Mid-Atlantic Coastal Acidification Network

WORKSHOP SUMMARY: FILLING GAPS AND IDENTIFYING DECISION POINTS

May 13, 2019
Baltimore, 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 is guided by a Steering Committee comprised of individuals from a wide range of expertise, affiliation, and location within the Mid-Atlantic region.

OVERVIEW AND MEETING OBJECTIVES

On May 13, 2019, MACAN convened a one-day workshop of network members including scientific experts, coastal managers, industry stakeholders, and others to discuss gap-filling strategies for monitoring, research, and stakeholder outreach needs in the Mid-Atlantic region, from south of Long Island, New York down to and including Virginia (see Appendices A and B). The meeting was held at the Sheraton Inner Harbor Hotel in Baltimore, Maryland. Meeting objectives included:

- Identify stakeholder concerns and associated information needs
- Prioritize a plan for working through gaps identified in each white paper
- Provide an update on the Industry Stakeholder Outreach Survey
- Map out various areas currently being worked by members to identify potential collaborations and opportunities to fill knowledge gaps.

[1] http://midacan.org/about-us
[2] https://maracoos.org/
[3] http://midatlanticocean.org/

INTRODUCTORY REMARKS
DR. GRACE SABA[4], CO-COORDINATOR FOR MACAN

ACKNOWLEDGEMENTS

Grace Saba 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, MARCO for funding support of the workshop and supplemental funding support for the MARCO-MACAN co-coordinator, and MARACOOS for supplemental funding support for the MACAN outreach coordinator, Kirstin Wakefield.

Acknowledgements were also given to Kaitlin Goldsmith, formerly with MARCO and previous MACAN co-coordinator, who recently transitioned into another career position. She, along with Grace Saba, was integral in the initiation and development of MACAN and its recent successes.

Kari St.Laurent, research coordinator and environmental scientist at Delaware Department of natural resources and environmental control, was thanked for graciously stepping in as interim MACAN co-coordinator after Kaitlin Goldsmith moved on.

Grace also thanked Kirstin Wakefield, the MACAN outreach coordinator with MARACOOS, for leading the recent outreach efforts as well as Anthony Himes, a graduate student at VIMS and a NOAA Ocean Acidification Program/Sea Grant Mid-Atlantic Ocean Acidification Fellow, who as part of his project is assisting with MACAN efforts, specifically the outreach efforts with Kirstin Wakefield.

Finally, acknowledgements were given to both Judy Tucker, Finance and Administration Manager at MARCO, and Katie Liming, who holds joint position as Program Assistant at MARACOOS and Program Coordinator at IOOS, for assisting with the workshop logistics.

SUMMARY OF RECENT MACAN ACTIVITIES

Grace Saba outlined the goals from the previous and first in-person MACAN workshop, hosted on May 9, 2017 in Annapolis, Maryland. These goals were:

- 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 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 determine key stakeholder concerns and needs regarding impacts to estuarine, coastal, and ocean species and ecosystems in the Mid-Atlantic.

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[4] 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)

- To identify additional information to be provided on the MACAN website.

Those goals, the feedback gained, and the connections established during that first workshop have driven the major tasks MACAN has focused on in the past two years. These tasks, and the progress made on each, was presented and included the:

I. Development of a working group focused on ecological research needs

This group, led by Grace Saba, worked to identify research gaps in the understanding of regional acidification impacts that will be used as a framework for researchers to focus future efforts. During these efforts, the group members first conducted a synthesis whereby data was compiled from a review of acidification and multi-stressor studies conducted on economically important groups and species in the Mid-Atlantic. From this synthesis, significant research gaps were observed and priorities were determined. The major takeaways include the following (but recommended priorities are described in more detail in the breakout group section below):

- Research gaps inhibit the ability to assess potential acidification impacts
- Vulnerable species and life stages should be prioritized in future research
- Multi-stressors and organism acclimation strategies require more research attention
- Ecosystem-level impacts need to be assessed through empirical studies and modeling
- Research priorities enable informed planning, management, and mitigation strategies

The product from this working group is a white paper entitled "Recommended Priorities for Research on Ecological Impacts of Coastal and Ocean Acidification in the U.S. Mid-Atlantic" by Saba et al. 2019 (available here: https://doi.org/10.1016/j.ecss.2019.04.022). All members of the working group were included as co-authors of the manuscript.

II. Development of a working group focused on acidification monitoring needs

This group, led by Kaitlin Goldsmith, worked to develop a robust monitoring plan for the Mid-Atlantic region from estuary to open ocean in order to improve understanding of the carbonate chemistry variability and change in the region.

MACAN recently developed a series of acidification monitoring maps showing locations of past and present acidification monitoring in the Mid-Atlantic. These maps can be found under the Oceanography theme on the Mid-Atlantic Ocean Data Portal[5]. The working group analyzed these maps to identify potential monitoring gaps in time and space in the Mid-Atlantic. The group members concluded that: a) The sampling frequency throughout much of the region is too low to adequately capture short-term episodic events and seasonal variability; b) Often, only one carbonate system parameter is measured, which does not allow full characterization of

[5] 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

acidification; and c) Most sampling is conducted at the ocean surface, but subsurface waters are typically more acidic. From these identified gaps, the group identified seven monitoring priorities for the Mid-Atlantic region:

1) Leverage existing infrastructure to include multiple carbonate chemistry parameters as well as other water quality parameters
2) Direct monitoring efforts in subsurface and bottom waters rather than limiting monitoring to surface waters
3) Identify the best available sensor technology for long-term, *in-situ* monitoring
4) Monitor across a salinity gradient to account for the complexity of estuary, coastal and ocean environments and further identify potential areas of enhanced vulnerability
5) Increase sampling frequency to capture variability
6) Include other drivers (e.g., freshwater discharge, nutrients, physiochemical parameters, etc.) that may affect acidification
7) Conduct or continue monitoring in specific ecological regions that may have enhanced vulnerability (e.g., the cold pool, estuarine systems, and cold-water coral habitat)

The product from this working group is a white paper entitled "Scientific considerations for acidification monitoring in the U.S. Mid-Atlantic Region" by Goldsmith et al. 2019 (available here: https://doi.org/10.1016/j.ecss.2019.04.023). All members of the working group were included as co-authors of the manuscript.

