Synthesis of Thresholds of Ocean Acidification Effects on Pelagic Mollusks

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August 23, 2018

Challenges in Using Ocean Plan for OA

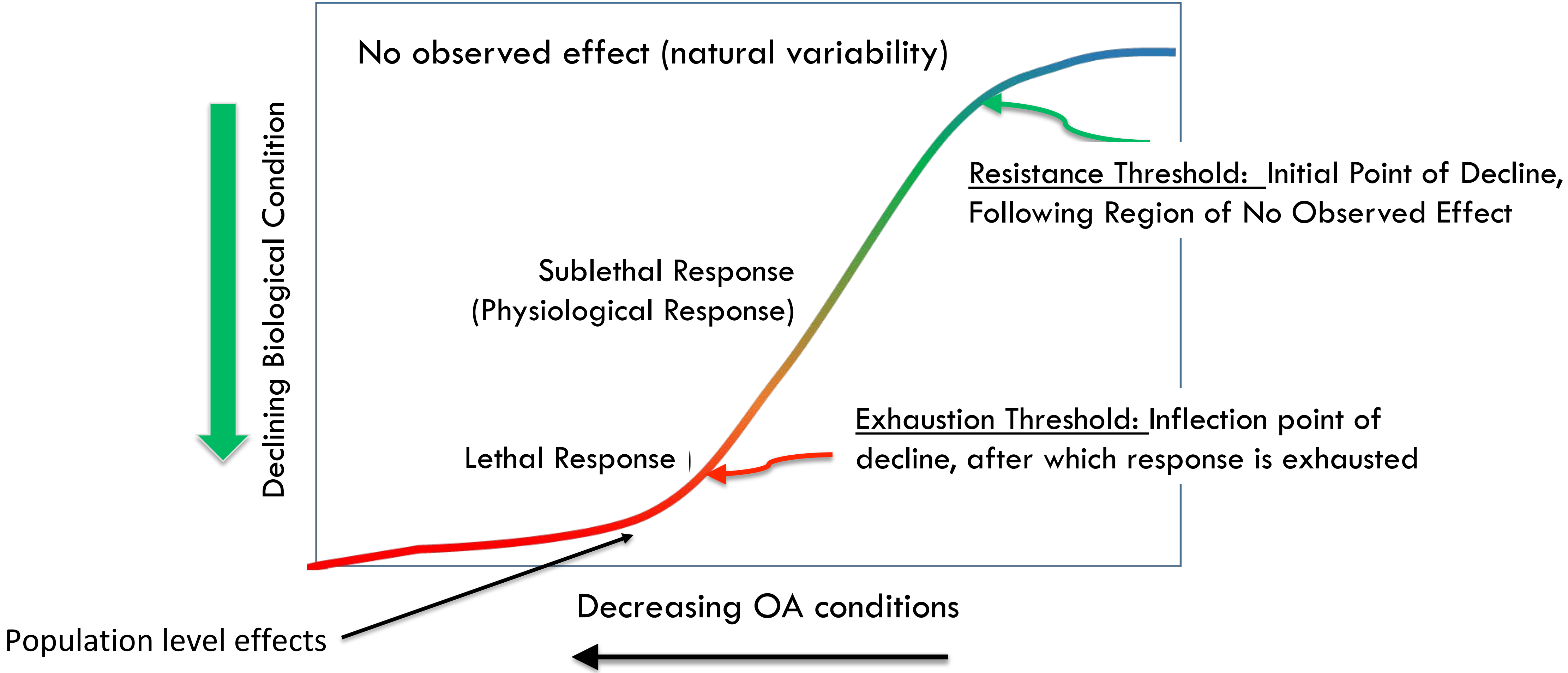
Use biologically relevant endpoints!

Complex process - How to go about this?

Biologically–Relevant Acidification **Endpoints** : Key Questions

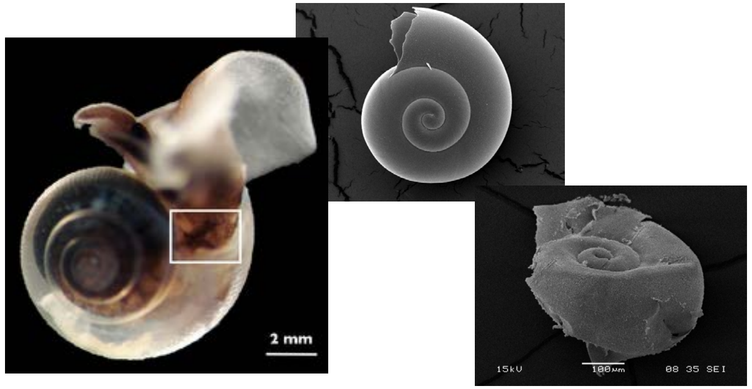
- Which **taxa** to select? What **habitats** do they represent?
- What is temporal basis for thresholds? Consider **magnitude, duration** and **frequency of exposure**
- How do we deal with **multiple stressors**?
- How can we translate this information from **individual** to **population level** effects?

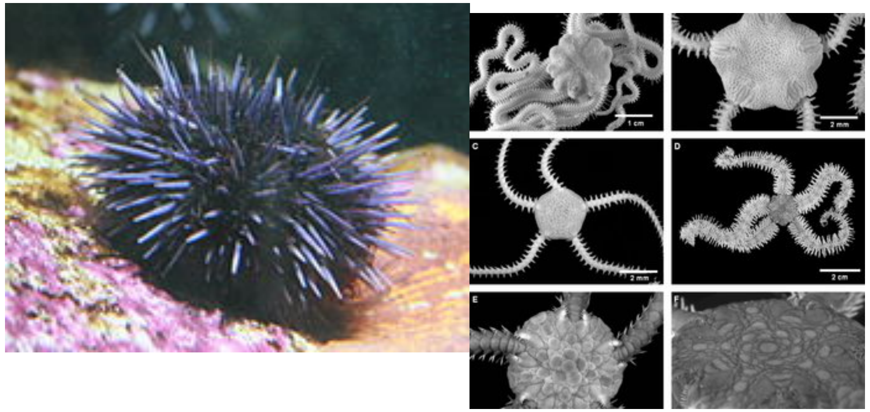
A Key Graphic that Shows **Ranges of Response**

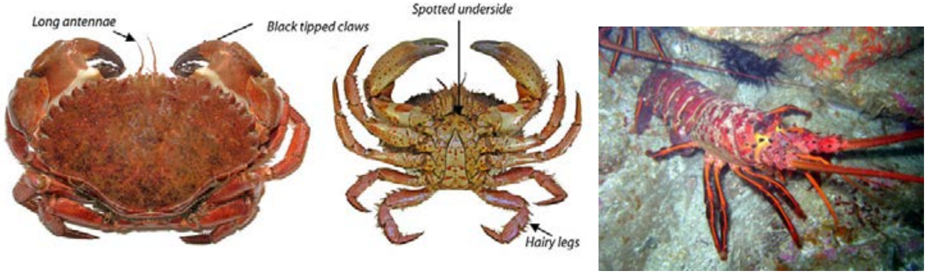


Selection of Three Focal OA Taxa and Their Habitats

Taxa	Habitat
Pteropods	Pelagic Calcifying Zooplankton (0-500 m)
Echinoderms	Shallow to deep-water; pelagic and epibenthic ecological importance
Crustaceans	Shallow to deep-water pelagic and epibenthic' commercial importance

