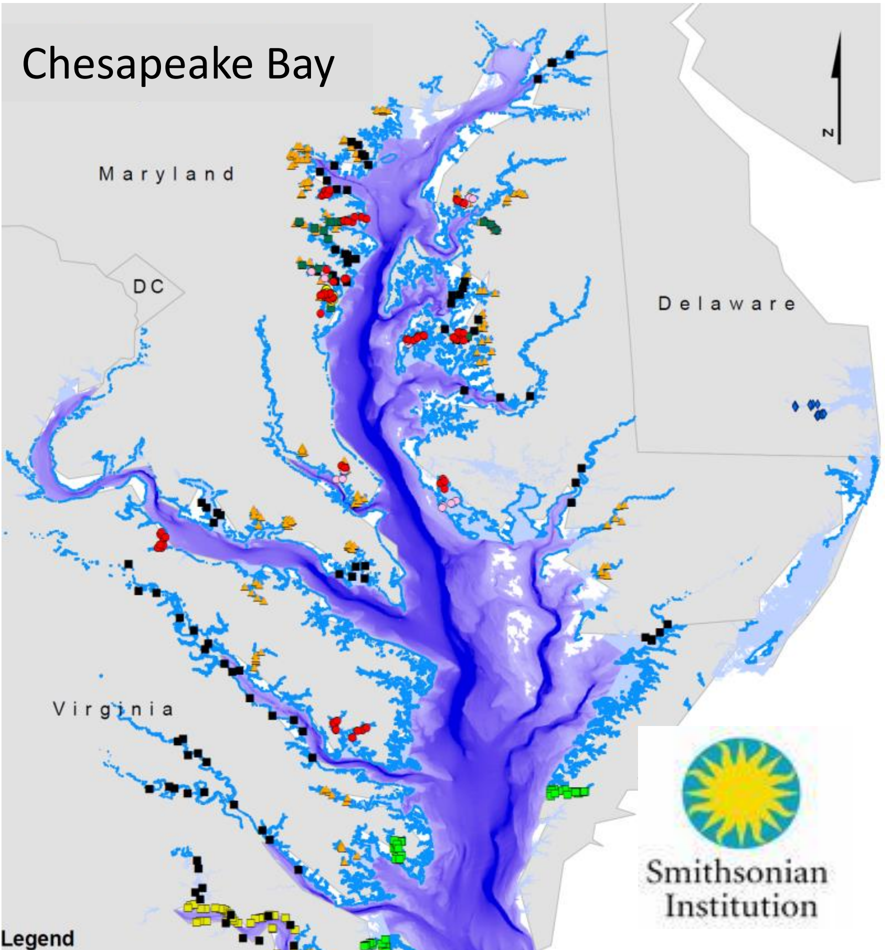
# Acidification in Chesapeake Bay: biological effects in an ecosystem context

Denise Breitburg
Smithsonian Environmental Research Center



Smithsonian Institution

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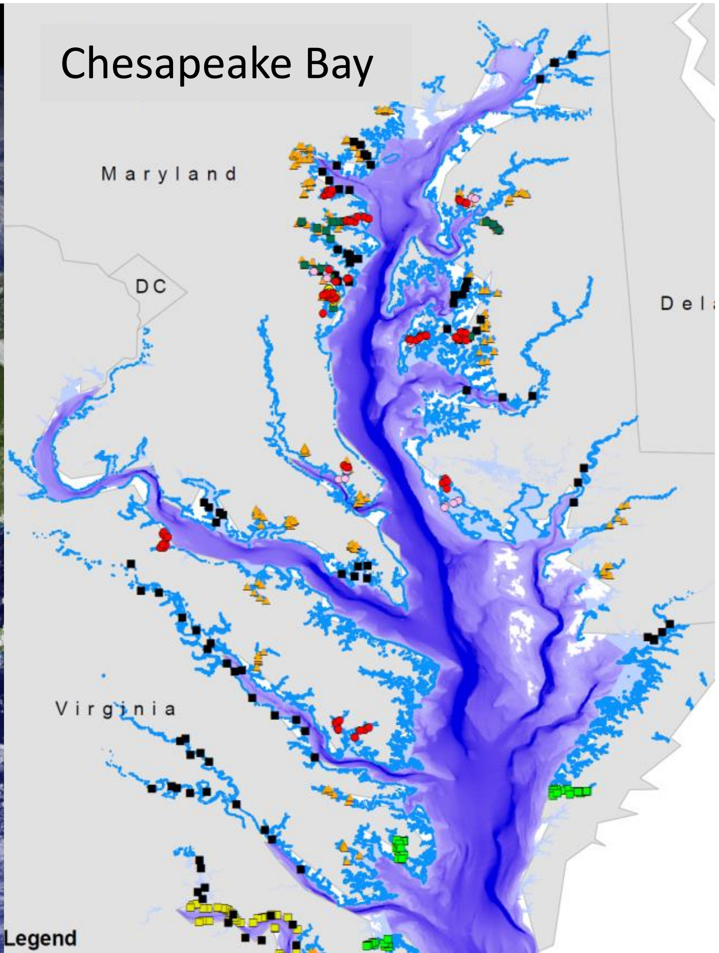
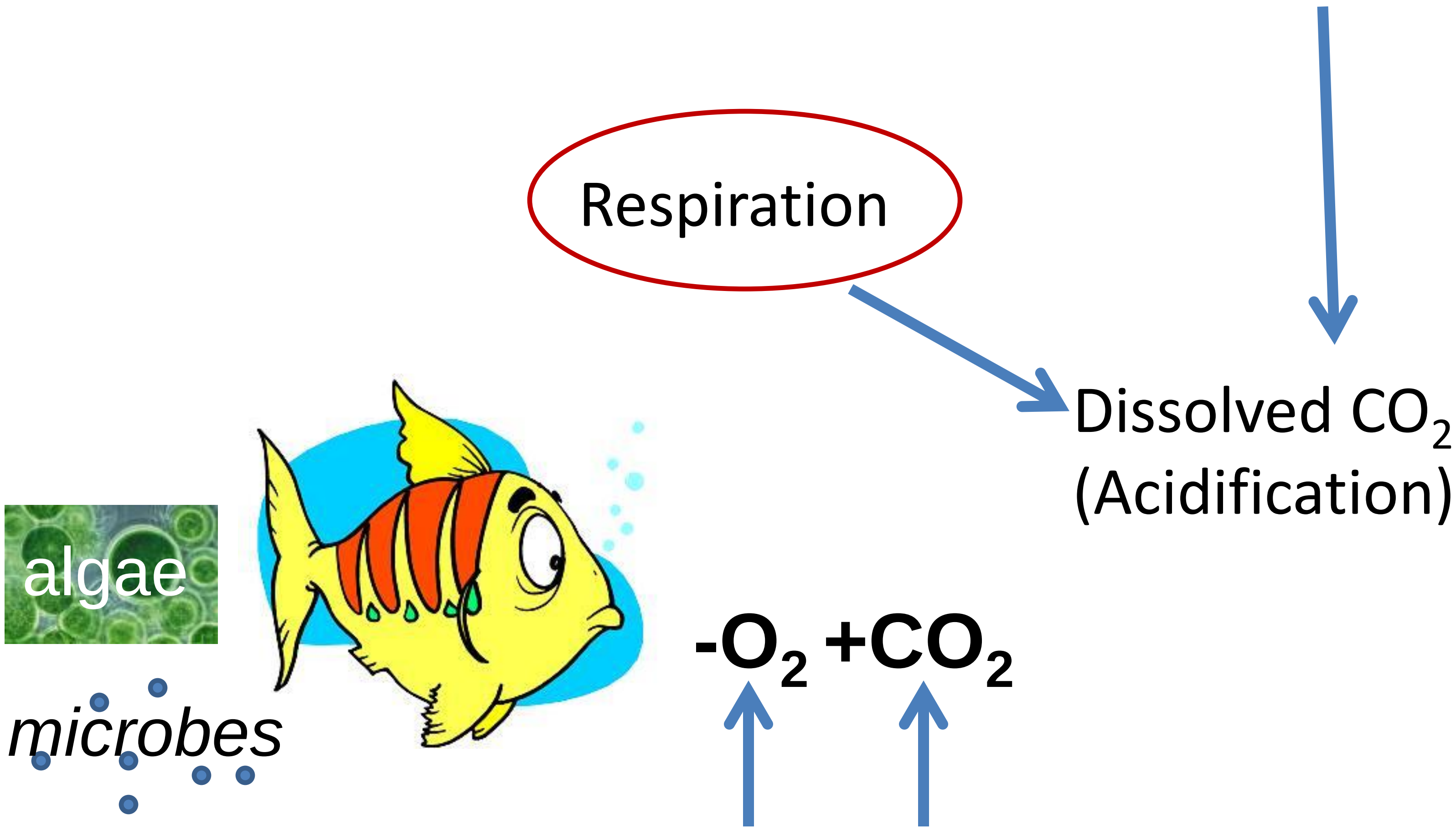


Challenges to predicting effects & managing an acidified Chesapeake Bay

Examples

# Respiration – driven Hypoxia



Atmospheric $CO_2$

Respiration

Dissolved $CO_2$
(Acidification)

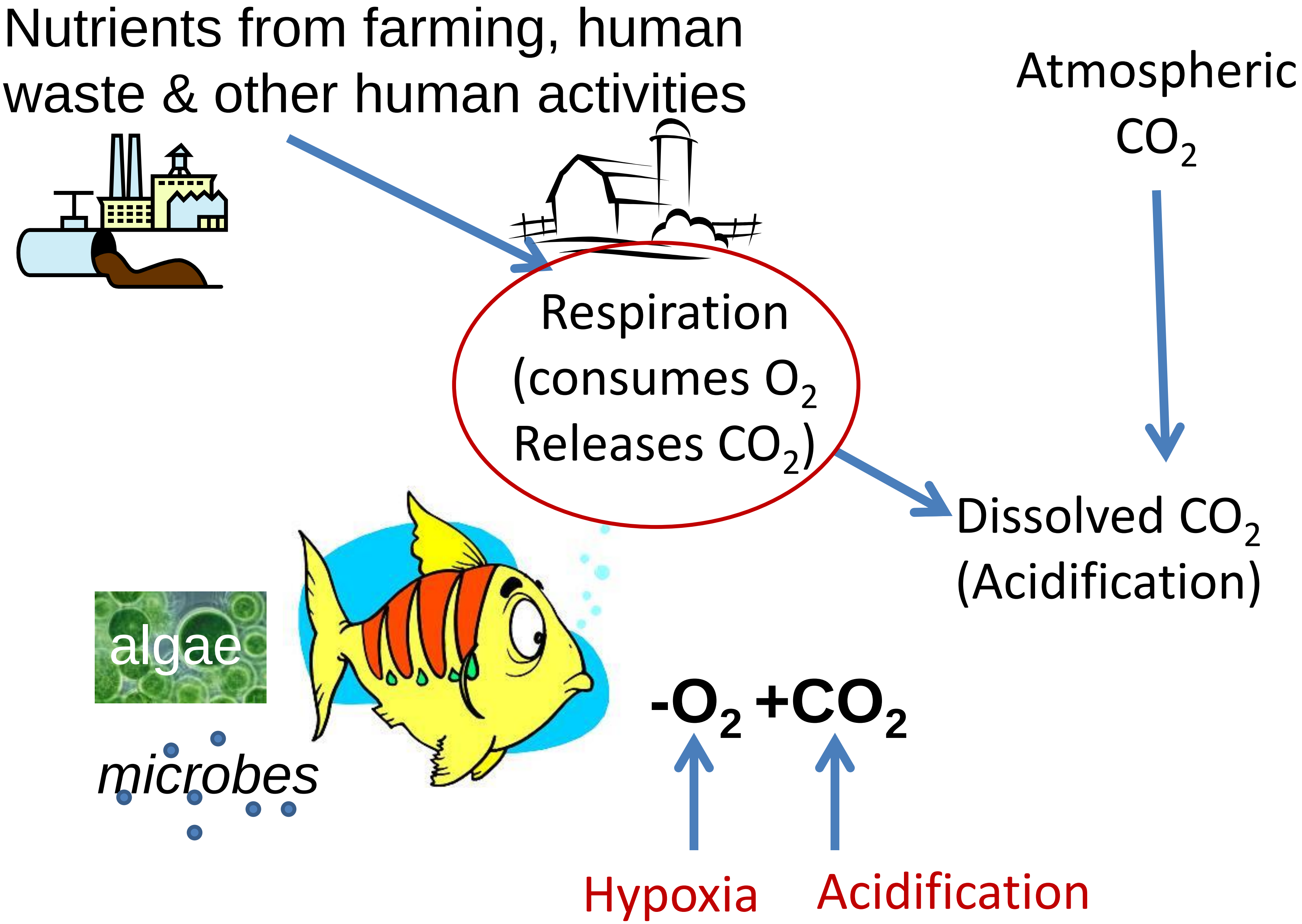
algae

*microbes*

**$-O_2$ $+CO_2$**

Hypoxia

Acidification



Nutrients from farming, human waste & other human activities

Atmospheric $CO_2$

Respiration ($consumes $O_2$ Releases $CO_2$)