III. Development and implementation of a MACAN Outreach Strategy

MACAN strives to create an active network of regional stakeholders to share information about the science, policy, and economic and ecological impacts of coastal and ocean acidification. Over the past year, MACAN has developed a website to serve as an information hub for stakeholders, a listserv to foster communication among network members, work groups, and a series of webinars to share stakeholder perspectives, research highlights, and management needs related to coastal and ocean acidification. While the listserv membership includes over 200 stakeholders, a small percentage of its members are actively participating. MACAN also lacks engagement from industry stakeholders. Thus, we have developed a cohesive outreach strategy to improve network engagement and increase network membership from industry stakeholders. This strategy addresses two goals that will be implemented in several ways:

Goal 1**:** Increase engagement of existing network members

- *Strategy 1: Survey MACAN's listserv members to gain a better understanding of its stakeholder base and identify ways to improve webinar and working group participation*. We conducted an online survey for our MACAN members to gain a better understanding of its stakeholder base and identify ways to improve webinar and working group participation. The results of this survey can be accessed on the MACAN website here.
- *Strategy 2: Increase participation in MACAN-sponsored webinars by network members.* To do this we will continue to provide webinars of interest to stakeholders and use the recently developed listserv user survey responses to guide webinar topic development.
- *Strategy 3: Increase MACAN's role as an information hub via the News and Events section on the MidACAN.org website and contributions to the broader national Ocean Acidification Information Exchange (OAIE; http://www.oainfoexchange.org).* These activities include: a)

Developing guidance for news and events submissions for posting on the MACAN and OAIE websites; b) Involving network members to suggest links for MACAN to post on its website that highlight research publications, public-private partnerships, research spotlights, conferences, etc.; and c) Query Mid-Atlantic Sea Grant programs, state extension programs, and regional partners about industry-specific outreach materials on ocean acidification.

Goal 2: Gain a better understanding of potential industry impacts and concerns related to coastal and ocean acidification to ensure industry needs are being met through MACAN's activities

- *Strategy 1: Conduct informal interviews or surveys with potential stakeholders, such as commercial and recreational fishermen, charter boat captains, the aquaculture industry, and the seafood industry.* We developed and distributed Qualtrics surveys tailored toward six specific industries (see description in Appendix C, page 25). The goal of these surveys is to gain a better understanding of potential industry impacts and concerns related to coastal and ocean acidification to ensure industry needs are being met through MACAN's activities. The surveys closed mid-June. Preliminary results were presented by Kirstin Wakefield at the workshop and are outlined below in the Overview of MACAN Stakeholder Survey and Preliminary Findings section.
- *Strategy 2: Increase industry awareness of, and participation in, MACAN-sponsored activities*. We will do this by posting upcoming events to industry specific listservs (e.g. ISSA, NESSA, East Coast Shellfish Growers Association), emailing listserv members to ask for suggestions of recently published articles or videos about industry stakeholders that can be highlighted in the News and Events section of MACAN's website, and attending meetings or working with existing groups throughout the region to provide presentations to the aquaculture industry to provide insight into the current work of the network.

WORKSHOP GOALS

Grace Saba ended her presentation with a brief discussion of the workshop objectives (listed above) and meeting agenda for the remainder of the day.

NETWORKING ACTIVITY

A networking activity was organized early in the meeting so that meeting participants could interact with others that share common concerns and/or expertise. This also served as a warm-up for productive ideas to share in the breakout sessions scheduled for later in the day.

The networking activity consisted of three rounds (20 minutes each) focused on a range of topics identified in a pre-workshop registration survey targeted toward identifying participants interests. The topic ideas at the different networking tables included:

- Shellfish and Oysters
- Finfish and Fisheries Impacts
- Coastal Bays and Estuarine Ecosystems
- Monitoring in coastal habitats and data accessibility

- Developing cost-effective monitoring protocols
- Defining Baseline and Thresholds for (Species) Resilience
- How to reduce impacts of future OA
- Impacts of multiple stressors

OVERVIEW OF MACAN STAKEHOLDER SURVEY AND PRELIMINARY FINDINGS

KIRSTIN WAKEFIELD[6], MARACOOS

In spring/summer 2019, MACAN is conducting Stakeholder Outreach Surveys to gain a better understanding of industry perspectives on acidification in estuaries, on the coast, and in the ocean. The goals are to identify: 1) Who are MACAN's industry stakeholders; 2) What are their information needs related to ocean and coastal acidification; 3) How do stakeholders prefer to communicate about ocean acidification; 4) How can MACAN engage stakeholders in future partnerships or outreach efforts to plan for or adapt to changing ocean conditions.

Surveys are being administered online to members of the regional aquaculture, commercial fishing, charter boat, and seafood industries and the recreational fishing community. MACAN partnered with cooperative extension agents, Sea Grant programs, state agencies, and fishery management councils to develop stakeholder lists and identify relevant listservs for survey distribution. Internet searches for charter boat captains and seafood business listings were also conducted. Survey links are posted on MACAN's website and on the Mid-Atlantic Fishery Management Council (MAFMC) website. Surveys were open through mid-June. The final survey summary will be posted on MACAN's website and emailed to MACAN's listserv in fall 2019.

PRELIMINARY SURVEY RESULTS

Over 200 stakeholders throughout the Mid-Atlantic region have responded to MACAN's surveys to date (Fig. 1). Recreational fishing stakeholders account for the largest group of respondents (n=84); seafood industry members account for the smallest group of respondents, and as such, were not included on this analysis (n=3). Slightly less than half (43%) of all respondents considered themselves to be somewhat knowledgeable about ocean acidification; however nearly 25% of the aquaculture industry respondents consider themselves to be very knowledgeable about ocean acidification. Outside of the aquaculture industry, MACAN is not very well known. Only 10-20% of commercial and recreational fishermen had heard of MACAN before the survey.

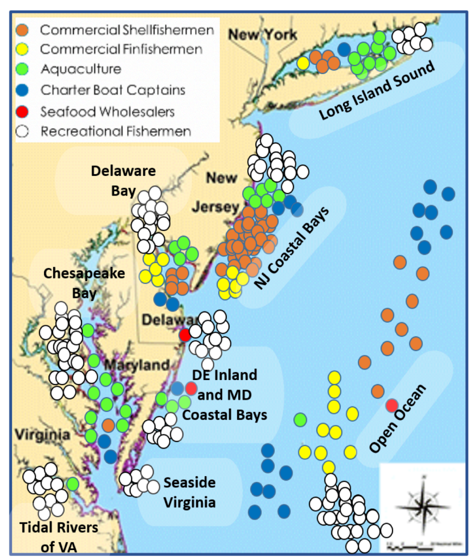

Figure 1. Areas where stakeholders primary fishing or business activities occur. (n=200)

[6] MACAN Outreach Coordinator for the Mid-Atlantic Regional Association Ocean Observing System (MARACOOS)

INDUSTRY SNAPSHOTS

AQUACULTURE (N=34)

Aquaculture stakeholders in the Mid-Atlantic farm a variety of shellfish and several types of kelp and algae. Only a few stakeholders who responded to the survey focus on aquaculture services and supplies. The majority of stakeholders are involved in oyster aquaculture (n=30), followed by hard clams (n=13) and bay scallops (n=8).

