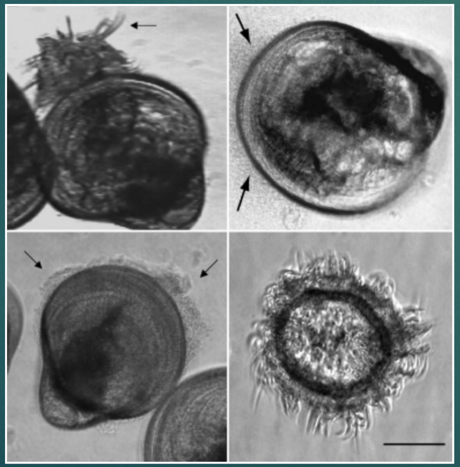
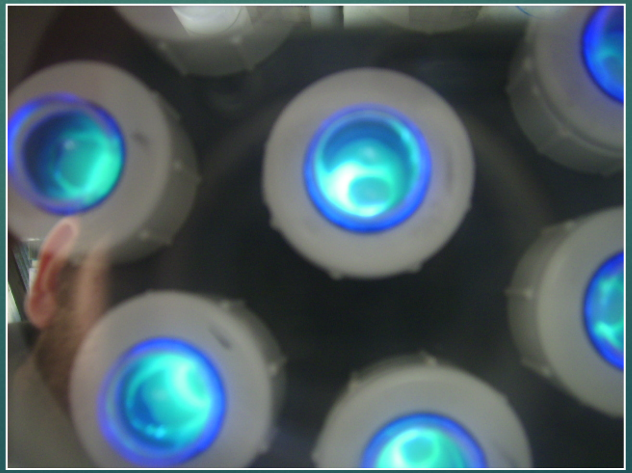
OA Impacts on the Pacific Northwest Oyster Industry

RESILIENCE THROUGH COLLABORATION AND ADAPTATION

Summer 2005

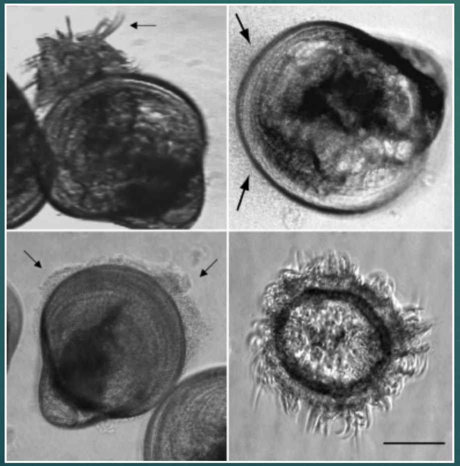
- Unusual and persistent mortality events at Molluscan Broodstock Program Hatchery/Nursery in Newport, OR
- Led to development of treatment systems targeted toward eliminating *vibrio tubiashii* from incoming seawater by Spring 2007

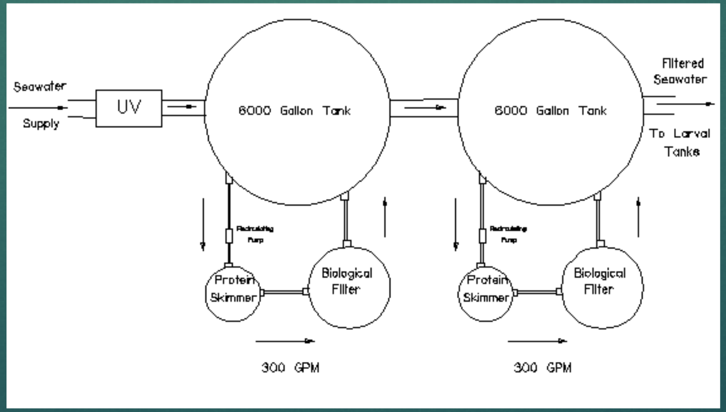




Fall 2007

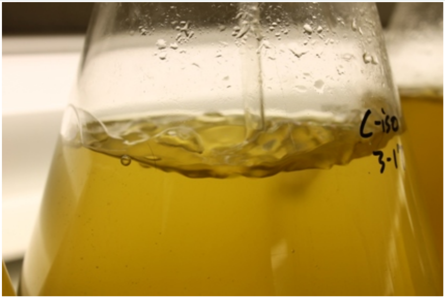
- Prolonged larval mortality at Whiskey Creek Shellfish Hatchery led to near-zero production throughout late summer / fall 2007
- Systems developed at MBP were upgraded to commercial scale for use at Whiskey Creek in 2008 growing season





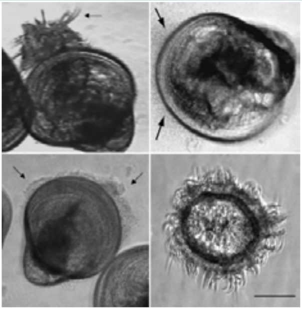
Spring 2008

- Treatment systems proved ineffective at improving production at Whiskey Creek
- Series of trials were conducted to investigate other potential causes of larval mortality



Feeding trials

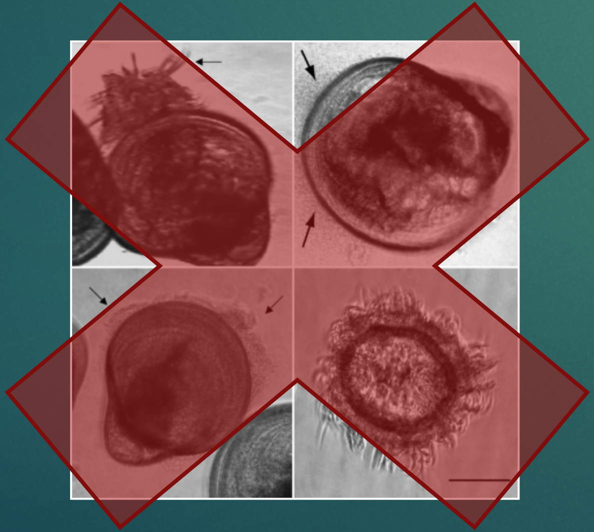
Broodstock Trials

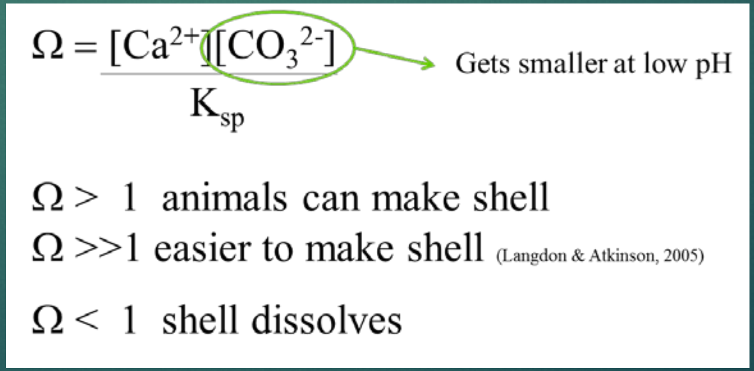


Vibrio Monitoring

July 2008

- Massive mortality in larvae of all size classes at Whiskey Creek
- Major upwelling event along the Oregon Coast transported low pH (7.6) seawater into Netarts Bay
- Managers shifted focus of research toward investigating the impacts of carbonate chemistry on larval survival





$$\Omega = \frac{[Ca^{2+}]\boxed{[CO_3^{2-}]}}{K_{sp}} \longrightarrow \text{Gets smaller at low pH}$$

$\Omega > 1$ animals can make shell

$\Omega >> 1$ easier to make shell (Langdon & Atkinson, 2005)

$\Omega < 1$ shell dissolves

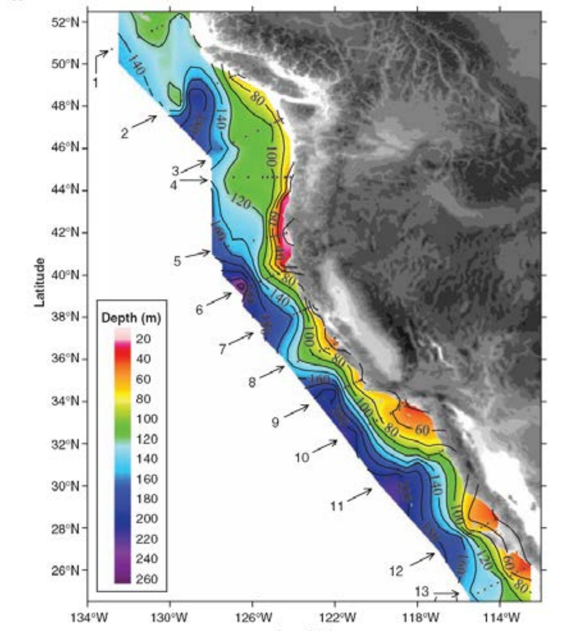
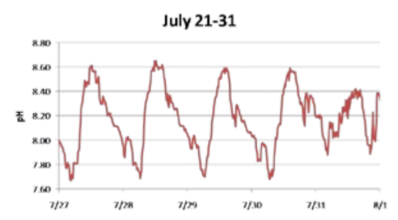


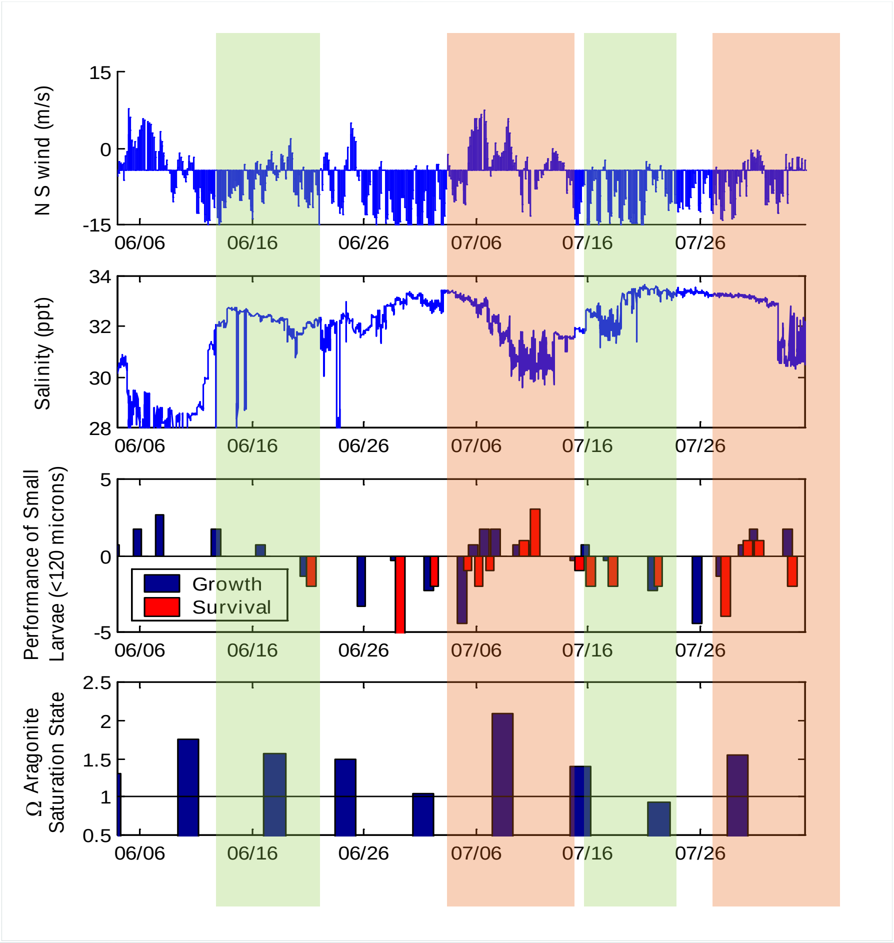
Fig. 1. Distribution of the depths of the undersaturated water (aragonite saturation < 1.0; pH < 7.75) on the continental shelf of western North America from Queen Charlotte Sound, Canada, to San Gregorio Baja California Sur, Mexico. On transect line 5, the corrosive water reaches all the way to the surface in the inshore waters near the coast. The black dots represent station locations.

