Winter as OA Refugia in Pacific Northwest Coastal Waters

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Wiley Evans, Katherine Harris, George Waldbusser

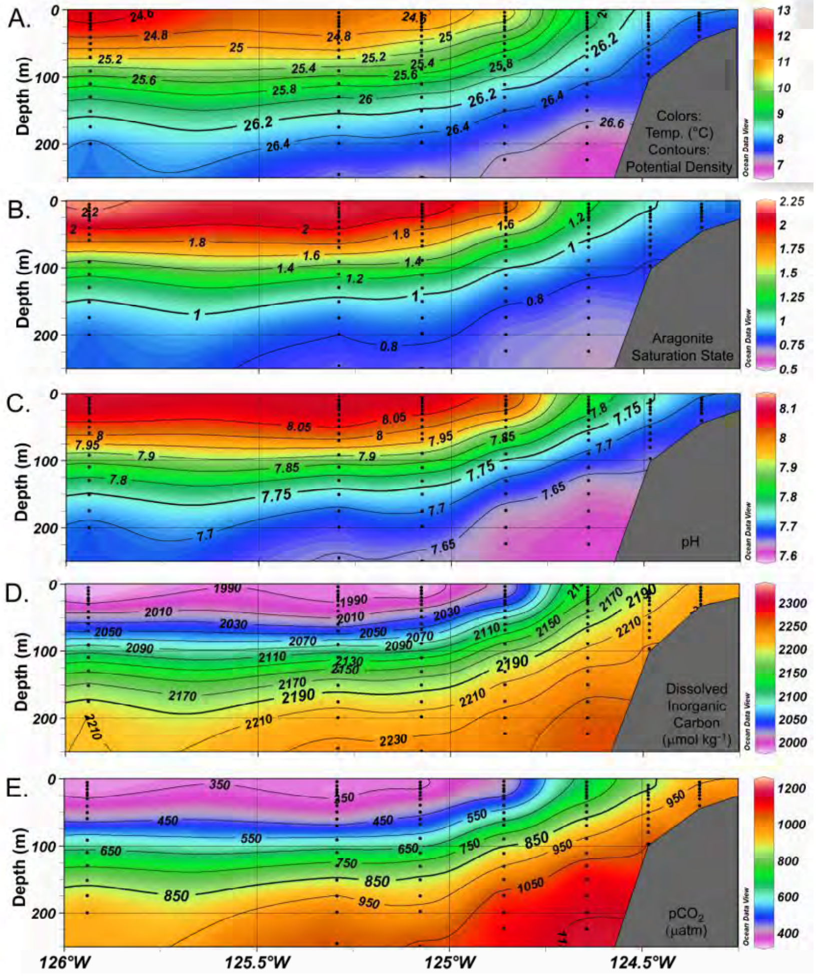
Also:

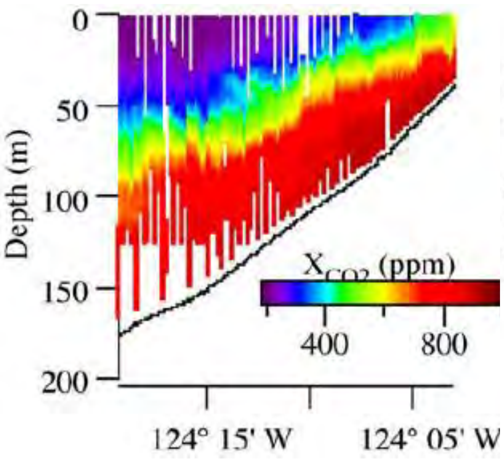
Miguel Goni, Angel White

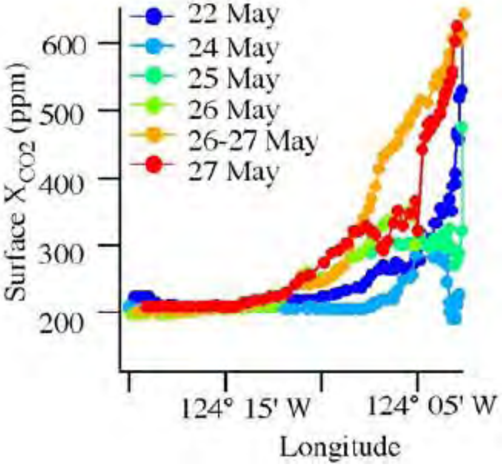
too.

Background: Ocean Acidification in Pacific Northwest Coastal Waters

1. Upwelled waters are high in CO_2 (Hales et al 2005; Van Geen et al 2000, Chavez, Feely et al 2008, Evans et al 2011, Harris et al 2013)
2. Upwelled waters outcrop near shore, with high-CO_2 signal (Hales, Van Geen, Feely) and influence bay chemistry (Barton et al 2012)
3. Coastal waters are influenced by anthropogenic CO_2 such that Ω is reduced by 0.2 in deep waters (Feely, Harris) and 0.5 in surface waters (Harris)