Stakeholders were asked if they had any concerns or questions about ocean acidification in relation to their business operations. Several themes emerged during analysis of the open-ended responses:

- What timeframe will acidification occur and when can we expect similar or worse conditions from the West Coast?
- What will be the impacts on oyster hatchery seed production and wild sets of oyster spat?
- How will a reduction in calcium carbonate production under acidic conditions affect my business?

> *"An acidic environment makes it difficult to produce calcium carbonate making oyster aquaculture extremely challenging. This means a loss of oyster production for our business and others. A smaller customer base buying seed and equipment impacts all facets of our business model." – Stakeholder response*

Concerned about the impacts of acidification on shellfish growth and development, aquaculture stakeholders are actively monitoring for acidification. About one-third of respondents currently monitor for carbonate chemistry; these locations are distributed throughout the Mid-Atlantic region. With such a broad geographic distribution of monitoring sites, this presents an opportunity for MACAN to facilitate information sharing between hatcheries and farms with well-established monitoring protocols and those looking to incorporate carbonate chemistry monitoring into their daily operations.

COMMERCIAL SHELLFISHERIES (N=46)

For the majority of Mid-Atlantic shellfishermen responding to the survey, commercial fishing is a supplemental source of income. Only about 1/3 of respondents consider commercial fishing to be their primary source of business. The top five shellfish respondents harvest from the Mid-Atlantic region are: hard clams (n=30), oysters (n=14), blue crabs (n= 14), whelk (n=7), and blue mussels (n=6). Several fishermen report fishing for other shellfish such as surf clams, horseshoe crabs, bay scallops, and grass shrimp.

Stakeholders were asked if they had any concerns or questions about ocean acidification in relation to their commercial fishing activities. Their open-ended responses related most frequently to concerns about the hard clam fishery.

> *"Yes, [I have concerns] but I don't know what questions to ask. Does it affect flavor, growth rate, or health of clam? Is it seasonal? Does it move? Is it like a red tide, then goes away, or is it getting progressively worse?"- Stakeholder response*

Stakeholders wanted to learn more about the signs and impacts of acidification on shellfish they target, particularly hard clam populations, life cycles, and recruitment. They expressed concern about the sensitivity of bay ecosystems vs. the ocean, noting that development is already affecting clam populations in the coastal bays. They also requested more information about ways to stop acidification from occurring.

COMMERCIAL FINFISHERIES (N=16)

In contrast to shellfishermen, 80% of commercial finfishermen responding to the survey indicate that fishing is their primary source of business. The most common species harvested by commercial finfishermen include: Bluefish, Dogfish, Squid/Butterfish, Menhaden, and Summer Flounder. Other species harvested include: mackerel, striped bass, scup, monkfish, Atlantic Herring, perch, tilefish, winter flounder, and sharks.

Stakeholders were asked if they had any concerns or questions about ocean acidification in relation to their commercial fishing activities. In addition to a need for basic information about acidification, several questions emerged during analysis of the open-ended responses:

- Does acidification have any bearing on water salinity?
- How will acidification affect fish spawning in estuaries?

In their open-ended responses, commercial finfishermen tended to be more concerned about the effects of pollutants and runoff on fish habitat than the effects of acidifying waters. Similar to commercial shellfishermen, they attribute changes in fisheries to development surrounding coastal bays.

> *"The most harm in our bay isn't from acidification, it's the chemical runoff from farmers and spraying Phragmites."- Stakeholder response*

As MACAN considers ways to engage commercial fishermen on acidification, illustrating how anthropogenic activities influence/tie-in with coastal acidification may be an important connection to focus on in future outreach efforts.

RECREATIONAL FISHERMEN AND CHARTER BOAT OPERATORS (N=105)

Of the six stakeholder groups surveyed to date, recreational fishermen have been the most responsive. Members of more than 27 fishing clubs, from Marlin and Tuna clubs in Long Island Sound to the Atlantic Coast Sportfishing Association, participated in the survey. Recreational fishermen selected Striped Bass, Flounder, Black Sea Bass, Bluefish and Weakfish/Sea Trout as the most popular species for their fishing activities.

Stakeholders were asked if they had any concerns or questions about ocean acidification in relation to their recreational fishing activities. In general, fishermen requested more information and where to find resources on acidification. Their concerns also included:

- What are the effects on shellfish? How will that impact the food web?
- What are the effects on fish/fisheries and on what timeframe?

- Will impacts 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?" -Stakeholder response*

As outreach materials are being developed for recreational fishermen, discussing the impacts of acidification in the context of popular recreational fish species, such as striped bass and flounder, can help MACAN and others build engagement within this community.

OPPORTUNITIES FOR STAKEHOLDER ENGAGEMENT

A secondary focus of the survey was to explore opportunities to engage industry members in future outreach and monitoring efforts. When asked about communication preferences, survey responses varied by industry. Although most stakeholders prefer to share information directly with MACAN's coordinators in email or informal conversations, commercial fishermen would like to learn more about acidification at regional association meetings. Recreational fishermen also recommended local club meetings as a forum for information sharing.

Despite a lack of knowledge about acidification, more than half of industry members are willing to participate in future public private/partnerships. Industry members express the most interest in monitoring water chemistry at their aquaculture sites or sites where they fish regularly. Recreational fishermen are also keen to share information with family, friends, and their fishing clubs.

FLASH TALKS FROM OCEAN ACIDIFICATION GRADUATE FELLOWS

During the workshop lunch, four of the six recently awarded NOAA Ocean Acidification Program/Sea Grant Mid-Atlantic Ocean Acidification Graduate Fellows presented flash talks focused on their research projects. Summaries of each of the presentations are described below:

"CHESAPEAKE BAY ACIDIFICATION: FROM DAILY FORECASTS TO HALF-CENTURY PROJECTIONS"
FEI DA, VIRGINIA INSTITUTE OF MARINE SCIENCE, COLLEGE OF WILLIAM & MARY

Coastal acidification is an environmental issue that is of increasing concern for shellfish aquaculturists and other stakeholders in the Chesapeake Bay. To better understand changes in the carbonate system of Chesapeake Bay, the existing Estuarine-Carbon-Biogeochemistry model embedded in the Regional-Ocean-Modeling-System (ChesROMS-ECB) will be extensively evaluated and enhanced using new high-quality carbonate system observations together with long-term monthly Chesapeake Bay Program water quality data. Model experiments will be conducted to isolate the primary physical and biological drivers of Chesapeake Bay acidification at different temporal and spatial scales. Additionally, in order to fulfill stakeholders' requests for acidification-related conditions in the Bay, ChesROMS-ECB will be used to generate automated daily nowcasts and 2-day forecasts of relevant acidification metrics; visualization and interpretation of these metrics and available real-time data will be provided online. For future management purposes, long-term projections will be conducted to investigate how Chesapeake acidification may change by 2025 and 2050 due to global change (i.e. increasing atmospheric CO_2, temperature, and sea-level) and local human impacts (i.e. changing nutrient inputs and riverine alkalinity). The relative importance of these multiple stressors will be examined. Two-way communication with stakeholders throughout the project will ensure that this information will be useful for Chesapeake Bay stakeholders.

