Mid-Atlantic Coastal Acidification Network

MEETING SUMMARY: THE MID-ATLANTIC COASTAL ACIDIFICATION NETWORK (MACAN) STATE OF THE SCIENCE WORKSHOP

May 9, 2017

Annapolis, Maryland

BACKGROUND

The Mid-Atlantic Coastal Acidification Network (MACAN)[1] is a nexus of scientists, tribal, federal, and state agency representatives, resource managers, and affected industry partners who seek to coordinate and guide regional observing, research, and modeling of estuarine, coastal, and ocean acidification in the Mid-Atlantic. Co-led by the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS)[2] and the Mid-Atlantic Regional Council on the Ocean (MARCO)[3], MACAN works to develop a better understanding of the processes associated with estuarine, coastal, and ocean acidification, predict the consequences for marine resources, and devise local adaptation strategies that enable communities and industries to better prepare and adapt. MACAN also helps to fulfill the needs of other regional entities where objectives align, such as working with the Mid-Atlantic Regional Planning Body (Mid-A RPB)[4] to help fulfill their needs as laid out in the Mid-Atlantic Regional Ocean Action Plan, Healthy Ocean Ecosystem Action 3[5]. MACAN is guided by a Steering Committee comprised of individuals from MARCO and MARACOOS, as well as representatives from the Mid-A RPB and regional experts.

[1] http://midacan.org/about-us

[2] https://maracoos.org/

[3] http://midatlanticocean.org/

[4] https://www.boem.gov/Mid-Atlantic-Regional-Planning-Body/

[5] https://www.boem.gov/Mid-Atlantic-Regional-Ocean-Action-Plan/; see page 42

OVERVIEW AND MEETING OBJECTIVES

On May 9, 2017, MACAN convened a one-day workshop of network members including scientific experts, coastal managers, industry stakeholders, and others to discuss the state of the science and monitoring and research needs in the Mid-Atlantic region, from south of Long Island, New York down to and including Virginia. The meeting was held at the Crowne Plaza Hotel in Annapolis, Maryland. This workshop built off of an earlier 4-part webinar series[6] MACAN hosted from December 2016 through March 2017. Meeting objectives were:

- To determine key stakeholder concerns and needs regarding impacts to estuarine, coastal, and ocean species and ecosystems in the Mid-Atlantic.
- To initiate development of a comprehensive monitoring plan (e.g. location of sampling sites, timing/intervals, types of sampling, etc.), building off knowledge of monitoring that currently exists, to further understand estuarine, coastal, and ocean acidification and its impacts in the region.
- To develop an initial list of regionally relevant species that may be vulnerable to acidification.
- To begin to identify key research gaps to be pursued by MACAN and its partners.
- To identify additional information to be provided on the MACAN website.

Kaity Goldsmith[7] and Grace Saba[8], co-coordinators for MACAN, opened the meeting at approximately 10:00 AM with welcoming remarks and a thank you to NOAA Office for Coastal Management and NOAA Ocean Acidification Program for their funding support of MACAN, followed by an overview of objectives and the agenda for the day.

STATE OF THE SCIENCE PRESENTATION

DR. BETH PHELAN; HOWARD MARINE SCIENCES LAB, SANDY HOOK, NEW JERSEY, NORTHEAST FISHERIES SCIENCE CENTER, NMFS, NOAA

INTRODUCTION

The workshop discussions were grounded by a presentation provided by Dr. Beth Phelan on existing acidification science in the Mid-Atlantic. This state of the science presentation described ocean

[6] http://midacan.org/webinars

[7] Project Manager for the Mid-Atlantic Regional Council on the Ocean (MARCO)

[8] Assistant Professor at the Center for Ocean Observing Leadership in the Department of Marine and Coastal Sciences at Rutgers University and Ocean Acidification Innovation Lead for the Mid-Atlantic Regional Association Ocean Observing System (MARACOOS)

acidification as the changes in seawater chemistry in direct response to the uptake of excess atmospheric carbon dioxide (CO_2). Several research stations in the United States indicate a relationship between rising levels of atmospheric CO_2 and the rising seawater CO_2 levels. As a result, the ocean is acidifying at a more rapid pace than at any other time in the historical record.

PRIMER ON SEAWATER CHEMISTRY

Dr. Phelan provided a primer on basic seawater chemistry (Figure 1). Atmospheric carbon dioxide gas enters the ocean because there is more of it in the atmosphere than in the surface of the ocean. It then combines with water to form carbonic acid (H_2CO_3), which is only partly why it is called acidification. It also forms a series of acid-base products: bicarbonate (HCO_3^-) and free hydrogen ions (H^+), resulting in a lowering of pH values. The increased availability of H^+ allows it to quickly react with carbonate (CO_3^{2-}) to form bicarbonate, thus decreasing the amount of available carbonate ions in the water column. The end result is that carbonate and the pH both decrease, and the concentrations of pCO_2, partial pressure of carbon dioxide (the measure of CO_2 concentration in seawater), and bicarbonate increase. Carbonate is used by many organisms to form shells and skeletons by combining it with calcium to form calcium carbonate ($CaCO_3$). Thus, when the amount of available carbonate is reduced, so is the saturation state of calcium carbonate.

