Recommendations for Developing a Statewide New Jersey Ocean Acidification Monitoring Network

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Introduction

Ocean acidification, resulting from the ocean's uptake of approximately one third of atmospheric carbon dioxide (CO_2; IPCC 2021) and subsequent changes in ocean carbonate chemistry, is a global-scale issue. As atmospheric carbon dioxide (CO_2) has increased over 40% since the 1800's (Dlugokencky & Tans 2020, Tans & Keeling, 2021), there has been a corresponding drop of 0.1 pH units, causing a 28% increase in ocean acidity – a rate of change 10x faster than anything experienced over the past 50 million years (IPCC 2019). Projections from the Intergovernmental Panel on Climate Change (IPCC) estimate that global ocean surface pH will decline by up to 0.44 pH units by 2099 compared to the preindustrial period under Shared Socioeconomic Pathway (SSP) 5-8.5 (IPCC 2021). Additionally, aragonite saturation state (Ωarag), a biologically-relevant measure of the capacity for the mineral calcium carbonate to form or to dissolve in seawater, is declining globally (Friedrich et al. 2012, Gattuso et al. 2015). By the year 2100, the total volume of water with Ωarag less than 1.0 is projected to increase from 76% to 91% under Representative Concentration Pathway (RCP) 8.5 (analogous to SSP5-8.5; Gattuso et al. 2015, IPCC 2021).

In addition to ongoing ocean acidification (OA) that is occurring globally at a relatively constant rate, the US Mid-Atlantic coastal region is subject to great complexity due to many stochastic nearshore physical, chemical, and biological drivers that can cause highly variable and episodic acidification events (Cai et al. 2020, Gledhill et al. 2015, reviewed in Goldsmith et al. 2019, Wright-Fairbanks et al. 2020). This 'coastal acidification' is driven by local drivers that includes: 1) freshwater riverine and storm water inputs characterized by lower pH and alkalinity that act to decrease the buffering capacity for CO_2 inputs (Cai et al. 2020, Kwiatkowski & Orr 2018); 2) high nutrient influx causing eutrophication that can contribute to bottom water acidification (Cai et al. 2011), and 3) upwelling of deep, low pH/Ωarag water into near-shore waters (Feely et al. 2008, Poach et al. 2019). Off the coast of New Jersey, upwelling tends to occur episodically in the summer as a result of sustained south-southwest winds (Glenn et al. 2004). Additionally, coastal currents, water mass intrusions, stratification, and mixing can influence the New Jersey shelf carbonate system on daily, seasonal, and interannual time scales (Salisbury & Jonsson 2018, Wanninkhof et al. 2015). In particular, strong seasonal stratification on the shelf traps a cold, subsurface water mass called the Cold Pool below the surface in the spring and summer (Houghton et al., 1982). Due to the resulting lack of mixing and ventilation between the surface and the Cold Pool, the trapped respired CO_2 in the subsurface water contributes to a spring to summer decline in bottom-water pH and Ωarag (Saba et al. 2019a; Wright-Fairbanks et al. 2020). Intense storms and increase wind in the fall act to eventually fully mix the water column, and with it bringing in warm, salty, highly alkaline slope water with Gulf Stream influence that acts to increase saturation states and alleviate potential acidification on the mid- to outer-shelf (Wright-Fairbanks et al. 2020).

Acidification in coastal shelf systems can have significant societal ramifications that range from economic losses to ecological consequences. Acidification can have strong, negative impacts on survival and calcification, and milder, but still negative, impacts on growth, development, energy allocation, acid-base equilibrium, and reproduction (reviewed in Kroeker et al. 2013;

Saba et al. 2019b). Information collected from a series of ocean acidification studies on 18 species economically important to the Mid-Atlantic determined that 65% of these species had a negative response to OA, 5% had a positive response to OA, and 30% had no measured response to OA (Saba et al. 2019b). Furthermore, a vulnerability study found that because of a combination of New Jersey's economic dependence on vulnerable commercial species and the presence of OA drivers in the area, southern New Jersey was determined to be one of the most socially vulnerable regions to OA effects (Ekstrom et al. 2015).

New Jersey State's Recent Ocean Acidification Objectives

New Jersey's climate change and ocean acidification efforts were advanced by Executive Order 89 which was signed into law by Governor Murphy in 2019. It created the Chief Resilience Officer position, the Bureau of Climate Resilience Planning, and the Interagency Council on Climate Resilience. EO 89 also directed NJDEP to write the Statewide Climate Change Resiliency Strategy with a Coastal Resilience Plan, and the first Scientific Report on Climate Change. This document states that "New Jersey is at increased risk to the effects of ocean acidification due to its economic dependence on shellfish harvests, with southern New Jersey counties ranking second in the United States in economic dependence on shelled mollusks." Coastal ecosystems will also be harmed by local amplifiers including eutrophication (excessive levels of nutrients and algal growth in water), freshwater runoff, and upwelling (rising of deep-level sea water to the ocean's surface). The chapter concluded with an analysis of gaps in the data surrounding OA. One issue is that the ecological impacts of ocean acidification on Mid-Atlantic marine life and ecosystems are not fully understood yet. The other primary concern is that the ocean acidification sampling technology and methodology needs to be more consistent in order to improve data accuracy.