"RESILIENCE TO OCEAN ACIDIFICATION IN CLAMS AND OYSTERS"

CAROLINE SCHWANER, STONY BROOK UNIVERSITY

The eastern oyster (*Crassostrea virginica*) and northern quahog (*Mercenaria mercenaria*) are vitally important to the economy, environment, and culture of the Mid-Atlantic region of the United States. Bivalves are a billion-dollar industry in the United States, and aquaculture has been good both commercially and for restoration programs. Estuarine habitats of oysters and clams are more susceptible to acidification than the open ocean because of eutrophication, increased algal productivity, and resulting increases in pCO_2. Elevated pCO_2 and a reduction of calcite and aragonite saturation states resulting from Ocean Acidification (OA) will have harmful impacts on marine bivalves specifically during early larval development. Despite the predicted negative consequences, variability within and between populations and species and the rich genetic diversity of oysters and clams could indicate that they might have natural genetic variation that could be a valuable source of resilience to OA. I aim to investigate if resilience to OA in the northern quahog and eastern oyster is genetically dictated, and if there is genetic differentiation between genes of interests (i.e., energy allocation, shell formation, and calcium and proton homeostasis). I will use gene expression studies and single-nucleotide polymorphism profiling to identify adaptive mechanisms and pathways associated with OA resilience. I will use gene silencing to validate findings and confirm the protective role of the most promising genes. The identification of genetic features associated with OA resilience is a highly-needed step for the development of marker-assisted selection of oyster stocks to be used for aquaculture and restoration.

"PHYSIOLOGY-BASED MODELING OF ESTUARINE FISHES AND ECOSYSTEMS UNDER OCEAN ACIDIFICATION"

TERESA SCHWEMMER, STONY BROOK UNIVERSITY

Information on the effects of ocean acidification at all levels of biological organization, from cells to ecosystems, is critical for conservation and management. In order to quantify responses of individual fish and populations to acidification and related stressors, physiological responses were measured and will be used to model population growth rate under different acidification scenarios. Temperature and DO often co-occur with high CO_2 in estuaries, so factorial combinations of CO_2 with each stressor were applied to offspring of the Atlantic silverside (*Menidia menidia*) from the time of fertilization in a series of laboratory experiments. We measured metabolic rates using microrespirometry on embryos and 1 day-post-hatch larvae and found that CO_2 alone has little effect on offspring, but that there are often significant interactions between CO_2 and the other stressors. We also measured abundance of ionocytes, cells that play a major role in acid-base balance for embryos and larvae. Preliminary results show that the relationship between ionocytes and CO_2 depends on temperature. These results, along with growth and survival measurements, will be used to model population growth of Atlantic silversides and summer flounder (*Paralichthys dentatus*), a commercially valuable species for which acidification experiments have also been done. Energetic costs will be modeled through the use of Dynamic Energy Budget (DEB) theory, with the DEB outputs then being used for a matrix population model.

"OCEAN ACIDIFICATION AND MICROBIALLY-MEDIATED SHELL CALCIFICATION IN THE EASTERN OYSTER, *CRASSOSTREA VIRGINICA*"
AMANDA ZAHORIK, UNIVERSITY OF DELAWARE

The Eastern Oyster, *Crassostrea virginica*, is a keystone species in coastal environments of the eastern United States, its population now greatly diminished by disease, overfishing, and habitat destruction. Climate change presents further risks to the Eastern Oyster: warming ocean temperatures threaten to increase the severity and reach of disease, and ocean acidification threatens the oysters' ability to form and maintain their protective shells. While many aspects of oyster health, particularly its immune and stress responses, have been studied extensively, the role of their host-associated microbial community, or microbiome, remains largely unexplored. Given the role that other host-associated microbiomes play in host health, particularly in pathogen defense and nutrient acquisition, it follows that the oyster microbiome may play an equally important role in oyster health and fitness. Our previous work characterized the bacterial community associated with oyster extrapallial fluid over an annual cycle. We identified several environmental factors which influenced seasonal cycling of the microbiome and host genetic markers which correlated with microbiome composition. We also identified core members of the oyster extrapallial fluid microbiome. Among these core members were the Desulfobacteria, a family which includes most known sulfate-reducing bacteria (SRB). These SRBs are associated with calcium carbonate deposition in other environments and are known members of the microbiomes of other marine calcifiers such as sponges and corals. We posited, therefore, that these bacteria may play a role in oyster shell calcification. To study this role more closely, and to gauge the effect of ocean acidification on the entire host-microbiome ecosystem, we proposed an eight-week study which will combine bacterial community sequencing, bacterial metatranscriptome sequencing, and targeted gene expression studies to examine: a) how low pH conditions affect the bacterial community structure and gene expression (and thus metabolic activity) in general; b) to examine how these conditions affect the abundance and activity of SRBs in particular; c) to identify any correlations between oyster shell calcification rates, SRBs, and/or the overall bacterial community.

BREAKOUT SESSIONS AND SUMMARY DISCUSSION

In order to facilitate discussions to address the workshop objectives, three breakout groups were organized. These included: 1) Filling Research Priorities, 2) Optimizing Existing Monitoring, and 3) Stakeholder Concerns and Associated Information Needs. Each breakout group was led by a facilitator and had an assigned note taker, and each breakout discussion was directed by guiding questions (see below). Two, 45-minute breakout sessions allowed for participants to attend their choice of two breakout groups during the workshop.

Group A: Filling Research Priorities*	Group B: Optimizing Existing Monitoring**	Group C: Stakeholder Decision Points and Associated Information Needs***

The goals of the breakout groups were as follows:

- Research Priorities and Optimizing Existing Monitoring: Prioritize gaps to work through and identify any potential individuals/groups best suited to complete the work needed

- Stakeholder Concerns and Information Needs: Determine what stakeholder concerns related to acidification are and what information is needed on what time scales in order to do so. Determine best way to provide necessary information to stakeholders.

A plenary discussion followed the individual breakout group meetings whereby the breakout group leads summarized major talking points (summarized below) and opened the conversation to the full group of workshop participants.

