Biologically Relevant Thresholds Are Needed to Support All These OA Action Plan Recommendations

• OA water quality goals

• Assess impact of local pollution sources

• Preserve, support and enhance the resilience of fisheries

• Carbon sequestration through natural and constructed systems
Use of Biologically–Relevant Endpoints As Approach Requires Answering Important Science Questions…

- Which taxa to select? What habitats do they represent?
- What is the scientific basis for thresholds, considering magnitude, duration, extent and frequency
- How do we deal with multiple stressors?
We Want OA Sentinel Taxa that Represent Different Habitats

- Surface
- 0 – 50m

Epibenthic species range shallow to deepwater habitats

- Adult stage-epibenthic
- Larval stage- pelagic

Echinoderms (e.g. sea urchins, and sea stars)

Decapods (e.g. crabs)

Epibenthic

PELAGIC

Pteropods (Sea Snails)

50-1,300m

Deep sea
Need a Key Graphic, By Taxa, to Support Management Decisions

Declining Biological Condition

OA Stress (e.g. decreasing pH)

No observed effect (natural variability)

Sublethal Response (Physiological)

Lethal Response
We Have This Key Graphic for Pteropods (and now, Echinoderms)!

Pteropod Synthesis Features 6 Thresholds with Magnitude and Duration

Unimpacted

- Mild Dissolution, 5 days
- Severe Dissolution, 14 days
- Calcification, 7 days
- Growth, 7 day
- Egg Development, 2 days
- Survival, 14 days

Severely Impacted

Aragonite saturation state ($\Omega_{ar}$)
We Convened Experts from Around the World to Help Us Get Consensus on Thresholds

Pablo Leon Diaz, Scottish Env. Agency, UK
Ella Howes, Nature Conservation, UK
Brian Hunt, UBC, Canada
Silke Lischka, GEOMAR, Germany
Amy Maas, Bermuda, USA
Clara Manno, BAS, UK
Brad Seibel, USF, USA
Rich Ambrose, UCLA, USA
Maria Byrne, University of Sydney, AU
Piero Calosi, Université du Québec, Canada
Karen Chan, Swarthmore College, USA
Sam Dupont, University of Gothenburg, Sweden
Jacqueline Padilla-Gamino, UW, USA
John Spice, University of Plymouth, UK
Nina Bednaršek, SCCWRP
Richard Feely, PMEL, NOAA
We Started With Comprehensive Data Compilation, Literature Review, and Data Analyses

Pteropod OA responses:
• 18 studies and 3k data points
• 22 response measures!
• One taxon

Echinoderm OA responses:
• 41 studies and 12k data points
• 237 response measures!
• Three taxa (Sea urchins, brittle stars, Sea stars)

Analyses to support decisions on excluding studies and combined disparate response measures
Analyses to identify “thresholds” for different response measures
Best Measure of OA Stress Varies By Taxonomic Group

- Omega Saturation state (Ωar) recommended for pteropods
  - Measure that directly relates to saturation state required for calcification

- Echinoderm experts leaning towards pH
  - More directly speaks to internal acid/base regulation
  - But we have some follow up analyses to see whether pCO2 is a better measure
Pteropod and Echinoderms Impacted over pH Ranges from 7.8 to 7.2 at Durations from 5 to 30 days

**PELAGIC**
- Pteropod Adults and Juveniles (2 to 14 days)
- Mild Dissolution
- Severe Dissolution
- Calcification
- Growth
- Egg Development
- Adult and Juvenile Survival

**EPIBENTHIC**
- Physiology and Behavior, Deepwater
- Physiology, Shallow
- Growth and Development, Shallow

OA Stress (e.g. decreasing pH)
- No observed effect (natural variability)
- Sublethal Response (Physiological)
- Lethal Response

**PELAGIC**
- Echinoderm Larvae (7 days)

**PELAGIC**
- Echinoderm Adult (7-30 days)
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.
We are Working on Habitat Suitability Index (HSI) Models as a Solution to this Issue

- HSIs are empirical, statistical models of relationship between environmental gradients and species abundance
  - Predict habitat suitability

- We have an pteropod HSI now, validated with experimental LC50 mortality data (redline), and independent observational dataset
Basic Principles:
When you apply these thresholds to monitoring data or model output, you are estimating habitat compression.

Habitat compression can be spatial or temporal.

Our team is beginning to work towards predictions of population level (single taxa) and ecosystem effects (trophic interactions).
Apply OA Thresholds and HSI Tool to Model Output As Multiple Lines of Evidence to Assess Habitat Compression

Working on Ways to Visual Results to Best Communicate Findings

- Adult Survival at 200 m depth, June to February ($\Omega = 0.95$, 14 days)
- HSI Modeled Prediction of High Quality (red) versus Low Quality (blue) Habitat from Temperature Dependent OA Impacts
Next Steps

• Utilize expert derived thresholds and HSI (pteropods only) to conduct assess vulnerability
  – SCCWRP is hosting modeling forum--OPC Vulnerability Assessment Workshop--in late spring 2019

• Third expert workshop on decapods to be held in the late spring 2019

• We look forward to coming back to update you on progress and preliminary findings of next year