Dissolved $CO_2$ (Acidification)

algae

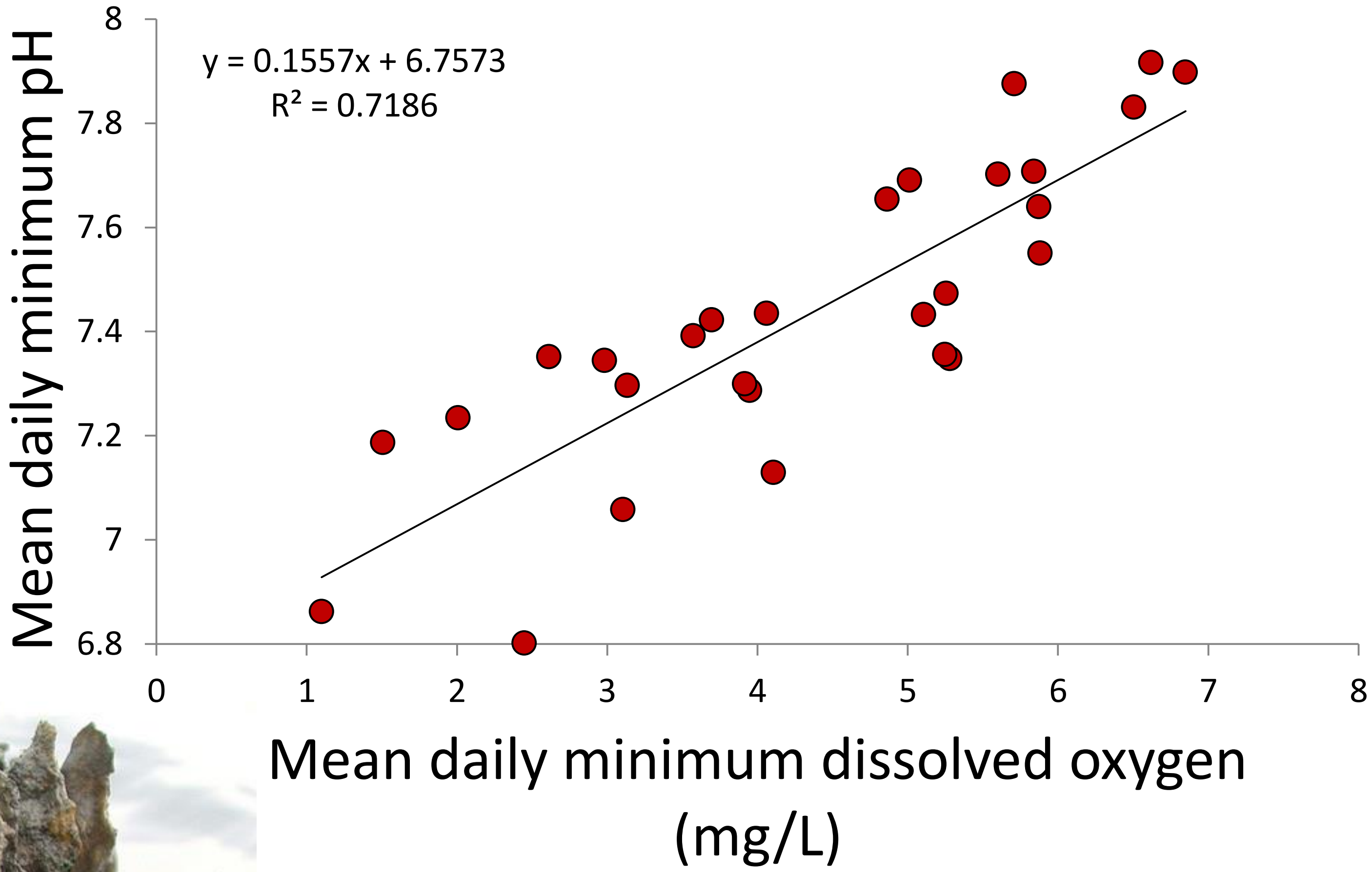
*microbes*

**$-O_2$ $+CO_2$**

Hypoxia

Acidification

**Challenge 1:** Can’t really consider acidification in Chesapeake Bay without looking at the potential interactive effects of hypoxia and acidification



(Breitburg et al, accepted pending revision)

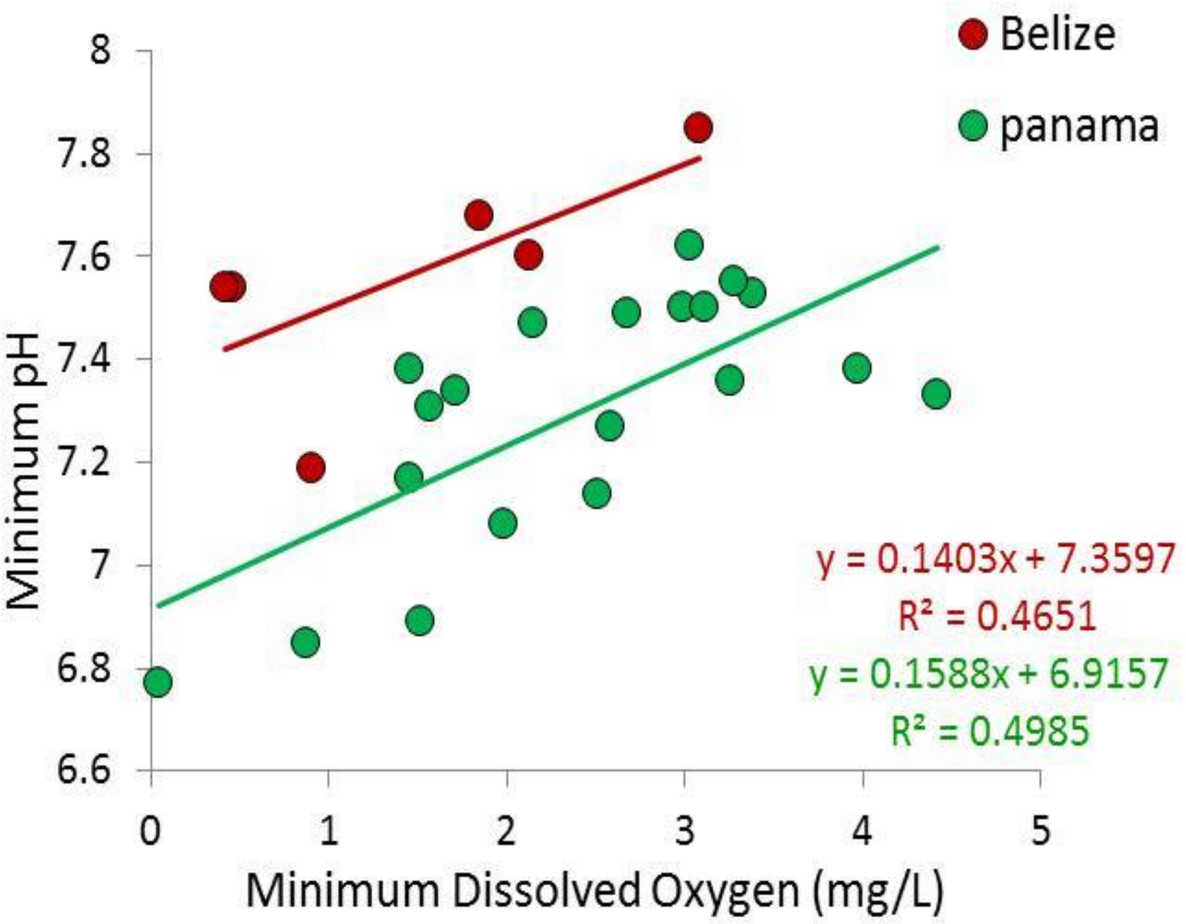
June – August 2004-2009: Data from MD-DNR shallow water monitoring program continuous monitoring sites with mean summer salinity >7.0 eyes on the bay

We can come up with fairly predictable relationships between hypoxia and pH.

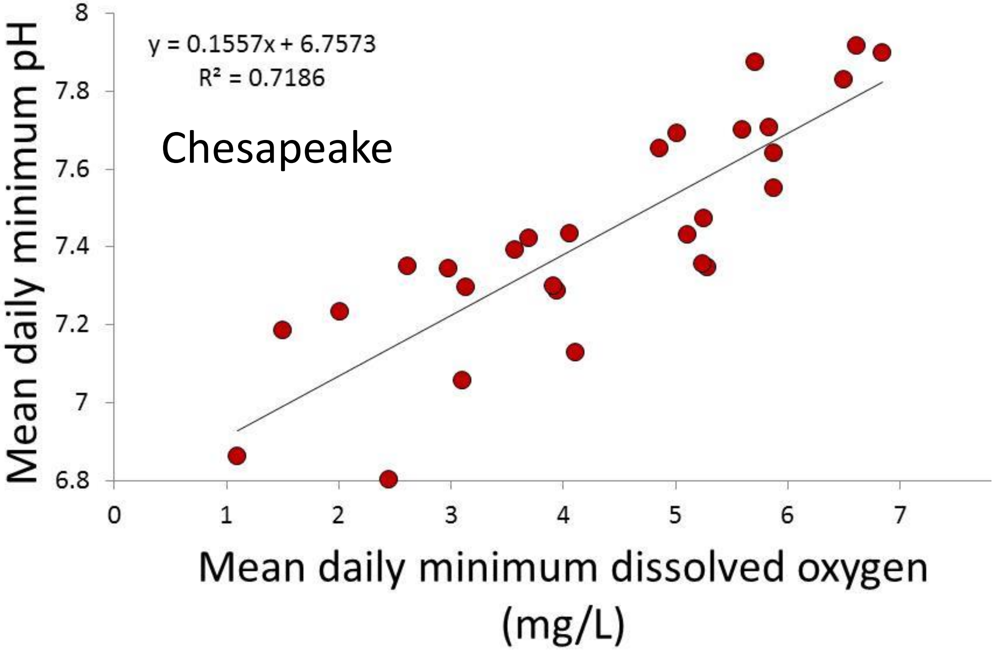
**Challenge 2:** Are DO criteria protective for pH effects?