TOPIC A: FILLING RESEARCH PRIORITIES
GRACE SABA, BREAKOUT LEAD

TOPIC SUMMARY AND DISCUSSION QUESTIONS

The present combination of highly variable observed responses, small-scale laboratory experiments, and limited species-specific and ecosystem-scale acidification studies hampers researchers' ability to assess the level of impact to be expected from acidification in the Mid-Atlantic region and what that will mean for our coastal communities. The recent white paper by Saba et al. 2019 (https://doi.org/10.1016/j.ecss.2019.04.022) discussed priorities for addressing these acknowledged gaps. The goal of this breakout group was to discuss how to rank these priorities and to identify any potential/interested individuals to begin progress on those identified research gaps. The recommended ecological research priorities for the Mid-Atlantic region identified in the paper included:

- *Multiple Drivers of Acidification*:
    - Develop models to quantify the relative controls on coastal acidification: anthropogenic CO_2, eutrophication, temperature, freshwater runoff, SLR
    - Investigate how acidification and climate-induced changes to biological communities will feedback into biogeochemical processes that drive carbonate system dynamics
- *Gaps for Major Taxa*:
    - Conduct a meta-analysis synthesizing existing research on Mid-Atlantic species to quantify biological responses and sensitivities to acidification and multi-stressors
    - Focus studies on regionally important species/life stages that have not yet been investigated for acidification and/or multi-stressor impacts
    - Expand research on target species and life stages considered vulnerable to acidification based on research findings
- *Recommendations for Experimental Design Improvements*:
    - Inclusion of multiple species assemblages
    - Testing responses from multiple stressors
        - Elevated pCO_2, low dissolved oxygen, elevated temperature, etc.
    - Incorporation of natural variability (daily, monthly, seasonal, episodic) of single and multiple stressors
    - Conduct studies to differentiate the causative effect of acidification (changes in pCO_2, pH, and/or saturation state) on an individual organism
- *Acclimation/Adaptation Capacity of Organisms*:
    - Determination of the mechanisms and rates of acclimatization and/or adaptation in regionally important nearshore coastal and offshore species under constant and fluctuating conditions
    - Conduct transgenerational studies on regionally important species

  - Evaluate the role food quantity/quality plays in acclimation potential
- *Ecosystem-level Research Considerations*:
  - Determine thresholds or tipping points for if and when a species may be lost due to ongoing acidification
  - Develop ecosystem models to determine how altered acidification-induced changes in biotic interactions will impact the food web, populations dynamics, and community structure
- *Connecting Potential Impacts to Ecosystem Services and the Economy*:
  - Incorporate additional ecosystem variables into economic models to improve predictions of economic scenario analyses and vulnerability assessments

Breakout Group Tasks and Questions for Discussion

- Rank the Priorities: What are the most important issues to tackle first?
- What are the funding agencies that would support these issues?
- Identify potential research/industry partnerships to facilitate research
- Identify people that can do the work to address the top priorities. Are any of you interested?

SYNOPSIS OF BREAKOUT DISCUSSIONS

In ranking the priorities, members of the breakout groups emphasized multiple stressors, experimental design improvements, and connecting impacts to ecosystem services and the economy. Major discussion points on each of these topics are summarized below.

Multi-stressors: Understanding sources of acidification from a multi-stressor standpoint needs to be considered. Land, atmospheric, and aquatic processes can all contribute to coastal and/or ocean acidification, yet these sources are typically not examined or quantified simultaneously. Lack of understanding of the relative contribution of the different sources, their variability, and how different stressors are connected make it difficult to design experiments and test organism response under natural conditions. Further, biologically-driven relationships between carbon dioxide (CO_2) and dissolved oxygen (DO) are more straightforward (higher CO_2, lower DO) compared to complex relationships between CO_2 and temperature.

Experimental design improvements: First, ecological research is tightly linked to carbonate chemistry observations. For instance, understanding the innate variability in the system is needed in order to design better experiments. Therefore, we need more research on sensor best practices and development, particularly new sensors that can provide reliable data across a wide range of salinities and *in situ* spectrophotometric pH and total alkalinity measurements. Conversely, ecological research can inform monitoring, specifically on data resolution needed and locations where observation systems need to be deployed. Second, researchers need to focus efforts on differentiating between exposure to acidification versus the impacts of or vulnerability to acidification. Here, time frames of exposure, variation in thresholds, and interactions with other stressors become important. Third, the group agreed that future laboratory single-species experimental efforts should be prioritized to include relevant and important species. However, more importantly future studies should focus on population and community responses to determine ecosystem-level impacts in a future, more acidic ocean. These studies should examine both direct and indirect (i.e., neurotransmitters vs. effects on prey) responses and could include those focused on invasive species, competition between species for space and/or resources, and predator-prey dynamics and community shifts. In an effort to investigate these processes, there is an immediate need for field-based studies including Free Ocean CO_2 Enrichment (FOCE) system experiments. Finally, modeling (both biogeochemical and ecological) will be an important component in the investigation of ecosystem-level response analysis. Therefore, modelers will require easy accessibility to data (and metadata) and in usable formats. Improved modeling of carbonate chemistry dynamics (biogeochemical models) in important habitats is necessary to develop forecasting ability, which is an area of research that industry has expressed a need for.

Connecting impacts to ecosystem services and the economy: Global economic models and/or dynamic energy budgets need to be included in order to underscore potential impacts of acidification on regional valuable marine resources.

Funding sources for gap filling could be sought through graduate fellowships (i.e., upcoming Margaret Davidson NERR Graduate Fellowship) and traditional funding agencies such as NSF and NOAA. With the increasing number of ocean carbon sensors on satellites, NASA may be a potential source for acidification-related funding in the future. Additionally, more agencies (i.e., Sea Grant, NOAA) are incorporating ocean acidification as a research priority and thus may be increasingly inclined to fund proposals focused on gap-filling the regional research and monitoring needs. Interagency groups (states, Environmental Protection Agency) may also play a future role as a funding source. If researchers can convey that there is a need for very specific measurements, NIST funding could potentially support sensor development/improvement needed for observations in ecologically important habitats. It was also highlighted that aquaculture-focused proposal calls have been more frequent from programs like NOAA and Sea Grant.

There are potential partnerships that could prove valuable for future research efforts. For sensors and carbonate chemistry measurements, collaborations with NIST could be valuable to ensure new sensor modifications and development incorporates research needs. Additionally, partnerships between researchers and oyster restoration groups that encompass a full phase of one or more restoration projects could provide information on carbonate chemistry dynamics and biodiversity in pre- and post-restoration periods.

TOPIC B: OPTIMIZING EXISTING MONITORING
KARI STLAURENT[7], BREAKOUT LEAD

TOPIC SUMMARY AND DISCUSSION QUESTIONS

The goal of this breakout group was to discuss which of the monitoring recommendations, identified in the recent "Scientific considerations for acidification monitoring in the U.S. Mid-Atlantic Region" white paper by Goldsmith et al. 2019 (https://doi.org/10.1016/j.ecss.2019.04.023), should be prioritized and to identify any potential/interested individuals to begin progress on those identified gaps. The

[7] Research Coordinator and Environmental Scientist, Delaware Department of Natural Resources and Environmental Control/ National Estuarine Research Reserve

monitoring priorities for the Mid-Atlantic region identified in the paper are outlined in the Workshop Introductory Remarks section above (page 4).