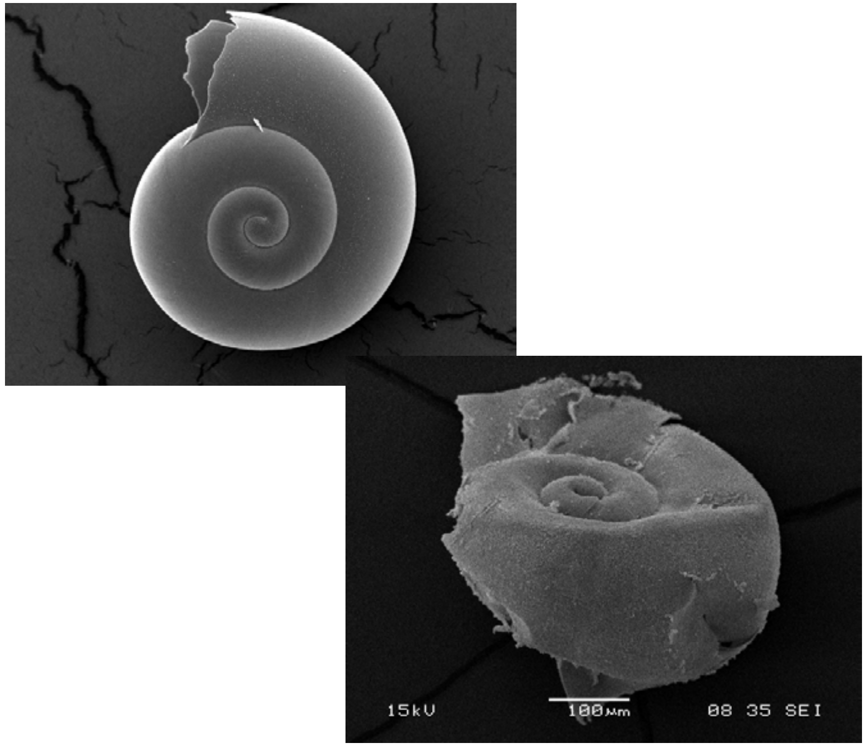


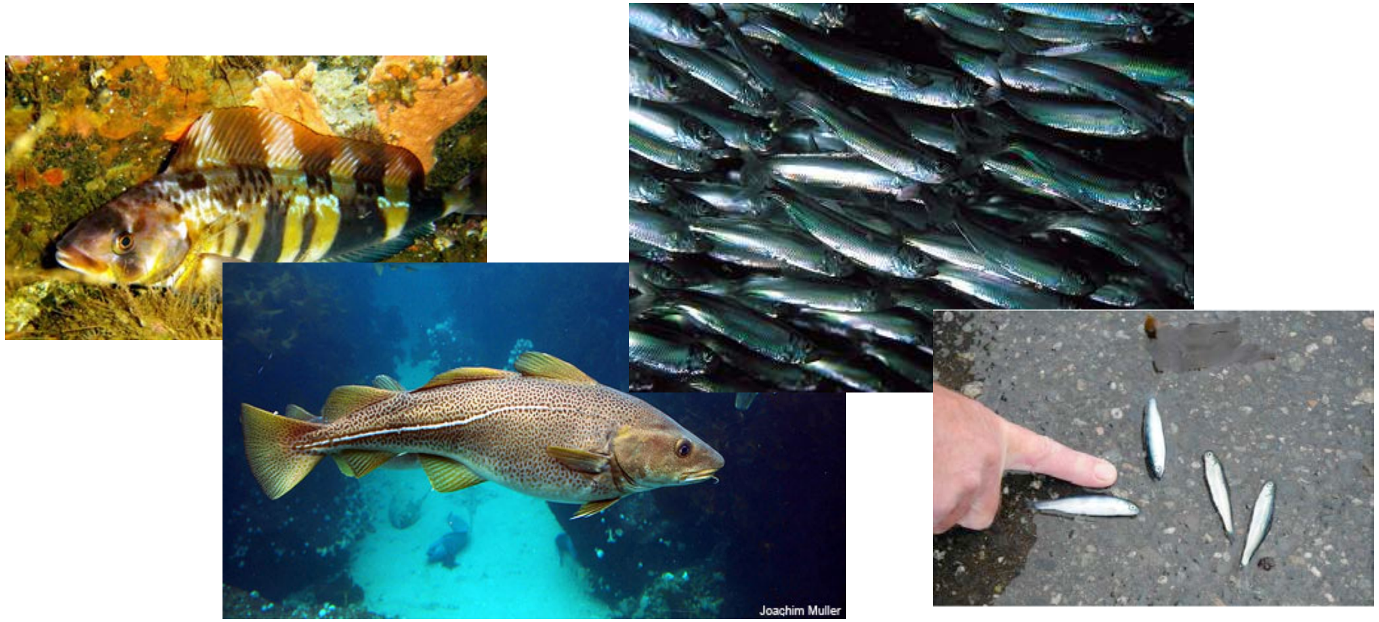




Why Pteropod as Focal Taxa?

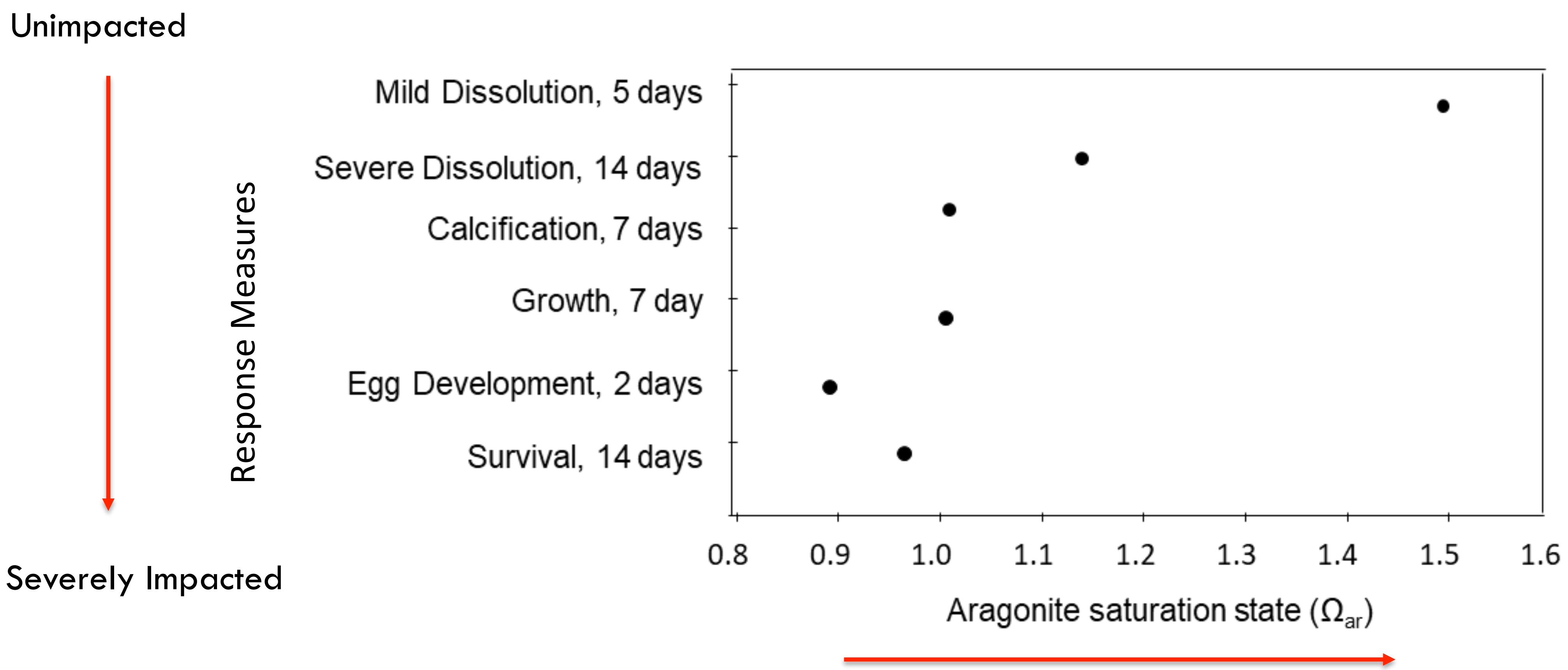
- Pteropods satisfy all the parameters in the decision criteria
  - Pelagic indicators
  - Extreme sensitivity to OA (shell dissolution)
  - Wide-spread distribution and ecosystem role





We Have This Key Graphic for Pteropods!

6 Thresholds with Magnitude and Duration



How did we arrive at this graphic ?

We Are Undertaking a Synthesis of Thresholds With a 4-step Approach

Sequential steps:

- Data collection and literature review
- Meta-analyses
  - simplification of the responses, exclusion or combination of responses
- Breakpoint analyses
  - Identification of thresholds
- Expert consensus

1st Step: Data Collection and Literature Review

- Global data compilation and synthesis to identify:
  - Which stress response measures are reported?
  - Which OA parameter best described stress response measure?
  - Confounding factors (life history, species)

We Have An Abundance of Data Supporting Derivation of Pteropods Thresholds

Pteropod responses to Ocean Acidification:

- *18 studies and 3k data points*
- *22 different response measures!*

Aragonite Saturation State Identified as the Best Measure of OA Stress

- Which OA measure to use?
- All of experiments measured responses against Ω_{ar}
  – experts confirmed that this is the best measure of stress response

- The range of experimental conditions represent the existing gradients in the CCS

Compiled Studies Featured 22 Various Response Measures

N	Type of effect	Response Measure	Units
1	Exposure	Individuals affected by dissolution	%
2		Surface Shell Dissolution	%
4		Deeper shell dissolution	%
5		Transmittance	%
6		Opacity	%
7	Physiological	Calcification as % Glow	%
8		Growth: diameter	mm
9		Growth: percent	%
10		Larval Growth	µm
13		Eggs Produced	$\#\cdot individual^{-1}$
14		Development Impairment	%
15		Egg organogenesis	%
16		Shell Length	µm
17		Dry mass	µg
18		Diameter	µm
19		Swimming Capacity	$cm\cdot s^{-1}$
20		Calcification	µmol CaCO3· $(g*h)^{-1}$
21		Respiration	µmol O2· $(mg\ WW*h)^{-1}$ µmol O2· $(g\ DW*h)^{-1}$
22		Excretion Rate	µmol N· $(g\ DW*h)^{-1}$
24		Gut Clearance	$1\cdot h^{-1}$
25	Lethal	Larval Survival	%
26		Survival	%

- Abundance, but…great complexity!
- Different measure for the same category of effects
- Different units
- Reduce down the amount of response measures
  - What to exclude or combine?

Meta-analyses Simplifies the Complexity of Responses

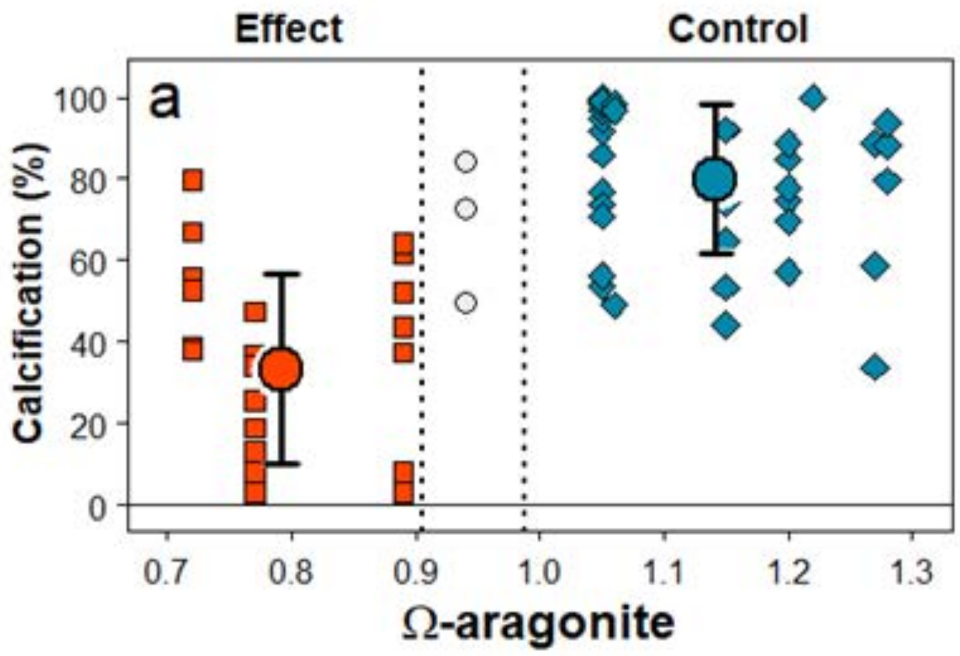
What is it?

