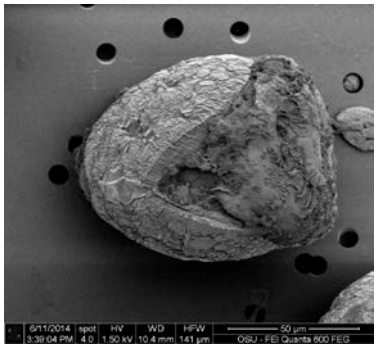
Oregon State UNIVERSITY OSU College of Earth, Ocean, and Atmospheric Sciences

A Crash-course in Ocean Acidification: Shellfish Edition

George G. Waldbusser, Burke Hales, and many others



Oregon State University Hatfield Marine Science Center Newport, Oregon

Sea Grant Oregon Coastal Science Serving Oregon

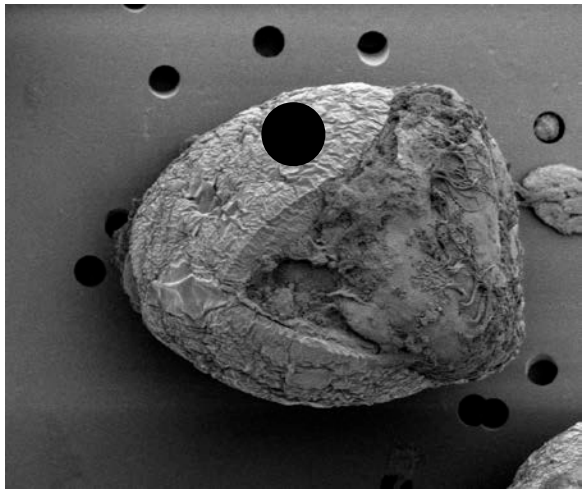
NSF

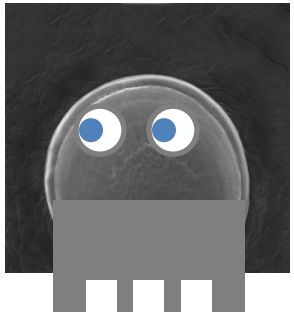
NOAA

USDA

Outline

1. Ocean Acidification: The Basics
2. Ocean Acidification: Local Scales
3. Other species responses (non-bivalves)
4. The Whiskey Creek Story and Oyster Seed Crisis
5. Bivalve Responses to OA (focus on larvae)
6. Adaptation strategies





SEATTLE BIKE BLOG

About Advertise Subscribe Bicycle Benefits Bike Maps Stolen Bikes Events Calendar

← FamilyRide: Mapping our bike corrals

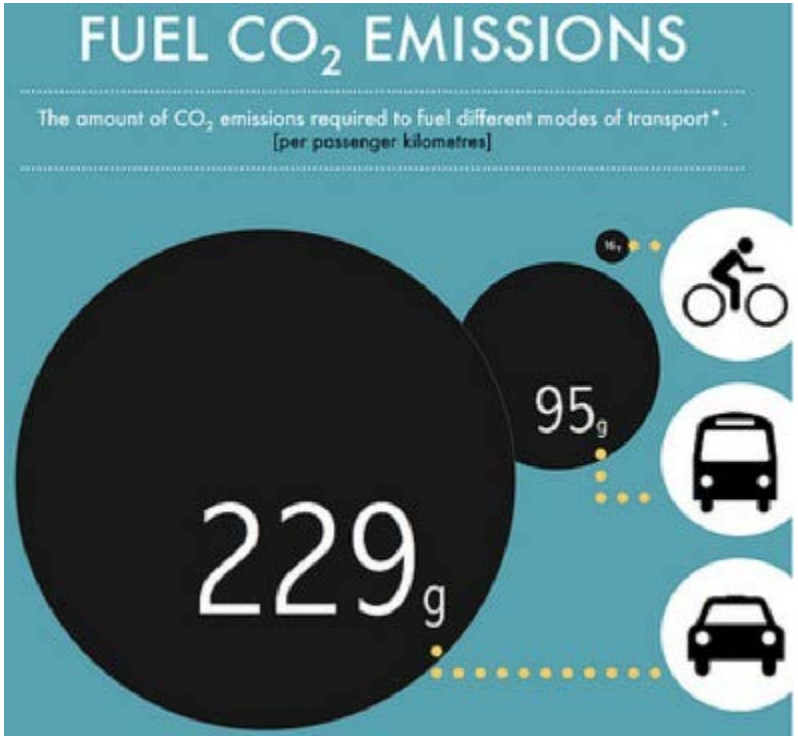
Rep. Orcutt says bicycle carbon emissions 'not a point worthy of even mentioning' →

State lawmaker defends bike tax, says bicycling is not good for the environment

Posted on March 2, 2013 by Tom Fucoloro

Representative Ed Orcutt (R – Kalama)

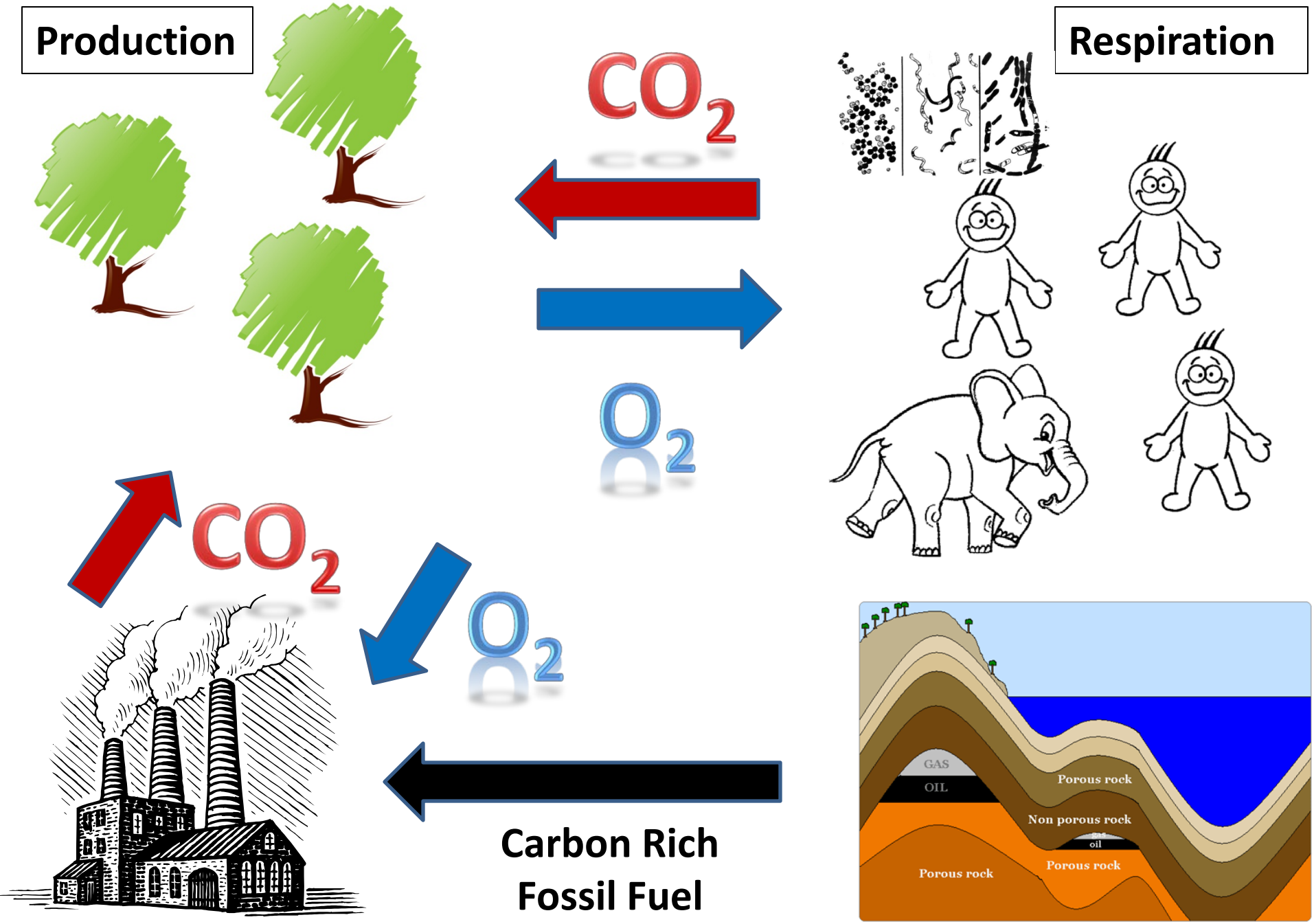
Representative Ed Orcutt (R – Kalama) does not think bicycling is environmentally friendly because the activity causes cyclists to have "an increased heart rate and respiration."



Source: European Cyclists Federation

"You would be giving off more CO2 if you are riding a bike than driving in a car," he said. However, he said he had not "done any analysis" of the difference in CO2 from a person on a bike compared to the engine of a car

"You can't just say that there's no pollution as a result of riding a bicycle."


Production
Respiration
CO_2
O_2
CO_2
O_2
Carbon Rich
Fossil Fuel
GAS
OIL
Porous rock
Non porous rock
oil
Porous rock
Porous rock

Going back in time to scale the magnitude of our carbon perturbation.

~80% To the Ocean

~10% To Seafloor Carbonates

~2% To Terrestrial Carbonates

~8% To Terrestrial Silicates

<u>~300 yr ago</u>
60 years until Declaration of Independence
Benjamin Franklin born (1706)
Piano Invented by Bartolomeo Cristofori

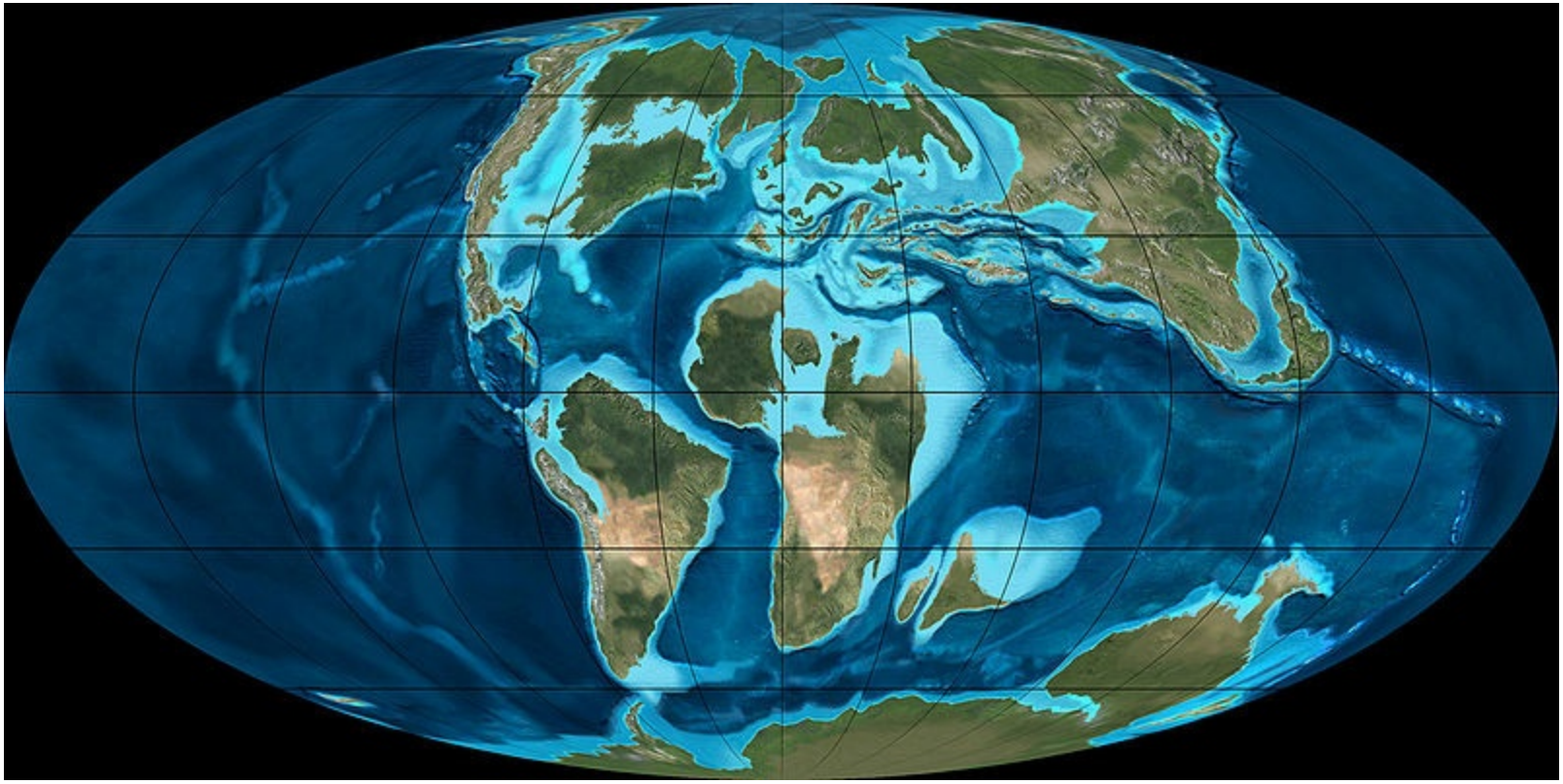
<u>~4000 yr ago</u>
Stonehenge Built
Bronze Age in China
Corn cultivation in Southwest N.A.

<u>~10,000 yr ago</u>
Retreat of Ice Sheets
Glacial Lake Outburst Floods, PNW
Rise of agriculture (along with rising CO2)

<u>~200,000 yr ago</u>
First modern humans
Oldest eruption of Mt. Shasta
Giant mammals inhabit the planet

~1M years to “absorb” a 1000PG fossil carbon perturbation

What about other times in the Earth's history when CO_2 was high?

