NECAN

Monitoring Priorities in the Northeast

Workshop Report

NERACOOS
NORTHEASTERN REGIONAL ASSOCIATION OF COASTAL OCEAN OBSERVING SYSTEMS

OAP
NOAA OCEAN ACIDIFICATION PROGRAM

NECAN
The Northeast Coastal Acidification Network

NROC
Northeast Regional Ocean Council

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Executive Summary:

The Northeast Coastal Acidification Network (NECAN) held a workshop November 2-3, 2023 to identify and recommend monitoring priorities for ocean acidification in the NECAN region. Prior to the workshop, NECAN had submitted monitoring needs to the Interagency Working Group on Ocean Acidification. One of the outcomes of the workshop was to prioritize these needs in terms of importance to user groups (Imp), feasibility (Feas), and cost. The table below provides the resulting rankings. The numbers are the rankings for each category (1st = highest ranking, 6th = lowest ranking). In the case of a tie, the lowest number (higher ranking) is used for both entries.

Monitoring need	**Imp**	**Feas**	**Cost**
Improve spatial and temporal scale of monitoring co-located OA variables and biological measurements to better resolve variability of acidification dynamics in concert with biological processes	1st	1st	2nd
Increase subsurface monitoring to understand how conditions vary at depth	2nd	1st	2nd
Increase the number of high-frequency monitoring assets that measure at least two of four carbon parameters	3rd	3rd	1st
Increase near real time and rapid response observing capacity to capture episodic events	4th	5th	5th
Fluxes and rates that would help parameterize and constrain regional modeling efforts to understand past conditions and project future trends	5th	6th	6th
Better spatial coverage of climate-quality observations	6th	4th	4th

General recommendations for a monitoring plan included the following:

- Providing technical assistance to monitoring groups, data management and data visualizations

- Developing maps of monitoring assets that include OA parameters
- Deploying new sensors (in collaboration with existing monitoring where possible), and
- Increasing understanding of OA biogeochemistry and impacts to biology to determine what monitoring is required.

Introduction:
The Northeast Coastal Acidification Network (NECAN) is the leading group in the region for the synthesis and dissemination of ocean and coastal acidification information. Established under the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) in 2013, NECAN is a partnership among government agencies, industry members, and the scientific community. NECAN serves as a conduit through which decision makers and stakeholders can provide guidance for regional research and monitoring. The NECAN region encompasses the coastal ocean from the high-water line out to the shelf-break from Long Island Sound to Nova Scotia.

Within the NECAN region (Maritime Canada to Long Island Sound), ocean and coastal acidification (OCA) has been a focus of several US state commissions since 2014. In each of the final reports, enhanced monitoring for OCA parameters has been recommended. National reports and Congressional direction also recommend more monitoring, both for ocean acidification(OA) (*i.e.*, CO_2-driven acidification absent the influence of coastal processes) and coastal acidification (*i.e.*, acidification including the influence of freshwater from land and coastally located respiration). However, these reports lack specifics on what form this monitoring should take. NECAN is a logical entity to develop a region-wide plan for monitoring. Indeed, NECAN is called out to lead this effort in many state commission reports and in the reauthorized Integrated Coastal and Ocean Observation System Act (ICOOS).

NECAN is also seen as a regional resource and contributor to US national reports such as those mandated under the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act; 33 U.S.C. Chapter 50, Sec. 3701-3708). The Interagency Working Group on Ocean Acidification (IWG-OA) includes Federal agencies that have mandates for research and/or management of resources and ecosystems likely to be impacted by OA. The IWG-OA prepares reports for Congress detailing research and monitoring plans, vulnerability assessments and progress on these activities. In 2023, an update to the Strategic Plan for Federal Research and Monitoring of Ocean Acidification was released, and NECAN was invited to provide input on monitoring priorities for Northeast US coastal waters (see below).