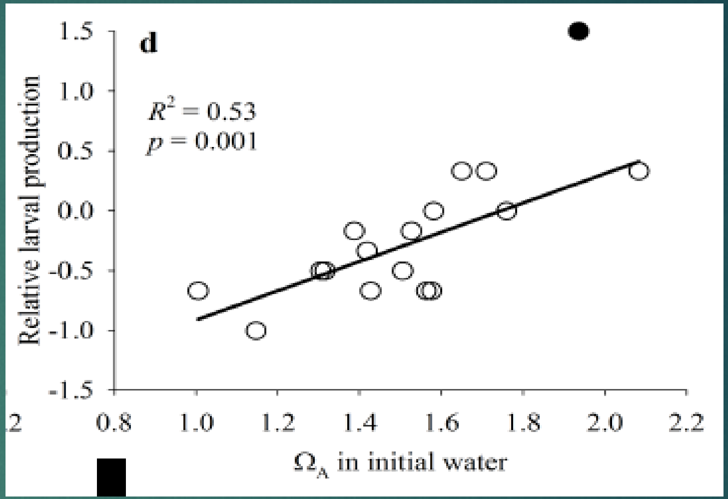
Summer 2009

- Comprehensive monitoring program initiated at Whiskey Creek in close collaboration with Oregon State University (Burke Hales lab)
- Comparison of monitoring data with hatchery production records showed a strong correlation between saturation state of spawn water and ultimate survival of larvae groups
- Commercial egg development bioassays confirmed the connection between initial spawn chemistry and ultimate survival of larval groups (‘carryover’ effects related to mortality by day 12)



2009 data published in Barton et al 2012





South winds produce downwelling

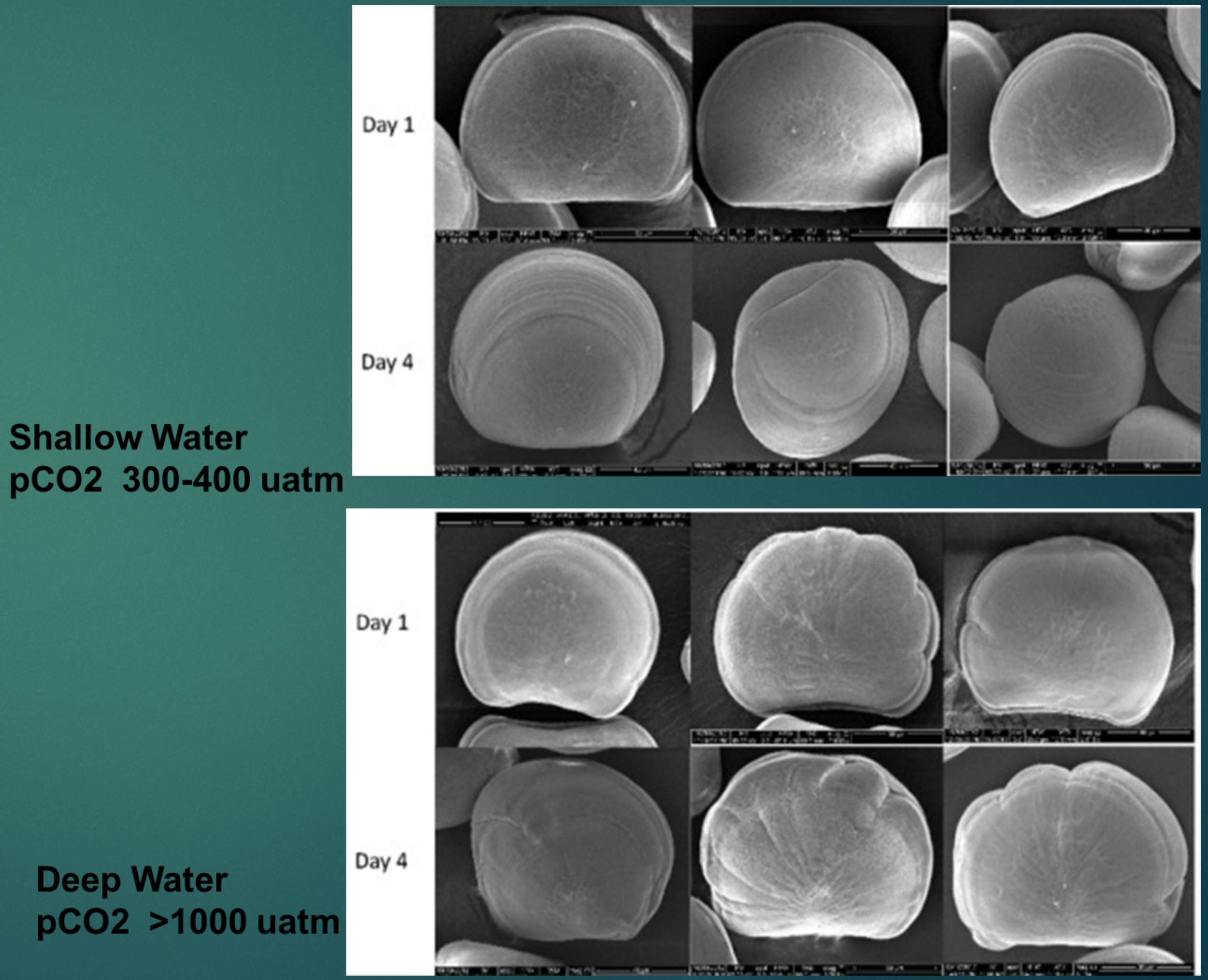
🟩
Lower salinity
$\Omega >> 1$ (easy to form shell)
Fast growth and good survival of small larvae

North winds produce upwelling

🟫
Higher salinity
$\Omega <= 1$ (difficult to build shell)
Poor growth and mass mortality of small larvae

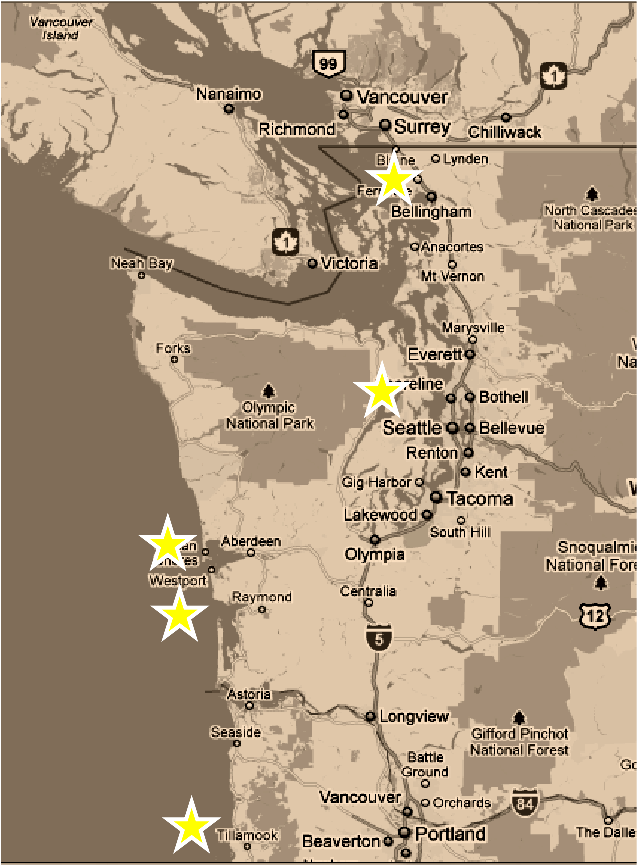
Spring 2010

- Formalized relationship between Whiskey Creek and the Waldbusser lab at OSU
- Work conducted by the Waldbusser lab provided insight into the mechaisms behind larval mortality observed in 2009



Spring 2010

- Award from Senator Maria Cantwell’s office/NOAA funds the PCSGA Monitoring Program
- Monitoring stations established in six areas of commercial importance to the shellfish industry
- Funding allowed construction of continuous pCO2 monitoring systems (‘Burkilators’) for hatchery sites



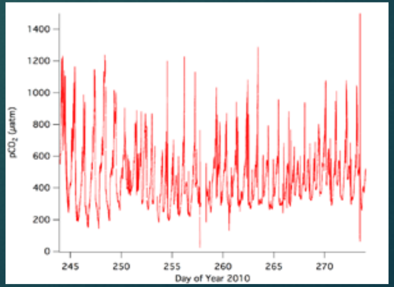
★ **Bellingham, WA-** Lummi Hatchery

★ **Dabob Bay, WA-** Taylor Shellfish Hatchery

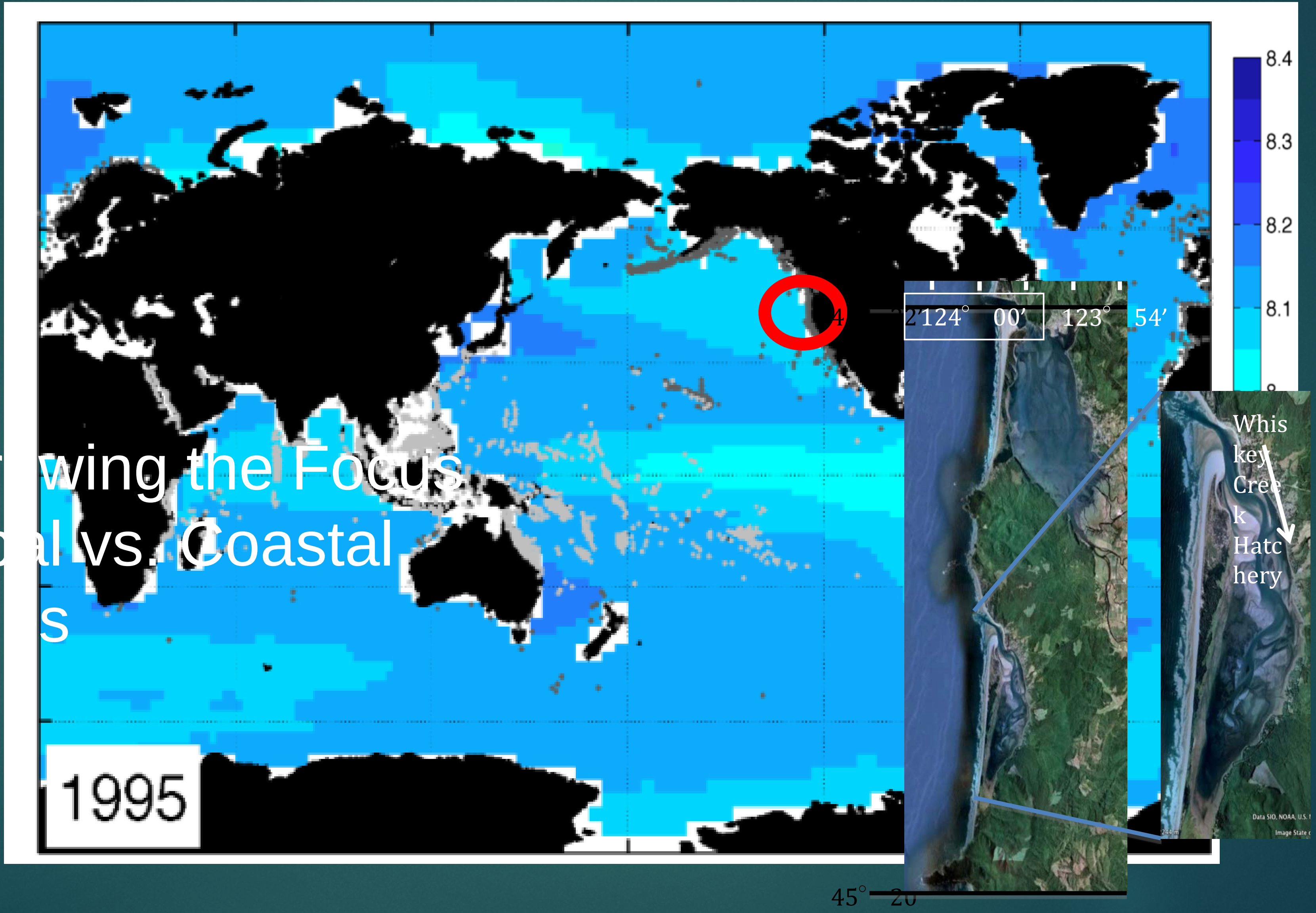
★ **Gray’s Harbor, WA-** setting stations

