

# Oysters and climate change

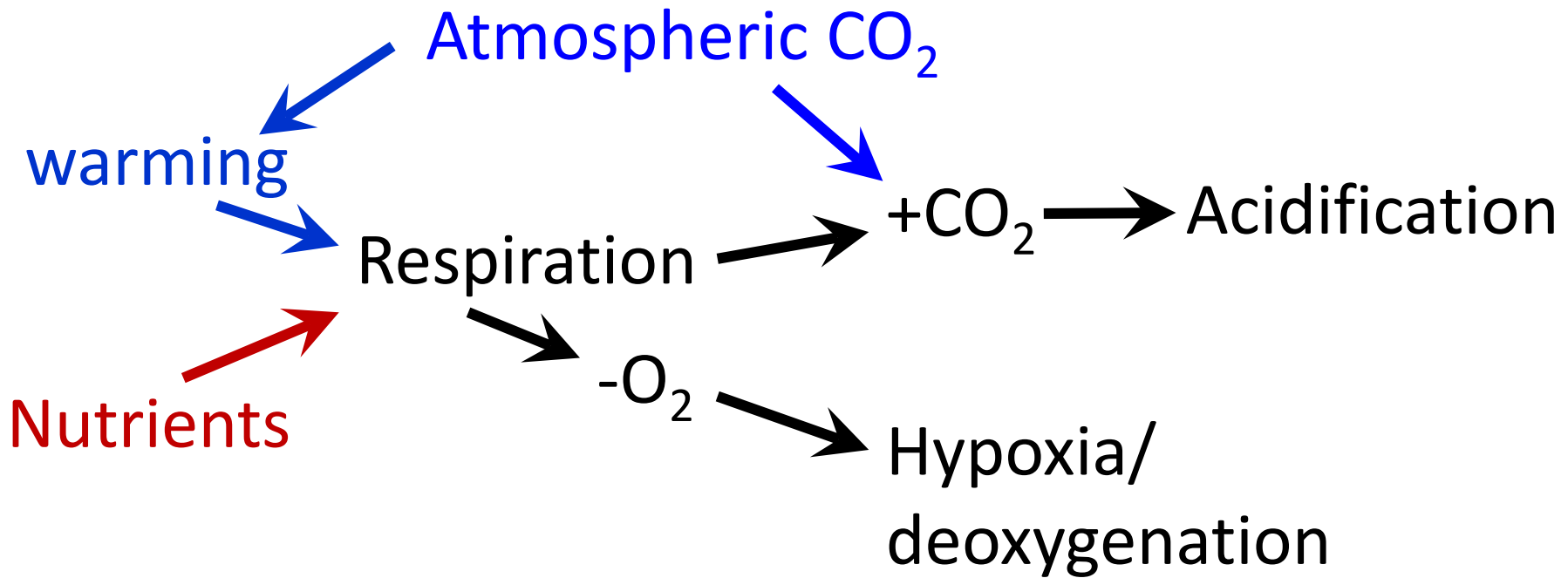
Monitoring for oysters  
in a changing Bay



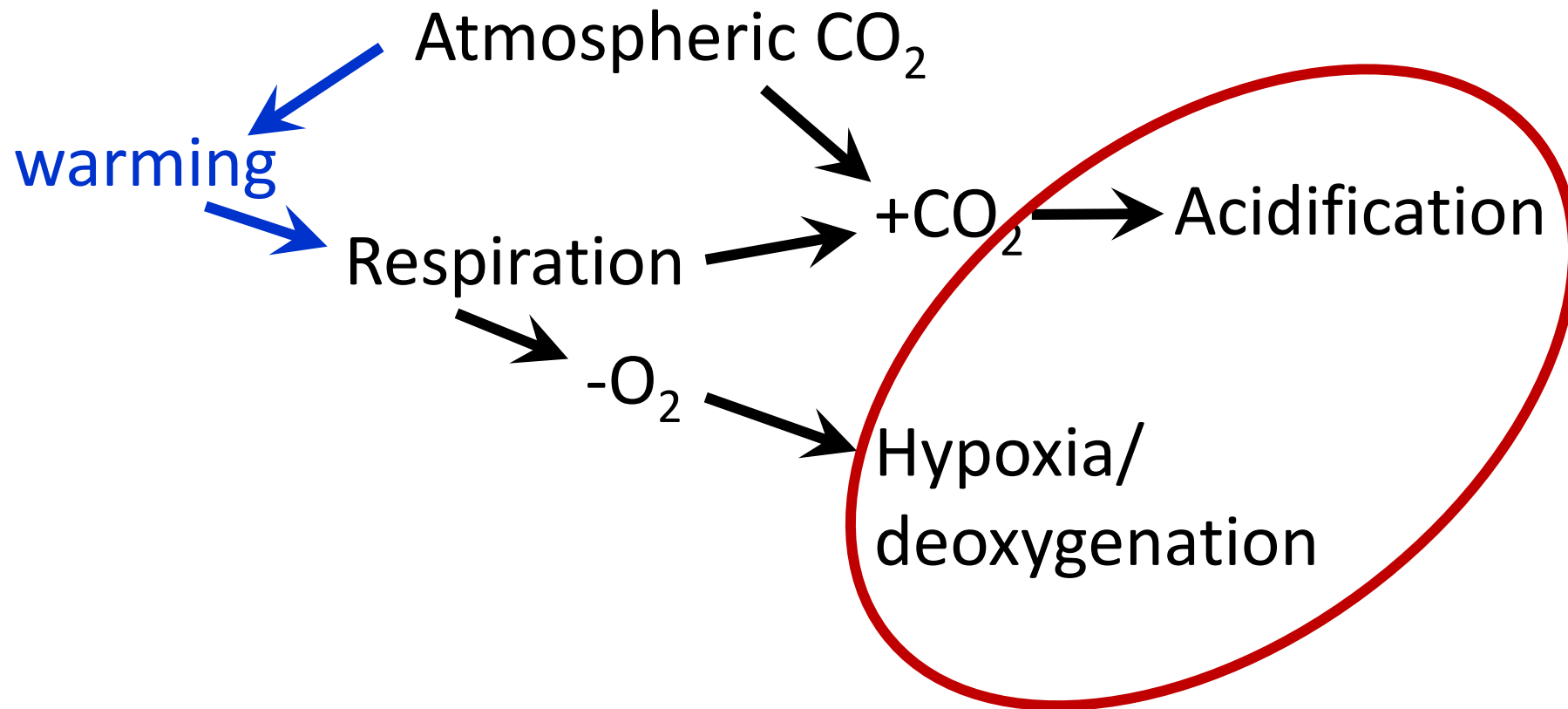
Denise Breitburg  
Smithsonian Environmental Research Center

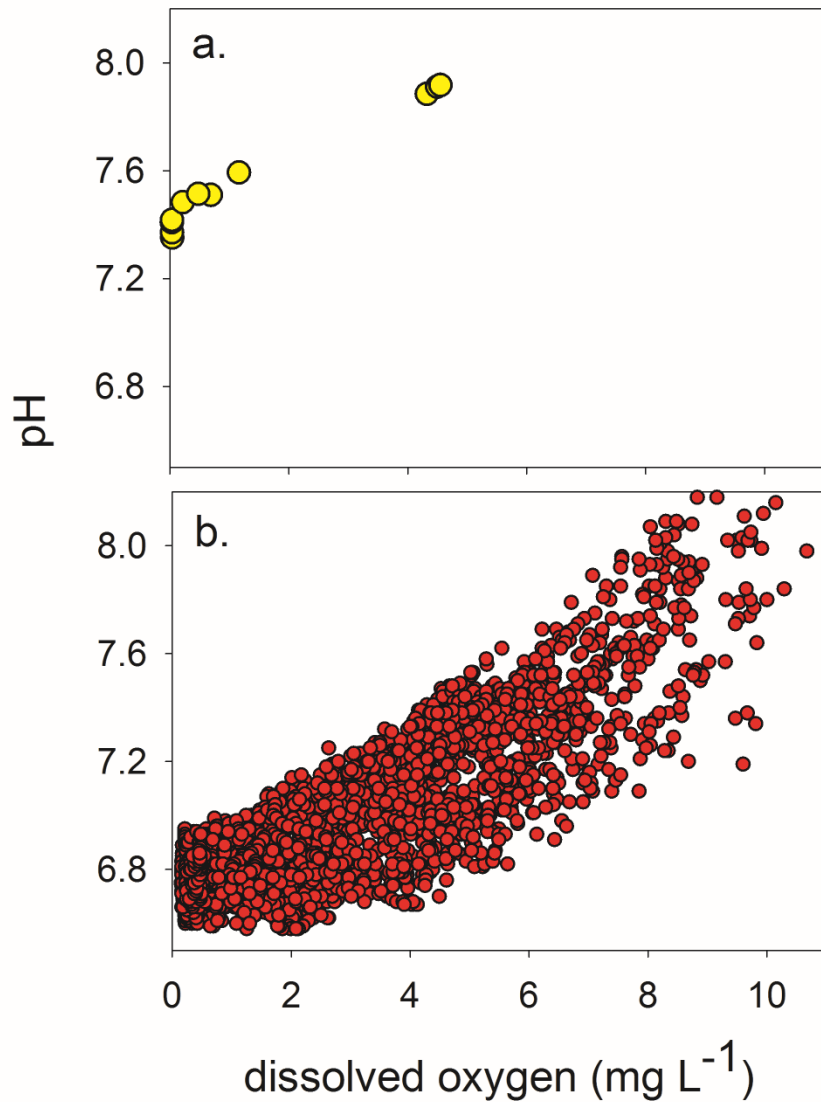
- Multiple stressor focus even more important with climate change
  - Considerations of what will get worse
  - Combined effects
- Keep doing what we're doing but add
  - total alkalinity
  - canaries (biological mimics)

# Acidification, warming and hypoxia are linked



# Multiple stressors – management, understanding



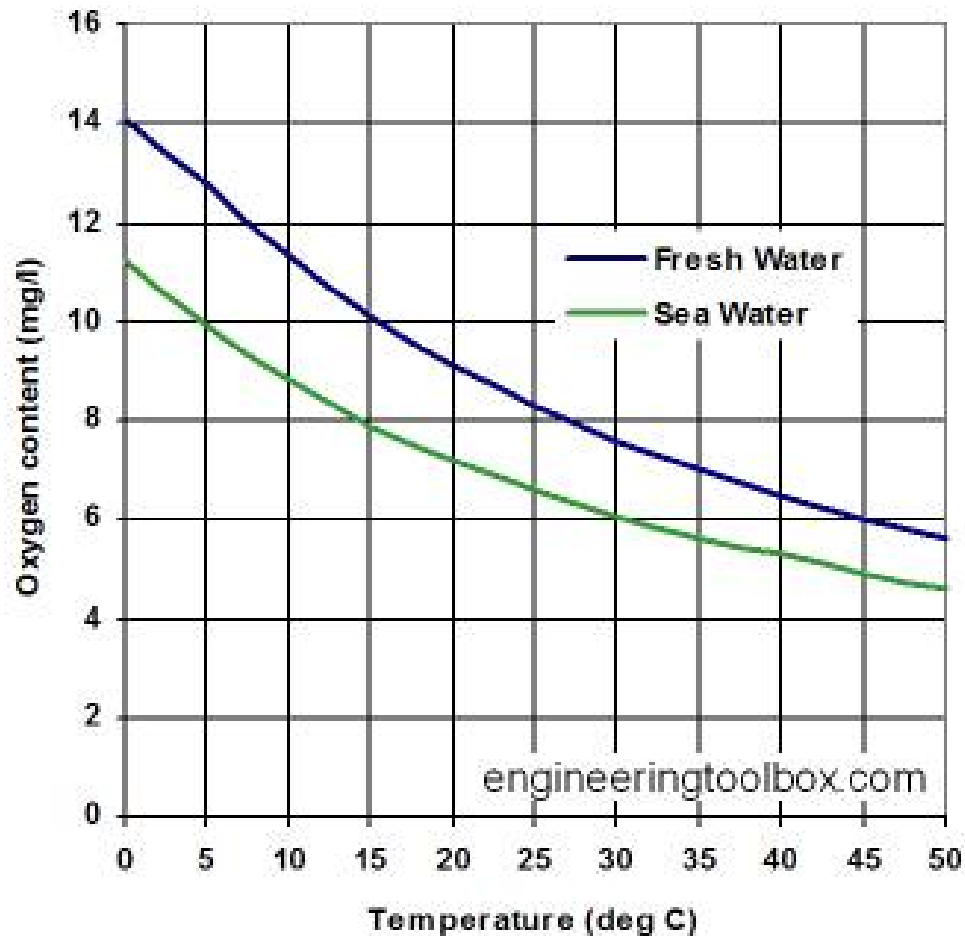


Costa Rica Dome  
0-1000 m

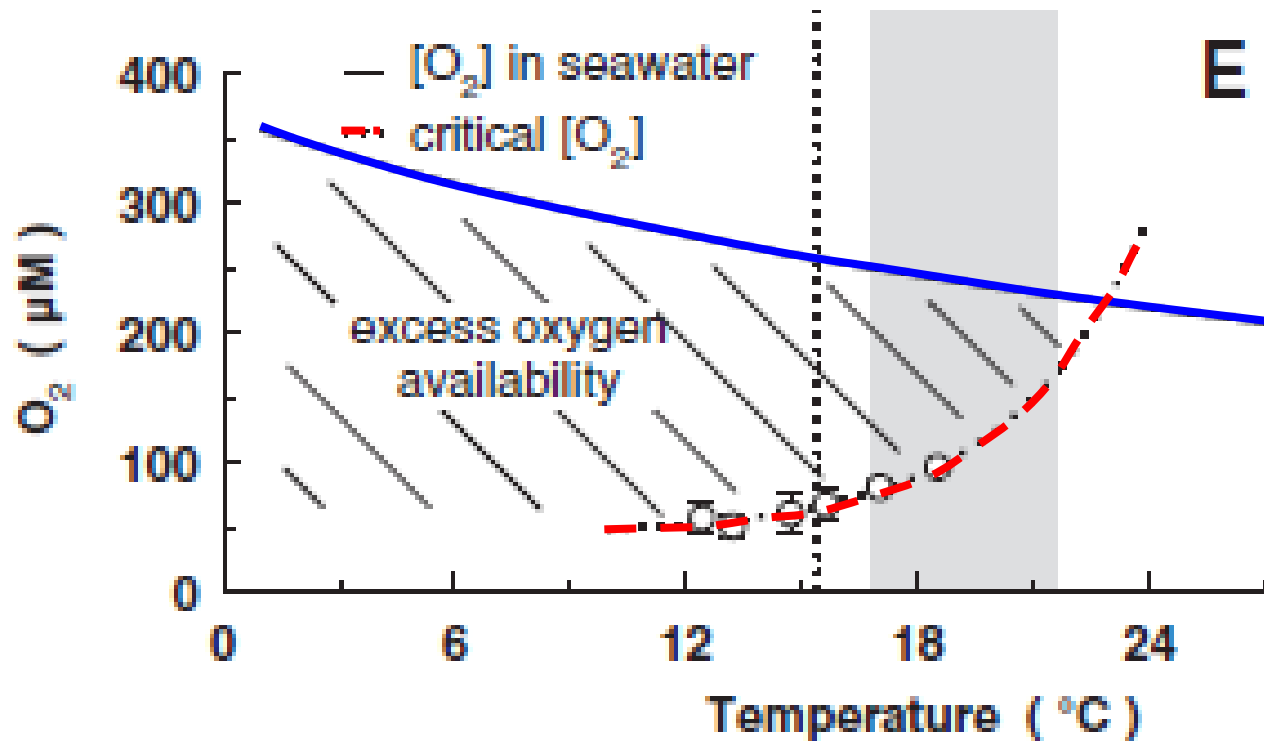
Estuarine salt marsh  
1 m

Breitburg et al., in press; data from Maas et al. 2014, Breitburg et al., unpublished

