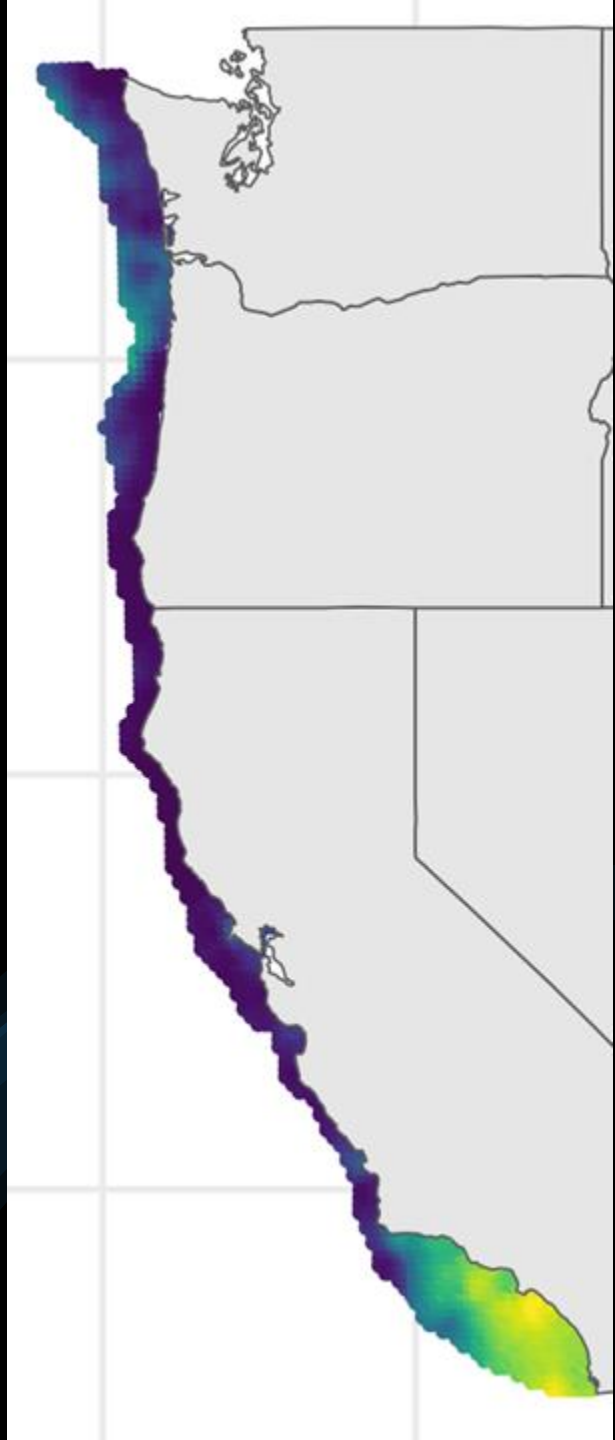
Spatial variability in multivariate climate vulnerability produces mosaic of risks and tradeoffs for four California Current shellfish species

Esther G. Kennedy

S01 #17844

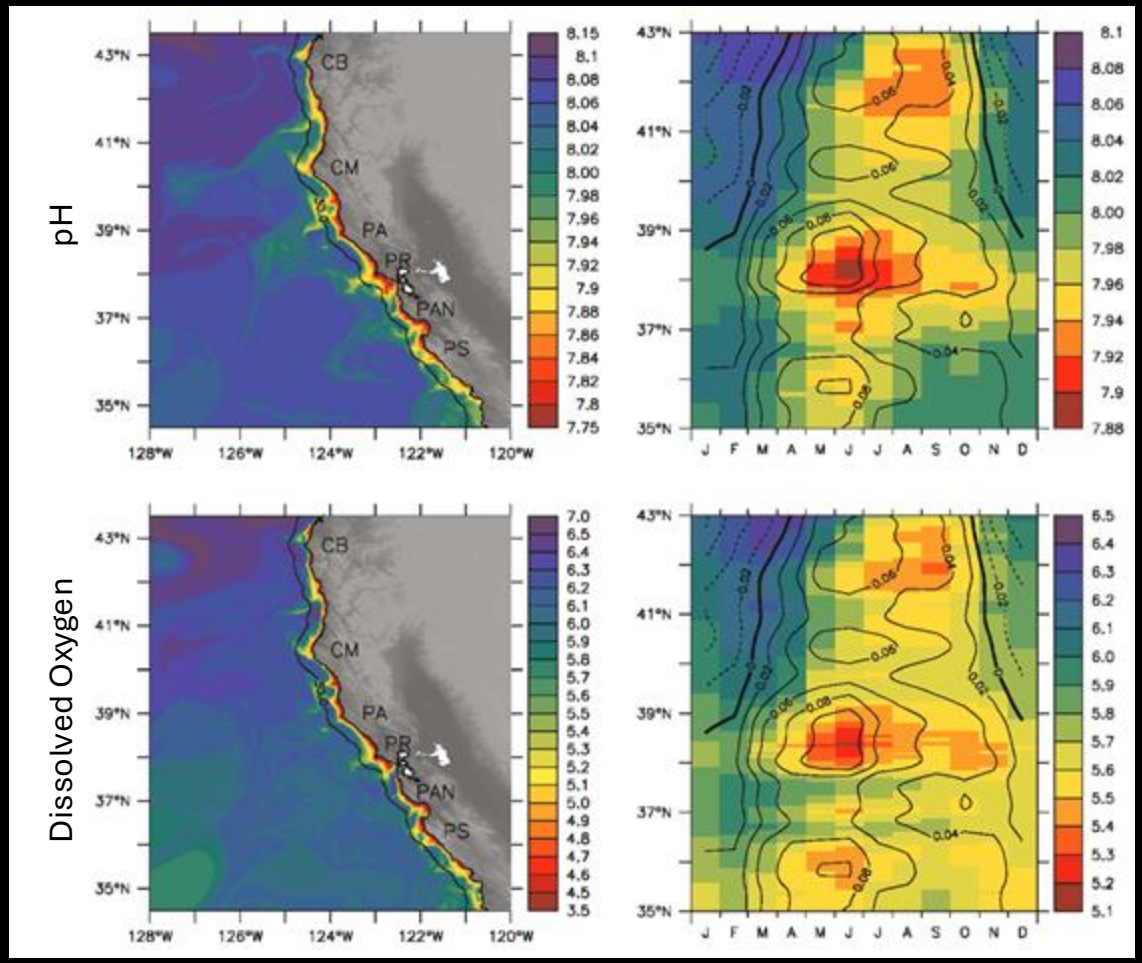


Exposure to stressful conditions in the CCS is spatially complex

- Upwelling drives most exposure to low DO or pH

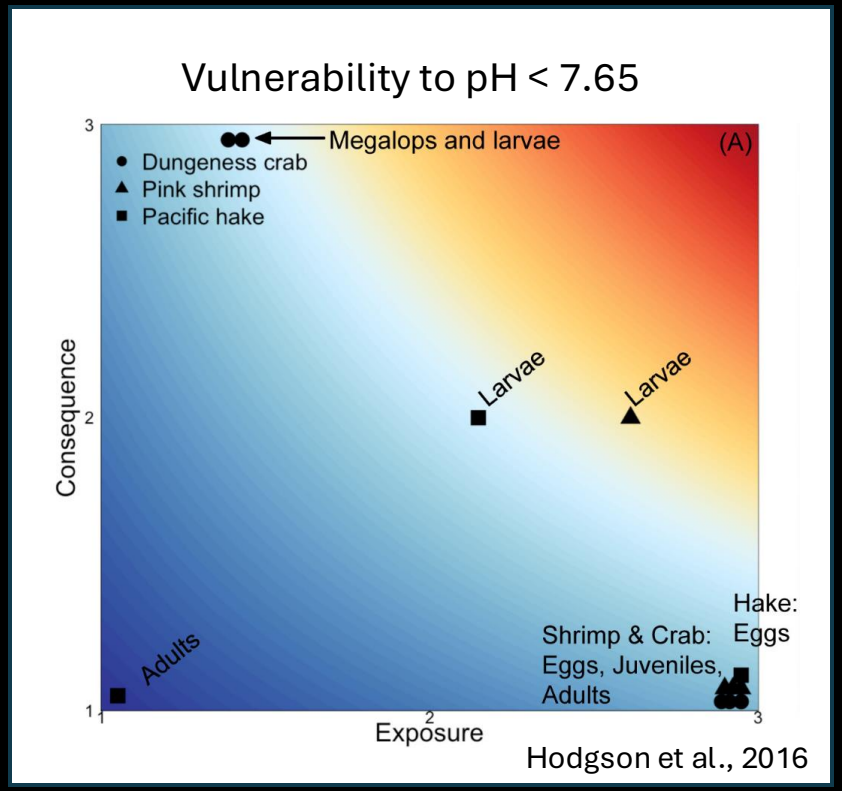
But…

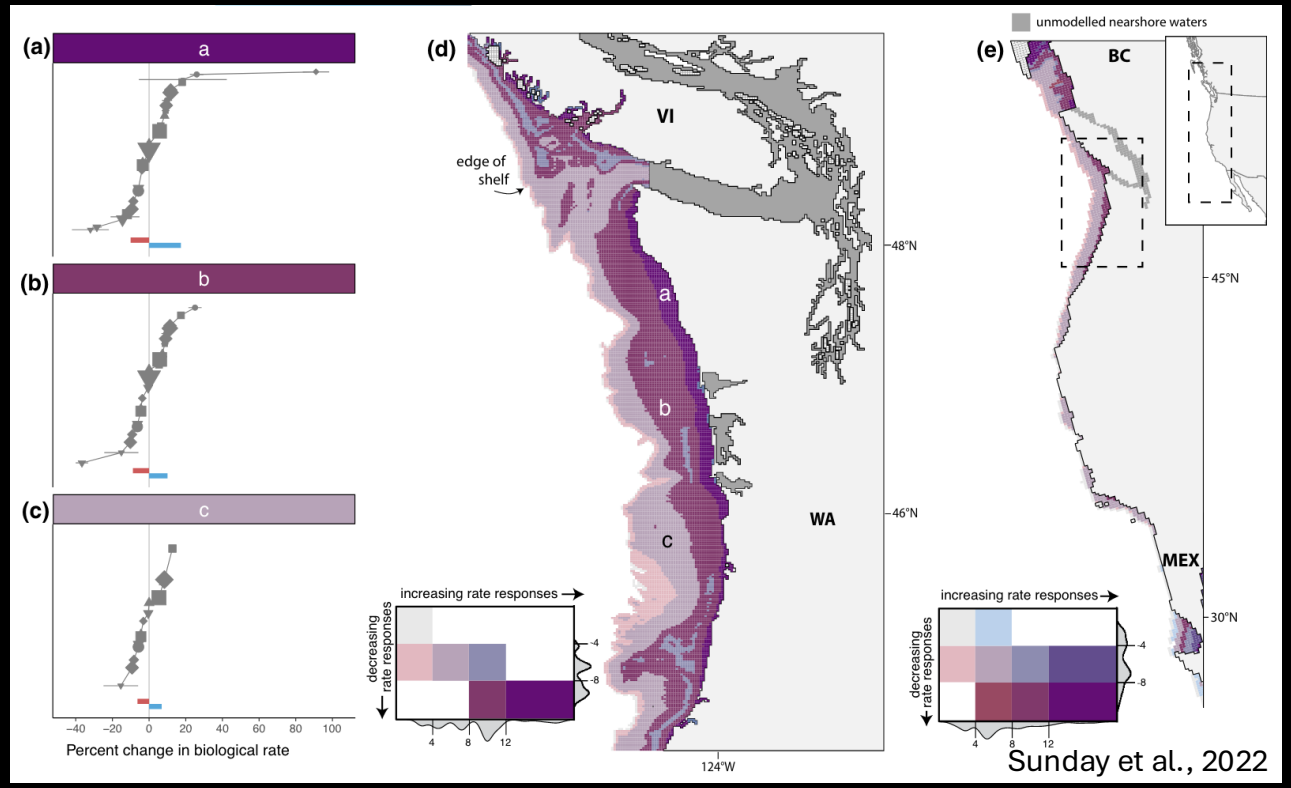
- Stratification can produce high temperatures with low DO/pH
- Marine heat waves (MHW) can suppress or alter upwelling patterns



Cheresh and Fiechter, 2020

How does spatial complexity impact vulnerability?