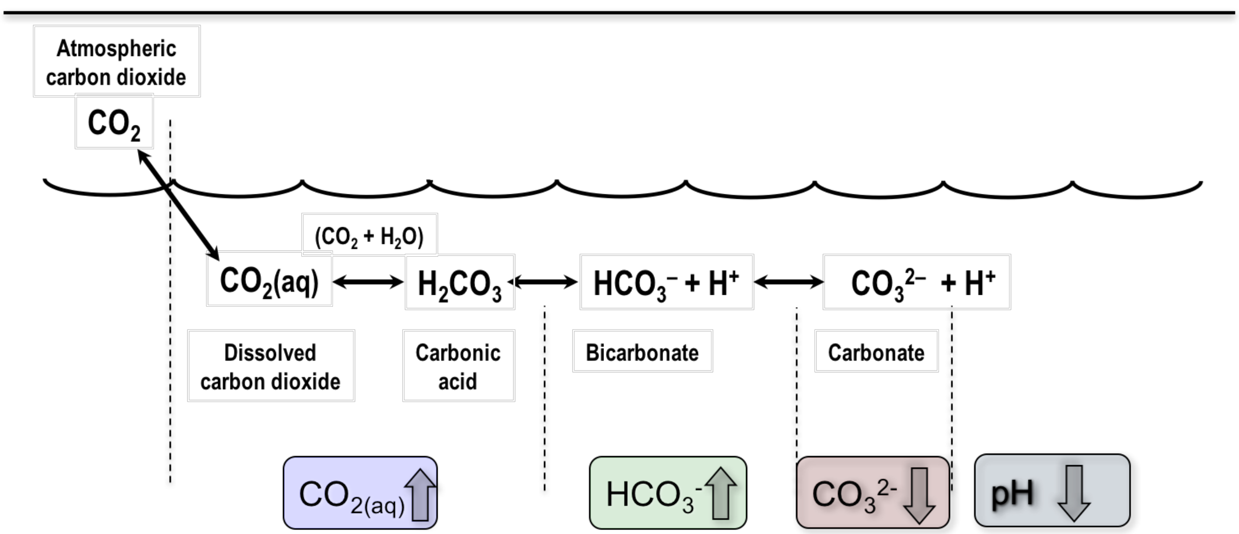

Figure 1: Graphical depiction of the chemical process of acidification.

These changes to ocean chemistry can be felt by a variety of organisms and can be exacerbated by other events and/or stressors such as upwelling events, local eutrophication (caused by runoff, erosion, and riverine inputs), low dissolved oxygen, and warm water temperatures. The Mid-Atlantic naturally has a wide range of pH conditions resulting from seasonal variability, with summer months tending to have lower pH values. Thus, questions remain regarding to what degree Mid-Atlantic species may be more naturally resilient to changing acidity than species endemic to other less variable geographies.

CASE STUDY

In recent years Mook Sea Farm in Walpole, Maine experienced difficulty with oyster larval production coinciding with runoff events. This difficulty included poor egg conversion, problems with early survival, cessation of feeding, poor growth, and a protracted larval phase. In April 2014, Mook Sea Farm partnered with researchers at University of New Hampshire to continuously monitor temperature, salinity, dissolved oxygen (DO), pCO_2, pH, alkalinity, and calcium carbonate saturation state (Omega). From those measurements, they developed a suite of management/mitigation tactics, with pCO_2 adjustments being a key mitigation factor. Changes applied to every spawn resulted in 100% spawning success in 2014 and 2015.

ECOLOGICAL IMPACTS

Impacts of acidification to organisms can be seen at various stages of life (including larval and juvenile) and to a variety of organismal biological and physiological processes (including growth, feeding, survival, etc.). Furthermore, research conducted by Chris Gobler, Professor at Stony Brook University, indicates that the impact of both high pCO_2 and low DO conditions on bivalves cause synergistic negative effects. Therefore, multiple stressors may have more severe impacts on organisms than one stressor alone. Dr. Phelan described a variety of research conducted on key Mid-Atlantic species and the findings, depicted in the table below:

Table 1: Summary of recent ecological research in the Mid-Atlantic region[9].

Organism	**Methods**	**Indicator Variable**	**Results**
Phytoplankton[10] (5 diatoms and 2 chlorophytes)	pCO_2 was manipulated to 4 levels	Growth rate	Mixed results: Specific growth rates at high pCO_2 were from 19 to 60% higher than in low pCO_2 treatments in 4 species and 44% lower

[9] Many ecological research projects presented contained unpublished work and have thus been redacted for the purposes of this summary.

[10] King AL, Jenkins BD, Wallace JR, Liu Y, Wikfors GH, Milke LM, Meseck SL (2015) Effects of CO2 on growth rate, C:N:P, and fatty acid composition of seven marine phytoplankton species. Mar Ecol Prog Ser 537:59-69. https://doi.org/10.3354/meps11458

			in 1 species; there was no significant change in 2 species. These species show relatively little sensitivity between present day CO_2 and predicted ocean acidification scenarios
Bay scallop, Hard clams, and Eastern oysters[11]	Fluctuating levels of pH and DO	Survival, growth, and development in the larval stage	Diurnal fluctuating periods of higher DO and pH do not provide a temporal refuge from hypoxia and acidification for larvae of bivalves

ONGOING RESEARCH PROJECTS

Dr. Phelan provided an overview for several ongoing research projects in the region. Below is a summary of those projects:

INTERACTIONS BETWEEN OCEAN ACIDIFICATION AND EUTROPHICATION IN ESTUARIES: MODELING OPPORTUNITIES AND LIMITATIONS FOR SHELLFISH RESTORATION[12]

The Chesapeake Bay is a large estuary with strong gradients and diversity of habitats. The oyster is an iconic species in the Chesapeake Bay, whose populations have been dramatically reduced, leading to substantial restoration activities. Because the carbonate system has not been well-characterized in the Chesapeake, the first goal of the project is to document the nature and variability of the carbonate system (accomplished in 2016). Because oysters play a role in the carbonate system, the project will measure carbonate system fluxes between intact oyster reefs and the overlying water under a variety of conditions. The project will then use those measurements of the water-column, sediments, and reefs to constrain numerical model simulations of the carbonate system in the Chesapeake Bay, using a coupled biogeochemical –hydrodynamic model. The project will use this model to explore the dynamics of the carbonate system at several space and time scales, and also quantify interactions between eutrophication and fossil acidification via a series of scenario simulations, altering nutrient inputs, temperature, and future atmospheric and oceanic pCO_2 concentrations. These simulations will be used to examine feedbacks between oyster reefs and eutrophication under fossil acidification, but also to

[11] Clark and Gobler, 2016; MEPS

[12] Jeremy Testa, University of Maryland Center for Environmental Science; Wei-Jun Cai, University of Delaware; Jeffrey Cornwell, W. Michael Kemp, and Ming Li, University of Maryland Center for Environmental Science; George Waldbusser, Oregon State University

quantify ecosystem services of oyster reefs and identify conditions and locations of potential restoration success.