★ **Willapa Bay, WA-**
Tokeland, Bay Center, and
Nahcotta monitoring stations

★ **Netarts Bay, OR-**
Whiskey Creek Shellfish Hatchery



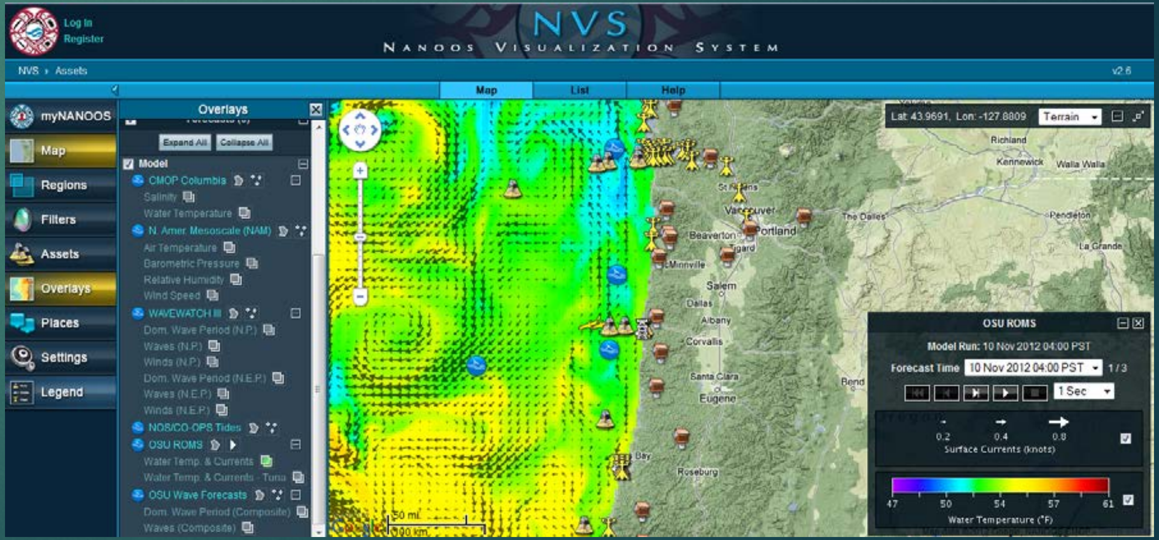
Narrowing the Focus – Global vs. Coastal Scales



Narrowing the Focus – Global vs. Coastal Scales

July 2010

- C-CAN workshop in Costa Mesa, CA
- Provided a forum for interaction between researchers, shellfish growers, and government agencies
- Ultimately resulted in definition of benchmarks for data quality (Ω measured within +/- 0.2)
- Helped formalize connection between PCSGA Monitoring efforts and IOOS web portal



Lat: 43.9691, Lon: -127.8809

Model Run: 10 Nov 2012 04:00 PST

Forecast Time 10 Nov 2012 04:00 PST 1 / 3

Summer 2011

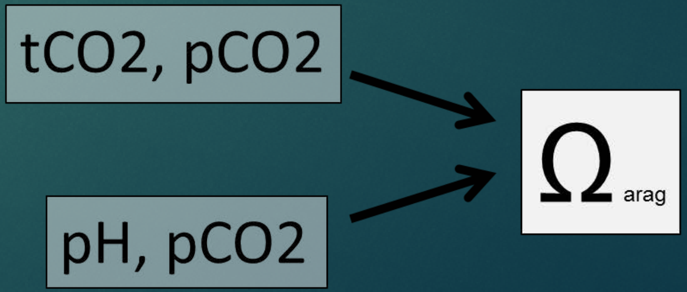
- Upgrade of monitoring equipment at Whiskey Creek allows near real time calculation of Ω through measurement of tCO2 and pCO2
- Addition of Durafet pH probes allows for independent calculation of Ω from several pairs of measured carbonate system parameters

Continuous measurement of *Saturation State*

$$\Omega = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp}}$$

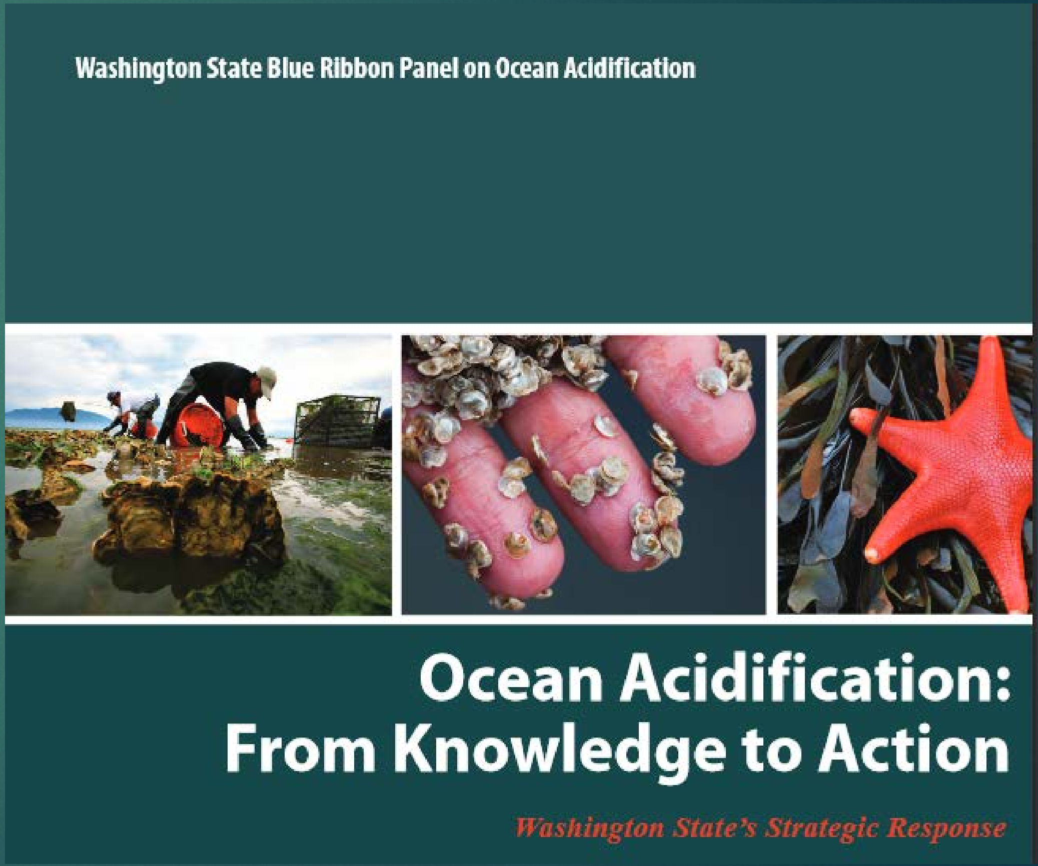
California Current Acidification Network (C-CAN) criteria-

Ω within +/- 0.2



Spring/Summer 2012

- WA state convenes a Blue Ribbon panel of Ocean Acidification experts
- Panel recommendations lead to formation of the WA Ocean Acidification Center
- Recommendations lead to additional funding for the PCSGA Monitoring Program, and funding for research to mitigate OA's impacts on commercial hatcheries
- Separate award from the OR legislature provides support for monitoring at Whiskey Creek, and for selective breeding to mitigate OA impacts on the PNW oyster industry



Washington State Blue Ribbon Panel on Ocean Acidification

Ocean Acidification:
From Knowledge to Action

Washington State's Strategic Response

FY 2013-2014 NOAA Activities

- NOAA funds development of three Burke-o-lators installed at shellfish growing sites in California and Alaska
- FY 2014 award ‘Turning the Headlights on High’ supports development of low cost pCO2 sensors to be deployed in important shellfish growing areas

OAP
NOAA OCEAN ACIDIFICATION PROGRAM

IOOS®
INTEGRATED
OCEAN
OBSERVING
SYSTEM

Putting Larvae in the Box

ADAPTATION STRATEGIES ADOPTED IN COMMERCIAL SHELLFISH HATCHERIES

Commercial Oyster Farming

Hatchery Production of Eyed Oyster Larvae

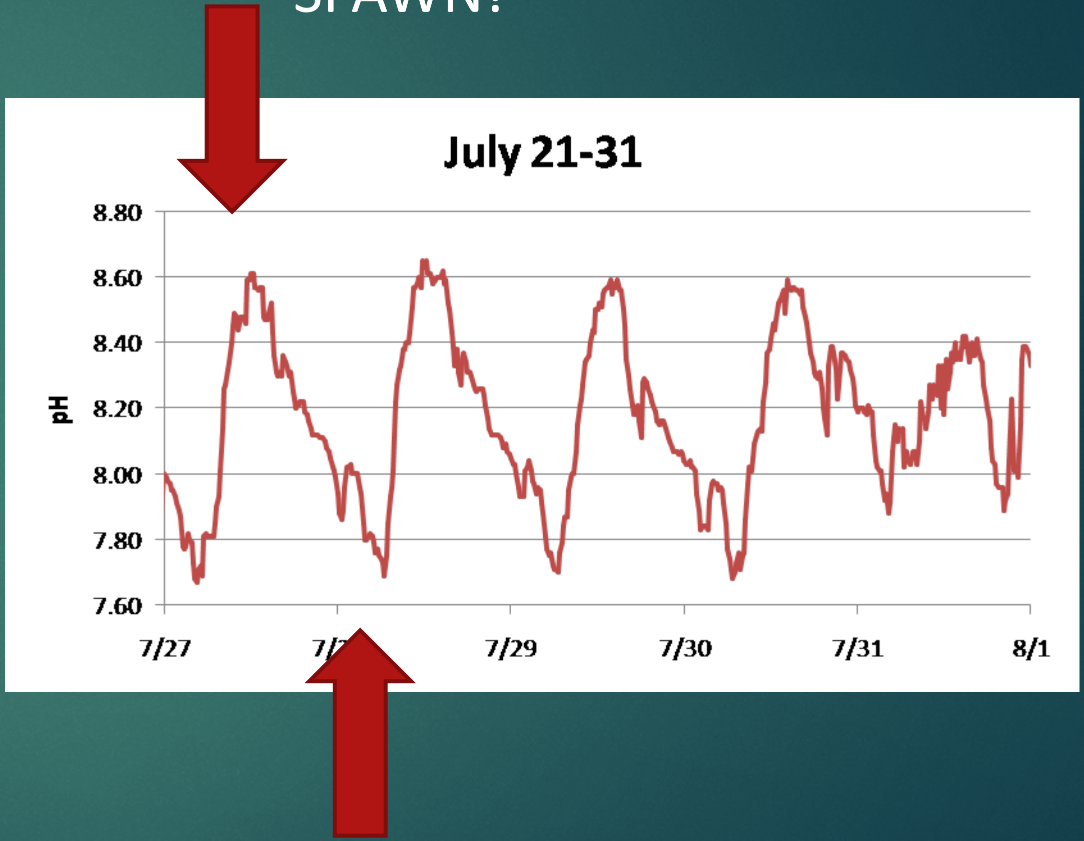
Plantout and Harvest of Adult Product

Managing around the problem

- **Put small larvae into tanks filled in the afternoon or overnight**
  - **- Works if the suns out**

- 24 hour notice- Upwelling takes a day or two to start up, so when winds from the North, fill tanks late in the day and spawn like crazy

SPAWN!



DON’T SPAWN!

Managing around the problem

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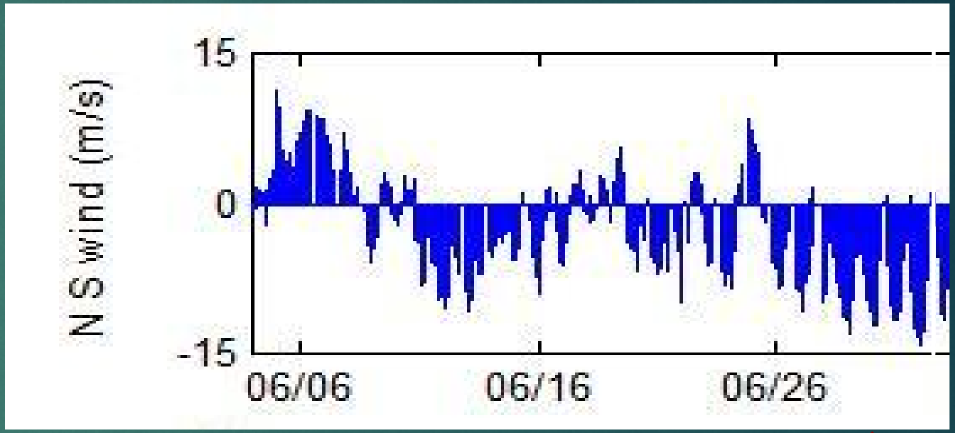
- **24 hour notice- Upwelling takes a day or two to start up, so when winds from the North, fill tanks late in the day and spawn like crazy**



SPAWN LOTS!

DON'T SPAWN!