O<sub>2</sub> solubility declines as temperature increases



As temperatures increase, oxygen solubility decreases AND oxygen requirements increase

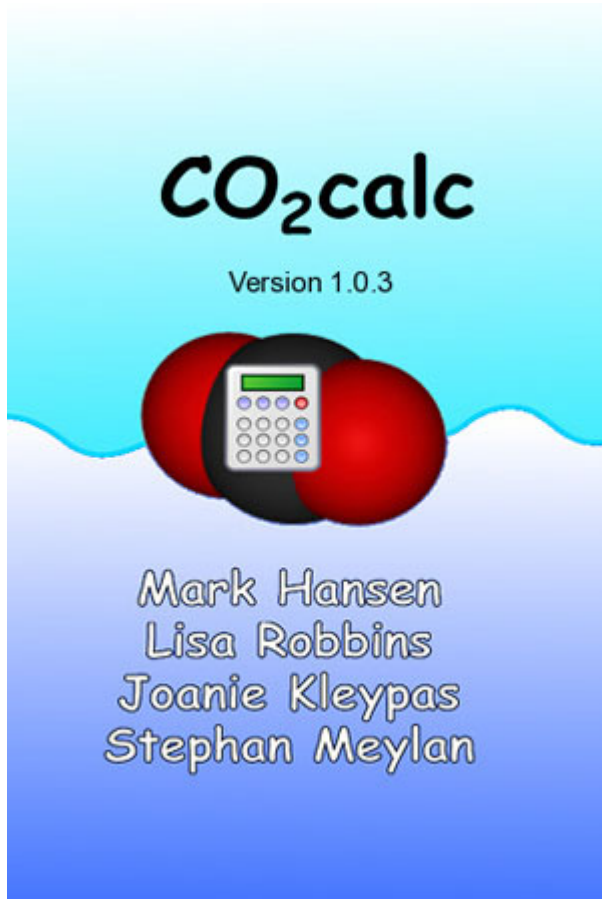


Sokolova et al. 2012

'limitations of both the amount of available energy and the rates of its acquisition and metabolic conversions result in trade-offs between basal maintenance of a stressed organism and energy costs of fitness-related functions such as reproduction, development and growth' ..and survival



# Calculating pH or $p\text{CO}_2$



CO<sub>2</sub>calc build 9 November 2010

Single-Point Mode    Batch Processing

Sample Information

Name	Date	Latitude in decimal degrees	New File...
Joe Calc	11/24/2010	8.63	Open File...
Comment	Time	Longitude in decimal degrees	~/Desktop/CO2SYS/IC
Golfo Dulce	3:31:28 PM	-83.11	<input checked="" type="checkbox"/> Record calculation

Input    Results

Results at input conditions    Results at adjusted conditions

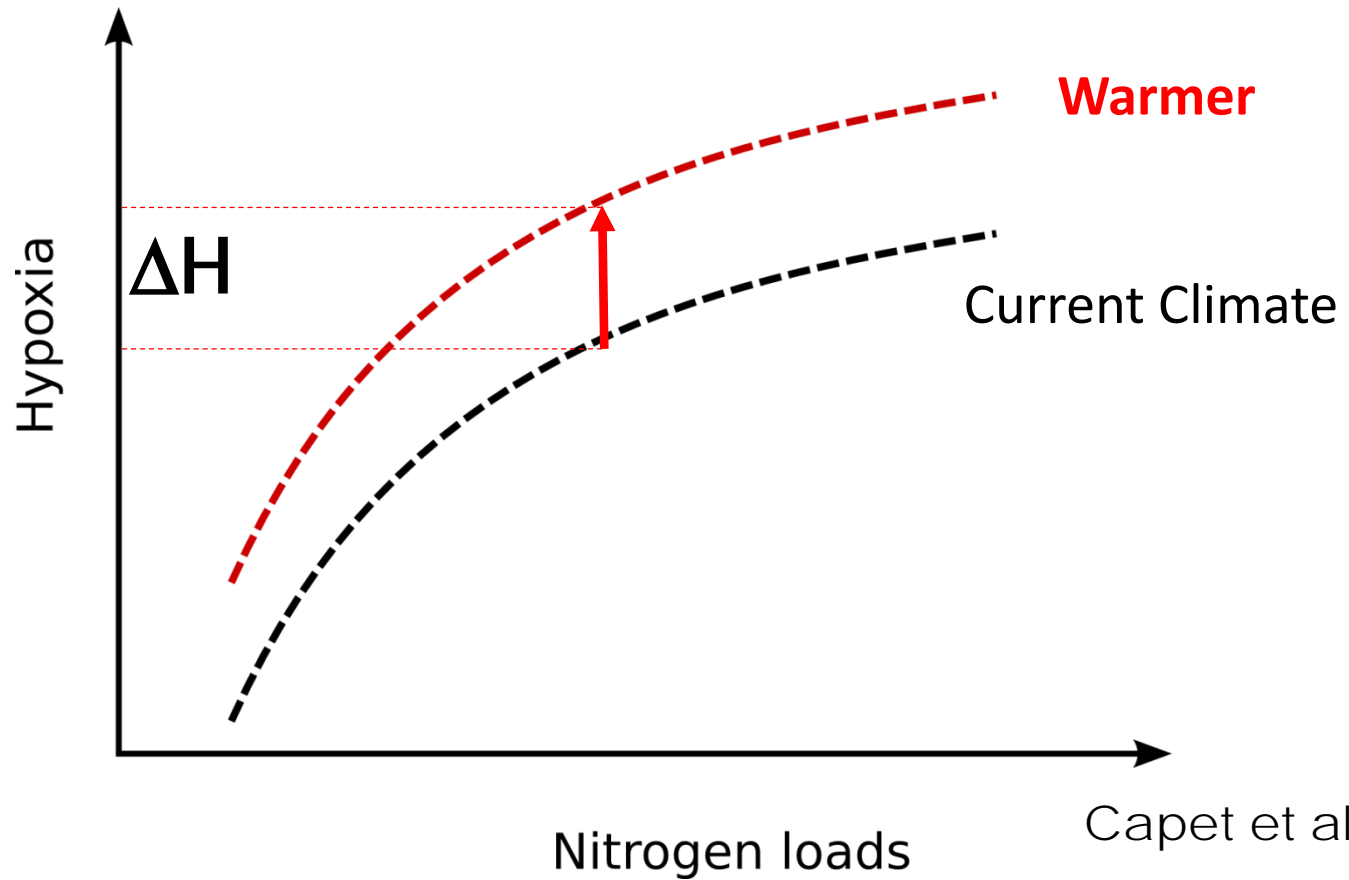
Physical Data (adjusted)	Carbonate Results (adj.)	Auxiliary Results (adjusted)	
Salinity	TA ( $\mu\text{mol/kgSW}$ )	HCO <sub>3</sub> ( $\mu\text{mol/kgSW}$ )	Si Alk ( $\mu\text{mol/kgSW}$ )
37.000	2300.000	1931.988	0.140
temperature (°C)	fCO <sub>2</sub> ( $\mu\text{mol/kgSW}$ )	CO <sub>3</sub> ( $\mu\text{mol/kgSW}$ )	Revelle
25.000	2100.000	148.285	11.676
Pressure (dbars)	pH (chosen scale)	CO <sub>2</sub> ( $\mu\text{mol/kgSW}$ )	$\Omega$ Ca
1.000	7.841	19.727	3.509
	fCO <sub>2</sub> water ( $\mu\text{atm}$ )	B Alk ( $\mu\text{mol/kgSW}$ )	$\Omega$ Ar
	702.079	66.994	2.319
Nutrient Data	pCO <sub>2</sub> water ( $\mu\text{atm}$ )	OH ( $\mu\text{mol/kgSW}$ )	xCO <sub>2</sub> (dry at 1 atm)
Total P ( $\mu\text{mol/kgSW}$ )	704.326	4.323	(ppm)
0.000	Air-sea CO <sub>2</sub> Flux (adj.)	P Alk ( $\mu\text{mol/kgSW}$ )	726.575
Total Si ( $\mu\text{mol/kgSW}$ )	Air-Sea Flux (mmol/m <sup>2</sup> /day)	0.000	build 9 November 2010
5.000	0.852		

CO<sub>2</sub> Constants: [Lueker et al., 2000](#)  
KHSO<sub>4</sub>: [Dickson \(1990a\)](#)  
pH Scale: Total scale (mol/kgSW)    Air-Sea Flux: [Wanninkhof, 1992](#)

Select Constants, Units, and Scales...    Process

# COASTAL OCEAN

Warming adds to eutrophication



Capet et al., 2013

## Other critical multiple stressor issues

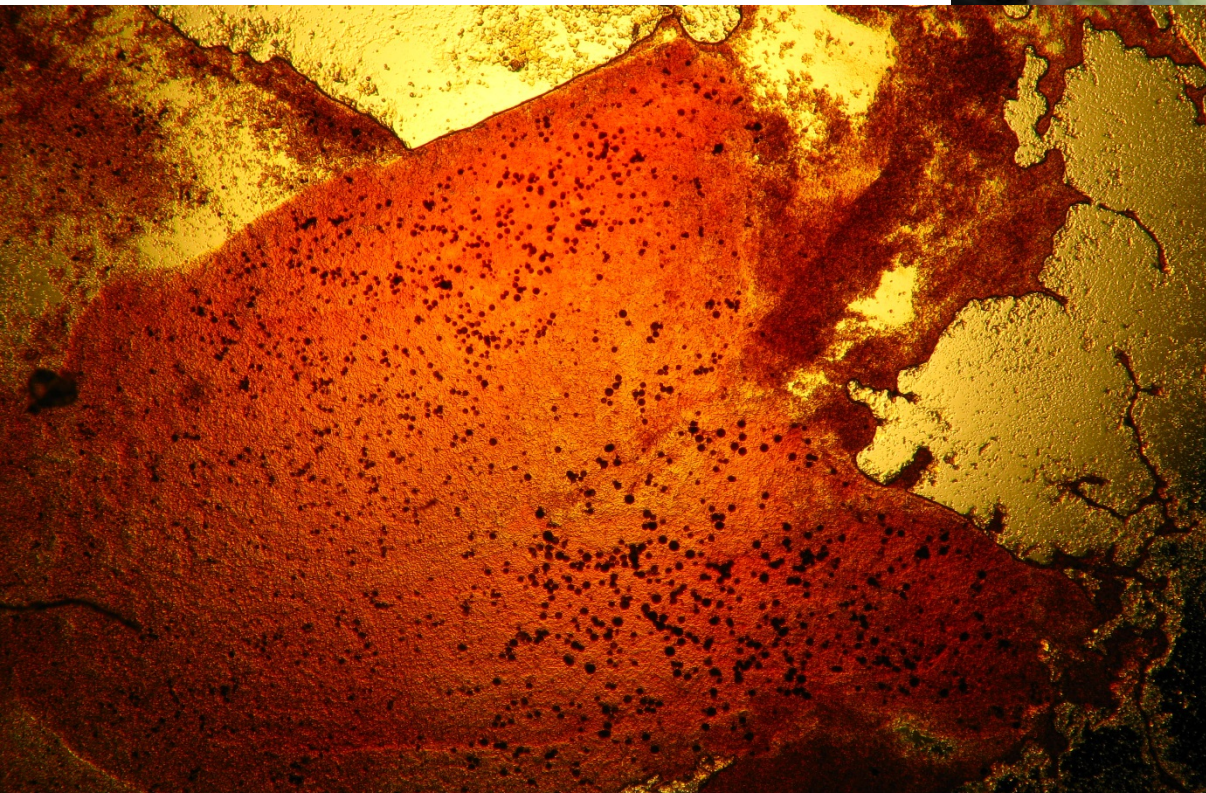
- Disease –salinity
- Temperature-disease
- Temperature – intertidal exposure
- Salinity & use of intertidal habitat

\*\*\*real need for downscaling of climate models

A few oyster examples

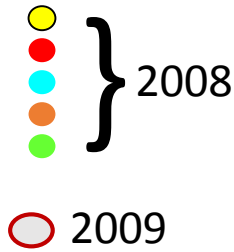
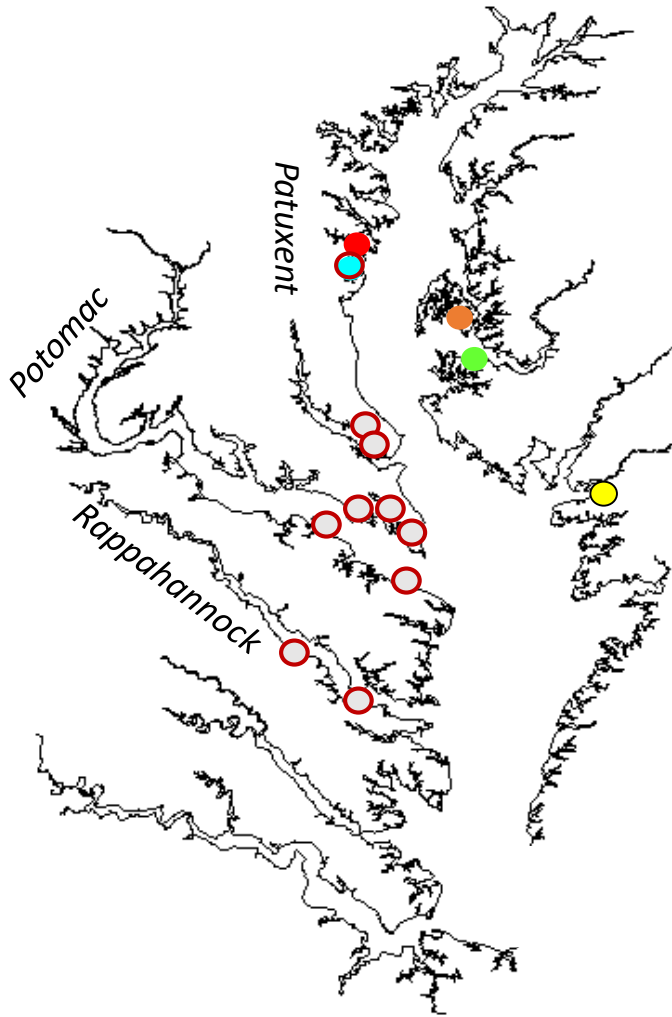


Is the susceptibility of oysters to *Perkinsus marinus* infections (dermo) increased by diel-cycling hypoxia & acidification in shallow water habitats?