- Statistical technique that summarizes the results of primary studies, and identify **patterns** across the large **variable** datasets.

We used it for:

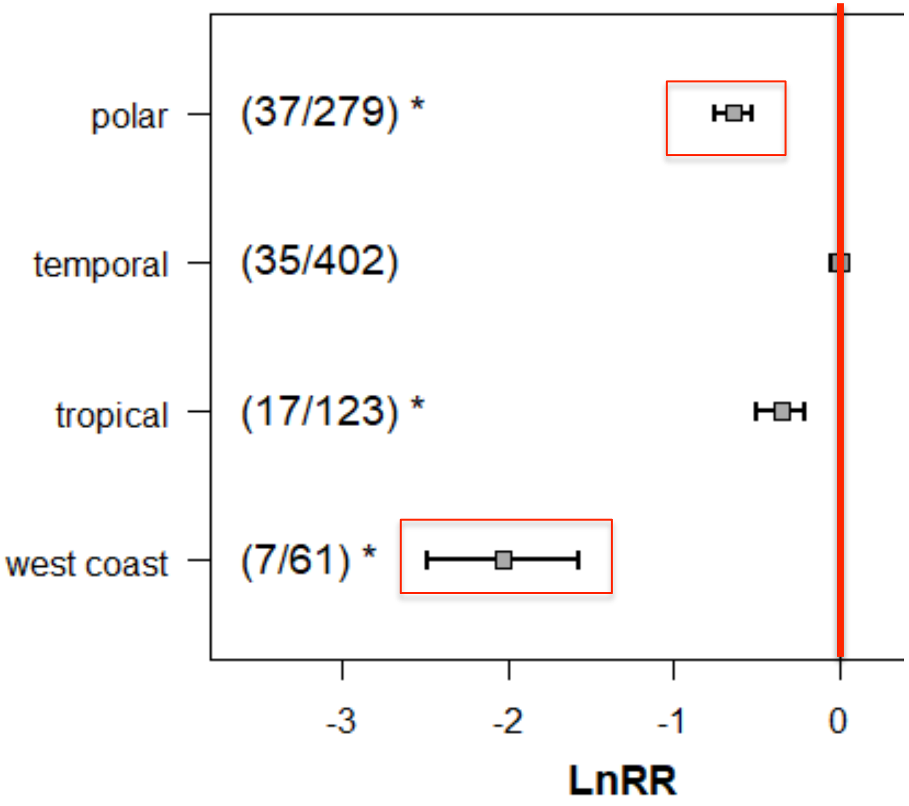
- **Evaluate robustness and signal:noise** ratio of response measure
  - Eliminate some (insignificant) response measure
  - Combine others
- **Evaluate the influence of confounding parameters** (life stage, duration, species…)
  - Combine or consider separately in threshold analyses?

Meta-analyses: How is It Done?



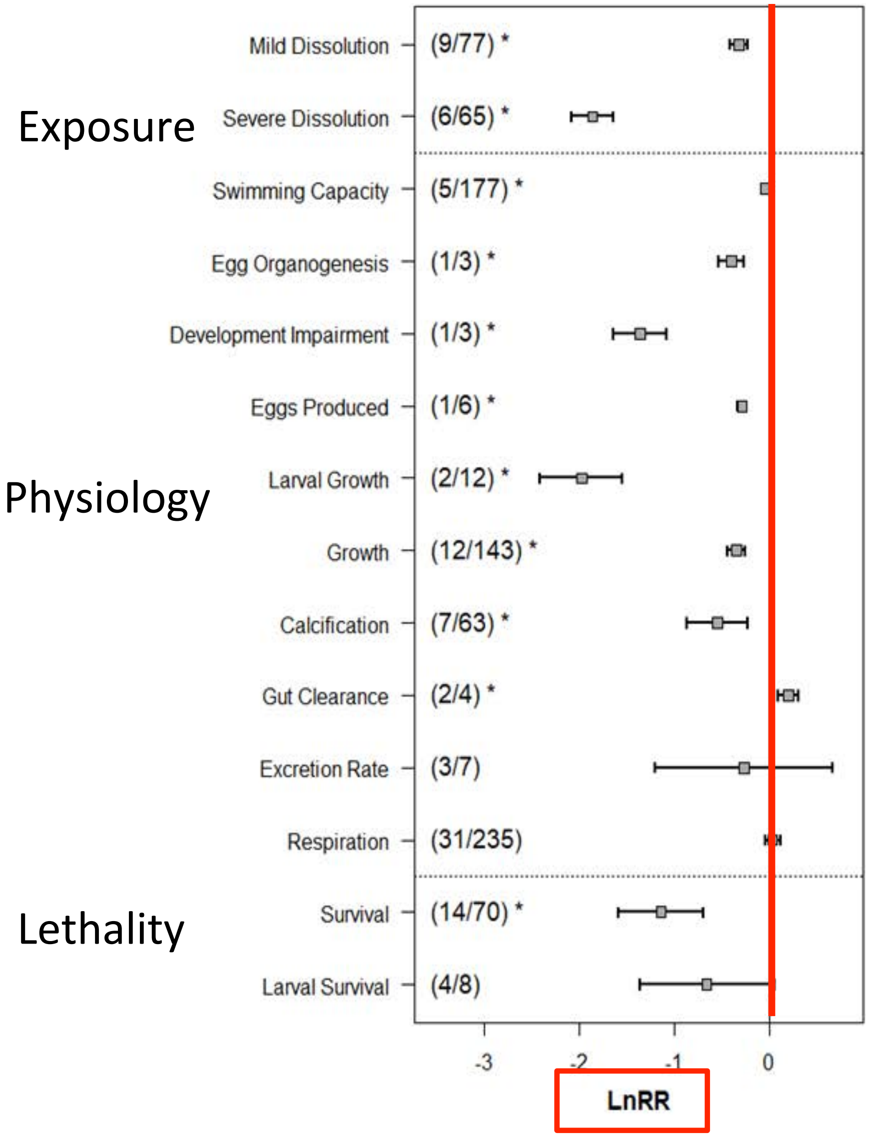
1) Raw data separated and **transformed** into a common currency, called 'effect size'**(LnRR)**
2) Assign confidence intervals

Meta-analyses: Interpretation of the Results?



Estimation of the
- **Significance**
- **Direction of response**
- **Magnitude**

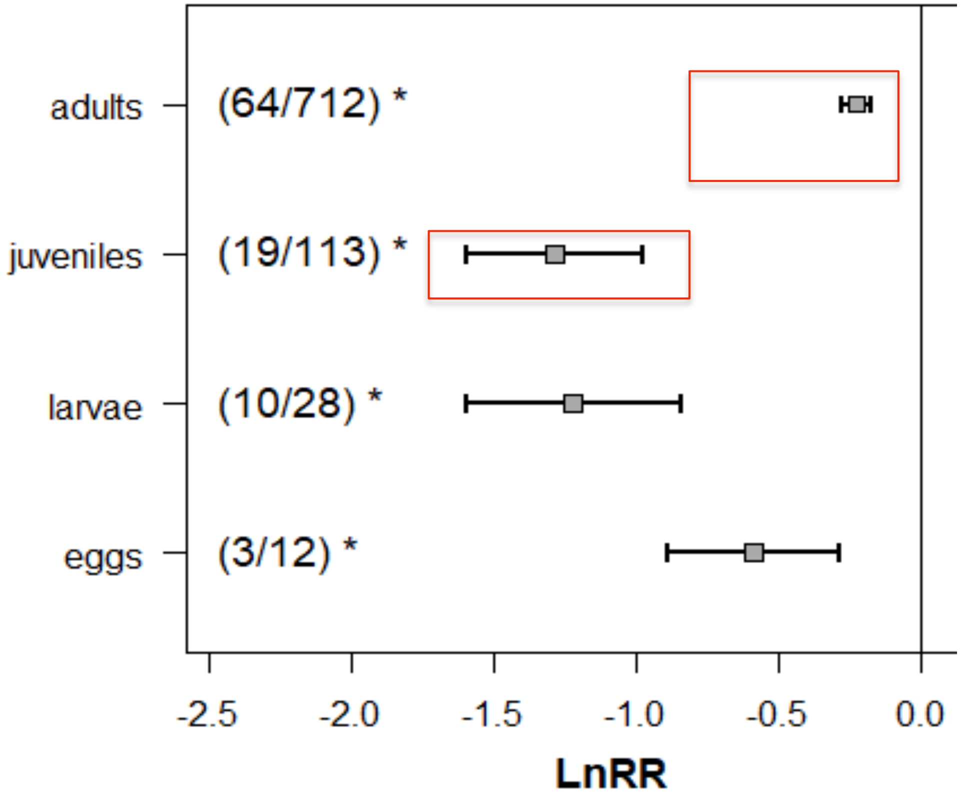
Majority of Response Measures Were Negatively Impacted by OA



- Significant negative LnRR response to OA (Ω_{ar})
- Across exposure, physiological and lethal response