PROBING MOLECULAR DETERMINANTS OF BIVALVE RESILIENCE TO OCEAN ACIDIFICATION[13]

Bivalves such as oysters and clams, represent the most important marine resource in several Atlantic states, and production of bivalve seed has recently suffered significant losses linked to ocean acidification in some of the largest hatcheries in the nation. Researchers will identify genetic features associated with resilience in an aim to provide the aquaculture industry with tools to select resilient shellfish stocks. Researchers will compare how acidification impacts the genetic variant and physiological assays (scope for growth, immunity, etc.) of hard clams, blue mussel, and eastern oysters. Preliminary results indicate marked impact of acidification on bivalve immunity and resistance to microbial infections.

FLEXING MUSSELS: DOES MYTILUS EDULIS HAVE THE CAPACITY TO OVERCOME EFFECTS OF OCEAN ACIDIFICATION?[14]

This research will assess acidification impacts in blue mussels. Researchers hope to determine cross generational adaption from multiple populations in Long Island Sound. Researchers will also determine tradeoffs in growth and development. The hope is that this work will help shellfish growers determine where to collect mussels to spawn for seed and improve stocks of mussels for aquaculture induced by ocean acidification in blue mussels.

SENSITIVITY OF LARVAL AND JUVENILE SAND LANCE AMMODYTES DUBIUS ON STELLWAGEN BANK TO PREDICTED OCEAN WARMING, ACIDIFICATION, AND DEOXYGENATION[15]

This research project will quantify the sensitivity of sand lance (*Ammodytes dubius*), a key forage fish, to the combined effects of a) temperature and pCO_2 and b) temperature, pCO_2, and DO. Researchers will measure growth and survival rates and swimming behavior.

GENETIC AND PHENOTYPIC RESPONSE OF LARVAL AMERICAN LOBSTER TO OCEAN WARMING AND ACIDIFICATION ACROSS NEW ENGLAND’S STEEP THERMAL GRADIENT[16]

---

[13] Bassem Allam, Emmanuelle Pales Espinosa; School of Marine and Atmospheric Sciences, Stony Brook University, NY

[14] Dianna K Padilla, Stony Brook University; Lisa Milke, Shannon Meseck, NOAA Northeast Fisheries Service, Milford Laboratory

[15] Hannes Baumann, University of Connecticut; David Wiley, Stellwagen Bank National Marine Sanctuary; Page Valentine, US Geological Survey; Les Kaufman, Boston University; Scott Gallager, Woods Hole Oceanographic Institution

[16] Richard Wahle, University of Maine; David Fields, Bigelow laboratory for Ocean Sciences; Spencer Greenwood, University of Prince Edward Island

Researchers will analyze the physiological (respiration rate) and behavioral (swimming, feeding) impacts of varying temperature and pCO_2 on the American lobster larvae. They will look at three subpopulations of lobster from Rhode Island, Southwest Maine, and Northwest Maine.

MODELING AND PREDICTION TOOLS

Modeling and prediction tools can help develop management decisions for commercial and/or recreational fishery species. In 2015, researchers at Woods Hole Oceanographic Institute developed *An Integrated Assessment Model for Helping the United States Sea Scallop (Placopecten magellanicus) Fishery Plan Ahead for Ocean Acidification and Warming*[17], which models environmental changes, scallop populations and economic conditions. The model numerically simulates oceanographic, population dynamic, and socioeconomic relationships for the U.S. commercial sea scallop fishery. The primary goal is to enrich resource management deliberations by offering both short- and long-term insight into the system and generating detailed policy-relevant information about the relative effects of ocean acidification, temperature rise, fishing pressure, and socioeconomic factors on the fishery using a simplified model system. Future work will explore different economic and management scenarios.

SUMMARY

In summary, Dr. Phelan explained that we know acidification is happening on the Atlantic U.S. Shelf at rates comparable to the global average, about a 30% increase in acidity since the Industrial Revolution[18]. This rate is unprecedented in earth's history. Many shell-forming marine organisms are very sensitive to changes in pH and carbonate ion concentrations, yet biological impacts to organisms will vary.

We do not yet know the effects of multiple stressors (OA compounded by temperature, reduced oxygen, nutrient enrichment, etc.). Differences between the coastal and open ocean system are also yet to be fully explored. We also do not fully understand the indirect effects of OA, such as impacts to predator-prey interactions or trophic pathways, that may alter food webs. Finally, the capacity for Mid-Atlantic species to acclimate or adapt to changing ocean conditions is unknown.

To answer the most pressing OA questions, researchers, resource managers, and stakeholders need to collaborate with each other. The region needs to observe/monitor and understand seasonal and regional variability to make reliable predictions of the impacts in the coastal and estuarine environments. Focused research is needed to examine multiple factors impacts on our resource species.

---

[17] https://www.coastalscience.noaa.gov/publications/detail?resource=tS8lY70Cufu49jN3DeTdYvSBhW7TOFctmP8Ik5DvBKw=

[18] Pacific Marine Environmental Laboratory. What is ocean acidification? *Retrieved from: https://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F*

BREAKOUT SESSIONS AND SUMMARY DISCUSSION

In order to facilitate discussions to address the workshop objectives, three breakout groups were organized. These included: 1) Monitoring Plan, 2) Research Gaps, and 3) Stakeholder Concerns and Needs. Each breakout group was led by a facilitator and had an assigned note taker, and each breakout discussion was directed by three guiding questions (see below). Three, 45-minute breakout sessions allowed for participants to attend all three breakout groups during the workshop. In addition to the three discussions for each breakout group, a 10-minute flash talk for each topic was presented to all participants during lunch. The flash presentation and discussions for each breakout group are summarized below.