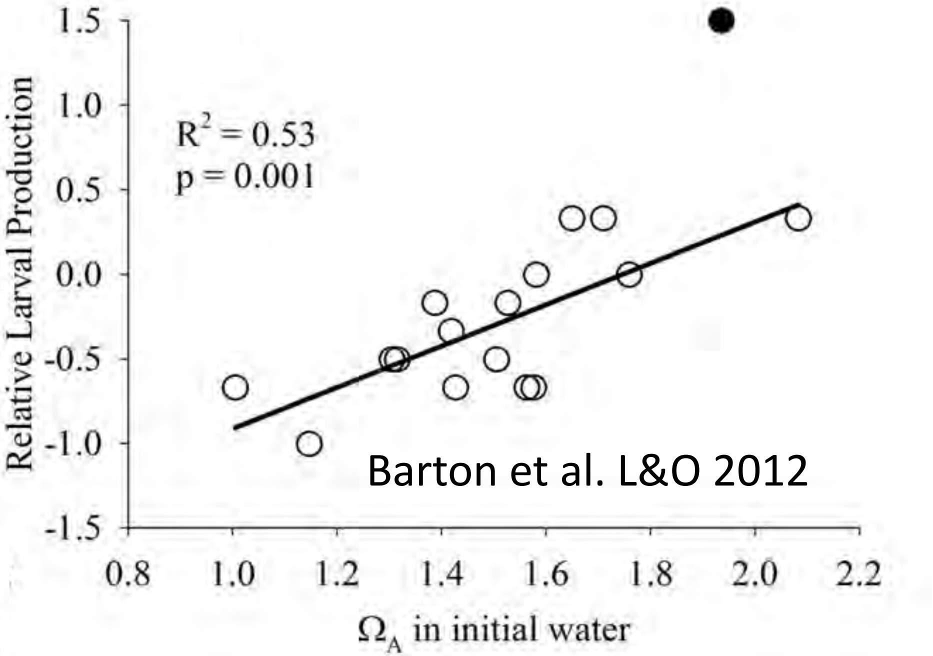




$$\Omega = \frac{[Ca^{2+}][CO_3^{2-}]}{K'_{sp,arag}}$$

Background: Ocean Acidification in Pacific Northwest Coastal Waters

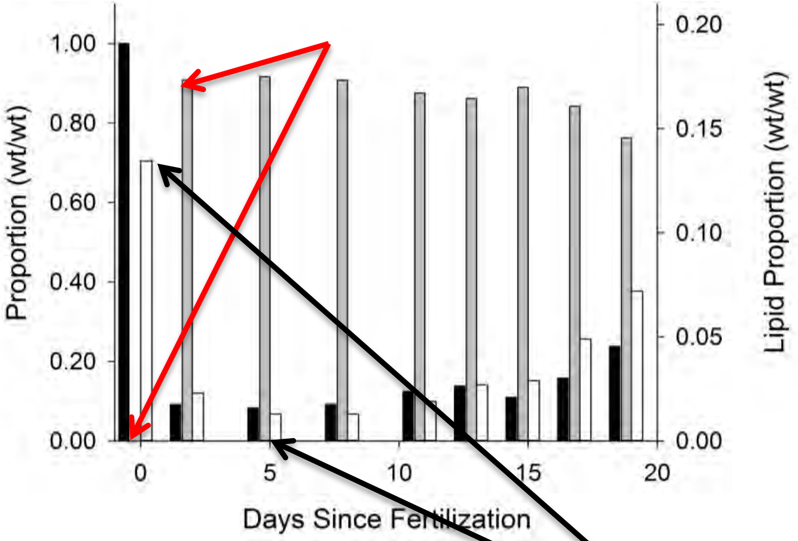
4. Early larval sensitivity to ambient-water shell-mineral stability under present-day conditions.



Barton et al. L&O 2012

$$W = \frac{\left[Ca^{2+}\right]\left[CO_3^{2-}\right]}{K'_{sp,arag}}$$

Shell content goes from 0 – 80% in two days

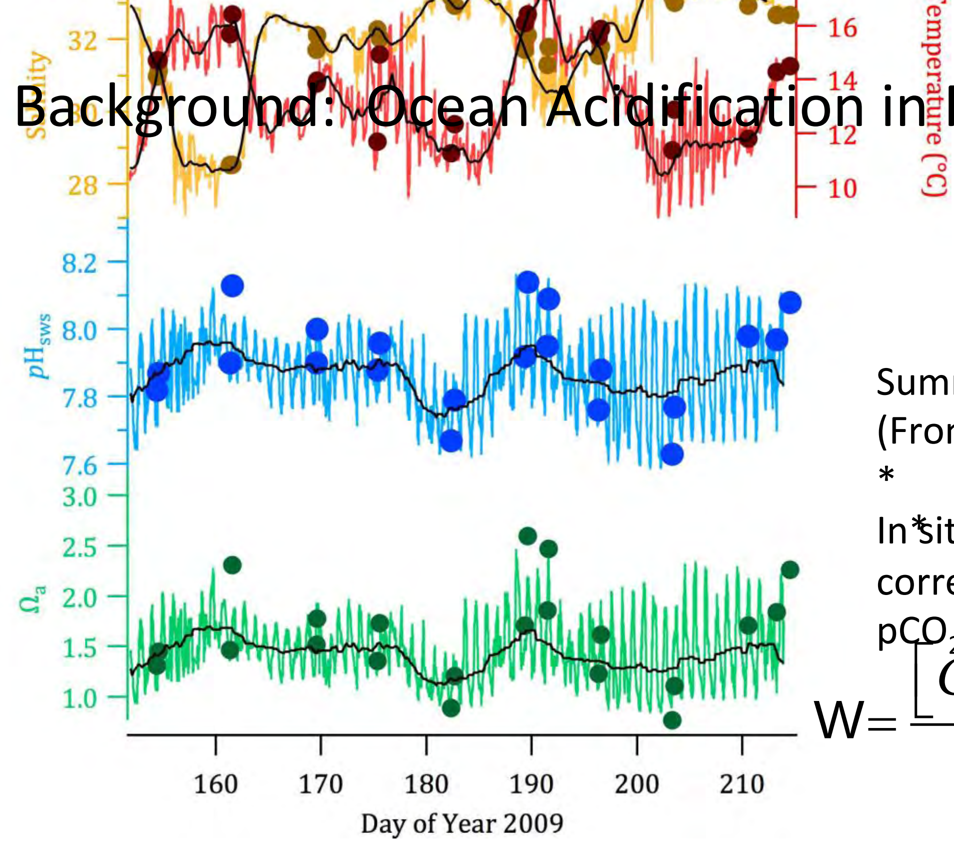


Waldbusser et al., GRL 2013

Energy reserves fall by 80%

5. Mechanism is energetically-costly kinetic acceleration of aragonite precipitation within first hours after hatching.

Background: Ocean Acidification in Pacific Northwest Coastal Waters



TCO_2*check*samples*
combined*with*in*situ*
monitoring*confirm*this.*

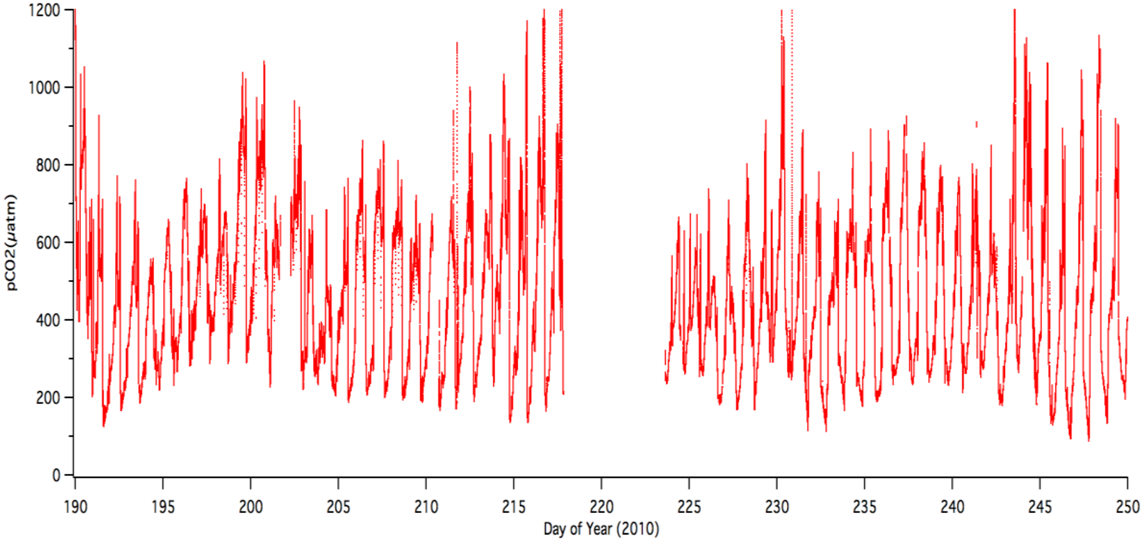
6. Is it Ω?