Breakout Group Tasks and Questions for Discussion

- Which of these monitoring priorities do you think are most important?
- What do we need to advance/establish these monitoring priorities?
  - Are there any funding opportunities you know of?
- Who is interested in helping the region advance the priority gaps?
- What does a robust monitoring program look like in 5 years? 10 years?
- What specific questions do you have that can only be addressed by a robust COA monitoring network?

SYNOPSIS OF BREAKOUT DISCUSSIONS

In ranking the priorities, members of the breakout groups emphasized expanding current monitoring efforts to leverage existing infrastructure and funding, focusing monitoring efforts in regions with enhanced vulnerability, and developing cost-effective options for monitoring. Major discussion points on each of these topics are summarized below.

Expand current monitoring to leverage existing infrastructure and funding: Many participants agreed that multiple Monitoring Priorities could be addressed concurrently. For example, a program could leverage existing infrastructure and pre-existing water quality monitoring programs to include a second OA parameter (#1), but that expansion should be prioritized in vulnerable and dynamic areas such as a salinity gradient (#4) and be used to increase OA sampling frequency (#5). Potential opportunities include working with water quality monitoring programs (state efforts, non-profits, etc.) to include additional parameters (total alkalinity was noted as a low hanging fruit), to monitor in tributaries, coastal bays, and estuarine systems, and to leverage established fixed (pH) stations to include a second parameter such as $p\mathrm{CO_2}$.

Focus monitoring activities in regions with enhanced vulnerability: Monitoring priority (#7), to conduct or continue monitoring in specific ecological regions that may have enhanced vulnerability, was also highlighted. Areas of enhanced vulnerability included shellfish beds; participants discussed the need for information from different environments in the Mid-Atlantic to better understand different organismal responses. All of this information is important to capture for modeling purposes as well as environmental education. Lastly, it was noted that water quality and shellfish health programs are usually not co-located, which is a detriment to understanding organismal responses to OA and multiple stressors.

Ultimately, this breakout group identified that multiple Monitoring Priorities should be implemented to best characterize and understand the vulnerabilities and variabilities of OA in estuarine systems. It was noted that information on the cost and required new effort to monitor OA would be beneficial as staff resources and funding are limited and monitoring expansion will be controlled by available resources.

Developing cost-effective monitoring programs: Participants agreed that data beyond pH are needed to have a robust monitoring program, however, more information on what that expansion would cost as well as guidance on which parameter and method to implement, is also a need. Participants also discussed ways engaged watermen could help collect OA data that would be low-cost and require minimal effort. This could include information on cheap sensors (such as Raspberry Pi pH sensors) or collecting water samples that could be given to a researcher at the dock for processing.

In order to advance the monitoring priorities identified in the breakout session, participants discussed the need for a comprehensive document that would consider the most cost-effective options for implementing and/or expanding an ocean acidification monitoring site. This document would ideally discuss and compare options for which OA parameters could be added to an existing or new program (based on the given research question), available sensor technologies including price, maintenance, staff time, and caveats (such as salinity ranges where a sensor would be accurate), and a list of certified laboratories which could perform analyses such as total alkalinity. Additional discussions included the consideration of sampling protocols (such as taking grab samples at a uniform time of day), exploring academic-state partnerships to overcome the lack of available monitoring funding, sharing information about lessons learned, and exploring whether to expand spatial (but less frequent) sampling or temporal sampling (at a single site).

The outcome of this discussion was a potential working group to create a document that would summarize and compare OA monitoring technologies. Five participants provided their emails and expressed interest in the possibility of forming a working group to create this product.

TOPIC C: STAKEHOLDER CONCERNS AND ASSOCIATED INFORMATION NEEDS
KIRSTIN WAKEFIELD, BREAKOUT LEAD

TOPIC SUMMARY AND DISCUSSION QUESTIONS

The goal of this breakout group was to identify key information needs from MACAN's industry stakeholders, including any data needs required for business decisions and the timescale on which those data would be most relevant.

Breakout Group Tasks and Questions for Discussion

- As stakeholders, what are your biggest concerns or challenges about OA?
- How can MACAN help you with your information needs to address these challenges?
- How would you like to receive this information from MACAN? What format would you prefer (workshop, direct email, focus groups, fact sheets)?
- What kinds of data do you need for decision-making, such as for policy or fisheries regulations or business-related?
- What timescale would be most useful to you for these types of data?

SYNOPSIS OF BREAKOUT DISCUSSIONS

Stakeholder Concerns and Data Needs: Oyster aquaculture stakeholders expressed concern about the effects acidification might have on seed mortality, brittleness of the top shell, and consistency of flavor. Top shell hardness and the brininess of the meat are important qualities for restaurant owners who source their products from local growers. Chefs build their daily menus around the taste of the oysters; brittle shells are less appealing to buyers. Research on the impacts of acidification on shell hardness and flavor could be beneficial to oyster growers in the Mid-Atlantic region. Stakeholders suggested MACAN provide outreach on acidification to chefs who are sourcing oysters and other shellfish from the Mid-

Atlantic region. One participant also suggested providing outreach to farmers on the relationship between nutrient reduction and oyster health.

Data needs for aquaculture stakeholders centered on pH, salinity, and other carbonate chemistry parameters. However, monitoring at aquaculture sites can be difficult for small business owners. With only a few employees, small business owners have limited manpower to devote to monitoring. Financial resources for sophisticated monitoring equipment may also be a limiting factor. Although continuous automated monitoring was expressed as a need for small business owners, a method to forecast pH and salinity in the three to seven-day range would be a favorable alternative when resources are limited. Stakeholders also expressed interest in a regional data model showing historical, current, and future predictions of acidification.

An acidification forecasting tool for the Chesapeake Bay is already under development by scientists at VIMS. The web-based tool includes a mobile-friendly app. Stakeholders can access nowcasts and forecasts for salinity and temperature in bottom waters, and pH, alkalinity, and aragonite saturation state in surface waters. The data are currently available at a resolution of 1 km, but VIMS will be refining the resolution to 100m. Posting the link on MACAN's website could inform local growers and seed suppliers about the availability of this tool.
https://www.vims.edu/research/topics/dead_zones/forecasts/cbay/acidification/index.php

Maryland growers can also locate continuous monitoring data for pH, salinity, and other parameters on MD DNR's Eyes on the Bay water monitoring program website:
http://eyesonthebay.dnr.maryland.gov/contmon/ContMon.cfm

Recreational fisheries stakeholders voiced a need for basic outreach about acidification. They requested more information about how acidification will affect recreationally important species of fish, how soon it will happen, and at what rate pH changes will occur. One participant suggested a review of recent studies on cobia and striped bass to learn more about species responses to OA as fish move outside their historic ranges. Several approaches to distributing outreach information to recreational fishermen were discussed, including via the regional fisheries councils, or using a more personal approach such as social media from "trusted" sources like MACAN, Sea Grant, etc.