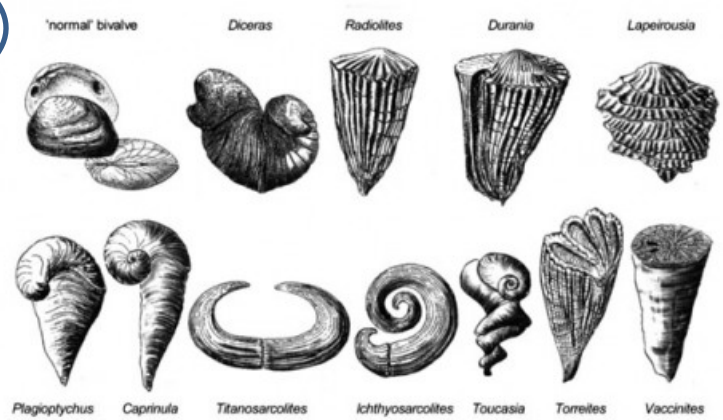


The Cretaceous Ocean (~145-65 Million Years Ago)

- Warm planet
- Shallow Inland Seas
- High Water
- pCO_2 ~ 1700 ppm
- Buffering 2x today's ocean

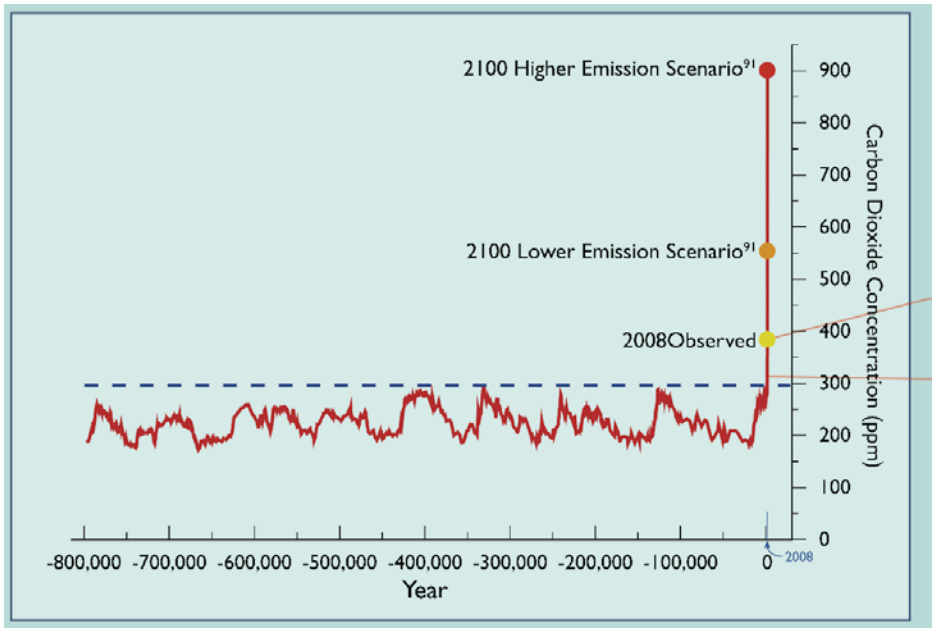
What reef building organism evolved during this period?

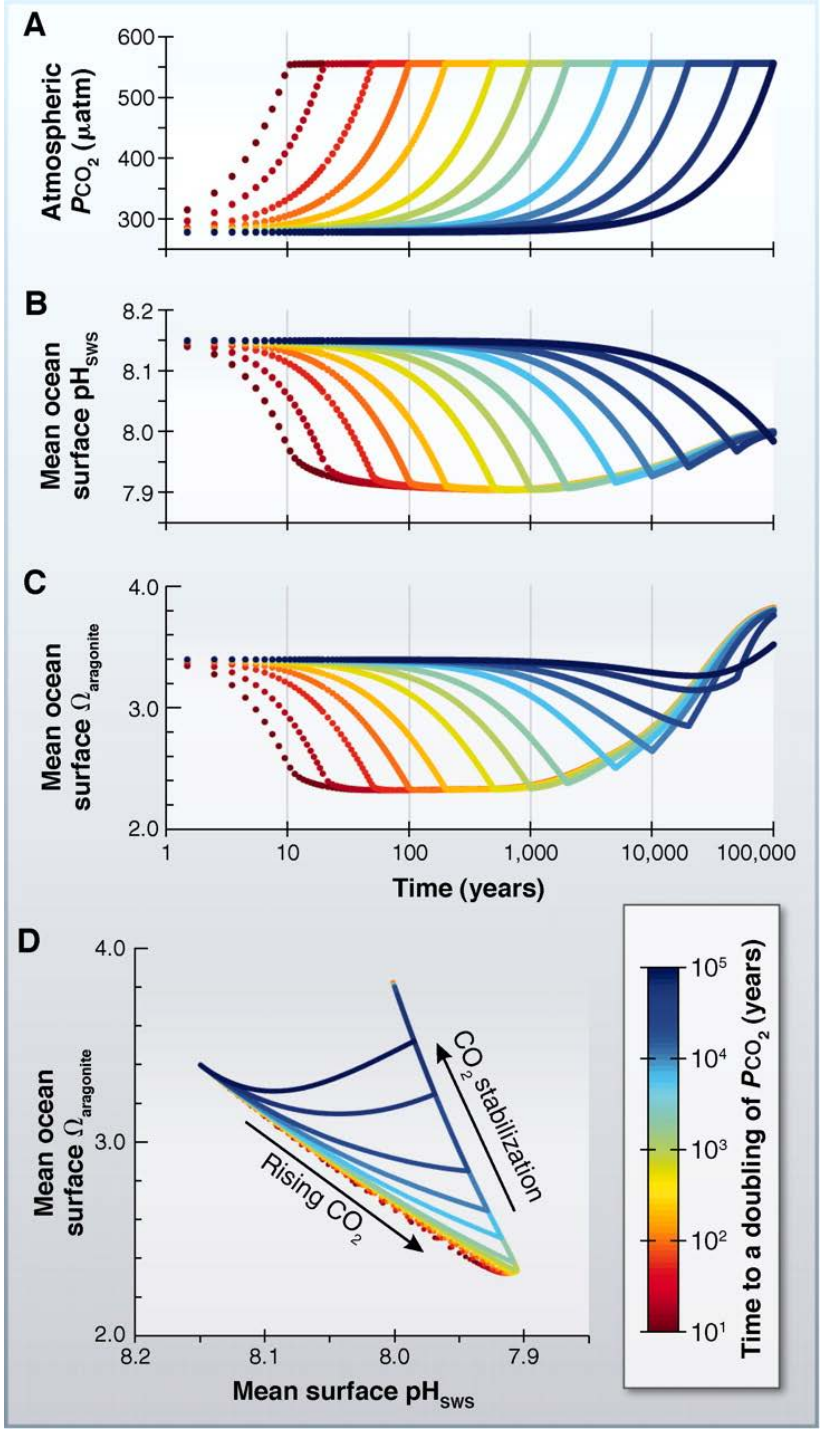
Bivalves as Dominant Cretaceous Reef Builders



Ocean Acidification (globally) is a temporal problem.

The Earth's buffering systems cannot keep up with our ability to extract reduced, fossil carbon and oxidize it.





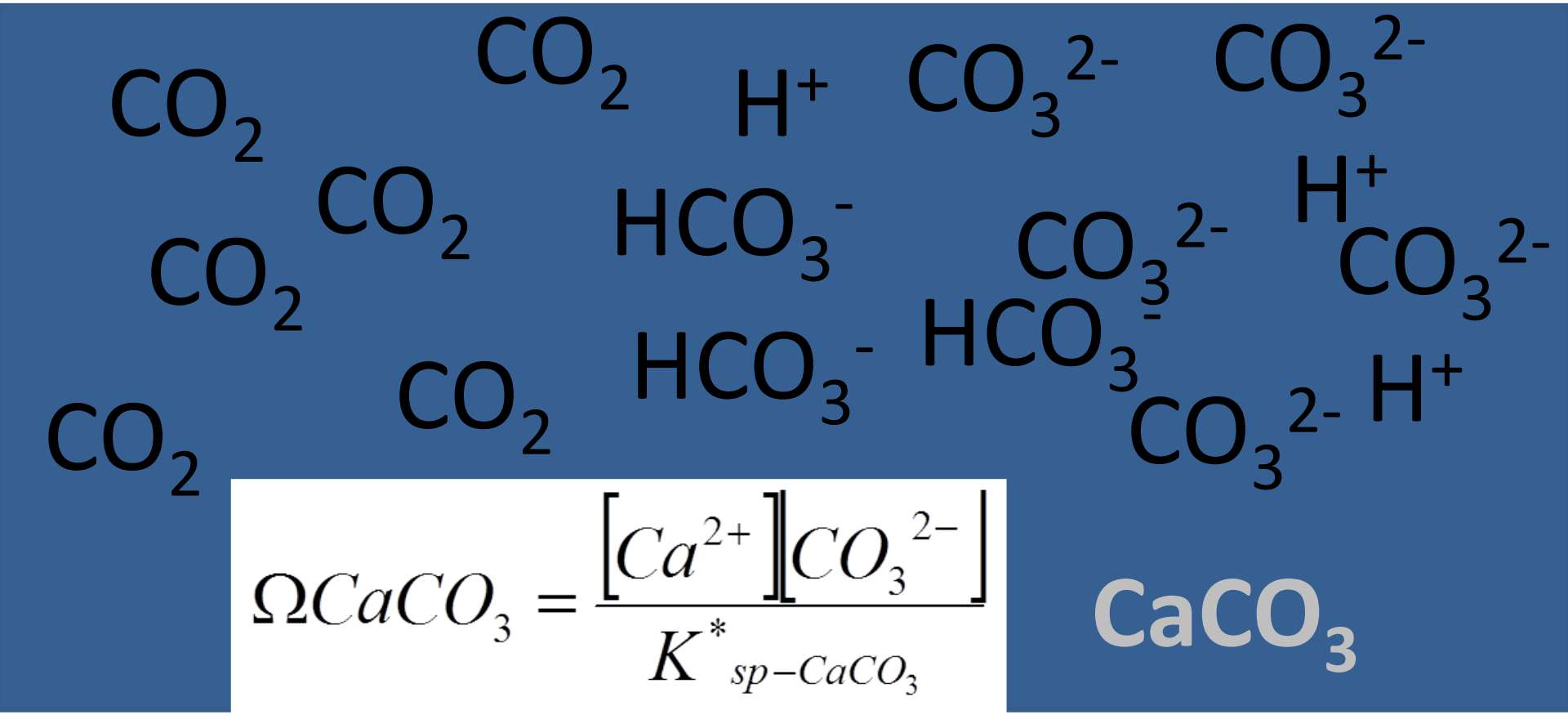
OA Fact #1: Atmospheric CO_2 is rising faster now than in the past ~1million years

The <u>Ocean</u> does the initial heavy lifting in keeping atmospheric CO_2 levels lower than they would be otherwise…

… nothing is free in this world however.

Ocean Acidification occurs because the **CO_2 increase** exceeds the rate of **Global Buffering Processes** (currently by at least 1000x).

The ocean is developing a "sour stomach"…

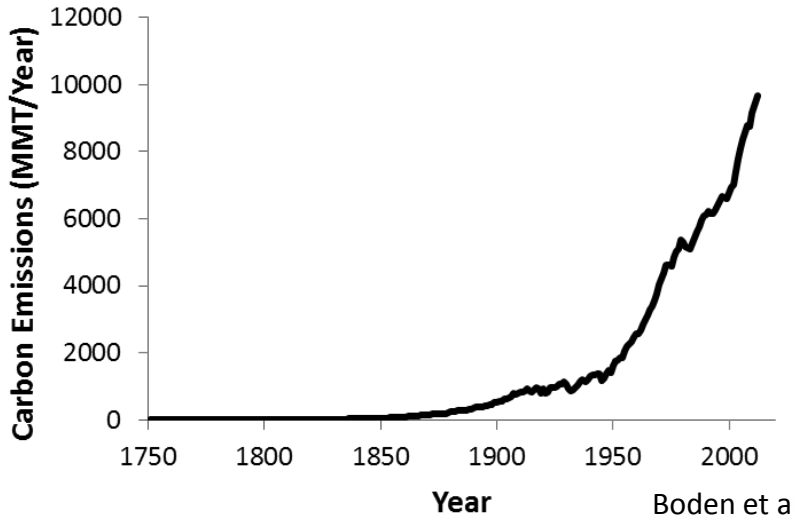


$$\Omega CaCO_3 = \frac{[Ca^{2+}][CO_3^{2-}]}{K^*_{sp-CaCO_3}}$$

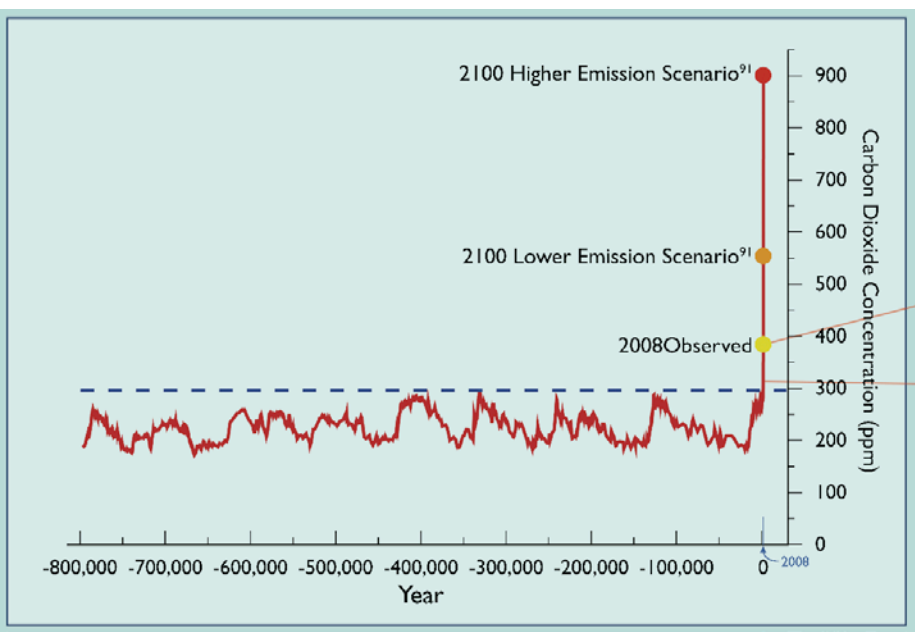
Importantly, seawater can dissolve Calcium Carbonate before water is "acidic".

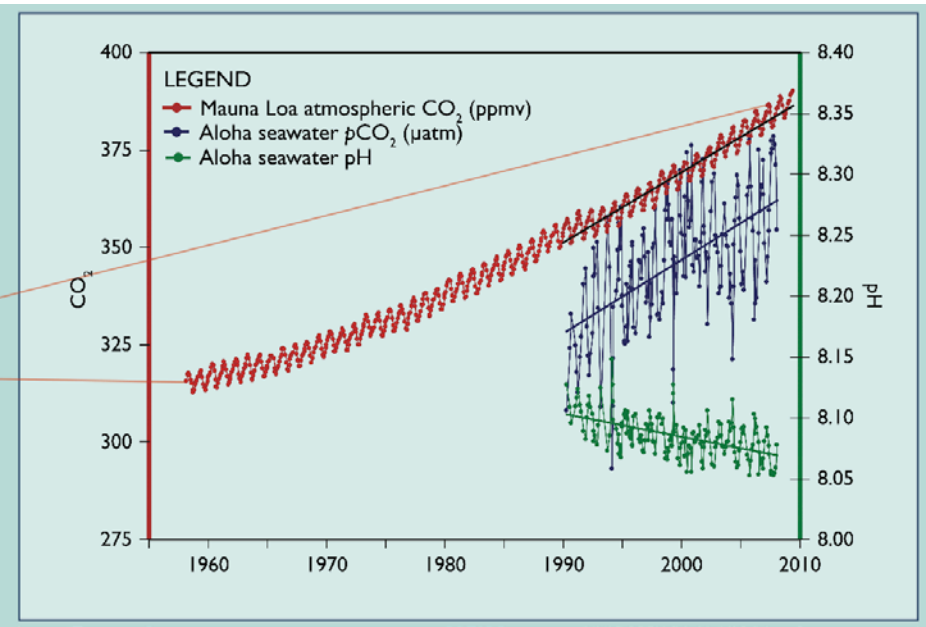
Impacts on organisms can appear before conditions are "corrosive".