Many previous vulnerability analyses in the region:

- Modeled environmental conditions and/or qualitative analyses
- Consider uncertainty, but not the spatial consequences

How does spatial complexity impact vulnerability?

1) What are the spatial patterns of vulnerability to environmental stressors?
2) How does uncertainty impact vulnerability maps?
3) How do marine heat waves impact vulnerability maps?

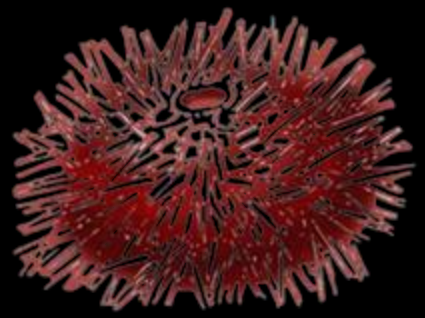
North Pacific Krill

Seafood Watch

Red Abalone

LA Times

Red Sea Urchin



Exploring Nature

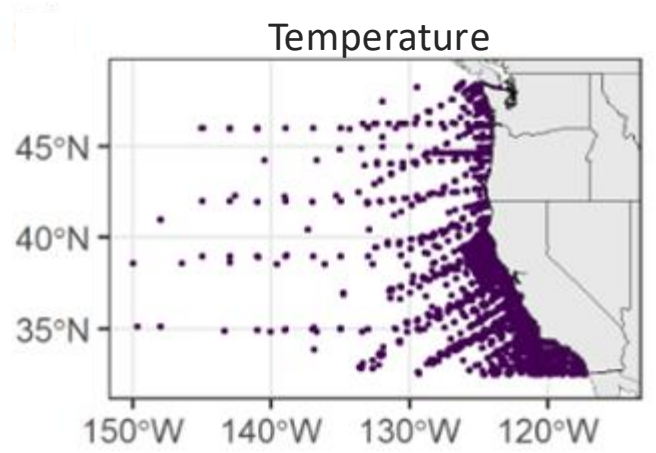
Dungeness Crab

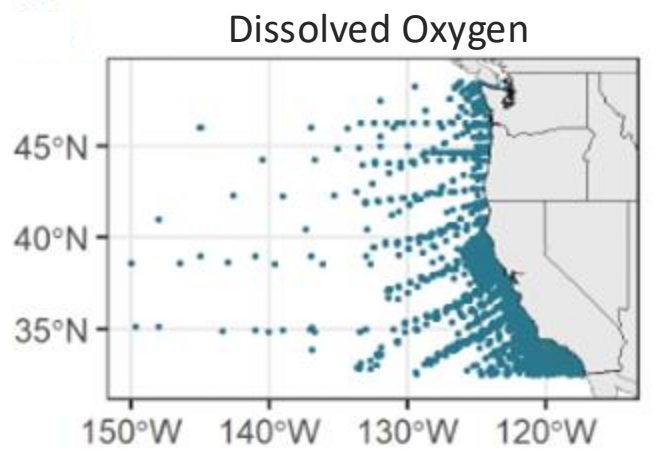
Charting Nature

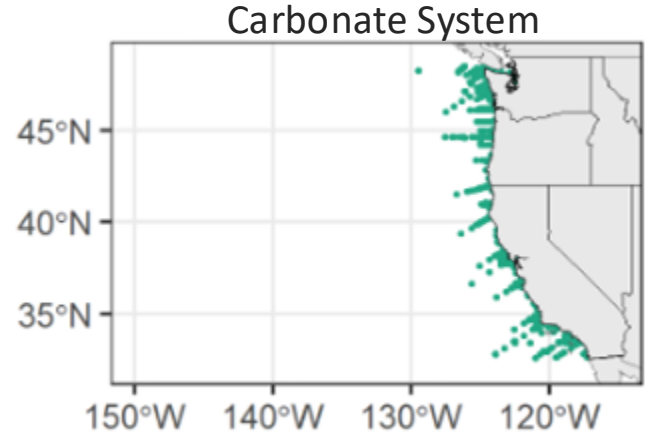
Dataset

Multistressor Observations of Coastal Hypoxia and Acidification (MOCHA) compilation

- NCEI Accession 0277984
- Oceanographic cruises, autonomous sensors, and shore-collected samples.
- Optimized for investigations of temperature, oxygen, and acidification stress.







Dataset: Kennedy et al., 2023, doi.org/10.25921/2vve-fh39.
Description: Kennedy et al., 2024, doi.org/10.5194/essd-16-219-2024

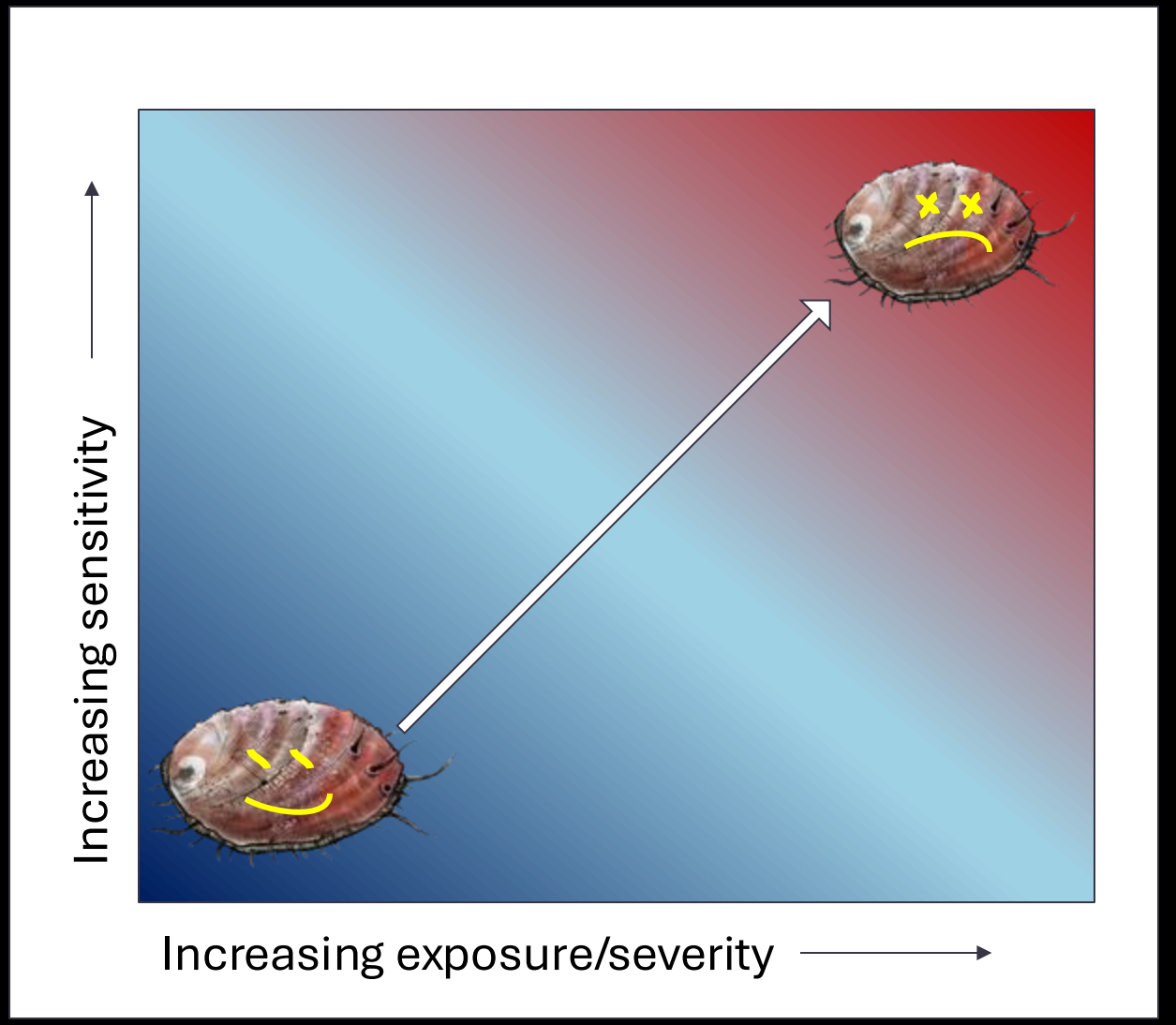
Methods: what is vulnerability?

$$V = E * S$$

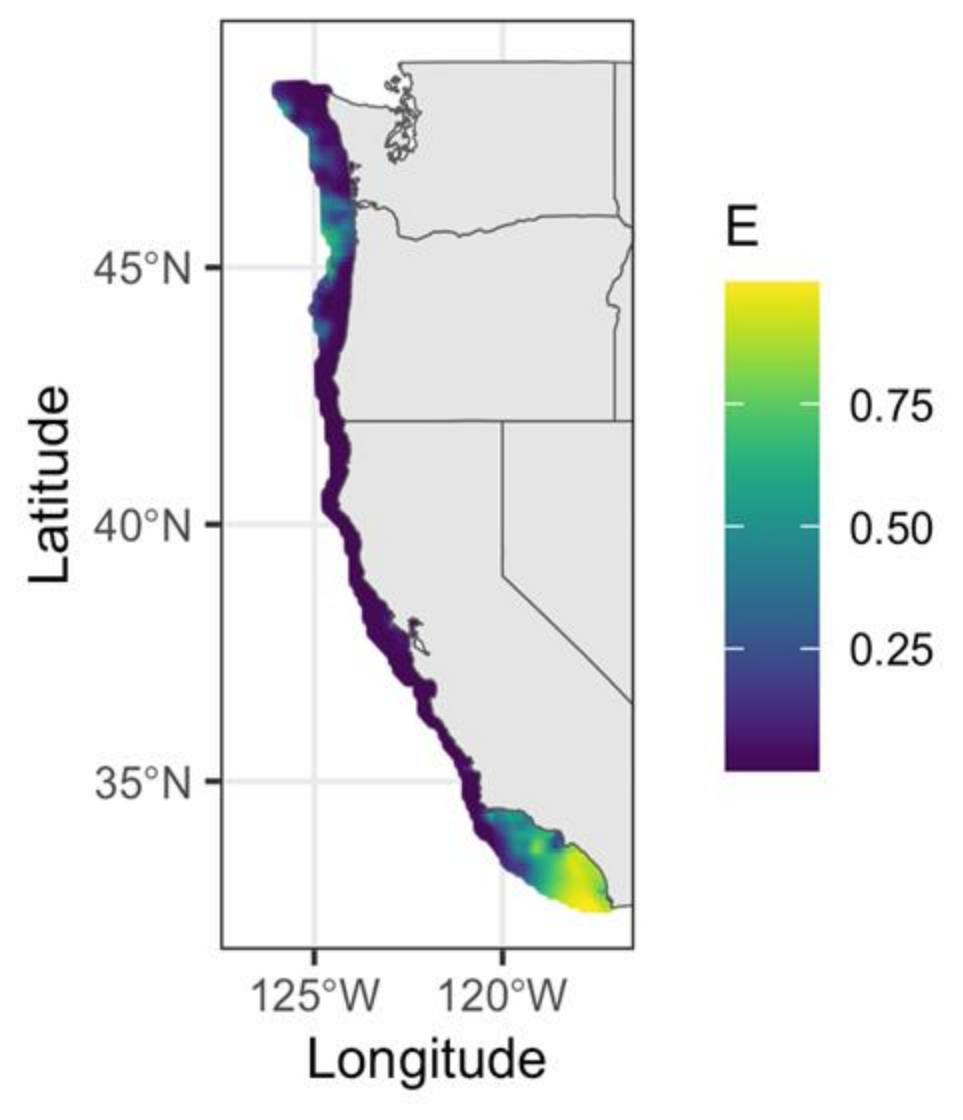
1) Exposure to a stress (E)
   a) Frequency, duration, or probability of encounter
   b) High temperature (T), low dissolved oxygen (DO), low pH (pH)
2) Sensitivity to that stress (S)
   a) Physiological consequences
   b) Often severity-dependent

$$V_{multi} = V_T + V_{DO} + V_{pH}$$

$$V_{MHW} = V_{T\ during\ heat\ waves}$$



Methods: exposure



The proportion of observations from a location below or above a threshold. E.g.:

- T > 12.5°C
- pH < 7.8
- DO < 60 µmol/kg

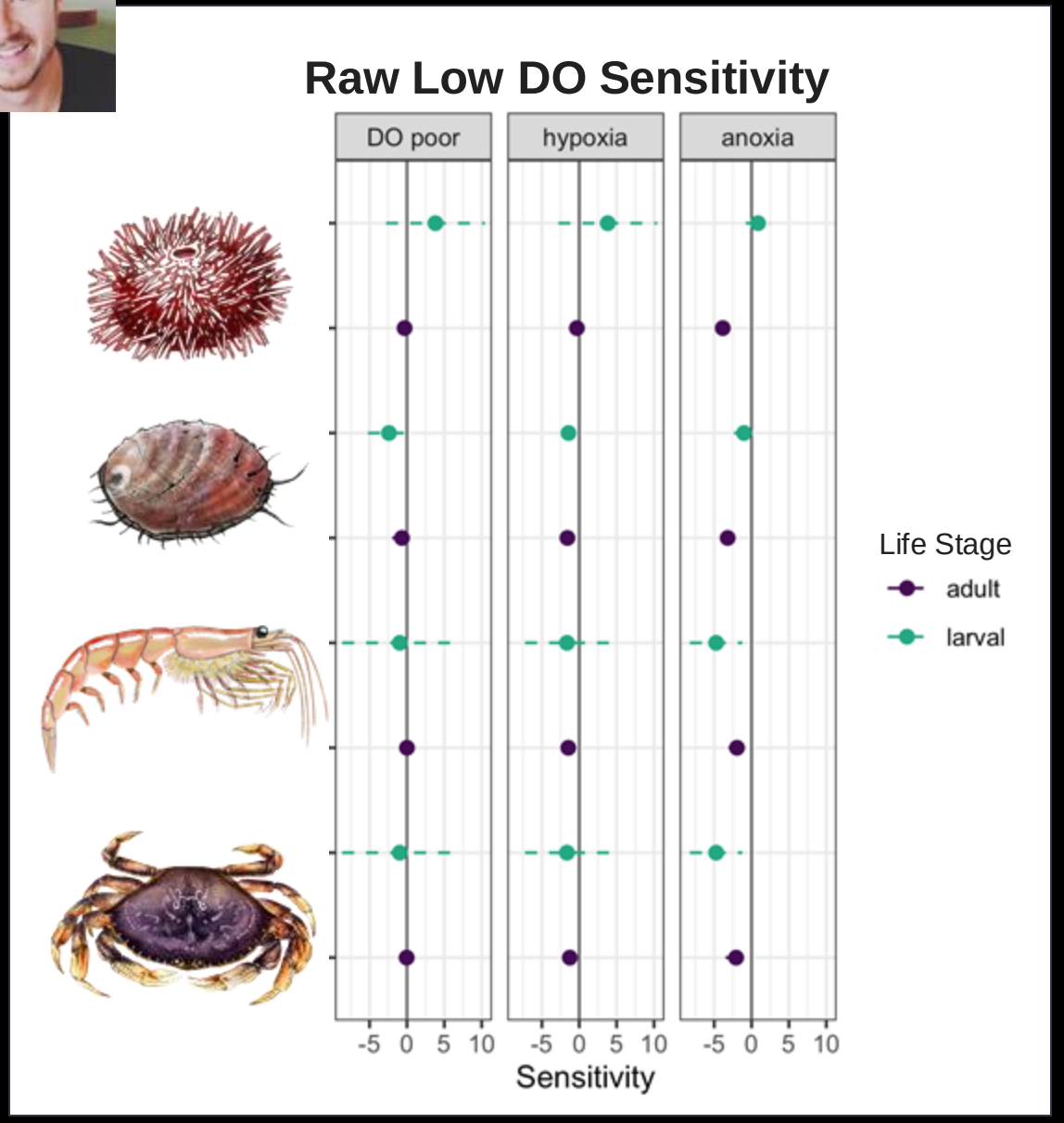
Species- or taxon-specific when possible

No explicit time parameter

Methods: sensitivity

Cumulative negative impacts on growth, fertility, or survival. Scaled from 0 (no reaction) to 1 (catastrophe)

- DO: metanalysis-derived odds ratios to three levels of low DO exposure (intensity).
- pH: metanalysis-derived log response ratios, modified by intensity.
- Temperature: sliding scale from the thermal optimum (no reaction) to critical temperature (catastrophe)



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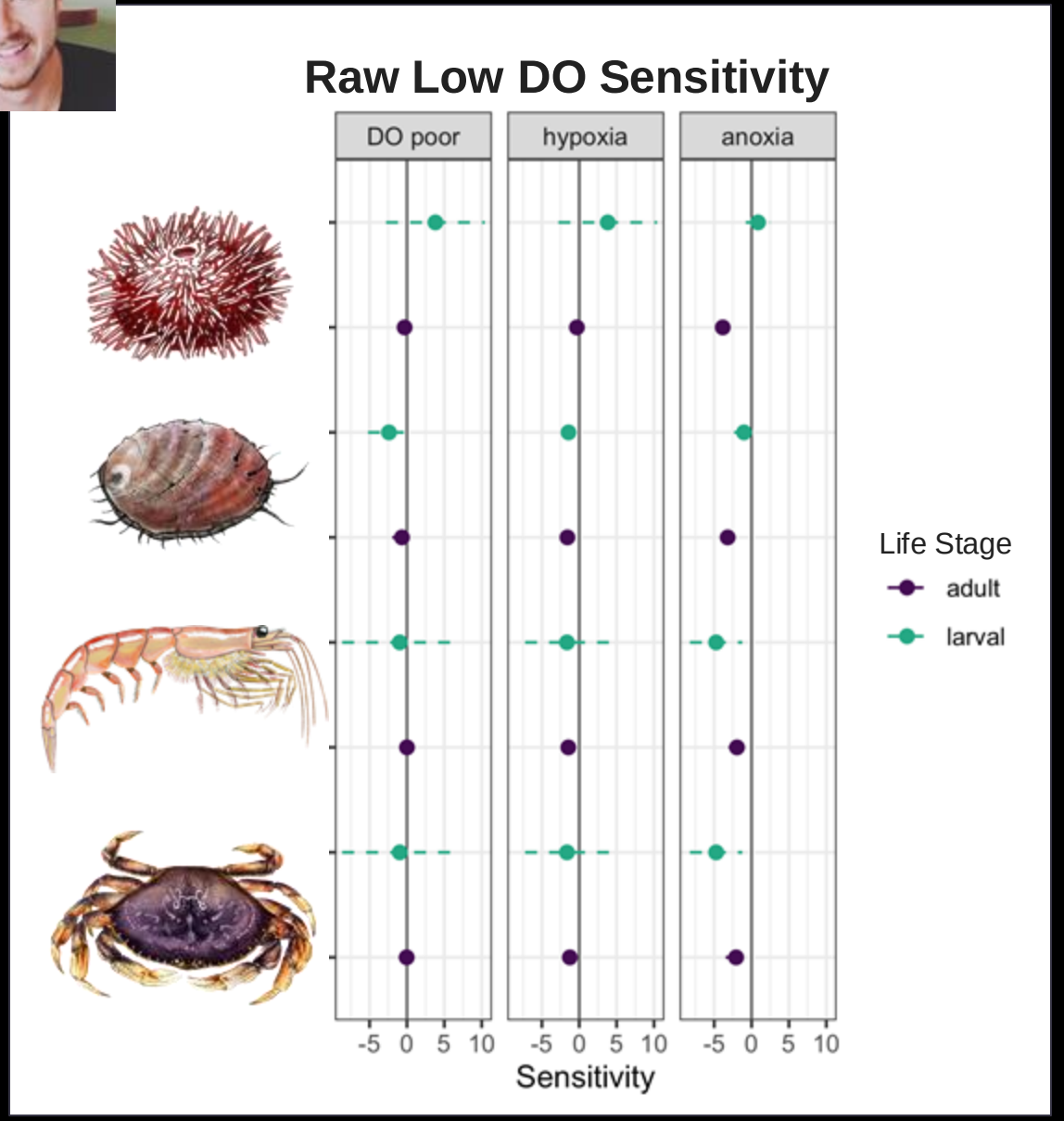

