Seasonal patterns of estuarine acidification in seagrass beds of the Snohomish Estuary, WA

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Speaker
Stephen Pacella, Cheryl A. Brown, T. Chris Mochon-Collura, George G. Waldbusser, Rochelle G. Labiosa, and Burke Hales

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Stephen Pacella\textsuperscript{1,2}, Cheryl Brown\textsuperscript{1}, TChris Mochon Collura\textsuperscript{1}, George Waldbusser\textsuperscript{2}, Rochelle Labiosa\textsuperscript{3}, and Burke Hales\textsuperscript{2}

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\textsuperscript{3}Region 10, US EPA
Outline of talk

1. Why do we need to understand more about carbonate chemistry in estuarine habitats?

2. How does OA manifest in these habitats on daily and seasonal time scales?

3. What does this mean for exceedance of physiological and water quality thresholds?

Background

Observations + OA Simulations

Daily and seasonal variability

Organism and management thresholds
1. Short-term fluctuations in carbonate chemistry, or “carbonate weather”, impact organismal fitness

Mangan et al., 2017 *Proc. R. Soc. B*

**Mytilus edulis** metabolic rates

<table>
<thead>
<tr>
<th>pH 8.10 static</th>
<th>pH 8.10 Fluc</th>
<th>pH 7.70 static</th>
<th>pH 7.70 Fluc</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO₂ (µmol O₂ DWg⁻¹ h⁻¹)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10</td>
<td></td>
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<td>12</td>
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<td>18</td>
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1. Short-term fluctuations in carbonate chemistry, or “carbonate weather”, impact organismal fitness

2. Carbonate weather is predicted to become more extreme with ocean acidification
   - OA increases baseline [TCO$_2$]
   - Local metabolism drives [TCO$_2$] variability
   - OA + metabolism = ↑baseline TCO$_2$ + ↑pH & pCO$_2$ variability

Intrinsic thermodynamic properties of the carbonate system, therefore widely applicable in metabolically intensive systems
Outline of talk

1. Why do we need to understand more about carbonate chemistry in estuarine habitats?
   - Improved understanding of natural vs. OA-forced signals of variability
   - Frequency, duration, and magnitude of organismal exposure to stressful conditions

2. How does OA manifest in these habitats on daily and seasonal time scales?

3. What does this mean for exceedance of physiological and water quality thresholds?

Background | Observations + OA Simulations | Daily and seasonal variability | Organism and management thresholds
Field sampling

July 2015 – April 2016

• 2 study sites in subtidal seagrass beds (0.5m - 4.5m)
• YSI, SeaFET, and SAMI pH deployments
• Grab samples for $T\text{CO}_2$ & $p\text{CO}_2$
Field observations

Hat Island

Mission Beach

RMSE = 0.074
R = 0.925
p<0.001

Burke-O-Lator pCO₂/TCO₂
Washington DOE PSS019 2014/15 samples
SeaFET/SAMI pH

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Field observations

**Hat Island**

- **RMSE = 0.074**
- **R = 0.925**
- **p<0.001**

- **Burke-O-Lator pCO₂/TCO₂**
- **Washington DOE PSS019 2014/15 samples**
- **SeaFET/SAMI pH**

**Calculated full carbonate system using in-situ pH and salinity-derived alkalinity (Alk_{sal})**

- **RMSE = 38**
- **R = 0.996**
- **P<0.001**

| Background | Observations + OA Simulations | Daily and seasonal variability | Organism and management thresholds |
C\textsubscript{anth} modeled using adaption of the $\Delta C^*$ method (detailed in Pacella et al., 2018)

Atmospheric CO\textsubscript{2} from the RCP 8.5 scenario

Estimated C\textsubscript{anth} agrees well with published values for contemporary surface waters in the California Current

How does OA affect daily and seasonal carbonate chemistry dynamics?
OA alters carbonate weather and seasonal climatology of carbonate chemistry

- OA reduces the ability of the system to buffer natural extremes, causing preferential amplification of low pH (and high pCO$_2$) during times of additive $C_{anth}$ and metabolic CO$_2$

- Most harmful carbonate parameters for coastal organisms are changing up to 2x more rapidly than medians
OA alters carbonate weather and seasonal climatology of carbonate chemistry