Seawater Treatment Systems - pH

Automated buffering systems installed in 2011 maintain constant pH in seawater supplied to the hatchery

Early season high pCO2 effects on larvae are very different than late season high pCO2 effects on larvae

- Early Summer - Direct Effects of Upwelling

  - Elevated pCO2 concentrations (and lower pH)

  - Slow growth and mass mortality of *small* larvae after 10-12 days

- Late Summer / Fall - Indirect Effects of Upwelling

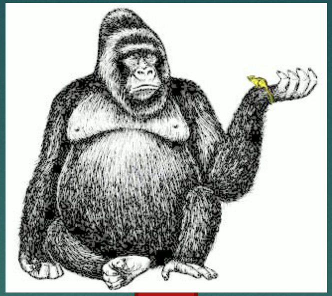
  - Prolonged upwelling through the summer leads to high concentrations of decaying organic matter and low O_2, high pCO_2 concentrations

  - Mortality of larvae of *all sizes* in the hatchery

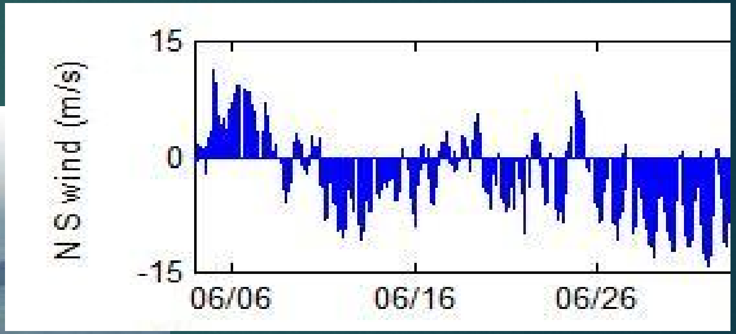
Seawater Treatment Systems – O_2 / ORP

Automated systems installed in 2013 maintain
High oxygen saturation in seawater supplied to the hatchery

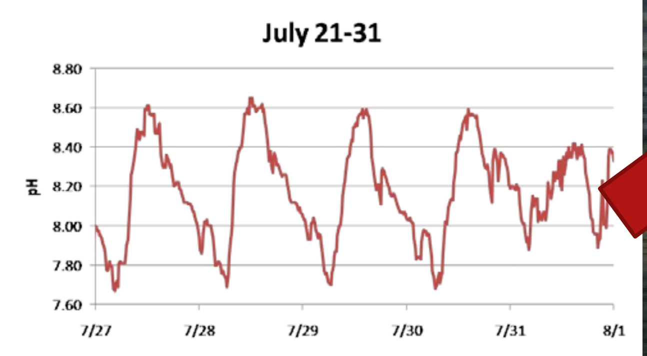
Drivers of pH variability observed in Netarts Bay



400 ppm

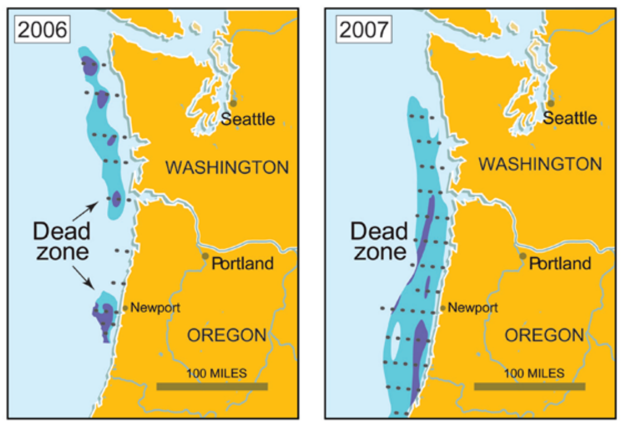


Photosynthesis and respiration of eelgrass/benthic macroalgae within Netarts Bay



Intrusion/relaxation of low pH, deep ocean water upwelled across the continental shelf and into Netarts Bay

Drivers of low DO concentrations observed in Netarts Bay

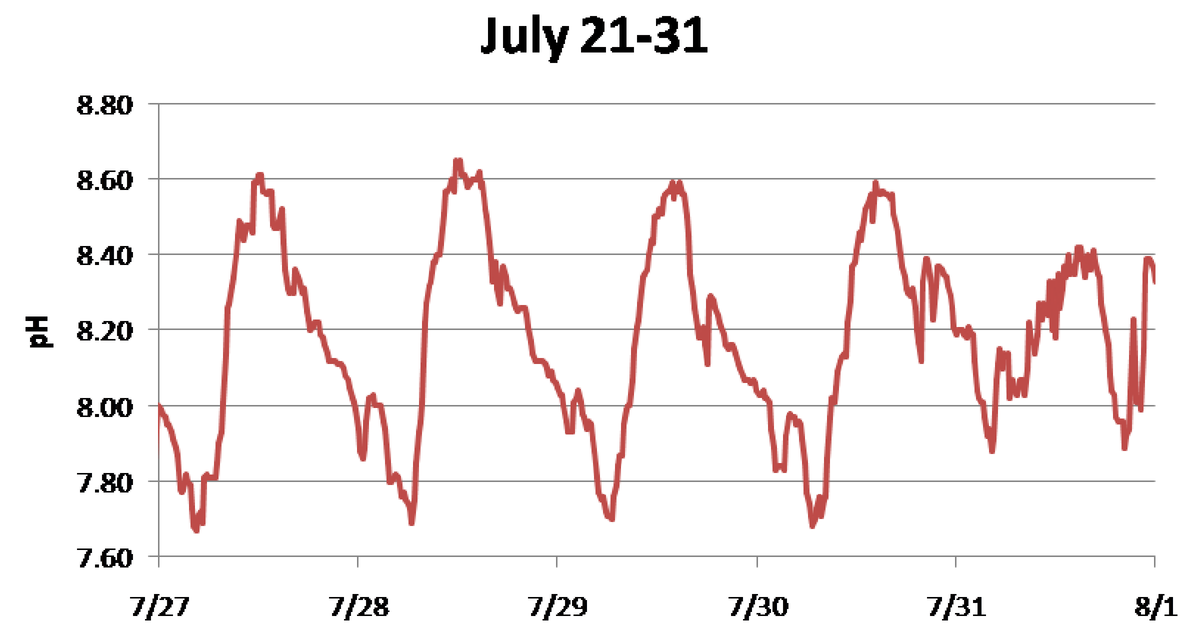


Decomposition of organic matter generated by photosynthesizers within Netarts Bay

Decomposition of organic matter generated by prolonged upwelling throughout the summer months

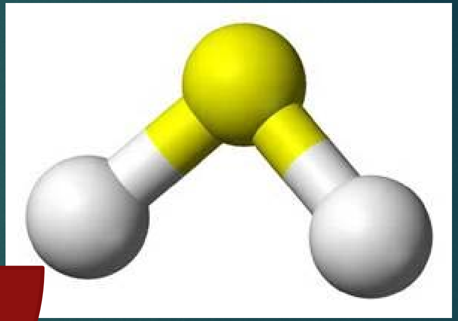
The "Butterfly Effect"

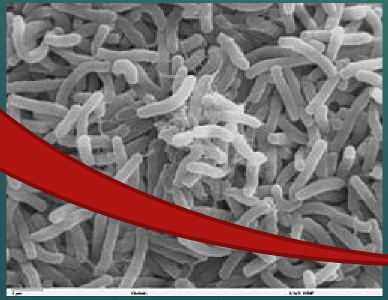
Non-linear respones
to acidification in
Coastal estuaries



Aren’t we done yet?!

Changes in speciation of compounds in coastal zone, particular in complexes with organic matter





Bacterial blooms associated with decomposing organic matt

Increased magnitude and duration of HABs over the continenta shelf

OA Impacts on the Pacific Northwest Shellfish Industry

Resilience through Collaboration and Adaptation

Oregon State University OSU College of Earth, Ocean, and Atmospheric Sciences

Ocean acidification impacts on the Pacific Northwest oyster industry: Resilience through collaboration and adaptation