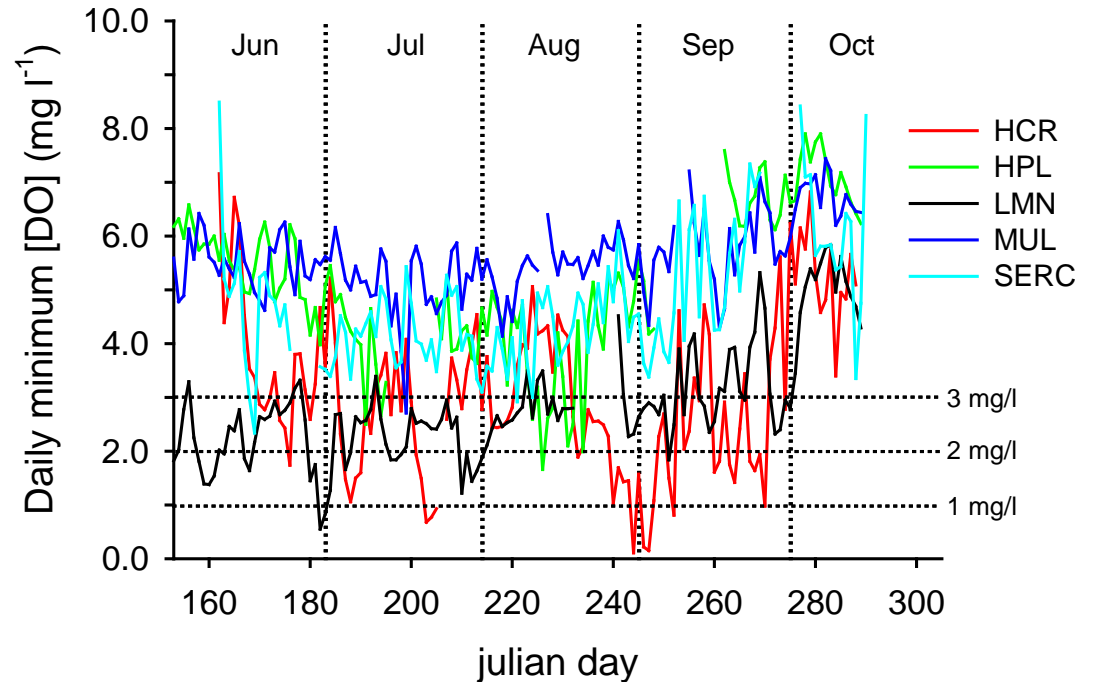


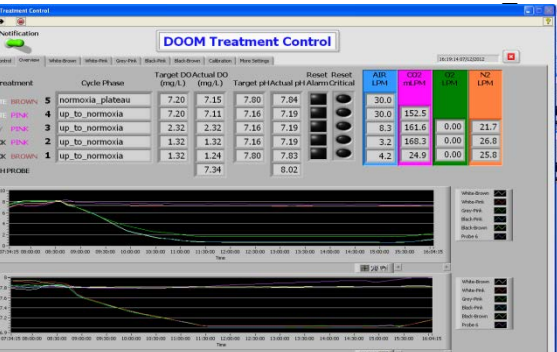
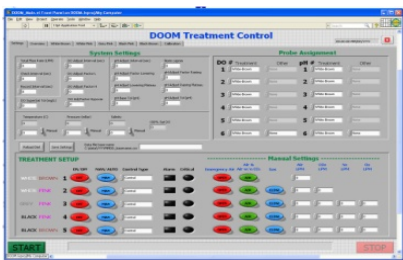
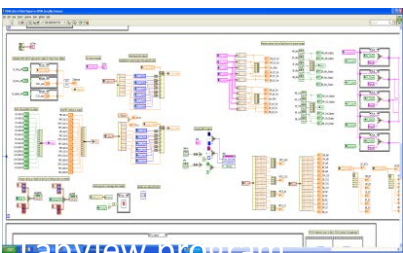
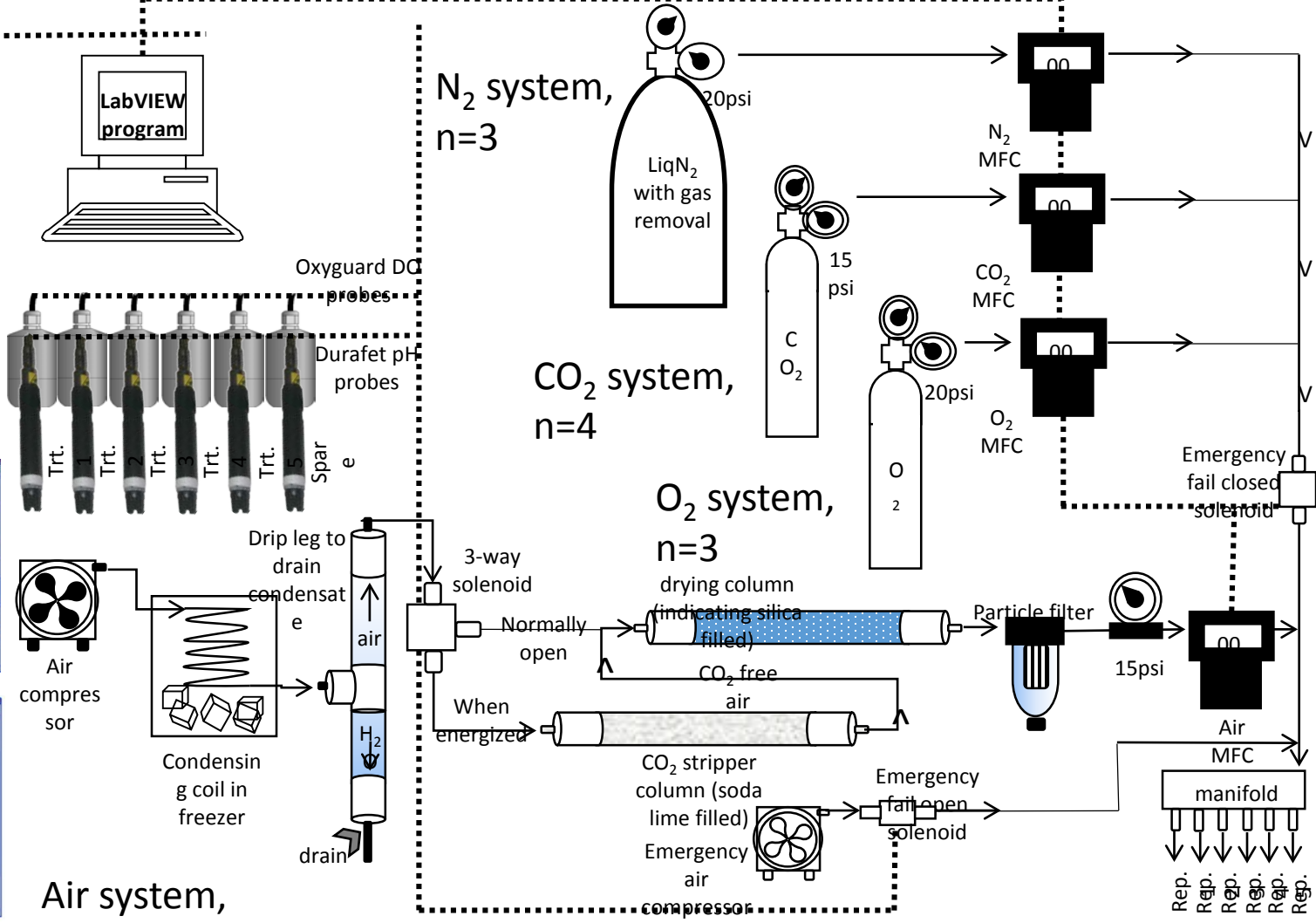
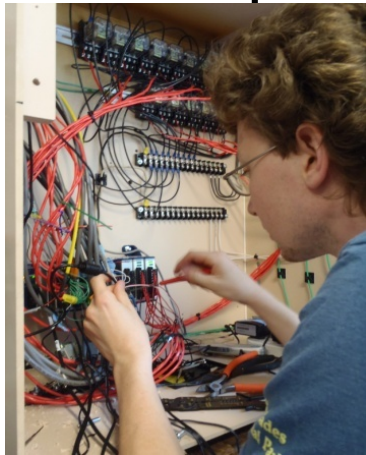
Low oxygen  
reduces hemocyte  
function in oysters-  
Boyd & Burnett

# Field experiment (2008-09)



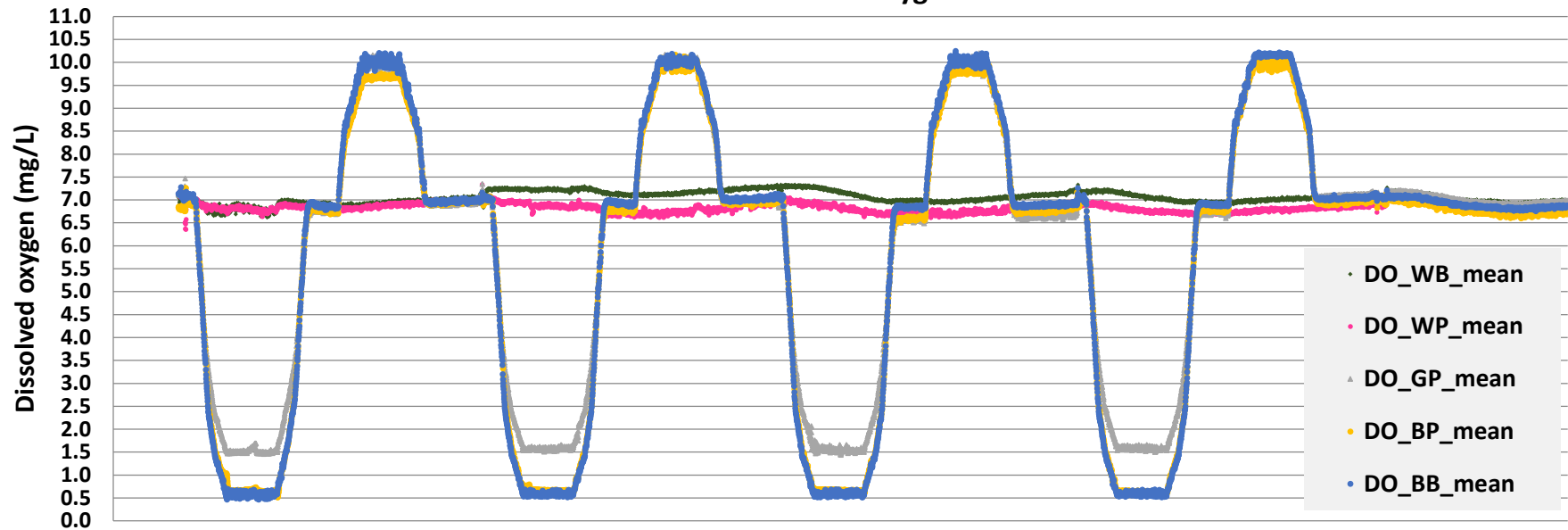
Darryl Hondorp (USGS)