Summer,*2009*
(From*Barton*et*al.,*L&O,*in*revision)*
*

How do we isolate Ω from other effects?

In*situ*continuous*T,*S,*pH*data*(YSI),*
corrected*with*discrete*samples*for*
pCO_2,*TCO_2*(Hales*lab).*

$$W = \frac{\left[Ca^{2+}\right]\left[CO_3^{2-}\right]}{K'_{sp,arag}}$$



6. Is it Ω (continued)?

Chemical Manipulations of Carbonate Chemistry (general approach):

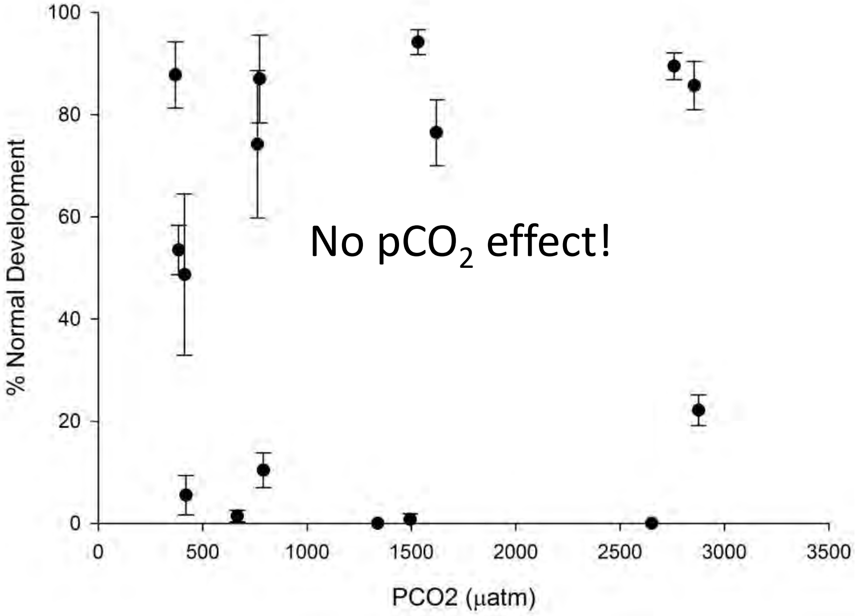
Manipulate Alkalinity and total CO_2 simultaneously to hold individual parameters constant:

pCO2 \ ΩAr:	4	2	1	0.5	
200	8.33	8.18	8.03	7.88	:pH_{sws}
400	8.18	8.03	7.88	7.73	:pH_{sws}
800	8.03	7.88	7.73	7.58	:pH_{sws}
1600	7.88	7.73	7.58	7.43	:pH_{sws}

Turns out this is challenging , but…

Waldbusser, Hales et al. in prep.

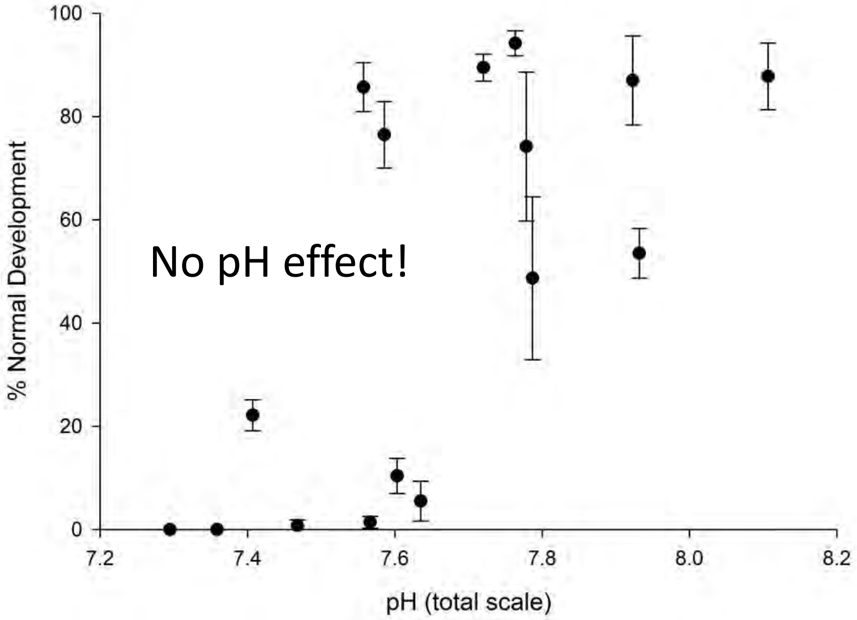
6. Is it Ω?



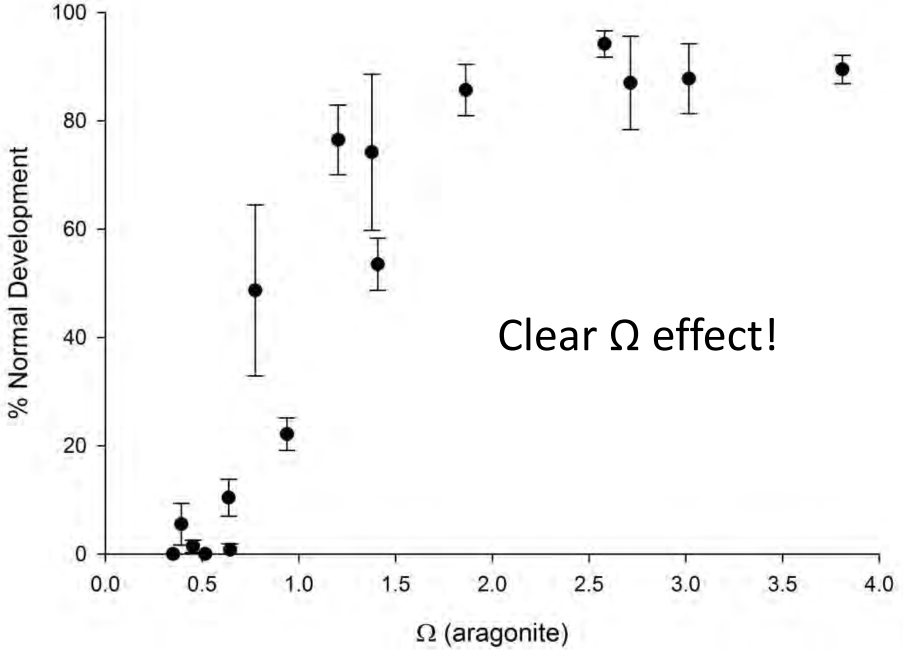
No pCO_2 effect!