TOPIC A: MONITORING PLAN

FLASH PRESENTATION: "MONITORING IN THE MID-ATLANTIC" DR. GRACE SABA, RUTGERS UNIVERSITY AND THE MID-ATLANTIC REGIONAL ASSOCIATION COASTAL OCEAN OBSERVING SYSTEM

Dr. Saba began by offering justification of why acidification should be monitored in the Mid-Atlantic. These reasons included the potential negative impact of acidification on several important commercial and recreational species and alterations of food webs and biogeochemical cycles. She also highlighted the need to better understand potential acclimation and adaptation strategies in organisms and how acidification interacts with other stressors relevant to the Mid-Atlantic region (temperature, dissolved oxygen, food availability, etc.).

She then presented the Mid-Atlantic Acidification Monitoring Map that was produced by MACAN to depict past, current, and ongoing acidification monitoring in the region. The monitoring map includes efforts from academic research, water quality monitoring for state natural resources, federal research, and monitoring by the commercial shellfish industry. The different types of sampling are differentiated by color and are referenced in a legend and include: 1) continuous monitoring (buoys, etc.), 2) research cruises, 3) ongoing fixed stations (sites sampled at regular intervals), and 4) former fixed stations (sites that were sampled historically). Additionally, the map is interactive – selecting a specific sampling location yields a pop-up box providing information on sampling entity, sample site name, a full list of all parameters measured, sampling timeframe, and a link to the data source (if available). Dr. Saba indicated that the monitoring map would be live for others to view on the MARCO Ocean Data Portal[19] shortly following the workshop.

[19] http://portal.midatlanticocean.org/

The production of this monitoring map was the first step in providing a detailed look at the spatial and temporal resolution of acidification monitoring in the Mid-Atlantic region and as such will allow for the identification of monitoring gaps. Grace Saba highlighted some of these gaps. First, with the exception of a few fixed autonomous stations, the sampling frequency throughout much of the region is too low to adequately capture short-term events such as the upwelling of low pH water near-shore. Second, even in cases where high-frequency observations are being recorded, often, only one acidification parameter such as pH is measured, which does not allow full characterization of acidification (including saturation states that can directly impact organisms that build calcified structures). This limits the utility of the data. And third, most sampling efforts are conducted in surface water which is problematic because it neglects subsurface waters that are typically more acidic due to the biological process of remineralizing sinking particulate organic surface material.

The intent of highlighting these gaps was to help guide the breakout discussions regarding how best to develop a Mid-Atlantic acidification monitoring plan, which Saba defined as "*A comprehensive network of monitoring that depicts estuarine, coastal, and ocean acidification across the Mid-Atlantic for management and research purposes*". Saba ended her presentation with a strategy to develop the monitoring plan: "Combine expertise from government, academia, and industry to aid in recommending regional priorities for specific sampling locations (important habitats, oceanographic features, upwelling, etc.), and appropriate type of sample collection and sampling frequency".

SYNOPSIS OF BREAKOUT DISCUSSIONS

The three Monitoring Plan breakout sessions were facilitated by Shep Moon, Coastal Planner at the Virginia Coastal Zone Management Program. Sarah Wilkins, Coordinator for the Chesapeake Bay Sentinel Site Cooperative, University of Maryland Sea Grant Extension, was the note taker.

Each Monitoring Plan breakout session started by giving the participants the opportunity to provide feedback on the Acidification Monitoring Map[20] that was presented during Grace Saba's flash talk. In general, the map was well-received and the participants expressed how helpful the map is in both identifying monitoring gaps and identifying ideal well-sampled locations that could be targeted for integrating additional sensors for more comprehensive sampling of carbonate chemistry parameters as well as others to look at multi-stressors. Suggestions for improvements to the map were to: 1) Increase map user interface and the ability to turn on or off layers; 2) Categorize source of data (e.g. industry, government, academic); 3) Include quality assurance/quality control (QA/QC) transparency; 4) Include pH scale in the metadata. Additionally, a few more sites were brought to the coordinators' attention to include in the next map update.

---

[20] This map posted under the Oceanography theme on the MARCO Ocean Data Portal Marine Planner (http://portal.midatlanticocean.org/visualize). This map is regularly updated as additional information about monitoring sites continued to emerge and develop.

The remainder of the discussion was guided by the following questions:

- What makes for a robust monitoring network in the region?
- What are major gaps in the current monitoring (including locations of sampling sites, timing/intervals, types of sampling, etc.)?
- Given limited resources, where and how should we focus monitoring priorities?

There was consensus that a robust monitoring network must:

- target areas of high impact in both estuarine and ocean shelf systems,
- sample using high quality calibrated sensor systems,
- include measurements of multiple carbonate chemistry parameters (at least 2)
- consider other water quality measurements for multiple stressors including dissolved oxygen, temperature, and dissolved nutrients,
- and incorporate data-assimilative modeling with predictive capabilities.

High impact areas were defined as those that contain high populations of ecologically and/or economically important species (e.g., oyster restoration areas), occur in areas that promote acidification events and where acidification is occurring most frequently and rapidly (locations prone to eutrophication, freshwater inputs, coastal upwelling), are impacted by additional stressors (e.g., locations with frequent low dissolved oxygen events), and/or are locations where society may be most vulnerable to acidification impacts. Adding additional monitoring sites for increased spatial coverage may not be the best approach. Instead, targeted sampling in identified high impact areas will result in a comprehensive, high quality, cost-effective monitoring network. This approach will provide high-resolution temporal sampling to better understand daily, seasonal, and inter-annual variability as well as long-term change in carbonate chemistry while still allowing comparisons between estuarine and ocean shelf systems. These data can then be incorporated into models with capabilities to perform regional hindcasts and projections.