OA Fact #2: The major portion of this increasing atmospheric CO_2 is due to fossil fuel emissions.



Boden et al. 2013



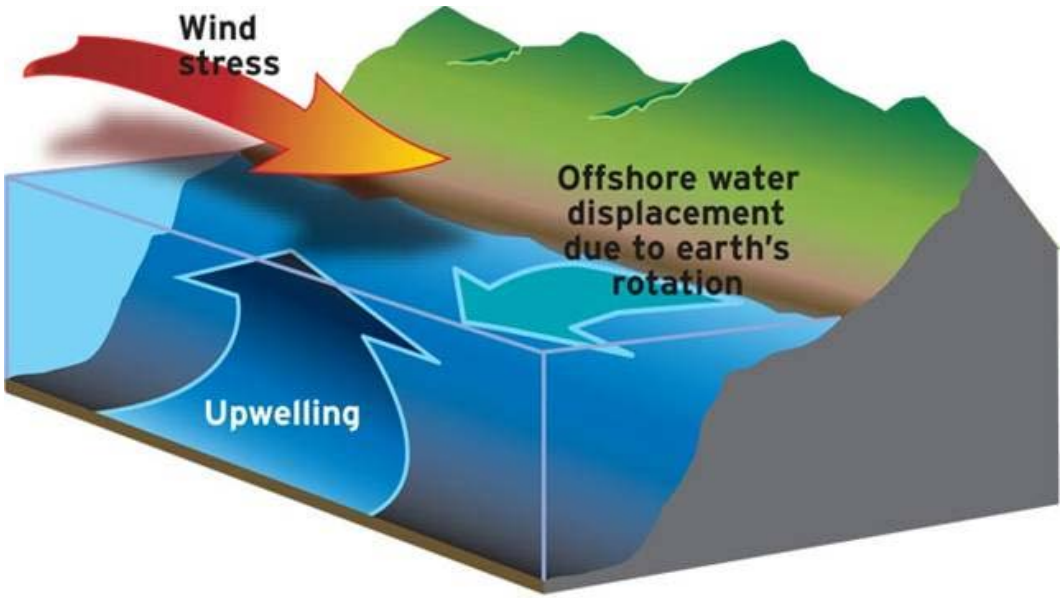


Ocean Acidification: Local Scales

Where organisms live, they don't care where the excess CO_2 comes from.

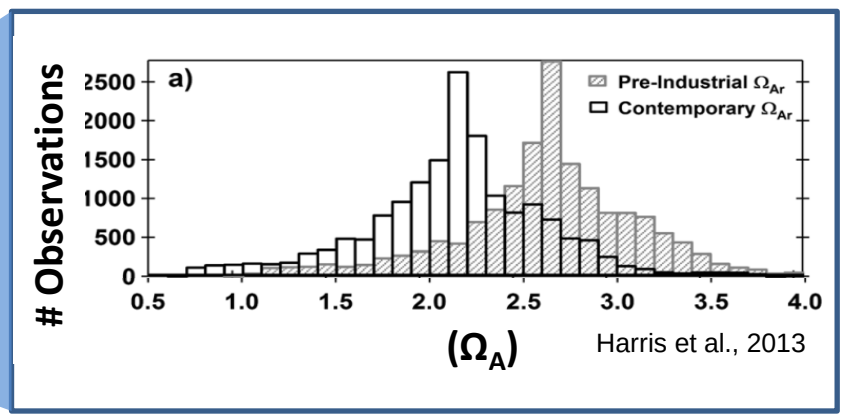
Fossil CO_2 is additive to local drivers

OA Fact #3: The PNW coast is an OA hot-spot: Fossil CO_2 is additive.



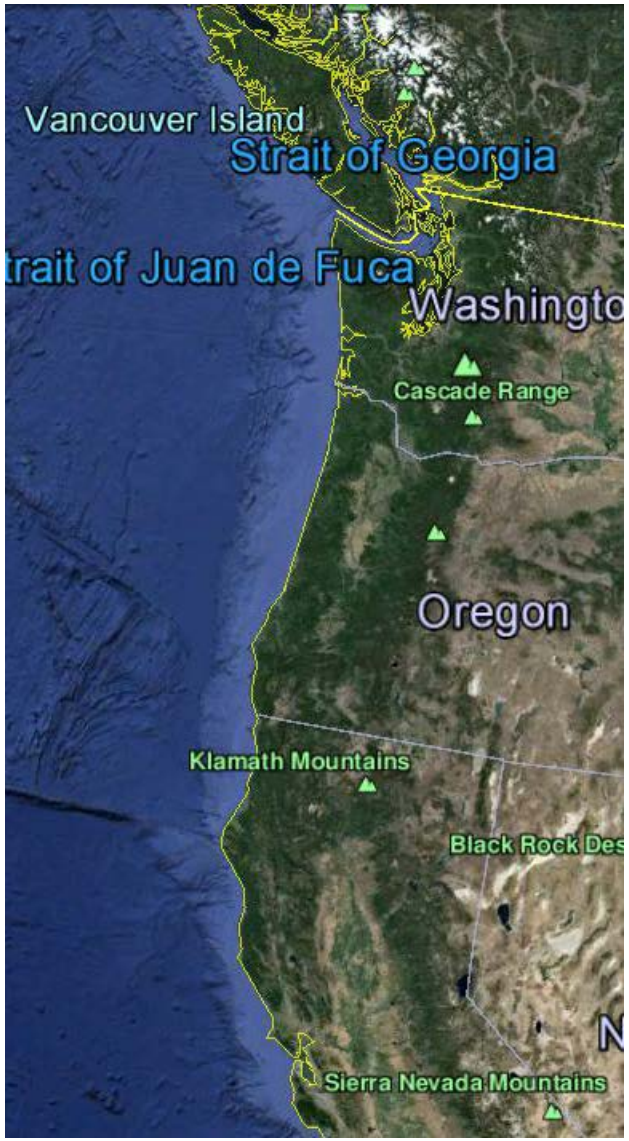
Upwelling = Nutrients, Fisheries Production, and Naturally Elevated CO_2.

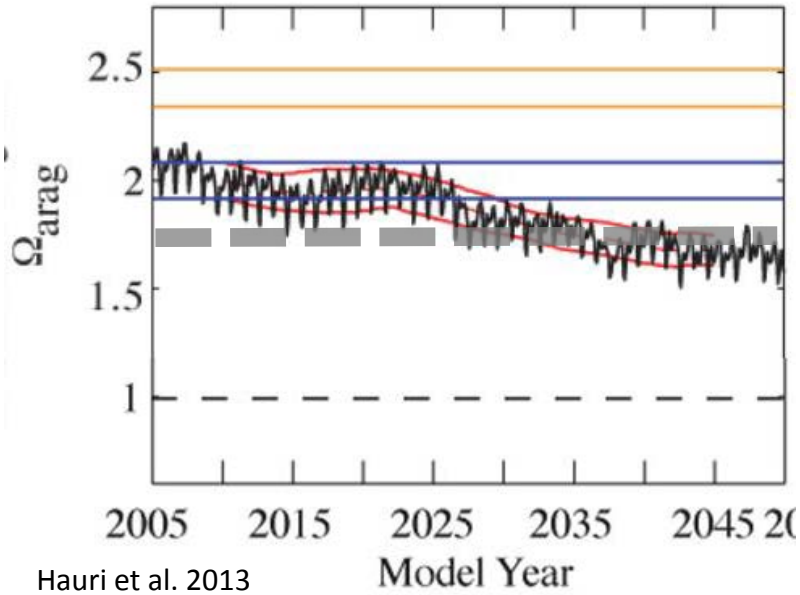
Baseline was set 30-50 years ago



- Undersaturation events projected to increase in frequency, intensity, and duration in coming decades (Hauri et al., 2013)

California Current: Acidification Hot Spot





Hauri et al. 2013

280 ppm CO_2

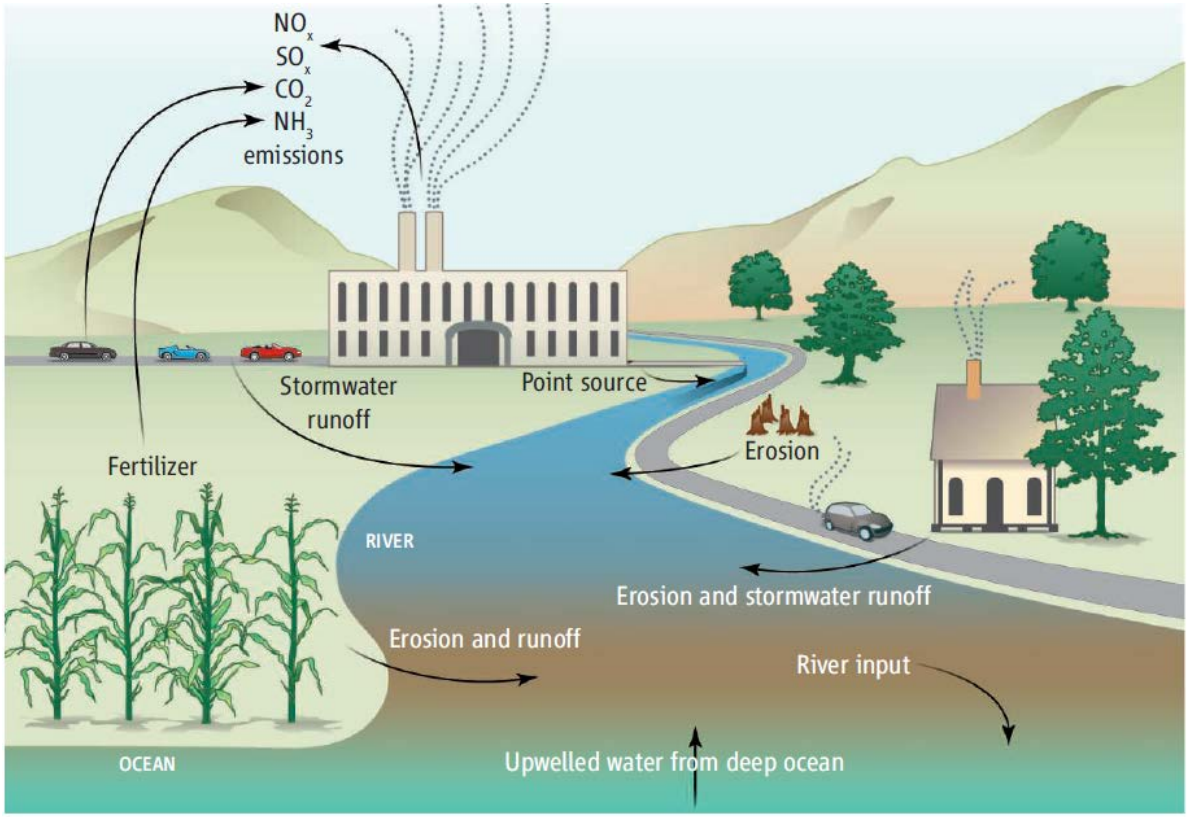
400 ppm CO_2

550 ppm CO_2

550 ppm is the low emissions scenario for 2100

Undersaturation events projected to increase in frequency, intensity, and duration in coming decades (Hauri et al., 2013)

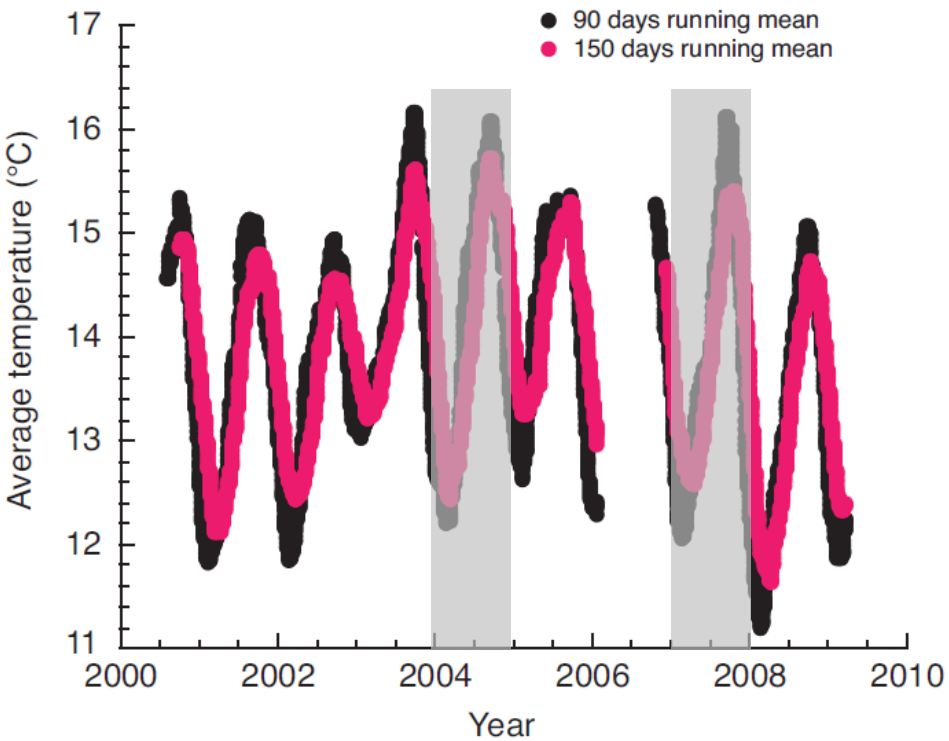
Acidification in the Coastal Zone: Carbonate Weather



Contributors to ocean acidification. In addition to global atmospheric CO_2, this figure depicts the major local (within 100 km) sources contributing to coastal ocean acidification. **Kelly et al. 2011**