As a result of these concerns, the Bureau of Climate Resilience and Bureau of Marine Water Monitoring combined efforts to create the OA Team. Since its inception, the OA Team has expanded to include partners across the NJ Coastal Management Program (NJCMP). The team engaged a team of experts at Rutgers, The State University of New Jersey ("Rutgers University") to fill knowledge gaps in science, learn about OA Action Planning from other coastal states, and outline elements to be used in New Jersey's eventual OA Action Plan. These findings were detailed in the Rutgers University Team's report titled, "Opportunities to Address Ocean Acidification Impacts in New Jersey: An Outline of Options for the New Jersey Coastal Management Program" (Saba et al. 2020). In 2021, New Jersey joined The OA Alliance, an international organization dedicated to bringing governments together in a concerted effort to combat ocean acidification. The OA Team and Rutgers are also working to fill regional and biological research gaps and expand stakeholder engagement. This work will all culminate into an OA Action Plan for the state.

Throughout the process of assessing other coastal states' focused OA Action Planning efforts, a key takeaway was developing a coordinated monitoring network is an essential foundation to a state OA initiative. Given the nature of state OA initiatives that rely on risk assessments informed by scientific monitoring results, the NJCMP OA Team and experts at Rutgers University recognized the development of a comprehensive, statewide monitoring network in New Jersey as a "first order" action.

Existing Monitoring in New Jersey

Several entities are performing ocean water monitoring off the coast of New Jersey. The sampling being performed by New Jersey and New York states include a combination of moored and vessel-based platforms. NJDEP water quality monitoring includes eight moored units measuring pH, and vessel-based estuarine sampling that includes pH, total alkalinity, nutrients, and other water quality parameters. NOAA is performing vessel-based monitoring including East Coast Ocean Acidification (ECOA) surveys every 3-4 years (NOAA Ocean Acidification Program, OAP) and seasonal Ecosystem Monitoring surveys (Northeast Fisheries Science Center). Academic groups, including Rutgers University and Stony Brook University, utilize gliders among other methods. Additional organizations like Jacques Cousteau National Estuarine Research Reserve (JC NEER) and Barnegat Bay Partnership (BBP) are using moored platforms for measurements of pH and/or $p\text{CO}_2$ and other state and city water quality monitoring initiatives typically include pH as a measurement variable.

Data tracked from the early 80's until now shows that Mid-Atlantic waters have increased in acidity (lower pH) over time with increases in $p\text{CO}_2$ (Xu et al. 2020). The impacts on Ωarag follow a less expected trend. While aragonite saturation state was on an expected decreasing trend in the early part of a time series analysis from measurements starting in 1982, it begins to stagnate around 2005. It was suggested that this was attributed to the intrusion of water from southern and offshore regions with high total alkalinity and saturation state. More specifically, this could be due to the increase in the Gulf Stream water mass with the northward shift of the Gulf Stream north wall (Xu et al. 2020). New Jersey sits at a point where lower saturation state northern waters mix with higher saturation state southern waters (Wanninkhof et al. 2015), thereby contributing to large spatial and temporal variability in the saturation states of New Jersey coastal waters. Additionally, seasonal changes have been found to impact the level, or intensity, of acidification (Wright-Fairbanks et al. 2020). During summer months, bottom 'Cold Pool' waters on the New Jersey shelf are isolated from surface waters, resulting in lower pH and Ωarag. However, surface to bottom mixing caused by increased winds and storms during the fall alleviate the low pH/Ωarag in bottom waters (Wright-Fairbanks et al. 2020). Nearshore waters off the coast of New Jersey can periodically exhibit low pH/Ωarag due to inputs of freshwater and runoff that is weakly buffered (Wright-Fairbanks et al. 2020).

While data collected so far has been extremely valuable in understanding event-based and seasonal dynamics, these data are still quite sparse in space and time. These data gaps need to be filled in order to not only establish a baseline climatology for carbonate chemistry to determine or project long-term changes, but also to better pinpoint times and/or locations where acidification is already an issue in important organism habitats. Specifically, **the state of New Jersey would benefit from higher sampling frequency, measurements of multiple**

carbonate chemistry parameters, higher resolution bottom water measurements, monitoring across the coastal salinity gradient, and co-located biological response monitoring.

Why a Comprehensive Statewide OA Monitoring Network?

The current acidification monitoring efforts in New Jersey are a mosaic of individual projects without cohesiveness. However, strategically linking these efforts and integrating resources in the development of a comprehensive statewide OA monitoring network would be a viable solution to this problem. This network would facilitate efforts through a coordinated membership that can cohesively identify observation gaps, coordinate observation efforts to maximize temporal and spatial coverage, and expand observing capabilities within the network. Mathis & Feeley (2013) identified four critical aspects of OA in coastal regions – spatial extent, temporal duration, level of intensity, and biological responses - that should be effectively integrated into a monitoring network. Complementary measurements or monitoring projects integrating these four aspects will be able to identify locations and/or times of vulnerability, determine mechanistic drivers of carbonate chemistry and rates of change, investigate interactions between physical, chemical, and biological variables, and spatially and temporally resolve data for model parameterization (Mathis & Feeley 2013). The scientific understanding gained from a comprehensive monitoring network would expand the management options available on the state level.

However, developing a statewide monitoring network does not come without its challenges. Availability of resources to support a network will likely be an obstacle. Creating a network is expensive, so the development of one must be strategic. Additionally, state representatives interviewed early on when discussing first steps of a New Jersey OA Action Plan commented that the coordination and facilitation of partners was a bigger challenge to developing a collaborative monitoring network than availability of resources. Ensuring consistent monitoring protocols and data quality assurance standards, conducting assimilated assessment of data from multiple partners, and facilitating openly accessible, timely and accurate delivery of monitoring data involves considerable facilitation. At least one state explained that, given limitations of resources, it was unable to develop a fully comprehensive statewide monitoring network and, as such, needed to collaborate with the science community to set priorities for enhancement of monitoring sites/locations that can act as “sentinels” to track OA trends.