Current gaps in Mid-Atlantic acidification monitoring were discussed. Many of the gaps identified were similar to those presented by Grace Saba in the flash presentation. First, many study sites identified in the Mid-Atlantic measure only one carbonate chemistry parameter, typically pH, and this is not sufficient to characterize the full carbonate system. Second, the sampling frequency of most current monitoring sites is too low to provide much understanding of carbonate chemistry dynamics and variability. And third, the lack of subsurface or bottom measurements of carbonate chemistry prevents us from knowing whether acidification is occurring at a given location and the extent to which it is occurring. Several other monitoring gaps were acknowledged during the discussions. The process of ocean acidification is much better understood compared to those dynamics in estuarine systems due to lack of comprehensive estuarine monitoring - a problem that is extremely relevant to the Mid-Atlantic because its developed coastal counties drain nutrients and other materials through the region's rivers into several major estuarine systems causing coastal and estuarine processes that can exacerbate ocean acidification. Additionally, the issue of multi-stressors in our region is recognized due to warming water temperatures and locations with recurrent eutrophication, coastal upwelling, and/or low dissolved oxygen. Yet we lack monitoring sites that are equipped to measure for multiple parameters to understand links between acidification and these other stressors, and this needs to be addressed in the monitoring plan. Furthermore, there is a need to better coordinate communication between research and industry (e.g., commercial fisheries) communities and collaboration to develop and/or maintain monitoring sites and perform QA/QC at willingly participating commercial facilities (e.g., at hatcheries). Finally, there is a need for a comprehensive analysis of historical acidification data for a more thorough understanding of the current acidification problem in our region. The results would provide the background necessary to identify additional monitoring gaps.

Many attendees expressed that the monitoring plan should ensure that monitoring is done for a purpose that connects to priority research and management questions. In doing so, target locations should be identified (oyster restoration areas, local amplifiers, or low DO regions as a few examples) and measurements with a full suite of parameters (at least 2 carbonate chemistry, temperature, DO, nutrients, etc.) should be conducted to examine coupling and multi-stressors impacts. Given limited resources, the developed monitoring plan should consider cost-effective approaches. In addition to building observatories on targeted sites, this also includes adding new sensors to existing platforms (e.g., moored buoys) and adding parameters to sample at ongoing fixed stations. These approaches will require significant coordination and communication within the research and natural resource communities and between them and the funding agencies. Additionally, the regional acidification community would benefit from partnerships between researchers and industry/citizen science to increase opportunistic sampling. No matter what the sampling approach, there is an overwhelming need for data QA/QC consistency and transparency to ensure that each site's acidification information is robust and can be used for inter-site comparisons and data-assimilative models. A guide to best practices for acidification sampling should be shared within the community and followed to ensure data consistency.

MACAN's plan for a robust monitoring network must:

- Target areas of high impact in both estuarine and ocean shelf systems,
- Sample using high quality calibrated sensor systems,
- Include measurements of multiple carbonate chemistry parameters (at least 2)
- Consider other water quality measurements for multiple stressors including dissolved oxygen, temperature, and dissolved nutrients, and
- Incorporate data-assimilative modeling with predictive capabilities.

TOPIC B: RESEARCH GAPS

FLASH PRESENTATION: "ECOLOGICAL RESEARCH GAPS ASSOCIATED WITH COASTAL ACIDIFICATION", DR. WHITMAN MILLER, SMITHSONIAN ENVIRONMENTAL RESEARCH CENTER

Dr. Miller began by explaining the reasons why coastal waters and estuaries are especially sensitive to the impacts of acidification. These systems are shallow and experience rapid temperature changes and high biological activity that strongly influence pCO_2 and pH (e.g., photosynthesis, benthic respiration, root respiration in tidal marshes). They also have dynamic and complex carbon dynamics which makes predicting chemical changes in coastal ecosystems more complicated than current air-sea equilibrium ocean acidification models, and have lower salinity that decreases the buffering capacity making coastal waters less resistant to pH change. Yet ecological effects of coastal acidification are not well understood. He identified several important habitat types in the Mid-Atlantic coastal region including oyster bars, seagrass meadows, tidal saltmarshes, hard and soft bottom benthos, and the water column.

There are an increasing number of studies looking at species-specific impacts of acidification, including some examining impacts on multiple life stages and/or multi-stressors. However, Dr. Miller expressed the need for more focused ecosystem-based studies because ecological balances may shift under acidification. These include changes in species interactions such as predator-prey interactions, competition for space and resources, and host/parasite interactions. Additionally, acidification may impact marine disease and invasive species dynamics. Shifts in ecological balance can alter entire food webs and ecosystems.

He emphasized that there is a clear linkage between research gaps and monitoring needs in order to understand current carbonate chemistry dynamics in coastal ecosystems and estuaries, how these will change in a future, higher CO_2 world, and how individual species, communities of species, and habitats will be affected by ongoing acidification. He described a pathway forward for monitoring and research to address these issues beginning with increasing both monitoring, for acidification but also for biota, as well as experimental studies to understand how variability and changes in carbonate chemistry will affect coastal biota and coastal ecology. If we can understand current dynamics and relationships, we can begin to build models that better predict the future of coastal ecosystems. This information will support better management decisions now and in the future.

SYNOPSIS OF BREAKOUT DISCUSSIONS

The three Research Gaps breakout sessions were facilitated by Sheryll Jones from the New York State Department of Environmental Conservation. Kim Hernandez of the Maryland Department of Natural Resources was the note taker.

The discussion was guided by the following questions:

- What species in the Mid-Atlantic are particularly vulnerable to acidification?

- Of those species, are there ones that are economically or culturally of particular importance to the region?
- Are there economically or culturally important species in the Mid-Atlantic which currently lack critical information regarding the impacts of acidification?

While the first guiding question targeted vulnerable "species" in the Mid-Atlantic, much of the conversation addressed the potential vulnerability of major taxa as well. Calcifying organisms were identified as a potentially vulnerable group and these included oysters, hard clams, sea scallops, bay scallops, ribbed mussels, and deep sea corals. Some crustaceans (blue crabs, horseshoe crabs, Jonah crab, Atlantic deep sea red crab, lobsters), finfish (striped bass, menhaden, flounder), mollusks (squid), and seagrasses were included in the discussion based on recent research findings and their ecological and economical importance. There was recognition that existing ecological impacts research needs to be synthesized better to identify likely gaps at both the species and ecosystem level.