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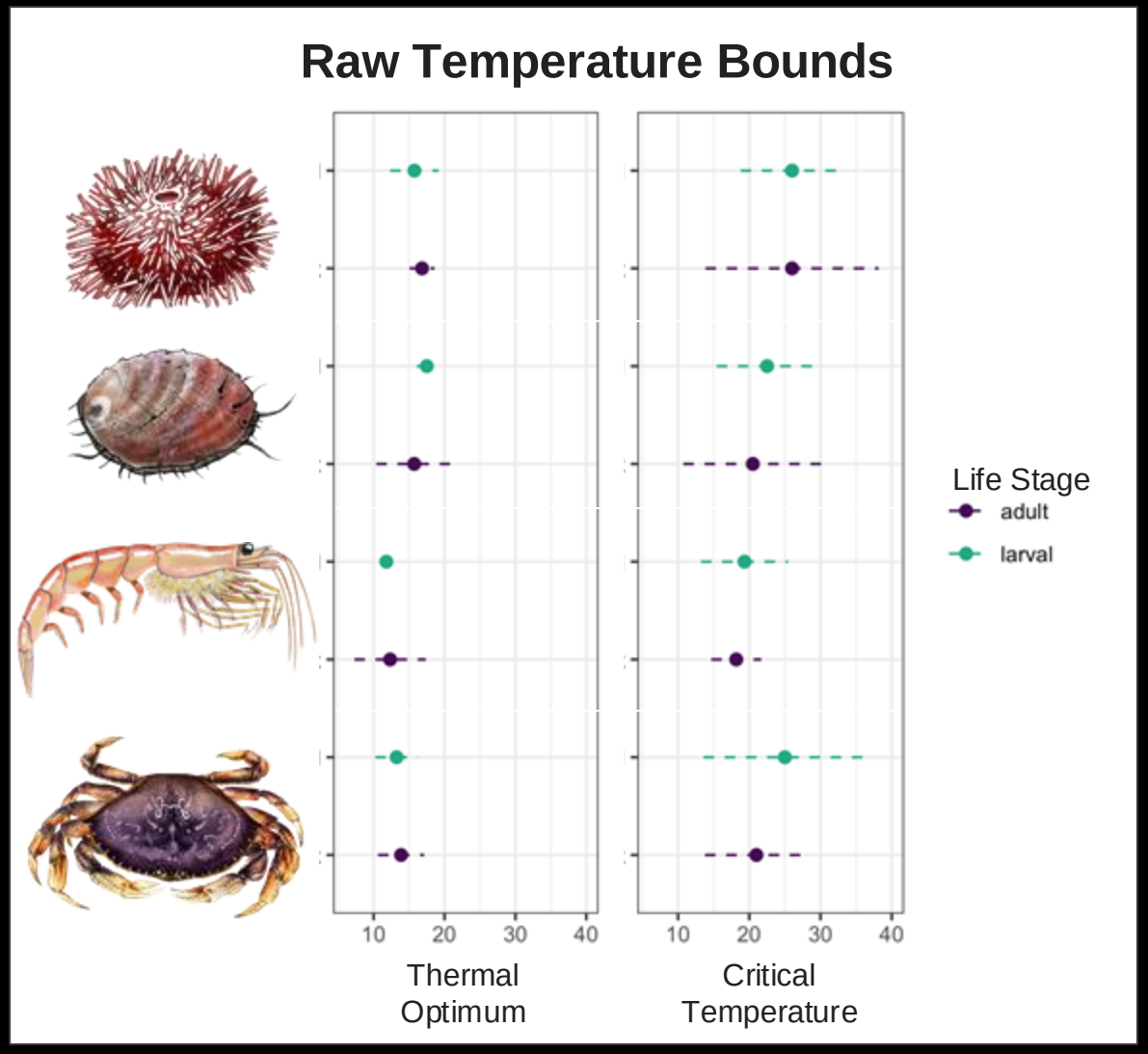
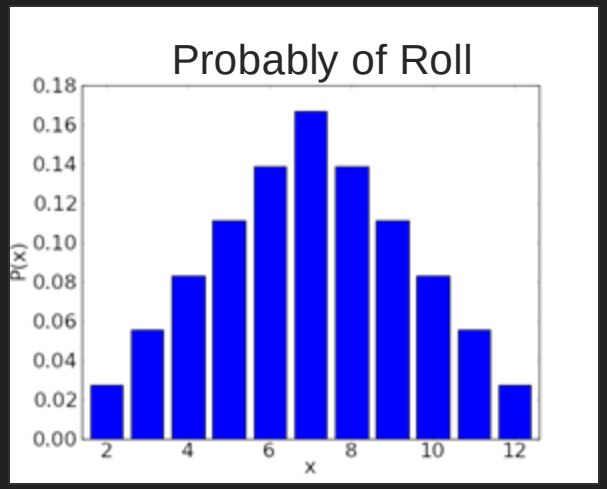
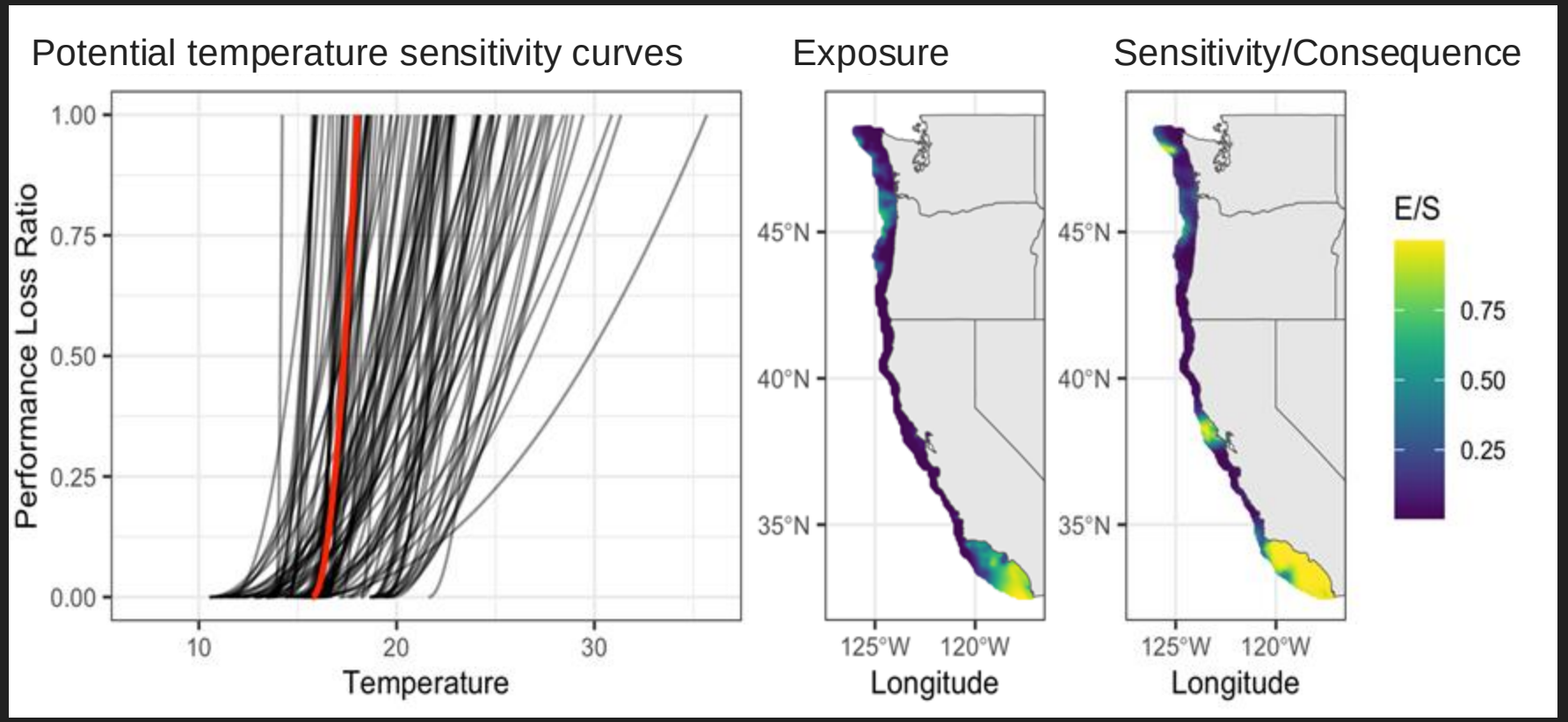


Methods: uncertainty mapping

Uncertainty in sensitivity → uncertainty in vulnerability and (for V_T) exposure.

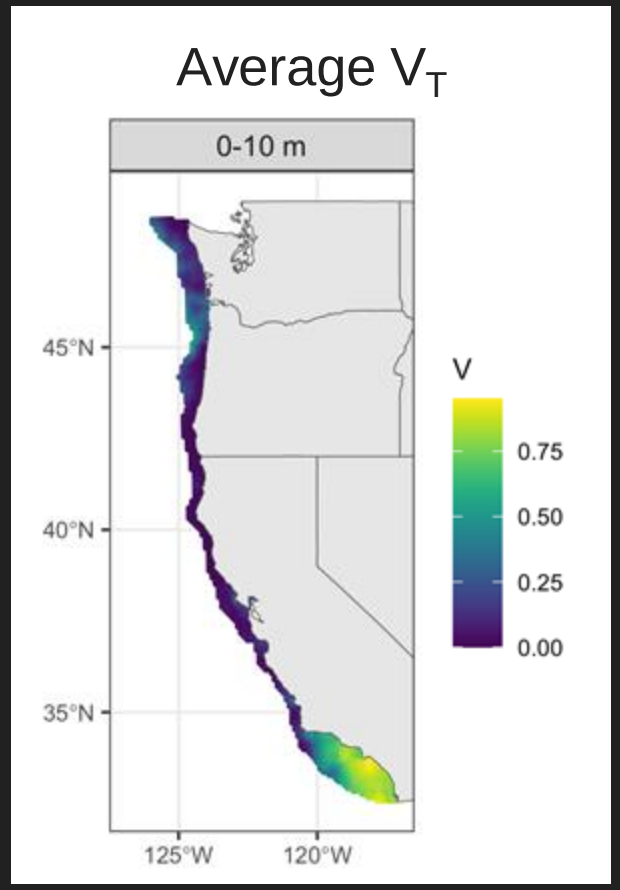
Bootstrapping incorporates the uncertainty by taking random draws to generate an ensemble of possible outcomes.

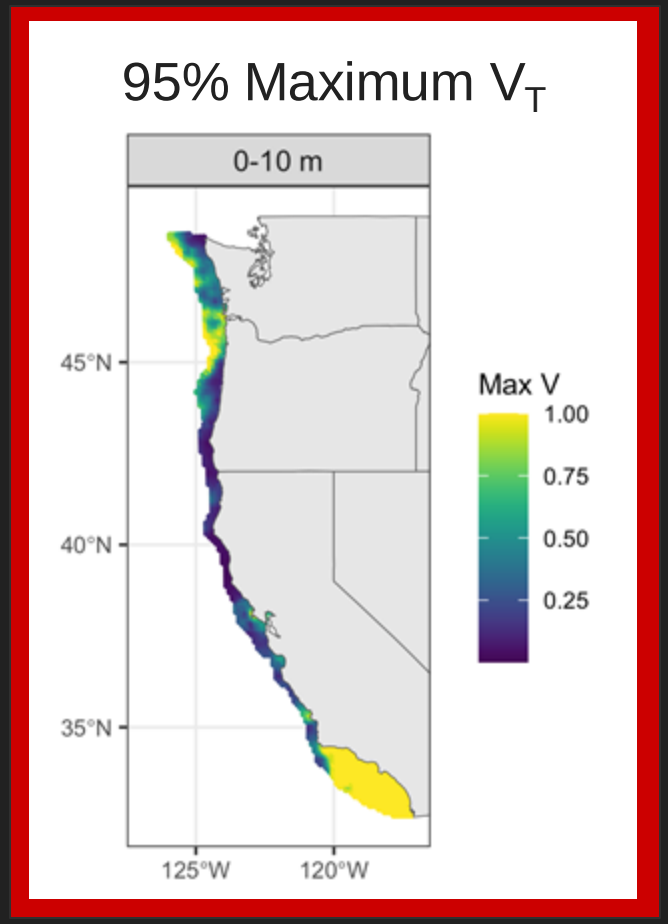


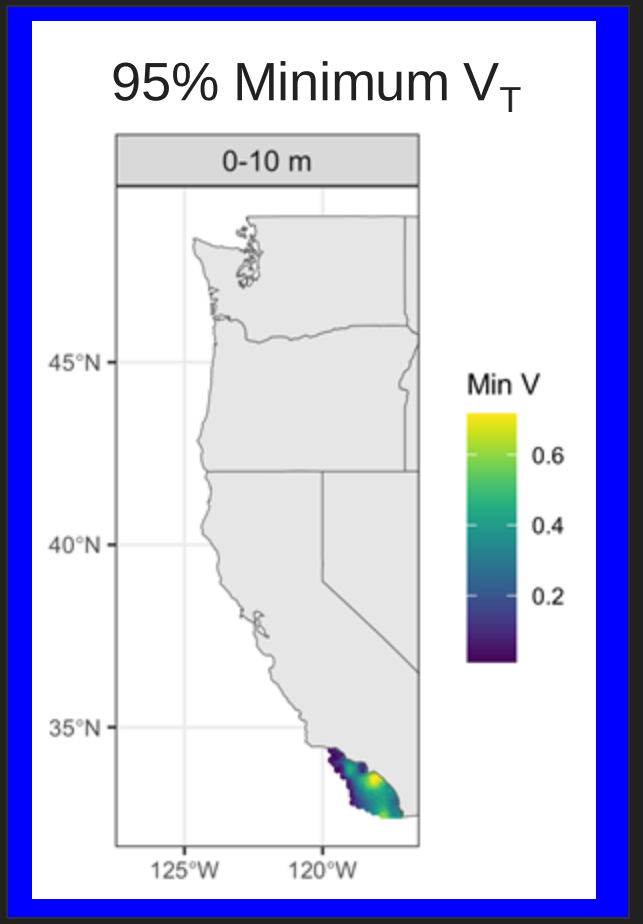


Temperature Vulnerability (V_T)

- V_T is highest in SoCal and surface waters.
- Worst case: PNW has substantial heat risk.
- Best case: SoCal is still dangerously hot.