- Measures not significant were excluded from next steps

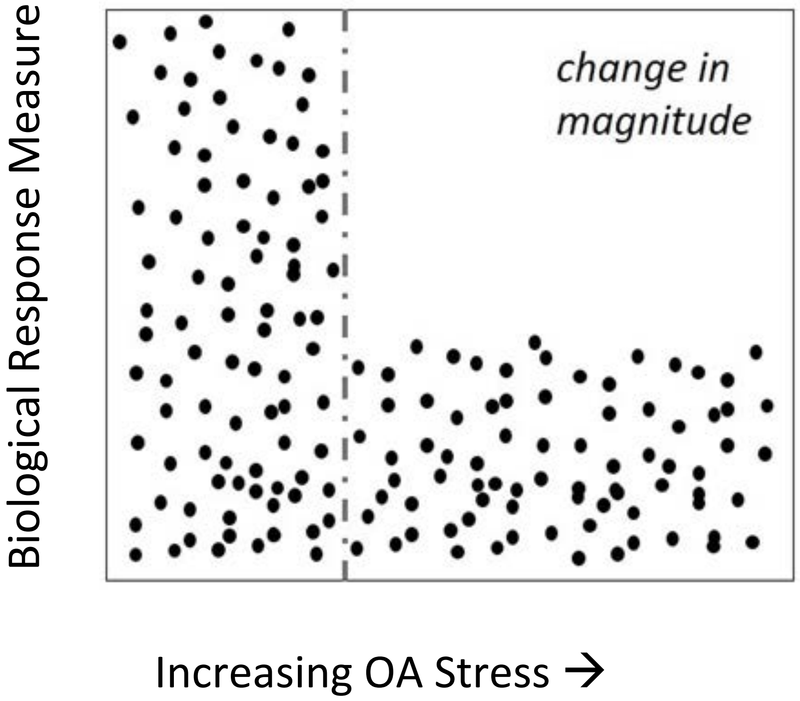
Life Stage and Regional Differences Contribute to Variability of Responses

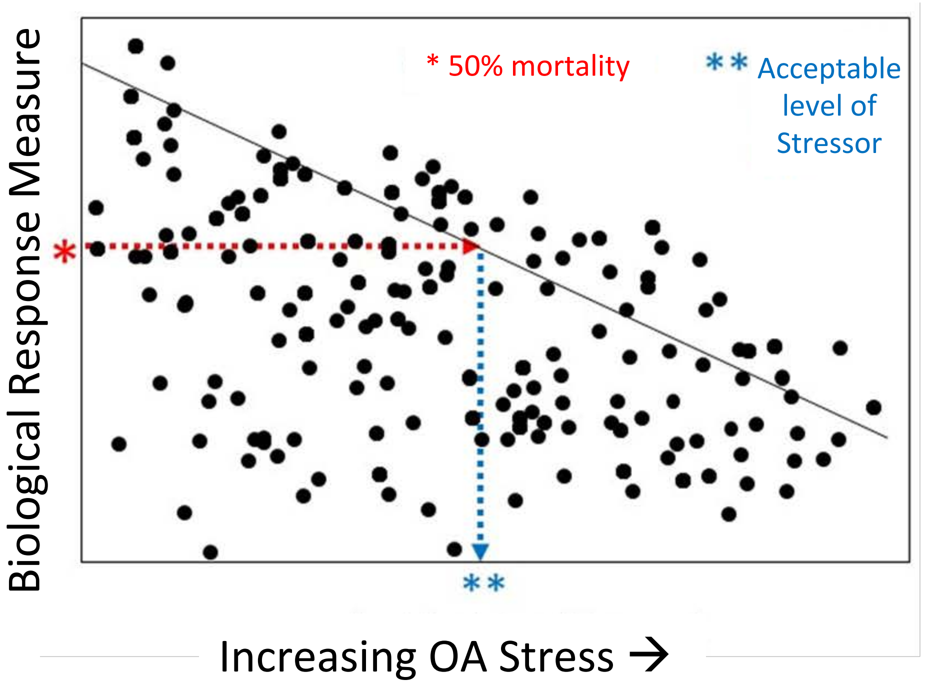


- Adults were less sensitive than larvae and juveniles
  - Important for threshold interpretation within the life history context
- Regional differences play a role
  - Experts only combined regional data when justified

Break-point and Changepoint Analyses

We Need Some Understanding of **Thresholds**

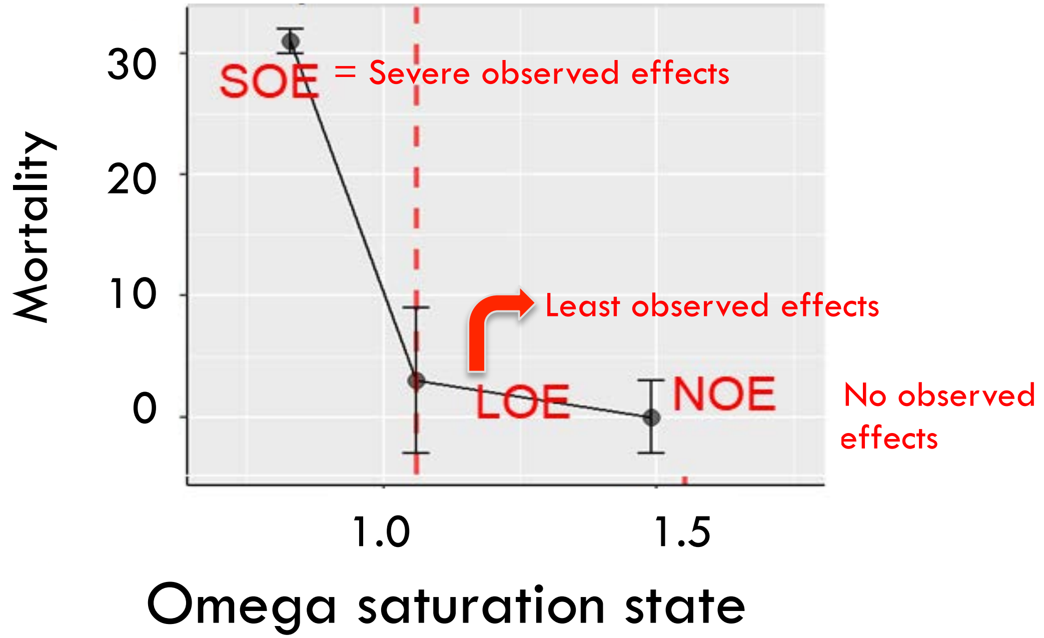


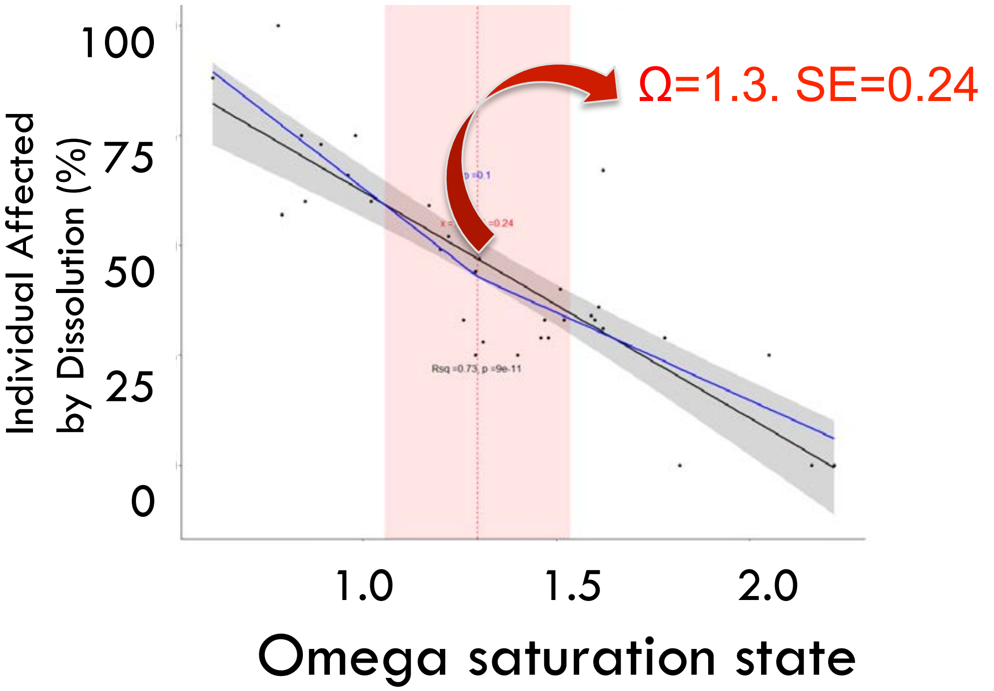


- Ideal scenario
- Discernible change in magnitude under stress
- Steep gradient

- Not easily discriminated
- Statistical analyses
- Endpoint in biological response (Y-axis) corresponding to the acceptable level of stress (X-axis)

Break-point and Changepoint Analyses Provide Preliminary Thresholds from Lab and in situ Studies



