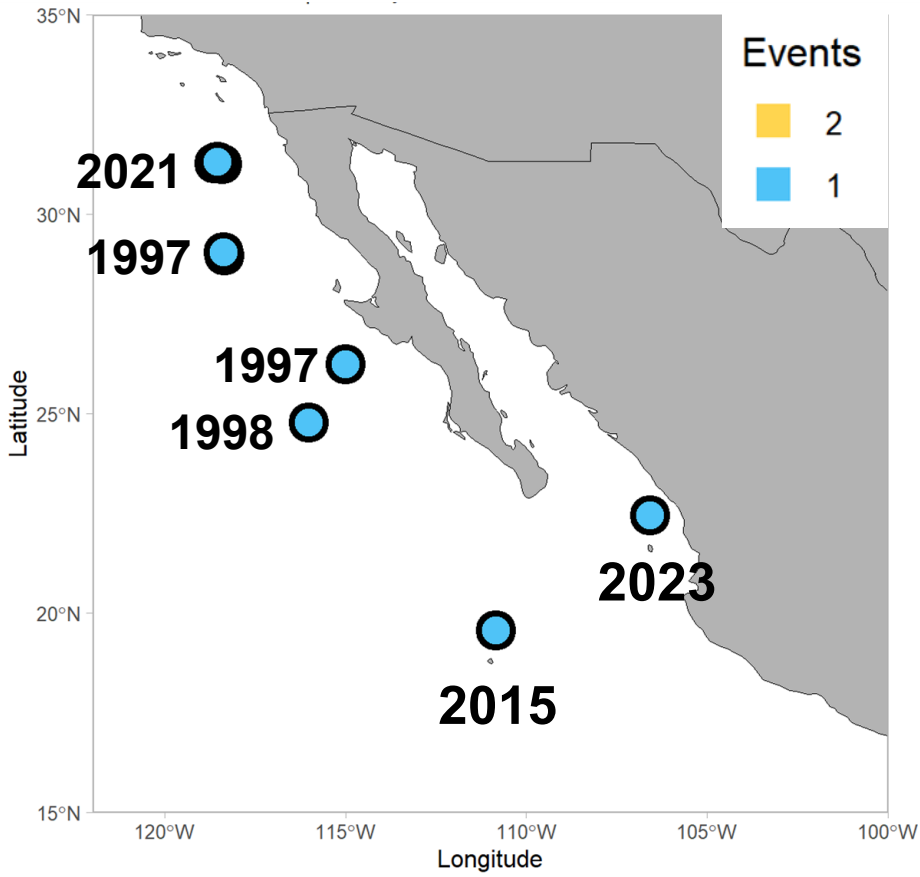
Triple Compound - Number of Events



Triple Compound - Gulf of Alaska



Triple Compound - Baja California



Conclusion

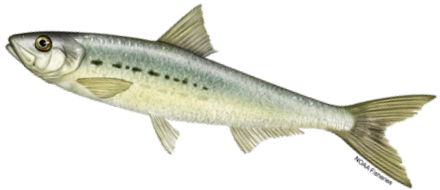
More individual and compound events in recent years

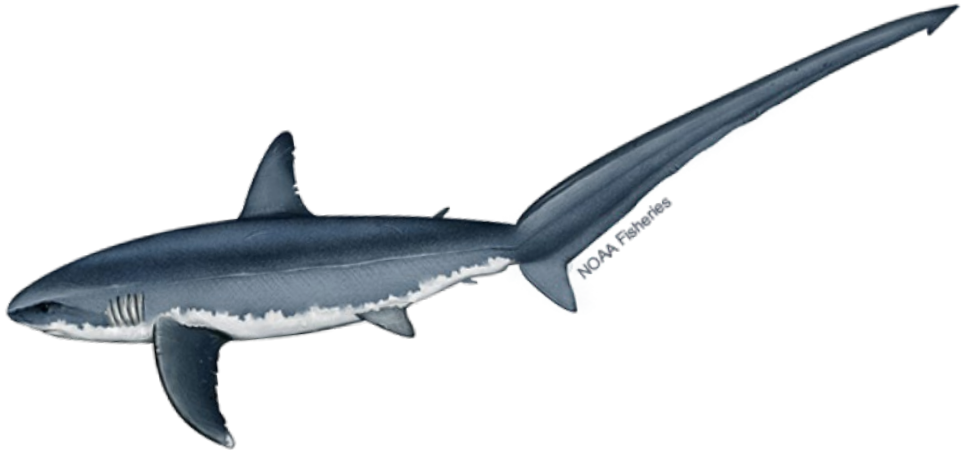
Spatial heterogeneity

Areas of note:

- Baja California
- Bering Sea & Arctic Ocean
- Far off SW California coastline
- Along coast of British Columbia





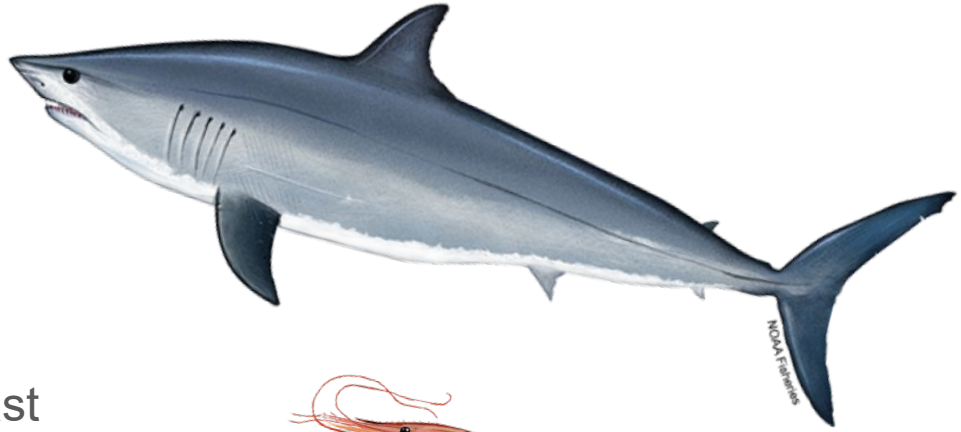


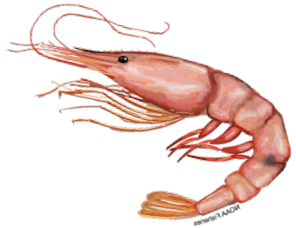
Future Work

Applying to refugia

Steps forward:

- **Step 1:** MOM6 Hindcast
- **Step 2:** ROMS monthly hindcast
- **Step 3:** ROMS monthly projections
- **Step 4:** Daily projection data,
  10km → 3km
- **Step 5:** Refugia based on species thresholds







Updates!

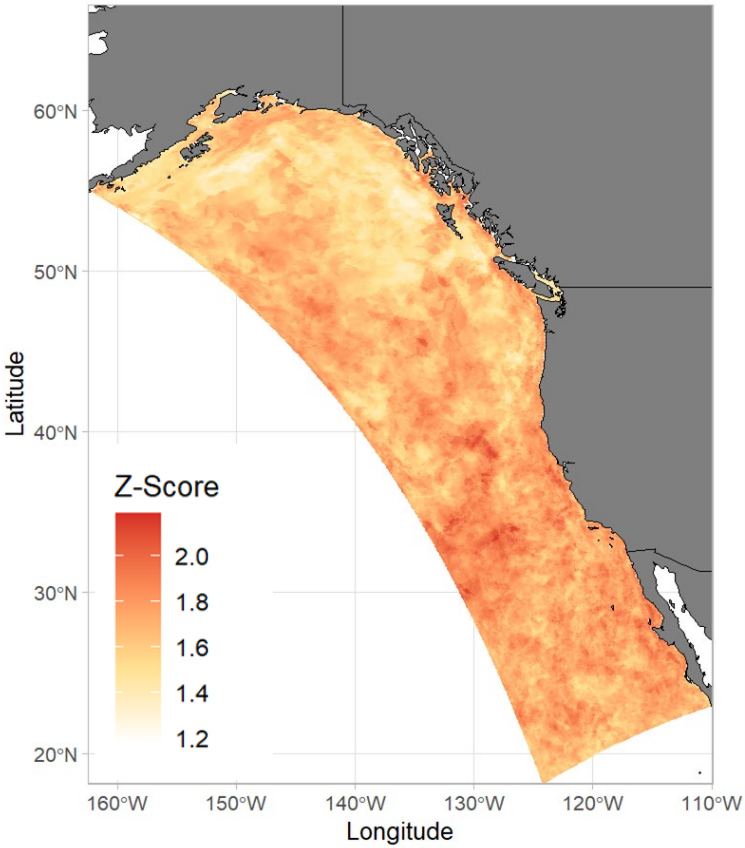
Changes to methodology

- Minimum duration: 2 months → 1 month
- Removed event merging

ROMS

- Finishing single extremes
- Hindcast, GFDL, IPSL, UKESM
- Baselines: fixed hindcast, moving
- Early, mid, late century splits

Hindcast SMHW Intensity



Contact:
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Thank You!

Funded by the NOAA Hollings Scholarship

References

- Cavole et al. (2016)
- Freeman et al. (2026)
- Gruber et al. (2021)
- Hobday et al. (2016)