PCO2/∧	~3	~1.5	~0.7	~0.4
~400	87.78	53.54	48.69	5.50
~700	87.00	74.20	10.39	1.42
~1600	94.22	76.49	0.74	0.00
~2800	89.50	85.71	22.13	0.00

Waldbusser, Hales et al. in prep.



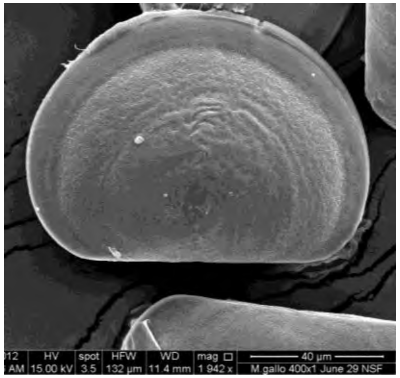
No pH effect!



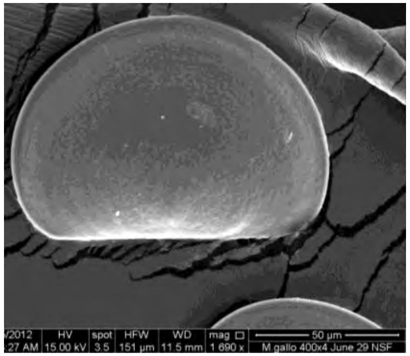
Clear Ω effect!