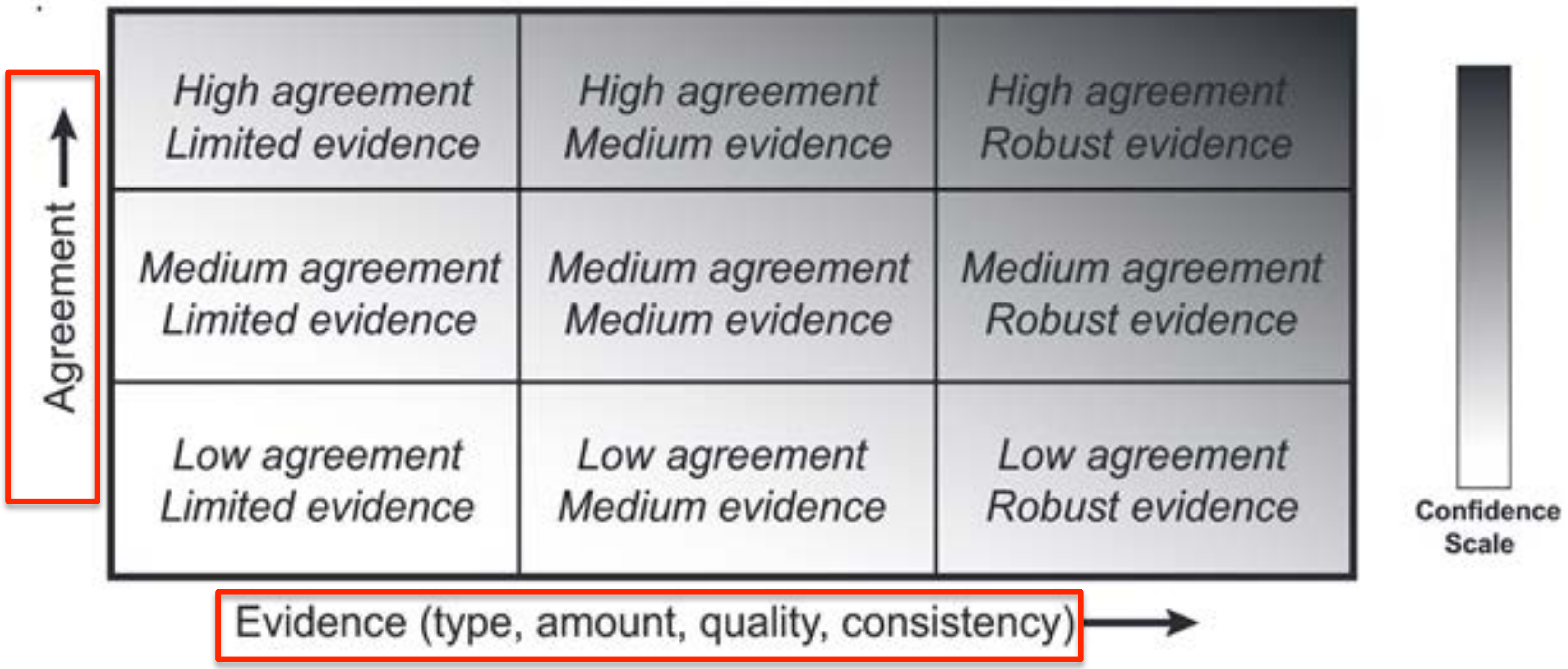


- Identified breakpoint before significant change in data: lowest observed effects (LOE) from experimental studies
- When possible, validate experimentally-derived LOE with the field-derived data to reduce uncertainty

Expert Consensus Was The Final Ingredient in Synthesis

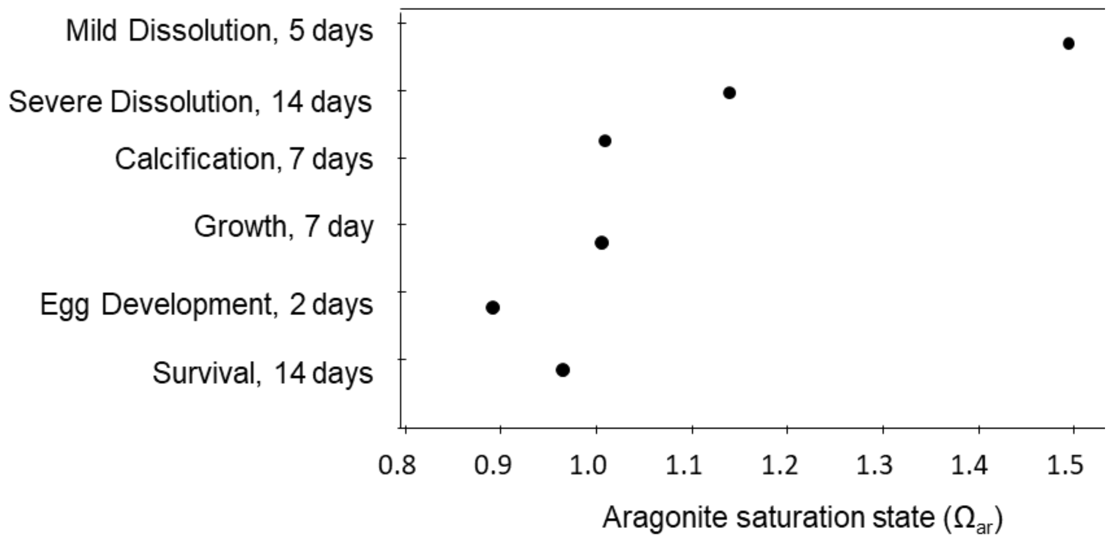
- Seven pteropod experts from across the globe
- Several steps:
  - reviewed the thresholds & meta-analyses
  - Voting on the importance of particular response measure
  - Rating of the thresholds (iterative process)
  - Solidify the Consensus

Expert Consensus Used IPCC Confidence Scale Approach to Assign Rating to Threshold



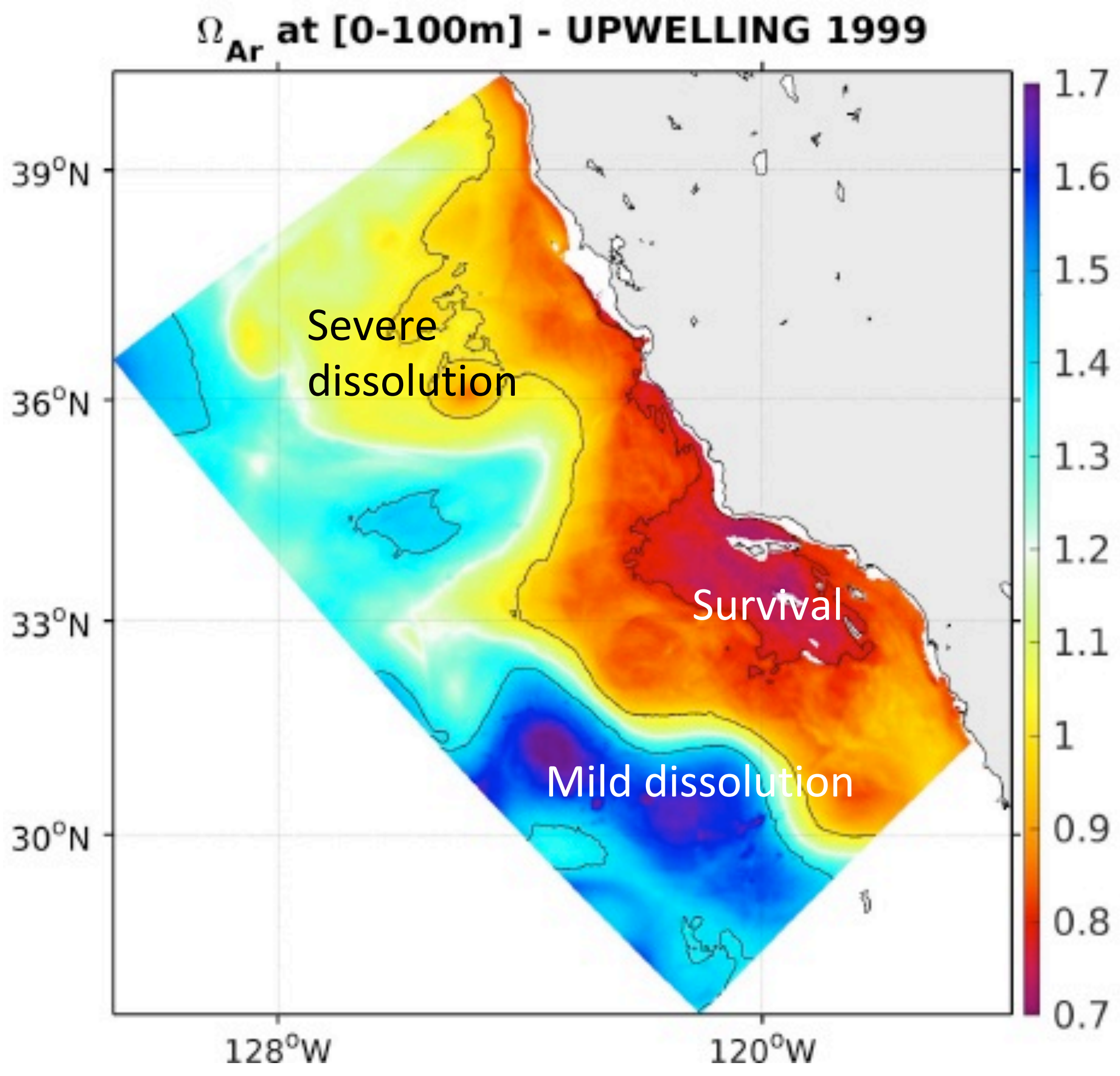
Based on IPCC methodology (Mastrandea et al., 2010)

Dissolution Measures Had the Greatest Confidence, and Survival the Lowest

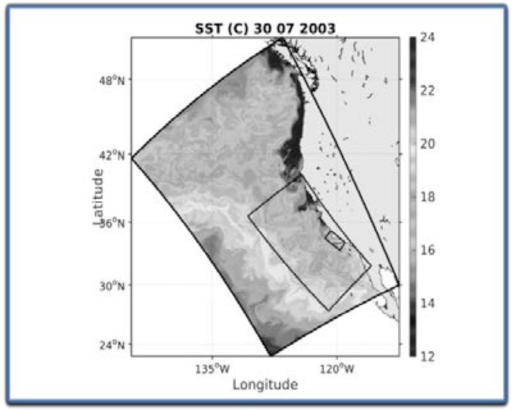


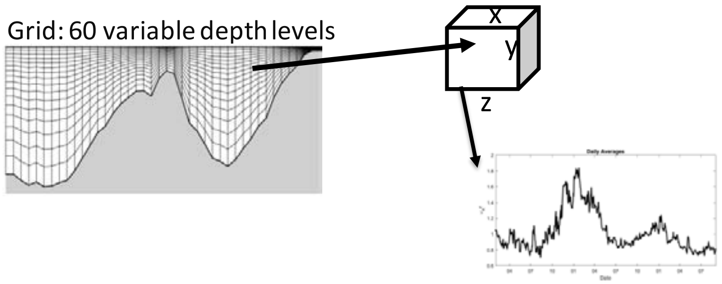
Not just thresholds but also confidence score related to threshold.
Ranging from very high (dissolution) to very low (egg development and survival).