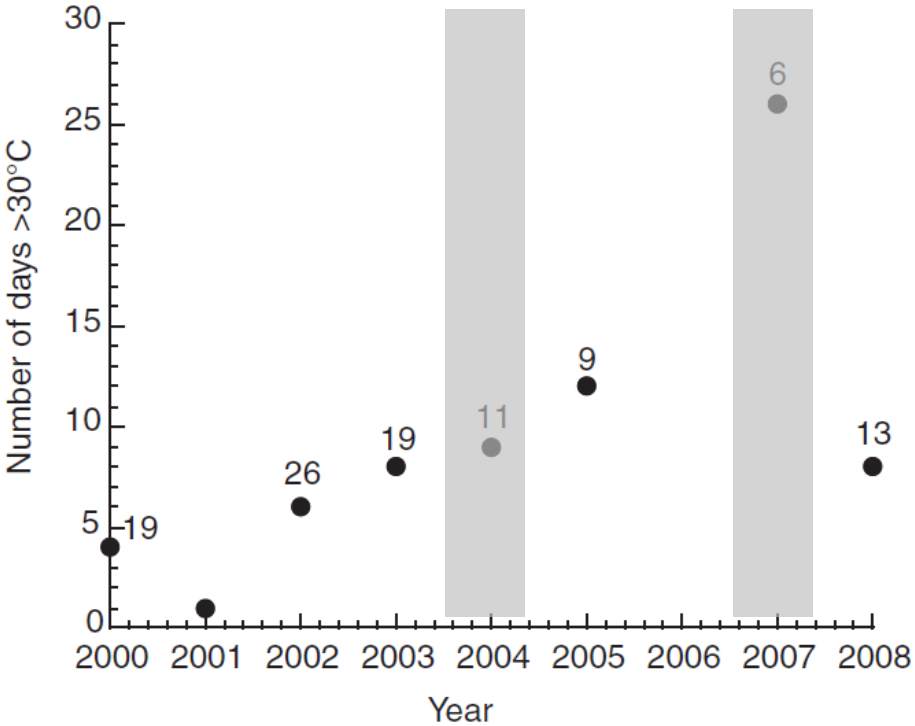
The local drivers can (and often will) be additive to the gradual baseline shift.
Effects can result in greater variability (e.g. eutrophication)…
This doesn't mean that the global baseline doesn't matter…

Mussel Body Temperature in the Intertidal Helmuth et al. (2010)



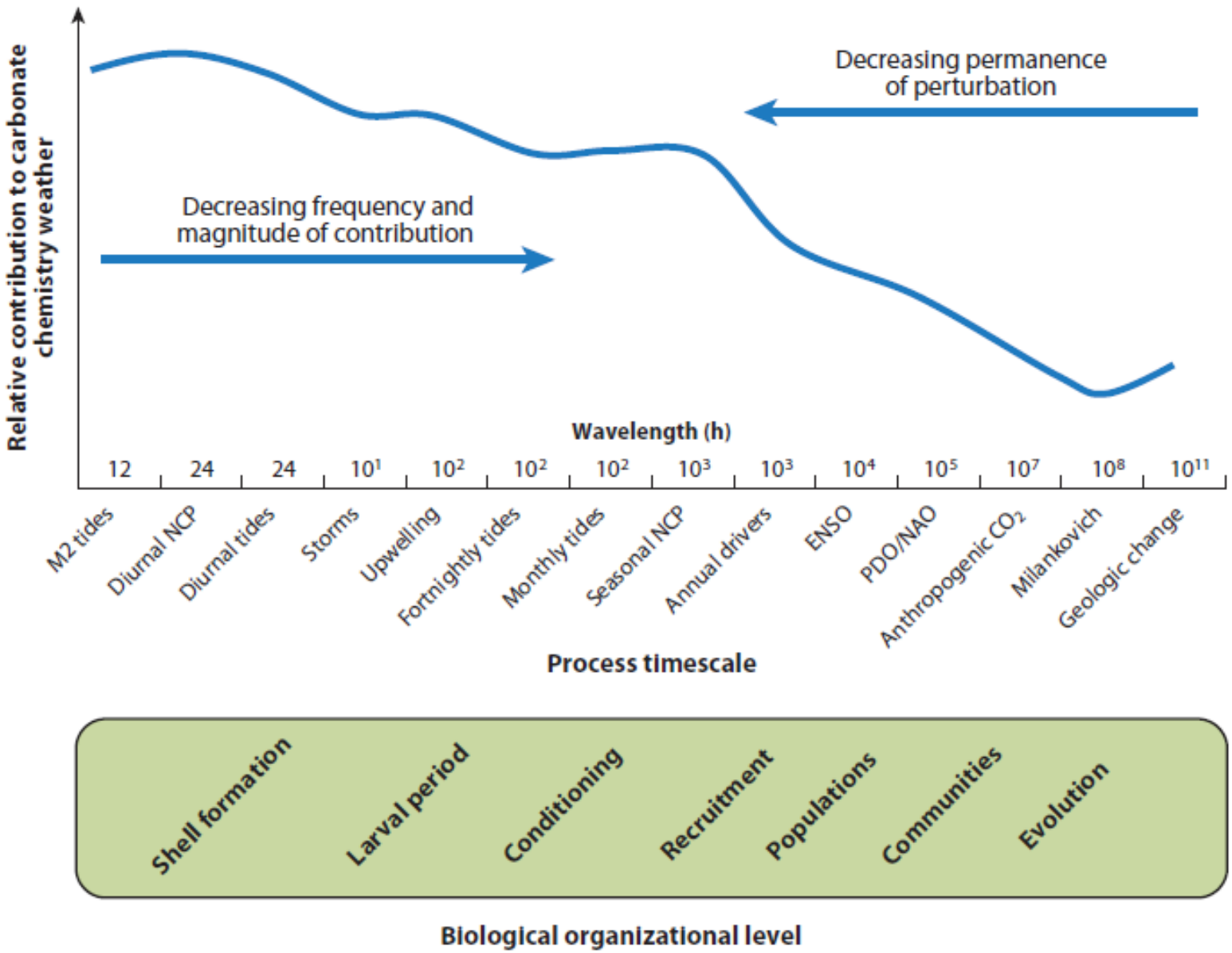
Average Temperatures

Extreme Events



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)

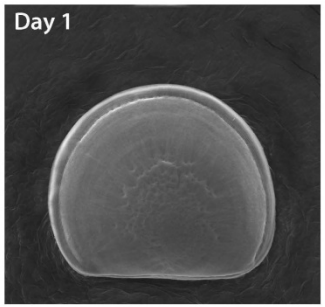
Carbonate Chemistry, Frequency, and Biology



Waldbusser and Salisbury 2014

Impacts on Marine Organisms





OA Fact #4: Marine organisms will respond differently to OA, some not at all.

Are you a glass half empty or half full kind of person?

Is the glass half-full or half-empty: College Major Edition

Psychology:
How does this glass of water make you feel?

Human Nutrition:
There isn't enough water here for a person's daily needs

Engineering:
This glass has a 50% overall inefficiency.

Business/Marketing:
Will the glass sell better marketed as half full or half empty?

English (Literature):
What is the symbolism of the glass not being completely full?

Women's Studies:
Would you give a man a full glass?

Undeclared:
I'm not really sure. Can you ask me later?

Philosophy:
How do I know the glass is there?

Law:
What do you want it to be?

Accounting:
This glass is 50% in the red.

Art:
The water doesn't compliment the air above it.

Of the experiments and studies conducted to date, roughly 50% of shell forming organisms appear to be sensitive to Ocean Acidification.

technically, the glass is always full.

OA results in “riskier” behavior of clown fish

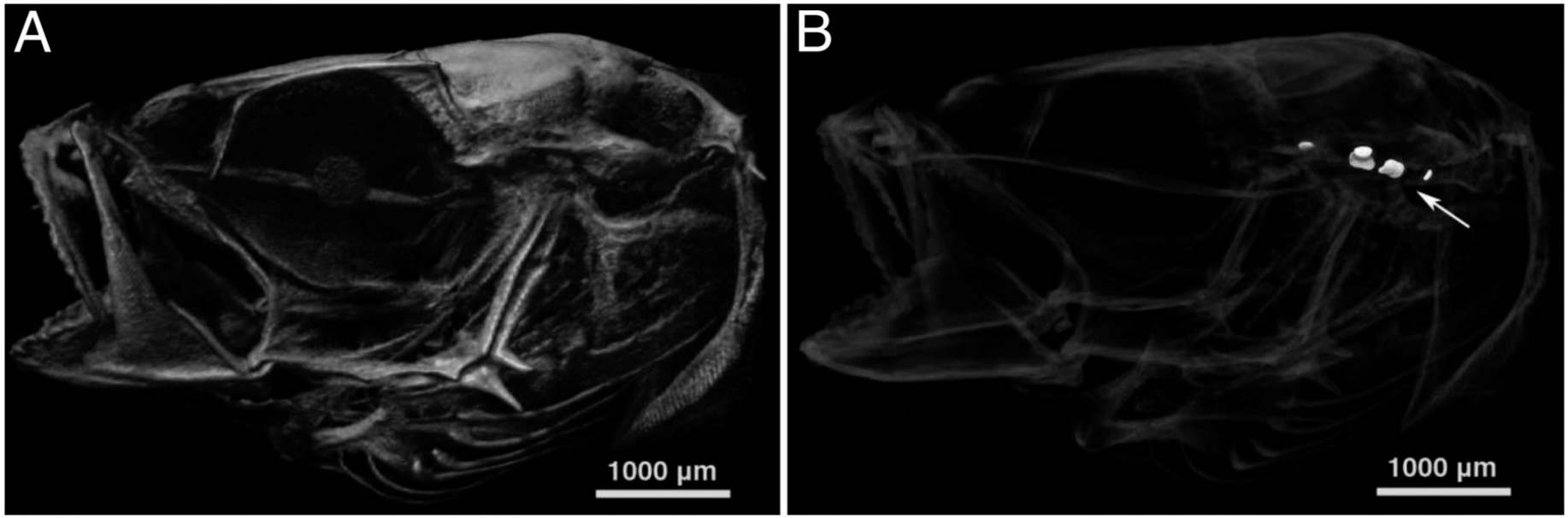
Fish seem to loose sense of smell, likely GABA Receptors are affected by higher CO_2. Munday et al. 2009

Ability of clown fish to hear sounds also appears to be affected…

CO_2-induced ocean acidification increases anxiety in rockfish via alteration of GABAA receptor functioning. Hamilton et al. 2014

"might exhibit a fatal attraction to predators at CO_2 and pH levels that could occur in our oceans by 2100 on a business-as-usual scenario of greenhouse gas emissions".

OA Changes Otolith Density in Cobia



Lateral view micro-CT imagery of a 22-d posthatch larval cobia head.

Actually increases the hearing range by ~50% at very high CO_2 levels (2000ppm)

Maybe "loss" of hearing in clown fish…

Sean Bignami et al. PNAS 2013;110:7366-7370

What about Crabs (larvae)?

Not really

A little bit

A bit more

None showed decreases in calcification
Adult blue crabs showed increased calcification…

The PNW Oyster Seed Crisis

Pacific Northwest Oyster Seed Crisis

nature International weekly journal of science

Home | News & Comment | Research | Careers & Jobs | Current Issue | Archive | Audio & Video | For Authors

News & Comment > News > 2013 > October > Article

NATURE | NEWS

US state declares war on acid waters

Washington announces science-based plan to tackle ocean acidification.

Virginia Gewin

27 November 2012

Rights & Permissions

Top Story

The Seattle Times
Winner of Nine Pulitzer Prizes

Local News

Home | News | Business & Tech | Sports | Entertainment | Living

Subscribe now to stay in the know.
Choose the subscription package that is right for you.

IN THE NEWS: Kings | State budget | Fired Medina police chief | Pacific Place Garage | North K

Originally published June 21, 2012 at 9:24 PM | Page modified June 22, 2012 at 1:34 PM

Willapa Bay oyster grower sounds alarm, starts hatchery in Hawaii

A Willapa Bay shellfish company is shifting some of its business to Hawaii because of ocean acidification that scientists believe is killing tiny oyster larvae in shellfish farms along Washington's coast.

The New York Times
Monday, October 1, 2012

Environment

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPI

ENVIRONMENT | SPACE & COSMOS

Mobile | Newsletters | RSS | S

Friday, December 27, 2013

The Seattle Times
Winner of Nine Pulitzer Prizes

Local News

OA Fact #5: There are impacts to PNW economy today due to ocean acidification.

A Blog About Energy and the Environment

April 12, 2012, 6:00 AM | 15 Comments

Study Links Raised Carbon Dioxide Levels to Oyster Die-Offs

By LESLIE KAUFMAN

Acidity in ocean killed NW oysters, new study says

Recommend 55

Comments (98)

E-mail article

Print

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

Forbes

New Posts +2 posts this hour | Most Popular Year's Hottest Startups | Lists Best Actors For The Buck | Vid Top C

7 Stocks to Sell for 2014

66 Share

117 Tweet

1 Share

0

David Ferris, Contributor
I write at the intersection of energy, climate and business.
+ Follow (82)

GREEN TECH | 7/26/2013 @ 8:45AM | 1,517 views

Baby Oysters In 'Death Race' With Acidifying Oceans

+ Comment Now + Follow Comments

HOME PAGE | TODAY'S PAPER | VIDEO | MOST POPULAR | U.S. Edition

The New York Times

Science

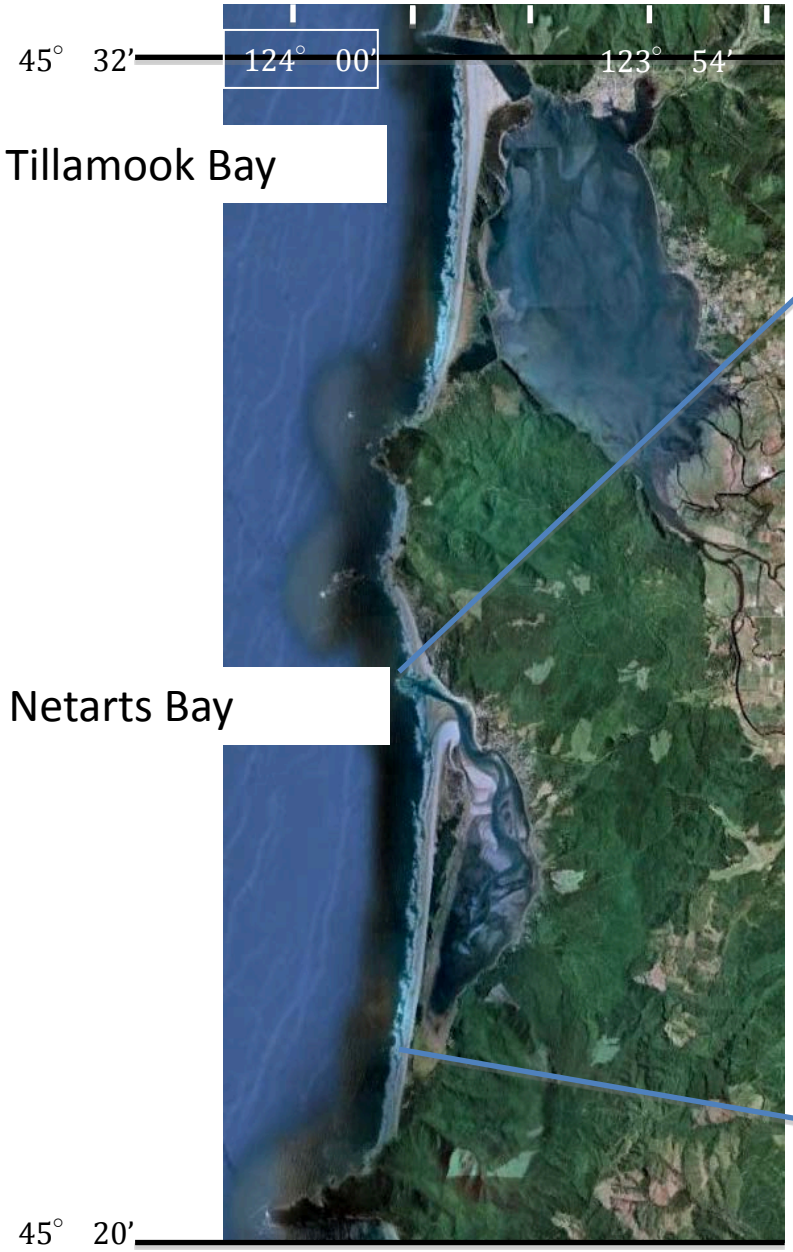
WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