6. Is it Ω?

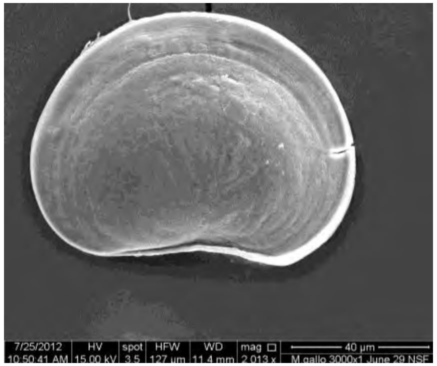
PCO2 = 412
Omega = 0.77



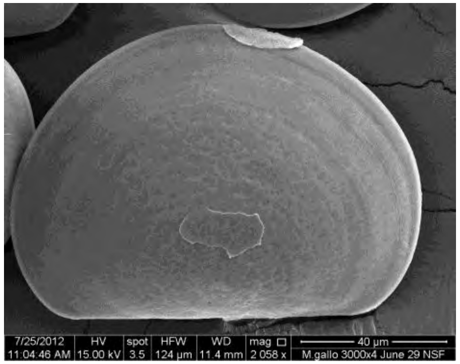
PCO2 = 368
Omega = 3.02



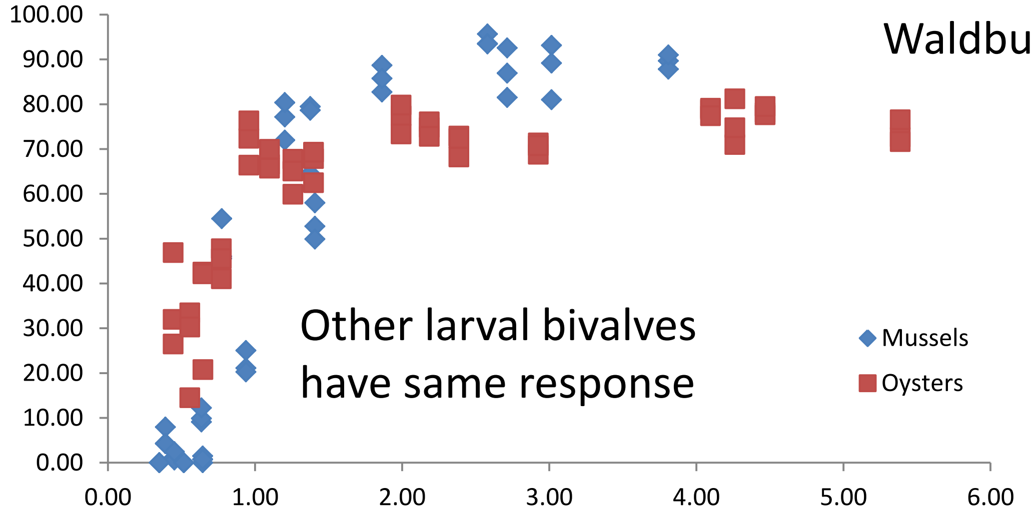
PCO2 = 2876
Omega = 0.94



PCO2 = 2758
Omega = 3.81



Imaging courtesy E. Brunner, OSU

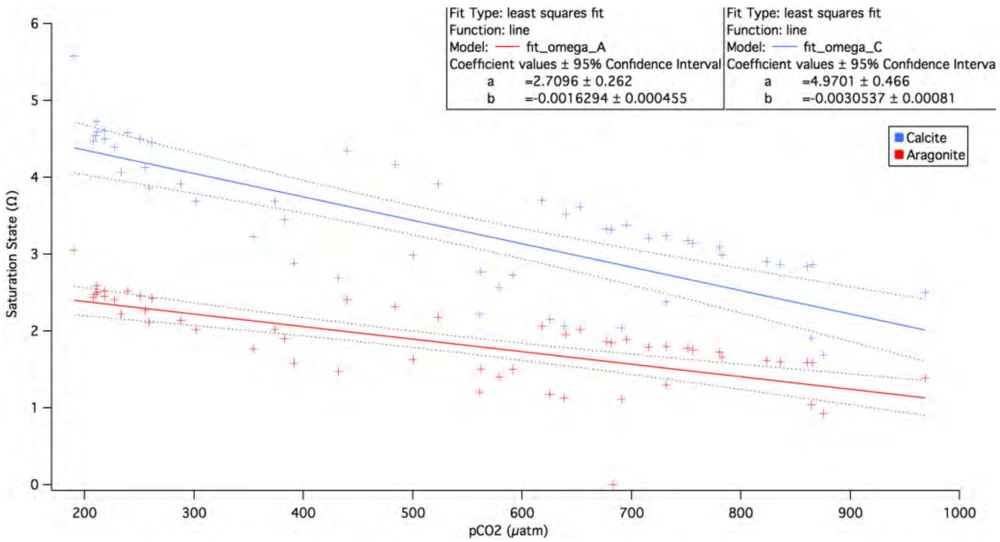


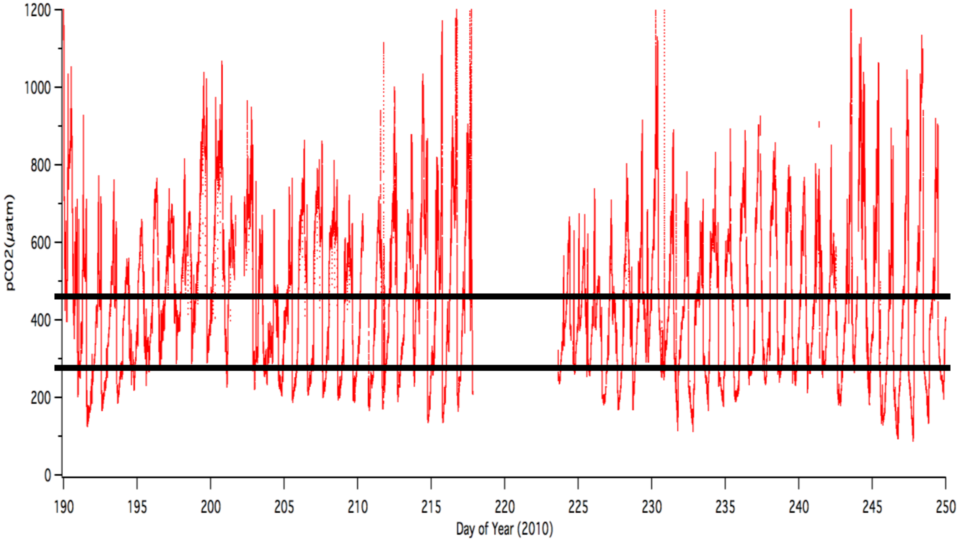
Other larval bivalves have same response

Waldbusser, Hales et al., in prep.

So, yes, it’s Ω

7. Does natural variability help or hurt?





Vance, 2012, MS Oregon State University

Using pCO_2 as proxy, threshold for break-even is at pCO_2 ~ **450 µatm**; threshold for no impact is at pCO2 ~ 280 **µatm**

Daily variability during a typical upwelling season

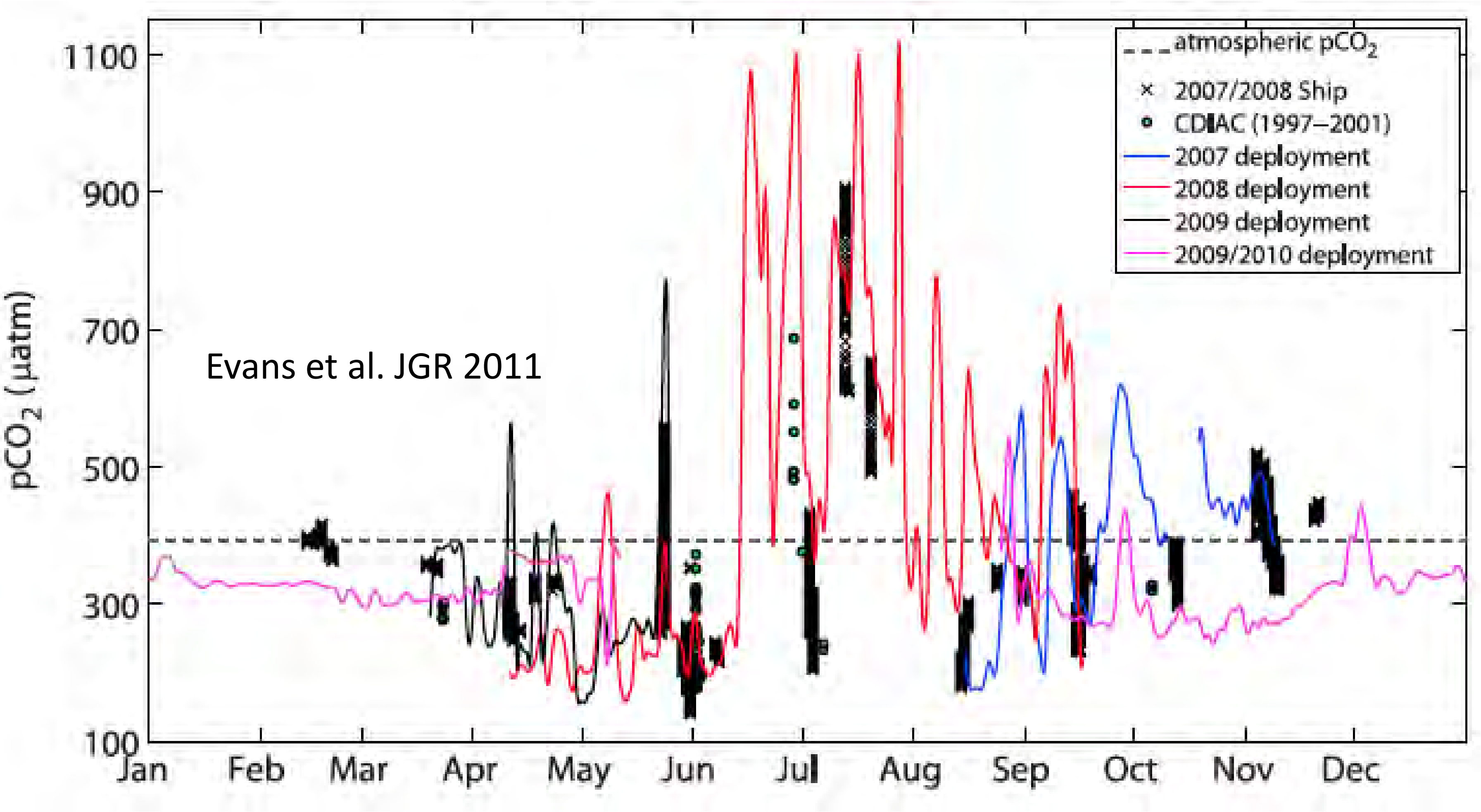
Break-even spawning/ growing conditions now ~50% of time;

No-impact conditions now <20%.

Invariant system would have fewer instances of harmful conditions (today).