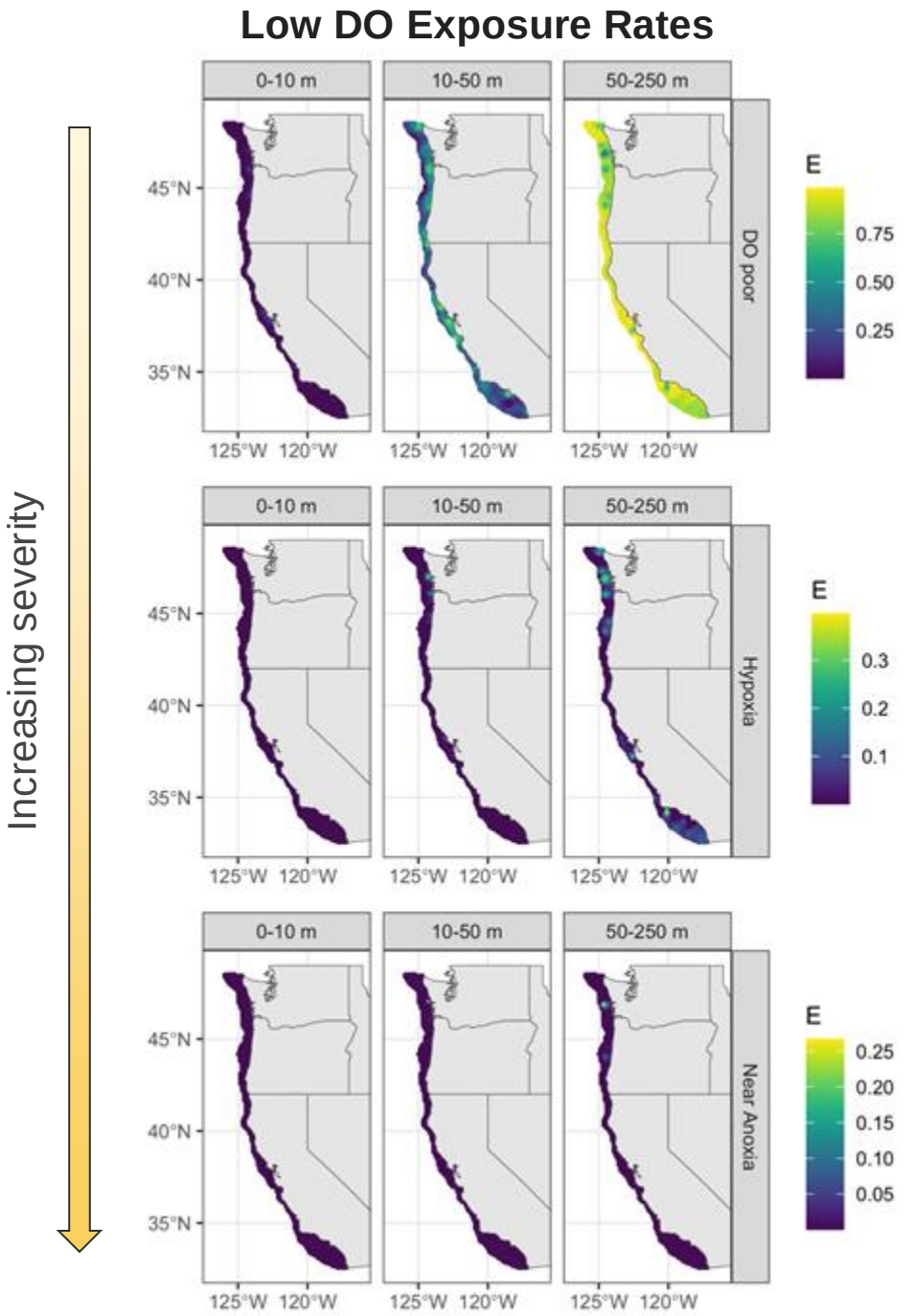






Exposure to low DO and pH

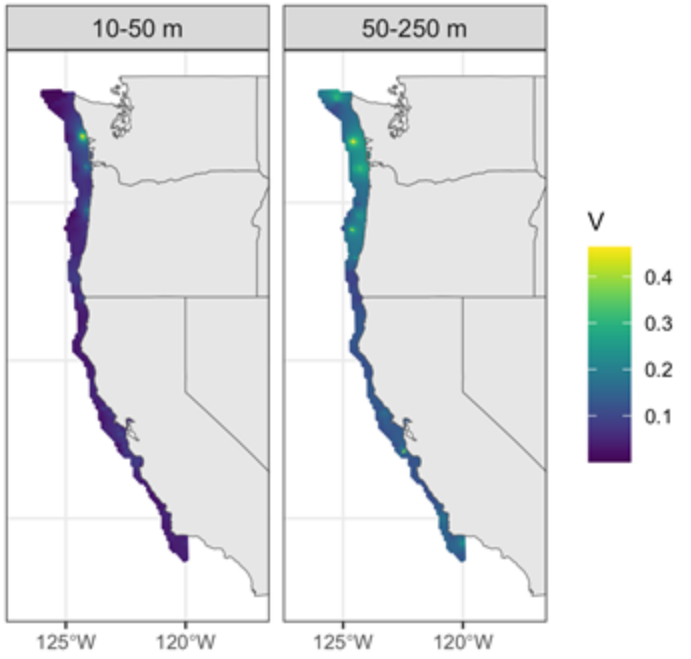
- Exposure increases in deep waters and where seasonal upwelling is strong
  - Pacific Northwest (PNW)
  - Central California
- Only the PNW has substantial exposure to severe low oxygen conditions
- Exposure to low pH closely resembles the “DO poor” maps



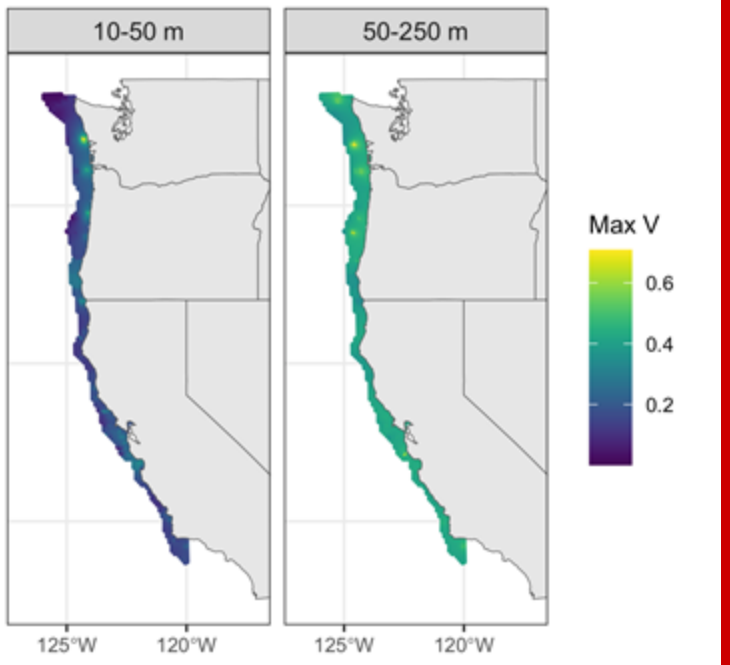
Dissolved Oxygen Vulnerability (V_{DO})

- V_{DO} is highest in subsurface waters in the PNW, low elsewhere.
  - Only region of exposure to severely low (hypoxic or anoxic) DO levels.
- Worst case: Moderately low DO levels are more consequential.
- Best case: highly localized risk.

Average V_{DO}



95% Maximum V_{DO}



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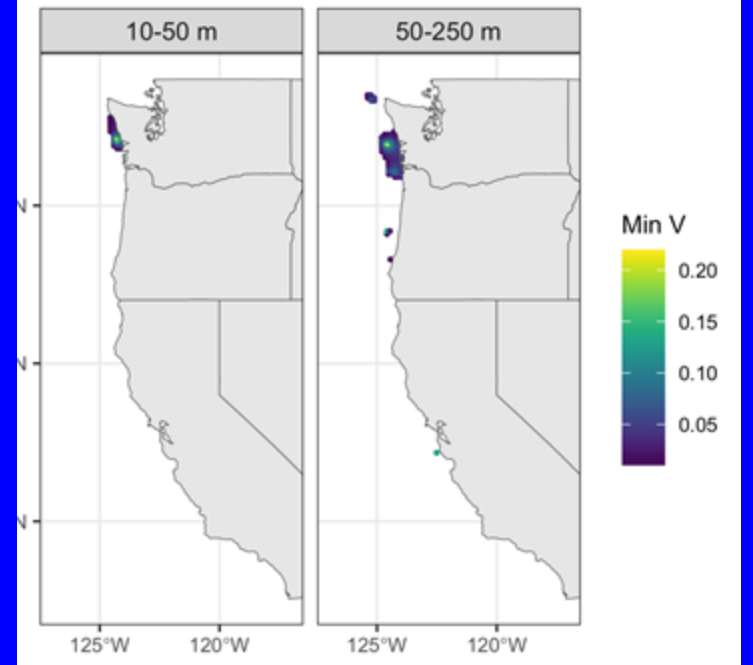
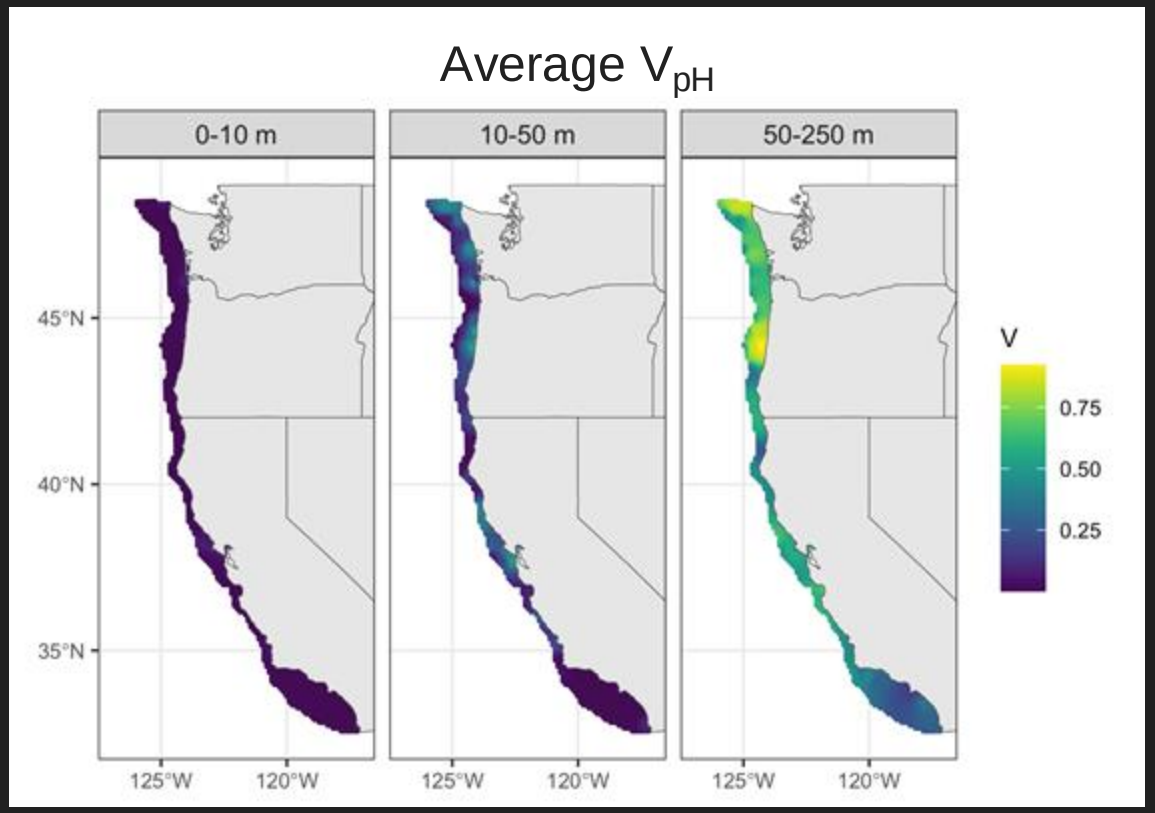
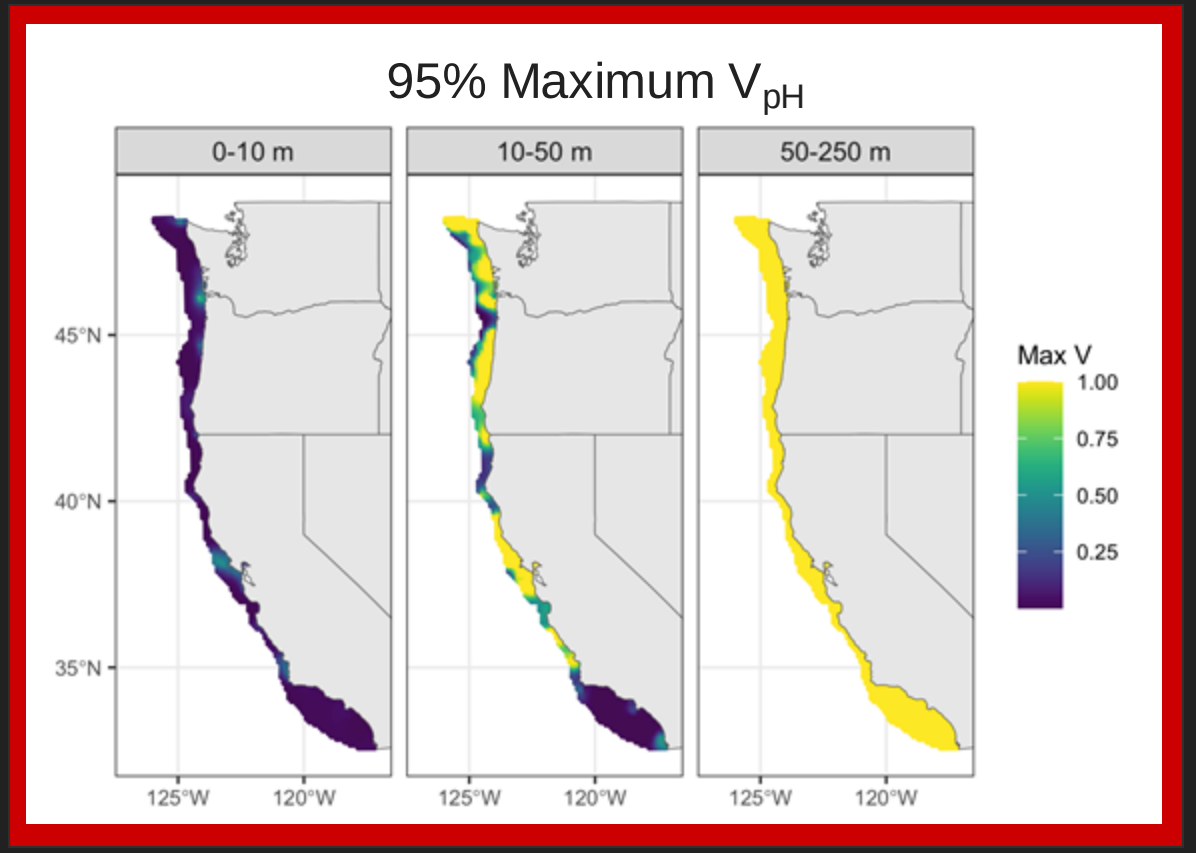