The Northeast Regional Ocean Council (NROC) is a voluntary forum for New England states and federal partners to coordinate and collaborate on regional approaches to support balanced uses and conservation of the Northeast region's ocean and coastal resources. Its committee on Ocean and Coastal Ecosystem Health works closely with NECAN to improve scientific understanding of ocean and coastal acidification and work with stakeholders to adapt to the effects of acidification. Many of the state and federal partners in NROC have robust monitoring programs to provide information for coastal management. Addition of OA monitoring is of interest to these partners.

To develop a more integrated and effective OA monitoring strategy, NECAN held a series of webinars to solicit insights from the regional network of OA experts including researchers, data generators, and user communities, culminating in a workshop to identify and recommend monitoring priorities for the NECAN region. A total of 12, 90 min webinars were held and archived on the NECAN website and the NERACOOS Youtube Channel. The NECAN Steering Committee is grateful to webinar speakers (see appendix one) for their discussions and insights.

Webinar themes

Monitoring serves several purposes, and the type, location and timing of monitoring done will need to be optimized for different uses. Therefore, webinars were solicited from experts under the following themes: Assessments, Biological Impacts, Modeling, Climate, Rapid Response, Indigenous Interests, Concerns, and Perspectives, User Needs and Products, and New Technologies.

Current Assessments: Many programs in the NECAN region are providing assessments of ecosystem status to various stakeholders. These cover a spatial range from individual estuaries to the entire Gulf of Maine. Monitoring activities are essential to these programs to provide information on acidification trends, controls and drivers, interactions with other stressors such as hypoxia and Harmful Algal Blooms, and impacts on important species and habitats.

Biological Impacts: There are 3 distinct NECAN sub-regions that warrant discrete monitoring efforts: The Gulf of Maine, Georges Bank, and the Mid-Atlantic (including Long Island Sound). These regions exhibit different trends in seasonal warming and phytoplankton dynamics, and sometimes support different genetic populations. Most of the work on biological impacts of OA has occurred in laboratory experiments, which allow the experimenter to manipulate water conditions and add other factors such as food quality, O_2,or temperature. Translating these lab studies into naturally living populations remains a challenge and requires monitoring of not only OCA parameters, but doing so alongside biological indices of response from individuals, populations and communities. More *in situ coincident* field measurements of chemistry and biology are needed to characterize environmental conditions and field experiments are needed to understand how OA functions as a stressor within a natural multi-stressor context.

Modeling: Observations from monitoring efforts increase the capacity to project future conditions of OA, or simulate historical conditions to understand past events. Observations are needed to constrain model boundary conditions and develop parameterizations of important processes. Evaluation of model performance requires independent monitoring data, which is important not only to understand how the model is working, but also to develop trust with the stakeholders expected to act on model findings. Real time access to observations is the only way to evaluate forecasts in near-real time and develop trust in the forecast system.

Climate: A profound issue in climate research and policy is understanding how much anthropogenic carbon (C) is being added to the world's oceans, where it is going, and how society can achieve carbon reduction goals. Similarly, efforts aimed at Marine Carbon Dioxide Removal (mCDR) require assessments of how much C can be safely and effectively removed by various actions, and whether these actions taken in concern with emission reductions are sufficient to achieve policy objectives. In relation to OA, it is important to know how anthropogenic C is contributing to acidification in both offshore and coastal waters. Understanding the impact anthropogenic C has on coastal carbon chemistry will help to discern if/when a system may be pushed beyond natural variability into conditions that species have not experienced. Long term climate-quality monitoring also provides a critical reference network against which to calibrate and harmonize regional/local weather-quality observations which can provide greater lower-cost coverage but generally of lesser quality. On decadal scales climate-quality time-series provide the necessary validation of long-term regional and global projection models to inform high-level international policy decisions.