Thresholds Can Be Applied to Model Output to Visualize Potential Habitat As Risk



- An example of the use of thresholds during an upwelling season





Next Steps on Expert Synthesis

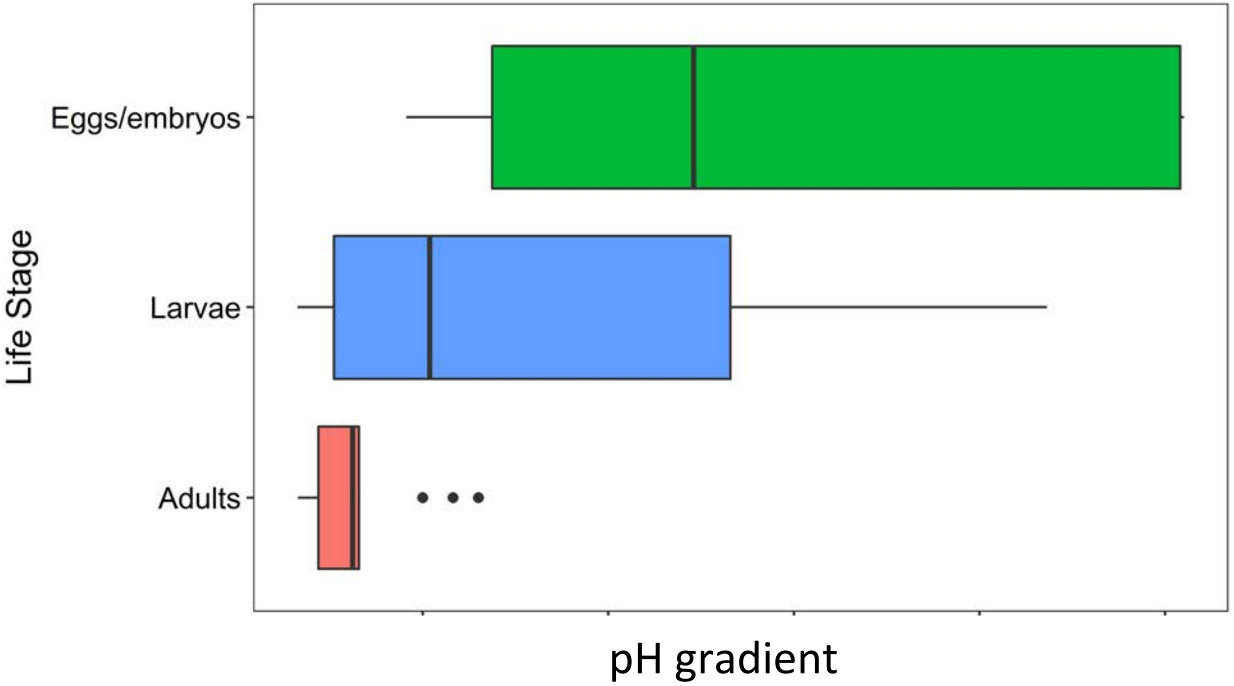
- Global review completed for echinoderms and crustaceans
  - Even more data available than for pteropods!
  - Echinoderms: 40 studies, 13k datapoints
  - Crustaceans: 19 studies, 10K datapoints

- Completed threshold analyses for echinoderms

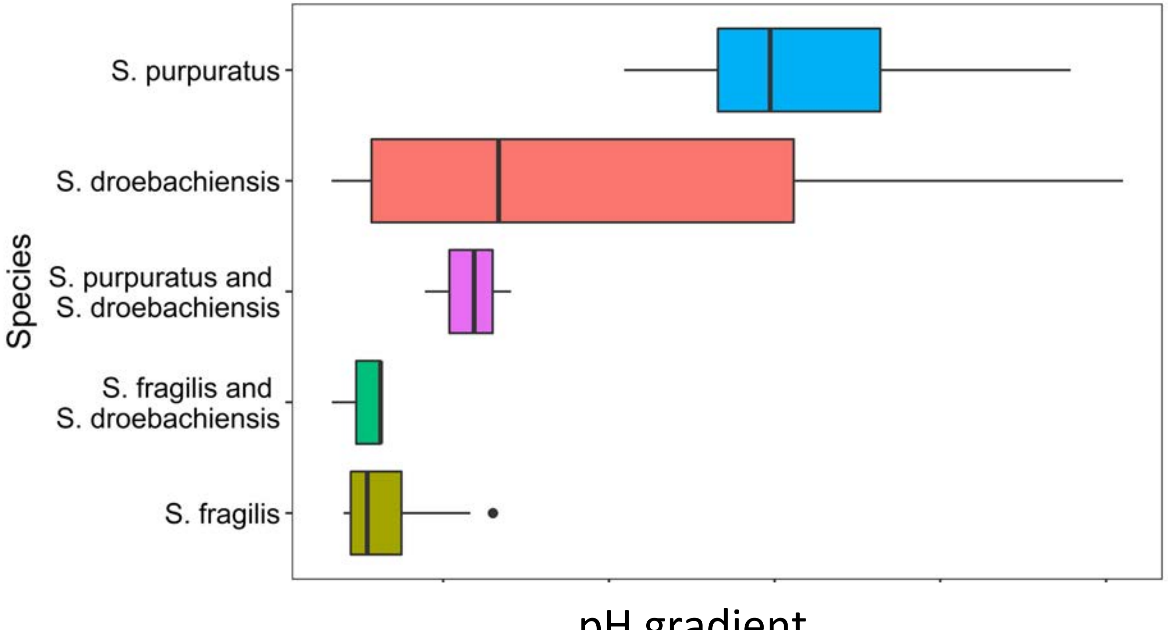
- Currently conducting meta-analyses for echinoderms and crustaceans

- Workshop planned for fall 2018 and spring 2019

Preliminary Breakpoints: Echinoderms



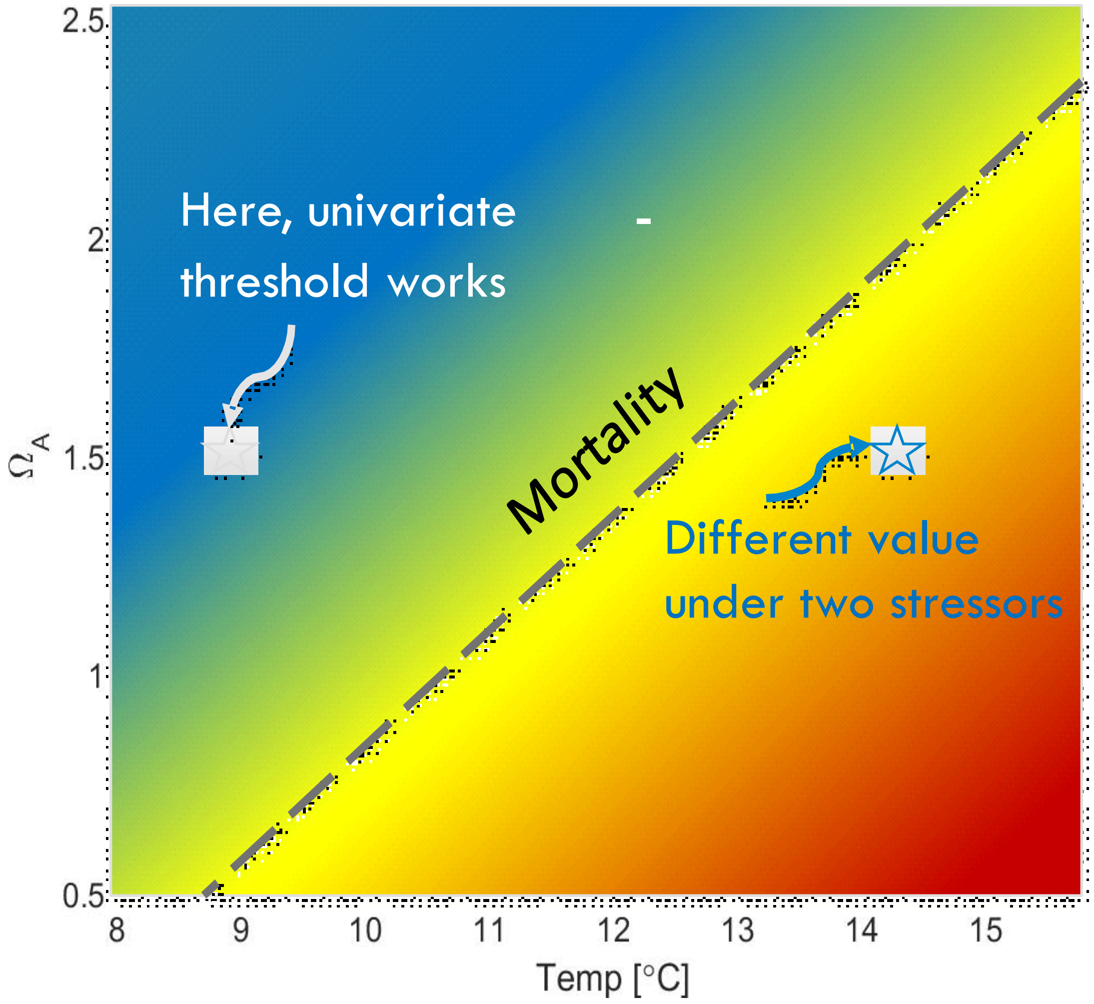
Similarity in parameters (life stage and taxa) with pteropods
Difference in OA parameter



Application of Single Stressor Thresholds is Challenging in Our Dynamic Ocean Environment

- So we know we can get to **univariate thresholds** with a straightforward, consensus-based process…
- But, applying them in the ocean can be more complicated.
  - OA, temperature and DO co-vary, results can be additive, synergistic, or antagonistic
  - How do we account for multiple stressor effects on habitat?