Winter conditions as OA refugia

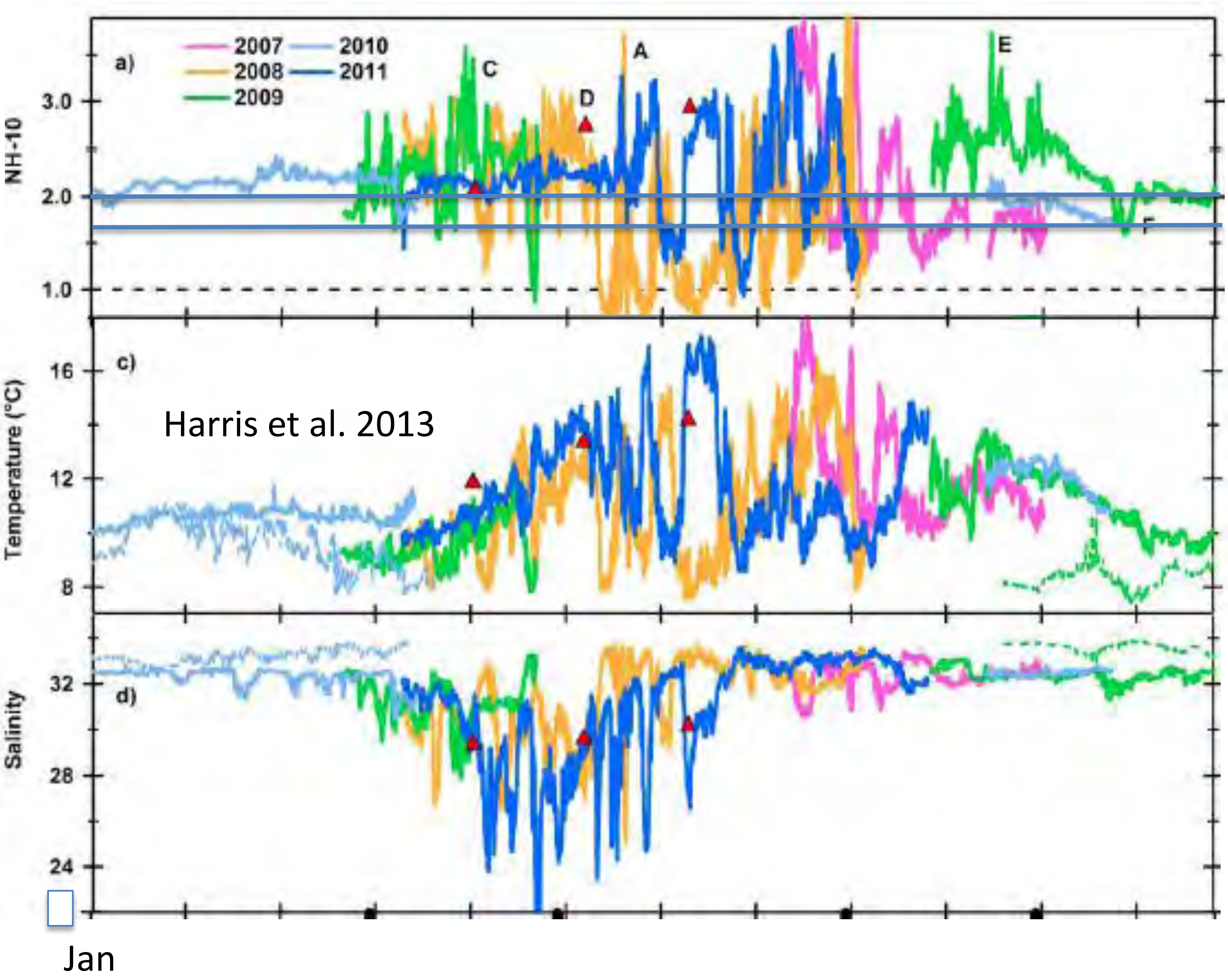
So, upwelling season is tough going for shell producers in early larval stages. When is it better to spawn?



Evans et al. JGR 2011

Time series data show that winter pCO2 levels are (surprisingly?) low

Winter conditions as OA refugia

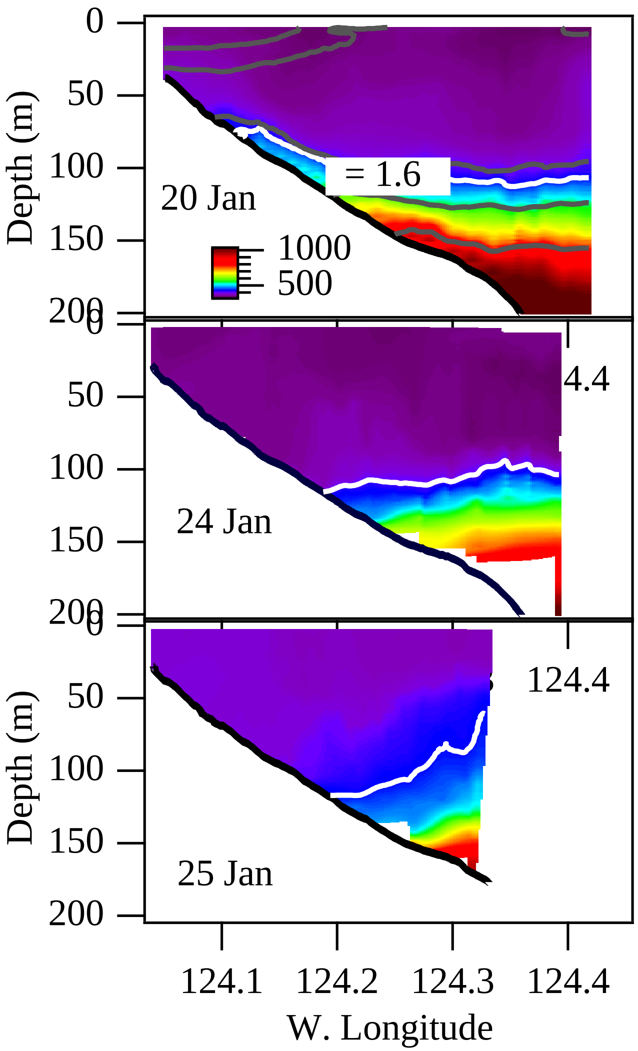


Harris et al. 2013

Combined pH/pCO$_2$/Salinity timeseries allow calculation of Ω.

Waters mostly above the ‘no effect’ threshold Nov-Mar; almost entirely above ‘break-even’ threshold.

Winter conditions as OA refugia



Wintertime low-CO_2 conditions persist across the shelf and throughout the water column.