Furthermore, engaging stakeholders is essential to advancing a coordinated OA initiative. Almost all states with active or developing OA Action Plans include extensive and substantial stakeholder engagement as part of their OA initiatives. This engagement can come in many forms, such as allowing for public commentary on proposed policy, and conducting educational outreach regarding the potential economic impacts of OA. In these states, the primary engagement of public stakeholders is generally with coastal conservation organizations and fish and shellfish industry representatives for which research and monitoring has shown the great impacts or potential impacts from OA, and they have reported that these engagement strategies led to important support for development of policy options and identifying support for science and monitoring. New Jersey does not currently have such a forum with which to begin a science-informed dialogue among stakeholders. Based on the experiences in other states, results from scientific monitoring have been critical to initial engagement of fishery and shellfish industry actors.

In order to obtain feedback from a diverse range of potential Network participants, Rutgers University and the NJCMP OA team jointly composed and facilitated a virtual workshop on November 19th, 2021, that focused on developing a New Jersey statewide OA monitoring network. Workshop attendees were invited to participate based on previous efforts that identified entities collecting OA data and entities whose partnership will be essential in building a strong monitoring network. Those invited included industry (e.g., commercial shellfisheries, commercial and recreational fin fisheries, hatcheries, aquaculture facilities, nurseries), offshore wind developers, state executive branch agencies, federal researchers, academic institutions, and non-profit organizations. The objectives of the workshop were as follows:

- Review the existing acidification monitoring in New Jersey state waters and the current observation gaps
- Collectively summarize locations, time periods, and potential approaches to optimize and expand monitoring in New Jersey
- Discuss required costs, logistics, and next steps needed to develop, coordinate, and maintain a statewide acidification monitoring network
- Discuss strategies for communication, engagement, and partnerships with industry stakeholders

The workshop summary report is complete and contains community feedback and guidance that have contributed to this Recommendations document for NJCMP consideration.

Steps Toward Developing a Statewide OA Monitoring Network

Five major recommendations are presented here that could be used as a framework to develop a statewide New Jersey OA monitoring network. The formation of an OA Working Group in Step 1 will undergo three major tasks that will culminate in recommendations to best optimize the monitoring network, based on a gaps analysis, designed to address management decision-making needs. Steps 2-5 will provide logistical and data management support for the recommended monitoring optimization to ensure the Network operation and maintenance delivers timely and decision-relevant information for the state.

1. Convene an OA Working Group

The OA Working Group (OAWG) could be more formally labeled a Task Force, Commission, Committee, or Team, but no matter what designation or structure the working group takes, Tasks 1-3 outlined in this section should be priority actions undertaken by the OAWG for New Jersey state. Historically, the development of an OA Task Force (or Commission, e.g. Maine) has been initiated through state legislature. The mission of the standing state OA Task Forces is to provide sound scientific advice to the state focused on evaluating the anticipated ecological and economic impacts of OA, identifying the various drivers contributing to ocean and coastal acidification, and to evaluate potential OA-focused adaptive measures or mitigation strategies (e.g., nutrient reduction, phytoremediation, monitoring and mitigation programs for aquaculture facilities and hatcheries). The findings of the OA Task Forces have typically culminated in state OA Action Plans, that ultimately recommended guidelines for targeted state actions to prepare for and reduce OA and its potential impacts.

All existing state OA Action Plans call for investments in research and monitoring of OA because the resulting data inform decision-making with sound science. However, how that research and monitoring are conducted, integrated into existing research and monitoring efforts, and ultimately synthesized into useful data products and information are specific to each state's vulnerability and needs. For example, California's Ocean Acidification and Hypoxia (OAH) Science Task Force addressed this by producing an inventory of the state's monitoring assets, conducting a gaps analysis, and proposing recommendations to fill those gaps targeted to decision-making needs (access here). State-specific vulnerabilities and needs can similarly be addressed for New Jersey through the establishment of an OAWG with one of its charges specifically focused on monitoring with the three following tasks: 1) Inventory current monitoring assets, 2) Assess gaps in monitoring, and 3) Recommend prioritization and gap filling approaches to enhance the state monitoring network toward decision-making needs.

Fortunately, some groundwork has been laid for these three tasks from recent previous efforts by the Mid-Atlantic Coastal Acidification Network (MACAN) and the efforts from the initial Rutgers-NJCMP OA team efforts. MACAN conducted a first-order inventory identifying locations in the Mid-Atlantic, including coastal New Jersey, where one or more metrics of ocean acidification was or is currently being measured (pH, a measure of how acidic or basic water is based on the amount of H^+ present; dissolved CO_2 or pCO_2, the concentration of CO_2 dissolved in the water; total alkalinity or TA, a measure of seawater buffering capacity; and/or dissolved inorganic carbon or DIC, the sum of the dissolved carbon species). The inventory included datasets from ongoing sampling efforts as well as past projects that collected those types of data. The final product consisted of OA monitoring maps that are accessible on the Mid-Atlantic Regional Council on the Ocean (MARCO) Ocean Data Portal that aided in the publication of "Scientific considerations for acidification monitoring in the U.S. Mid-Atlantic Region" (Goldsmith et al. 2019). However, this inventory was limited to data collected in estuarine and coastal shelf environments (less so in freshwater), and has not been updated since about 2018. Further, the initial report by Saba et al. (2020) included a section that narrowed down the MACAN inventory to those specific to New Jersey coastal waters and made a first pass at identifying spatio-temporal monitoring gaps and recommending approaches to fill those gaps. While these efforts provide a solid foundation to start, an OAWG consisting of experts from a much broader range of profession, expertise, and geography will enable a more comprehensive inventory and therefore will better inform a gaps analysis and decision-relevant gap filling strategy.