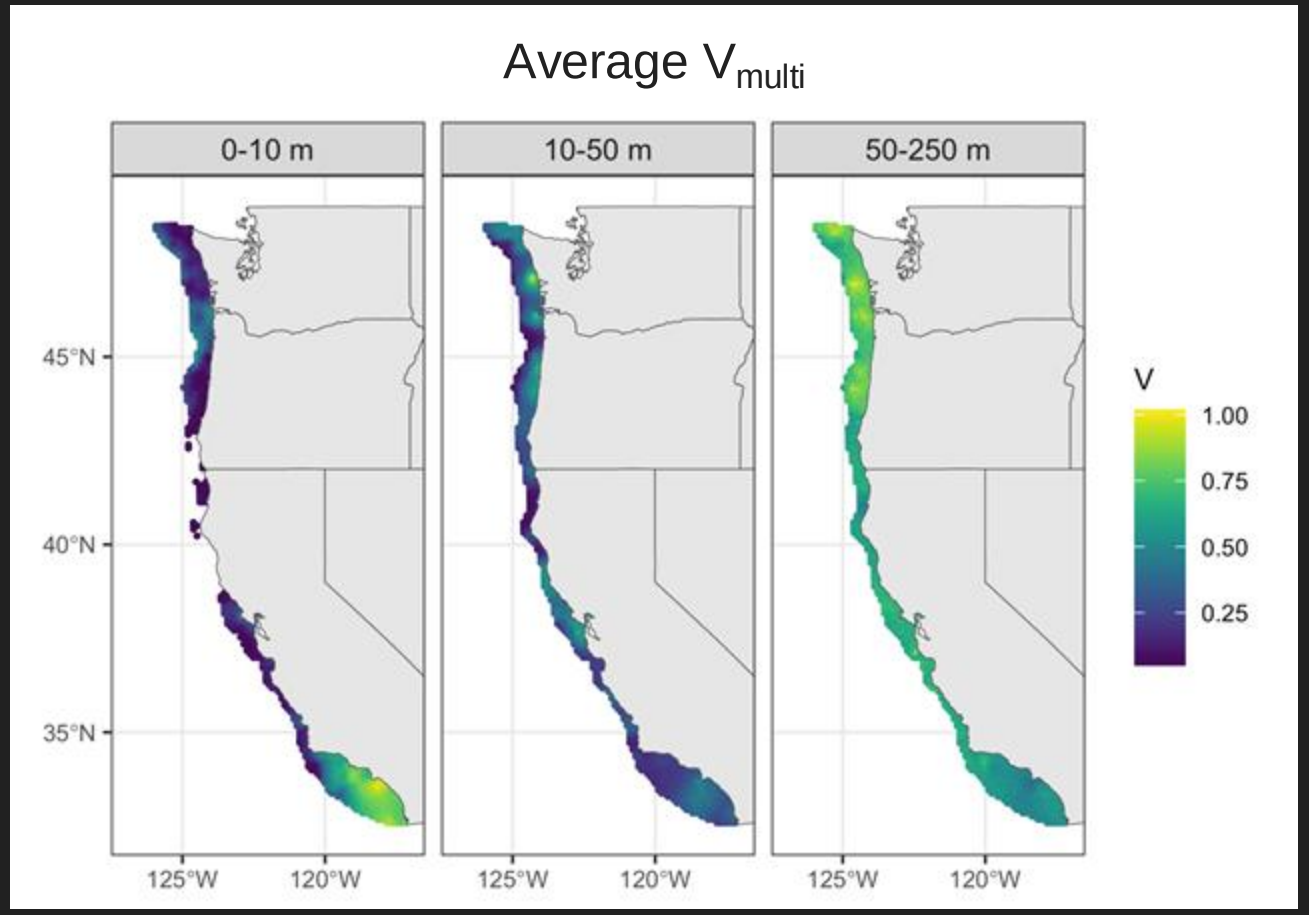
Low pH Vulnerability (V_{pH})

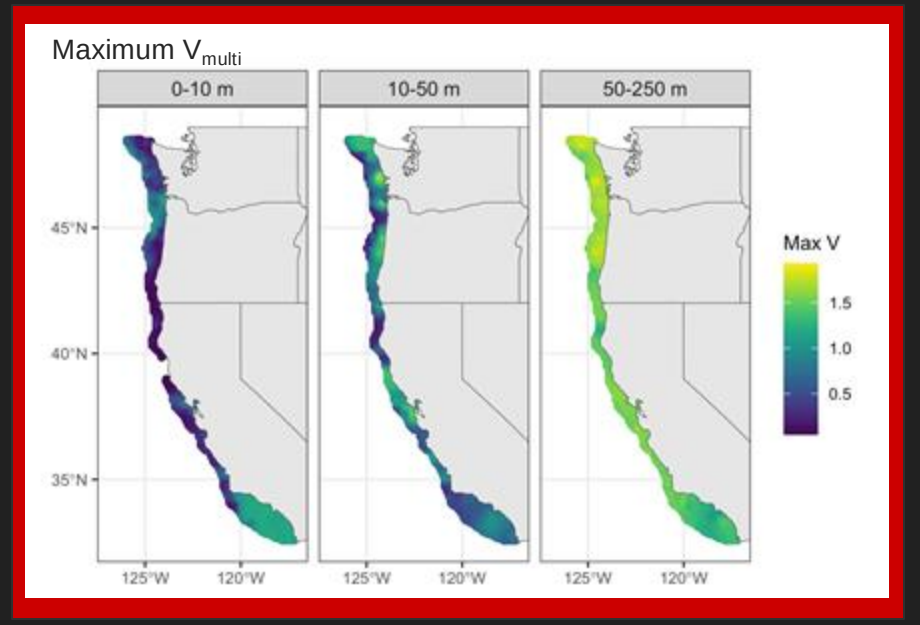
- High vulnerability is ubiquitous in deep waters, clustered in upwelling centers in middle depths.
  - SoCal is a relative refuge.
- Huge uncertainty in krill sensitivity → either catastrophic risk below 10 m depth, or no risk at all anywhere.

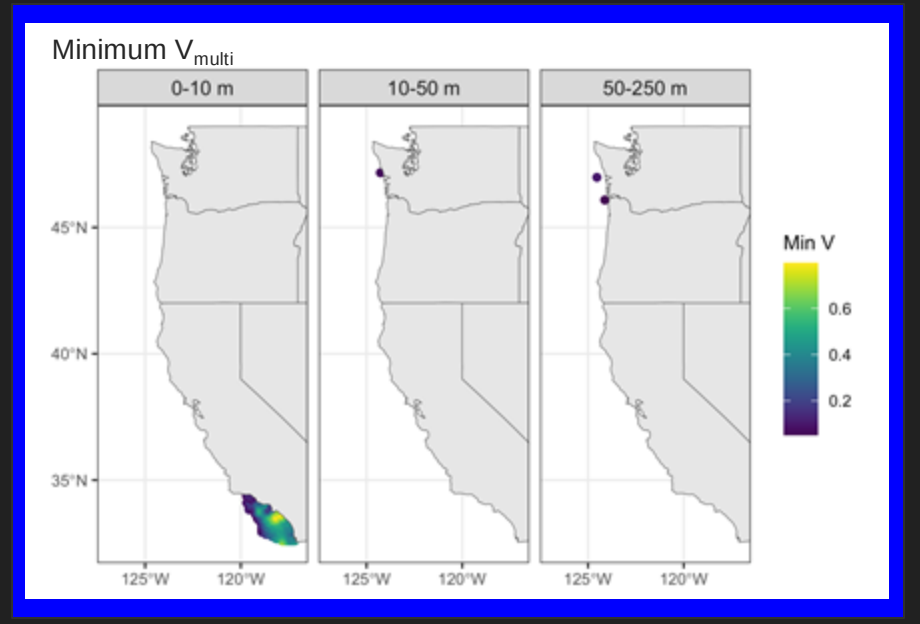




Multistressor Vulnerability (V_{multi})



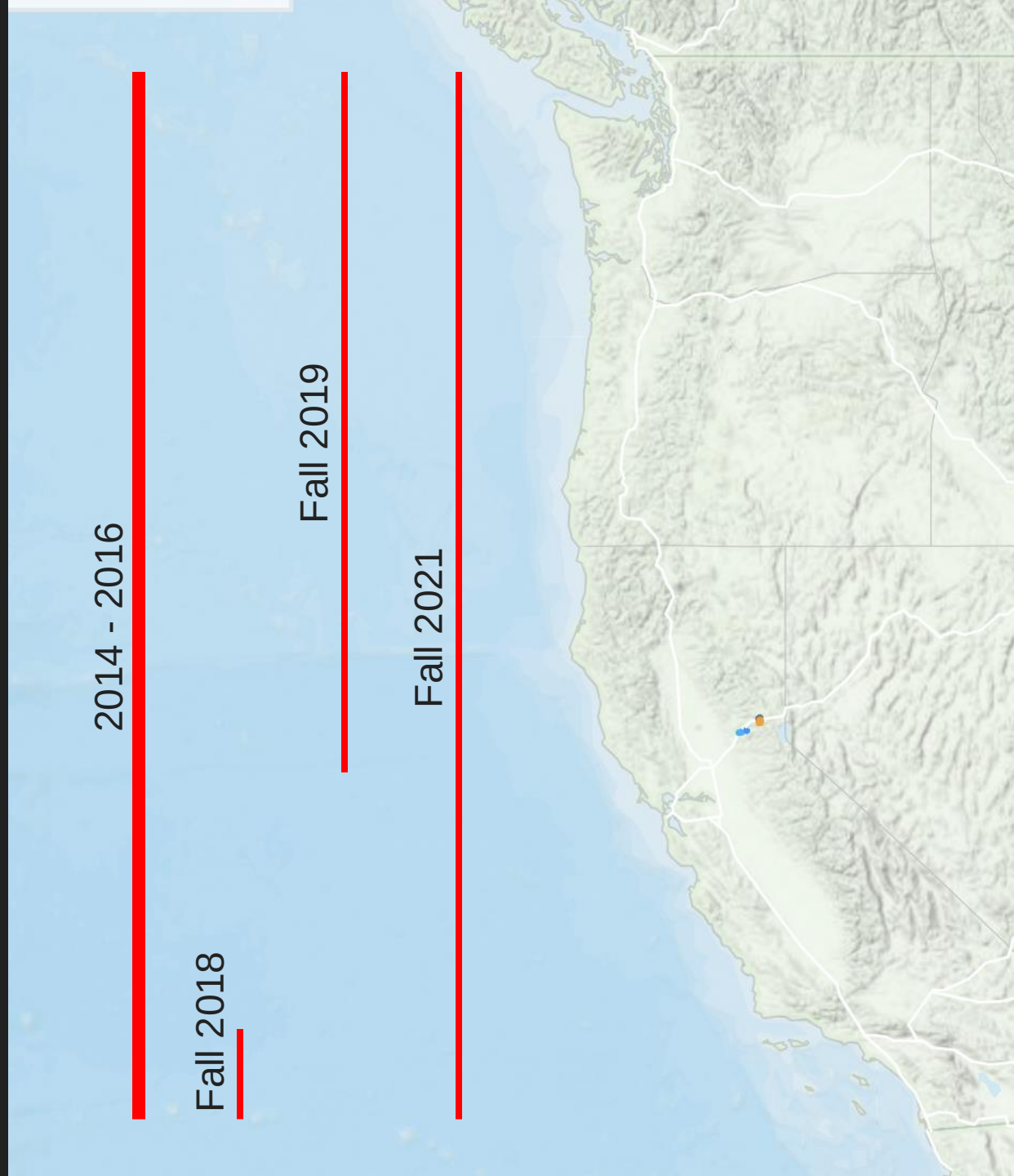




Is V_T a product of MHWs?