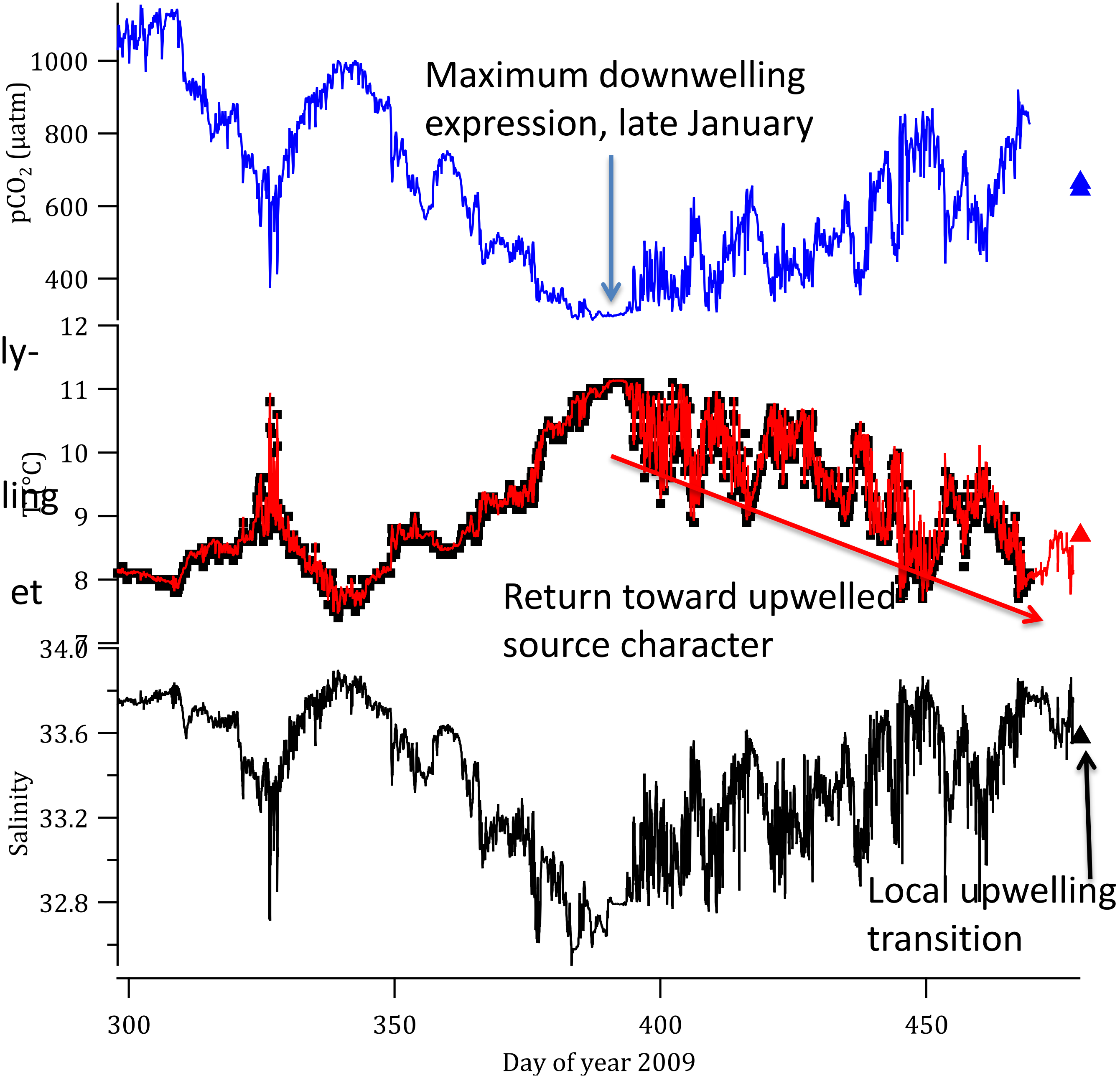
High-CO_2 waters are present, but forced down and offshore by winter downwelling circulation.

‘Break-even’ threshold is forced down and offshore by downwelling forcing.

Surface waters reach values as low as ~340 µatm.

But that water starts to encroach before local winds are upwelling favorable.

Likely caused by coastally-trapped internal waves propagating northward from persistently upwelling regions in northern California (sensu Hickey et al 2007)



Bottom boundary layer water at 130m isobath

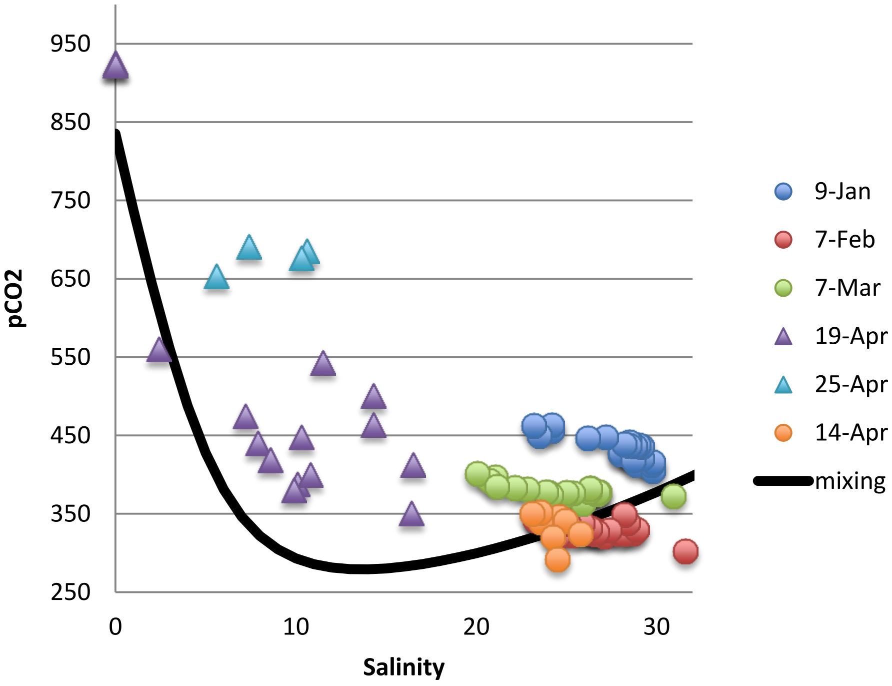
Maximum downwelling expression, late January