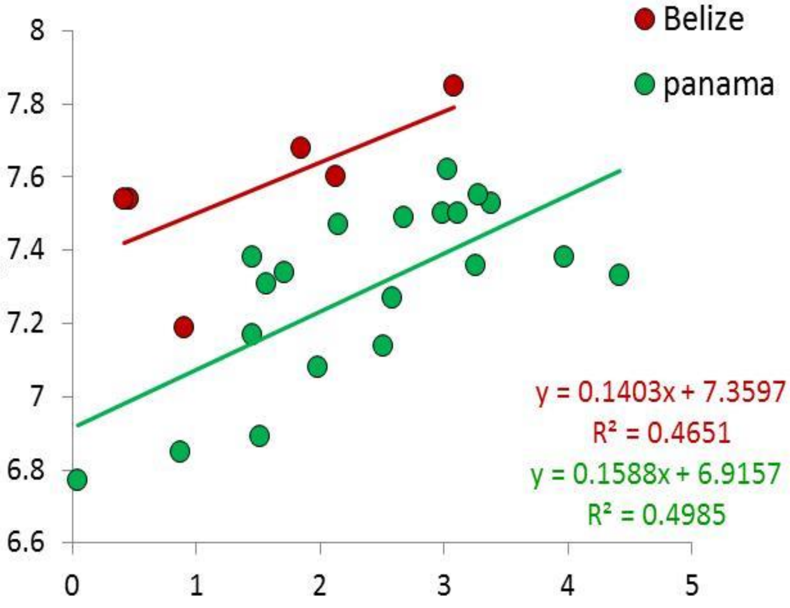
# Respiration-driven acidification

# Mangrove ponds in Belize & Panama



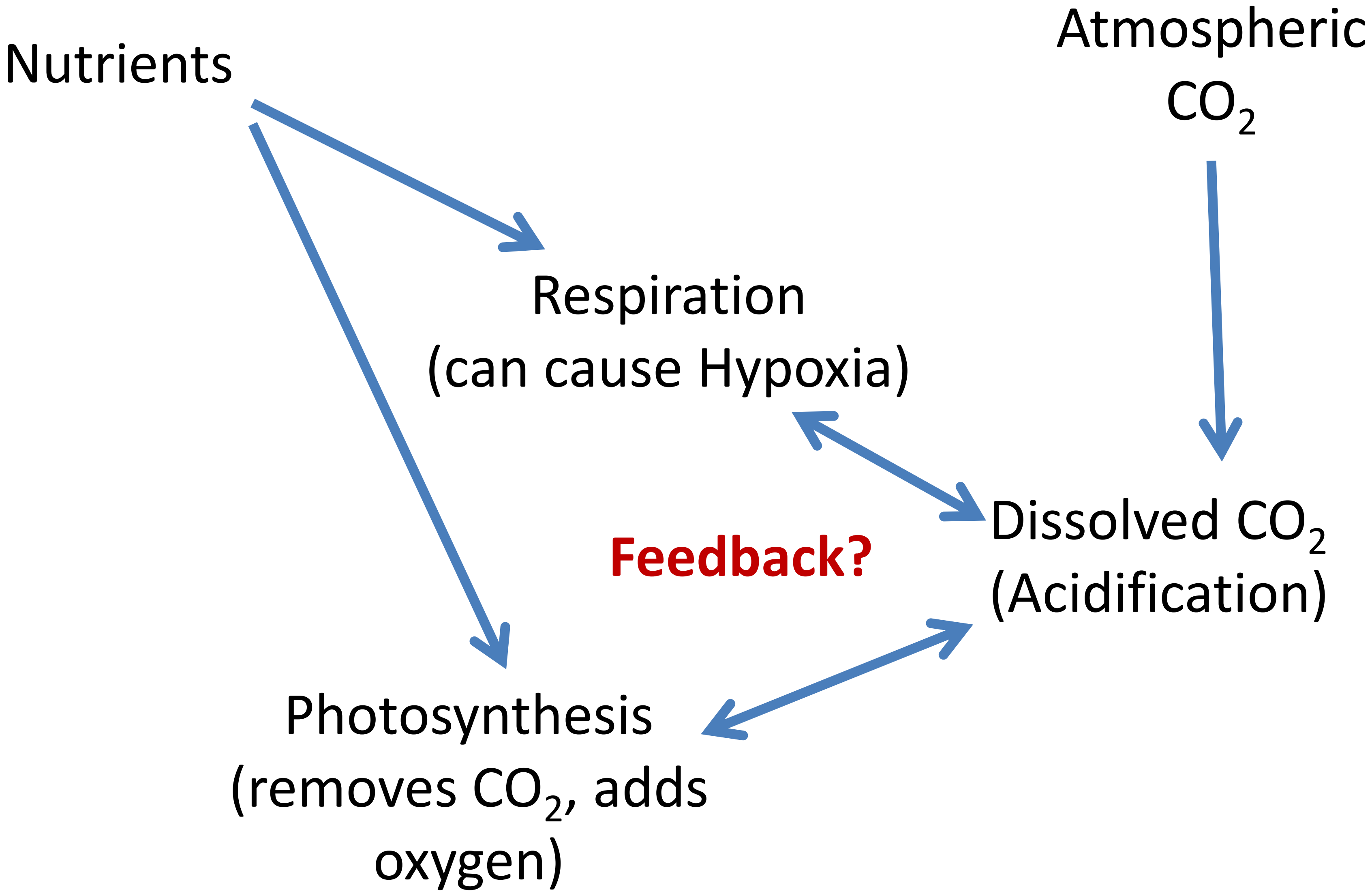
Gedan, Breitburg & Feller, unpublished





Some low pH is natural

**Challenge 3:** How much of the acidification in Chesapeake Bay is natural vs caused by human activities?



Nutrients

Atmospheric $CO_2$

Respiration
(can cause Hypoxia)

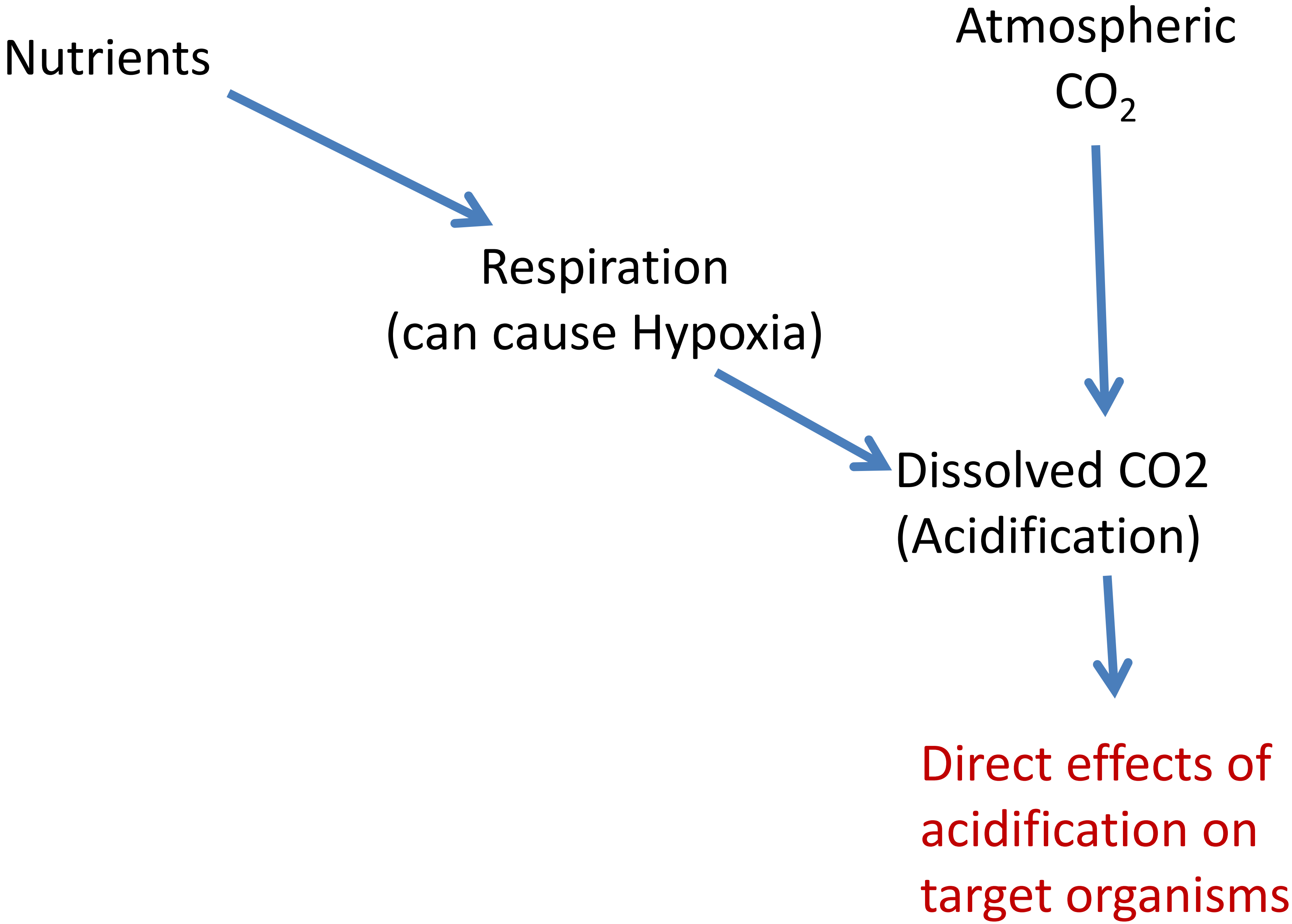
**Feedback?**

Dissolved $CO_2$
(Acidification)

Photosynthesis
(removes $CO_2$, adds oxygen)

# **Challenge 4:** Predicting combined effects of atmospheric $CO_2$ + nutrient related acidification on $pCO_2$/pH: Are there important feedbacks or are the sources simply additive?

We can’t wait to test potential biological & ecological responses until we have this answer, but we ultimately need this to predict acidification effects



Nutrients

Atmospheric $CO_2$

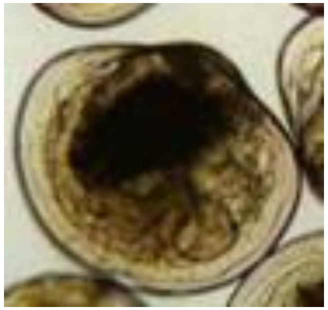
Respiration
(can cause Hypoxia)

Dissolved CO2
(Acidification)

Direct effects of
acidification on
target organisms

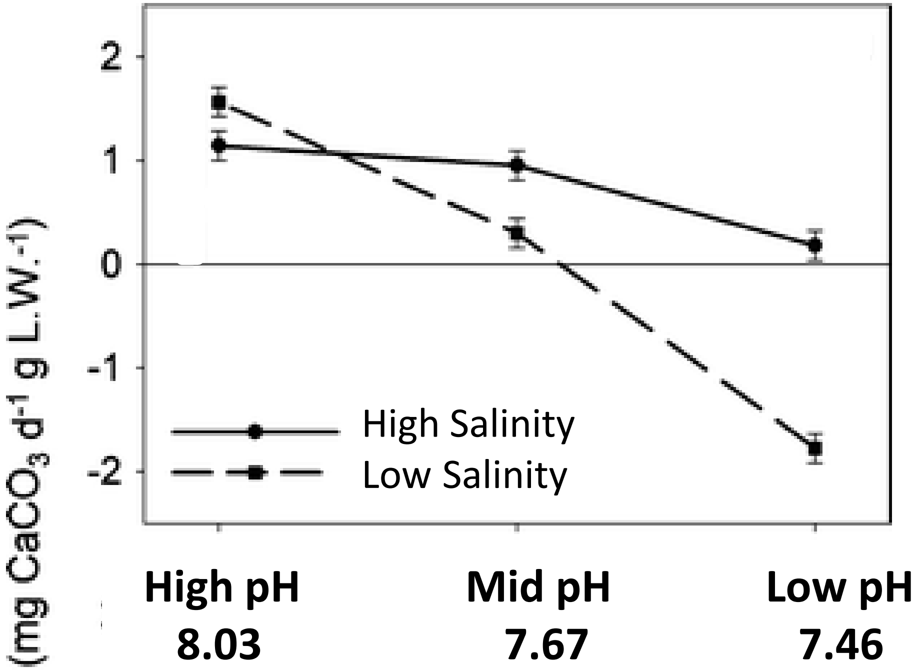
# Bivalve larvae show reduced calcification and growth at pH levels that occur in US coastal waters

Decreased survival
Delayed metamorphosis
Smaller size at metamorphosis
(Talmage & Gobler 2009)



Reduced growth and calcification rates (Miller et al. 2009, Waldbusser et al. 2010)

# Acidification may make restoration more difficult or less successful

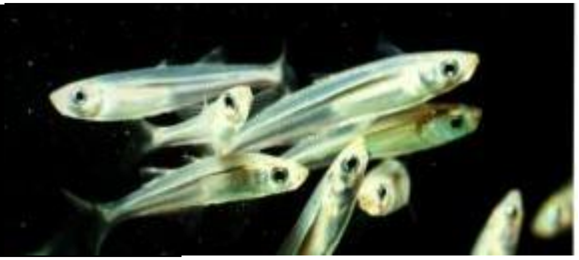


- Strongest effect of acidification may be in low salinity areas that are refuges from disease (Waldbusser et al. 2010)

- Continuous exposure reduces the immune response of oysters (Boyd & Burnett 1998)

# Fish

- Atlantic silverside: Reduced larval survival & growth
Dependent on time of year and parental exposure
Murray et al. 2014
- Inland silverside: Reduced larval survival (Seth Miller)



impaired olfactory ability caused larvae to settle on reefs at times they would be more vulnerable to predators. (Devine et al., 2012)

Summer flounder:
Reduced embryo survival
Larvae with less energy reserves
Metamorphose at smaller size
Developmental abnormalities
(Chambers et al., 2014)