George G. Waldbusser and many others

Oregon State University Hatfield Marine Science Center
Newport, Oregon

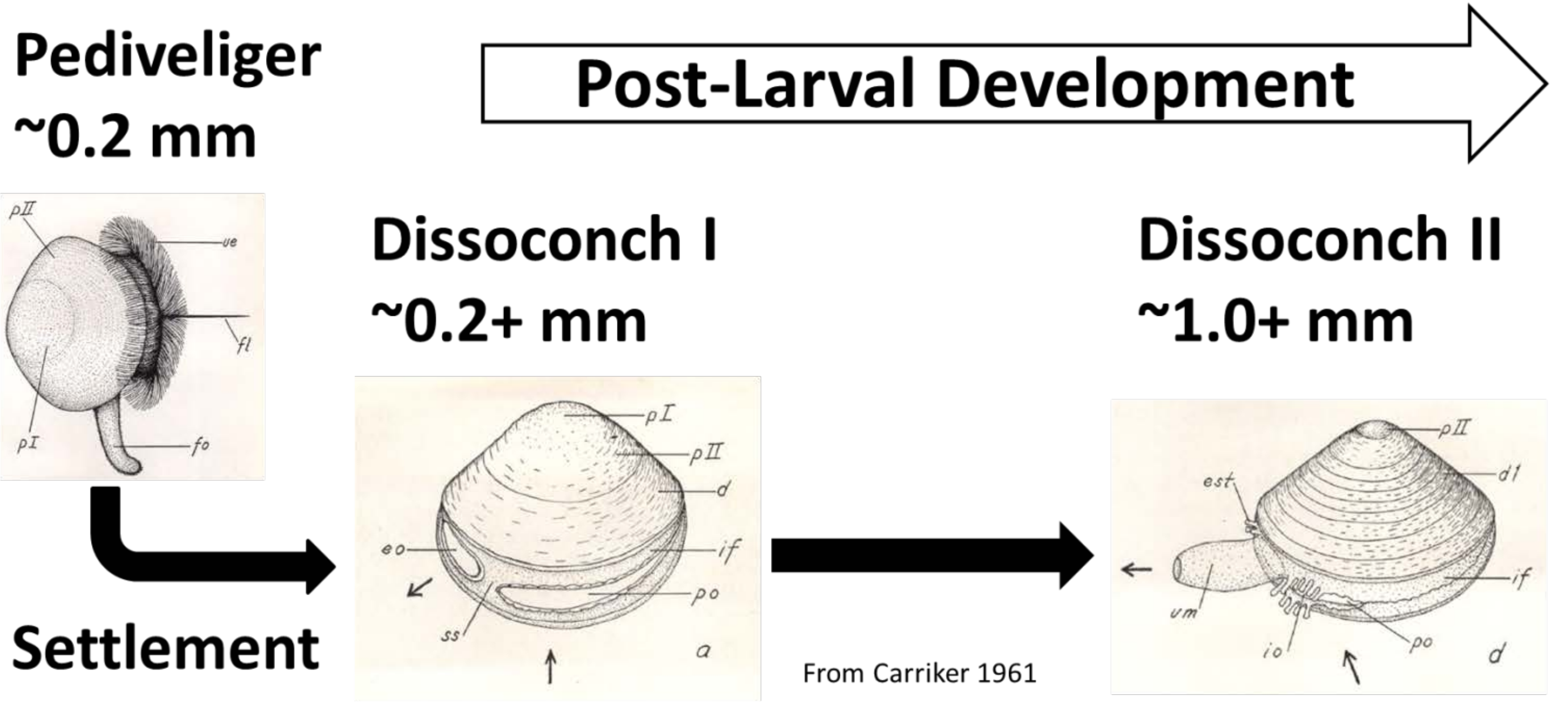
NSF

Sea Grant Oregon
Coastal Science Serving Oregon

I received a phone call from Mark Wiegert early in 2010…

-Lazy Larvae when CO_2 is high
-Poor production and survival

I was finishing up work with Mark Green on juvenile hard clams…



Pediveliger
~0.2 mm

Post-Larval Development

Dissoconch I
~0.2+ mm

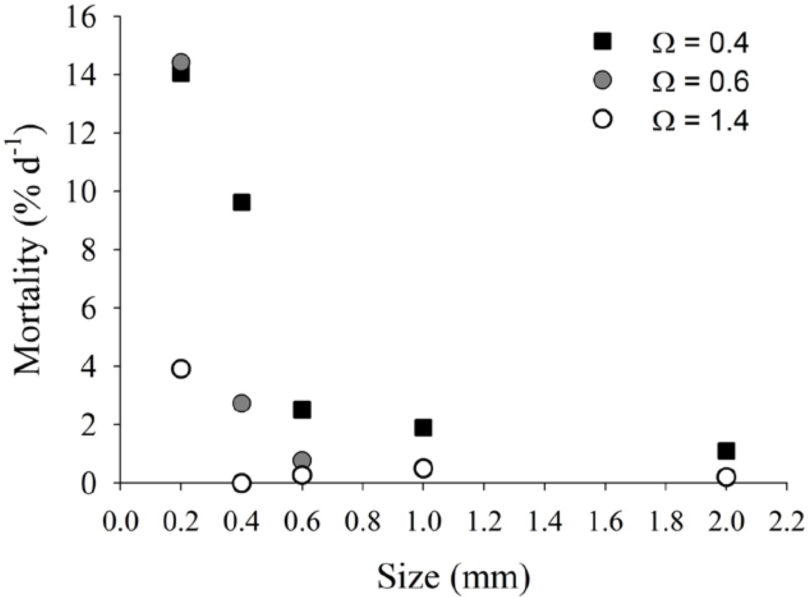
Dissoconch II
~1.0+ mm

Settlement

From Carriker 1961

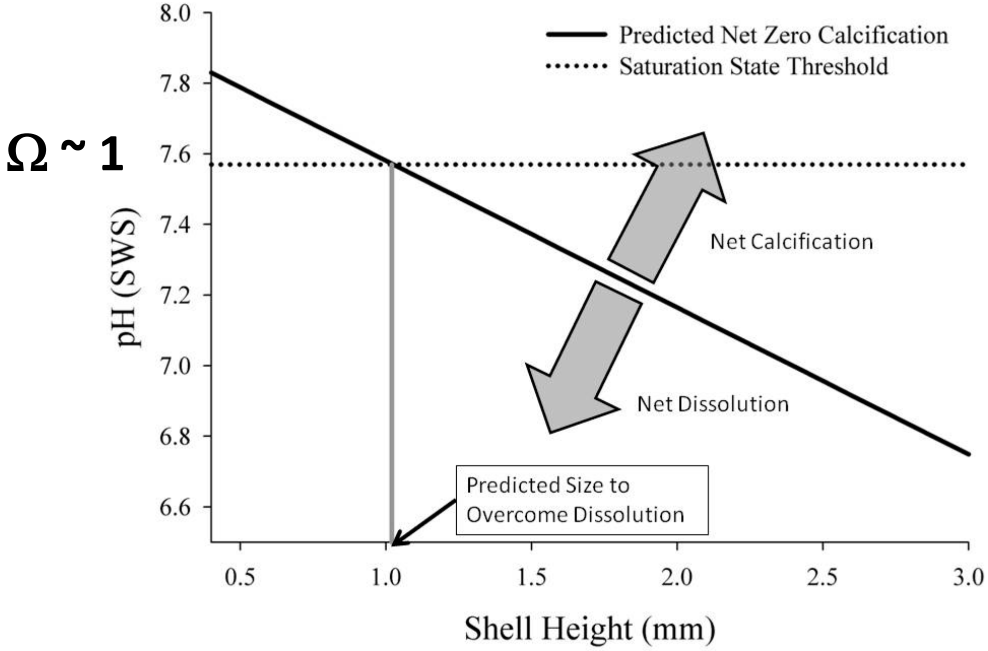
A couple important clues (from hard clams)

Survival



Green et al. 2004, 2009

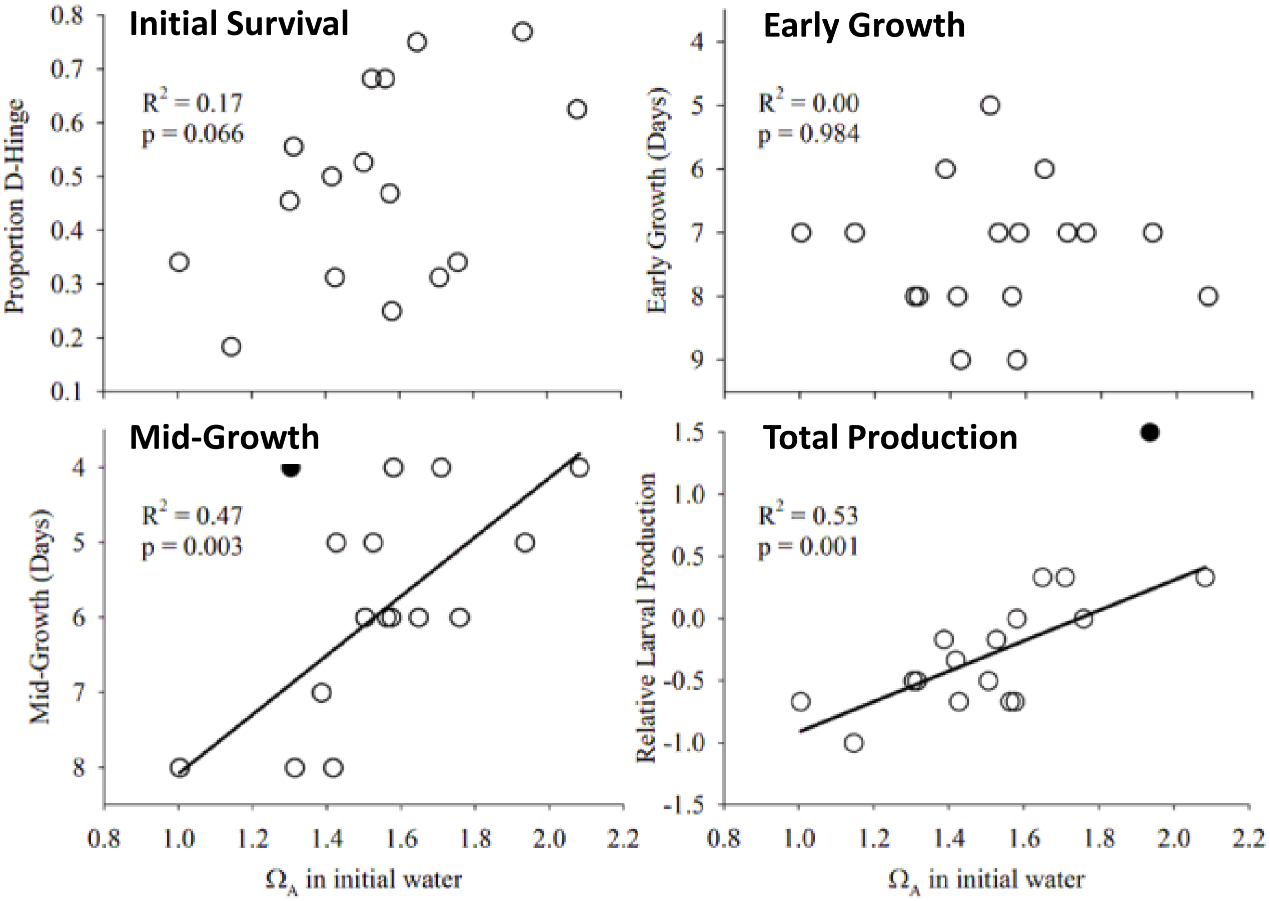
Growth



Waldbusser et al. 2010

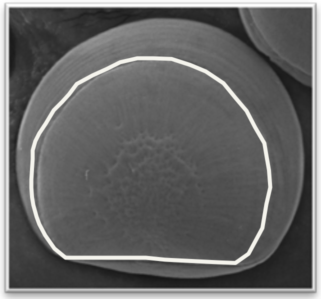
Effects were size dependent ***(temporally variable)*** *and appeared to be related to an energetic bottleneck…*

Sub-Lethal OA impacts manifest later…

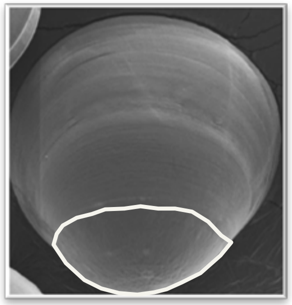


Barton et al., 2012

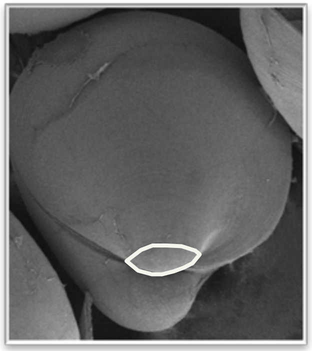
Initial Survival



Early Growth



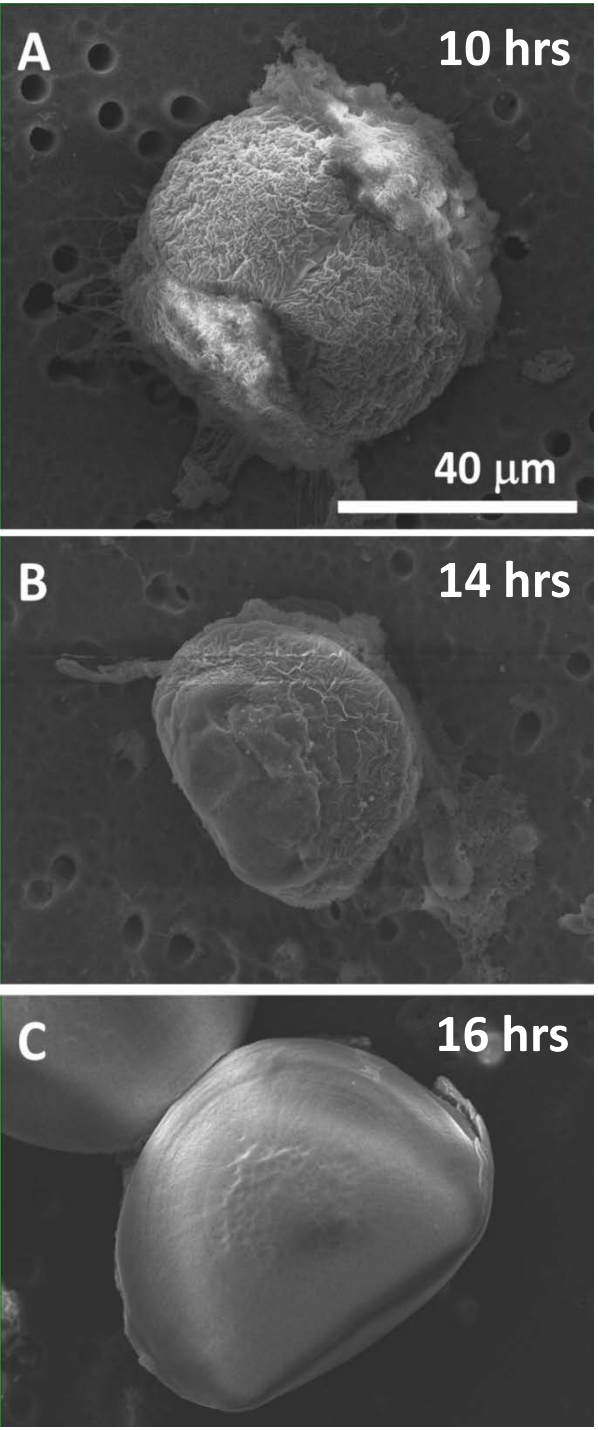
Mid-Growth

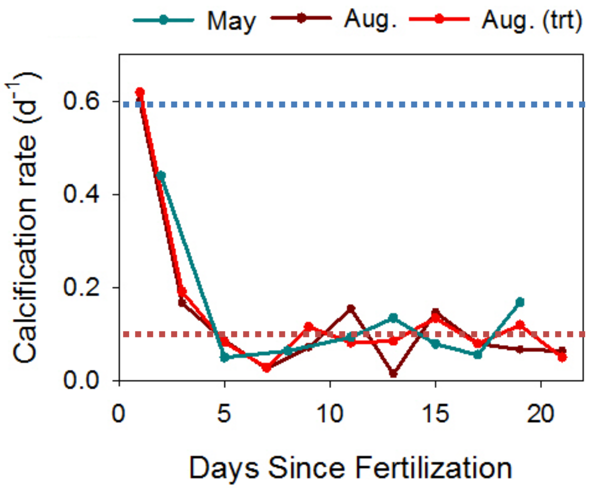


$$$

Over 50% of the hatchery production is explained by Ω_A in the first 48 hours!

Why Ω Matters at this Stage…





Brunner et al. in prep

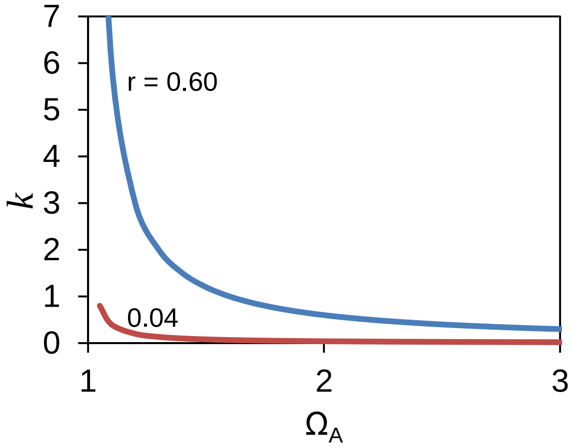
1) Within 48 hours, 80-90% of body weight is added as $CaCO_3$

2) Calcification surfaces more "exposed".