The definition of "important" with respect to species was discussed: what makes an organism important in the Mid-Atlantic? Here, importance was further described as ecologically and/or economically important. The groups identified deep sea corals, ribbed mussels, and horseshoe crabs as ecologically important species in the Mid-Atlantic. However, food sources of potentially impacted species should be recognized as ecologically important as well, and thus need to be considered in future research, specifically ecosystem-based research. The groups agreed that economically important species include those that are commercially or recreationally fished, such as oysters, clams, scallops, and fish managed by the Mid-Atlantic Fisheries Management Council (MAFMC) and/or the Atlantic States Marine Fisheries Commission (ASMFC). Oysters are a high-priority target due to economic, cultural, and historical importance. Blue crabs and clams have high historical relevance in the region. Sea scallops are economically important, while bay scallops in Virginia have been targeted for restoration efforts. Ribbed mussels are currently being cultivated for use in living shorelines in Delaware. Horseshoe crabs are ecologically important because they are a food source for migratory shorebirds.

The discussion on research gaps focused not only on single species responses, but also on multi-stressors, food webs/ecosystems, and research approaches. Single-species highlighted as priorities for research to understand vulnerability to acidification include MAFMC-managed species (summer flounder, scup, black sea bass, mackerel, squid, butterfish, bluefish, tilefish, monkfish, spiny dogfish, surfclams, and ocean quahogs), ASMFC-managed species (American eel, American lobster, Atlantic croaker, Atlantic herring, Atlantic menhaden, Atlantic striped bass, Atlantic sturgeon, black and red drum, black sea bass, bluefish, coastal sharks, horseshoe crab, Jonah crab, northern shrimp, scup, shad and river herring, Spanish mackerel, spiny dogfish, spot, spotted seatrout, summer and winter flounder, tautog, and weakfish), other commercially important fisheries (oysters, sea scallops, blue crabs, Jonah crab, Atlantic deep sea red crab), ecologically important species (deep sea corals, ribbed mussels, horseshoe crabs), marine mammals and sea turtles, and migratory species. There was much discussion on the need to better understand the vulnerability, tolerance, resilience, and adaptation potential of diadromous species that migrate between the ocean and estuaries as part of their life histories due to the range of environmental conditions they encounter. Additionally, research on populations of a species utilizing different areas would be helpful to understand resilience and answer local adaptation questions. Some attendees also suggested identifying a Mid-Atlantic species that would be representative of the impacts of acidification in the region as a whole, a "mascot" species.

While there is a need to fill in knowledge gaps of acidification impacts on important species, there was recognition that acidification does not directly impact all organisms. Instead, impacts of acidification on food sources or predators can indirectly impact a specific species, a specific life stage of an organism, and impact populations. Biodiversity could also be affected by acidification. This was justification to indicate that ecosystem-focused studies on acidification impacts are a necessity in order to understand how the interconnectedness of the system and biodiversity may be affected. Future single species and ecosystem studies need not only to address responses and vulnerability to acidification, but also responses to multi-stressors, and acclimation and adaptation capacities and strategies in order to better understand how acidification will impact the Mid-Atlantic coastal system.

In identifying research priorities MACAN must:

- First develop a synthesis of existing data on acidification impacts,
- Consider ecologically important species managed by the MAFMC or ASMFC,
- Consider potential ecosystem impacts,
- Consider impacts from multi-stressors,
- Consider transferability of research, and
- Consider proxies.

Research approaches should consider connectivity to ecosystem services. Additionally, experiments should be designed to 1) mimic real-world variability and gradients in order to be applied to the larger system; 2) increase transferability of results to other systems or organisms, for example, experiments designed to understand mechanisms underpinning biological responses; and 3) look at proxies that tell us about the expectation of groups of species/organisms/ecosystems.

TOPIC C: STAKEHOLDER CONCERNS AND NEEDS

FLASH PRESENTATION: "STAKEHOLDER NEEDS AND CONCERNS" BY DANIEL J. GROSSE[21], PARTNER AND CO-FOUNDER OF TOBY ISLAND BAY OYSTER FARM IN CHINCOTEAGUE ISLAND, VA

[21] Mr. Grosse is also president and co-founder of TerrAqua Environmental Science and Policy, LLC (terraqua.org), an environmental consulting company; adjunct professor at the University of Maryland University College Graduate Program in Environmental Management (umuc.edu/academic-programs/masters-degrees/environmental-management.cfm); and senior associate at Ocean Associates, Inc. (oceanassoc.com). Dan is also the president of the East Coast Shellfish Growers Association, and currently sells oysters and clams throughout the Washington D.C. region.

Mr. Grosse discussed needs and concerns of oyster hatcheries of the Mid-Atlantic as they relate to increasingly acidic conditions. He explained that oyster numbers plummeted over the past century due to overharvesting, habitat destruction, and disease. Oyster production is now bouncing back, growing 5-10% per year, through farming and restoration efforts, and harvests are now > 150 million per year. However, after news of devastating losses at hatcheries on the Pacific Coast and poor oyster seed growth at Mook Sea Farm on the East Coast (Maine), there are growing concerns in the shellfish industry about acidification impacts. There is particular concern in the Mid-Atlantic community because there are several sources of increased acidity in prime oyster habitats including eutrophication-induced acidity, riverine input, and nearshore upwelling of acidic deep water. Because most negative impacts from acidification tend to occur in the oyster's young life stages, hatcheries would likely be most directly impacted. However, those companies that run nurseries and grow-out operations will also be severely impacted if seed oyster sources are endangered.