ENVIRONMENT | SPACE & COSMOS

OBSERVATORY

Oyster Shells Are an Antacid to the Oceans

Pacific Northwest Oyster Seed Crisis



Whiskey Creek Shellfish Hatchery

50-80% of oyster spat for growers in PNW

Netarts Bay

Functions like a lagoon
Supported native oysters
Nearly complete tidal flushing
Production/Respiration
Abundant Seagrass

Pacific Northwest Oyster Seed Crisis

Whiskey Creek Shellfish Hatchery

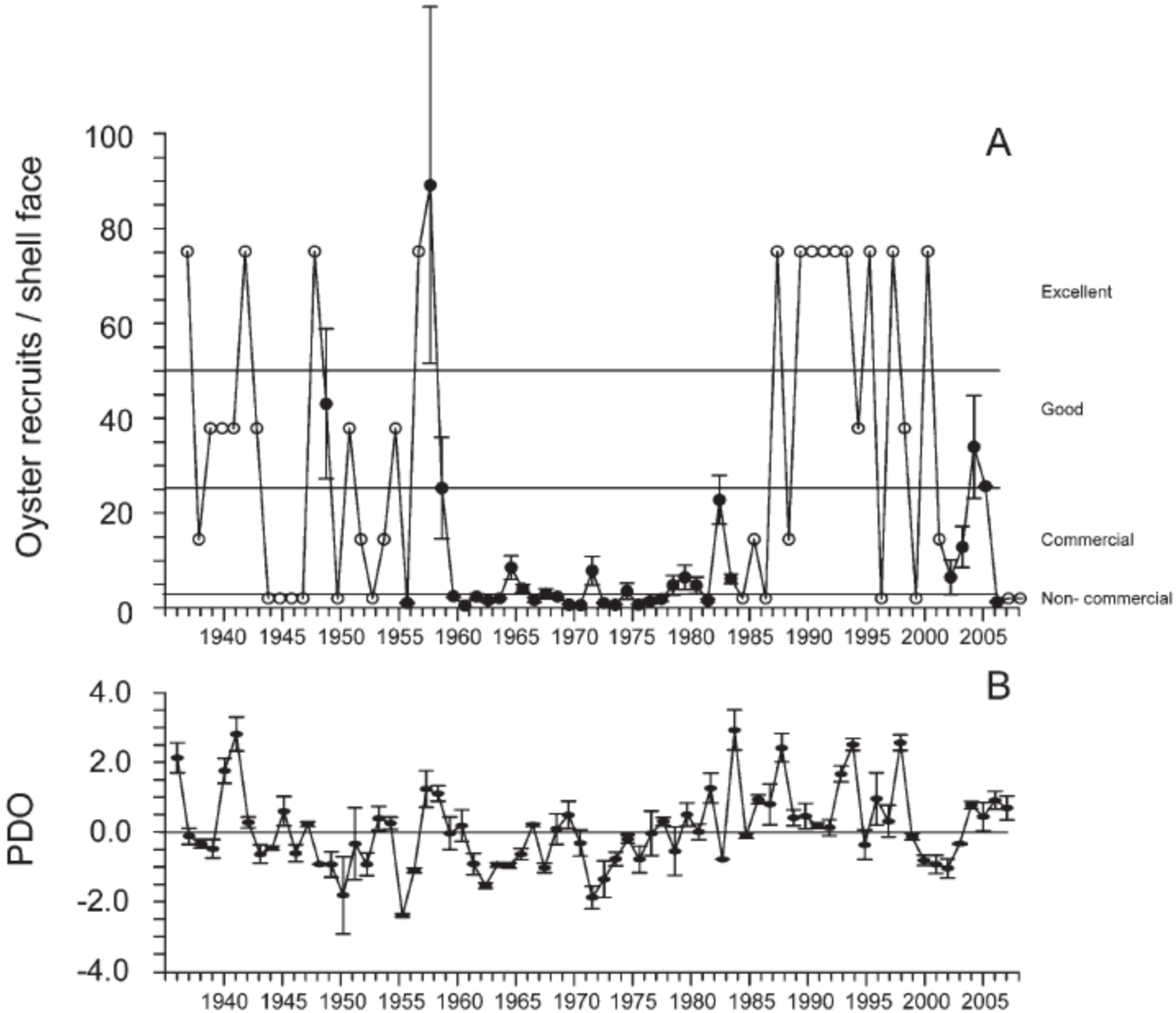
PNW Oyster Seed Crisis

2006 Persistent Hatchery Failures
2008 Hatchery running at loss
Disease (Vt)?
2009 Link to high CO_2 water
2010 Selective Pumping
2011 Buffering Water (Tums)
2012 WA Blue Ribbon Panel
2013 Early Spawning

Oyster industry relies on 3 commercial hatcheries (WCH hatchery only independent one)
2-3 hatcheries have had failures and now treating water (3rd non-reporting)

Industry is valued at ~$110M per year and supports 3200 jobs in rural areas.
Whiskey Creek supplies oyster seed to the independent growers in PNW.

Recruitment of Pacific Oysters in Willapa Bay, WA



Dumbauld et al. 2011

Pacific Northwest Oyster Seed Crisis: Willapa Bay, WA

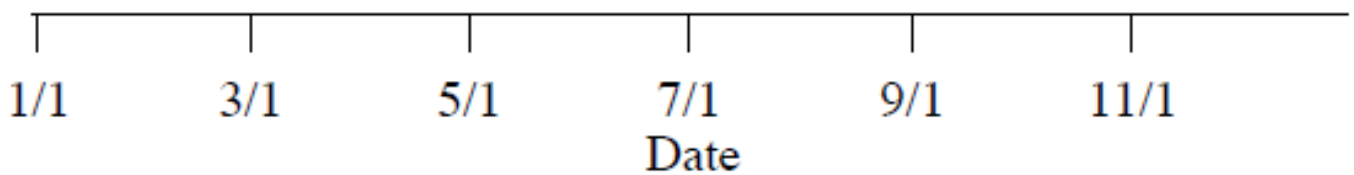
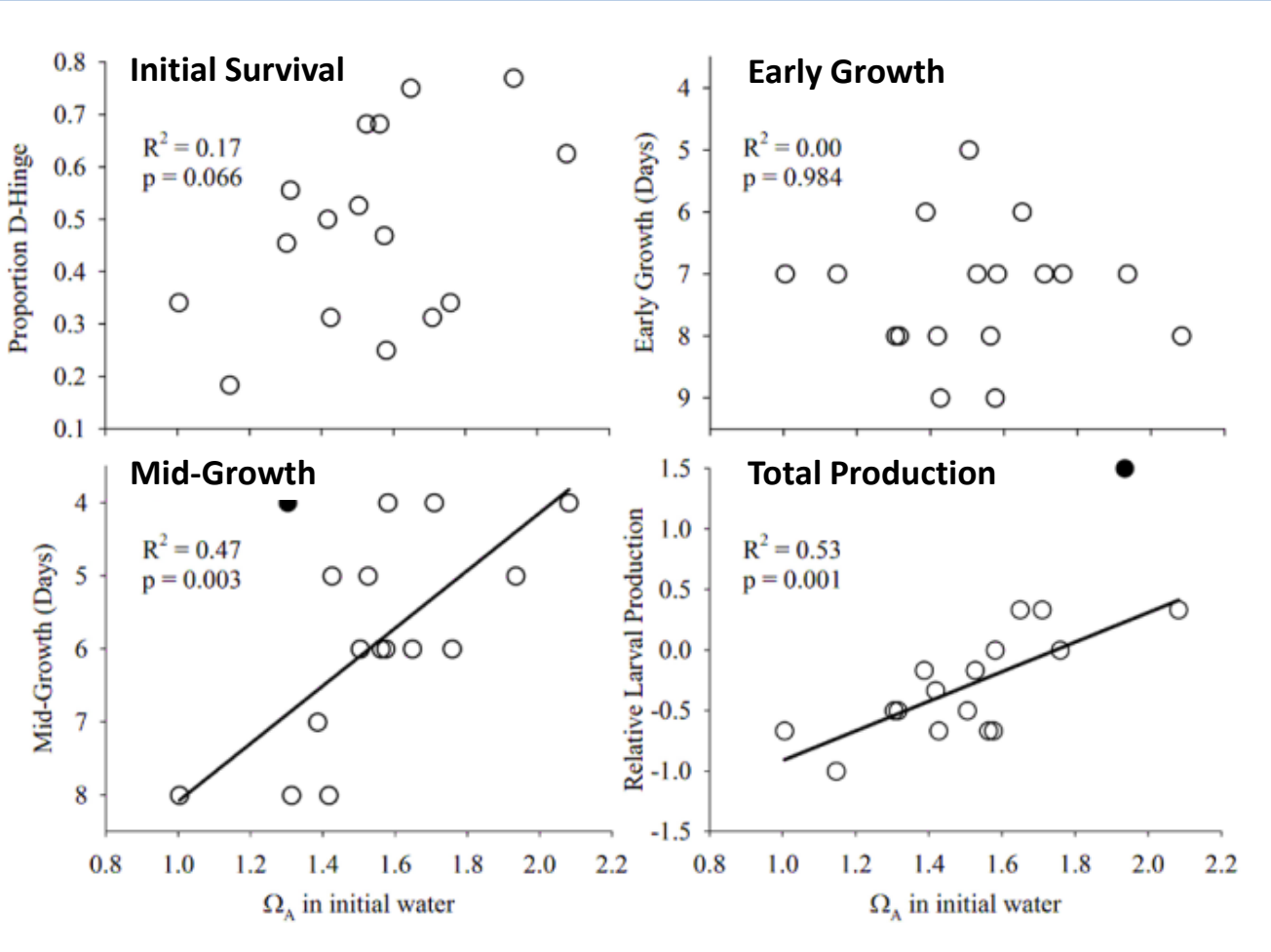


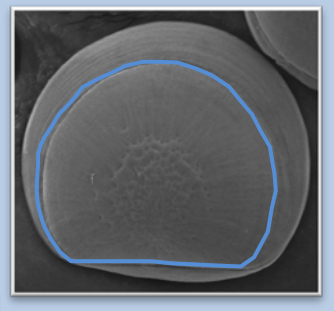
Figure 6. Intervals of thermal (red bars) and Ω_{ar} optimum conditions, for both modern (blue bars) and estimated pre-industrial conditions (purple bars; See Figure 7). Hales et al. in review