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

$$r = k(\Omega - 1)^n$$

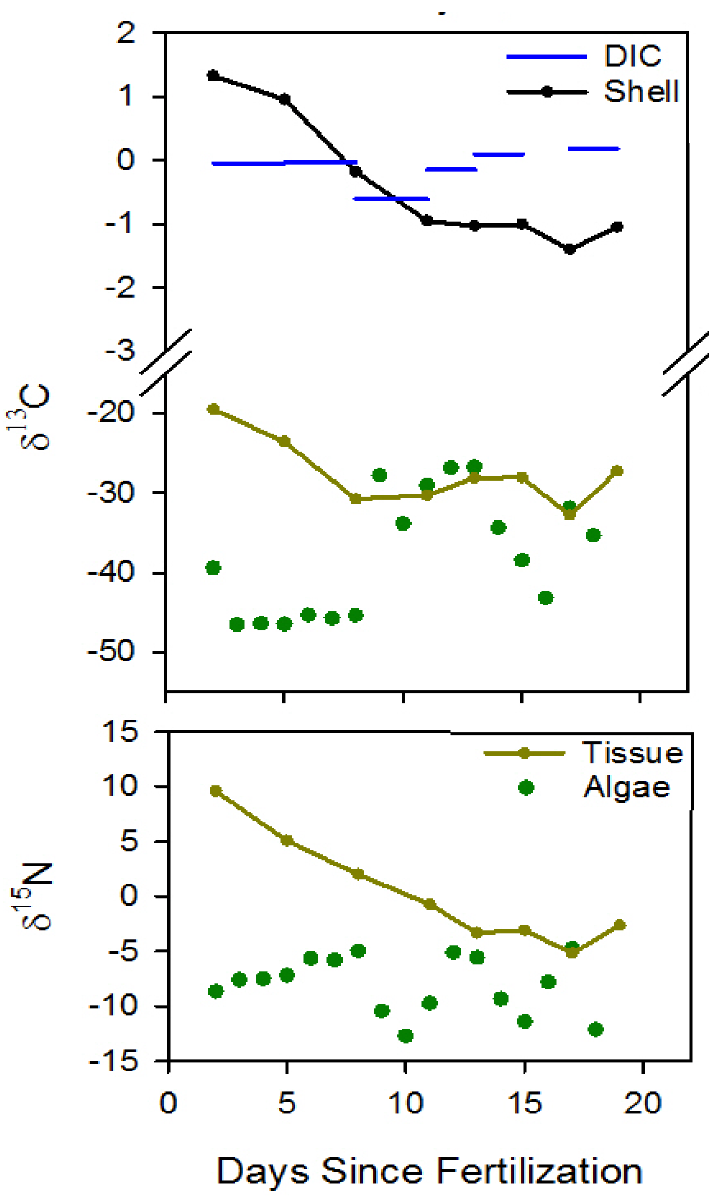
r = calcification rate
k = rate constant
Ω = saturation state
n = rate order (1)



1) Rate of Calcification!

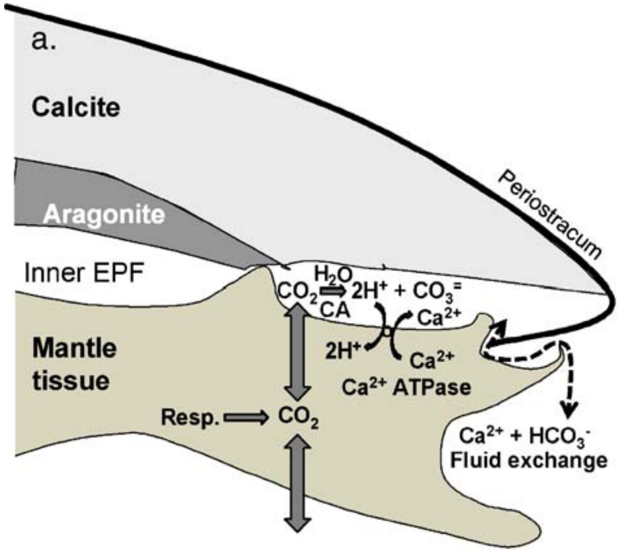
Waldbusser et al., 2013, in press

Support for Direct Saturation State Sensitivity



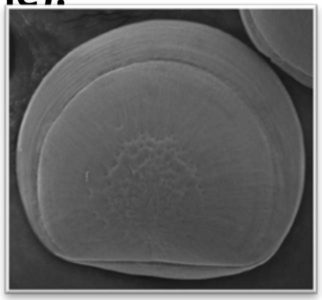
Waldbusser et al. 2013, Brunner et al (in prep)

2) More light Carbon indicates better control of calcification site

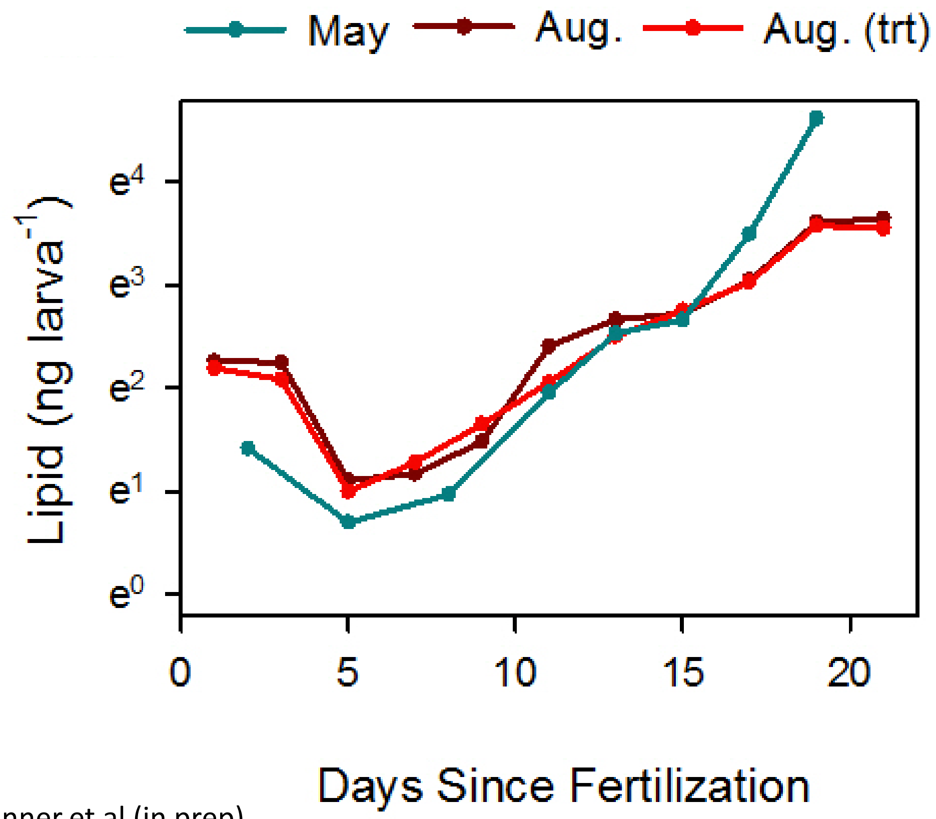


From McConnaughey & Gillikin 2008

3) Cannot feed until D-hinge shell is made, and larvae hit energetic low 5-7 days (lazy larvae syndrome).



Egg reserves provide energy for initial shell formation



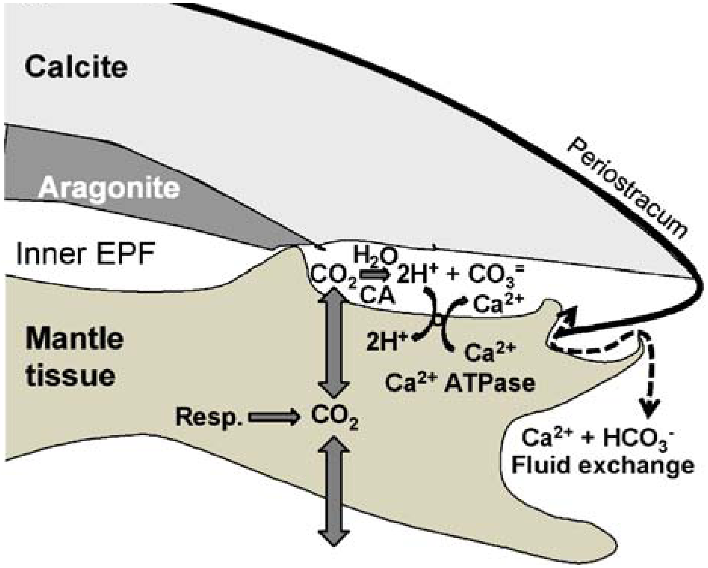
Brunner et al (in prep)

Egg size sets the larval “lunch bag”

Calcification is biologically mediated and requires energy to accelerate

$$r = k(\Omega - 1)^n$$

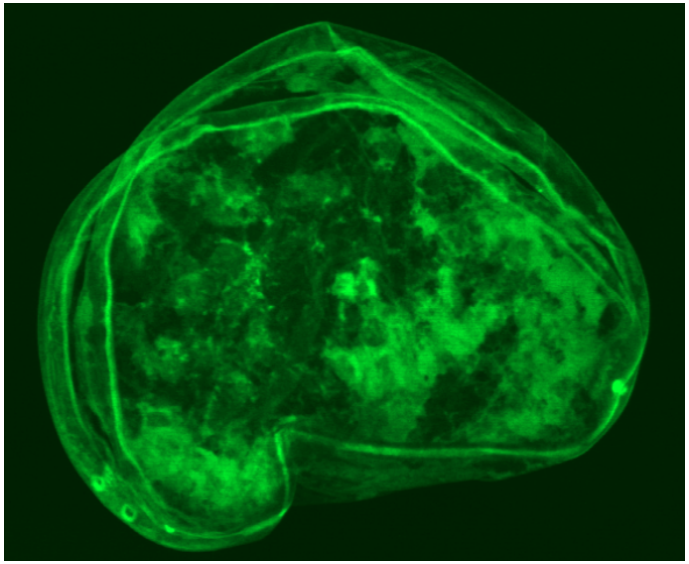
Proton-pumping to maintain Ω_A



McConnaughey & Gillikin 2008

Different bivalves (as adults) have different ability to seal the EPF.

Organic matrix (protein) synthesis

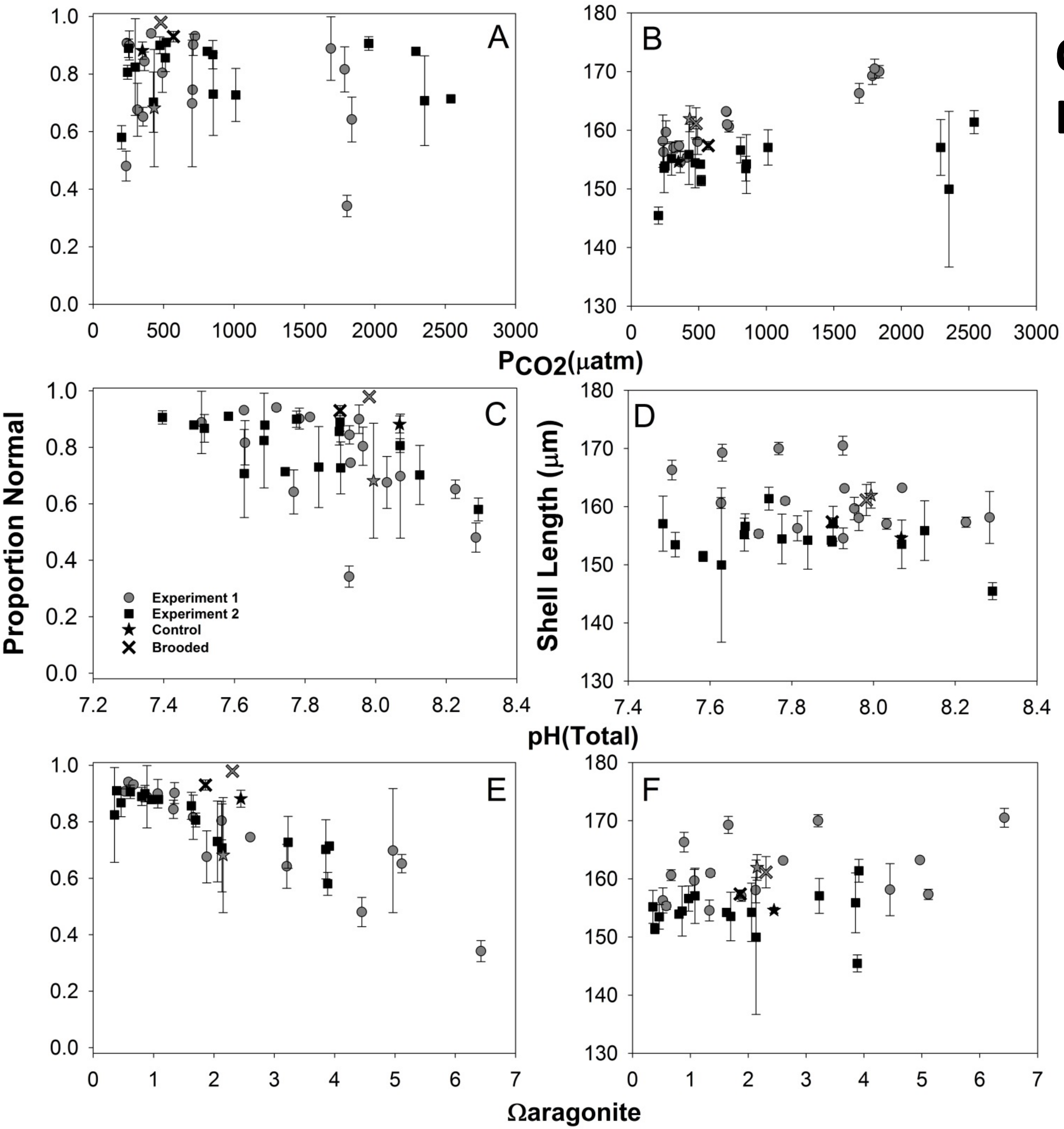


Weiss & Schonitzer, 2006

This is where the bulk of energy is associated with shell formation.