Task 1: Inventory Current Monitoring Assets

The recommendations presented here are motivated by those undertaken for the recent West Coast OAH Monitoring Inventory that includes 247 projects and 4,103 assets, which in combination describe the OA and hypoxia monitoring network (sampling sites) on the West Coast (access here). The New Jersey OAWG could choose to undergo this task directly, or establish a subgroup (e.g., Inventory Task Force) to conduct the inventory. The inventory would consist of a catalog of previous and ongoing monitoring projects that would include data collected as well as metadata about each collected dataset (e.g., information on data collection entity/project leads, variables measured, platform for measurement, date range of data collection, location where data can be accessed). The inventory should represent what chemical, physical, and biological monitoring already exists (from nearshore freshwater to offshore slope) that can then inform Tasks 2 (gaps analysis) and 3 (strategic gap filling approach).

The OAWG would first decide on inclusion criteria that would need to be met for the dataset/project to be included in the inventory. These could include, but are not limited to, datasets/sampling efforts that are limited to those measured in the field (not laboratory-based manipulations), only ongoing projects (not past efforts), have a component of repeatability to assess changes over time at sampling locations, and measure at least one metric of ocean acidification. The OAWG should take care to include enough relevant criteria that will inform locations and times of existing carbonate chemistry measurement, but not too much that could either limit useful data from being included in the inventory or add more detail than necessary. Next, the OAWG should create an inventory template that will be distributed to monitoring entities to gather the necessary detailed information for integrating into the inventory. Another decision that will need to be made is the platform type for hosting the inventory. The West Coast OAH Monitoring Inventory uploaded their inventory to ArcGIS online and created a Web App, and this option could be considered for New Jersey. Finally, after a quality control process and a round of review on the submitted inventory templates, the information should be integrated into the chosen platform.

In designing the inventory, the ability for updating and maintenance should be built in to keep the inventory current; however, this may require additional funding and workforce. Effectiveness could be improved by designing and implementing a streamlined data submission process. Communication with entities conducting freshwater and ocean observations within the state and the broader region (e.g., MACAN participants, researchers at NOAA Northeast Fisheries Science Center, investigators funded by NOAA OAP) will be key to ensure the inventory captures all relevant projects. Once the inventory is set up and in maintenance mode, it will be useful in communicating needs to support grant proposals, building foundations for collaborations, and approving direct investments in specific bodies of water.

Task 2: Assessment of Gaps in Monitoring

We now have some understanding of seasonal dynamics of carbonate chemistry through high resolution glider-based missions (Wright-Fairbanks et al. 2020). In New Jersey shelf waters, low pH in nearshore waters associated with freshwater input can occur year-round, and low pH/omega has been detected in bottom 'Cold Pool' water during summer.

Injections of warm, salty, highly alkaline offshore slope water onto the coastal shelf during episodic interactions with warm core rings or during fall mixing act to alleviate acidification. So, while we can say something about intensity and seasonality, we can infer little about spatial extent, duration, and *in situ* biological impacts due to lack of spatial and temporal resolution sampling and coordinated, co-located biological monitoring. These specific attributes become very important in terms of understanding whether they meet or surpass organism threshold tolerances.

Several gaps in observations were recently outlined for the Mid-Atlantic region in Goldsmith et al. (2019) and are relevant to those in New Jersey waters. These are outlined in Saba et al. (2020) and included here with some modifications based on feedback obtained during the November 2021 New Jersey OA monitoring network workshop. They include the:

- *Need for higher sampling frequency:* With the exception of a few fixed autonomous stations (e.g., buoys), the sampling frequency is too low to adequately capture short-term episodic events that could have immediate impacts to industries and managed ecosystems.
- *Need to enhance spatial resolution while monitoring across a salinity gradient*: It is important to monitor different habitats across different salinity gradients as well as major sources of inputs, such as rivers, wetlands, and upstream of source waters to understand the spectrum of impacts to the region. There is a preliminary understanding that OA impacts coastal marshes and is simultaneously influenced by inputs from terrestrial and freshwater bodies, but current monitoring does not focus on these interactions yet. Efforts to monitor along a salinity gradient would also account for the complexity of estuary, coastal and ocean environments and further identify potential areas of enhanced vulnerability. There is particular interest in understanding the evolution (and biological impacts) of the naturally acidic Pineland water as it moves downstream. Additionally, boundaries such as river plumes where freshwater and saltwater converge are also important physically, chemically, and biologically and should be considered. In order to maximize efficiency in data collection (and its cost), there is a need to evaluate how much resolution (in both time and space) is needed to make decisions about a specific study area.
- *Need for measurements of multiple carbonate chemistry parameters:* Few current monitoring efforts combine frequent monitoring with an adequate number of carbonate system parameters for monitoring the status of acidification. Two or more parameters are needed to fully characterize carbonate chemistry and define the status of acidification, including calculations of Ωarag.
- *Need for high-resolution depth-profiling measurements*: Most current sampling is done in surface waters, but subsurface waters are typically more acidic due to the biological remineralization of sinking particulate organic surface material. This has been observed in New Jersey coastal shelf waters (Saba et al. 2019a). Furthermore, this is not only a multi-stressor issue but also one of the most important gaps to address for coastal acidification due to subsurface or bottom waters becoming increasingly or episodically more acidic in response to eutrophication, simultaneously with decreasing dissolved oxygen. Additionally, benthic flux

monitoring has not been considered in the OA plan so far but may prove to be insightful as interactions with sediments are likely an important factor for benthic dwelling organisms.

