Ocean and Coastal Acidification in the Mid-Atlantic: the What, the Why, & the Risks

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Hooked on Ocean Acidification Mini-Series: February 18, 2021
MACAN Efforts to Address Gaps

• 2019 Stakeholder Survey

Figure X. Map of locations where stakeholders fish commercially or recreationally, or have aquaculture operations in the Mid-Atlantic region.
MACAN Efforts to Address Gaps

- 2019 Stakeholder Survey
MACAN Efforts to Address Gaps

• 2019 Stakeholder Survey

Which Statement Best Describes Your Understanding of Coastal and/or Ocean Acidification?

- Aquaculture Industry
- Charter Boat Captains
- Commercial Finfishermen
- Commercial Shellfishermen
- Recreational Fishermen

Legend:
- Very Knowledgeable
- Somewhat Knowledgeable
- Not Very Knowledgeable
- I do not understand, but would like to learn more
- I do not understand
2019 Stakeholder Survey

Questions from Fishermen

- What are the effects of OA on shellfish? How will that impact the food web?
- What are the effects of OA on fish/fisheries? What’s the timeframe?
- Will impacts of OA be more severe in coastal regions vs. ocean waters?

“Does this mean that the ocean and the bay are becoming more acidic? What is the baseline for acidity? How do our activities affect the acidity?”
Earth’s Natural “Greenhouse Effect”

Global Carbon Cycle

- Gas Exchange Between Air and Ocean
- Net Accumulation in Ocean
- Photosynthesis
- Respiration
- Circulation
- Rivers and watersheds
Earth’s Enhanced “Greenhouse Effect”
Ocean Acidification

Driven by the ocean’s absorption of increasing atmospheric carbon dioxide (CO$_2$)
Increase in seawater $\text{CO}_2$:

- Increase in seawater carbonic acid, $\text{H}_2\text{CO}_3$
The chemistry of OA: carbonate chemistry

Increase in seawater CO₂:

• Increase in seawater carbonic acid, H₂CO₃
• Release of hydrogen, H⁺, ions into the seawater
• Decrease pH = increase ocean acidity

\[
\text{CO}_2(g) \rightarrow \text{CO}_2(aq) + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^- \rightarrow H^+ + CO_3^{2-}
\]

\[\uparrow \text{CO}_2, \quad \downarrow \text{pH}\]
Increase in seawater CO$_2$:

- Increase in seawater carbonic acid, H$_2$CO$_3$
- Release of hydrogen, H$^+$, ions into the seawater
- Decrease pH = increase ocean acidity
- Decrease in CO$_3^{2-}$ ions (buffering process)

↑CO$_2$, ↓pH
The chemistry of OA: carbonate chemistry

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CO$_2$(g)  \rightarrow  CO$_2$(aq) + H$_2$O  \rightarrow  H$_2$CO$_3$

Ca$^{2+}$ + CO$_3^{2-}$ \rightleftharpoons CaCO$_3$

(dissolution)  (calcification)

↑ CO$_2$,  ↓ pH
The chemistry of OA: carbonate chemistry

Increase in seawater CO$_2$:

• Increase in seawater carbonic acid, H$_2$CO$_3$
• Release of hydrogen, H$^+$, ions into the seawater
• Decrease pH = increase ocean acidity
• Decrease in CO$_3^{2-}$ ions (buffering process)
• Can impact calcification in organisms

\[ \text{Ca}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{CaCO}_3 \] (dissolution) \quad (\Omega < 1)

\[ \text{CaCO}_3 \rightleftharpoons \text{Ca}^{2+} + \text{CO}_3^{2-} \] (calcification) \quad (\Omega > 1)
Human-Driven Change

February 15, 2021

Last CO₂ reading: 416.06


http://keelingcurve.ucsd.edu/
February 15, 2021


CO₂ Concentration (ppm)

1750 1800 1850 1900 1950 2000

Last CO₂ reading: 416.06

http://keelingcurve.ucsd.edu/
Ocean acidification: The “Other” CO$_2$ Problem

CO$_2$ Time Series in the North Pacific

Data: Mauna Loa (ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt) ALOHA (http://hahana.soest.hawaii.edu/hot/hot-dogs/bestraction.html) ALOHA pH & pCO$_2$ are calculated at in-situ temperature from DIC & TA (measured from samples collected on Hawaii Ocean Times-series (HOT) cruises) using co2sys (Peltier, v25b06) with constants: Lueker et al. 2000, KSO4: Dickson, Total boron: Lee et al. 2010, & KF: seacarb
Ocean acidification: The “Other” CO₂ Problem