- **Hat Island**
  - Summer: 1765, 2015, 2100
  - Winter: 1765, 2015, 2100
  - Spring: 1765, 2015, 2100

**Graphs:**
- **pH**
- **pCO₂**
- **Ω_{arag}

**Seasonality Changes:**
- **[H⁺] seasonality:** +60% → +225%
- **pCO₂ seasonality:** +70% → +300%
- **Ω_{arag} seasonality:** -15% → -50%

**Background Observations + OA Simulations**
- Daily and seasonal variability
- Organism and management thresholds
Outline of talk

1. Why do we need to understand more about carbonate chemistry in estuarine habitats?
   • Improved understanding of natural vs. OA-forced signals of variability
   • Frequency, duration, and magnitude of organismal exposure to stressful conditions

2. How does OA manifest in these habitats on daily and seasonal time scales?
   • $C_{\text{anth}}$ reduces ability of system to buffer natural carbon cycling
   • High pCO$_2$ and low pH conditions changing most rapidly
   • Carbonate weather and seasonal climatology more extreme for pH and pCO$_2$, dampened for $\Omega_{\text{arag}}$

3. What does this mean for exceedance of physiological and water quality thresholds?
Interaction between “natural” and OA-driven changes to buffering capacity controls the timing of crossing of physiological and water quality thresholds.

**pH**

*C. magister* larvae survival

(Miller et al., 2016 *Mar. Biol.*)

**pCO₂**

Hypercapnia


**Ω_{arag}**

Early *M. californianus* development

(Waldbusser et al., 2015 *PLoS ONE*)

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Interaction between “natural” and OA-driven changes to buffering capacity controls the timing of crossing of **physiological** and water quality thresholds.

Regular exceedance of pH and $p\text{CO}_2$ thresholds by mid-century…

…currently in acceleration of $\Omega_{\text{arag}}$ exceedance?
Interaction between “natural” and OA-driven changes to buffering capacity controls the timing of crossing of physiological and water quality thresholds.

**Phenology of Dungeness crab**

<table>
<thead>
<tr>
<th>Location</th>
<th>Moulting/mating</th>
<th>Egg deposition</th>
<th>Larval duration (range of time)</th>
<th>Settlement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oregon–Washington</td>
<td>March–June</td>
<td>October–December</td>
<td>January–March</td>
<td>April–August</td>
</tr>
<tr>
<td>Puget Sound</td>
<td>April–September</td>
<td>October–December</td>
<td>February–May</td>
<td>June–August</td>
</tr>
<tr>
<td>British Columbia</td>
<td>No data</td>
<td>September–February</td>
<td>December–June</td>
<td>July–Later</td>
</tr>
</tbody>
</table>

Overlap of poor environmental conditions driven by OA and phenology of OA-sensitive life stages creates potential for organismal impacts.

>10% annual exceedance by 2050, 14 years and 100ppm atmospheric CO₂ earlier due to reduced buffering.

Interaction between “natural” and OA-driven changes to buffering capacity controls the timing of crossing of physiological and **water quality** thresholds

EPA’s recommended criterion states that the pH of marine waters “should not be changed more than 0.2 units outside the naturally occurring variation”

**Changes to seasonal climatology**

**Changes to carbonate weather**
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3. What does this mean for exceedance of physiological and water quality thresholds?
   - Earlier exposure to more severe stressful conditions for organisms
   - OA drives variable time to exceedance of existing recommendations for water quality criteria
Key Take-aways

1. Estuaries are naturally dynamic chemical environments, which primes these systems for more rapid and severe changes to the CO$_2$ system with OA
   - Analogous to naturally high-CO$_2$ upwelling zones

2. The interaction of natural CO$_2$ cycling and C$_{anth}$ in these habitats causes high $p$CO$_2$, low pH, and low $\Omega_{arag}$ conditions to change most rapidly
   - Indices most relevant for organismal impacts

3. Understanding OA effects on time scales relevant for organisms will help identify times of synchronous threshold exceedance and OA-sensitive life stages

How does magnitude and duration of threshold exceedance translate into organismal/ecosystem impacts??
# Acknowledgments

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