- *Need to observe OA with other stressors*: Other stressors such as temperature, pollutants (namely excess nutrients that result in eutrophication), algal blooms (both benign and harmful species), and hypoxia may also interact with the acidification of local inshore and nearshore waters.
- *Need for co-located biological response monitoring*: Because most of what we know about organism response is a result of single-species laboratory studies and may not capture realistic, natural conditions or variability, simultaneous measurements of biological response indicators (e.g., survival, development, productivity, growth) need to be co-located with carbonate chemistry observations.
- *Need to evaluate what monitoring is required to understand baseline conditions*: With such a dynamic complex coastal system with respect to high daily, annual, interannual fluctuations, setting boundaries to determine a background level spatially and temporally is challenging. However, it is an important effort to undertake in order to plan for sustained monitoring that will allow the development of climatologies in order to track long-term changes in the system.

With these gaps in mind, the OAWG should evaluate the updated state monitoring inventory and ask questions similar to those asked during the California OAH Task Force gaps analysis: 1) Spatial: Is monitoring occurring in the right places, especially in relation to upcoast versus downcoast monitoring, cross-shelf monitoring and monitoring vertically within the water column? 2) Temporal: Is monitoring taking place at the right times? 3) Parameters: Are the right indicators being monitored? 4) Data quality: Are parameters being monitored well, particularly in terms of consistency and high-accuracy equipment? (see McLaughlin et al. 2017); 5) Data availability: Is the collected monitoring data easily accessible?

This task could be undertaken through a formal gaps analysis using similar approaches as those used for identifying gaps in the acidification monitoring network of the California Current System described in Taylor-Burns et al. (2020). The authors utilized the West Coast OAH Monitoring Inventory to identify times and locations where existing monitoring efforts were inadequate to fully characterize the carbonate system, including aragonite saturation state. They used a modified moderate approach that fell between more simplistic methods (Asch & Turgeon 2003) and the more involved methods of Frolov et al. (2013). Through this analysis, they identified three key monitoring gaps, one of which was at the mouth of the San Francisco Bay. The authors suggested this was due to the limited number of assets located throughout the dramatic salinity gradient at this location, and they highlighted that closely clustered assets are more ideal for a monitoring network in a highly dynamic location, similar to that concluded in White & Bernstein (1979).

The Task Force should also evaluate locations where ongoing monitoring is occurring and consider if/where the long-term datasets exist, which of these are at risk of losing capacity, what sites are providing little value now but could easily be augmented to provide lots of value, and if there are existing sampling sites in highly relevant proximity of industry and aquaculture (e.g., near hatcheries, large scale nurseries, high density growout locations).

TASK 3: Prioritize and fill gaps to improve network

Before the more technical process of developing or enhancing an OA monitoring network begins, there first needs to be a consensus on which questions the network is designed to answer. Data gaps should strategically be filled so that they solve actionable problems rather than gather data for the sake of gathering data. In 2016, the West Coast Ocean Acidification and Hypoxia Science Panel (WCOAH-SP) looked into the key attributes needed for developing an OAH monitoring network. Several were identified, the most important being that the monitoring network supports the needs of decision-makers. Therefore, the OAWG should ask for example, what kinds of information will we get from a comprehensive monitoring network and what kinds of decisions can we make from it? From this, the OAWG could narrow down the list of questions that New Jersey's OA network will be designed to answer by establishing a base understanding of where New Jersey is most vulnerable and what authority NJDEP has to act. An impactful monitoring network will provide specific and rigorous measurements to both scientists and managers. Scientists can use the data to examine potential ecosystem changes at times and locations relevant to important habitats for species they care about. However, data collection cannot be based purely off of academic interests, but needs to incorporate actionable concerns as well. Managers can use the data to guide their policy, budgeting, staffing, and research decisions. How to measure this depends on what exactly managers need to know most.

Filling monitoring gaps should be prioritized based on how relevant each gap is to management needs and decisions. The Task Force should assess how well *existing* data collection systems provide actionable data for those decisions and then determine the *future* investments that will most improve the state's ability to manage. The exact place to measure, then, should be decided based on what is most interesting from a management perspective and what could best address the public concern. Investments in the additional monitoring necessary to fill gaps should also provide a return on investment in the form of providing the state actionable information. In order to prioritize gap filling, there are three pieces of information needed at the outset that should be obtained from outcomes of the gaps analysis. One is a description spatially, of what locations are presently at risk of low pH impacts, another is temporal trends, if OA is worsening over time, and the third is an understanding about if and where spatial and temporal variability exist. Once this information is established, managers must consider what authority they have to act on the data, what species most need to be protected, and which communities are at most risk. However, due to lack of monitoring at certain times and locations, we may not know areas and times when OA is problematic. Certain natural processes are not fully understood in terms of how they influence or are influenced by OA. In these cases, these are true gaps and the Task Force should decide if/how monitoring should be structured to fill these gaps.