Atmospheric CO₂ has increased 40% since the 1800s
- Drop of 0.1 pH unit = 28% increase in ocean acidity
- Rate of change 10x faster than anything experienced over the past 50 million years
- Occurring globally
Ocean Acidification - Projections

- CO₂ is projected to double by 2100 (IPCC)
  - Additional drop of 0.2-0.3 pH units
  - Equivalent to 100-150% increase in ocean acidity

2014 IPCC Fifth Assessment Report (AR5)
Ocean Acidification Drivers in Mid-Atlantic

Wanninkhof et al. 2015
Ocean Acidification Drivers in Mid-Atlantic

Warm, salty, well buffered Gulf Stream

Cold, higher CO₂, weakly buffered Labrador Sea Slope Water

Wanninkhof et al. 2015
Drivers of Coastal Acidification

High variability and extremes in high CO\(_2\)/low pH due to a combination of natural and anthropogenic (human-caused) biogeochemical and physical processes.

NOAA Sea Grant
NJ Observations - Gliders

- Understand the baseline/climatology of OA conditions
- What are the seasonal conditions in known fisheries habitats?

Atlantic Surfclam
*Spisula solidissima*

Atlantic Sea Scallop
*Placopecten magellanicus*

Saba et al. 2019
Wright-Fairbanks et al. 2020
Long Island Sound Observations

L-to-R = West-to-East

Wallace et al. 2014
Gobler & Baumann 2016
Chesapeake Bay Observations

Cai et al. 2017
Observation Needs

- High sampling frequency
- Measurements of multiple carbonate chemistry parameters
- High-resolution depth-profiling measurements
- Monitor across a salinity gradient
- Observe OA with other stressors
- Co-located biological response monitoring

*Goldsmith et al., 2019*
Observation Needs

- High sampling frequency
- Measurements of multiple carbonate chemistry parameters
- High-resolution depth-profiling measurements
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- Observe OA with other stressors
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Mid-Atlantic would benefit from a comprehensive statewide monitoring network that can cohesively act to address observation needs

Goldsmith et al., 2019
QUESTIONS?
Acidification Impacts on Organisms

Kroeker et al. 2013
Acidification Impacts on Organisms

- Reproduction
- Olfactory
- Behavior
- Swimming ability
- Susceptibility to disease

AND......

- Biotic interactions
- Biodiversity
- Ecosystem
- Acclimation???
- Adaptation???

Kroeker et al. 2013
Acidification Impacts on Organisms

General Takeaways:

• Highly variable responses between species and even individuals
• Young life stages seem to be most susceptible
• Effects are typically subtle and even indirect
• Ocean acidification interacts with other stressors
• Food availability is very important to potential acclimation
Potential Impacts on Mid-Atlantic Species

*Saba et al. 2019: Estuarine, Coastal and Shelf Science*

Data compiled from a review of acidification and multi-stressor studies conducted on economically important groups and species in the Mid-Atlantic:

- 18 species comprising of crustaceans, mollusks, finfish and elasmobranchs (from 59 studies)
- Species managed by MAFMC, ASMFC, NEFMC, NOAA and/or States
- Wide range of response variables
Potential Impacts on Summer Flounder Larvae

Chambers et al. 2014

- At high CO$_2$/low pH:
  - Decreased embryo survival
  - Larvae at hatching were larger but had less energy reserves
  - Higher number and severity of tissue and organ malformations
Potential Impacts on Summer Flounder Juveniles

Davidson et al. 2016

Mean specific growth rates:
- Were lower after longer exposure in all treatment conditions
- Were lowest at extreme DO and pH, but driven more by DO
  - High mortality experienced at longer exposure to these extreme conditions

<table>
<thead>
<tr>
<th></th>
<th>Normoxic</th>
<th></th>
<th>Moderate DO</th>
<th></th>
<th>Extreme DO</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 0–10</td>
<td>Day 10–20</td>
<td>Day 0–10</td>
<td>Day 10–20</td>
<td>Day 0–10</td>
<td>Day 10–20</td>
</tr>
<tr>
<td>Static pH</td>
<td>4.12 (T1)</td>
<td>3.57 (T1)</td>
<td>2.87 (T3)</td>
<td>2.07 (T3)</td>
<td>3.27 (T1)</td>
<td>2.59 (T1)</td>
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<tr>
<td></td>
<td>3.15 (T2)</td>
<td>3.11 (T2)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>3.79 (T3)</td>
<td>3.67 (T3)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Moderate pH</td>
<td>3.72 (T1)</td>
<td>3.67 (T1)</td>
<td>3.48 (T2)</td>
<td>3.12 (T2)</td>
<td>2.25 (T1)</td>
<td>2.42 (T1)</td>
</tr>
<tr>
<td>Extreme pH</td>
<td>4.04 (T1)</td>
<td>2.97 (T1)</td>
<td>3.11 (T3)</td>
<td>2.09 (T3)</td>
<td>2.04 (T2)</td>
<td>2.26 (T2)</td>
</tr>
</tbody>
</table>
Potential Impacts on Striped Bass

Acidification effects on larval striped bass, *Morone saxatilis* in Chesapeake Bay tributaries: A review

Lenwood W. Hall Jr.