In sea urchin larvae OA energy reallocation is greater to protein synthesis than cross membrane ion pumps (Pan et al. 2015)

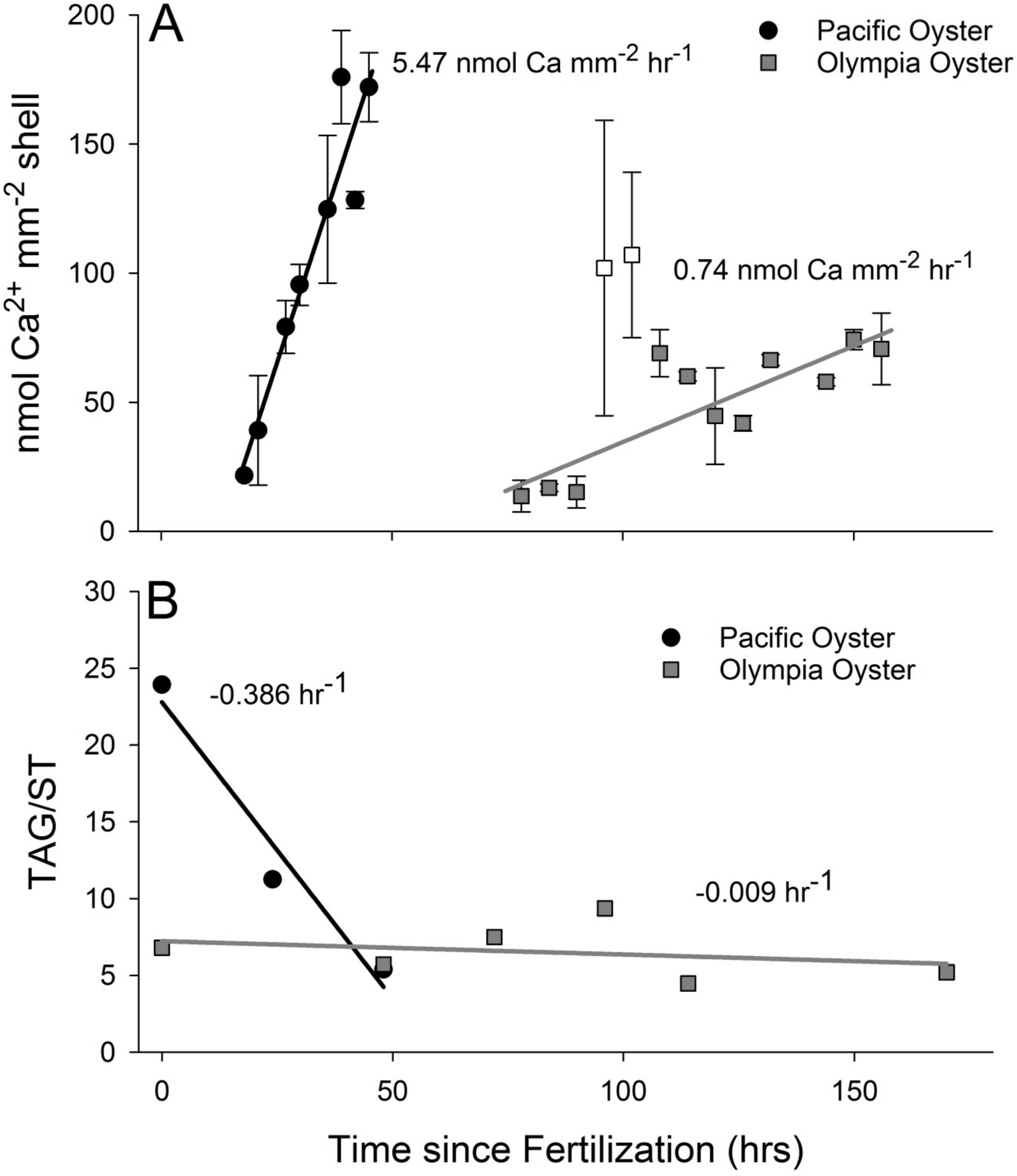
Olympia Oyster Larvae



During the same developmental stage so sensitive for Pacific Oysters, Olympia Oyster Larvae show no acute response.

WHY?

Waldbusser et al. in review



Waldbusser et al. in review

First Shell Calcification

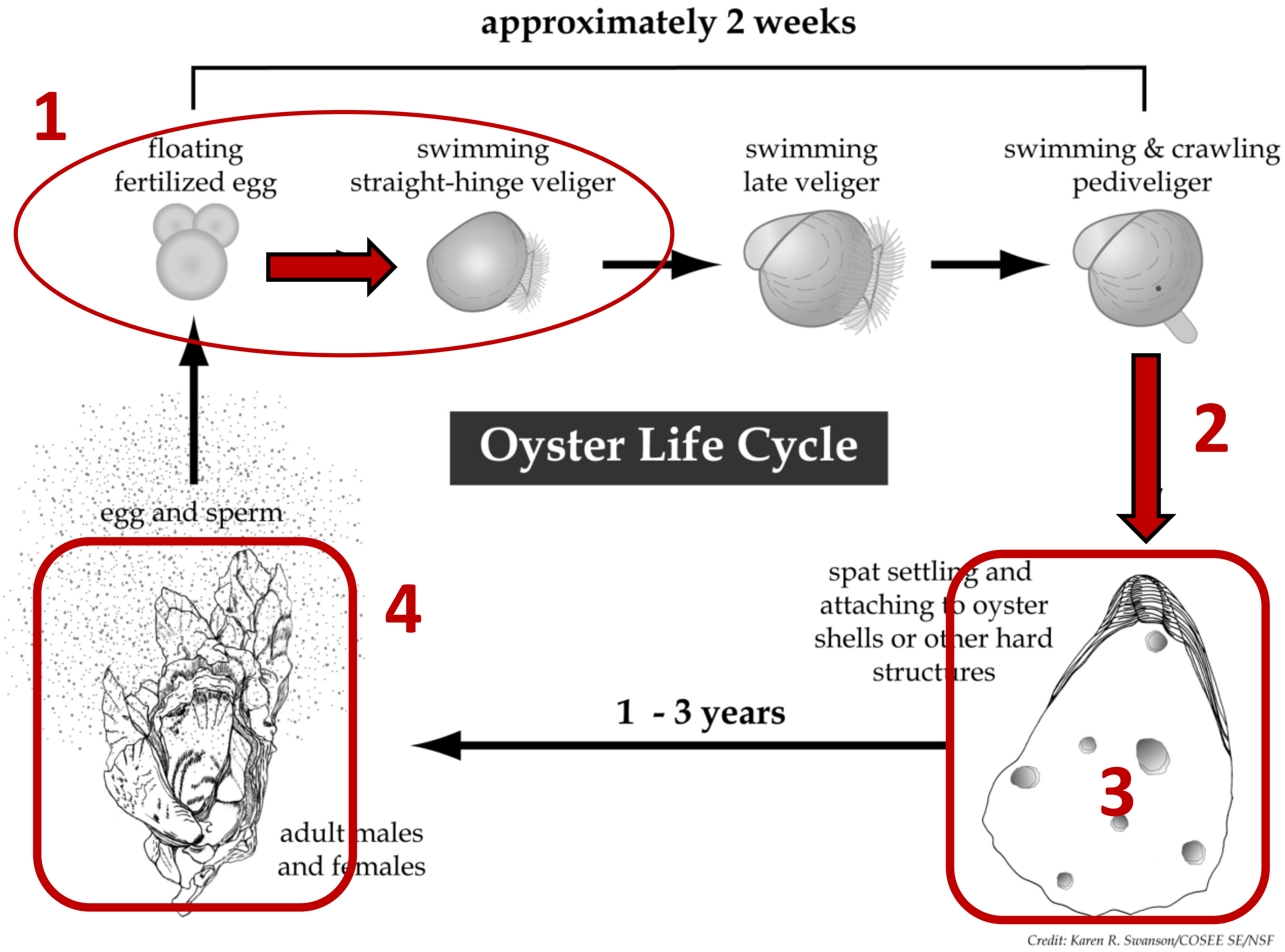
How Fast…

Energy Consumption

How Expensive…

Important to note total lipids are higher in Olympia oyster larvae, but the allocation of energy lipids to structural lipids is ~ 5x lower.

Life History Bottlenecks…

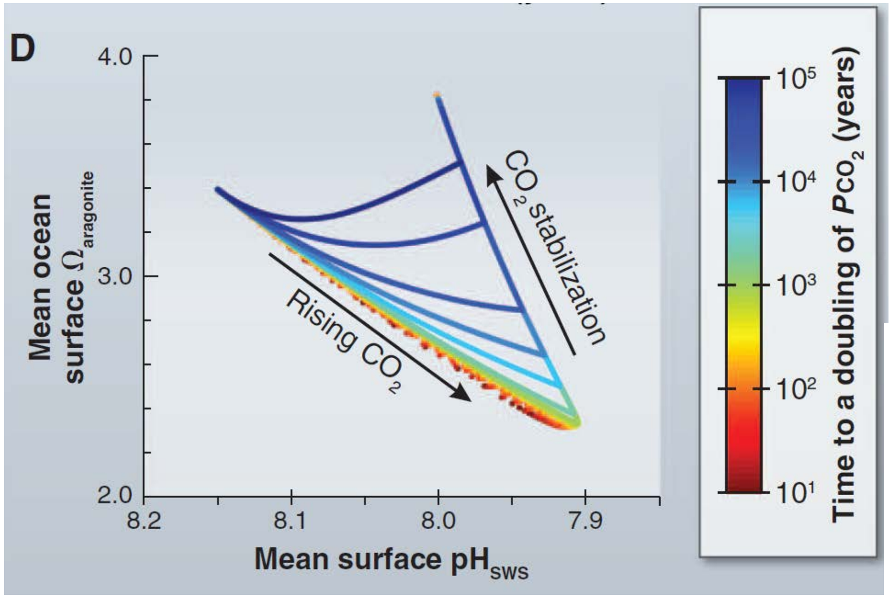


Credit: Karen R. Swanson/COSEE SE/NSF

It's not that other points don't matter, but these are especially critical periods

Environmental Relevance

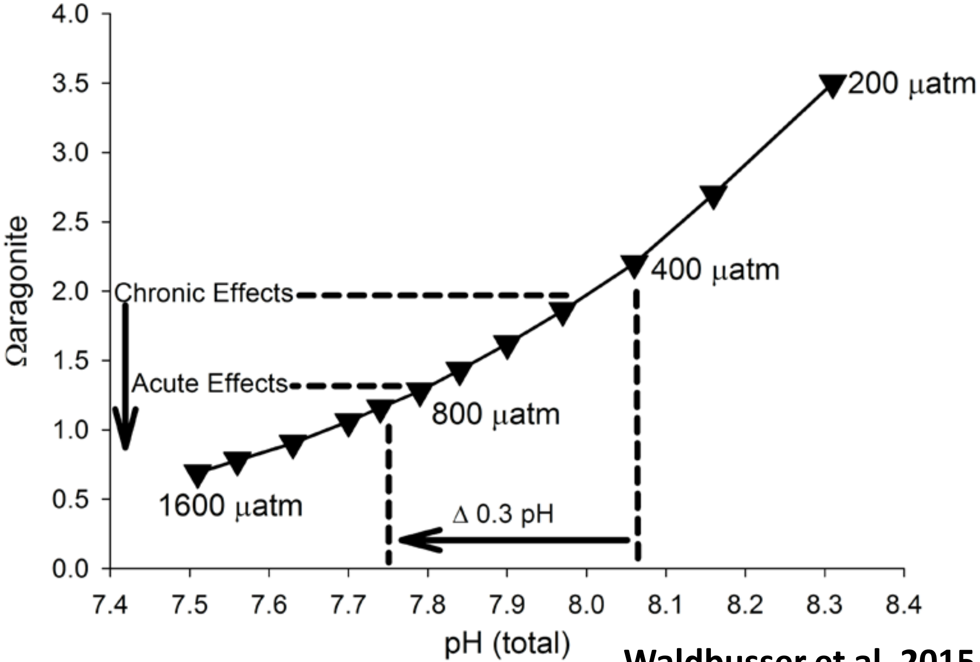
1. Differences between past and today CO_2 changes