Take home message: We need additional **tools** to assist with interpretation of thresholds under multiple stressors.



Solution: Habitat Suitability Index (HSI) models

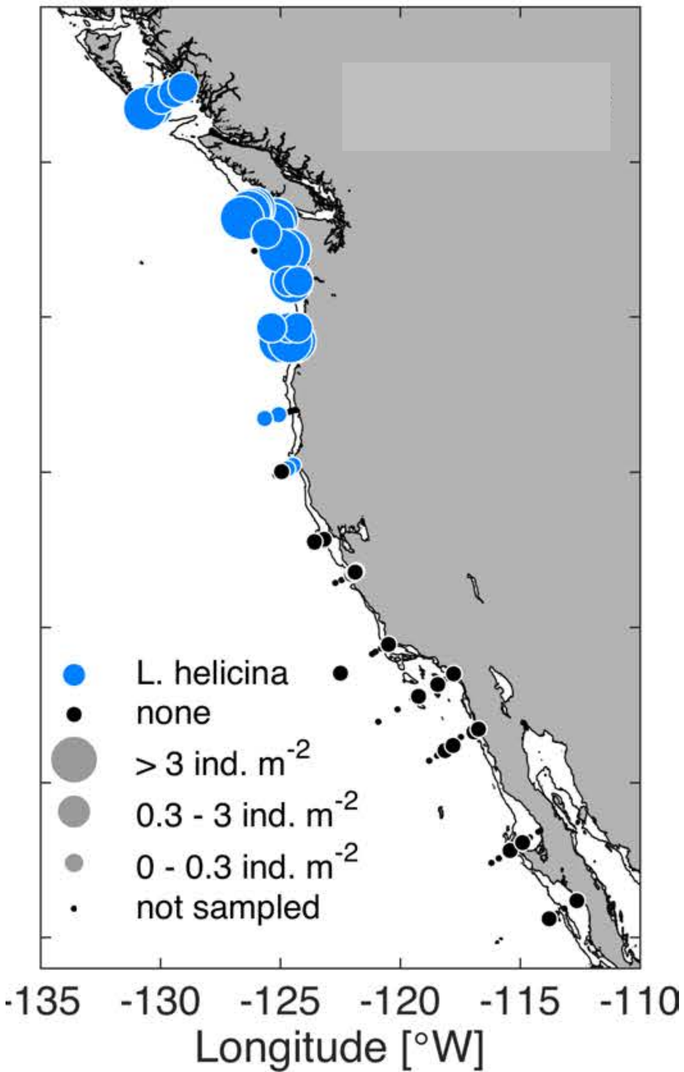
- HSIs are statistical models that define relationship between environmental gradients and species abundance or P/A
  - Combination of mechanistic or empirical approach
  - Can be used to describe nonlinear (interactive) relationship with multiple stressors
  - Predict **habitat suitability**

  - *We have an example such tool for pteropods now…*

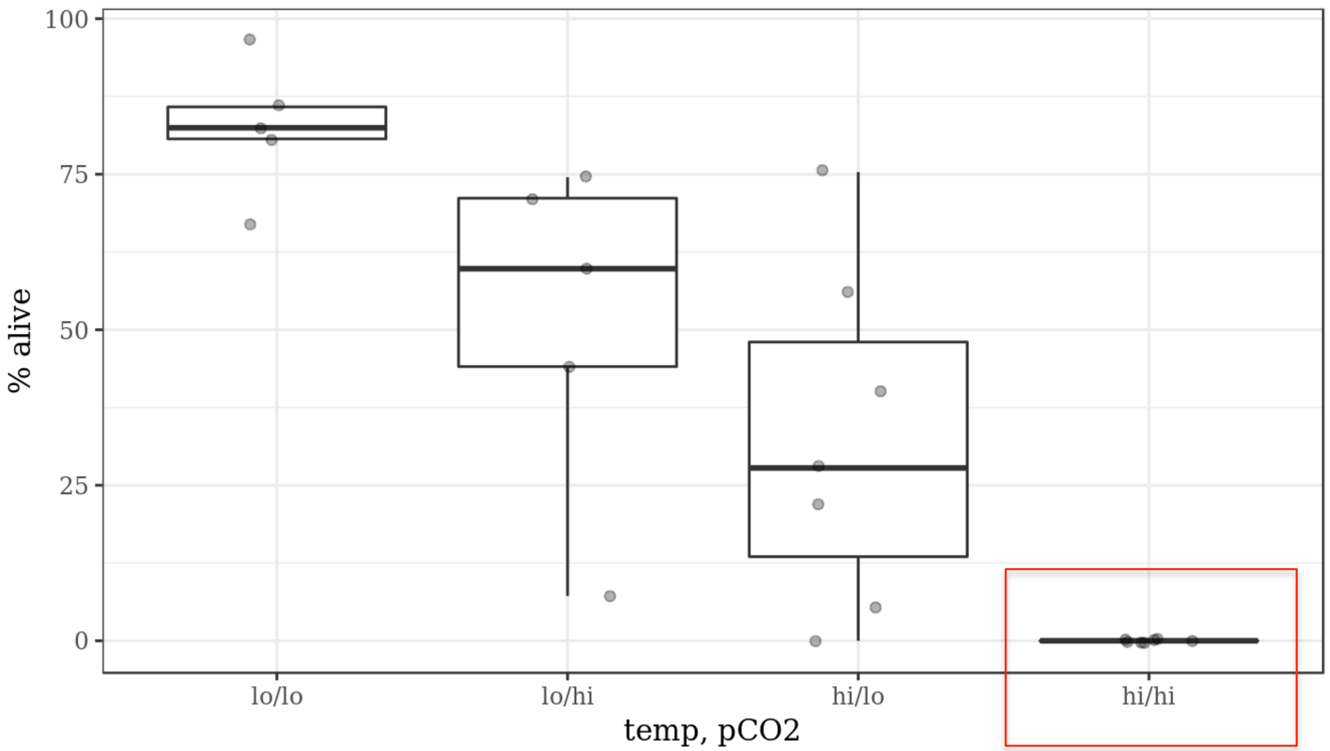
Developing Pteropod HSIs

What are inputs?

- *Mechanistic model*: Experimental data from multiple-stressor experiments (OA, thermal stress)
- *Empirical model*: Field data
  - time series of pteropods along the US West Coast on abundance and environmental parameters for almost entire decade combined with physical-chemical data
  - One of the largest spatial dataset (NOAA WCOA cruises)

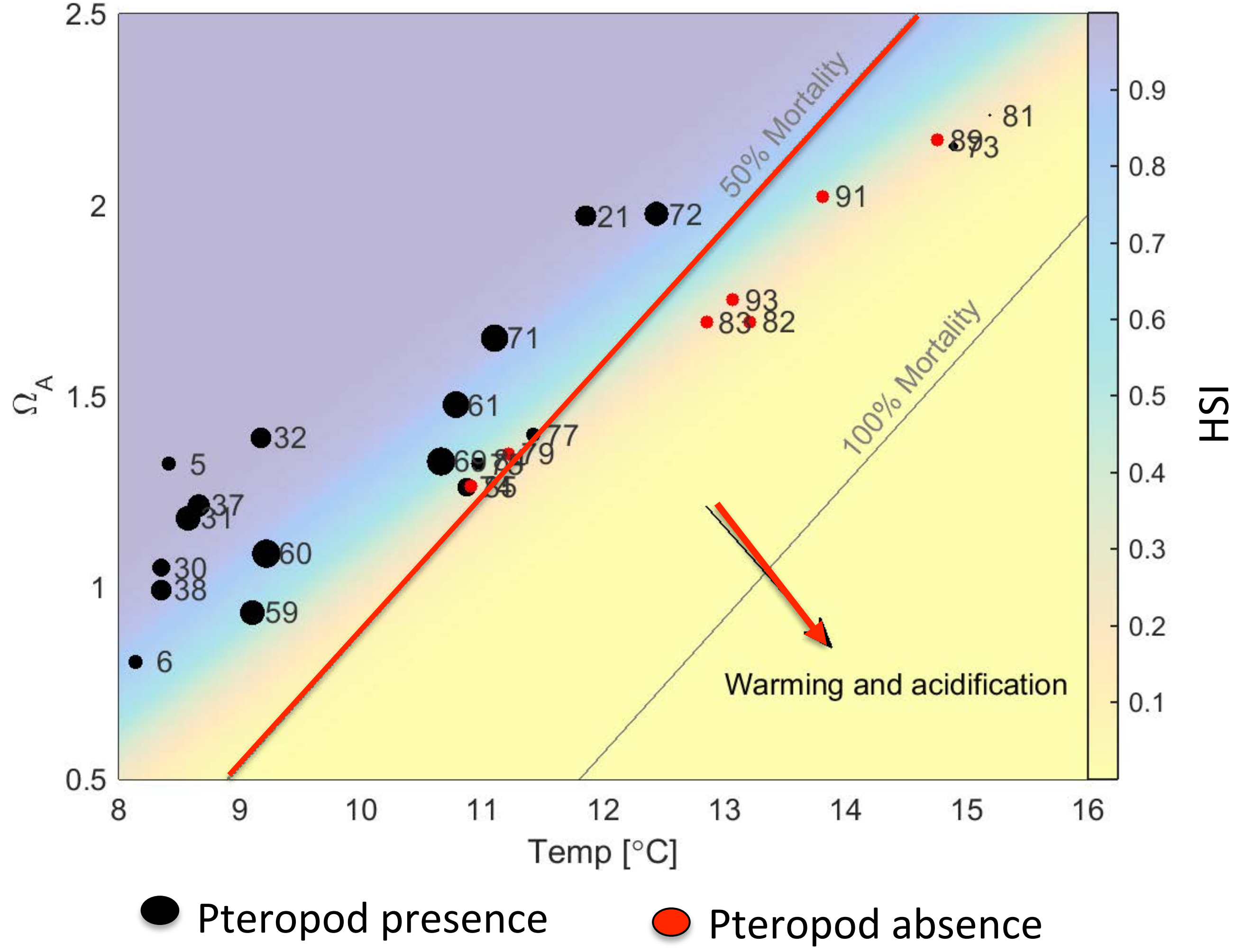


Experimental results directly applied to HSI



- *Mechanistic model*
- We used experiments to provide evidence of OA-T stress
  - Single stressor: partial survival
  - Combined: complete mortality
- Translated these two experimental parameters as drivers of *in situ* **mortality**