*Water, Air, and Soil Pollution* 35, 87–96(1987) | Cite this article

*Reductions in striped bass populations in the 70s/80s were linked to larval mortality from acidified conditions in tributaries of the Chesapeake Bay, but other stressors were also likely important.

*No effect of pH on survival of juvenile striped bass, even at extreme low levels of dissolved oxygen and pH*

Responses of juvenile Atlantic silverside, striped killifish, mummichog, and striped bass to acute hypoxia and acidification: Aquatic surface respiration and survival

Rachel L. Dixon, Paul A. Grecay, Timothy E. Targett

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

journal homepage: www.elsevier.com/locate/jembe
Significant Research Gaps

Of the 35 managed species in our region, 69% (24 species) have not yet been investigated for acidification impacts.

Saba et al. 2019
Estuarine, Coastal and Shelf Science

<table>
<thead>
<tr>
<th>Group</th>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molluscs</td>
<td>Atlantic surfclam(^a)</td>
<td><em>Spisula solidissima</em></td>
</tr>
<tr>
<td></td>
<td>Illex squid(^a)</td>
<td><em>Illex illecebrosus</em></td>
</tr>
<tr>
<td>Crustaceans</td>
<td>Atlantic deep-sea red crab(^c)</td>
<td><em>Chaceon quinquedens</em></td>
</tr>
<tr>
<td></td>
<td>Horseshoe crab(^b)</td>
<td><em>Limulus polyphemus</em></td>
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<tr>
<td></td>
<td>Jonah crab(^b)</td>
<td><em>Cancer borealis</em></td>
</tr>
<tr>
<td>Finishes</td>
<td>American eel(^b)</td>
<td><em>Anguilla rostrata</em></td>
</tr>
<tr>
<td></td>
<td>Atlantic croaker(^b)</td>
<td><em>Micropogonias undulatus</em></td>
</tr>
<tr>
<td></td>
<td>Atlantic mackerel(^a)</td>
<td><em>Scomber scombrus</em></td>
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<tr>
<td></td>
<td>Atlantic menhaden(^b)</td>
<td><em>Brevoortia tyrannus</em></td>
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<tr>
<td></td>
<td>Atlantic Sturgeon(^b)</td>
<td><em>Acipenser oxyrinchus</em></td>
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<tr>
<td></td>
<td>Black drum(^b)</td>
<td><em>Pogonias cromis</em></td>
</tr>
<tr>
<td></td>
<td>Black sea bass(^a,b)</td>
<td><em>Centropristis striata</em></td>
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<tr>
<td></td>
<td>Bluefish(^a,b)</td>
<td><em>Pomatomus saltatrix</em></td>
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<tr>
<td></td>
<td>Butterfish(^a)</td>
<td><em>Peprilus triacanthus</em></td>
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<td></td>
<td>Monkfish(^a)</td>
<td><em>Lophius americanus</em></td>
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<tr>
<td></td>
<td>Offshore hake(^c)</td>
<td><em>Merluccius albidos</em></td>
</tr>
<tr>
<td></td>
<td>Red hake(^c)</td>
<td><em>Urophycis chuss</em></td>
</tr>
<tr>
<td></td>
<td>River herring(^b)</td>
<td><em>Alosa pseudoharengus, Alosa aestivalis</em></td>
</tr>
<tr>
<td></td>
<td>Shad(^b)</td>
<td><em>Alosa sapidissima</em></td>
</tr>
<tr>
<td></td>
<td>Silver hake(^c)</td>
<td><em>Merluccius bilinearis</em></td>
</tr>
<tr>
<td></td>
<td>Spanish mackerel(^b)</td>
<td><em>Scomberomorus maculatus</em></td>
</tr>
<tr>
<td></td>
<td>Spot(^b)</td>
<td><em>Leiostomus xanthurus</em></td>
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<tr>
<td></td>
<td>Spotted seatrout(^b)</td>
<td><em>Cynoscion nebulosus</em></td>
</tr>
<tr>
<td></td>
<td>Tautog(^b)</td>
<td><em>Tautoga onitis</em></td>
</tr>
<tr>
<td></td>
<td>Golden tilefish(^a)</td>
<td><em>Lopholatilus chamaelonticeps</em></td>
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<tr>
<td></td>
<td>Blueline tilefish(^a)</td>
<td><em>Caulolatilus microps</em></td>
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<tr>
<td></td>
<td>Winter flounder(^b)</td>
<td><em>Pseudopleuronectes americanus</em></td>
</tr>
<tr>
<td>Elasmobranchs</td>
<td>Spiny dogfish(^a,b)</td>
<td><em>Squalus acantbias</em></td>
</tr>
<tr>
<td></td>
<td>Winter skate(^c)</td>
<td><em>Leucoraja ocellata</em></td>
</tr>
</tbody>
</table>
Additional and new studies focused on these important species are needed to investigate their responses to acidification and specifically include:

- The potential impacts to various life stages
- Acclimation and adaptation potential
- Potential thresholds of acidification
- Impacts on the food web, populations dynamics, and community structure

Investigate mitigation strategies for aquaculture facilities, hatcheries, nurseries, and impacted waterways

Connect organism and ecosystem responses to ecosystem services and the economy
High Regional Social Vulnerability

Ekstrom et al. 2015
The most commercially important shellfish species in New Jersey include the Atlantic sea scallop, Ocean quahog, Atlantic surfclam, blue crabs, and the eastern oyster. Commercially and recreationally important finfish in NJ include Atlantic mackerel, summer flounder, black sea bass, and squid.

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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</thead>
<tbody>
<tr>
<td>Total Revenue</td>
<td>$552,315,000</td>
<td>$510,297,000</td>
<td>$435,977,000</td>
<td>$476,778,000</td>
<td>$512,081,000</td>
</tr>
<tr>
<td>Finfish &amp; Other</td>
<td>$119,630,000</td>
<td>$130,357,000</td>
<td>$124,379,000</td>
<td>$119,146,000</td>
<td>$116,461,000</td>
</tr>
<tr>
<td>Shellfish</td>
<td>$432,685,000</td>
<td>$379,941,000</td>
<td>$311,598,000</td>
<td>$357,633,000</td>
<td>$395,620,000</td>
</tr>
</tbody>
</table>

**Total Landings Revenue in the Mid-Atlantic (National Marine Fisheries Service 2017)**

Marine resources in the Mid-Atlantic have ecological, economical, social, and cultural significance.

New Jersey’s commercial fishing industry is the fifth largest in the United States and provides more than 50,000 jobs.

Economic scenario analyses and vulnerability assessments starting to include acidification.
Industry Need Leads to Policy Actions

80% decrease in oyster production in 2008/2009 linked to ocean acidification
Industry Need Leads to Policy Actions

80% decrease in oyster production in 2008/2009 linked to ocean acidification

Ocean Acidification Blue Ribbon Panel

A panel of science and policy experts to address the effects of OA on WA’s shellfish resources

In March, Gov. Chris Gregoire convened an Ocean Acidification Blue Ribbon Panel, the first of its kind in the nation.

• Convened in 2012

• Identified 42 actions toward increasing “capacity to understand, reduce, remediate, and where possible adapt to the consequences of ocean acidification” – First state OA Action Plan

• Region-wide impact led to multi-state Pacific Coast Collaborative
Several other U.S. States Follow Suit

State Department of Environmental Conservation Releases Final Ocean Action Plan for New York
Plan introduces integrated, adaptive approach to managing, restoring, and protecting state's ocean resources

New Law Creating Ocean Acidification Task Force Leads The Nation

- Many states join OA Alliance (International Alliance to Combat OA)
- Bipartisan support for 4 OA bills currently in House committee
- Regional Acidification Networks established (e.g., MACAN)

U.S. Member States in the International OA Alliance
- California
- Hawaii
- Maine
- Maryland
- New York
- Oregon
- Virginia
- Washington
NJDEP Recognizes OA Risks

- Discussion of OA in their 2020 NJ Scientific Report on Climate Change

- In response to the 2020 NJ Global Warming Response Act 80x50 Report:
  - The New Jersey Office of Policy and Coastal Management in partnership with the Bureau of Climate Resilience Planning and the Bureau of Marine Water Monitoring within NJDEP seeks to plan a broader statewide initiative to incorporate science-informed policies and programs associated with OA nested within the agency’s overall climate change efforts.
How Can You Help?

Reduce nutrient runoff by decreasing fertilizer usage on lawns and gardens and adding native vegetative buffers.

Save electricity: Switch to LED light bulbs and use Energy Star devices and appliances.

Talk about it! Teach your friends and family about acidification and how they can help.

Take advantage of mass transit options in your area to decrease emissions.
Thanks!
saba@marine.rutgers.edu