- MHW status as defined by the State of the California Current annual reports and NOAA's "Blob Tracker"
- Temperature vulnerability only

How much was temperature overall temperature vulnerability driven by marine heat waves?



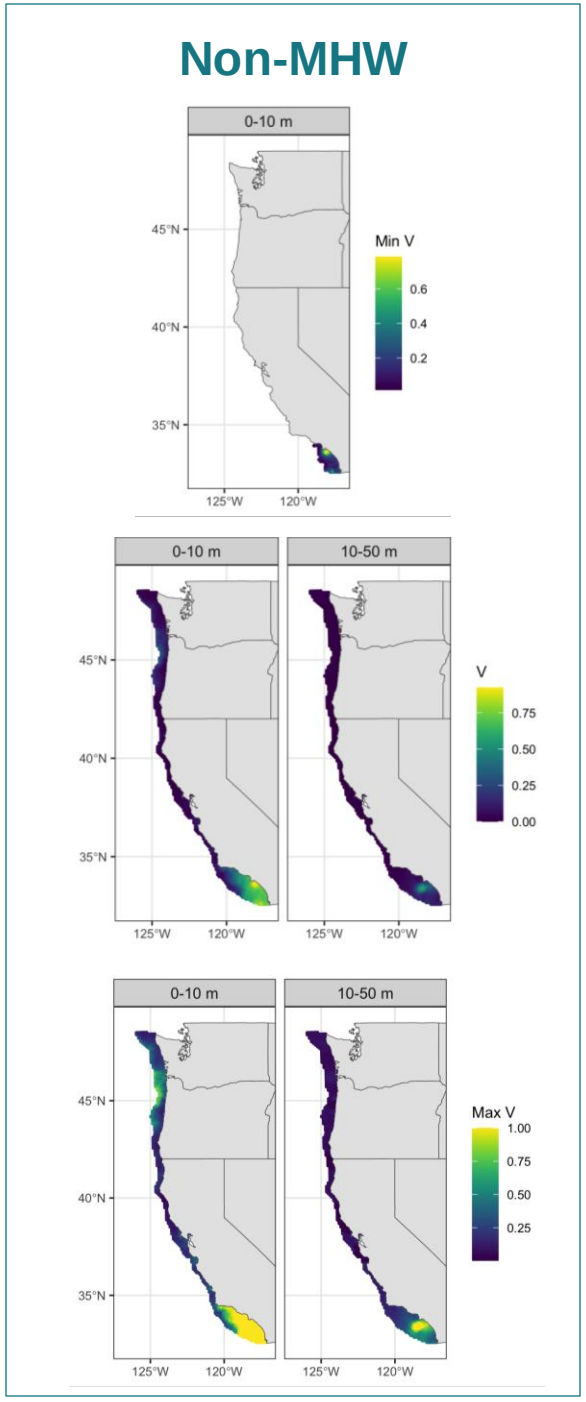
V_T is high even without heat waves

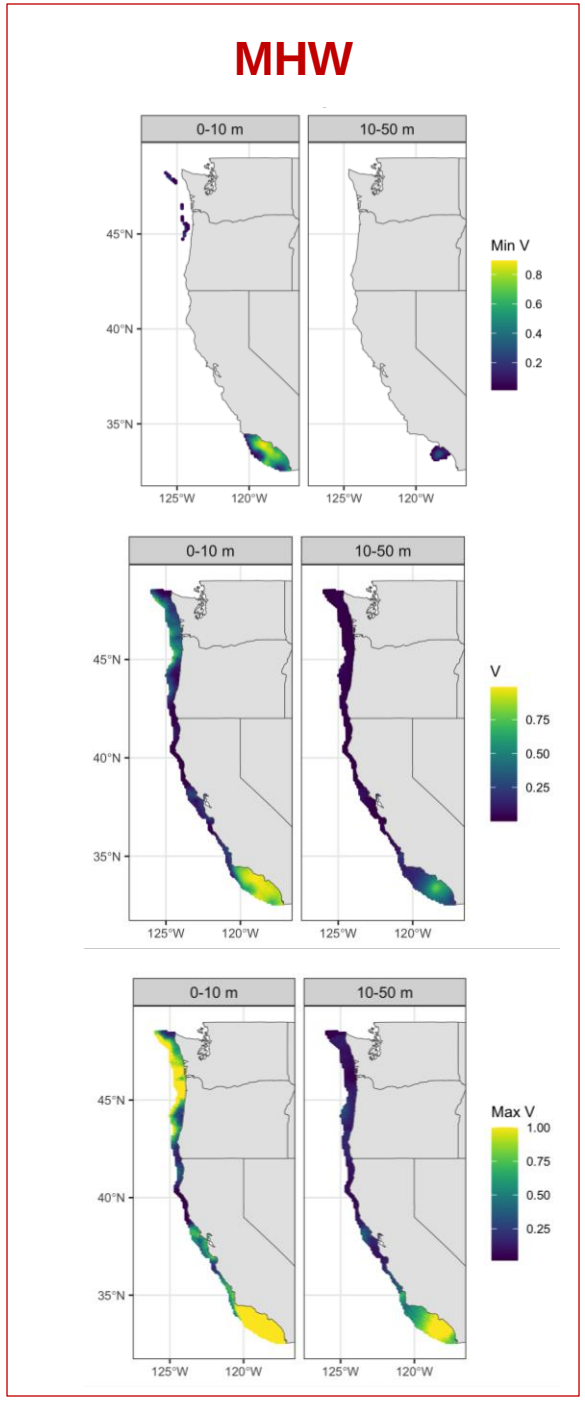
- For temperature-sensitive species, the status quo is already hot.
- Large changes are limited to surface waters but…
  - The localized increase in heat stress at mid-depths is likely more important.
- Spatial extent of catastrophic maximum risk is much larger.

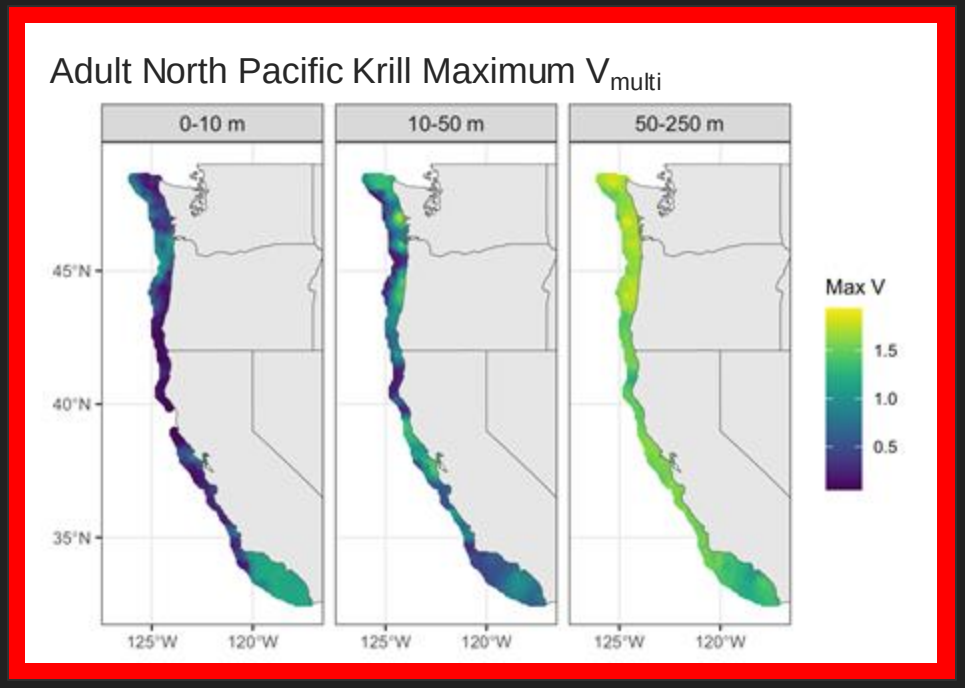
Minimum V_T

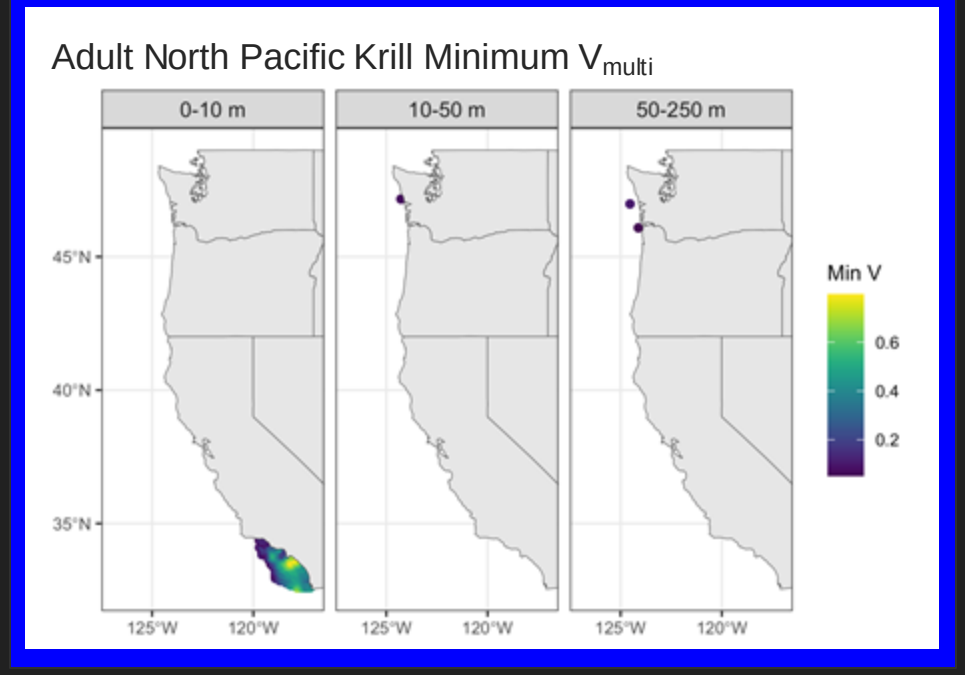
Mean V_T

Maximum V_T









Risk and information tradeoffs

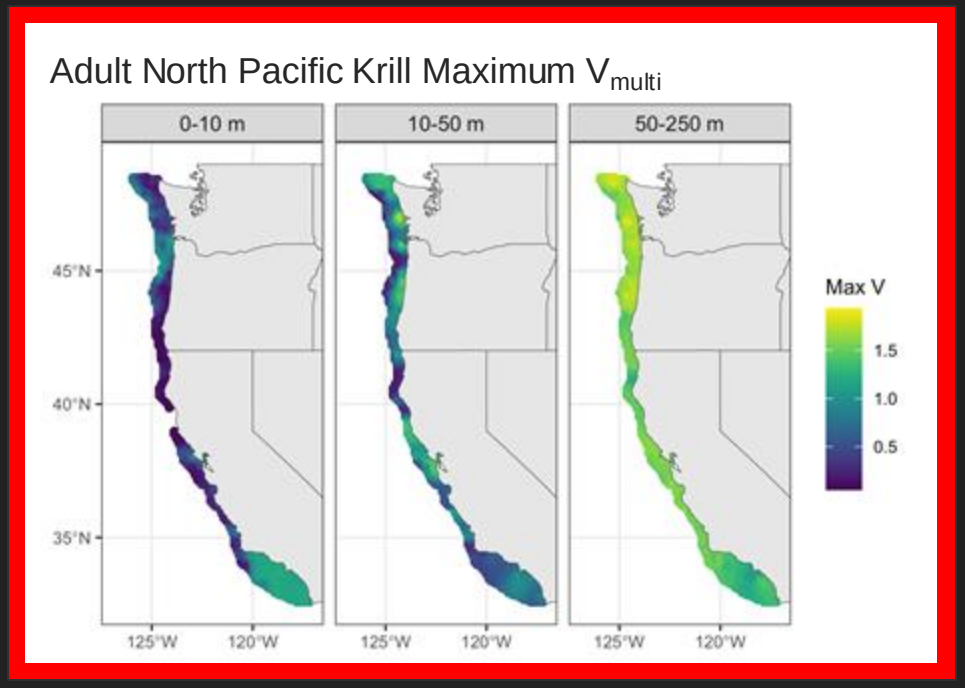
1) Avoiding one stressor can mean exposure to others.