While there is concern for the industry and the jobs it supplies, there is also hope for adaptation and mitigation strategies that have already begun to show success on both the West and East coasts of the U.S. Hatcheries have the advantage of mitigating acidification by monitoring incoming source water and adjusting water chemistry prior to contact with oyster larvae and seed. On the East Coast, acidification monitoring has been established at Mook Sea Farm as well as several Virginia hatcheries. These monitoring efforts are a result of partnerships between industry and academia (Mook Sea Farm with University of New Hampshire; Virginia hatcheries with VIMS and Virginia Tech). Since the start of monitoring in 2014, there has been 100% spawning success at Mook Sea Farm.

Communication between industry representatives on the West and East coasts has proved successful for the development of monitoring systems and mitigation strategies now being implemented by some Mid-Atlantic oyster farming operations. A continued open line of communication is necessary to maintain and improve national oyster operations. Additionally, continued partnerships between industry and research communities are needed to improve coordination of both short-term and long-term data collection at hatcheries. Dan expressed that these partnerships are essential because the growers cannot collect all the necessary data and do not have the expertise to interpret the data, especially on the time scales needed for successful mitigation. Furthermore, more research is needed in order to better understand how acidification will affect different species and to develop potential mitigation strategies and cost-effective monitoring equipment. There is a recognition that oysters have adaptive capabilities, as they have evolved in highly variable estuarine conditions, and research should focus on identifying these capabilities to shed light on the potential for genetic-based breeding programs for acidification tolerant oysters. Finally, he called for increased education about acidification to the general public and the government in order to support the shellfish industry.

SYNOPSIS OF BREAKOUT DISCUSSIONS

The three Research Gaps breakout sessions were facilitated by Sherilyn Lau at the Environmental Protection Agency. Katie Liming with MARCOOS was the note taker.

The discussion was guided by the following questions:

- What are major concerns regarding the impacts of acidification on species and ecology in the Mid-Atlantic?
- Are people aware of possible mitigation or adaptation ideas to prevent the most negative impacts of acidification?
- What would be helpful to your industry in addressing your concerns regarding acidification and its impacts?

Stakeholders (including commercial fishing [blue crab, striped bass, summer flounder], aquaculture [oyster], natural resource managers, ecological restoration groups, recreational users, potentially the shipping and boating industry, etc.) share many of the same concerns of acidification researchers. Ecosystem services, shoreline protection, food web dynamics, water quality/filtration all have the potential to be impacted by acidification. The lack of knowledge of carbonate chemistry dynamics in coastal systems as well as species-specific and ecosystem-level responses to acidification and multi-stressors is most concerning. For aquaculture, the lack of low-cost sensors and the spatial diversity of operation locations, from different tributaries to the mainstem of estuarine systems with highly variable properties, make comprehensive monitoring challenging. This variability, both spatially and on multiple timescales, makes understanding dynamics at each location necessary, not just for commercial operation sites but also locations where restoration efforts are underway or planned. Although there have been significant recent investments into acidification research, there is still a lack of understanding of organisms' thresholds, tolerance, and resilience to acidification to, for example, be able to predict if self-sustaining oyster reefs are conceivable. Some important organisms, such as the horseshoe crab which is a keystone species in Delaware Bay, have thus far been neglected in acidification research. The shellfish industry is most concerned with oyster seed stocks because of the known impacts of acidification on oyster larval, settlement, and initial shell-building life stages. Additionally, there may be some organisms that can tolerate acidification. However, with adaptation, organisms may need to make energetically costly physiological adjustments that may impact other important factors such as reproduction rates, fat content, and meat content – all of which could negatively impact industry.

The workshop attendees identified several potential mitigation/adaptation strategies for prevention or relief of negative acidification impacts. First, there has been success at hatcheries monitoring and buffering source water for the most vulnerable early developmental stages of oysters. These efforts require robust monitoring and rapid response for mitigation. Second, using seagrasses (East coast) or kelp (West coast) for mitigation are promising in that the algae will remove excess pCO_2 and nutrients. However, complications can arise from this technique in that the oyster harvesting process can damage or destroy seagrasses, making this strategy unsustainable in locations where oyster harvesting takes place. However, there may be opportunities to use a patchwork design to incorporate both mitigation techniques. Third, efforts to reduce other stressors such as stormwater runoff or total maximum daily loads that can reduce buffering capacity or lead to eutrophication-induced acidification, respectively, should also be considered. Developing green infrastructure (living shorelines) to decrease nutrient loading/increase DO/buffer waters would also alleviate these other stressors. Fourth, establishing selective breeding techniques to increase resistance to fluctuations in carbonate chemistry is currently being done on the West coast and may prove successful. However, this can take several decades before it's effective. Lastly, on a global scale, new policies are needed to curb carbon emissions. There was recognition that there needs to be more research focused on mitigation/adaptation options, and that using several different approaches would be beneficial.

Stakeholders expressed the need for 1) Targeted education and outreach to various stakeholders, 2) Cost-effective monitoring approaches, and 3) Partnerships with the research community for monitoring, data QA/QC, and determining thresholds and adaptation potential for organisms. Acidification is not well understood by many stakeholders at the moment, partially due to a need for communication of what the research community knows about acidification. There is a need to synthesize existing knowledge and translate it to stakeholders to include a description of carbonate chemistry and acidification processes, what scientists already know about acidification, predictions for how conditions will change in future, and potential impacts to the economy. Stakeholders also need to be engaged in monitoring protocols and considerations for mitigation/adaptation/policy/management strategies. Cost-effective monitoring is necessary because of the high number of and high variability between industry operation locations. Instruments need to be inexpensive, but also easy to operate, capable of measuring carbon chemistry in real-time at short time intervals (hourly), and be able to provide robust data at low salinities. Research-industry partnerships will boost efforts for monitoring, enhance data quality, increase understanding of carbonate chemistry dynamics and organism response to prioritize acidification impacts, and help to create consensus of low risk-high impact scenarios and estimate costs to fishing/aquaculture for mitigation/adaptation techniques. The research community expressed great interest in the opportunity to better engage decision makers through the voices of industry partners who support additional research. Insight gained during these breakouts is important to consider in developing a monitoring plan and research priorities for the Mid-Atlantic region.