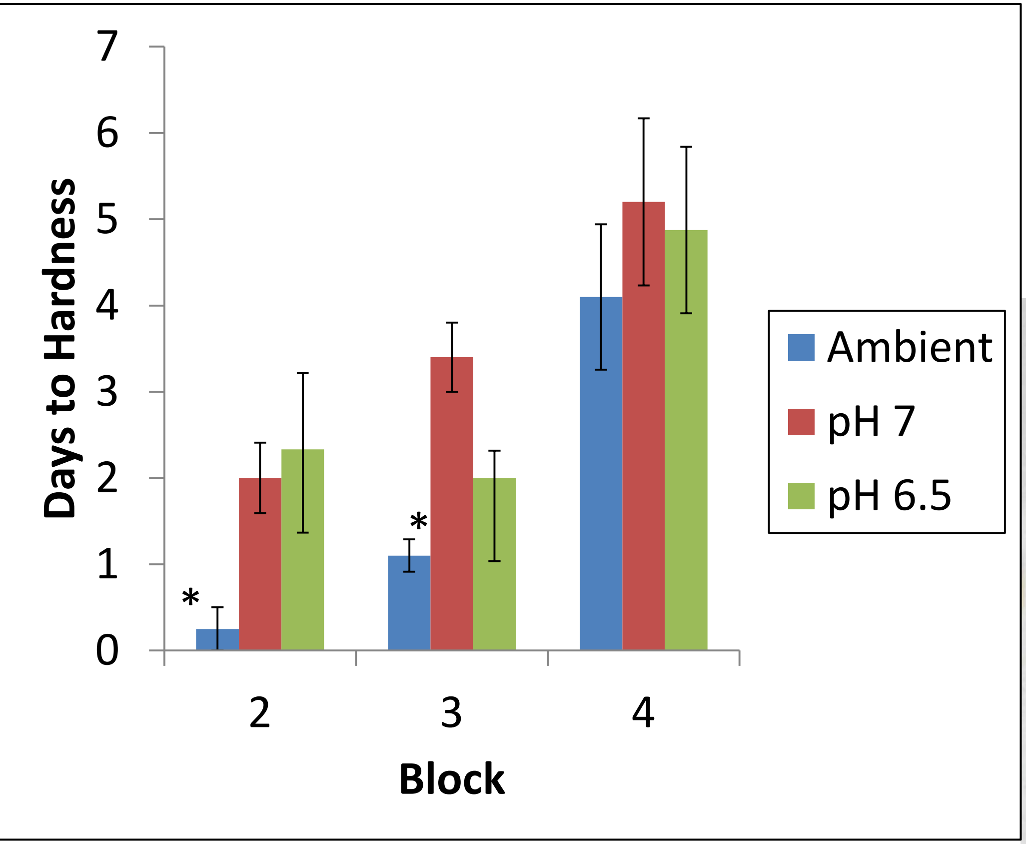
Failure to learn to respond appropriately to a common predator. (Ferrari et al. 2011)

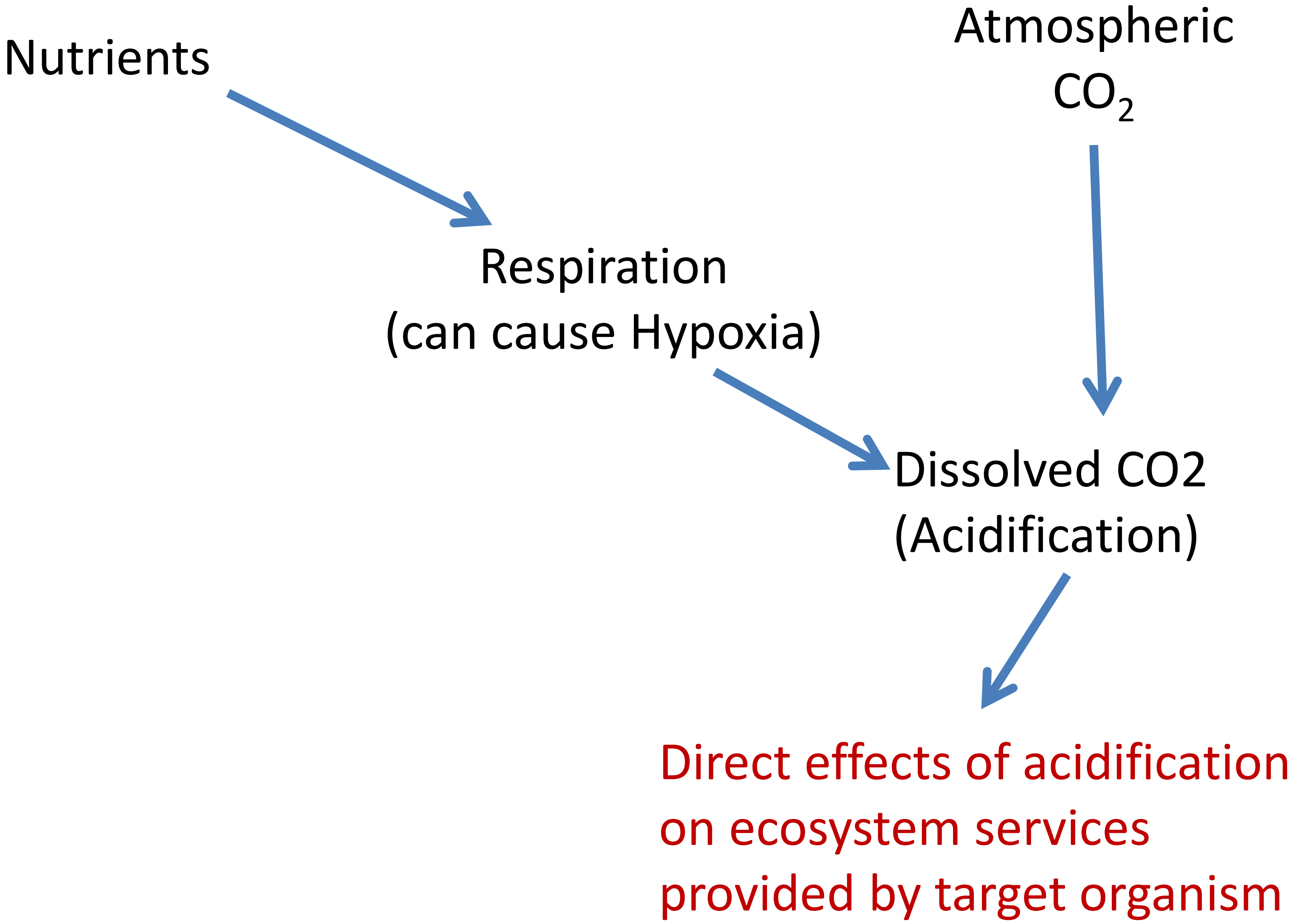
Increased otolith size in juvenile cobia (Bignami et al., 2013)

# Blue crab

Lane & T. Miller, unpublished

# Acidification increases crab hardening time





Nutrients

Atmospheric CO$_2$

Respiration
(can cause Hypoxia)

Dissolved CO2
(Acidification)

Direct effects of acidification on ecosystem services provided by target organism

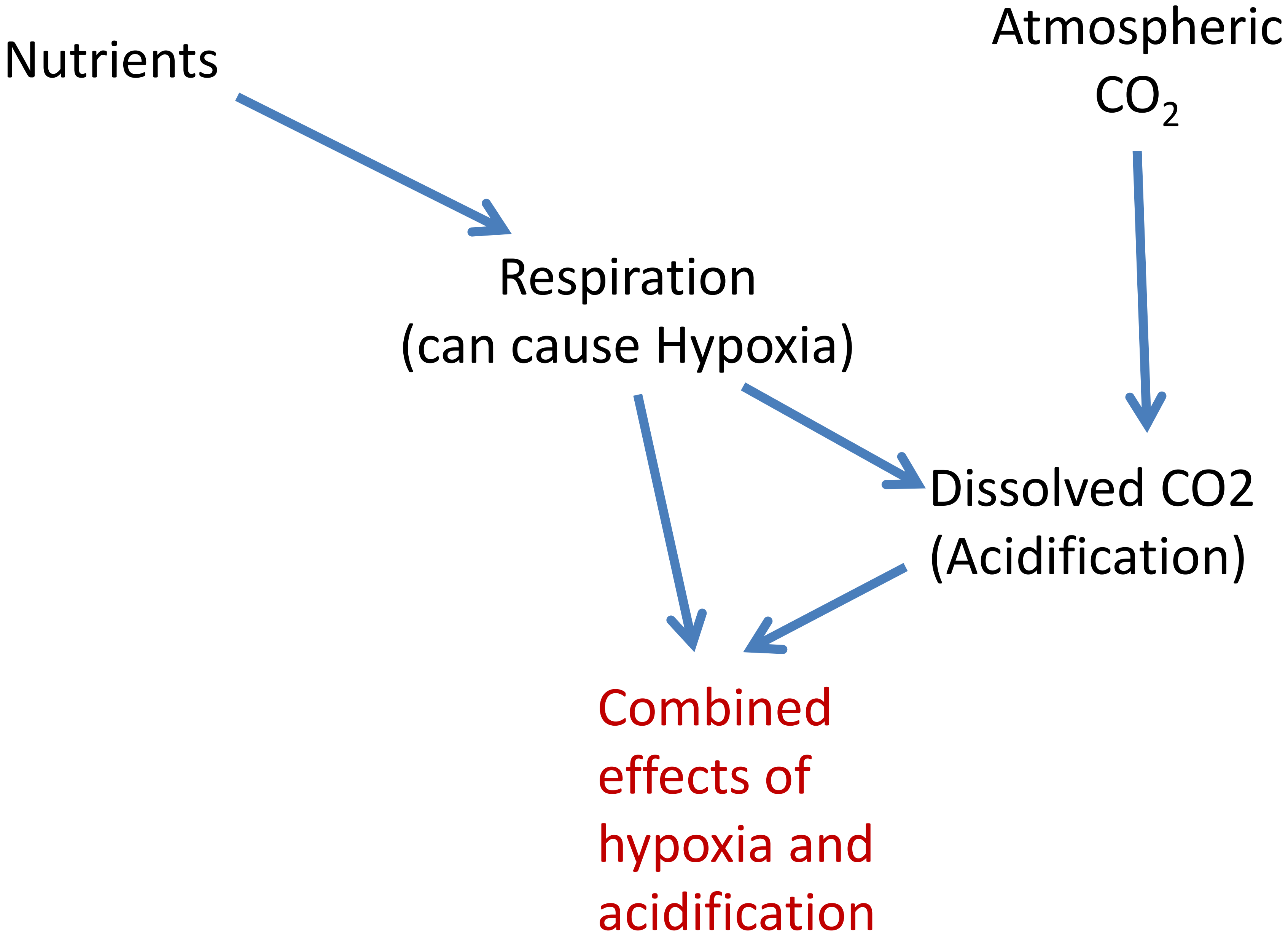
# Clean oysters = less food for associated oyster reef invertebrates

pH = 7.9 pH = 7.45

Keppel et al., unpublished

# Lots of species, lots of potential effects.

**Challenge 5:** Identifying key species, mechanisms and interactions while being open to surprises



Nutrients

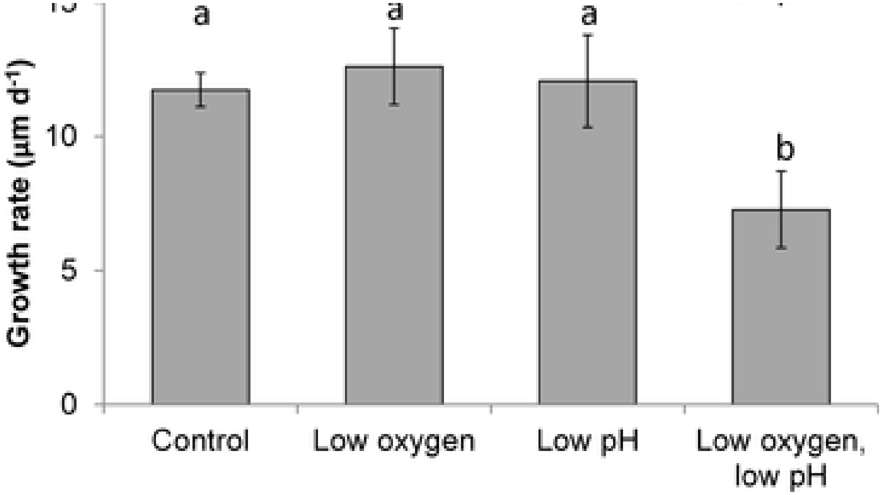
Atmospheric
$CO_2$

Respiration
(can cause Hypoxia)

Dissolved CO2
(Acidification)