Hönisch et al. 2012

2. In coastal zones and estuaries freshwater inputs will change alkalinity.

3. Variables in the carbonate system do not respond linearly to increasing CO_2.

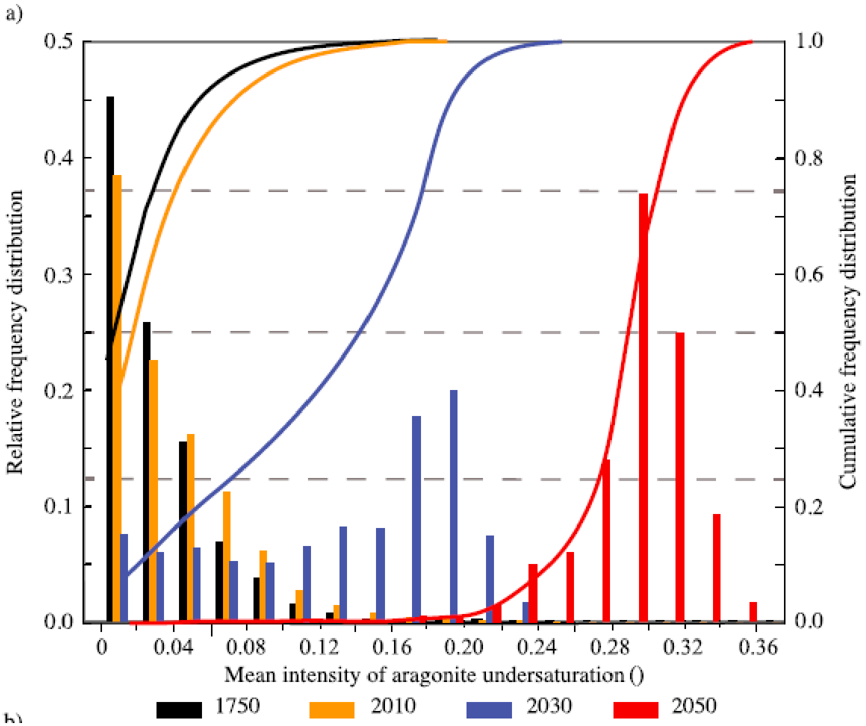


Waldbusser et al. 2015

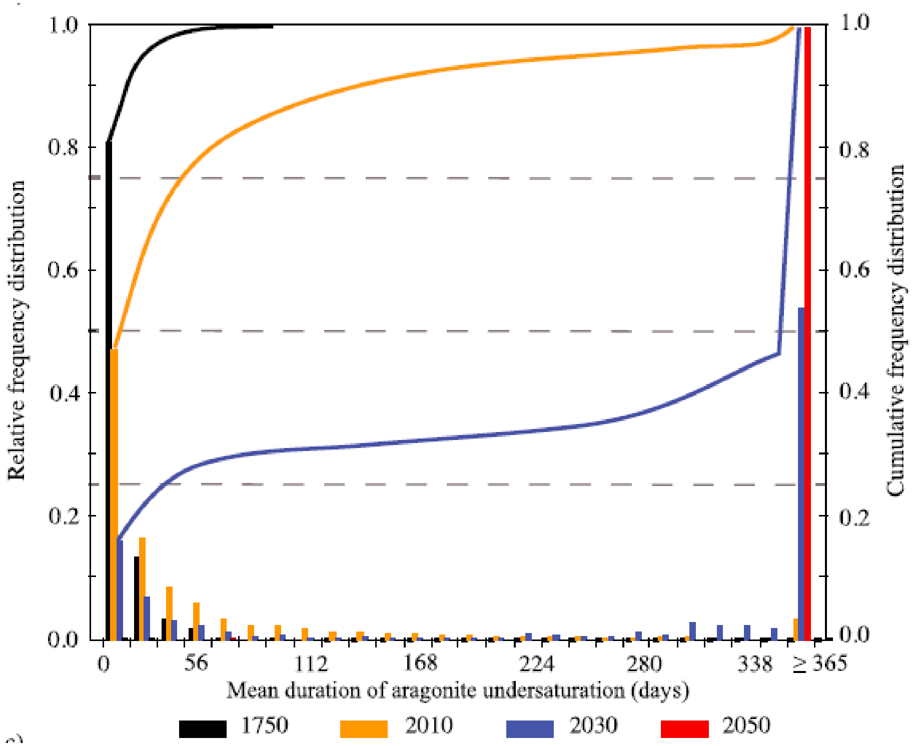
Frequency, Magnitude, and Duration… (Hauri et al. 2013)

Model Projections for the California Current Ecosystem

Intensity = Threshold - Ωmean



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)?

Optimal Physical Conditions for Larval Development in Willapa Bay (Hales et al. in review)

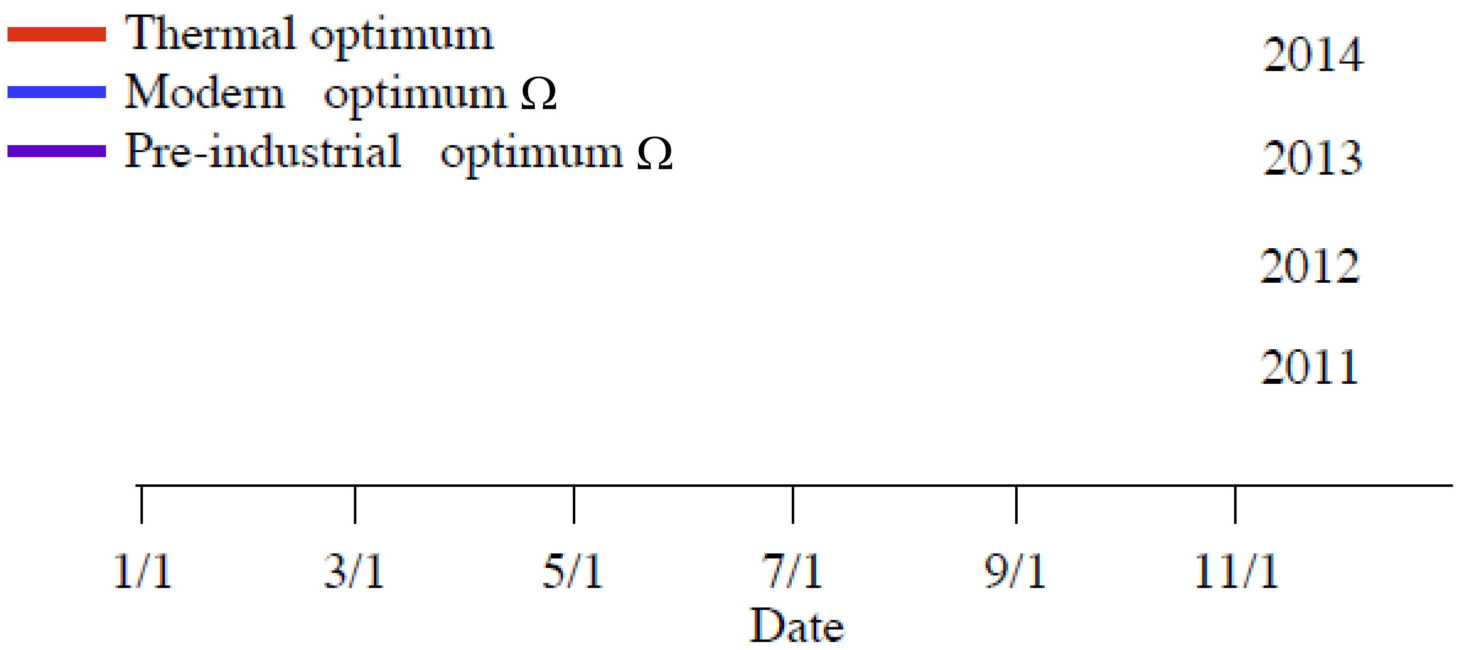
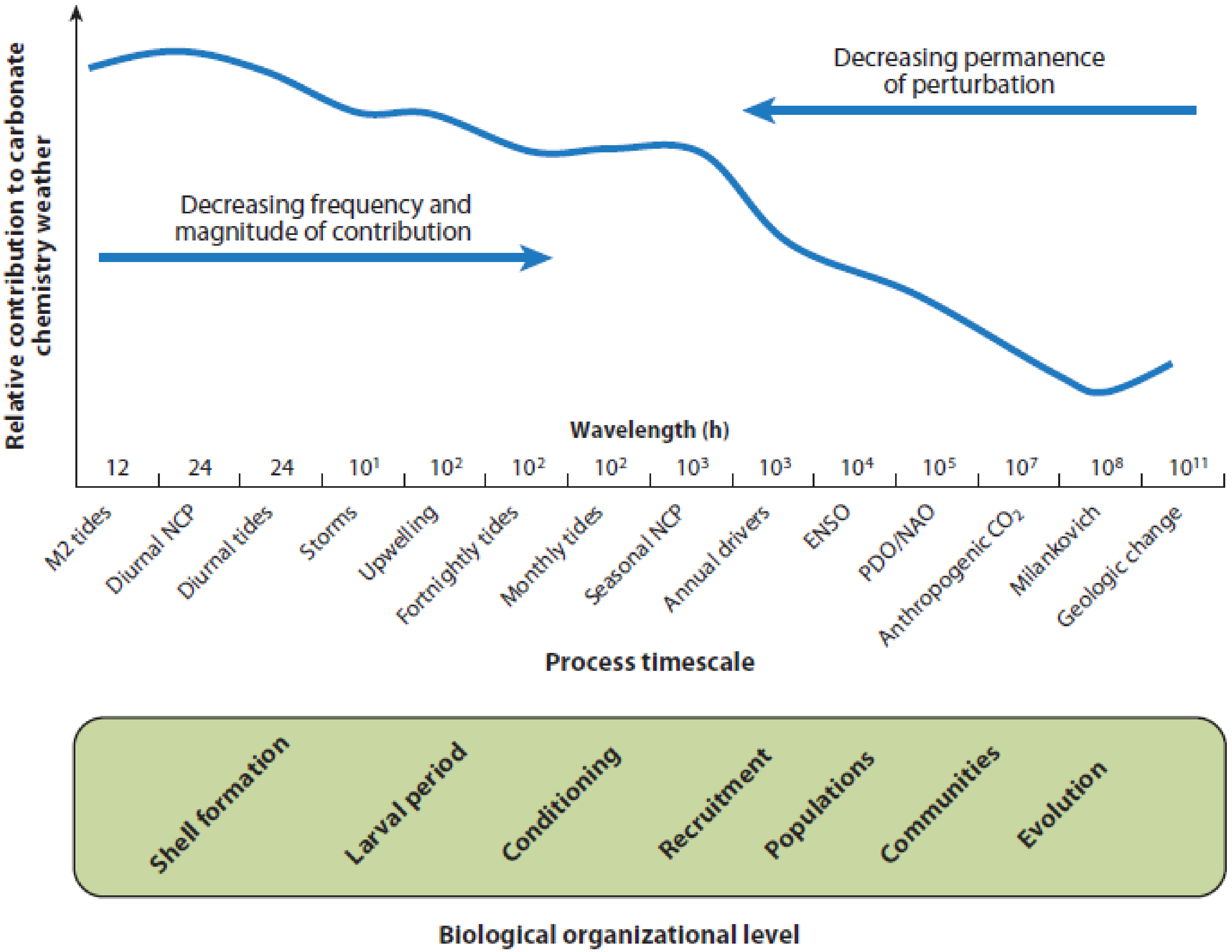


Figure 6. Intervals of thermal (red bars) and Ω_{ar} optimum conditions, for both modern (blue bars) and estimated pre-industrial conditions (purple bars; See Figure 7).

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…

So Timing and Traits are (nearly) Everything…



Waldbusser and Salisbury 2014

So Timing and Traits are (nearly) Everything…

and that's where much of the effort has and is being put into adapting (stakeholders) to new chemistry regimes in the ocean.

Hatcheries are only one component of the production cycle (but an important one).

Back to Alan