Impacts of ocean acidification on bivalve production in the U.S. Pacific Northwest

George G. Waldbusser and many others...
\[ pH \approx -\log_{10} \left( \sqrt{K_1 \cdot K_2 \cdot \frac{[CO_2^*]}{[CO_3^{2-}]}} \right) \]

\[ \Omega_{CaCO_3} = \frac{[Ca^{2+}] [CO_3^{2-}]}{K_{sp-CaCO_3}} \]
What is Ocean Acidification

Boden et al. 2013

Surface Ocean

Hönisch et al. 2012
California Current: Acidification Hot Spot

Harris et al., 2013

Hauri et al. 2013

280 ppm CO$_2$
400 ppm CO$_2$
550 ppm CO$_2$

550 ppm is the low emissions scenario for 2100

Hauri et al. 2013
Intensity and Duration of Under-saturation in the CCE (Hauri et al. 2013)

- ROMS-Ecosystem Model, 2 day mean interval, bottom shelf waters
- $\Omega$ Threshold = 1

**Intensity** = Threshold - $\Omega_{\text{mean}}$

**Duration** = Days > Threshold

- Increasing CO$_2$(atm) increases **Intensity** and **Duration** of extreme events
- System is beginning to change more rapidly, and will accelerate
- Adjusting the thresholds to biological (bivalve larval) relevance (~2.0)?
Oregon Estuaries pH- Connection to upwelling

Wind data from OrCOOS- NDBC 46050, pH from South Slough NERR

2002 earlier spring transition or stronger upwelling

2005 later spring transition or weaker upwelling
What does this mean for bivalves in these habitats and the people dependent on them for a living?
Pacific Northwest Oyster Seed Crisis

The New York Times
Saturday, October 21, 2012
Environment

Environmental

A Blog About Energy and the Environment
By Leslie Kaufman

Study Links Raised Carbon Dioxide Levels to Oyster Die-Offs

Acidity in ocean killed NW oysters, new study says
Researchers said Wednesday they have conclusive evidence that ocean acidification is at least partly responsible for killing oysters on the West Coast.

By Craig Welch
Seattle Times environment reporter
Whiskey Creek Shellfish Hatchery

PCO₂ (µatm) Time Series
Running Daily Average

Hales and Vance unpub
Carbonate Chemistry, Frequency, and Biology

- Process timescale:
  - M2 tides
  - Diurnal NCP
  - Diurnal tides
  - Storms
  - Upwelling
  - Fornightly tides
  - Monthly tides
  - Seasonal NCP
  - Annual drivers
  - ENSO
  - PDO/NAO
  - Anthropogenic CO2
  - Milankovich
  - Geologic change

- Biological organizational level:
  - Shell formation
  - Larval period
  - Conditioning
  - Recruitment
  - Populations
  - Communities
  - Evolution

Waldbusser and Salisbury 2014
Bivalve Life History and Bottlenecks

approximately 2 weeks

floating fertilized egg → swimming straight-hinge veliger → swimming late veliger → swimming & crawling pediveliger

Oyster Life Cycle

spat settling and attaching to oyster shells or other hard structures

1 - 3 years

Credit: Karen R. Swanson/COSEE SE/NSF
Anthropogenic CO$_2$ has in some years shorted the “Ω window of opportunity” for natural oyster reproduction, and in other years it hasn’t had any impact...
Ocean Acidification impacts manifest later...

Over 50% of the hatchery production is explained by $\Omega_A$ in the first 48 hours!

Barton et al., 2012
Why Saturation State Should Matter...

1) Within 48 hours, 80-90% of body weight is added as CaCO₃

2) Calcification surfaces more “exposed”.

3) Until this, feeding not possible, and energy is limited.

\[ r = k(\Omega - 1)^n \]

- \( r \) = calcification rate
- \( k \) = rate constant
- \( \Omega \) = saturation state
- \( n \) = rate order (1)

1) Rate of Calcification!

Waldbusser et al., 2013
Decoupling Carbonate Parameters to Understand Larval Bivalve Responses
Environmental Relevance

- Saturation state changes more quickly than pH
- Closer to saturation state thresholds
Saturation state is the primary variable of importance for these larvae.

Little to no pH impact until very low values, and only in undersaturated conditions.

Same pattern in shell length of NORMAL larvae.

Waldbusser et al. 2015

M. gallo C. gigas
Comparison of Native and Non-native Mussel Larvae

*M. californianus versus M. galloprovincialis*
Comparison of Native and Non-native Mussel Larvae

Hanging out in a OA Hot-spot doesn’t seem to help *M. californianus*

Waldbusser et al. 2015b
What about Native Oysters?
This doesn’t mean *O. lurida* are impervious to OA, excellent work on chronic/carry-over effects by Hettinger et al.

*O. lurida* in prep

Waldbusser et al.
Calcification Rates

**O. lurida**
calcification rate is > 7x slower during the same development stage!!!

Waldbusser et al. in review
The U.S. West Coast Shellfish Industry:
1) Believes OA is happening
2) Have felt the impacts of OA
3) Believes they can adapt
4) Looks to take the lead in adapting

Mabardy et al. 2015
Although we are seeing OA effects on the oyster industry in the PNW, it may not be the most vulnerable to OA impacts on industry...

Our efforts in the PNW have allowed the industry to rebound and we continue to help implement adaptation strategies.
OA as a Multiple Stressor

Same experiments looking at respiration rates and a feeding metric in *M. californianus*
Respiration Rate responds to pH (as expected).

Proportion Feeding to $P_{CO2}$.

Waldbusser et al. 2015b
Methods (decoupling carbonate variables)

Manipulating DIC and Total Alkalinity to “decouple” carbonate system parameters.
Methods

Closed Bottle Incubations (500 ml BOD bottles)

Shell Development and Length of Normal Shells
48 hrs and 120 hrs

16 chemistry treatments, with 3 replicates each + several controls
Triplicate counts for development
Measured shell length of all “Normal” larvae

End up scoring ~100 larvae per sub-replicate, and have ~60 BOD bottles...

Only Acute Effects
For the normally developed larvae, decreases in saturation state make smaller larvae. Smaller scope for growth means making shell is more expensive, or something else is requiring more energy.
While climate change is a global phenomenon, to an organism, all relevant environmental changes are very local as the organism moves through space and time. (Helmuth et al. 2010)