Combined
effects of
hypoxia and
acidification

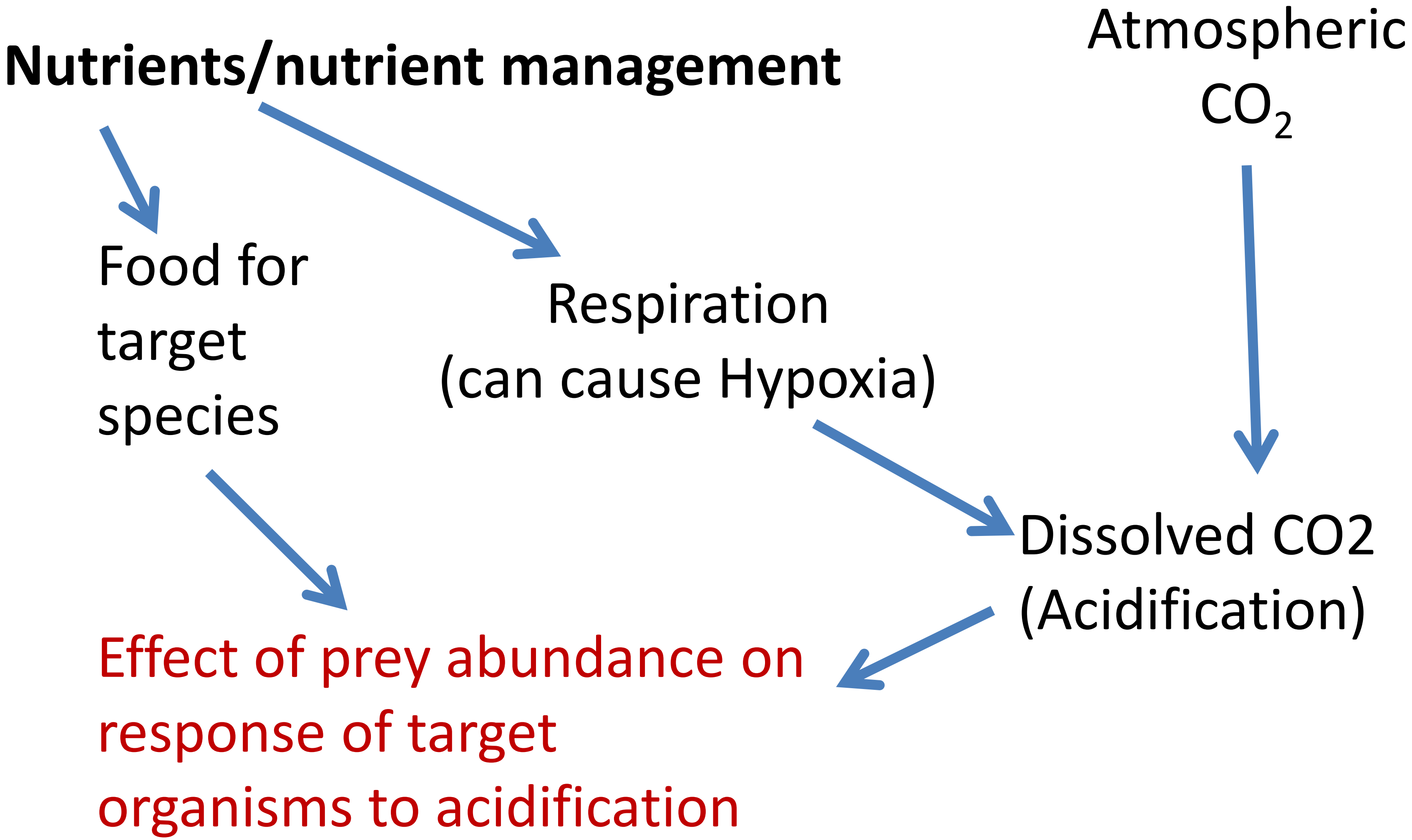
# Hypoxia plus acidification (HYpHOXIA) can sometimes have greater combined effects than either stressor alone




**Hard clams**

Gobler et al 2014

**Challenge 6:** Predicting effects of multiple stressors when one of those stressors is acidification.



**Nutrients/nutrient management**

Atmospheric $CO_2$

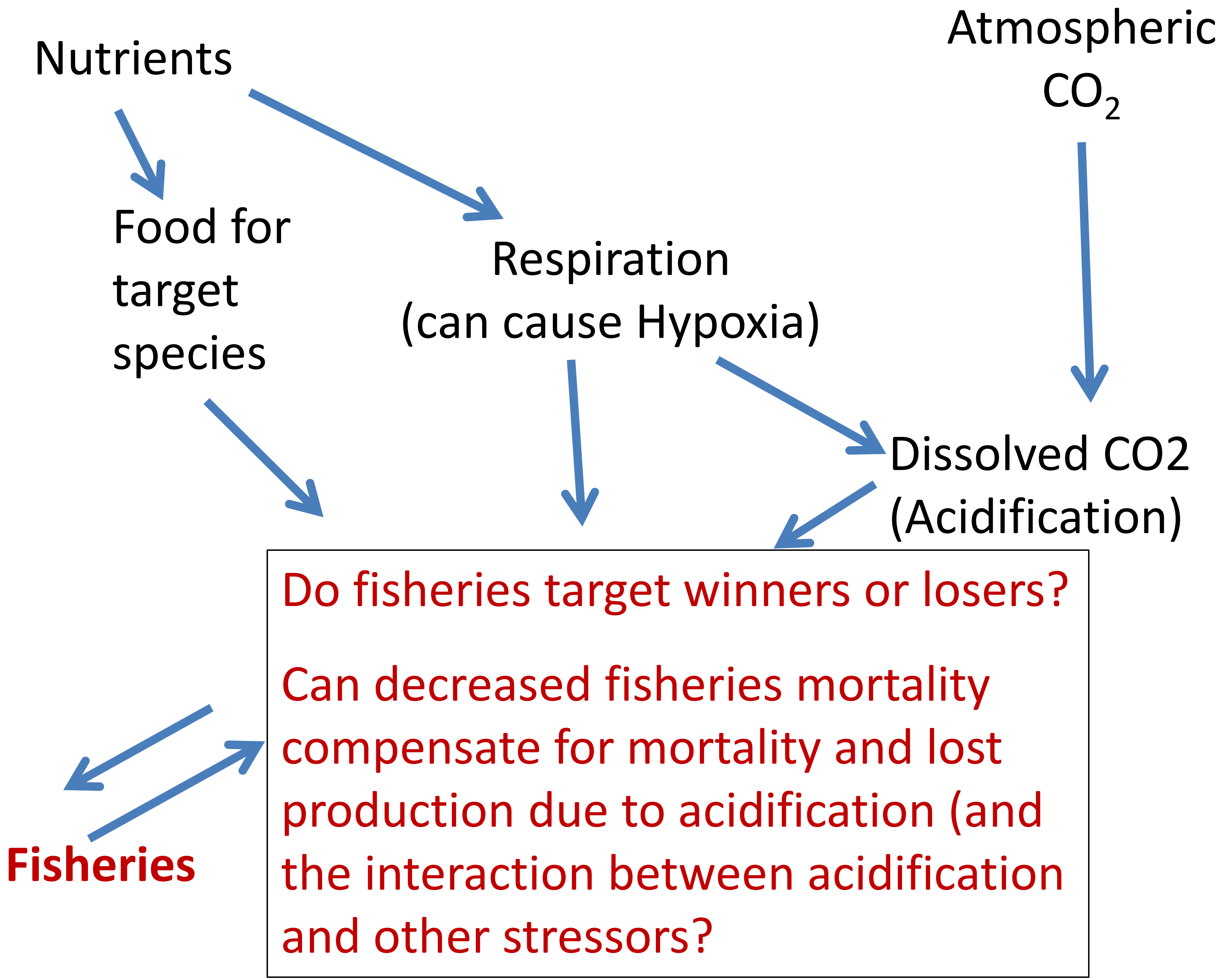
Food for target species

Respiration (can cause Hypoxia)

Dissolved CO2 (Acidification)

Effect of prey abundance on response of target organisms to acidification

*Energetic costs of acidification



Nutrients

Atmospheric $CO_2$

Food for target species

Respiration (can cause Hypoxia)

Dissolved CO2 (Acidification)

Do fisheries target winners or losers?

Can decreased fisheries mortality compensate for mortality and lost production due to acidification (and the interaction between acidification and other stressors?

**Fisheries**

# Southeast Australian marine ecosystem (Griffith et al, 2011: Atlantis model)

- Effects of fisheries and acidification were not simply additive
- Fishing either partially mitigated or exacerbated effects of acidification
- Heavy fishery exploitation eventually affected the 'ability of the ecosystem to respond to acidification, leading to accelerated biodiversity loss, regime shifts and changes in trophic structure.'

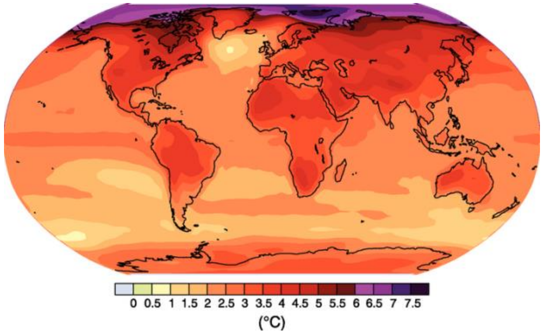
**Challenge 7:** Good fisheries food-web models that can incorporate effects of acidification and other stressors

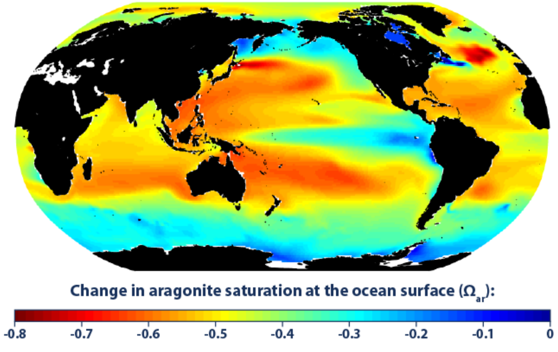
# Temperature is also rising:

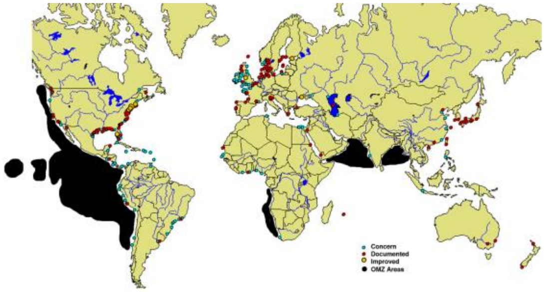
Low pH reduces tolerance of red abalone larvae to high temperatures (Zippay & Hofmann 2010)

http://www.divebums.com/week/2007/Sep17-2007/red-abalone_kevin-lee.jpg

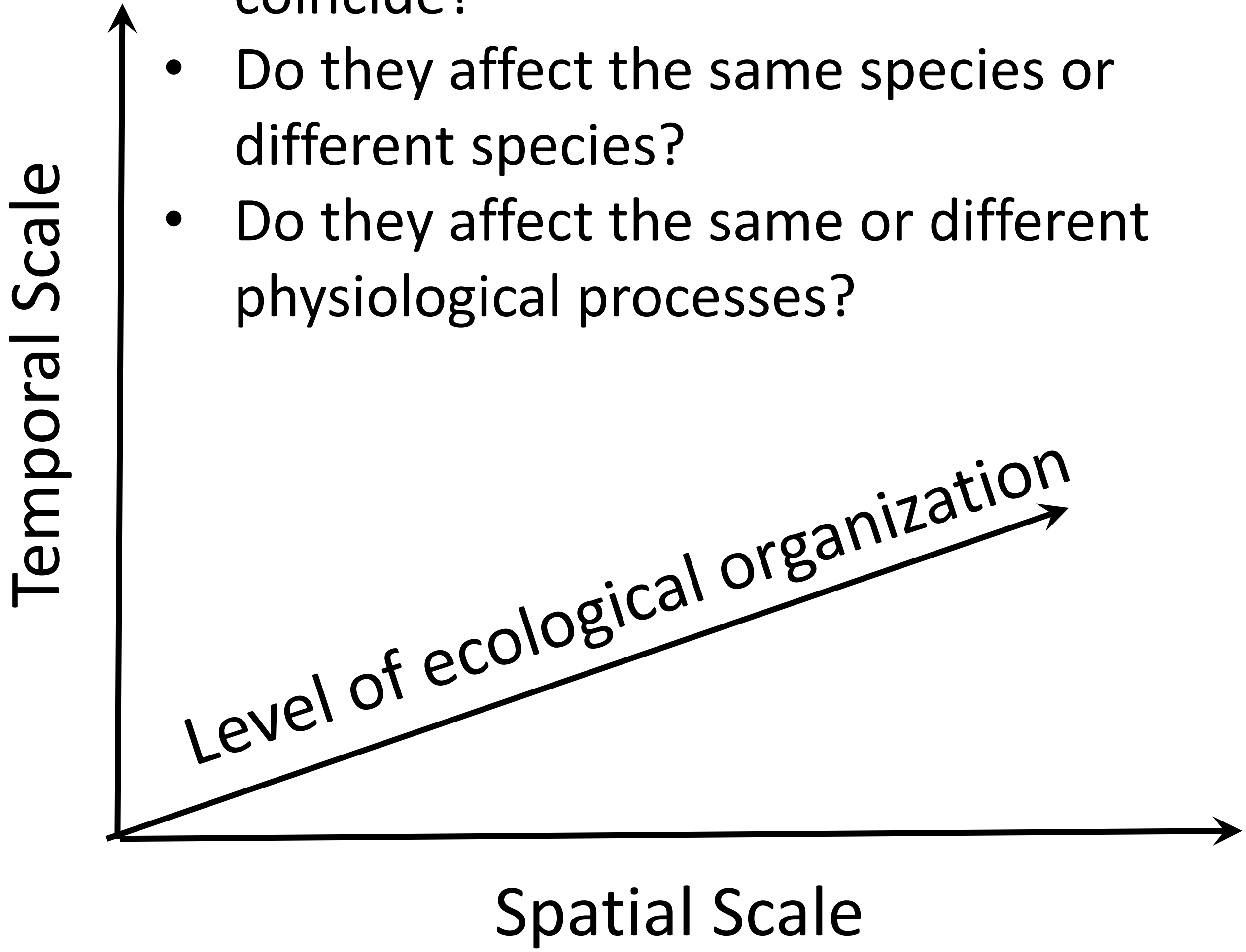
# Co-occurrence of multiple stressors & their effects







- Do stressors occur in sequence or coincide?
- Do they affect the same species or different species?
- Do they affect the same or different physiological processes?