From there, the state can better plan where high-density sampling is needed and identify specific locations with insufficient monitoring that should be prioritized for enhancement.

The two approaches for developing or enhancing a monitoring network include leveraging existing data collection programs (adding sensors/metrics to an existing site) or adding new monitoring sites. New Jersey would likely benefit from investing in a combination of the two approaches to strategically maximize spatio-temporal and discipline (metric) coverage, and implementation of these different approaches would likely depend on available funding to support them. Both approaches will require significant and productive partnerships. Therefore, the OAWG should discuss strategies for communication, engagement, and partnerships with a diverse range of stakeholders, including industry.

Because founding new monitoring initiatives are prohibitively expensive, leveraging existing data collection programs would be a first-order gap filling charge. Some initial strategies for optimizing existing observations to fill monitoring gaps for the state of New Jersey were offered in Saba et al. (2020) and could be further discussed as options by the broader OAWG: 1) Synthesize data and develop data products from the repository of previous and ongoing OA monitoring efforts: A data synthesis component that regularly integrates statewide datasets could be used to develop products for a range of industry and policy stakeholders such as a “report card” indicating OA status and trends; 2) Optimize existing glider-based coastal observation programs with sensors measuring pH and estimating total alkalinity to resolve the full carbonate system: Rutgers University and Stony Brook University have glider programs with frequent missions in New Jersey coastal waters. Some of their ongoing programs already support deployments of gliders fitted with pH sensors with the ability to calculate total alkalinity from glider-based salinity. However, a majority of gliders deployed through other programs – those focused on hurricane, marine mammals, fisheries, and offshore wind development baseline research – do not include pH sensors. The addition of a pH sensor on these glider missions would add significant high spatio-temporal resolution sampling of pH; and 3) Coordinate with partner agencies to add additional carbonate chemistry parameters to existing vessel-based monitoring stations or stationary moorings. Several programs are currently monitoring a variety of water quality and other parameters, including pH, for inshore and nearshore waters in New Jersey. Based on feedback obtained at the November 2021 New Jersey OA monitoring network workshop, many of these entities conducting regular vessel-based water quality monitoring at fixed stations, would be willing to collect discrete samples for one or more carbonate chemistry parameters (pH, $p\text{CO}_2$, TA, DIC) in order to fully resolve the carbonate system including Ωarag. Taylor & Burns (2020) states: “Aragonite saturation state is the most direct link between acidification condition and biological response, and defining aragonite saturation state constrains the entirety of the inorganic carbon system, allowing inferences of numerous parameters that can be used to evaluate biological effects of changing ocean chemistry. Without aragonite measurements, the rest of this information is lost—thus, an ideal monitoring network will contain carbonate complete monitoring assets to allow users to calculate aragonite saturation state from the data collected at each asset”. Another benefit of augmenting existing water quality-focused monitoring as most of these programs operate in either or both freshwater and estuarine systems, this augmentation would be a cost-effective option to filling the significant gaps in these habitats that support the socio-economically important Eastern oyster, including oyster aquaculture facilities, hatcheries, and growout locations. Existing fixed platforms, such as buoys operated by the National Data Buoy Center and U.S. Army Corp of Engineers (ranging between 20 and 200 km offshore on the New Jersey shelf), could be utilized as options for optimization by incorporating pH and $p\mathrm{CO}_2$ sensors, along with measurements of temperature and salinity. This would not only allow for including two or more carbonate chemistry sensors to fully characterize OA, but would also greatly enhance temporal resolution to capture episodic events (e.g., upwelling, big seasonal bloom) and seasonal cycles. Finally, offshore wind platforms, once operational, could be options for mounting pH and $p\mathrm{CO}_2$ sensors to enhance temporal presence on the New Jersey coastal shelf.

Identifying and prioritizing new locations for monitoring OA may be necessary if the gaps analysis reveals a significant lack of spatial resolution in certain locales and no leverageable ongoing monitoring exists. The OAWG should then be intentional in recommending the placement of new monitoring programs (discrete and/or sensor-based sampling) where they can unearth additional information on OA processes not fully understood including along the freshwater-ocean gradient. New monitoring programs might include partnerships with industry groups to begin monitoring at economic sites of interest. There are several potential benefits in developing these relationships, both for the state gap-filling needs and for the industry partners. Partnerships with commercial and recreational fisherman would produce samples from both nearshore and offshore waters and these measurements would be co-located with biology (e.g., presence/absence, abundance, biomass). Partnerships with the shellfish industry to locate monitoring near, or at, potentially OA sensitive culture facilities would also be helpful. Many hatcheries are already measuring the water inside of their facility but do not have the financial means or expertise to measure ambient water. State-funded ambient water monitoring could resolve the issue. Monitoring at or near these facilities would offer another opportunity to couple biological performance metrics with the chemistry data. Additionally, most key management decisions are informed by models. Establishing new monitoring locations may be necessary to improve or parameterize coastal OA models or assess their performance. Models are used to define the areas most and least vulnerable to OA change, assess the likely effectiveness of reducing local nutrient and carbon inputs, and then decide where the best locations for mitigation are. Confidence in these models is therefore critical.