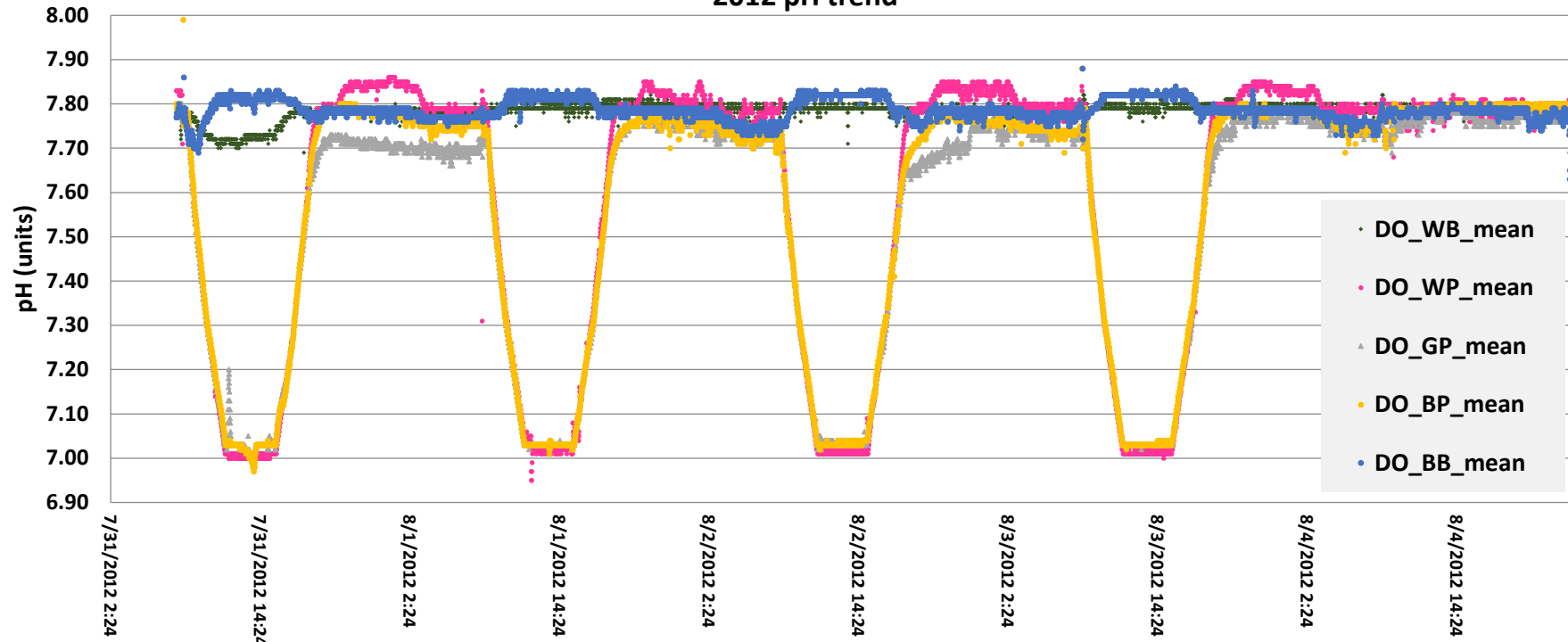


Burrell et al., accepted pending revision

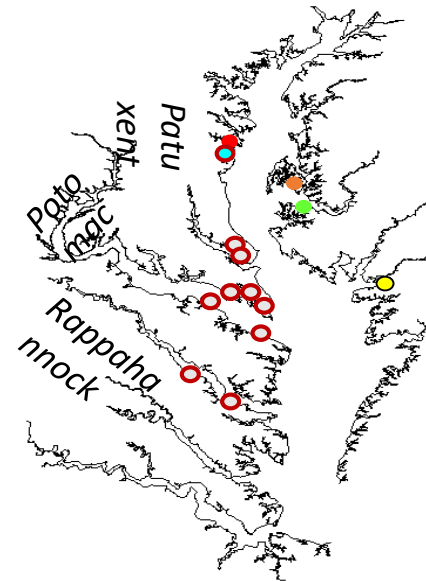
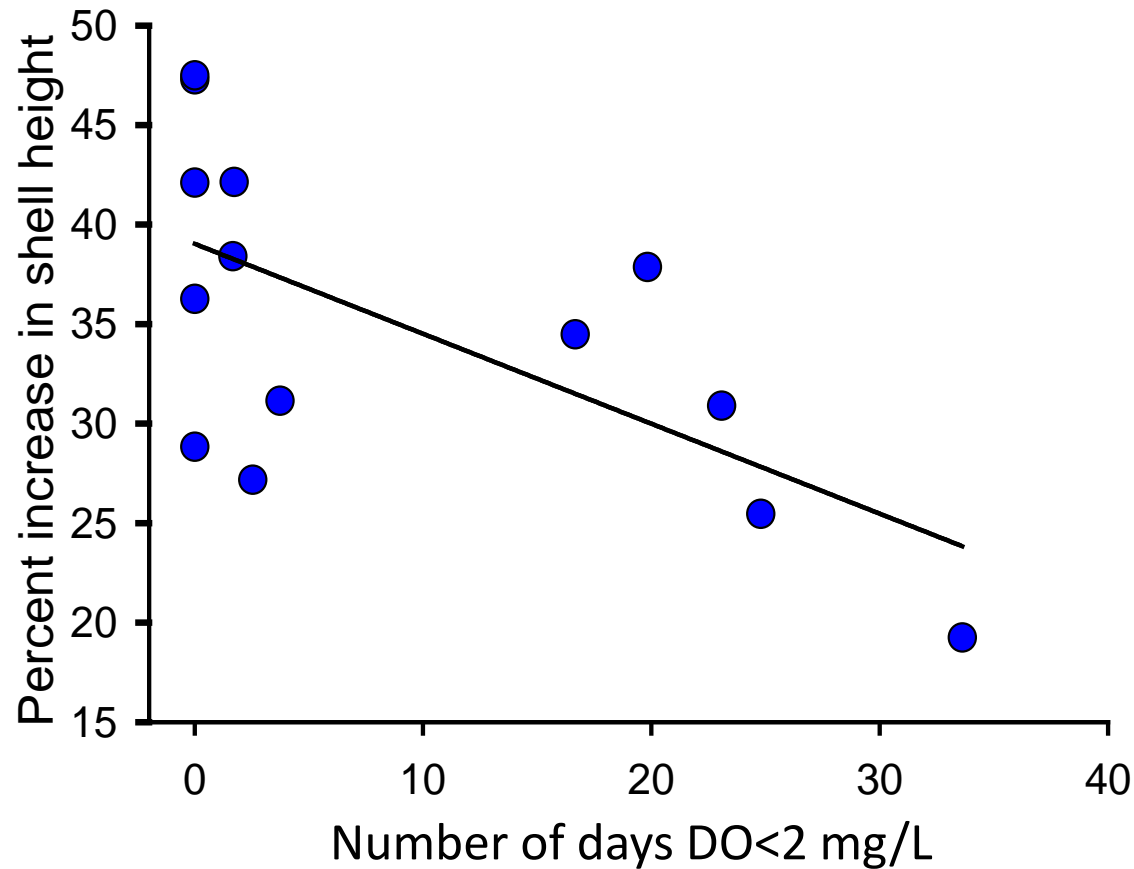
### 2012 dissolved oxygen trend



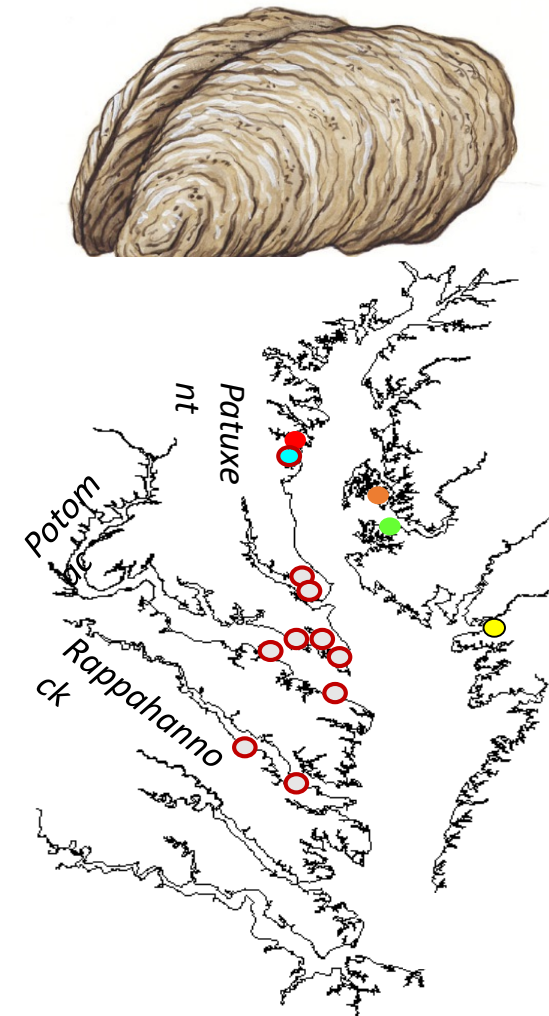
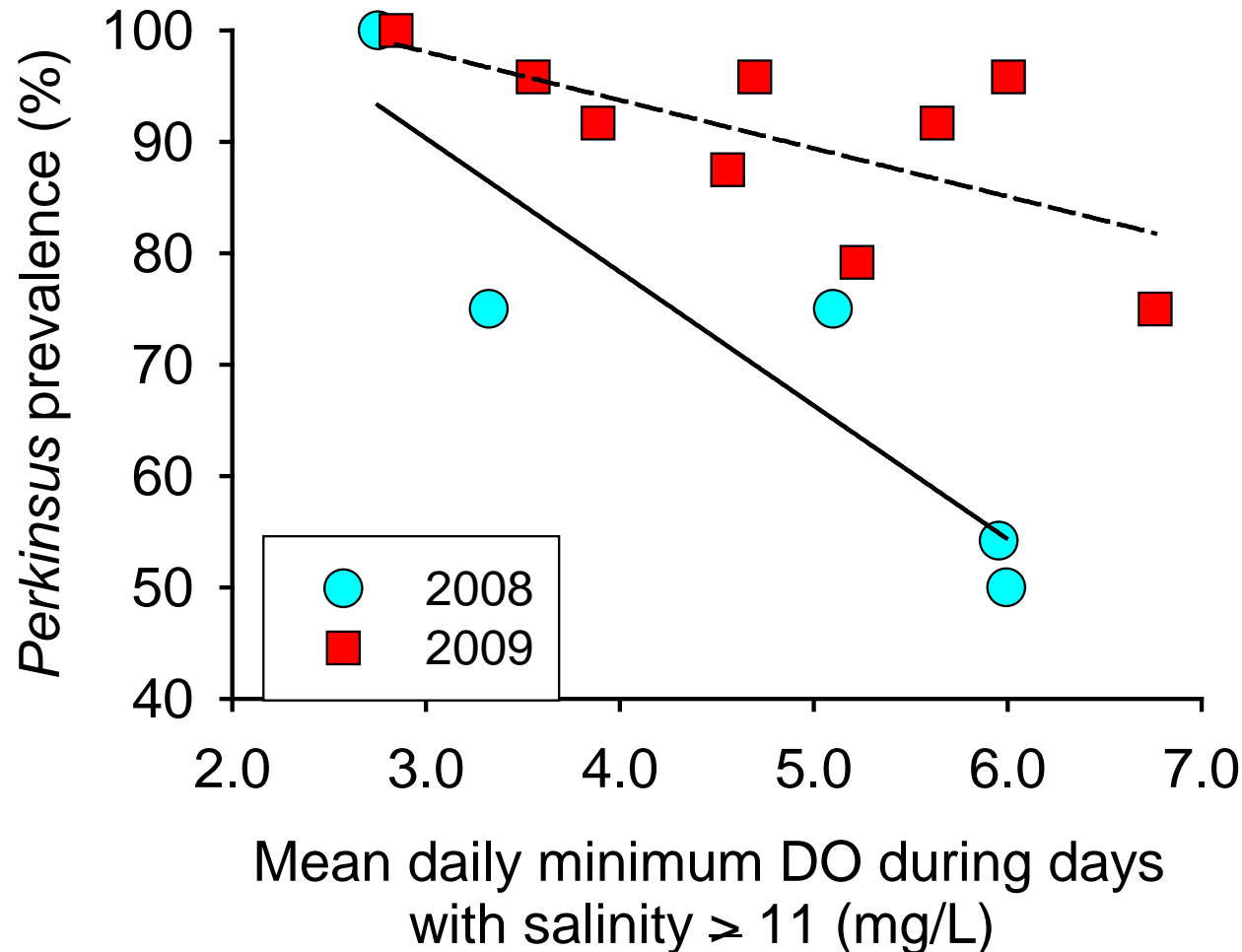
### 2012 pH trend



# Diel cycling hypoxia can decrease growth rates adult oysters

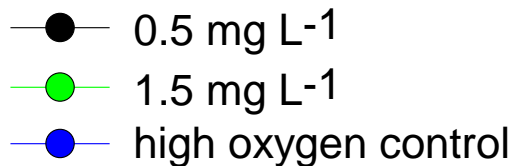
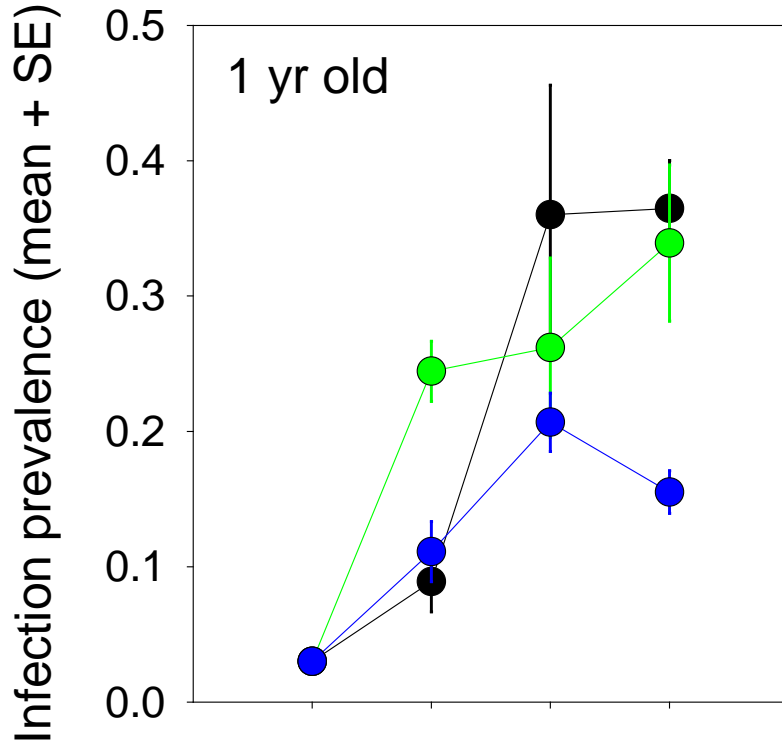