Hatchery Records to Determine Responses

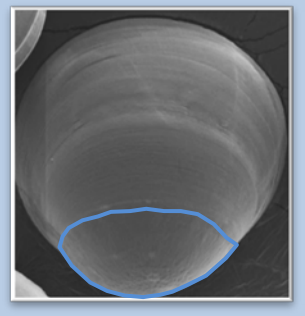


Barton et al., 2012

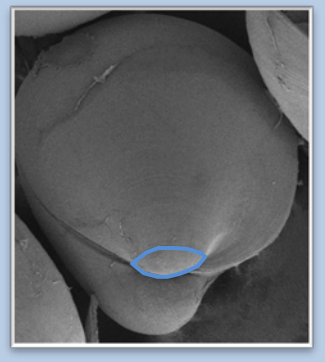
Initial Survival



Early Growth



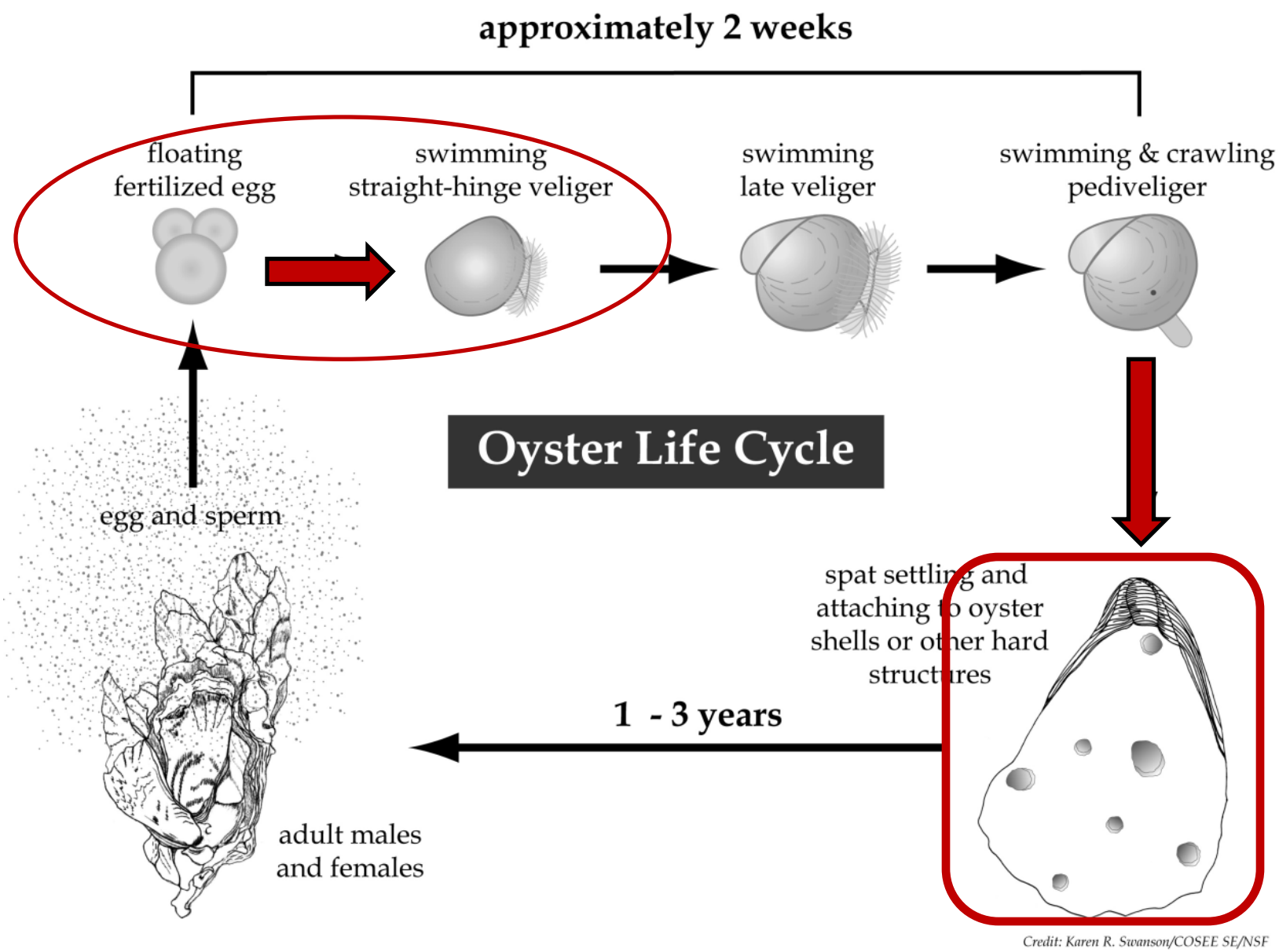
Mid-Growth



$$$

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

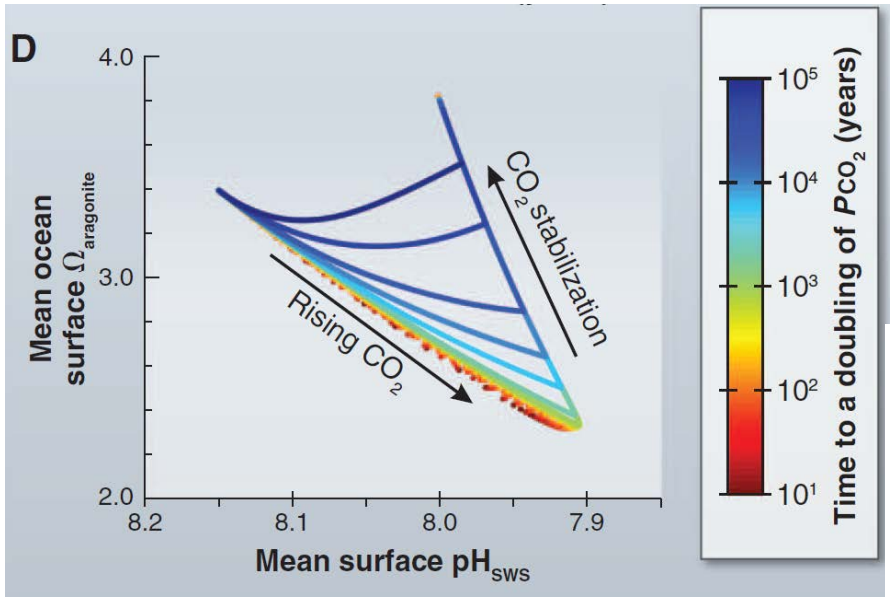
Bivalve Life History and Bottlenecks



Why Saturation State Could/Should Matter to Bivalve Larvae

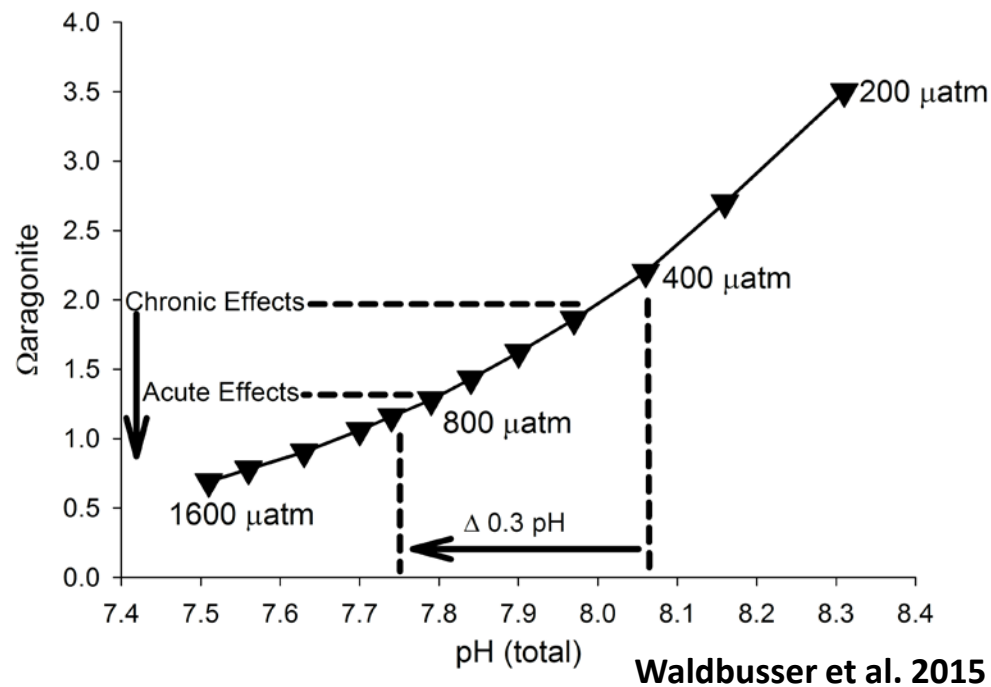
What component of the carbonate system matters most to bivalve larvae, and why does it matter?

1. Differences between past and today CO_2 changes



Hönisch et al. 2012

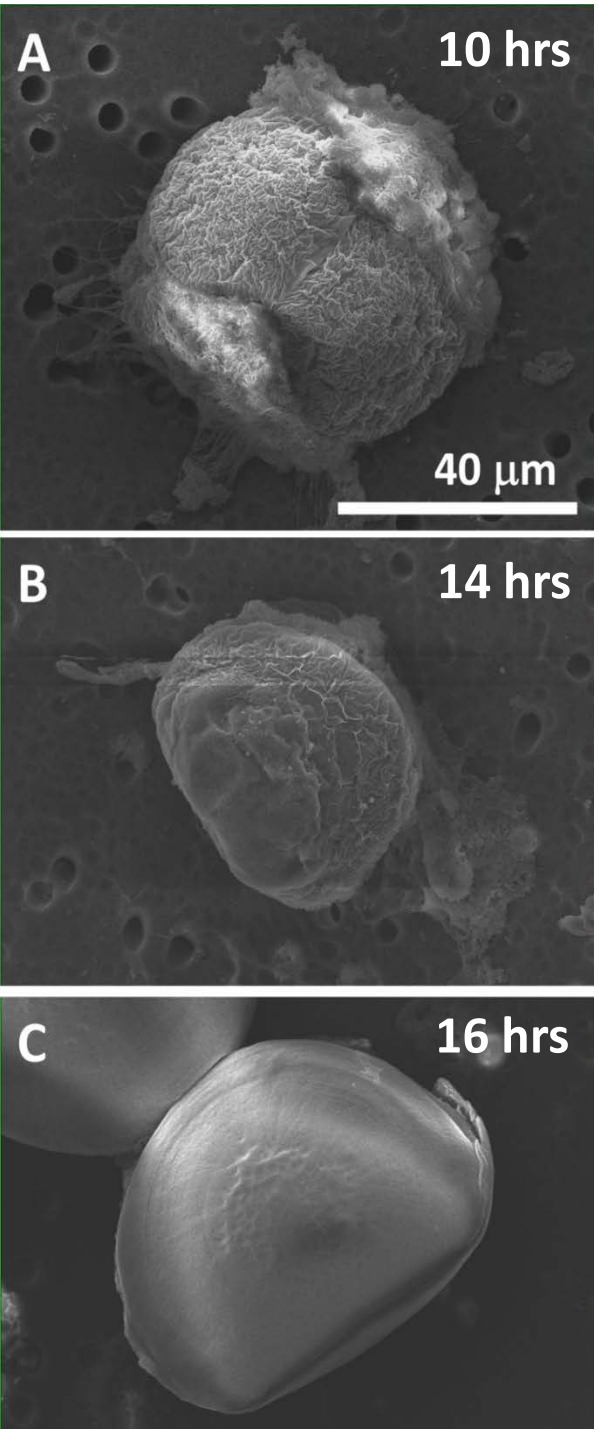
2. In coastal zones and estuaries freshwater inputs will change alkalinity.

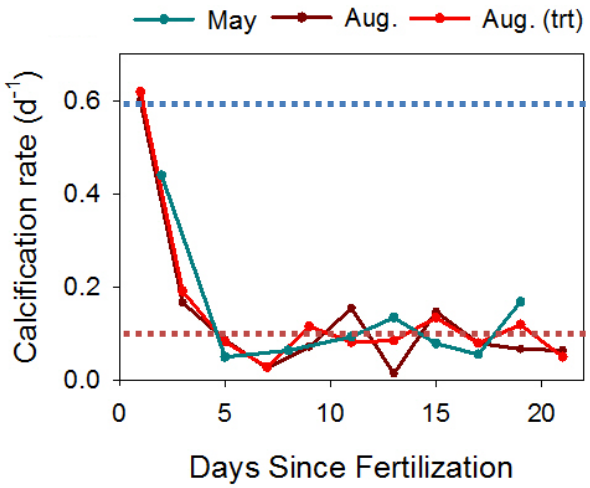


Waldbusser et al. 2015

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

Why Saturation State Should Matter…





Brunner et al. in prep

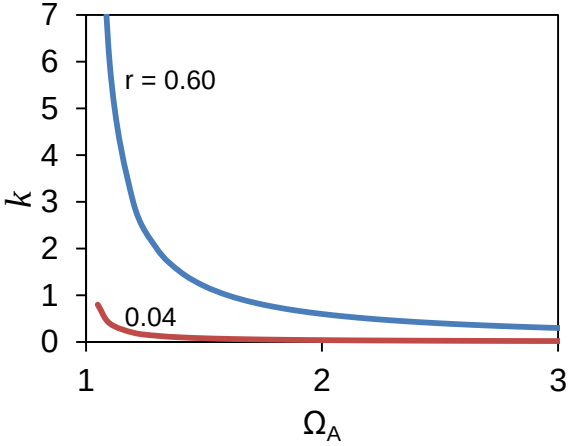
1) Within 48 hours, 80-90% of body weight is added as $CaCO_3$

2) Calcification surfaces more "exposed".

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

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

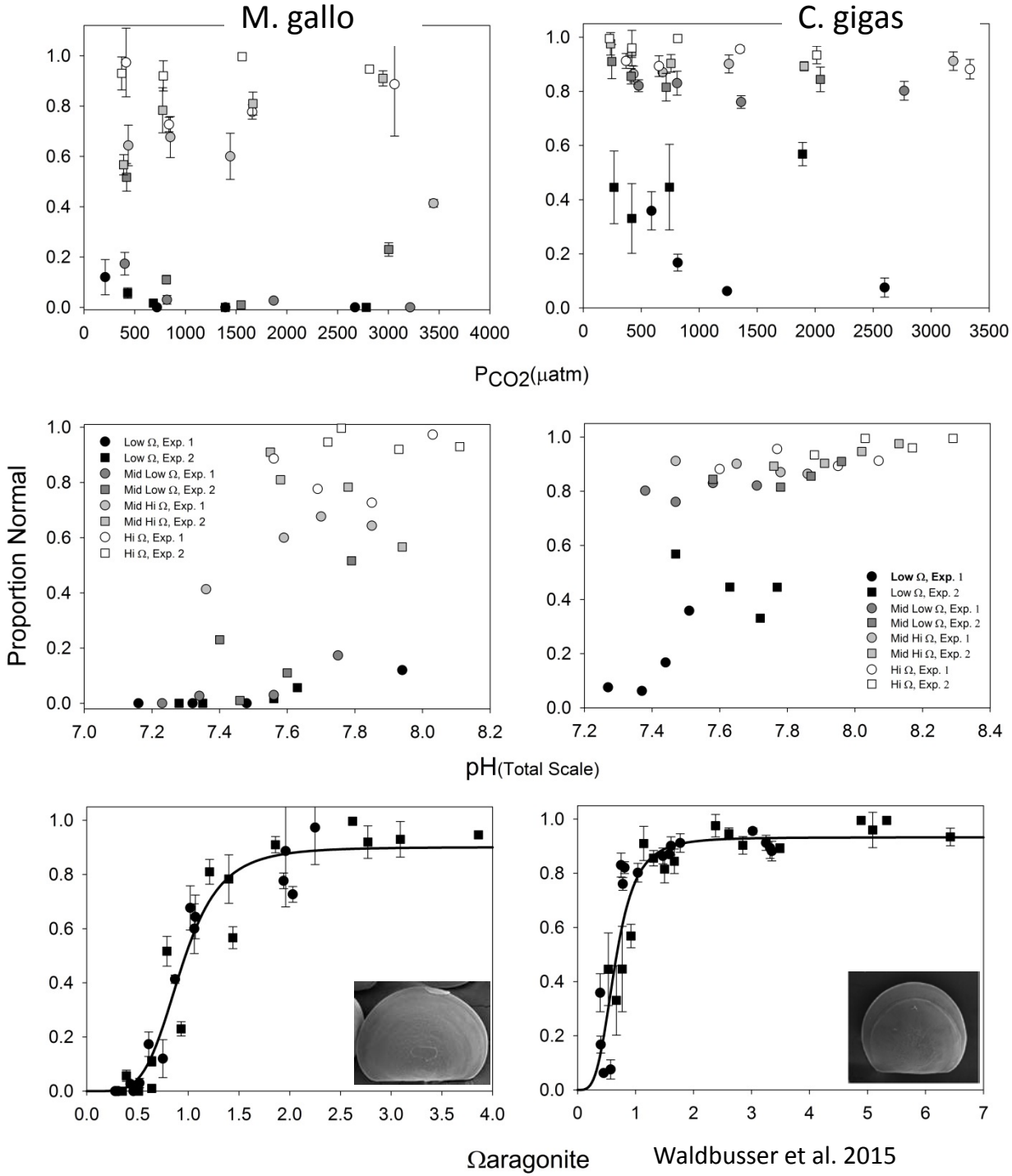
r = calcification rate
k = rate constant
Ω = saturation state
n = rate order (1)



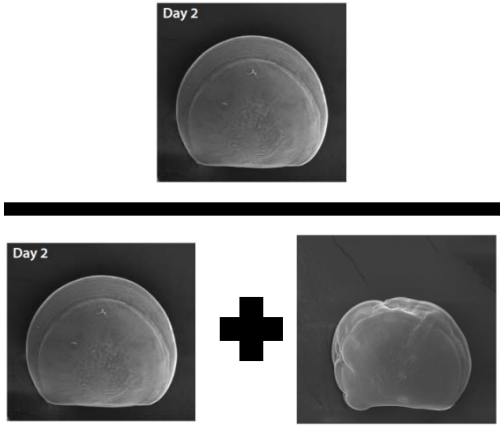
Rate of Calcification!