The OAWG should also acknowledge the following considerations for gap-filling:

- Better connecting chemical and biological monitoring was considered the most important recommendation for other states developing OA monitoring networks. It has also been highlighted as a top priority by federal research programs such as NOAA OAP (see NOAA OAP Research Plan 2020-2029). The state makes management decisions primarily around protecting biota, yet most OA monitoring is focused on chemistry. There needs to be a connection forged between changes in chemistry and the impacts OA has on marine life, which can be accomplished with synchronized biological and chemical measurements. Most information we have pertaining to the response of marine organisms to OA is from controlled laboratory experiments. These studies are helpful in determining initial water quality thresholds, but field studies are needed to confirm those results and must cover a wide array of OA exposure conditions. In California's efforts to enhance their OAH monitoring network, two approaches were recommended for improving the biological information needed for management. One is to standardize, advance, and incorporate biological measurements of OA effects into pre-existing regional chemistry monitoring programs. The other is to add OA related chemistry parameters to pre-existing biological monitoring programs. The California Task Force ultimately decided to focus more heavily on the first approach because it offered better data quality control and was more effective at registering early warning signs of OA impacts than the second approach. Potential biological variables that could feasibly be paired with the chemical samples include observations of damaged bodily structures (evidence that the animal has been exposed to acidification), oxidative stress or measurements of shell strength (evidence that the animal's functioning is negatively impacted), and eDNA (presence/absence measurements to determine acidification conditions at which the species is no longer present). The New Jersey OAWG would need to investigate which existing (or new) sampling programs could feasibly and financially augment efforts to include one or more biological metrics. One such possibility is the East Coast Ocean Acidification (ECOA) cruises which travel between the Gulf Coast and Maine every 3-4 years. These cruises cover several transects, two of which are in New Jersey coastal waters. The cruises collect measurements of all four carbonate chemistry parameters (pH, TA, pCO_2, DIC) and biological parameters, including net primary production (the rate at which phytoplankton produce biomass) and community respiration (total amount of CO_2 produced by an individual organism). At the November 2021 New Jersey OA monitoring network workshop, there were suggestions of adding additional biological samples to these cruises (i.e., zooplankton sampling, fish acoustics) if funding and logistics allowed

- The type of equipment used to monitor also centers around the questions the network is trying to answer. High quality sensors are most accurate for climate-grade applications, but that accuracy comes with a larger price tag. A possible solution is to establish a few anchor sites with high quality sensors and then several peripheral sites with lower cost sensors to complement the anchor site data. The increased availability of high-quality, low-cost sensors could greatly enhance data collection as well as the expansion of collaborating Network partners, including industry (Wang et al. 2019).
- Considerations of platform types and placement of those platforms and sensors should also link carbonate chemistry with their respective drivers. For instance, freshwater inputs lower pH and Ωarag in nearshore coastal waters year-round with fluctuations in intensity due to episodic precipitation events. Therefore, having a more year-round consistent temporal presence (e.g., mooring) in locations of persistent freshwater input should be prioritized. This would also enable the ability

to capture near-shore acidification events due to episodic upwelling of low pH/Ωarag that typically occurs during summer. Alternatively, low pH/Ωarag occurs seasonally (late spring – early fall) in bottom Cold Pool waters in the mid-shelf coastal Mid-Atlantic (off the coast of New Jersey) due to low ventilation with surface water and high bacterial respiration. Installing a monitoring system that can capture carbonate chemistry spring-fall throughout the full water column and the horizontal extent of the Cold Pool (e.g., gliders) would provide valuable information on duration, extent, and intensity of seasonal acidification.

- A statewide initiative, and continued participation in regional acidification networks (i.e., Mid-Atlantic Coastal Acidification Network), would be mutually supportive in providing valuable data and increasing science and monitoring capacity

2. <u>Enhance availability for discrete sample analysis</u>

As highlighted above, a first order approach to gap-fill monitoring needs, particularly those focused on adding additional carbonate chemistry measurements to fully resolve the carbonate system, is to leverage existing monitoring programs regularly conducting vessel-based water quality monitoring at fixed stations. At the November 2021 New Jersey OA monitoring network workshop, several attendees representing a range of water quality monitoring organizations around the state indicated interest in getting involved and would be willing to add discrete water collection (pH, TA, DIC) to their sampling routine, if there was sufficient funding to support the effort. While there would be necessary training involved to ensure proper protocols in sample collection, preservation, and storage, the larger hurdle identified by the workshop participants was the lack of accessibility for discrete sample analysis at a laboratory that uses community-accepted quality control standards. NJDEP operates a laboratory to process samples collected by NJDEP, but there is currently no statewide lab that can be contracted to analyze water samples collected by other entities. There are also a few academic institutions and academic working groups with the ability to analyze samples using the required quality control standards. Data collected for regulatory purposes must be approved by EPA, DEP, or USGS. Regulatory usage data must also be analyzed in a certified lab, and some labs may be certified for only a few of the total parameters that are to be tested. EPA may be the only technically certified lab in the nation.

To relieve the limitation of sample analysis in this leveraged optimization approach, NJDEP would need to define what constitutes a “certified” lab and then compile a list of acceptable analysis laboratories from which a monitoring group could easily access and develop partnerships. In the case of academic laboratories, they typically do not go through a formal certification process for carbonate chemistry samples; however, they use community-accepted quality control protocols (Dickson et al. 2007) and certified reference materials (CRMs obtained from Professor Andrew Dickson at University of California San Diego, Scripps Institution of Oceanography). Several of these labs have also participated in a blind calibration inter-laboratory comparison procedure, in collaboration with Andrew Dickson’s lab, to ensure high analytical accuracy and precision. Additionally, or alternatively to defining and using a list of certified labs, NJDEP could expand capacity at its marine water monitoring lab in Leeds Point to analyze most or all carbonate chemistry samples there.