# Diel-cycling hypoxia can increase the intensity and prevalence of *P. marinus* infections

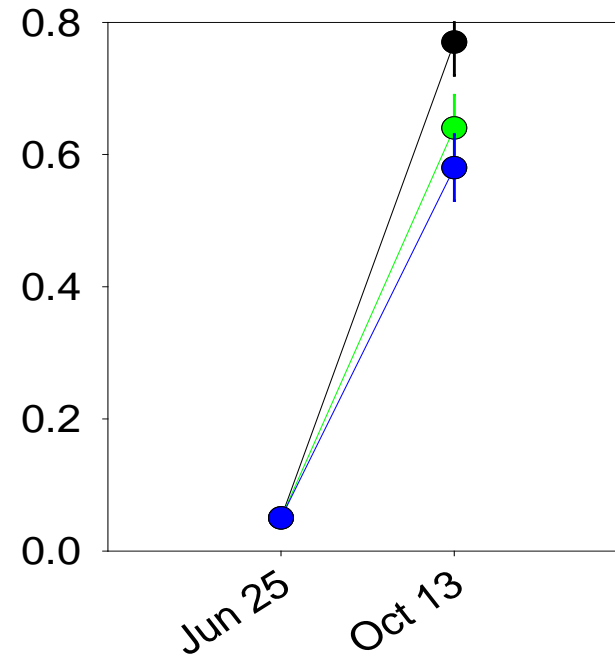


# Diel-cycling hypoxia increases acquisition of *P. marinus* infections in experimental oysters

2009

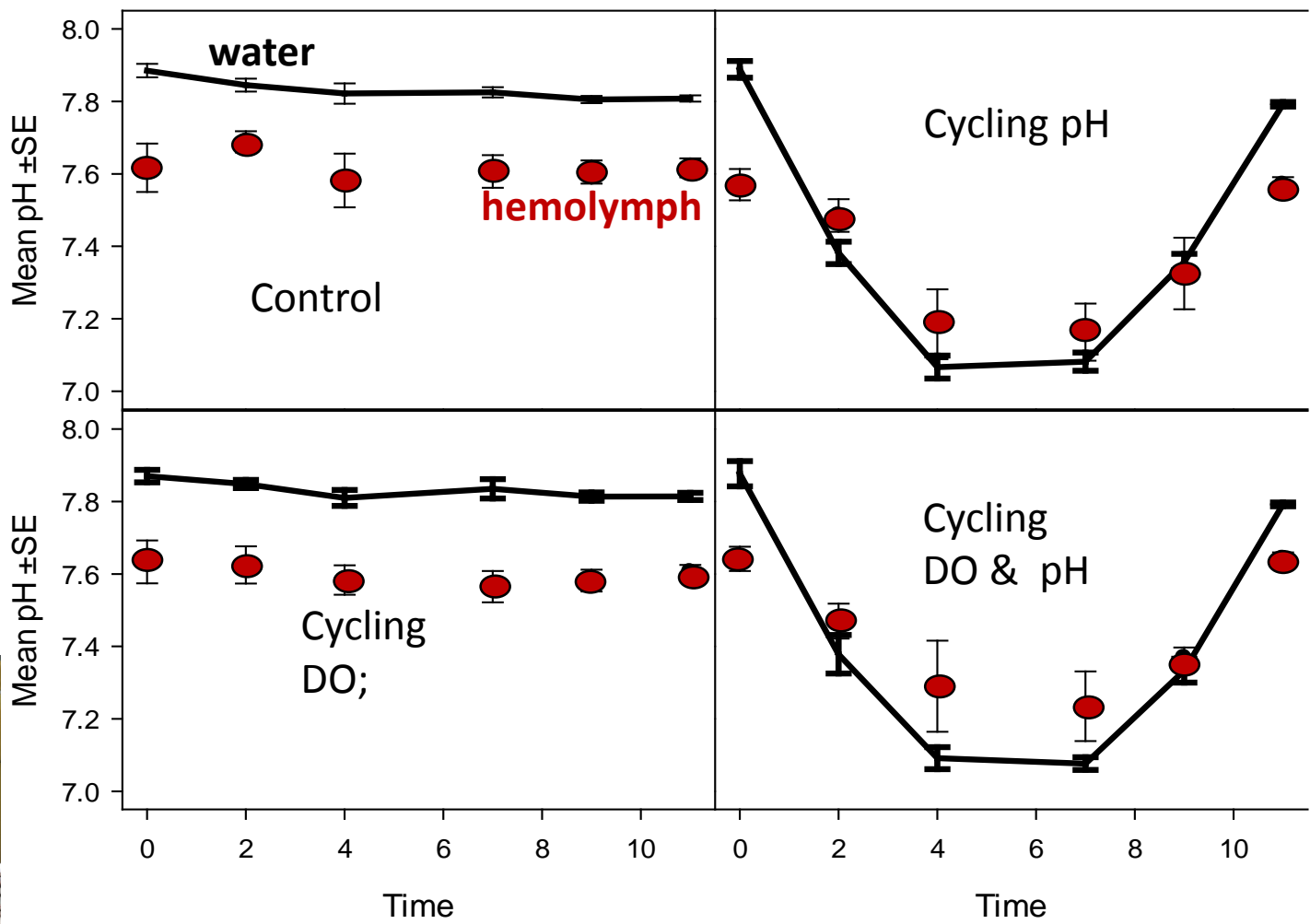


2010



Breitburg et al., 2015

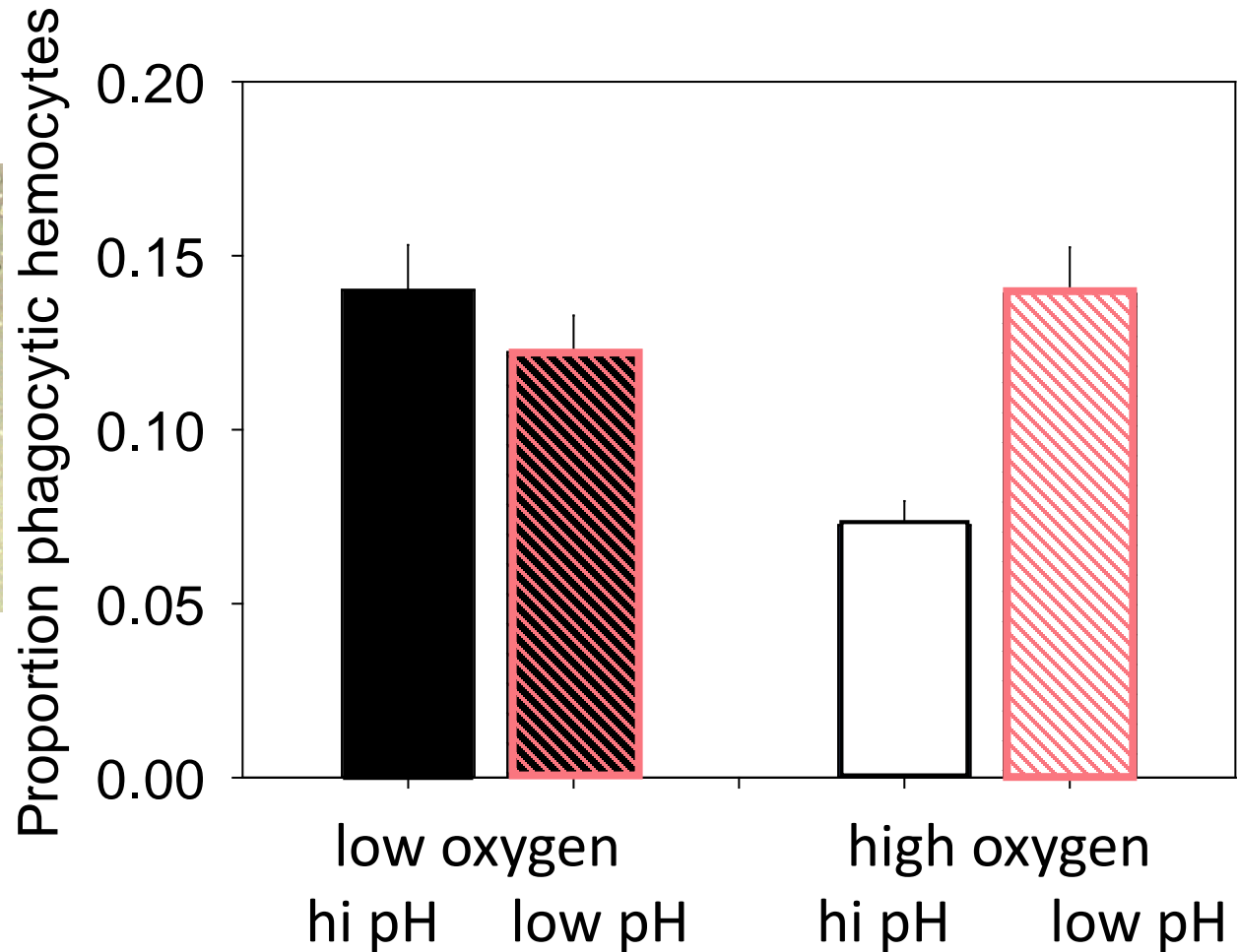
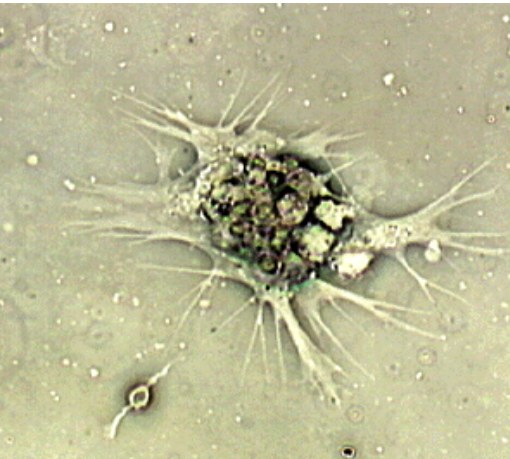
# Hemolymph pH affected by water pH



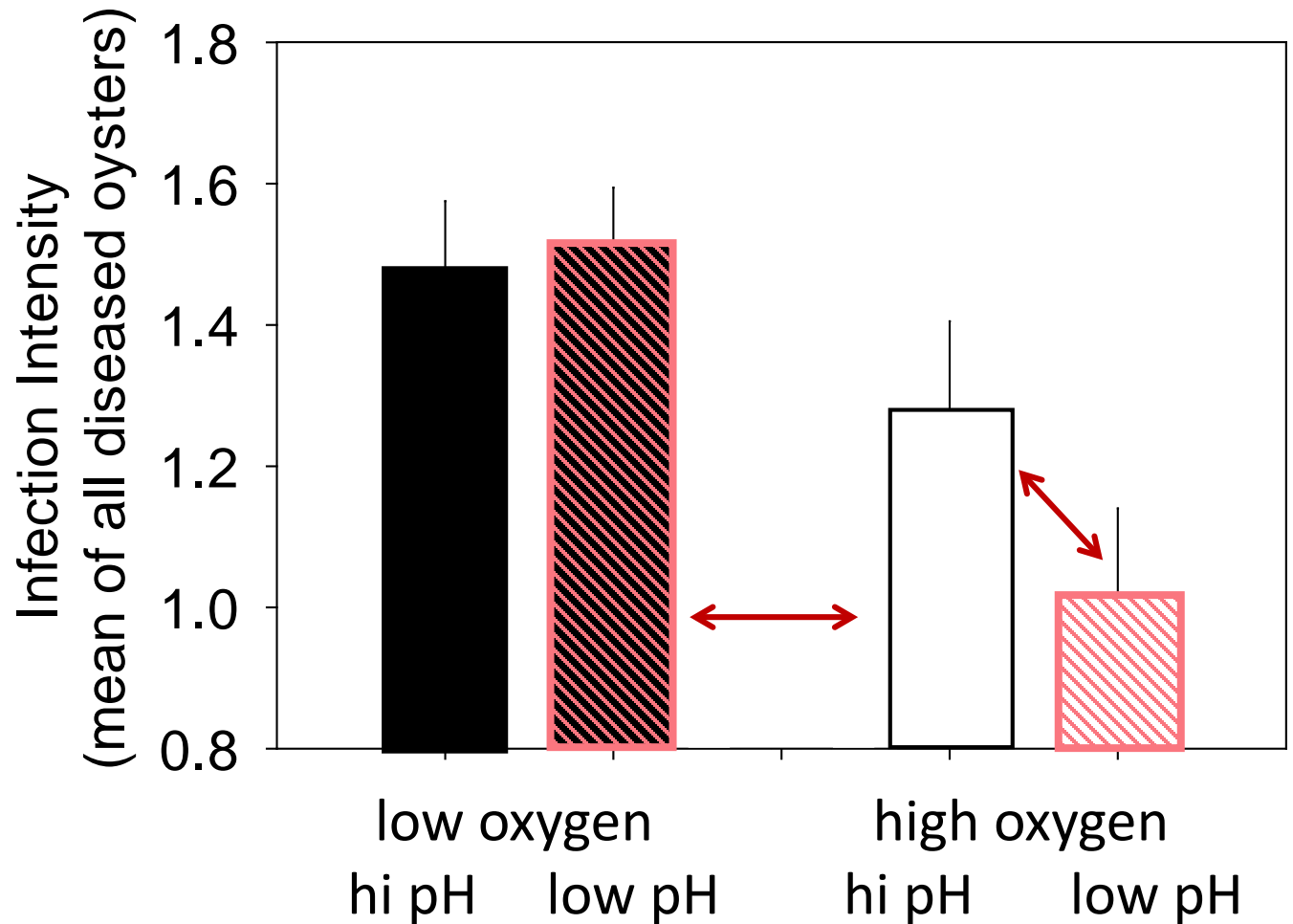
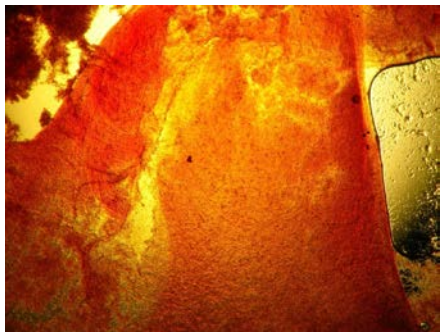
Virginia Clark - 2014

# Cycling (DO, CO<sub>2</sub>, DO+CO<sub>2</sub>) stimulates hemocyte function

(cycling down to DO = 0.5, pH = 7.1)



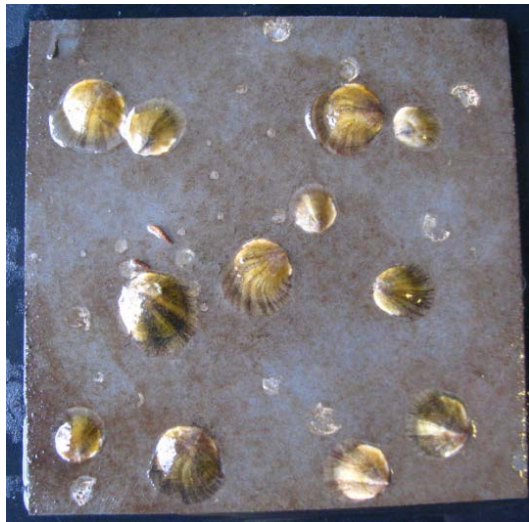
# Stimulation of hemocytes only reduces infection progression when oxygen is high



Juvenile growth reduced by cycling low pH at low salinity

Low salinity year

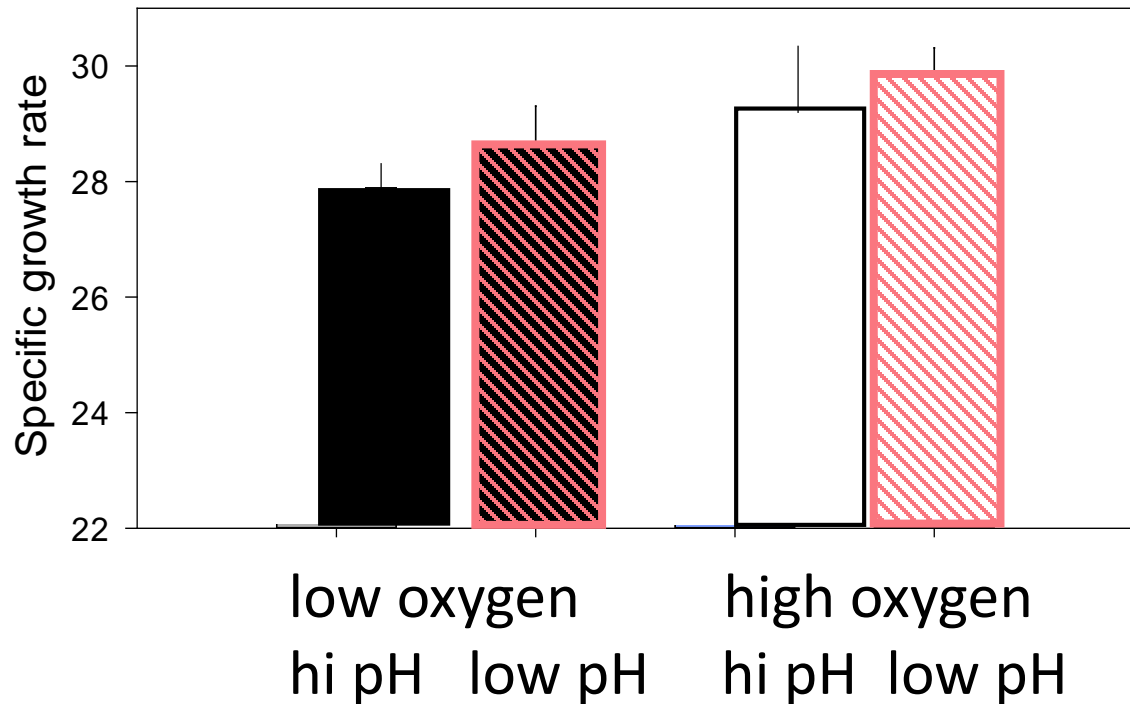
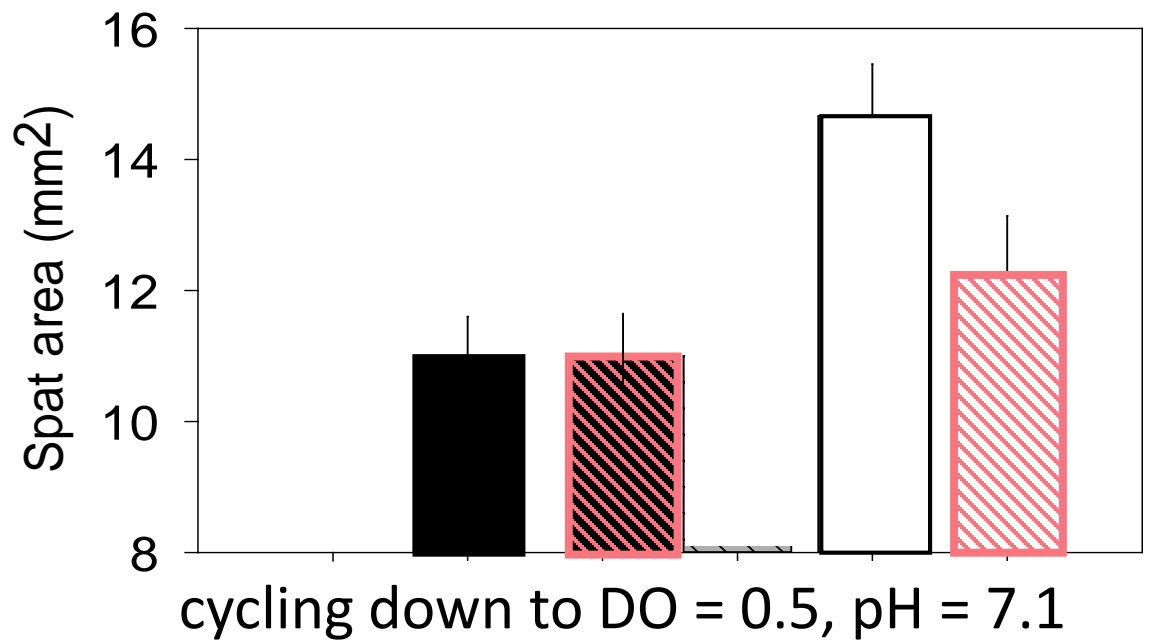
$$\Omega_{\text{Calcite}} = 0.69$$