Participants also suggested including restoration stakeholders in MACAN's outreach efforts, including those organizing living shoreline projects, artificial reef restoration, and shell recycling partnerships with local restaurant.

Stakeholder Outreach: Communicating More Effectively to Build Engagement: Participants noted that MACAN serves a role as a curator of "trusted" information for stakeholders. The network can push outreach information out to organizations such as Ocean Conservancy, MARACOOS, Sea Grant Programs, East Coastal Shellfish Growers Association, etc. to better reach stakeholders.

Participants discussed how the terminology used in acidification outreach can be confusing to stakeholders. An effort should be made to clarify the difference between ocean and coastal acidification and to explain how the different drivers, e.g. rainfall, eutrophication, or atmospheric CO_2, contribute to acidification.

Creating a message that is more personal to stakeholders is key to building engagement. Participants in the breakout session highlighted the differences between the Mid-Atlantic region and the West Coast and other regions served by the CAN networks. In contrast to the collapse of the shellfish aquaculture industry in Washington State in the 1990's, the Mid-Atlantic hasn't experienced an "OA crisis" to galvanize its stakeholders. Without seeing direct effects of acidification, participants remarked that it can be difficult for Mid-Atlantic stakeholders to understand the relevance. Communicating about coastal acidification in terms of how it affects the water where people fish or the recreationally important fish (e.g. flounder) they fish for, can help stakeholders gain a better understanding of why acidification might be relevant to them and how it might impact them directly. For example, O'Chang's video, "Acid in the Gulf of Maine", (https://vimeo.com/163050036) has been a very popular community-focused education tool about the impacts of OA on lobsters and local sea life. Participants suggested a similar product could be developed specific to the Mid-Atlantic region.

Several participants emphasized that the estuaries in our region are very different from one another; each has different drivers of coastal acidification. Preparing targeted outreach with a state-specific focus could help stakeholders better understand local drivers of acidification and the impacts acidification may have on local fishery resources, aquaculture operations, etc.

NEXT STEPS

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

1) Completing a summary of results for Outreach Survey and appropriate follow-up as needed
2) Following-up with potential collaborative groups/individuals as interested/requested
3) Potentially developing new MACAN working groups focused on outreach, policy or monitoring technologies
4) Organizing webinars on topics of interest highlighted at the workshop
5) Continuing to work regionally to address knowledge gaps.

The meeting adjourned at approximately 4:45PM.

APPENDIX A: WORKSHOP AGENDA

Filling Gaps and Identifying Decision Points:

MACAN Workshop 2019 Agenda

Sheraton Inner Harbor Hotel
300 South Charles Street, Baltimore, MD 21201
May 13, 2019

Objectives

- Identify stakeholder concerns and associated information needs
- Prioritize a plan for working through gaps identified in each white paper
- Provide an update on the Industry Stakeholder Outreach Survey
- Map out various areas currently being worked by members to identify potential collaborations and opportunities to fill knowledge gaps

Agenda

9:30-10:00AM Registration and Networking

10:00-10:30AM Workshop Overview and Networking Activity Introduction

(Grace Saba, Rutgers University/MARACOOS)

10:30-10:45AM Break and Transition to Networking Tables

10:45-11:45AM Networking Activity

- Three rounds of networking (20 min each) based on topics related to Concerns about Acidification, Monitoring, and Information Gaps.

11:45-12:15PM Overview of MACAN Stakeholder Survey and Preliminary Findings

(Kirstin Wakefield, MARACOOS)

12:15-1:15PM Lunch and Flash Talks

- *Fei Da, Virginia Institute of Marine Science, College of William & Mary*: "Chesapeake Bay acidification: from daily forecasts to half-century projections"
- *Caroline Schwaner, Stony Brook University*: "Resilience to Ocean Acidification in Clams and Oysters"
- *Teresa Schwemmer, Stony Brook University*: "Physiology-based modeling of estuarine fishes and ecosystems under ocean acidification"

- *Amanda Zahorik, University of Delaware*: "Ocean Acidification and Microbially-Mediated Shell Calcification in the Eastern Oyster, *Crassostrea virginica"*

1:15PM Transition to Breakout Groups

1:15-2:00PM Breakout Groups (1st round – choose 1)

Group A: Filling Research Priorities	Group B: Optimizing Existing Monitoring	Group C: Stakeholder Concerns and Associated Information Needs

- Goals:
  - Research Priorities and Optimizing Existing Monitoring: Prioritize gaps to work through and identify any potential individuals/groups best suited to complete the work needed
  - Stakeholder Concerns and Information Needs: Determine what stakeholder concerns related to acidification are and what information is needed on what time scales in order to do so. Determine best way to provide necessary information to stakeholders.

2:00-2:15PM Break

2:15-3:00PM Breakout Groups (2nd round – choose 1)

Group A: Filling Research Priorities	Group B: Optimizing Existing Monitoring	Group C: Stakeholder Concerns and Associated Information Needs

3:00-3:45PM Plenary Discussion

- Summary and Discussion – Breakout Group A: Filling Research Priorities
- Summary and Discussion – Breakout Group B: Optimizing Existing Monitoring
- Summary and Discussion – Breakout Group C: Stakeholder Concerns and Associated Information Needs

3:45-4:15PM Next steps and closing remarks

(Kari St.Laurent, Delaware NERR/Delaware DNREC)

Speaker Bios

Fei Da

(B.S., Oceanographic Science, Nanjing University, China; M.S., Marine Science, Virginia Institute of Marine Science, College of William & Mary)

Fei Da is a Ph.D. student in the Department of Biological Sciences at Virginia Institute of Marine Science. He is currently a Mid-Atlantic Sea Grant / NOAA Ocean Acidification Program Graduate Research Fellow (in Ocean, Coastal, and Estuarine Acidification). He uses coupled physical-biogeochemical models to study how physical and biological processes impact the carbonate system, and how local human activities and global climate change impact acidification in the Chesapeake Bay.