3. Adopt Community Best Practices to Ensure Data Quality Control

There was consensus among workshop participants that any state monitoring participants should adopt similar best practices protocols and data quality assurance and quality control procedures to ensure data quality, standardization, and ease of synthesis. Adopting common best practices will require workforce effort and monetary support, particularly to train data collectors and data providers the adopted procedures in data quality assurance, quality control, and integrating the standardized, quality-controlled data into databases for open access. NJDEP's data collection standards, methodology for collecting samples, along with guidance on the appropriate equipment for collecting such data, would be necessary. A cohesive list of the exact parameters that DEP needs measured and the level of importance for each would be helpful as well.

Best practices for data standards are becoming common place, many are already the standard, community-adopted protocols or are in the process of obtaining user community approval. These protocols are also specific to sensor and/or sample type. These could be adopted and utilized for New Jersey state monitoring. For instance, there is an established Quality Assurance/ Quality Control of Real Time Oceanographic Data (QARTOD) for pH sensor data (U.S. Integrated Ocean Observing System 2019). These methods are utilized for the glider-based pH observations, and a recent best practices document specific to glider pH was recently published (Thompson et al. 2021) and will be pushed forward for broader community review. Community-adopted protocols for discrete pH, TA, and DIC typically follow Dickson et al. (2007), but a recent paper by Jiang et al. (2022) focuses on best practices for discrete data that includes data standards for submitting data and metadata to established open access databases (e.g., NCEI) and should be considered by New Jersey state.

4. Develop Network Data Management

NJDEP should decide if the monitoring inventory consists only of data locations (GIS enabled so the locations of data collection can be mapped online easily) and metadata parameters, or if the data should be housed together in a specified data repository. The former option is sufficient for a gaps analysis and, if regularly updated and maintained, would allow for successful evaluation of implemented gap filling measures. The latter option would facilitate ease of data access and synthesis efforts. Either option will require a dedicated project manager to update and maintain, but the latter would require significantly more time and resources.

The monitoring inventory needs a pre-established portal to reside. Oregon structured their inventory as a spreadsheet of projects and assets. It is GIS enabled so the locations of data providers can be mapped online easily, but they highlighted the need to dedicate a project manager focused on inventory updating and maintenance. One option for New Jersey is to house their inventory in the MARCO (Mid-Atlantic Regional Council on the Ocean) Mid-Atlantic

Ocean Data Portal[1] or the MARACOOS (Mid-Atlantic Regional Association Coastal Ocean Observing System) OceansMap[2] which already have respective teams dedicated to their operation and maintenance.

If NJDEP decides to house all relevant data in a common data repository, significant effort would be needed to inventory, integrate, archive all datasets. NJDEP may opt to house the data repository; however, if the data repository becomes too large, external storage may be required. Establishing a data repository for the monitoring data to live within should allow for the easy accessibility by a diverse range of users as well as movement of information between systems. Data input should be standardized (e.g., indicators for missing data, similar standard names/abbreviations, similar quality control flags, standardized calculation of various parameters) to ensure ease of accessibility, updating and maintenance, and translation. Furthermore, a data product that requires the manual translation of information is unsustainable. Funding for both the monitoring data and monitoring network should be collaborative at the regional and state levels.

5. Coordinate the OA Network

Developing and maintaining a statewide OA monitoring network will require significant coordination, in terms of not only developing the partnerships that will be necessary to optimize the network but also in managing the frequent workload that will be necessary in maintaining the monitoring inventory. As mentioned in the above section, a dedicated project manager would be necessary to keep the monitoring inventory up to date. NJDEP would need to assign the governance or ownership of the OA monitoring network, and therefore the entity and supervisor(s) a project manager would report to. This project manager could also serve more broadly as the OA monitoring network coordinator if their skillset allowed. If supporting a full-time person is not financially feasible, the tasks could be shared between two people (or more), acting as co-coordinators, serving different but complementary roles (e.g., one managing the inventory, the other serving an outreach role for developing and maintaining partnerships and communicating with various stakeholders). And if the job responsibilities are aligned with existing positions within the governing entity, merging the Network tasks with existing tasks would be a cost-effective approach to support Network coordination. This is the approach taken by the two co-coordinators of MACAN, whose Network tasks are aligned with those of their relative entities – MARCO and MARACOOS. NJDEP will need to assess financial support that could be dedicated to Network development and operation, and develop the most cost-effective approach for successful Network coordination.

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[1] https://portal.midatlanticocean.org

[2] https://oceansmap.maracoos.org

Lessons from Other States

Other states that developed OA monitoring networks similar in scope to that proposed here, have graciously shared some key lessons to keep in mind as New Jersey progresses: 1) the network should be inclusive in terms of its geographic scope and partners, 2) the network must be sustainable in terms of developing personal connections between local communities and the data, focusing on the metrics that will inspire continued support, and being easily updated, 3) the network’s desired outcomes should be established ahead of time.

Contributors to this Document

This document was reviewed and approved by the New Jersey Department of Environmental Protection’s Coastal Management Program Ocean Acidification Team that includes: Megan Rutkowski, Russell Babb, Helaine Barr, Lauren Drumm, Heather Genievich, Karl Hartkopf, Kevin Hassell, Megan Kelly, Elizabeth Lange, Bob Schuster, and Katherine Todoroff. We also would like to extend thanks to external reviewers from the Mid-Atlantic Coastal Acidification Network (MACAN) community who also provided feedback on this document.

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