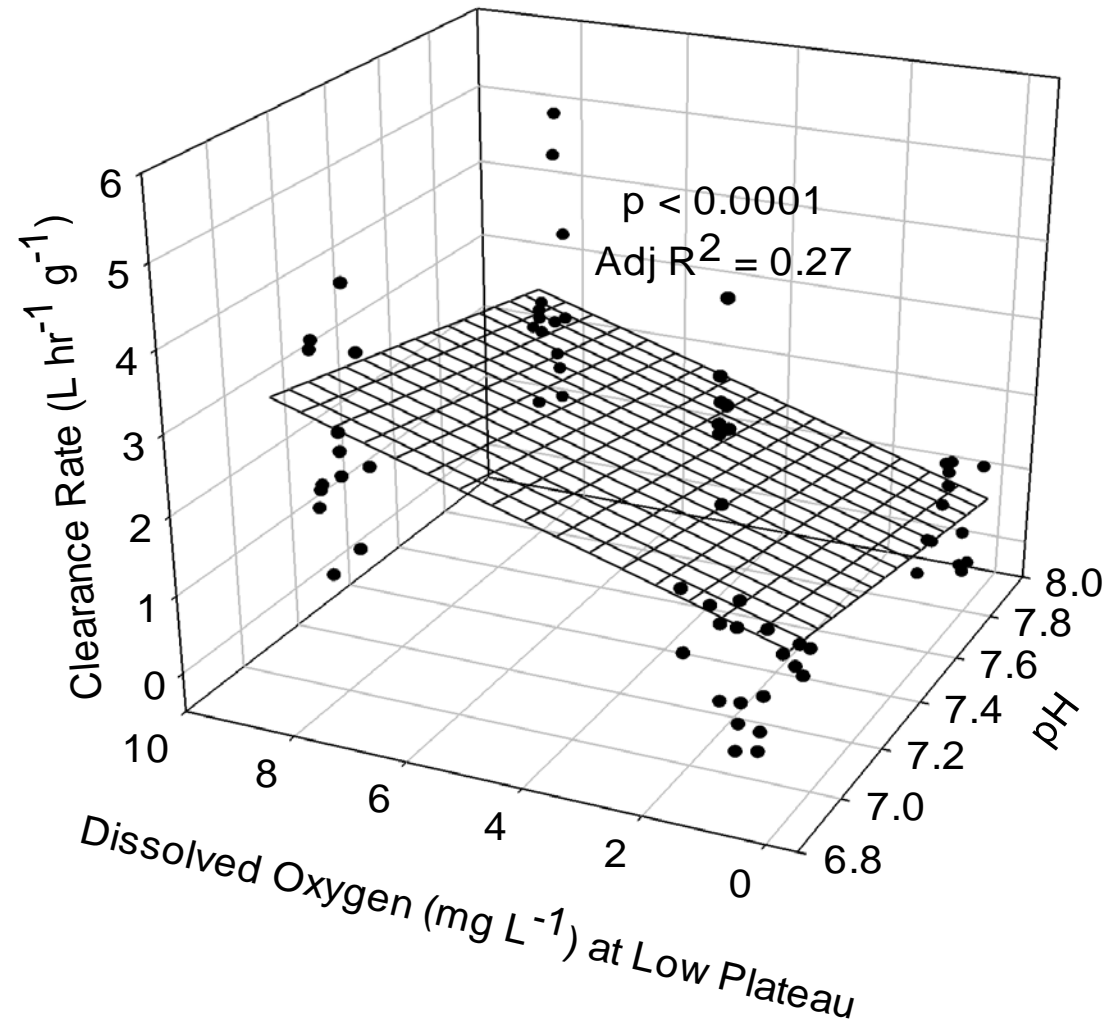
High salinity year

$$\Omega_{\text{Calcite}} = 1.87$$

Keppel et al., 2015



# Low pH slightly increases oyster filtration rates

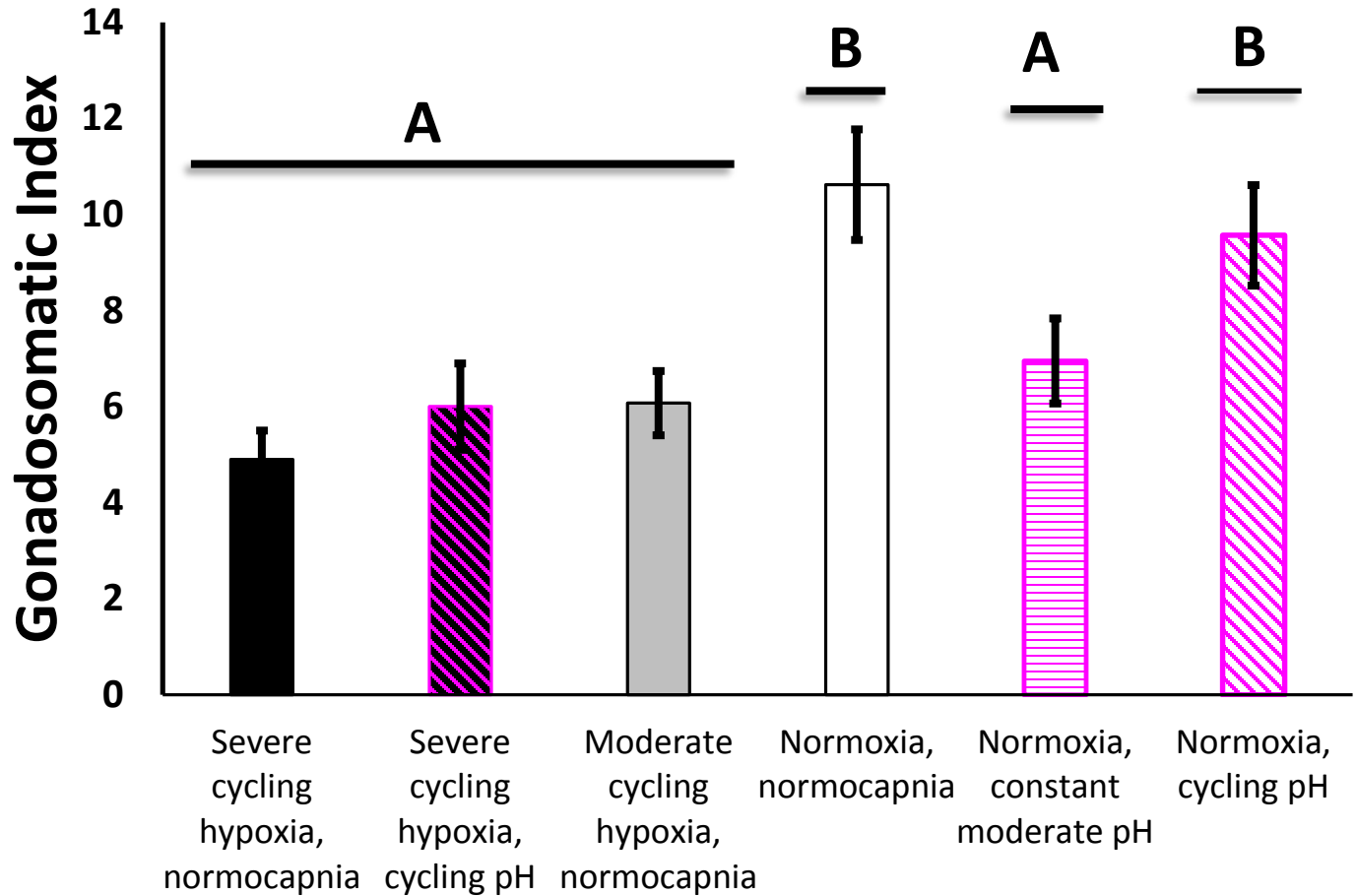


Clark 2014.

2 way ANOVA then Planar regression

	Normoxia Target: 7.5 mgL <sup>-1</sup>	Moderate cycling DO Target: 1.3 mgL <sup>-1</sup>	Severe cycling DO Target: 0.5 mgL <sup>-1</sup>
Normcapnia Target: 8.00	DO: 7.34 pH: 7.90	DO: 1.24 pH: 7.90	DO: 0.54 pH: 7.90
Cycling pH Target: 7.00	DO: 7.34 pH: 7.00		DO: 0.53 pH: 7.00
Constant pH Target: 7.45	DO: 7.34 pH: 7.45		

All oysters, including non-reproductive



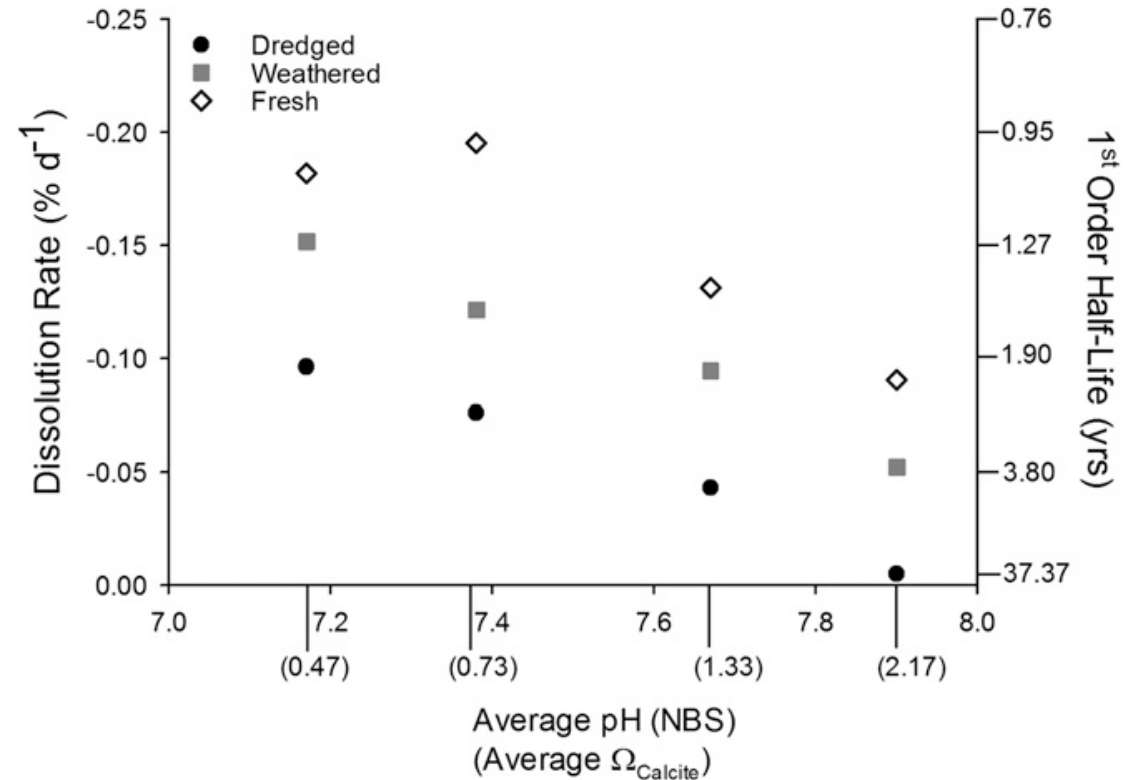
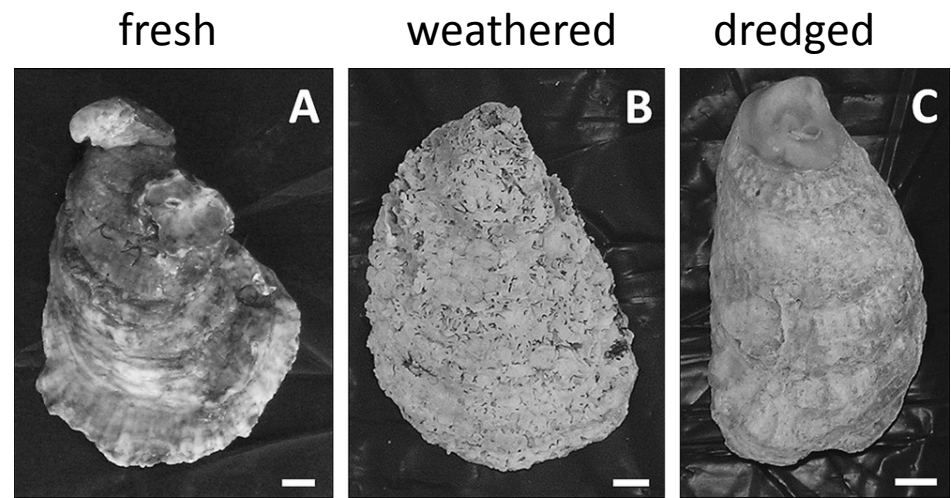
Logit-transformed; Gender and treatment independent variables