Stakeholders expressed interest in understanding:

- The impacts of acidification on ecosystem services,
- How multiple stressors will impact ecosystems,
- Organismal thresholds, tolerance, and resilience to acidification,
- Developing local mitigation and adaptation techniques, and
- Developing cost effective monitoring technologies.

WEBSITE DISCUSSION

The MACAN website, MidACAN.org, was launched prior to the workshop with an initial four webpages, *Home*[22], *About Us*[23], *Overview*[24], and *Resources*[25]. Workshop attendees viewed these four pages and then provided feedback. Some suggestions for the website included:

- An additional webpage geared towards possible actions individuals can take to combat acidification.
- Highlighting people or projects with short rotating spotlight profiles.
- A description of the variety of partners included in the network and/or a list of institutions and research consortiums engaged in acidification work.
- A description of parameters that are important measurements for acidification.

Attendees were urged to tell MACAN co-coordinators about research and events as they become available to the public.

NEXT STEPS

The MACAN co-coordinators concluded the meeting with some highlights of next steps including:

1) The need to advance the current monitoring map[26] and develop a monitoring plan based on discussions during the workshop,
2) Development of MACAN research priorities based on discussions during the workshop,
3) Continued coordination of acidification research, outreach, and education in the Mid-Atlantic through MACAN.

The meeting adjourned at approximately 4:45PM.

---

[22] http://midacan.org

[23] http://midacan.org/about-us

[24] http://midacan.org/overview

[25] http://midacan.org/resources

[26] http://portal.midatlanticocean.org/visualize/#x=-73.24&y=38.93&z=7&logo=true&controls=true&dls%5B%5D=false&dls%5B%5D=1&dls%5B%5D=516&basemap=Ocean&themes%5Bids%5D%5B%5D=14&tab=data&legends=false&layers=true

APPENDIX A: WORKSHOP AGENDA

MAY 9TH, 2017 10:00AM-5:00PM
CROWNE PLAZA ANNAPOLIS
173 JENNIFER RD., ANNAPOLIS, MD 21401

OBJECTIVES

- To determine key stakeholder concerns and needs regarding impacts to estuarine, coastal, and ocean species and ecosystems in the Mid-Atlantic.
- To initiate development of a comprehensive monitoring plan (e.g. location of sampling sites, timing/intervals, types of sampling, etc.), building off knowledge of monitoring that currently exists, to further understand estuarine, coastal, and ocean acidification and its impacts in the region.
- To develop an initial list of regionally relevant species that may be vulnerable to acidification.
- To begin to identify key research gaps to be pursued by MACAN and its partners.
- To identify additional information to be provided on the MACAN website.

AGENDA

9:30-10:00AM	Coffee and Registration
10:00-10:15AM	Welcome and Introduction to MACAN
10:15-10:45AM	State of the Science in the Mid-Atlantic: *Dr. Beth Phelan, Fisheries Ecologist, Northeast Fisheries Science Center*
10:45-11:00AM	Explain Breakout Sessions
11:00-11:15AM	Break and relocate to breakout session
11:15-12:00PM	Breakout Session 1 *(choose 1)* Group A: Monitoring plan* / Group B: Ecological research gaps** / Group C: Stakeholder concerns and needs***
12:00-1:00PM	Lunch and Flash Presentations *Presentation A Monitoring in the Mid-Atlantic: Dr. Grace Saba, MARACOOS/Rutgers University* *Presentation B Ecological research gaps: Dr. Whitman Miller, Smithsonian Environmental Research Center*

	Presentation C Stakeholder concerns and needs: Daniel Grosse, Toby Island Bay Oyster Farm, LLC
1:00-1:45PM	Breakout Session 2 (*choose 1)*

Group A: Monitoring plan*	Group B: Ecological research gaps**	Group C: Stakeholder concerns and needs***

1:45-2:30PM	Breakout Session 3 (*choose 1)*

Group A: Monitoring plan*	Group B: Ecological research gaps**	Group C: Stakeholder concerns and needs***

2:30-2:45PM	Break
2:45-3:15PM	Summary and Discussion – Breakout Group A: Monitoring plan
3:15-3:45PM	Summary and Discussion – Breakout Group B: Ecological research gaps
3:45-4:15PM	Summary and Discussion – Breakout Group C: Stakeholder concerns and needs
4:15-4:45PM	MidACan.org website discussion
4:45-5:00PM	Next steps and closing remarks

**Facilitator Shep Moon, Coastal Planner, Virginia Coastal Program, Virginia Department of Environmental Quality*
***Facilitator Sheryll Jones, New York State Department of Environmental Conservation*
****Facilitator Sherilyn Lau, Environmental Protection Agency*

APPENDIX B: ATTENDEE AFFILIATIONS

MACAN Workshop Attendee Affiliations
Chesapeake Bay Foundation
Chesapeake Bay Program
Chesapeake Bay Sentinel Site Cooperative
Delaware National Estuarine Research Reserve
Maryland Department of Natural Resources
Maryland Sea Grant
Mid-Atlantic Fisheries Management Council
Mid-Atlantic Regional Association Coastal and Ocean Observing System
Mid-Atlantic Regional Council on the Ocean
Monmouth University
New Jersey Department of Environmental Protection
New Jersey Sea Grant
New York Department of Environmental Conservation
NOAA Chesapeake Bay Office
NOAA National Sea Grant College Program
NOAA Northeast Fisheries Science Center
NOAA Ocean Acidification Program
NOAA Office for Coastal Management
Oyster Recovery Partnership
Rutgers University
Smithsonian Environmental Research Center
The Ocean Conservancy
Toby Island Bay Oyster Farm
U.S. Environmental Protection Agency
U.S. Integrated Ocean Observing System
University of Delaware
University of Maryland Center for Environmental Science
Virginia Department of Environmental Quality
Virginia Institute of Marine Science