Rapid Response: Tasked ad-hoc monitoring missions can provide for timely assessments of anomalous conditions and provide high fidelity characterization of an event necessary for understanding rapid changes in the ecosystem (e.g. event-driven acidification and hypoxia). While routine long term monitoring is important to identify trends, establish climatologies against which to discern anomalies, and better understand regional drivers and effects, episodic events may require enhanced or targeted monitoring, which in turn may require different sensors, monitoring approaches, platforms, or support and decision-making processes. When developing a monitoring plan, it is important to identify resources, beyond those required for routine monitoring needs, that can be brought to bear rapidly in the case of an event, and to develop a strategy to support those resources during such an event.

Indigenous Interests, Concerns, and Perspectives: Indigenous people have been users and stewards of ocean and coastal resources throughout their histories. Indigenous communities often view the natural world through a different lens than western-based ways of science. Their interests center on traditional ways of living, cultural touchstones, and historical food sources. For an ocean acidification observing system, it will be important to look at the data through their importance to key species of interest to Indigenous communities. For some Indigenous communities, conditions of their local waters where they grow or harvest shellfish and/or safeguard historical and cultural sites are important concerns.For others, integration and synthesis of data in the context of the entire regional ecology is important, especially in understanding and conserving migratory species.

User Needs and Products: A broad array of monitoring technologies offer new and valuable tools that can be applied towards a range of environmental challenges. However,the precise set and configuration of monitoring tools which is to be applied is optimized only when a clear understanding of how the acquired data is to be applied. A monitoring configuration suitable for a short-term environmental assessment of a lease area may not be useful for deriving regional decadal trends necessary towards informing national or international assessments. Therefore, it's necessary to optimize and prioritize a monitoring configuration that is carefully guided by user needs. How the data is to be synthesized and packaged in a format readily applicable for decision support should be considered at the outset of a monitoring effort. Such considerations can inform decisions about the necessary coverage and frequency requirements. Many of these uses are included in the topics above, but developing specific tools and products should be an aim for monitoring programs.

New Technologies: The variability of coastal systems and the number of processes impacting coastal acidification require a variety of monitoring methods. New sensors, technologies and platforms can assist in providing monitoring data. New sensor technology and analytical techniques can add physical or biological context to core OA measurements, while new platforms can expand the spatial and temporal coverage of sensor measurements. However, while new OA sensor technology is on the horizon, it is important to recognize that the current, commercially available sensor technology is not ideally suited for complete carbonate system monitoring. Sensor deployments can help provide an observational foundation, but sensors themselves are insufficient without the platforms, facilities, and people which combine together to form a monitoring network.

Regional Monitoring Needs

Input from the webinars informed NECAN's input to the IWG-OA report. The following monitoring needs were provided after the webinar discussions, but before the workshop was held:

Improve spatial and temporal scale of monitoring co-located OA variables and biological measurements to better resolve variability of acidification dynamics in concert with biological processes

It is important to differentiate the relative importance and impacts of acidification processes at temporal scales relevant to regional biological processes and in areas important to regional resources. This can require biological and carbonate monitoring to be conducted simultaneously. Some programs in the NECAN region already take OA parameters with biological data, but expansion of these efforts will help to identify biological impacts of OA.

Increase near real time and rapid response observing capacity to capture episodic events

This will inform the vulnerability of marine resources relevant to industries and marine resource managers with potential drivers of events in a multi-stressor space and build climate knowledge as well as resilience in end users of monitoring data in the region. These observations can also provide evaluation of model performance and to develop trust with the end users expected to act on forecasted conditions.

Increase the number of high-frequency monitoring assets that measure at least two of four carbon parameters.

Four parameters can be used to characterize the oceanic carbonate system. These are pH (a measure of hydrogen ion concentration or acidity), pCO_2 (the partial pressure of CO_2 in the water), DIC (Dissolved Inorganic Carbon) and TA (Total Alkalinity, the concentration of molecules like carbonate and bicarbonate in the seawater that can neutralize acid). Pairing two of these four, together with appropriate chemical dissociation constants, allows for the estimation of the other two parameters as well as other useful metrics such as the saturation state of calcium carbonate (omega, Ω). The resulting complete model of the carbonate system is more informative for understanding biological vulnerability.