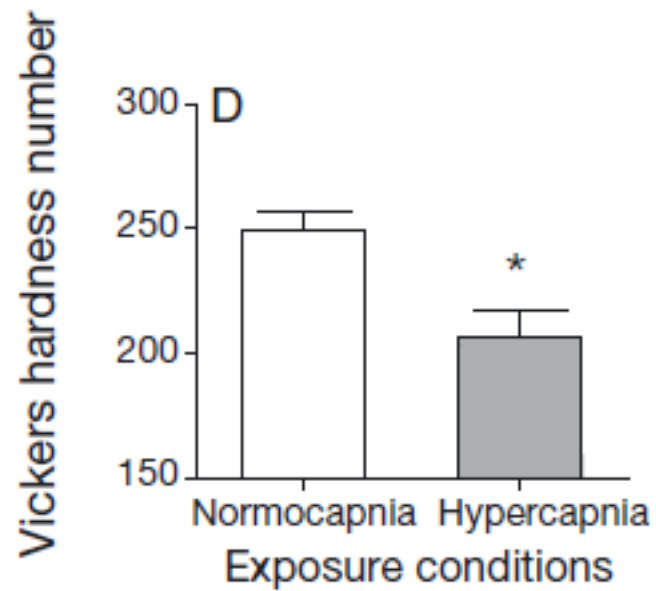
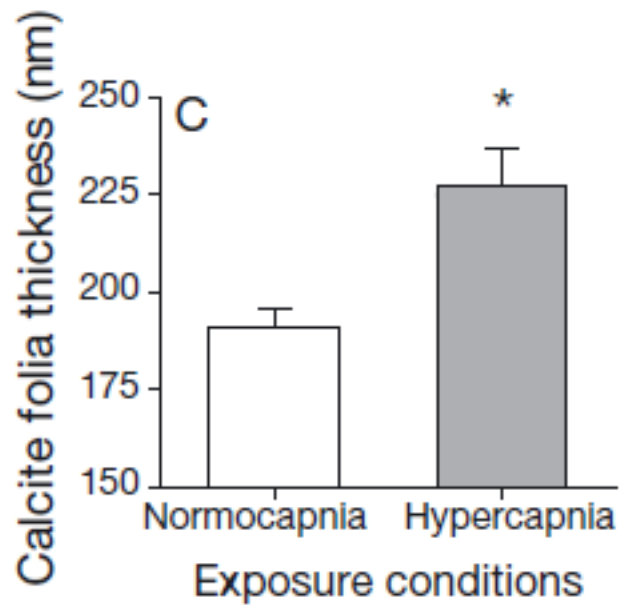
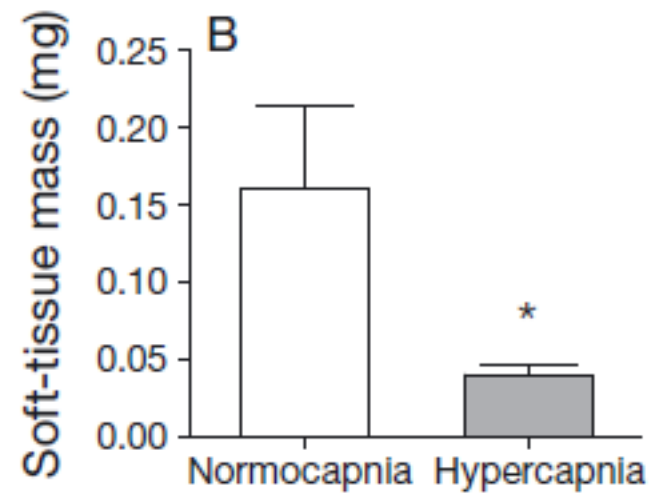
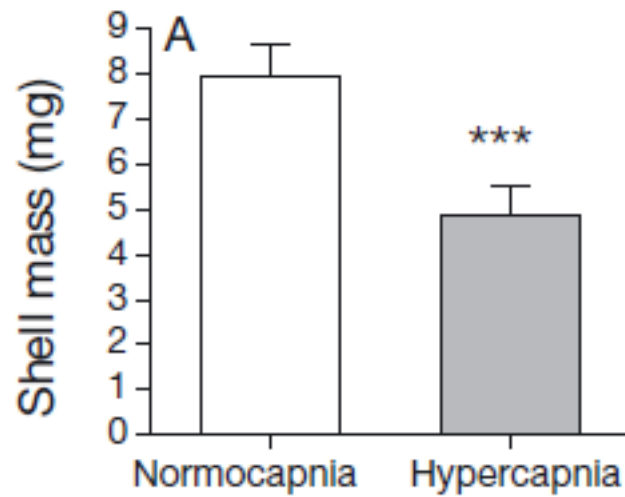
Significant effect of gender ( $p < 0.0001$ ), Significant effect of treatment ( $p = 0.0013$ )

Scattered other studies...

# Low pH increases shell dissolution rate

Waldbusser et al., 2011





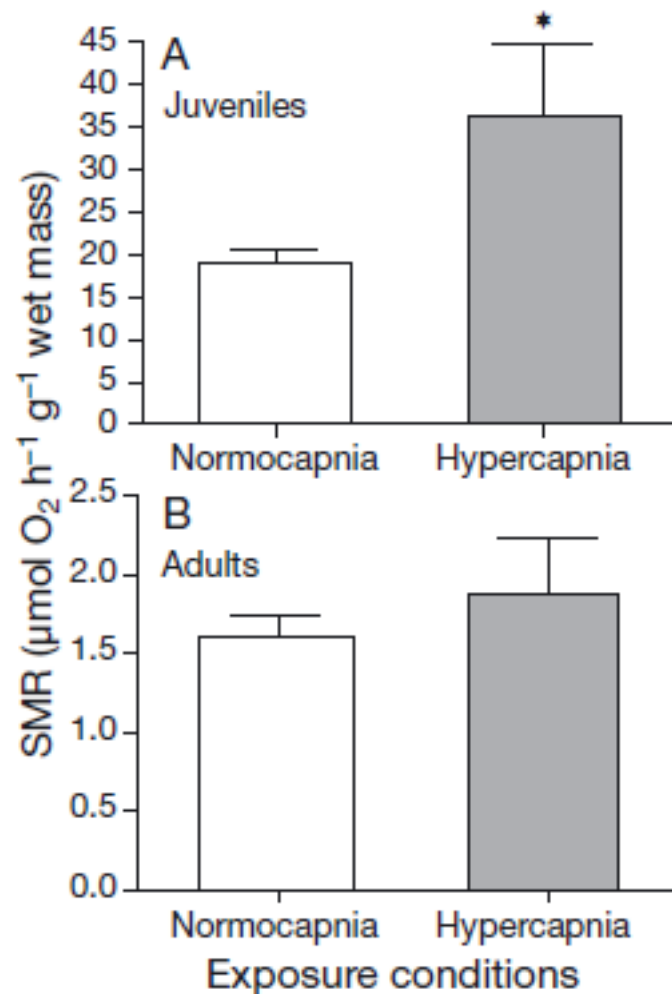
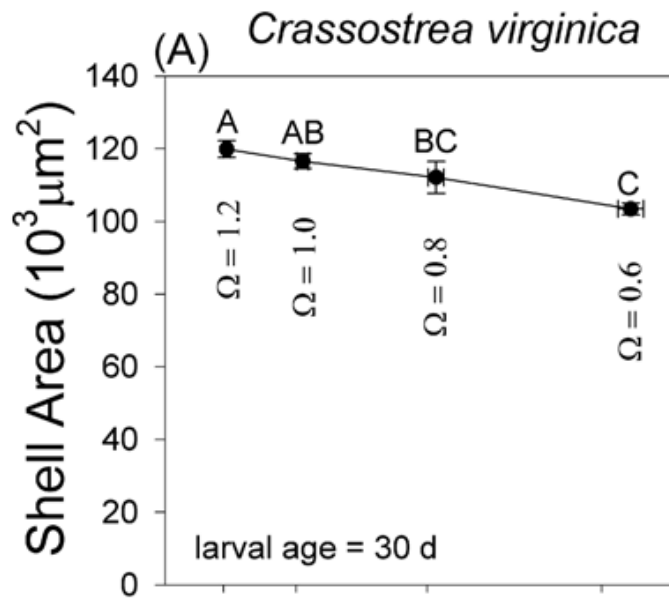
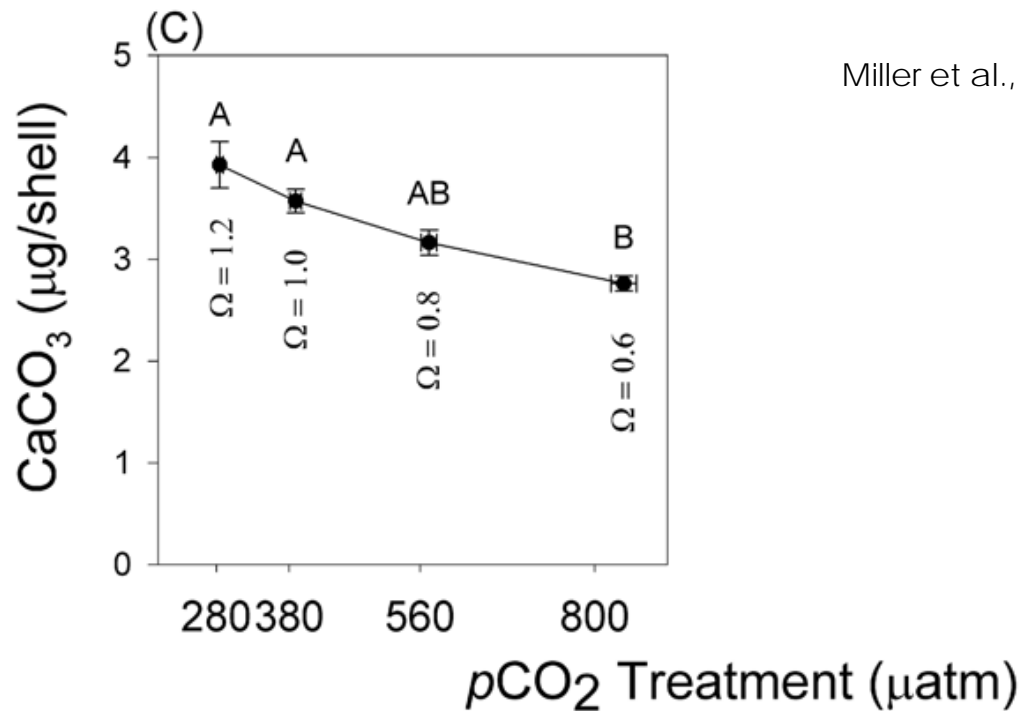


Fig. 4. *Crassostrea virginica*. Standard metabolic rates (SMR) of (A) juveniles and (B) adults exposed to different atmospheric  $\text{CO}_2$  levels. SMR was measured as oxygen consumption rate ( $\text{MO}_2$ ) at  $20^\circ\text{C}$  and normalized for 1 mg (juveniles) or 10 g (adults) soft-tissue mass. Differences in mass-specific  $\text{MO}_2$  between adults and juveniles reflect allometric effects on metabolism. \* $p < 0.05$  (vs. normocapnic value).  $n = 5$  to 12



Modest increases in  $p\text{CO}_2$  reduce growth and calcium carbonate content of shells of *C. virginica* larvae



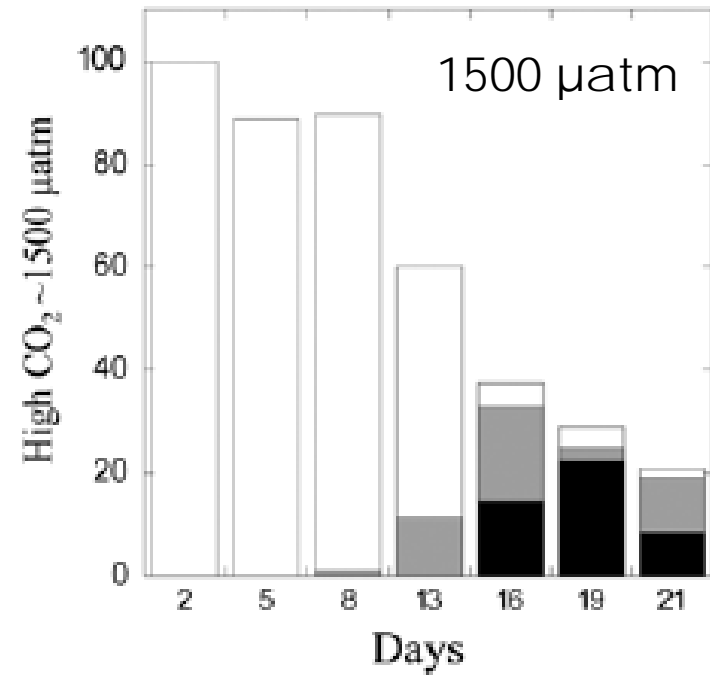
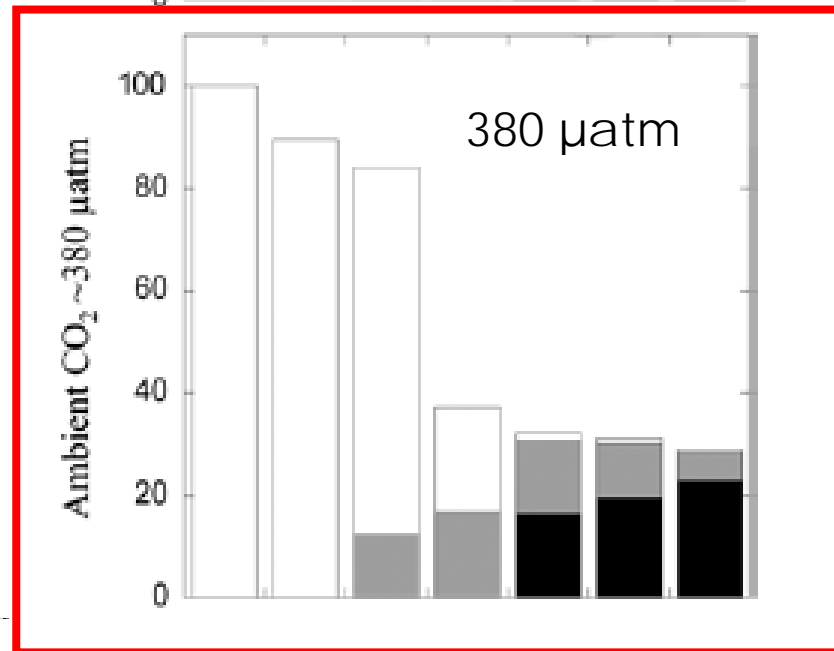
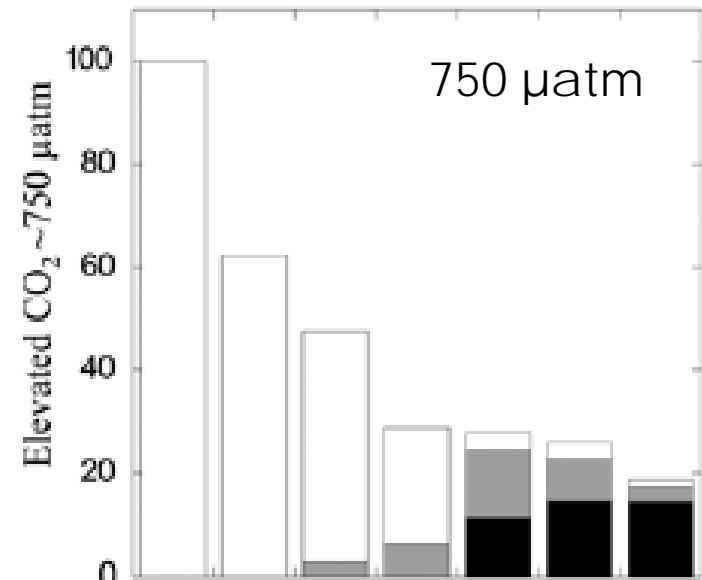
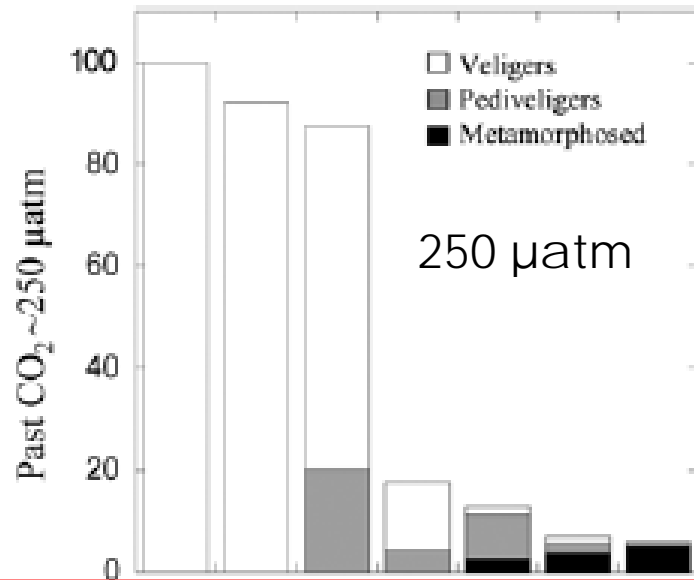
Miller et al., 2012