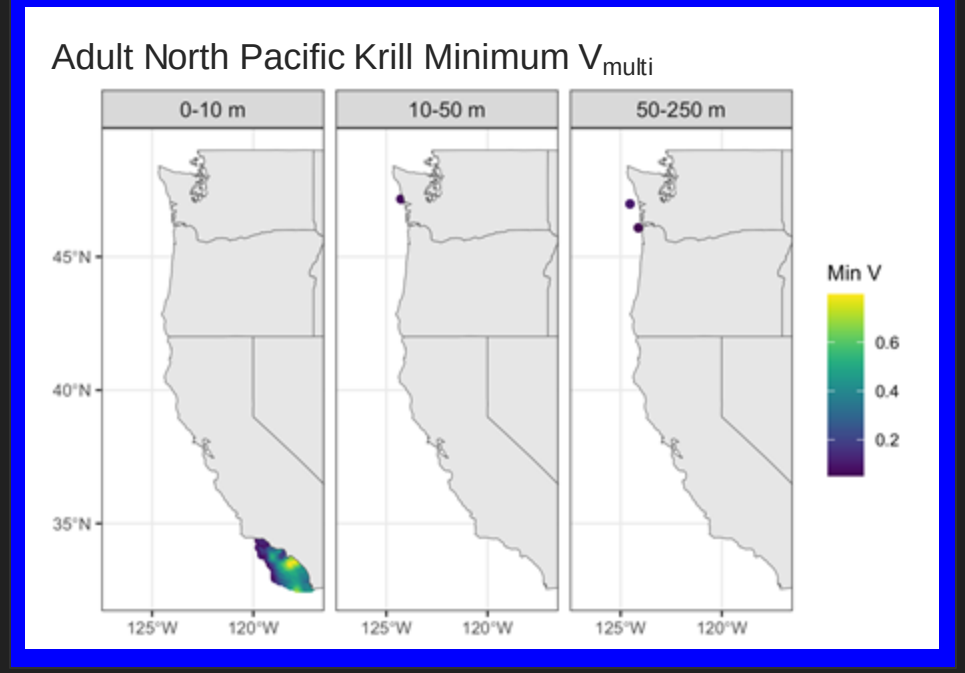
2) Uncertainty in drives extreme changes in the geography and magnitude of expected stress.

3) Reducing fundamental uncertainty is difficult.

- Better constraints on sensitivity are more valuable than oceanographic certainty.
- Specificity reduces both sensitivity uncertainty and applicability.

4) MHWs magnify risk and uncertainty, but do not control V_T.





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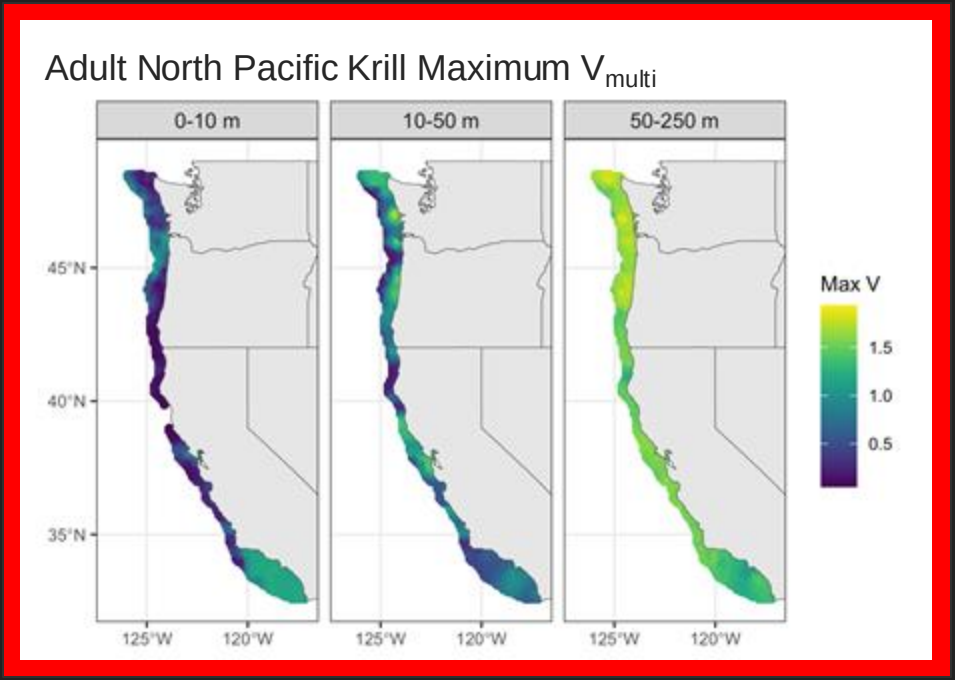

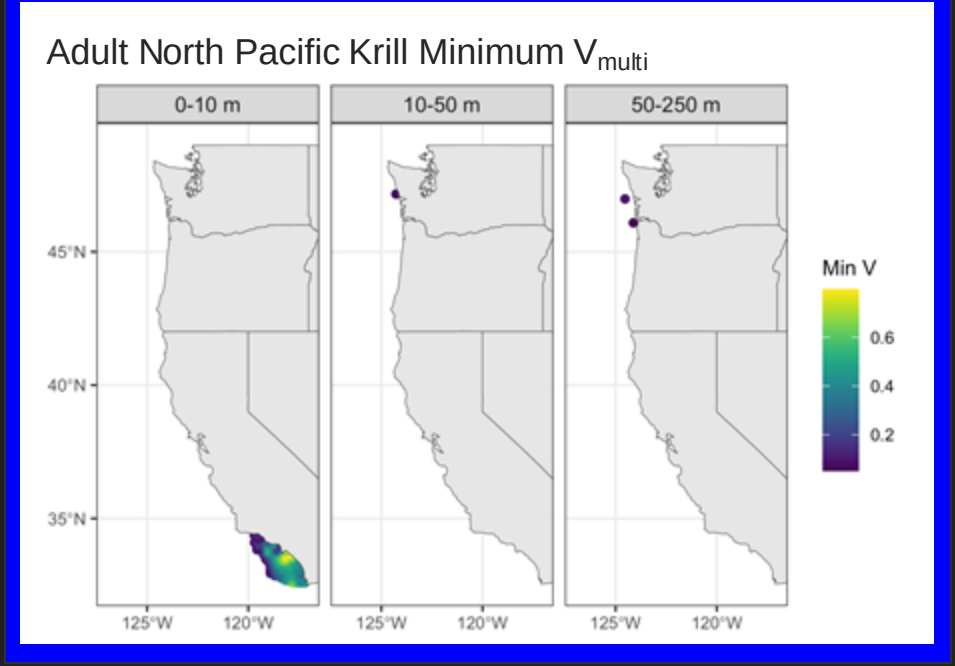

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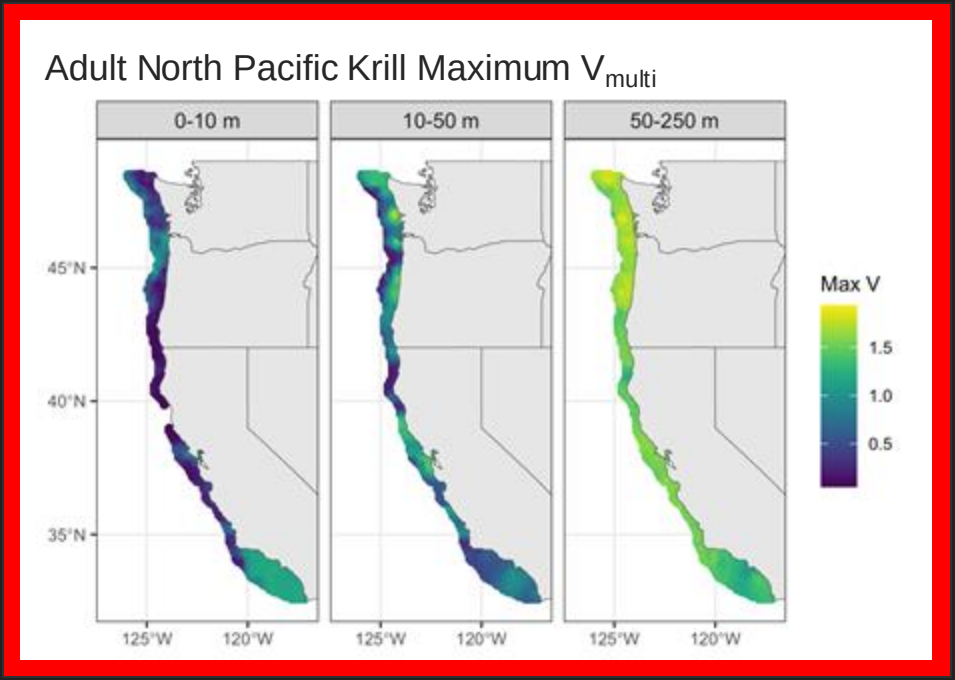

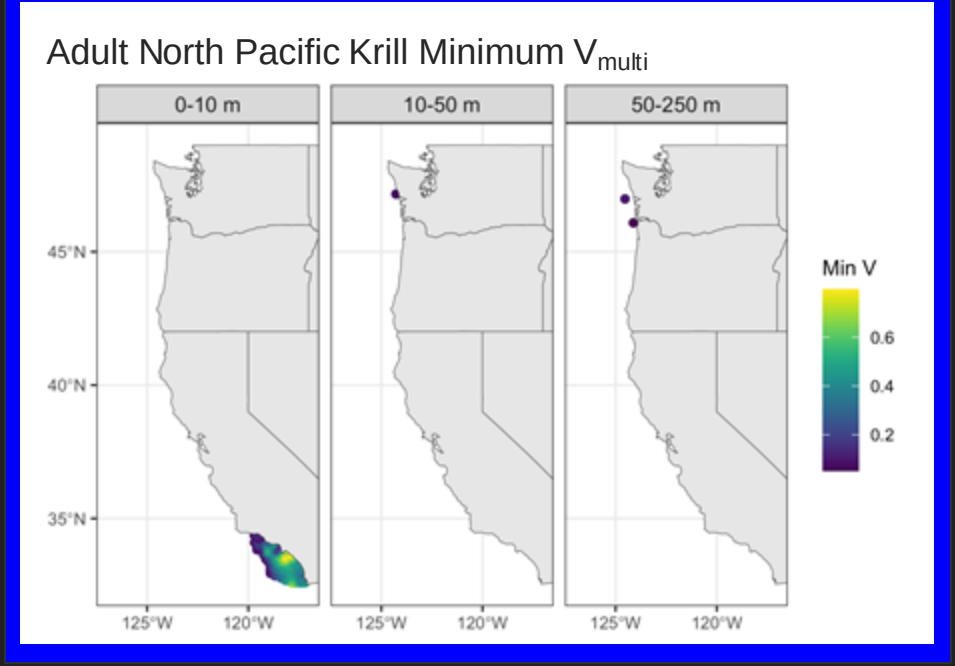

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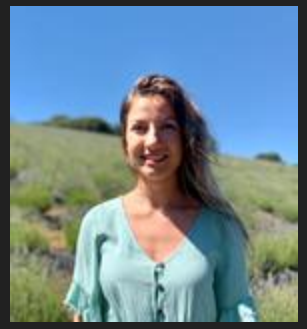

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