Waldbusser et al., 2013

Proportion Normal



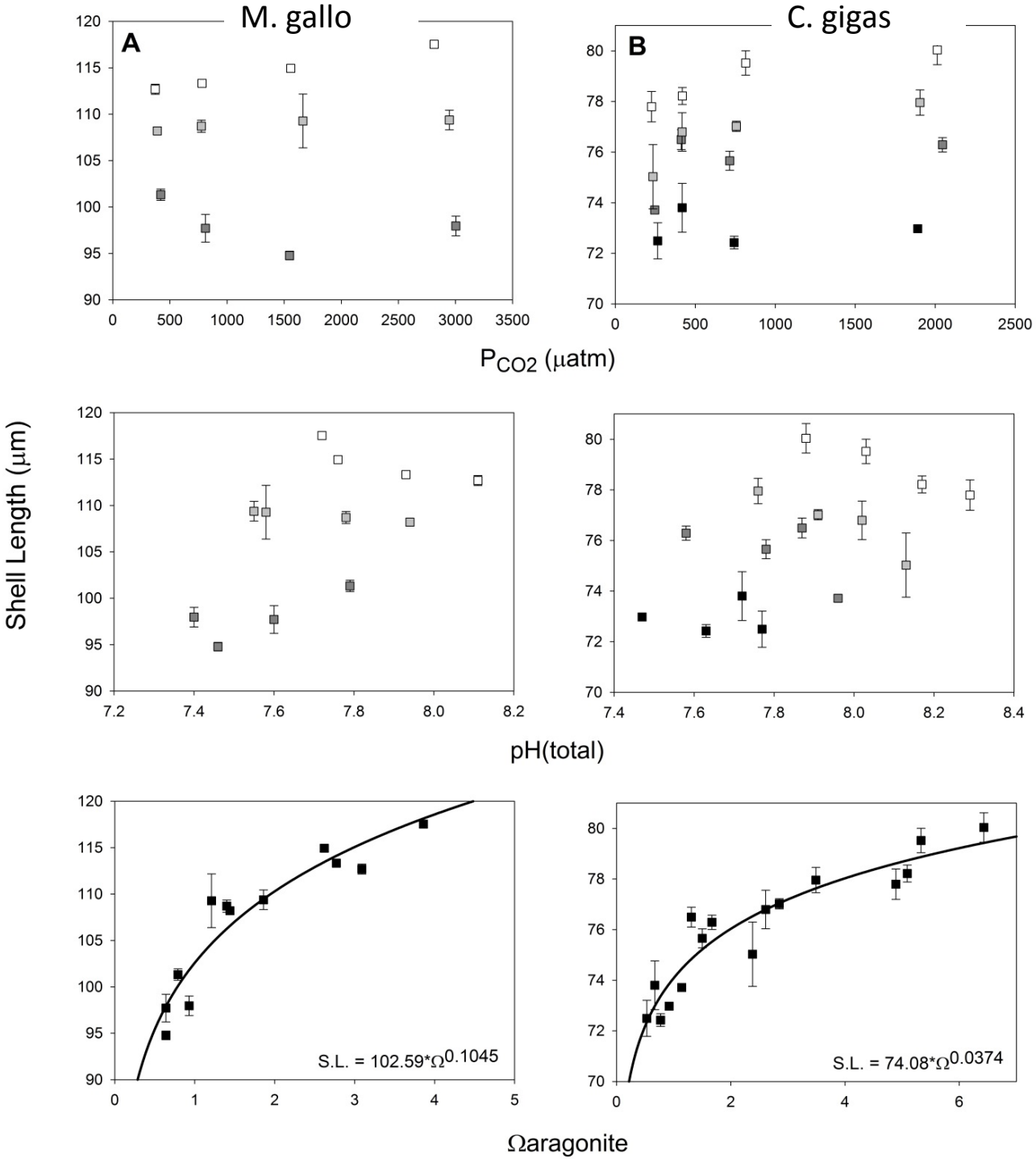
Waldbusser et al. 2015

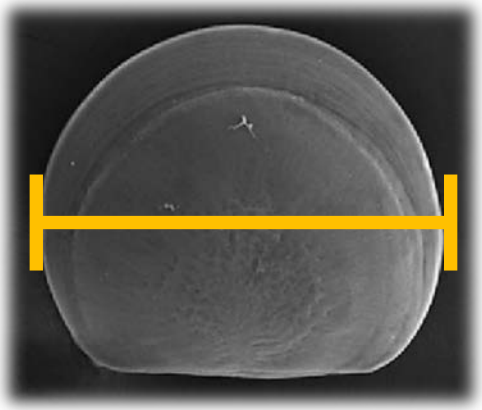


Saturation state is the primary variable of importance for these larvae.

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

Shell Length Normal





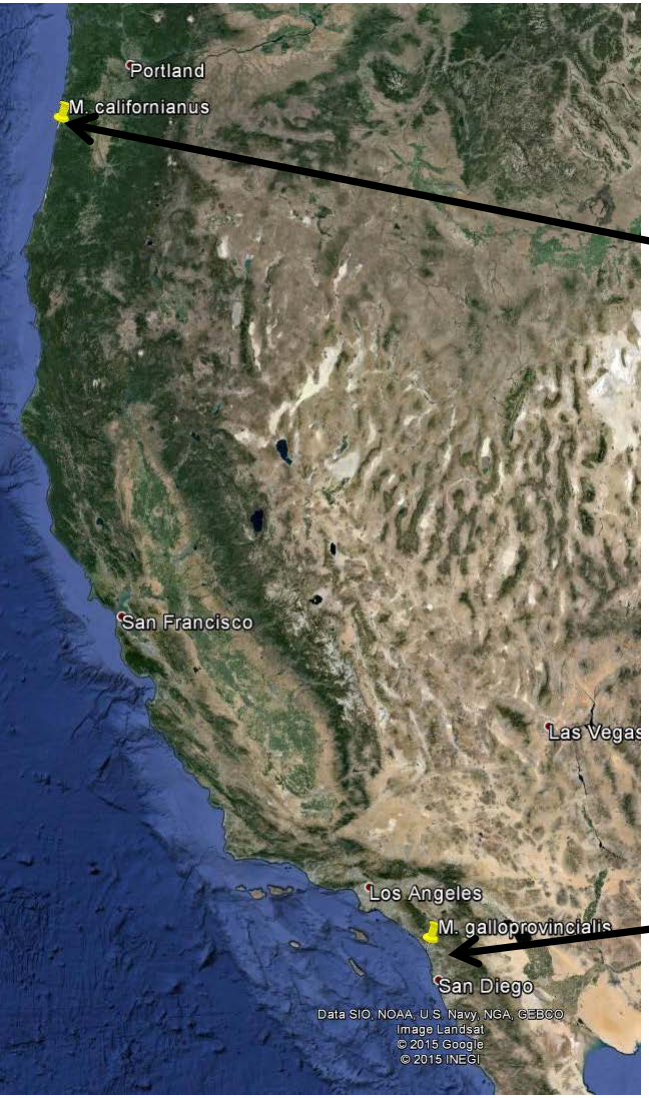
For the normally developed larvae, decreases in saturation state make smaller larvae.

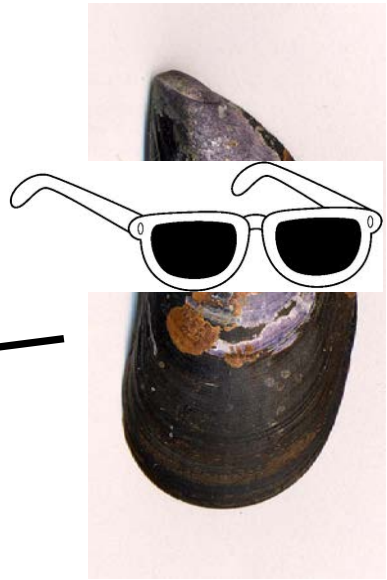
Smaller scope for growth means making shell is more expensive, or something else is requiring more energy.

Waldbusser et al. 2015

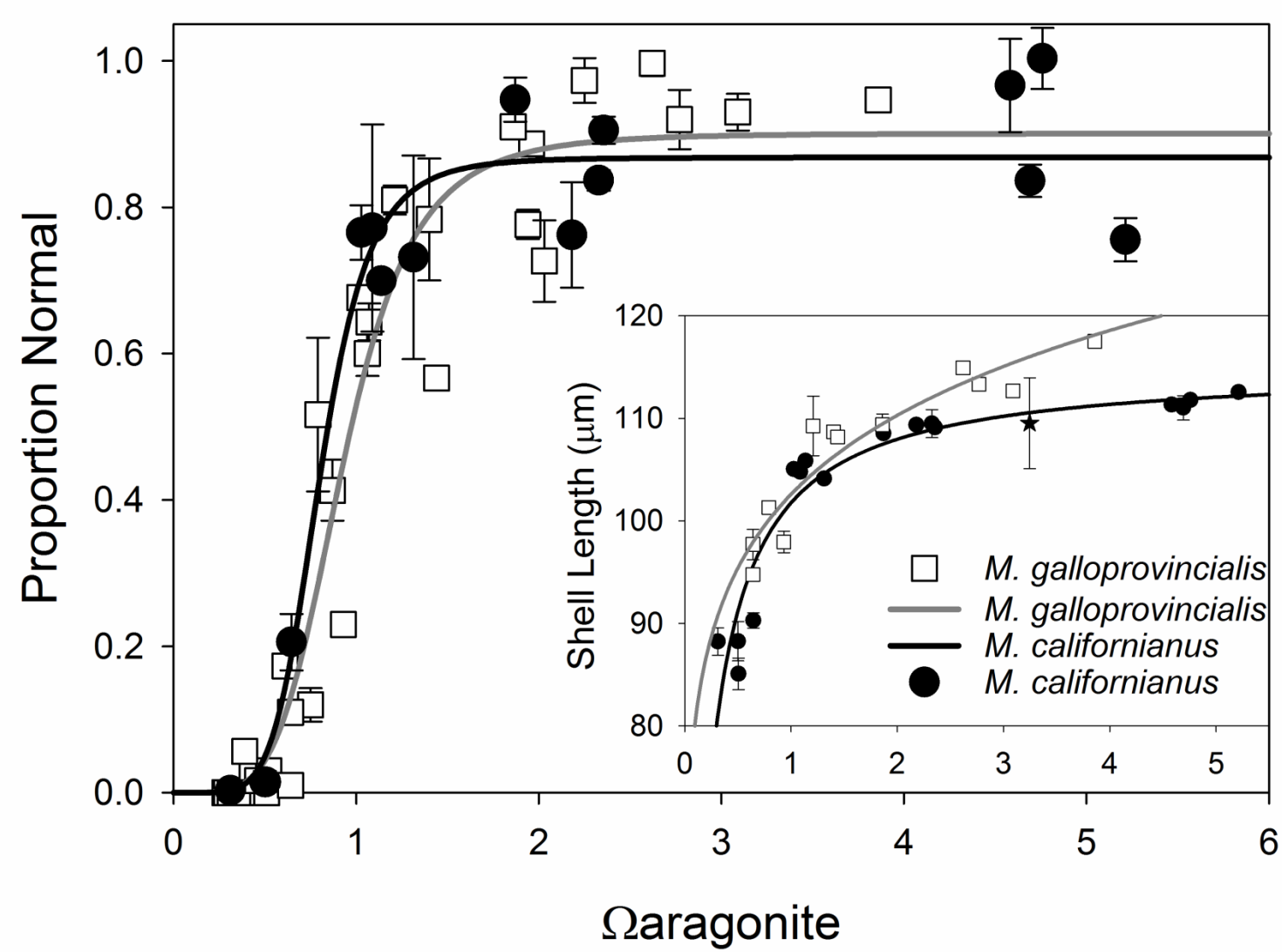
Comparison of Native and Non-native Mussel Larvae

M. californianus versus M. galloprovincialis





Comparison of Native and Non-native Mussel Larvae



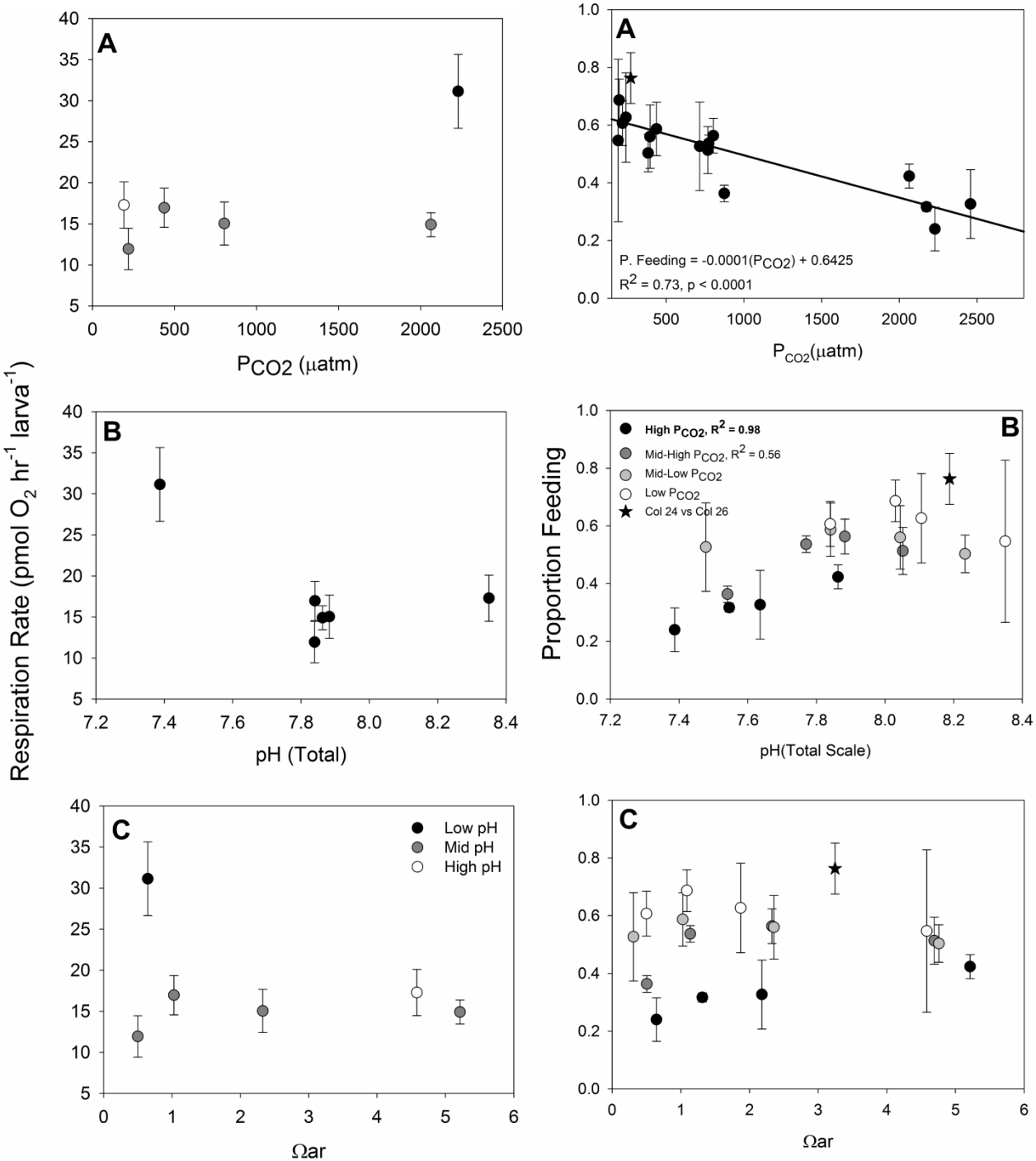
Hanging out in a OA Hot-spot doesn't seem to help *M. californianus*

Waldbusser et al. 2015

OA as a Multiple Stressor

Same experiments looking at respiration rates and a feeding metric in *M. californianus*

OA as a Multiple Stressor



Respiration Rate responds to pH (as expected).