Temporal Scale

Level of ecological organization

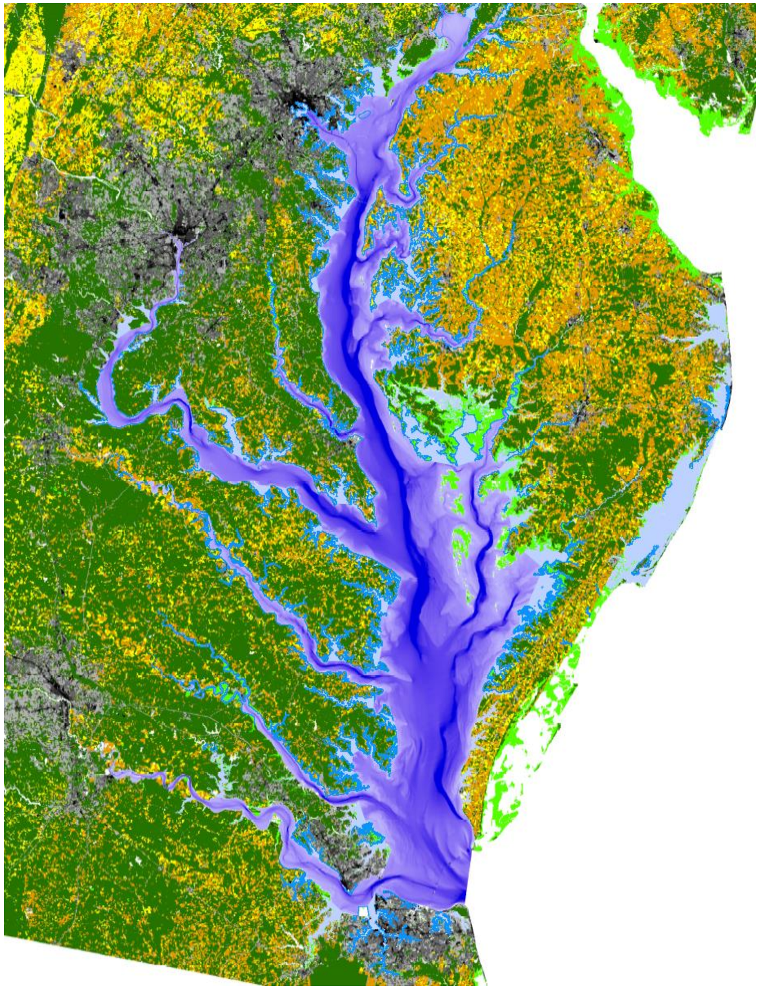
Spatial Scale

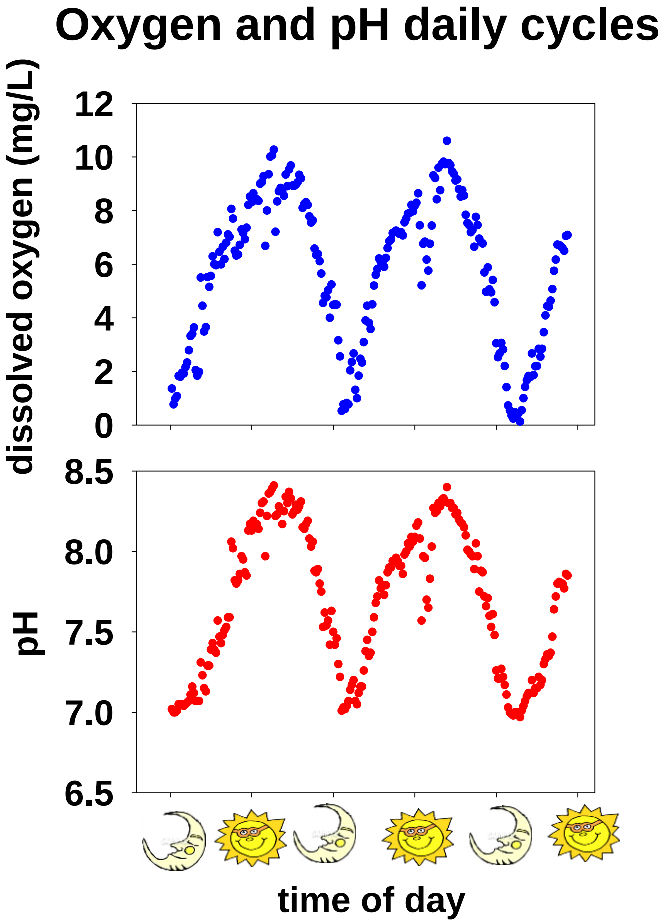
# **Challenge 8:** Cycling conditions may have different effects than constant conditions

temporal patterns are a major difference between respiration-driven and atmospheric $CO_2$-driven acidification

# Are cycling conditions fundamentally different?

- Interaction with circadian rhythms of physiological processes & behaviors



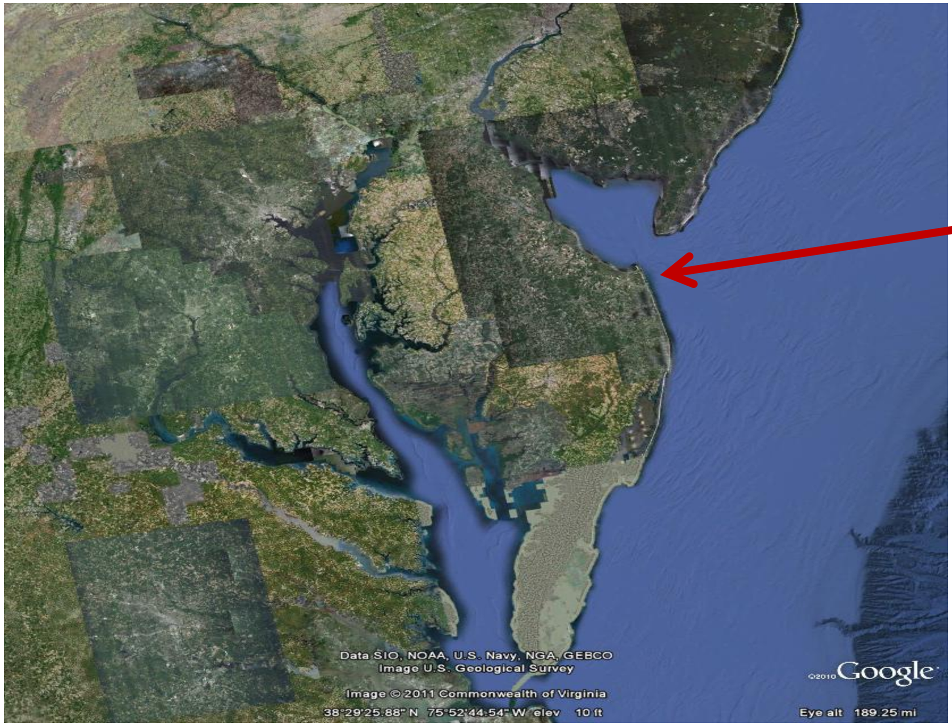


MD-DNR: eyesonthebay.net

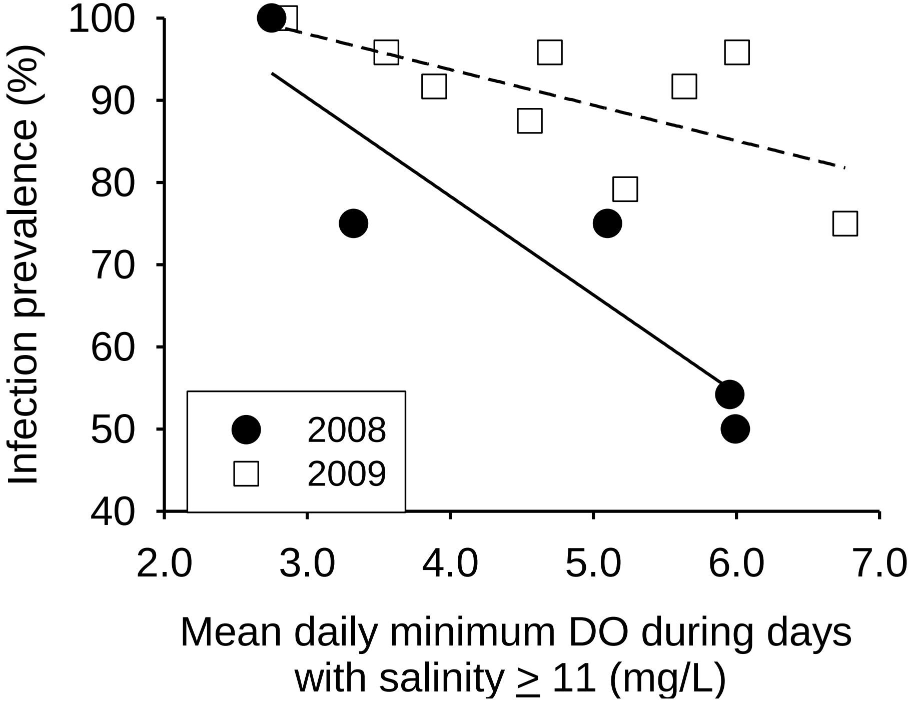
# Diel-cycling hypoxia affects fish growth & behavior

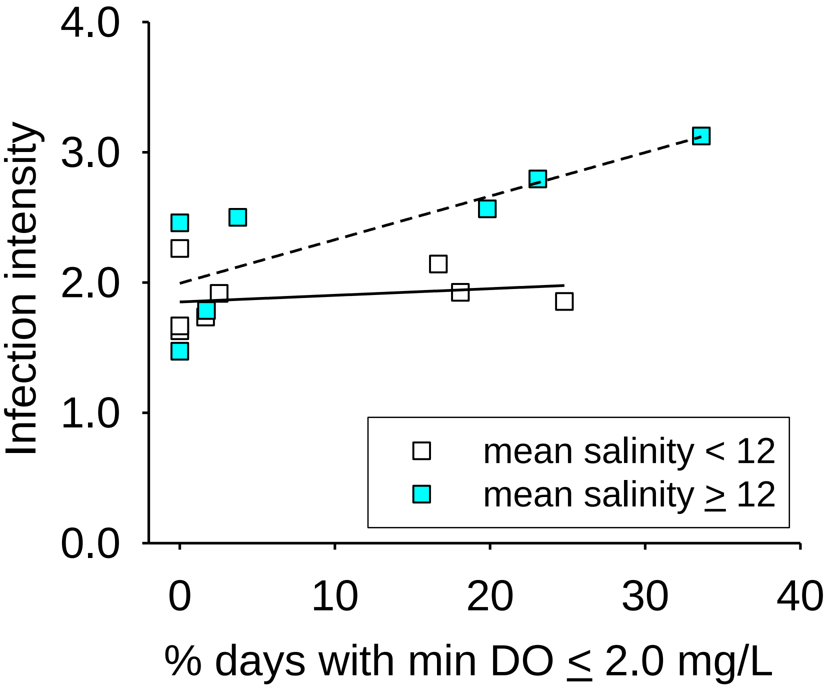
Energetic cost of highly variable environment