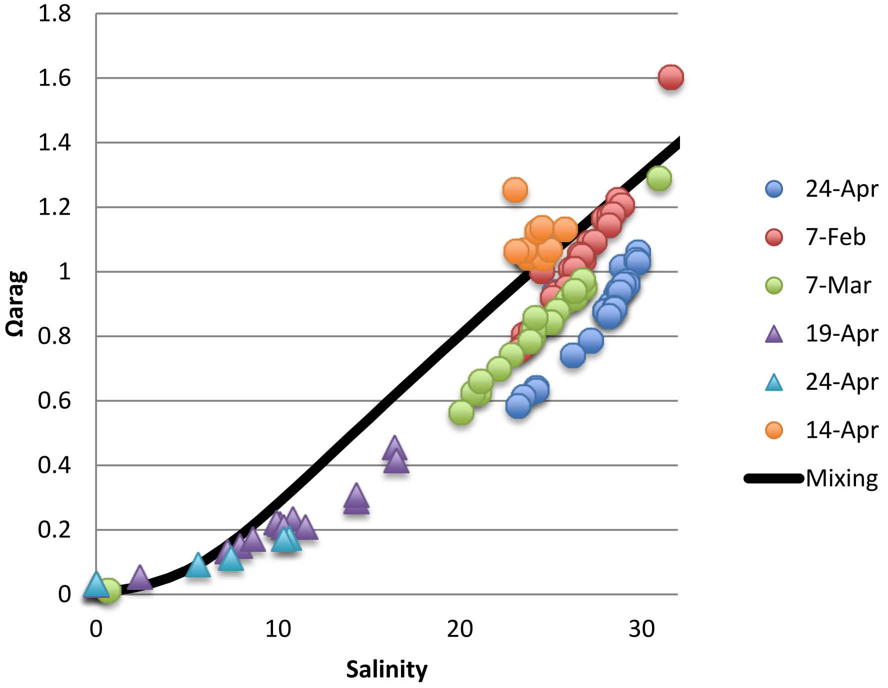
Return toward upwelled source character

Local upwelling transition

Winter conditions as OA refugia

Signature of winter coastal river discharge:

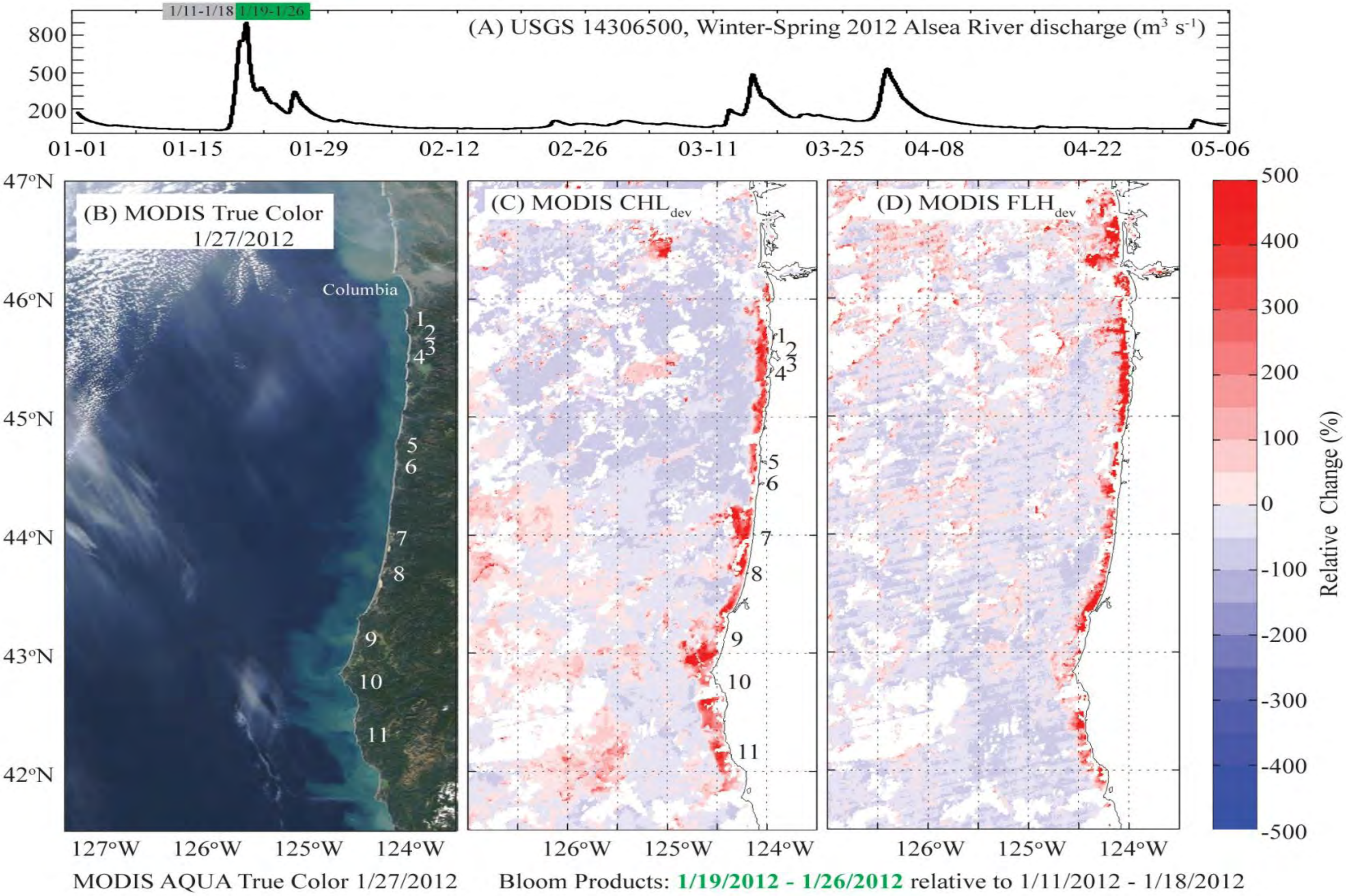




pCO$_2$ (and pH) seem inoffensive, but Ω is low.

Winter conditions as OA refugia

Coastal waters respond to winter flood events by blooming, lowering CO_2 and raising Ω



White, Goni et al., unpubl. ; see also Chase et al., GRL 2007

Conclusions:

1. Pacific Northwest coastal waters experience low-Ω conditions caused by the additive effects of natural variability and anthropogenic forcing.

2. Oysters and mussels (and clams…) show similar susceptibility in early larval stages to current conditions.

3. Anthropogenic factors have increased frequency, intensity, and duration of harmful events.

4. Winter observations show much more favorable conditions, with low-Ω events mostly absent.

5. Coastal rivers/estuaries deliver low-Ω water to the coastal ocean.

6. But these waters are high in nutrients (N, P, Si, Fe), and support coastal primary productivity, which drives coastal Ω back up.

Are there ecosystem adaptations threatened by changing carbon cycles?

- Native oysters and mussels seem to spawn outside of the upwelling periods this may be for non-OA reasons (on-shelf retention of larvae, e.g.), but also has benefit of avoiding most extreme low-Ω events.
- Remote forcing brings high-CO_2 source waters far inshore of the shelf-break, well before local upwelling winds. Moderate weakening of winter downwelling forcing will result in rapid exposure of the inner shelf to high-CO_2 conditions.
- Is river input at an optimum? Anomalous southward, on-shore excursion of Columbia River waters led to low-Ω conditions in early Spring 2011.