Grace Saba

(B.S., Aquatic Biology, University of California, Santa Barbara; Ph.D., Marine Science, Virginia Institute of Marine Science, College of William & Mary)

Grace Saba is an Assistant Professor in the Department of Marine and Coastal Sciences at Rutgers University. As one of the faculty in the Rutgers University Center for Ocean Observing Leadership (RU COOL), she also serves as the Ocean Acidification Innovation Lead for the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS). In this role, she is a co-coordinator of the Mid-Atlantic Coastal Acidification Network (MACAN). Her broad research interests are in the fields of coastal marine organismal ecology and physiology, with emphasis on how organisms interact with their environment and other organisms, how physiological processes impact biogeochemistry), and how climate change impacts these processes.

Caroline Schwaner

(B.S., Environmental Science, Emory University; M.E.M, Coastal Environmental Management, Duke University)

Caroline Schwaner is a a PhD student at Stony Brook University's School of Marine and Atmospheric Sciences and a Mid-Atlantic Ocean, Coastal, and Estuarine Acidification Graduate Research Fellow. Her research focuses on identifying molecular markers associated with resilience to ocean acidification in the eastern oyster and the northern quahog.

Teresa Schwemmer

(B.S., Marine Biology, University of Rhode Island)

Teresa Schwemmer is a Ph.D. student at the Stony Brook University School of Marine and Atmospheric Sciences. As a Sea Grant Mid-Atlantic Ocean Acidification Fellow, Teresa is developing a model to predict population-level effects of ocean acidification on the Atlantic silverside, *Menidia menidia*. She is broadly interested in the impacts humans have on marine systems and how marine animals cope with anthropogenic stressors. She is also interested in communicating marine science to the public, particularly with regard to climate change and ocean acidification.

Kari St.Laurent

(B.S., Environmental Science, B.A. Environmental Chemistry, Roger Williams University; Ph.D., Oceanography, Graduate School of Oceanography, University of Rhode Island)

Kari St.Laurent is an environmental scientist for the Delaware Department of Natural Resources and Environmental Control and the Research Coordinator for the Delaware National Estuarine Research Reserve. She is a member of the Mid-Atlantic Coastal Acidification Network (MACAN) steering committee and currently acting as co-lead for MACAN. Her broad research interests are on the topics of environmental organic chemistry, black carbon, emerging and legacy contaminants, blue carbon, biochar, and understanding climate change impacts to marine ecosystems and processes.

Kirstin Wakefield

(B.A. Biology, with Distinction, M.S. Marine Biology and Biochemistry, University of Delaware Graduate College of Marine Studies)

Kirstin Wakefield is the stakeholder liaison for the Mid-Atlantic Regional Association Coastal Ocean Observing System MARACOOS). She is currently helping to coordinate MACAN's stakeholder outreach and engagement plan. Her interests lie in scientific communication, ocean literacy, climate change, fisheries management, and stakeholder outreach.

Amanda Zahorik

(B.S. Biotechnology/Biochemistry, Rutgers University)

Amanda is a graduate student at the University of Delaware and NOAA Ocean Acidification Program/Delaware Sea Grant fellow. She is a member of VEIL (Viral Ecology and Informatics Lab) under the direction of Drs. Shawn Polson and Eric Wommack. VEIL is a microbial ecology group which studies viral and bacterial communities in a variety of environments, from marine to soil. Its various research projects are all united by two broad questions about the microbial communities it studies: who's there, and what are they doing? Amanda's environment of interest is the Eastern Oyster: specifically, the microbial community which is associated with the oyster's extrapallial fluid, and what role they may play in oyster health, disease resistance, and shell calcification.

APPENDIX B: ATTENDEE AFFILIATIONS

MACAN Workshop Attendees and Affiliations
Kathy Brohawn, Maryland Department of Natural Resources
Katherine Bunting-Howarth, New York Sea Grant
Sara Coleman, Oyster Recovery Partnership
Fei Da, Virginia Institute of Marine Science
Jeff Deem, Virginia Marine Resources Commission Finfish Management Advisory Committee
R. Kyle Derby, Chesapeake Bay National Estuarine Reserve Research at Maryland Department of Natural Resources
Marjorie Friedrichs, Virginia Institute of Marine Science
Bryan Gomes, ClearSharkH2O
Matthew Gray, University of Maryland Center for Environmental Science
Anthony Himes, Virginia Institute of Marine Science
Shannon Meseck, NOAA Northeast Fisheries Science Center
Bruce Michael, Maryland Department of Natural Resources
Whitman Miller, Smithsonian Environmental Research Center
Erica Ombres, NOAA Ocean Acidification Program
Ryan Ono, The Ocean Conservancy
Julie Reichert-Nguyen, Oyster Recovery Partnership
Emily Rivest, Virginia Institute of Marine Science
Peter Rowe, New Jersey Sea Grant
Grace Saba, Rutgers University/MACAN/Mid-Atlantic Regional Association Coastal and Ocean Observing System (MARACOOS)
Robert Schuster, New Jersey Department of Environmental Protection
Caroline Schwaner, Stony Brook University
Teresa Schwemmer, Stony Brook University
Kari St.Laurent, Department of Natural Resources and Environmental Control/Delaware National Estuarine Research Reserve
Jeremy Testa, Chesapeake Biological Laboratory
Vogt Oyster Farm
Kirstin Wakefield, MARACOOS
Grace Walker, Old Dominion University/Virginia Sea Grant/MARACOOS
Judith Weis, Rutgers University
Elizabeth Wright-Fairbanks, Rutgers University
Amanda Zahorik, University of Delaware

APPENDIX C: MID-ATLANTIC STAKEHOLDER OUTREACH SURVEY ANNOUNCEMENT

MACAN
Mid-Atlantic Coastal Acidification Network

Mid-Atlantic Stakeholder Outreach Survey

Dear Members of aquaculture, commercial fishing, seafood, charter boat and recreational fishing organizations in the Mid-Atlantic:

The Mid-Atlantic Coastal Acidification Network (MACAN) would like to hear from you! MACAN 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 ocean and coastal acidification. MACAN would like to gain a better understanding about how our stakeholders see coastal and ocean acidification affecting business operations or recreational fishing activities now or in the future. We would also like to hear your thoughts about opportunities we can provide to raise awareness and encourage participation in regional efforts to monitor for and adapt to coastal and ocean acidification.

Please help us by participating in MACAN's Stakeholder Outreach Survey. To access the survey, click on your industry or affiliation from the list below. The survey should take about 5-10 minutes to complete. Your responses are voluntary and anonymous.

Please respond by June 14, 2019

Aquaculture Industry Survey	Seafood Industry Survey
Commercial Shellfish Industry Survey	Recreational Fishermen Survey
Commercial Finfish Industry Survey	Charter Boat Industry Survey

This survey is a collaborative effort led by Rutgers University. For more information, please contact Dr. Grace Saba, Assistant Professor, Center for Ocean Observing Leadership, Department of Marine and Coastal Sciences, Rutgers University, 71 Dudley Rd, New Brunswick, NJ 08901. Email: saba@marine.rutgers.edu