Targett lab – U Del



# Diel-cycling increases prevalence and intensity of *P. marinus* infections in oysters (Breitburg et al, accepted pending revision)





MD-Sea Grant

# Shallow Water Hypoxia - Tipping the Balance for Individuals, Populations and Ecosystems

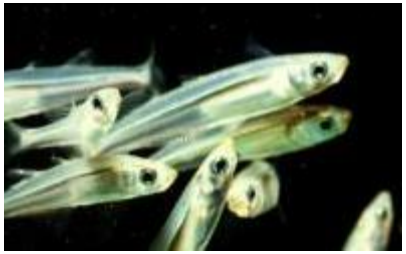
Breitburg, Targett, Rose, Michael, Townsend (Funding NOAA-CSCOR)

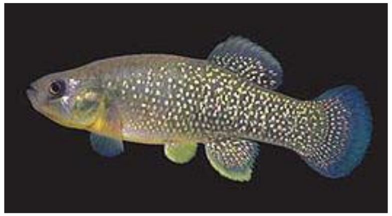
Focusses on current conditions – So we have not pushed the acidification part of our experiments as hard as we should if we want to consider future scenarios

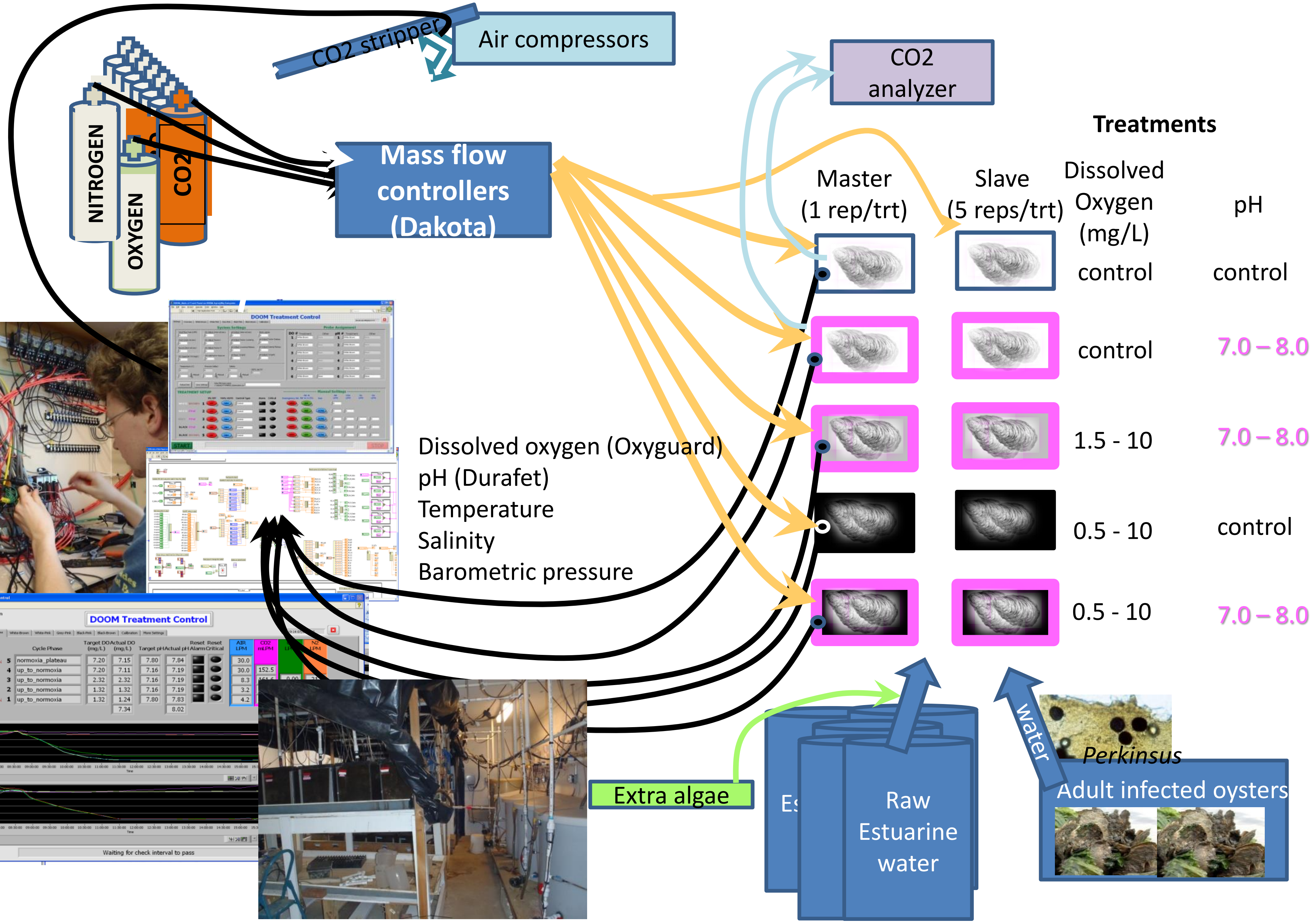
Oyster disease dynamics

Oyster growth rates

Juvenile fish growth rates and fish behavior







**DOOM Treatment Control**

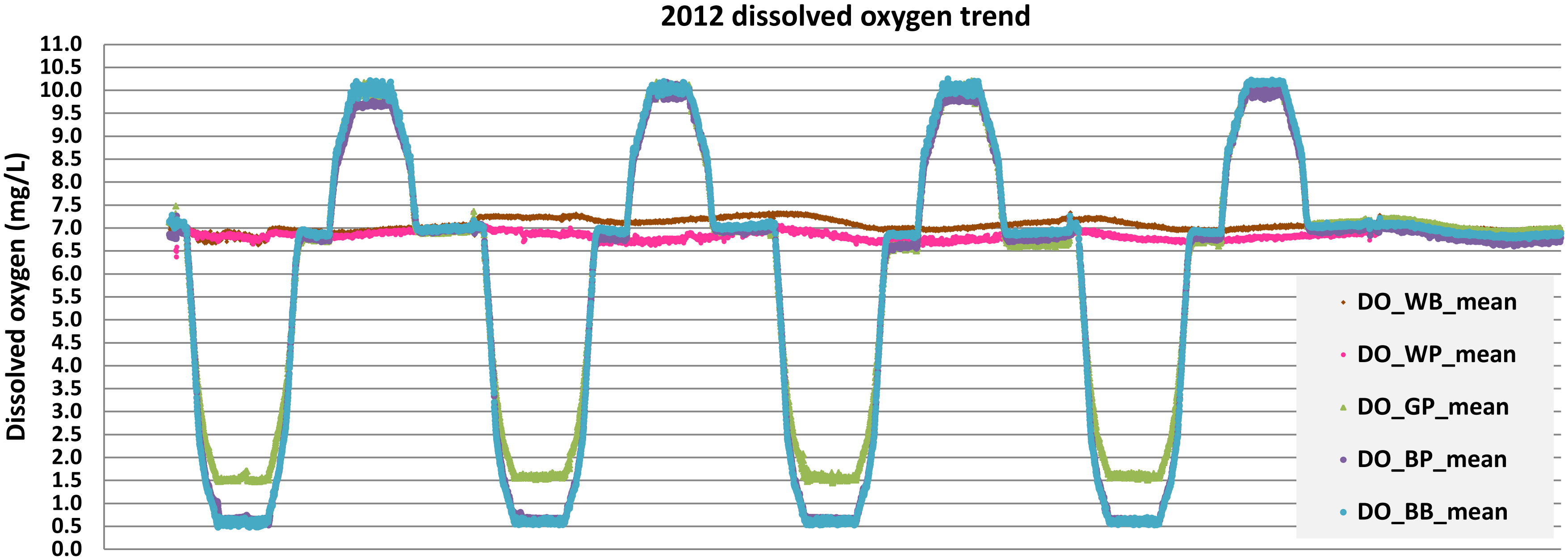
| | Cycle Phase | Target DO (mg/L) | Actual DO (mg/L) | Target pH | Actual pH | Reset Alarm | Reset Critical | AIR LPM | CO2 mLPM |
|---|---|---|---|---|---|---|---|---|---|
| 5 | normoxia_plateau | 7.20 | 7.15 | 7.80 | 7.84 | | | 30.0 | |
| 4 | up_to_normoxia | 7.20 | 7.11 | 7.16 | 7.19 | | | 30.0 | 152.5 |
| 3 | up_to_normoxia | 2.32 | 2.32 | 7.16 | 7.19 | | | 8.3 | |
| 2 | up_to_normoxia | 1.32 | 1.32 | 7.16 | 7.19 | | | 3.2 | |
| 1 | up_to_normoxia | 1.32 | 1.24 | 7.80 | 7.83 | | | 4.2 | |
| | | | 7.34 | | 8.02 | | | | |

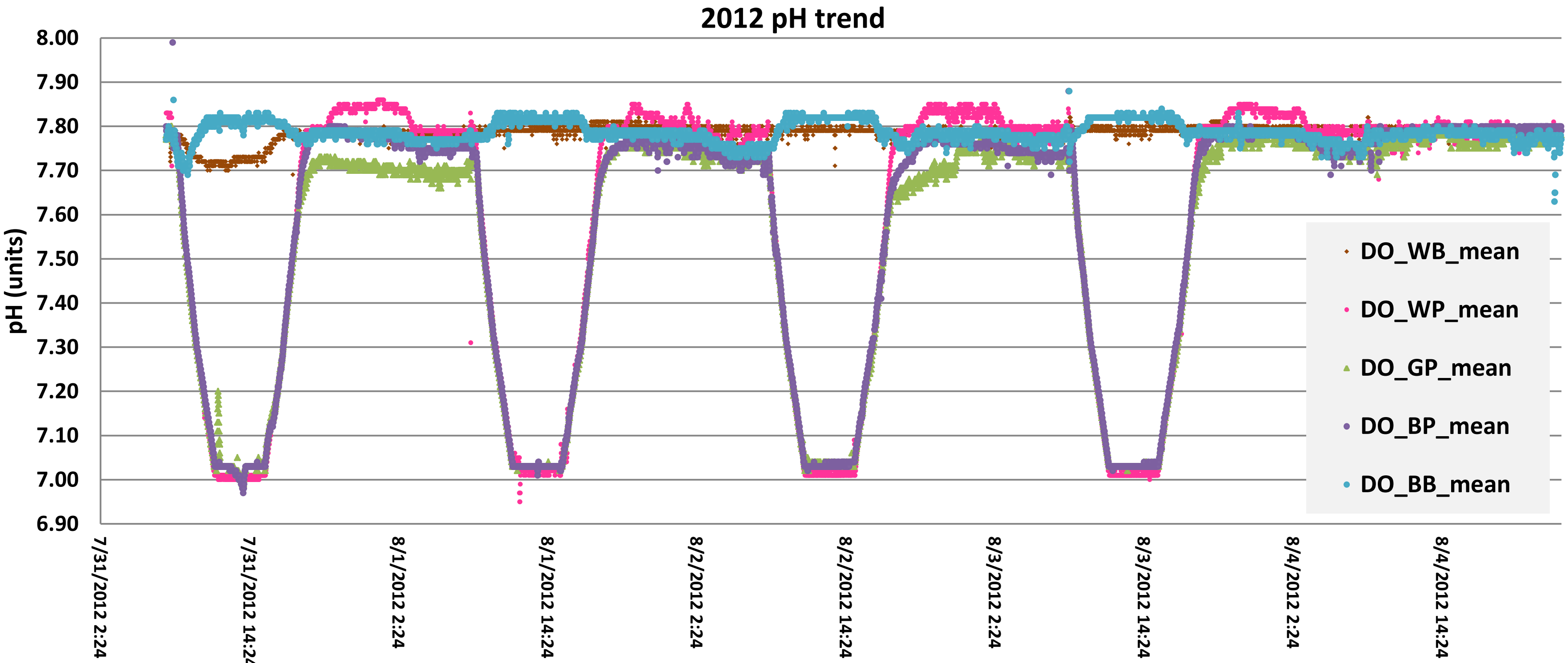
Waiting for check interval to pass

Dissolved oxygen (Oxyguard)
pH (Durafet)
Temperature
Salinity
Barometric pressure

