Acidification in Chesapeake Bay: biological effects in an ecosystem context

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Challenges to predicting effects & managing an acidified Chesapeake Bay

Examples
Respiration – driven Hypoxia

Atmospheric CO$_2$

Dissolved CO$_2$
(酸化)

microbes

-algae

Hypoxia

acidification

- O$_2$ + CO$_2$

Respiration

Hypoxia

酸化

Acidification
Nutrients from farming, human waste & other human activities

Respiration (consumes $O_2$ Releases $CO_2$)

Atmospheric $CO_2$

Dissolved $CO_2$ (Acidification)

Hypoxia

Acidification

-algae

-microbes
Challenge 1: Can’t really consider acidification in Chesapeake Bay without looking at the potential interactive effects of hypoxia and acidification
Mean daily minimum pH

Mean daily minimum dissolved oxygen (mg/L)

(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Gedan, Breitburg & Feller, unpublished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

Respiration (can cause Hypoxia)

Feedback?

Photosynthesis (removes CO$_2$, adds oxygen)

Atmospheric CO$_2$

Dissolved CO$_2$ (Acidification)
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

Respiration (can cause Hypoxia)

Dissolved CO₂ (Acidification)

Atmospheric CO₂

Direct effects of acidification on target organisms
Bivalve larvae show reduced calcification and growth at pH levels that occur in US coastal waters.

**Hard clams**

- Decreased survival
- Delayed metamorphosis
- Smaller size at metamorphosis

*(Talmage & Gobler 2009)*

**Oysters**

- 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)

- Failure to learn to respond appropriately to a common predator.
  (Ferrari et al. 2011)
- 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)
- Increased otolith size in juvenile cobia (Bignami et al., 2013)
Acidification increases crab hardening time

Blue crab
Lane & T. Miller, unpublished
Nutrients

Respiration (can cause Hypoxia)

Atmospheric CO\textsubscript{2}

Dissolved CO\textsubscript{2} (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

Respiration  (can cause Hypoxia)

Dissolved CO2  (Acidification)

Atmospheric CO\textsubscript{2}

Combined effects of hypoxia and acidification
Hypoxia plus acidification (HYpHOXIA) can sometimes have greater combined effects than either stressor alone.

**Challenge 6:** Predicting effects of multiple stressors when one of those stressors is acidification.
Nutrients/nutrient management

Food for target species

Respiration (can cause Hypoxia)

Effect of prey abundance on response of target organisms to acidification

Atmospheric CO$_2$

Dissolved CO$_2$ (Acidification)

*Energetic costs of 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?)
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)
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?
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

Oxygen and pH daily cycles

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).

Infection prevalence (%)
40
50
60
70
80
90
100

2008
2009

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

Master (1 rep/trt)
Slave (5 reps/trt)

Treatments
Dissolved Oxygen (mg/L)
P H
control
control
control
control

Raw Estuarine water

Extra algae

Adult infected oysters

Dissolved Oxygen (Oxyguard)
Ph (Durafet)
Temperature
Salinity
Barometric pressure

Air compressors

Mass flow controllers (Dakota)

CO2 striping

CO2 analyzer

Perkinsus

NITROGEN
OXYGEN

CO2

Dissolved CO2

NITROGEN

Mass flow controllers

LabVIEW program

Barometric pressure

NITROGEN

NITROGEN

NITROGEN

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NITROGEN
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

Thanks to NOAA-CSCOR, SI and MD-Sea Grant for funding, and to collaborators, students, postdocs & technicians for many long hours and for sharing ideas.