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

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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?
Project background and motivation

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

- Background
  - Observations + OA Simulations
  - Daily and seasonal variability
  - Organism and management thresholds

![Graph showing metabolic rates of Mytilus edulis](image-url)
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?
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 $T_{CO_2}$ & $p_{CO_2}$
Field observations

Hat Island

RMSE = 0.074  
R = 0.925  
p<0.001

Burke-O-Lator pCO$_2$/TCO$_2$  
Washington DOE PSS019 2014/15 samples  
SeaFET/SAMI pH

Mission Beach

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

Hat Island

RMSE = 0.074
R = 0.925
p<0.001

Burke-O-Lator pCO$_2$/TCO$_2$
Washington DOE PSS019 2014/15 samples
SeaFET/SAMI pH

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

Hat Island

RMSE = 0.28
R = 0.934
p<0.001

Background Observations + OA Simulations

Daily and seasonal variability Organism and management thresholds
*OA simulations from 1765-2100*

$C_{\text{anth}}$ modeled using adaption of the $\Delta C^*$ method (detailed in Pacella et al., 2018)

Atmospheric $CO_2$ from the RCP 8.5 scenario

Estimated $C_{\text{anth}}$ 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

Pacella et al., 2018 PNAS
OA alters carbonate weather and seasonal climatology of carbonate chemistry

Hat Island
Mission Beach
pH
pCO$_2$
Ω$_{arag}$

↑[H$^+$] seasonality
+60%  +225%

↑pCO$_2$ seasonality
+70%  +300%

↓Ω$_{arag}$ seasonality
-15%  -50%

↑pCO$_2$ seasonality  +60%  +225%

↓Ω$_{arag}$ seasonality  -15%  -50%

% change in seasonality since 1765

pH ([H$^+$])
pCO$_2$
Ω$_{arag}$
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?
   • $C_{anth}$ 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 $Ω_{arag}$

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

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

**pH**

*Background*

Observations + OA Simulations

Daily and seasonal variability

Organism and management thresholds

**pCO$_2$**

Median +/- 90% interquantile range

*Summer*

*Winter*

*Spring*

**Ω$_{arag}$**

*Early $M.\ californianus$ development*

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

(C. magister larvae survival)

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

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 $pCO_2$ thresholds by mid-century…

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

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 CO$_2$ earlier due to reduced buffering.

**Phenology of Dungeness crab**

<table>
<thead>
<tr>
<th>Location</th>
<th>Moulting/mating</th>
<th>Egg deposition</th>
<th>Hatching</th>
<th>Larval duration (range of time)</th>
<th>Settlement</th>
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</thead>
<tbody>
<tr>
<td>Oregon-Washington</td>
<td>March–June</td>
<td>October–December</td>
<td>January–March</td>
<td>130 (89–143)</td>
<td>April–August</td>
</tr>
<tr>
<td>Puget Sound</td>
<td>April–September</td>
<td>October–December</td>
<td>February–May</td>
<td>150</td>
<td>June–August</td>
</tr>
<tr>
<td>British Columbia</td>
<td>No data</td>
<td>September–February</td>
<td>December–June</td>
<td>No data</td>
<td>July–Later</td>
</tr>
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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

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”
Outline of talk

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   • 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?
   • Earlier exposure to more severe stressful conditions for organisms
   • OA drives variable time to exceedance of existing recommendations for water quality criteria
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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<thead>
<tr>
<th>RARE project team:</th>
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<td>Walt Nelson</td>
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