Preserve spatial coverage of climate-quality observations

Climate-quality observations are vital to attribute drivers of coastal ocean acidification, which is necessary to track progression of ocean acidification in the region and inform action. Climate quality is defined as data of quality sufficient to assess long term trends with a defined level of confidence. With respect to OA, this is to support detection of the long-term anthropogenically-driven changes in carbon chemistry over multi-decadal timescales. To reach climate quality, observations must adhere to international community best-practices with respect to methods and permissible uncertainties which require that a change in the carbonate ion concentration be detectable within a relative standard uncertainty of 1%. This implies an uncertainty of approximately 0.003 in pH; of 2 μmol kg^{-1} in measurements of total alkalinity and total dissolved inorganic carbon; and a relative uncertainty of about 0.5% in the partial pressure of carbon dioxide. . Presently NOAA has in place a climate-quality observing system comprising a fixed-based time-series station within the Gulf of Maine, quadrennial coastal OA surveys, and underway shipboard measures of pCO_2 that meet these requirements. A key goal for any observing network is to ensure that the measurements made are of appropriate quality for their intended purpose, and that they are comparable one with another- even though such measurements are made at different times, in different places, and in many cases by different instruments, maintained by different groups. This climate-quality NOAA OA Network (NOA-ON) provides a necessary reference dataset (Coastal Ocean Data Analysis Product in North America (CODAP-NA)) against which other observing efforts can be checked against allowing for this comparability and critical to anchoring proxy-based algorithms based on weather-quality datasets. While expansion of this network was not presently deemed the highest regional priority to the workshop participants, there was recognition of the importance to preserve it and ensure it doesn't succumb to obsolescence.

Increase subsurface monitoring to understand how conditions vary at depth

Many species of interest in the NECAN region (scallops, lobsters, cod, sand lance) have a short pelagic stage (days to months) then inhabit the benthic environments. These environments are currently undersampled relative to surface waters. Deep, bottom, and porewater monitoring is necessary to characterize environments where these species live and evaluate vulnerability. Sampling around the gonad development and spawning cycles would help provide information about recruitment.

Fluxes and rates that would help parameterize and constrain regional modeling efforts to understand past conditions and project future trends.

Modeling is necessary to characterize OA trends and impacts to ecosystems as well as to forecast and project conditions into the future. Observations are required to develop parameterizations and evaluate models to ensure simulated feedbacks are well constrained. These activities reduce structural uncertainty in the models that generate forecasts and projections.

Workshop results

The workshop (see Appendix 2) included breakout group discussions around the webinar themes and the monitoring needs submitted to IWG-OA. Suggestions emerged on monitoring within each theme, and the IWG-OA monitoring needs were prioritized using 3 criteria: importance, feasibility and cost.

Suggestions on monitoring from webinar discussions for each theme:

Current Assessments:

Many monitoring programs that are active in the region are used primarily for water quality and habitat/ecosystem characterization. To reduce effort an OA monitoring system should build upon existing monitoring efforts where appropriate (*e.g.*, NERRs, NEPs, NMS, MWRA, NMFS, AZMP etc.). The long time series of other parameters (*e.g.*, O_2) within these monitoring programs might provide useful proxies for acidification. Adding OA to existing monitoring may require technical assistance on how to pick sites and equipment, troubleshooting, and standards for monitoring and intercalibration. Inclusion of subsurface and benthic monitoring where species reside will make OA measurements more useful. Measurements should cover all seasons with time series to identify trends and anomalies. This can help to identify important habitats and/or time periods for more intensive measurements. Integration of OA measurements into the suite of ecological drivers (temperature, salinity, oxygen, nutrients, harmful algal blooms would be helpful and may lead to the development of multi-stress indicators for important species. Ships of opportunity may provide valuable platforms, and a pilot program with a few ships could be explored.