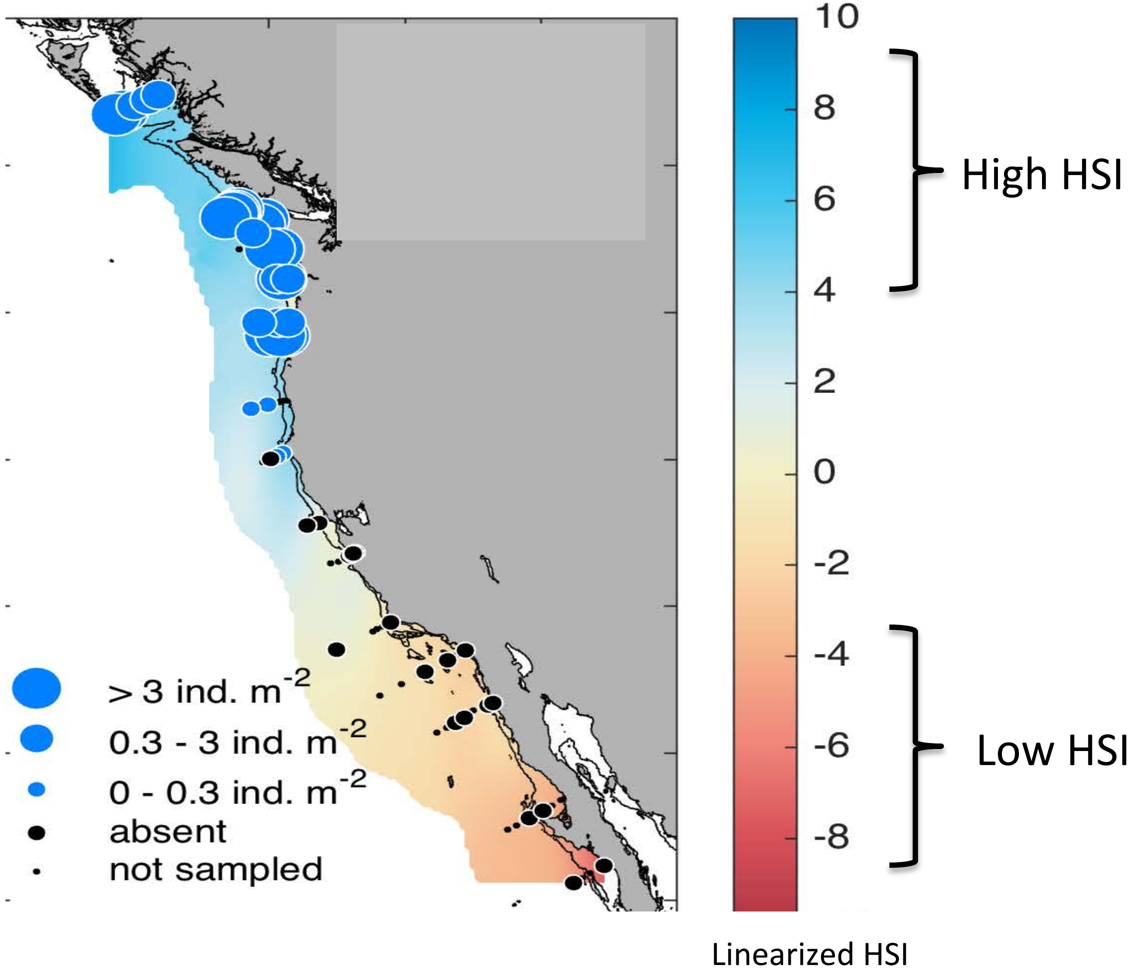
Conceptual Representation of Habitat Compression from Two Interactive Stressors



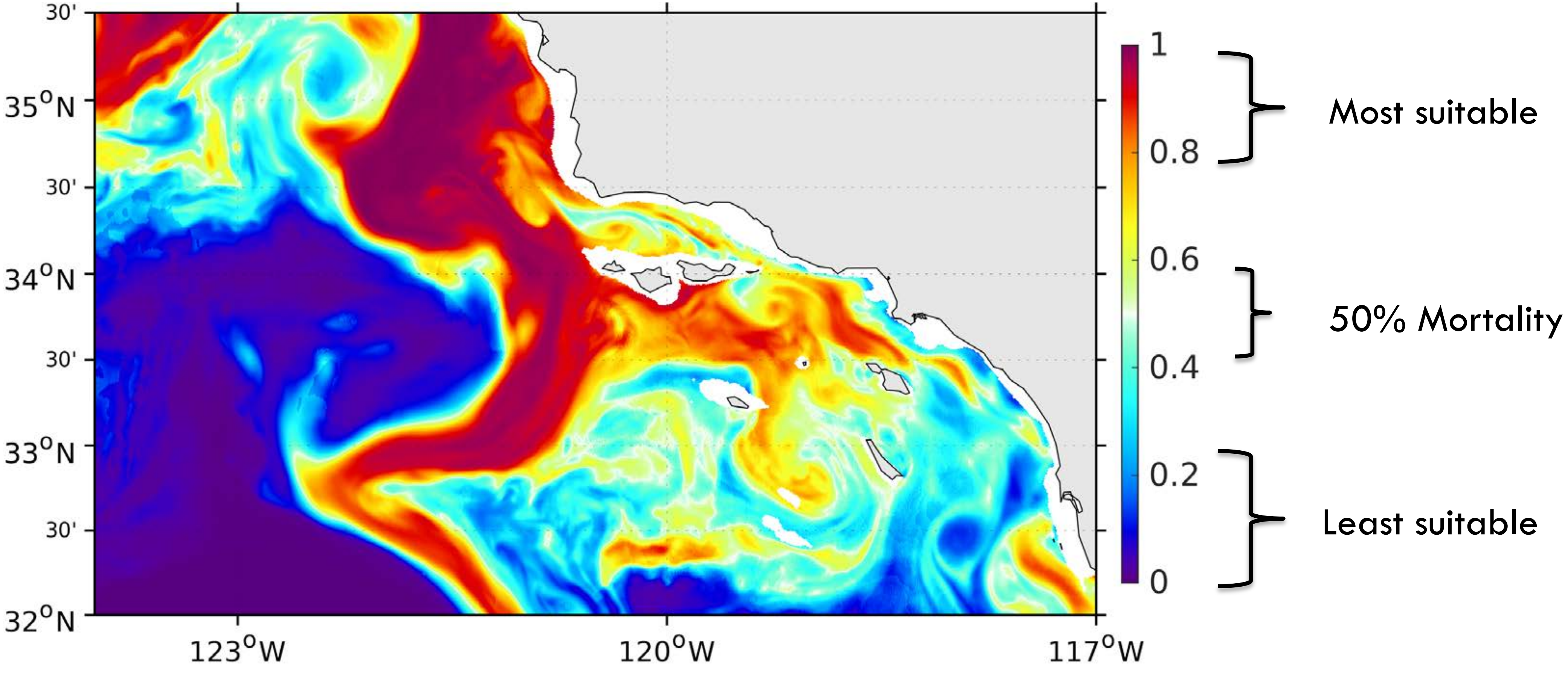
- Observed P/A in the T-OA space closely follows 50% mortality line
- HSI change when adding an additional stressor
- Transition from one threshold under univariate stressors to a mortality line as indicator of P/A under multiple stressors

Our HSI successfully predicts pteropod distribution

- We found high habitat suitability Index in the north; low in the South (HIS)
- We can start predicting population level effects based on the suitable habitat



HSI Application in the high resolution model output



Biologically-Based Assessment Endpoints for Pollution Impact on OA in the SCB: Take Home Messages

- We have a **key graphic** of synthesized thresholds for **pteropods**
  - *We went through a 4-step process with experts to get this consensus*
  - *Work on echinoderms is advancing rapidly*
  - *These thresholds can be used to interpret monitoring and model output*
- We have developed HSI statistical model to consider how multiple stressors impact available habitat
  - We can use the model to **visualize habitat compression**
  - Empirical model helps us translate OA thresholds from **individual to population** level effects
- Numerous applications ongoing—Martha will talk about one of them.

Which Taxa To Use?

<u>We Have Criteria for Selection of Taxa</u>

- Nearshore, far-ranging distribution
- Sensitivity to OA or/and low oxygen impacts
- Representative Habitat, e.g.
  - Pelagic
  - Soft bottom
  - Rocky reef
- Mode of impact
  - E.g. Calcifier versus Non-calcifier
  - Life stage consideration
- Data availability
- Management endpoint: Valuable role in ecosystem or commercially important