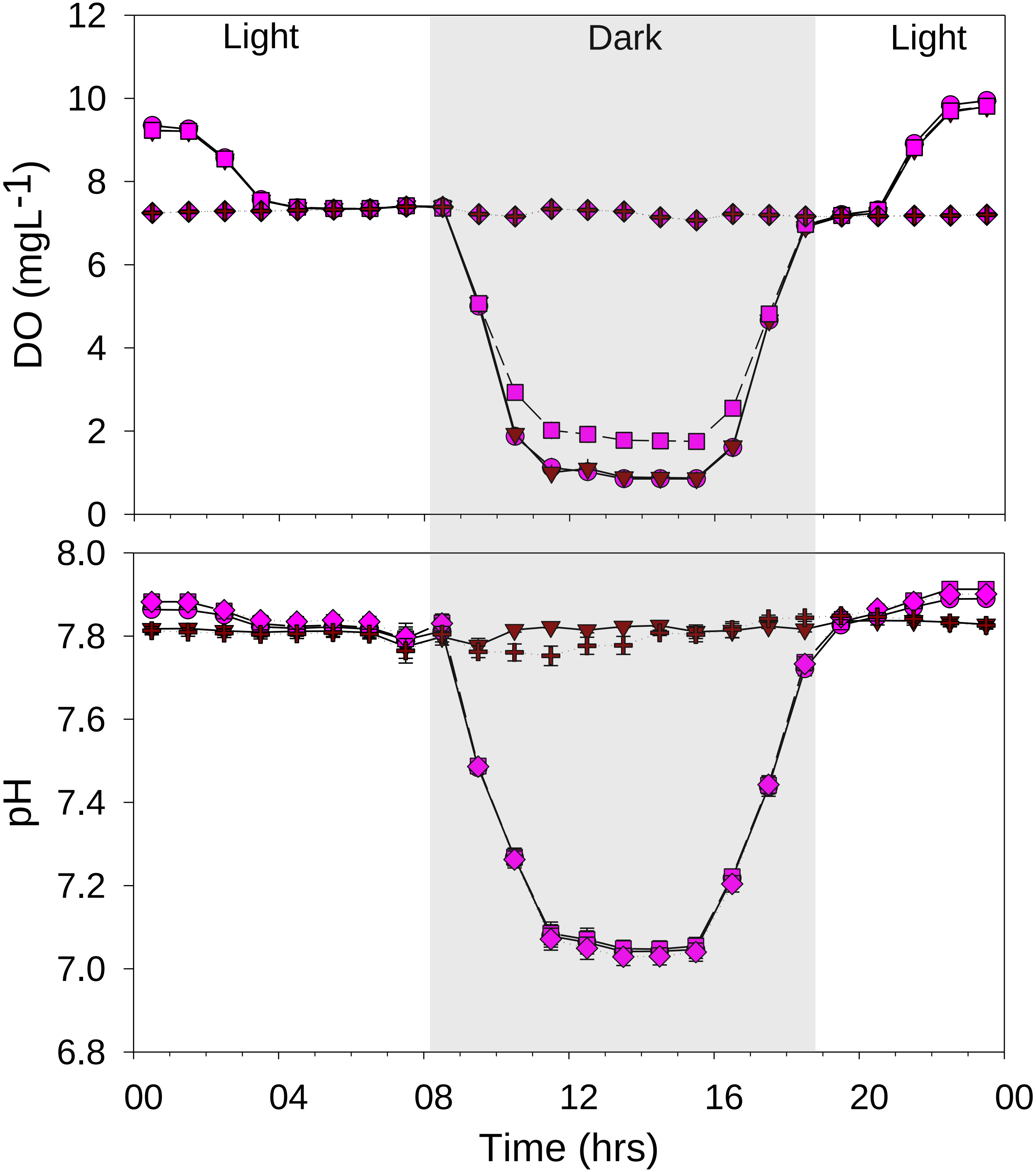
**Treatments**

| Dissolved Oxygen (mg/L) | pH |
|---|---|
| control | control |
| control | 7.0 – 8.0 |
| 1.5 - 10 | 7.0 – 8.0 |
| 0.5 - 10 | control |
| 0.5 - 10 | 7.0 – 8.0 |

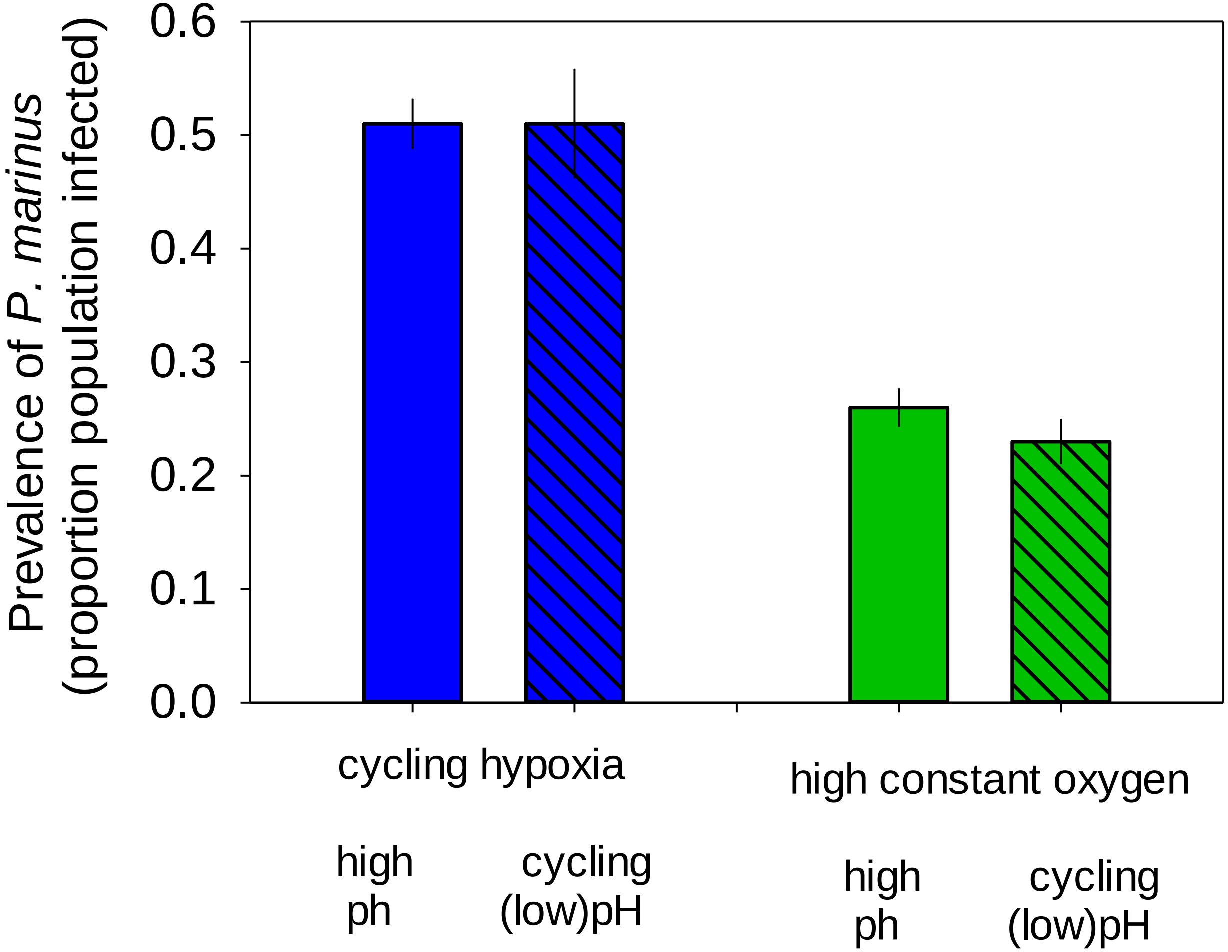

2012 dissolved oxygen trend
Dissolved oxygen (mg/L)
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
DO_WB_mean
DO_WP_mean
DO_GP_mean
DO_BP_mean
DO_BB_mean


2012 pH trend
pH (units)
8.00
7.90
7.80
7.70
7.60
7.50
7.40
7.30
7.20
7.10
7.00
6.90
DO_WB_mean
DO_WP_mean
DO_GP_mean
DO_BP_mean
DO_BB_mean
7/31/2012 2:24
7/31/2012 14:24
8/1/2012 2:24
8/1/2012 14:24
8/2/2012 2:24
8/2/2012 14:24
8/3/2012 2:24
8/3/2012 14:24
8/4/2012 2:24
8/4/2012 14:24

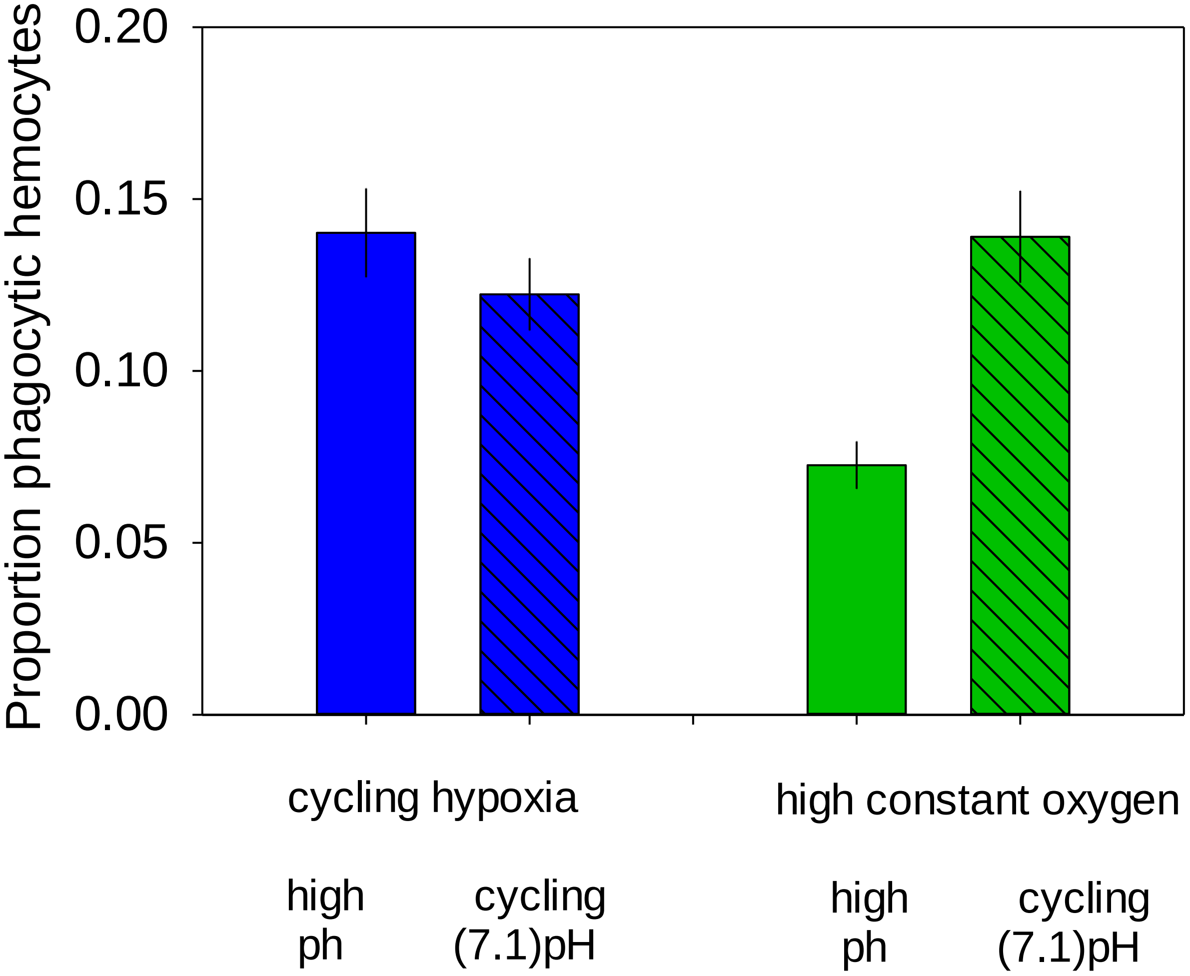
# 2012


Light
Dark
Light
DO (mgL-1)
12
10
8
6
4
2
0
pH
8.0
7.8
7.6
7.4
7.2
7.0
6.8
00
04
08
12
16
20
00
Time (hrs)

# Severe cycling hypoxia increases Dermo prevalence & intensity, but cycling pH to 7.1 does not



- Holding oyster hemocytes at a constant pH of 7.1 reduces their activity (Boyd & Burnett 1998),
- But cycling to the same pH stimulates the immune response



# Menidia beryllina

Seth Miller, D. Breitburg, et al., unpublished

- Juveniles are tolerant and show no growth reduction at constant and cycling pH conditions that kill larvae

# Major challenges, but important

1) Hypoxia connection
2) Protective criteria
3) Identifying anthropogenic component
4) Are CO2 sources additive
5) Identifying more important biological experiments/measurements
6) Multiple stressors
7) Food web/upper trophic level models
8) Variable vs constant conditions

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