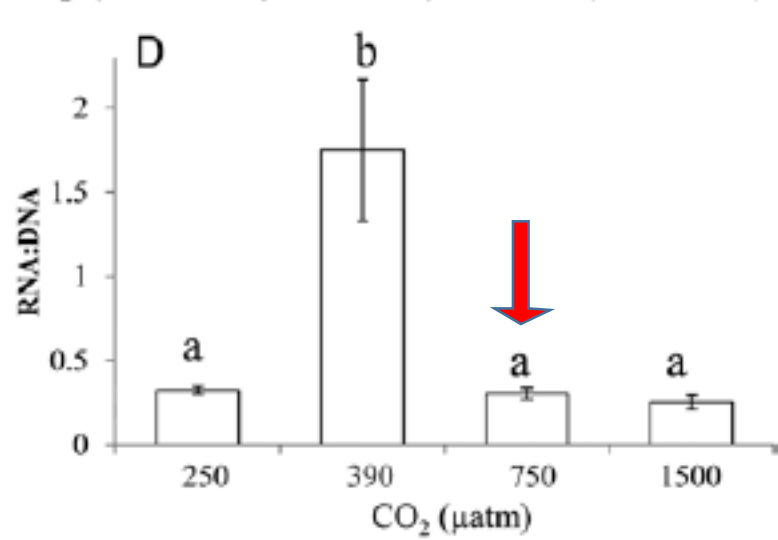
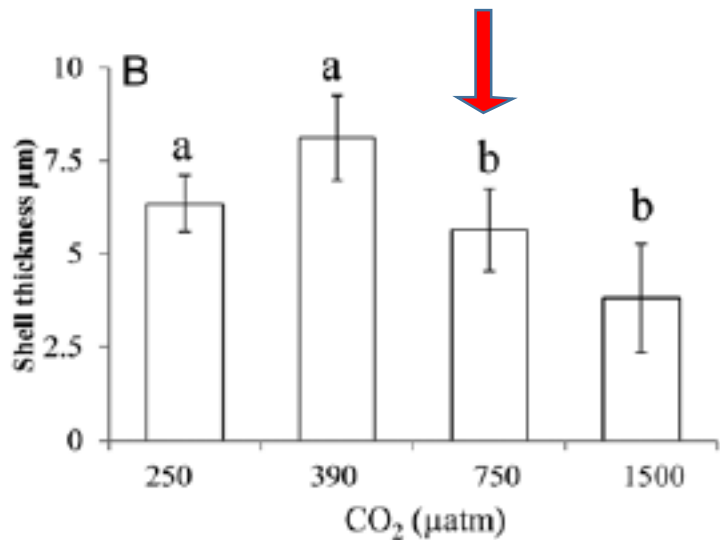
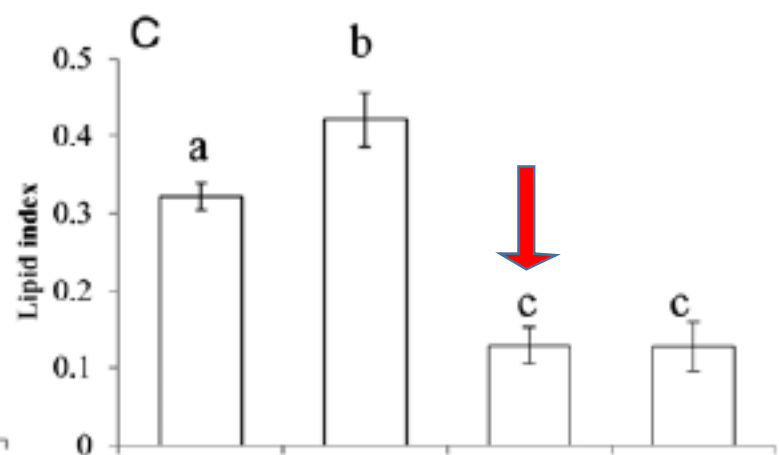
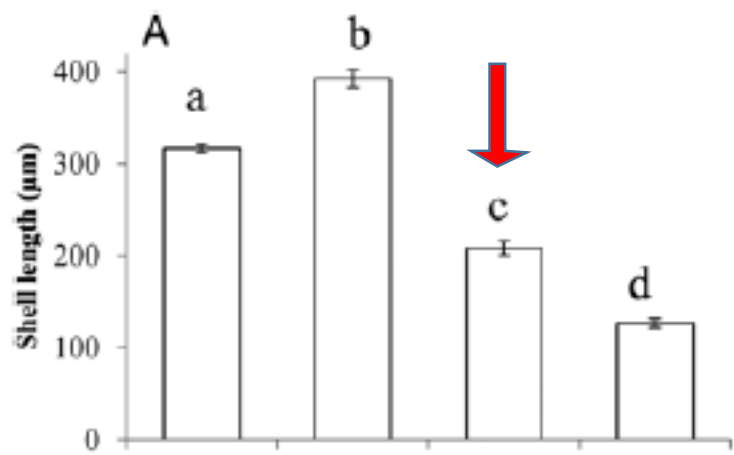
# Gobler & Talmage - larvae

**Table 1:** Temperature, pH, carbonate chemistry, alkalinity and salinity ( $\pm 1$  SD) during the four-level carbon dioxide experiment

Parameter	Pre-industrial CO <sub>2</sub>	Ambient CO <sub>2</sub>	Elevated CO <sub>2</sub>	Elevated CO <sub>2</sub>
Temperature (°C)	24 $\pm$ 1.0	24 $\pm$ 1.0	24 $\pm$ 1.0	24 $\pm$ 1.0
pH	8.32 $\pm$ 0.01	8.16 $\pm$ 0.02	7.93 $\pm$ 0.001	7.68 $\pm$ 0.05
Partial pressure of CO <sub>2</sub> ( $\mu$ atm)	249 $\pm$ 7.15	394 $\pm$ 26.7	745 $\pm$ 23.0	1430 $\pm$ 162
Saturation state of calcite	5.67 $\pm$ 0.06	4.27 $\pm$ 0.20	2.822 $\pm$ 0.06	1.69 $\pm$ 0.19
Saturation state of aragonite	3.68 $\pm$ 0.04	2.77 $\pm$ 0.13	1.83 $\pm$ 0.04	1.10 $\pm$ 0.12
Total dissolved inorganic carbon ( $\mu$ mol l <sup>-1</sup> )	1710 $\pm$ 11.8	1790 $\pm$ 31.3	1932 $\pm$ 14.2	2040 $\pm$ 11.5
CO <sub>3</sub> <sup>2-</sup> ( $\mu$ mol l <sup>-1</sup> )	227 $\pm$ 2.45	171 $\pm$ 8.33	113 $\pm$ 2.14	67.8 $\pm$ 7.43
Total alkalinity ( $\mu$ mol l <sup>-1</sup> )	2020 $\pm$ 8.41	2040 $\pm$ 35.3	2070 $\pm$ 12.6	2090 $\pm$ 11.8
Salinity	30.0 $\pm$ 1.0	30.0 $\pm$ 1.0	30.0 $\pm$ 1.0	30.0 $\pm$ 1.0

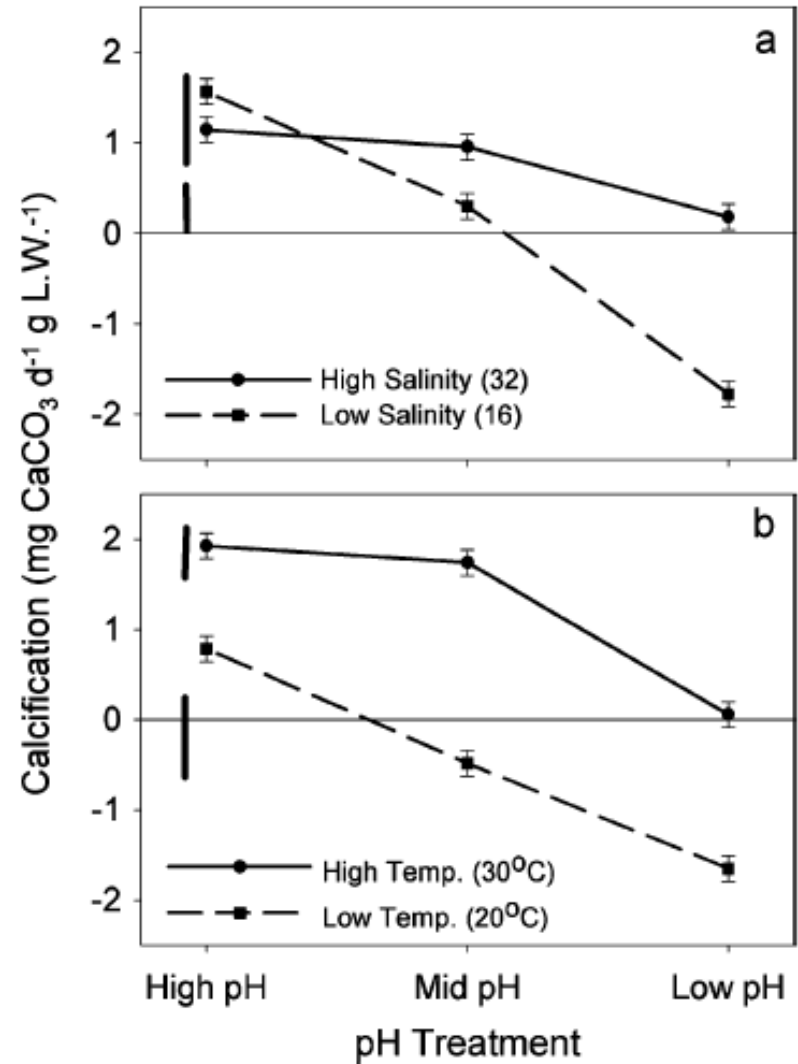
# Percent survival highest at 380 $\mu\text{atm}$





# Temperature, salinity, pH and the interaction between salinity & pH affect calcification by juvenile oysters

Temp.	Salinity	pH Treatment	pH
20	32	High	8.29
		Mid	7.66
		Low	7.56
30	32	High	8.14
		Mid	7.85
		Low	7.43
30	16	High	7.92
		Mid	7.66
		Low	7.46
20	16	High	7.76
		Mid	7.52
		Low	7.41



# Increasing temperature increases oxygen uptake rates – especially and low to medium salinity

Shumway & Koehn 1982

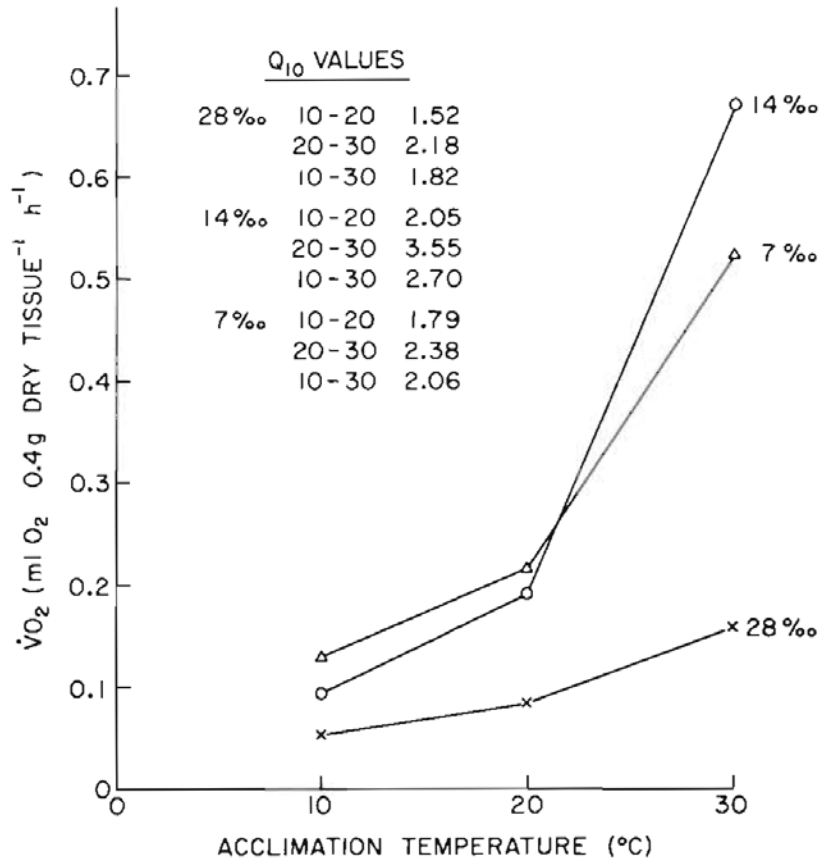


Fig. 2. *Crassostrea virginica*. Effect of acclimation to different temperatures and salinities on  $\dot{V}O_2$ . Data for 'standard' oyster

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# Negative effects found

Temperature	
oxygen	
CO2/pH	
Salinity	
Disease	
Temp*oxygen	
Temp*pH	
Temp*salinity	
Temp*disease	
Oxygen*disease	
Salinity*pH	
...etc	

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- Multiple stressor focus important with climate change
- Keep doing what we're doing (temperature, salinity, pH, chl, DO, disease metrics)but add
  - total alkalinity
  - canaries (biological mimics and sentinals)
- Take measurements where oysters really occur – water column for larvae, right on the bottom for metamorphosis, and juvenile & adult stages
- Use continuous measurements to capture minimum DO, pH, salinity and maximum temperature

## Why sentinals?

Integrates environmental variables

Can measure multiple responses – growth, reproduction, disease

Problem – year to year genetic variation in sentinals

## Mimics

Could be useful for measuring internal temperatures caused by intertidal exposure

Spat collection plates could help standardize measures of potential recruitment