Proportion Feeding to P_{CO2}.

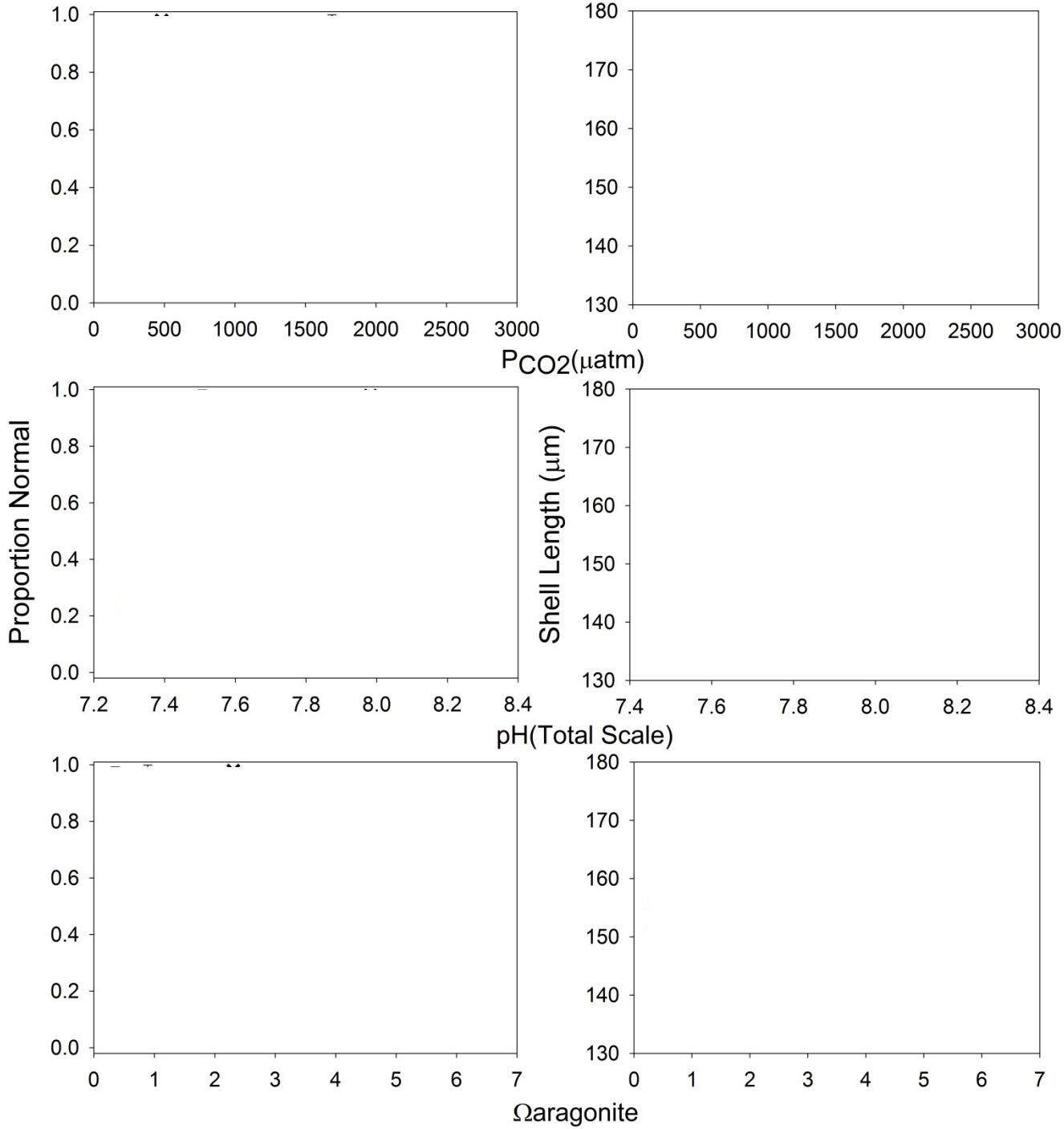
Waldbusser et al. in review

The Mighty Olympia Oyster

Same experiments as above, but we've extracted brooding larvae to measure their response during the same developmental phase as the others…

And their appears to be no positive benefit of brooding on development and growth under "normal conditions".

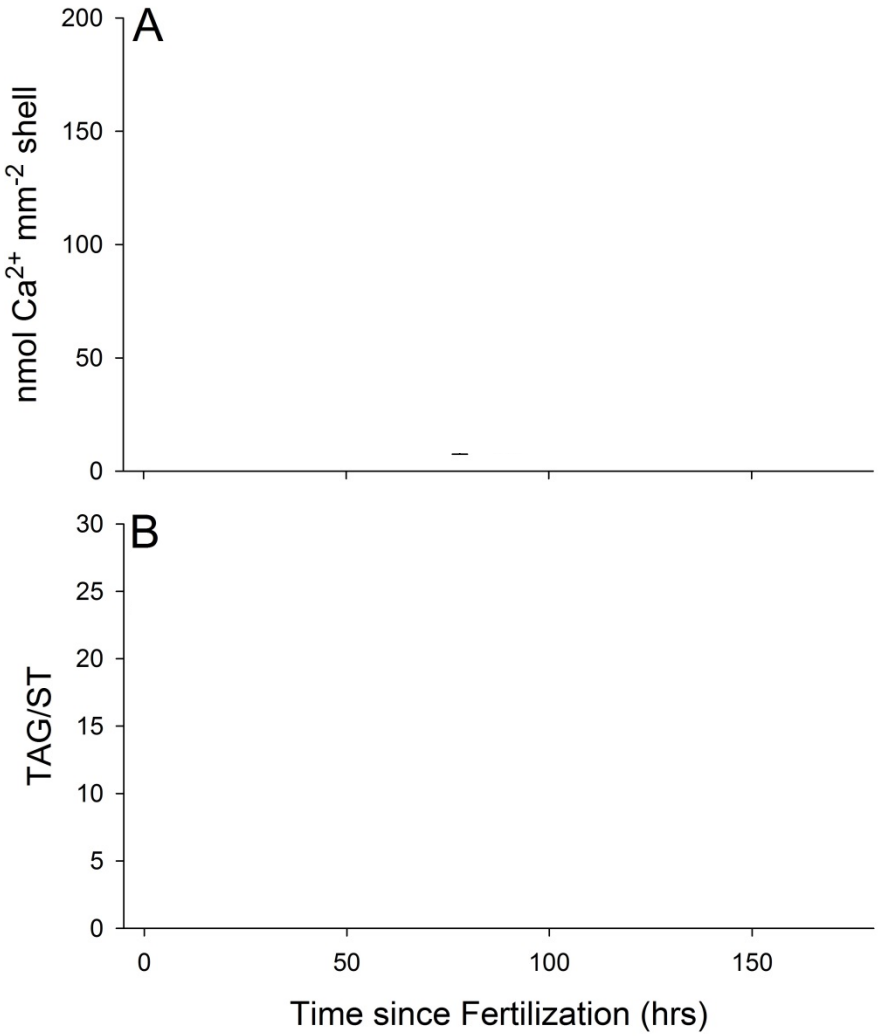
O. lurida



This doesn't mean O. lurida are impervious to OA, excellent work on chronic/carry-over effects by Hettinger et al.

Waldbusser et al. in prep

Calcification Rates



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

Waldbusser et al. in prep

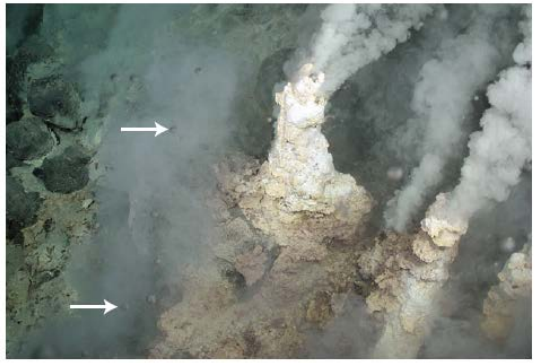
In case you are the eternal optimist…

LETTERS
PUBLISHED ONLINE: 12 APRIL 2009 | DOI: 10.1038/NGEO500
nature geoscience

Survival of mussels in extremely acidic waters on a submarine volcano

Verena Tunnicliffe[1,2]*, Kimberley T. A. Davies[1]†, David A. Butterfield[3], Robert W. Embley[4], Jonathan M. Rose[1] and William W. Chadwick Jr[5]

c



d

Mussels survive at saturation states less than 0.1…

Those mussel shells are so thin they are transparent, the same species at other less “acidic” vents nearby have shells that are nearly 3-4X thicker.

Also chemosynthetic, nearly 40 years old (~6 cm), and all appear to be the same age…

What the (US) shellfish industry is doing?

Margaret Pilaro Barrette and Bob 'Skid' Rheault Become a fan

Executive Directors of the Pacific and East Coast Shellfish Growers Associations

Future Proofing the Shellfish Industry

Posted: 06/17/2015 1:39 pm EDT | Updated: 06/17/2015 1:59 pm EDT

Shellfish farming is hard work, and growers depend on Mother Nature to feed and nurture our crops. Growers work at the mercy of tides, storms, predators and changing water quality. Around the nation thousands of people in rural coastal areas make their living growing oysters, clams and mussels. Thousands more harvest wild shellfish. Shellfish are the financial backbone for many coastal communities, adding

What is the industry doing?

Currently in 2 of the 3 commercial oyster hatcheries in the PNW, use the "Tums" solution is used to treat water coming into the hatchery.

Improving the carbonate chemistry has vastly improved production, but hasn't eliminated all failures…

Breeding, breeding, breeding

Molluscan Broodstock Program

Hatfield Marine Science Center
Oregon State University

http://www.hmsc.oregonstate.edu/projects/mbp
Phone: 541-867-0231
E-mail: chris.langdon@oregonstate.edu

Habitat Level Refugia: Shells and Seagrass?

About 1 MT of shell material are removed from the global ocean annually.

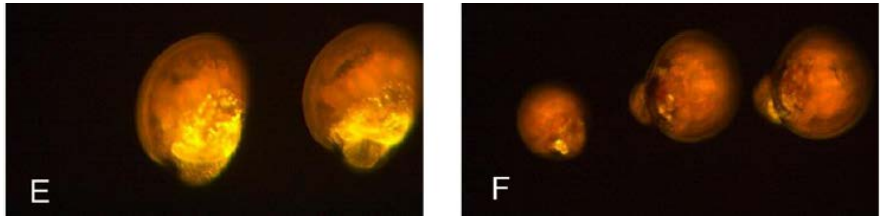
Bivalves are gregarious

When they die they leave their hard parts (shells) behind

Biological Monitoring with Industry

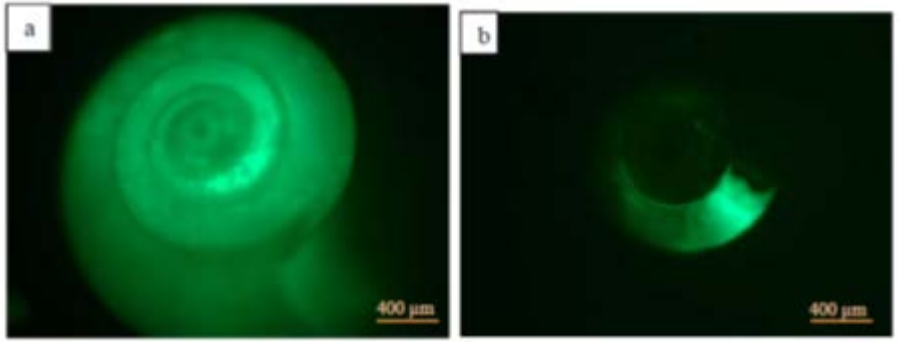
Improve survival through screening of OA impacts

With Annaliese Hettinger



Ben Kheder et al. 2010

Nile Red stain for lipid content



Bednaršek et al. in prep

Calcein stain for calcification activity

<u>Industry Partners:</u>

Taylor Shellfish Farms: Willapa Bay, WA
Whiskey Creek Shellfish Hatchery: Netarts Bay, OR
Nevør Shellfish Farm: Netarts Bay, OR
Oregon Oyster Farm: Yaquina Bay, OR

Thoughts

- **Overall we know a lot, but specifics become less clear**
- **Do we need to document the long-term trend in the noise?**
- **Proxies for monitoring**
- **Focus on certainty in communicating the science (comfort with uncertainty)**
- **Care in the literature (Science is a work in progress)**
- **Tolerance versus traits, what does natural selection act on?**
- **Vulnerability is more than just environmental hazard (resiliency)**
- **Value in being proactive versus reactive**
- **Collaboration and partnerships are needed**