Biological Impacts:

Most efforts to understand the biological impacts of OA have been lab-based, and often short term. Field experiments are rarer, but necessary. Field experiments should be done in concert with modeling efforts that predict OA conditions for verification. Experimental data can be used to develop thresholds and indicators for important species (e.g., scallops. sand lance. lobster). Data from industry (e.g., hatcheries) could be very useful, but may be proprietary and will need consideration on how to include these in a database. It will be important to have an inventory and/or map of observing assets and biological monitoring to see where OA may overlap and/or complement existing biological monitoring. A variety of monitoring platforms will be required. Buoys provide temporal coverage at one location, whereas gliders or ships of opportunity provide wider spatial coverage over a short time frame.

Climate:

It will be important to maintain current monitoring, extend coverage further to the north, and add deep waters/benthos. It is also important to have seasonal coverage to understand trends. For groups entering into these efforts, best practices and guidance for climate-quality measurements will be needed. A map of long-term monitoring stations will show where gaps occur. Climate mitigation efforts such as marine Carbon Dioxide Removal (mCDR) require siting guidance (isolated from long-term monitoring sites) as well as monitoring to evaluate effectiveness and biological impacts. In many cases, there is a need for new technologies to develop OA sensors. Exploration of other platforms such as ships of opportunity and offshore wind development could provide new sites.

Indigenous interests, concerns, and perspectives:

Indigenous communities generally have two broad categories of interest: nearshore, site-specific interest in aquaculture, shellfish fisheries, and cultural resources that can be quite localized to individual tribal communities; and broader ecosystem stewardship, often centered on sea-run fishes. Communities are not homogenous and OA monitoring will need to adapt approaches and provide local autonomy where appropriate. Different communities may want different involvement along a spectrum of connection. Many Indigenous communities require capacity building, which will vary among groups and could include technical sensor operations, data analysis, interpretation, application, and fundamental education. Others may want information that they cannot generate themselves. Continued engagement must be ongoing with communities about the impacts of OA in concert with other changes in the coastal environment. The Passamaquoddy and Wampanoag communities might be ready to begin collaborative efforts building on their current monitoring in the NECAN region.

New technologies

There are many examples of emerging approaches, platforms and sensors. Gliders, saildrones and Imaging Flow Cytobots are in use and could be modified with OA sensors. Sensors for pCO2 and pH are commercially available, but that pair of parameters has the highest uncertainty in calculating the rest of the carbonate system. New capability exists on an experimental basis to measure DIC, but with a limited capacity to build and a small user base, it is not viable for commercialization. Other approaches may provide proxies from commonly measured environmental variables (Temperature, Salinity, O_2, NO_3) and efforts to develop these proxy relationships should be undertaken. Due to saturation state often being of interest, there should be efforts to develop methods to measure carbonate directly.

Rapid response

Rapid ecosystem change is happening against the backdrop of climate scale change. We need long enough data sets to identify a baseline and develop thresholds and triggers for warnings. In addition to understanding the scope of the event (both immediate and any longer term impacts), there should be an ability to predict future events. Similarly, documenting what happened during extreme events is valuable, but the implication of the event must be communicated to broader audiences and inform management decisions. Several activities are required: mobilize resources to collect and analyze data; communicate during and after the event within the science community and to environmental managers; have a playbook of responses that can be rapidly applied, and have funding and support that can be accessed. Funding is challenging to maintain with a readiness for rapid response, but some programs have examples. It will be helpful to develop scenario planning that accounts for episodic events. NECAN and/or NERACOOS can help to connect the human network through an email chain or social media.

User needs and products

Each user group has different needs for their unique purposes. The Clean Water Act requires an ability to determine impairment status, which would benefit from identifying hotspots and understanding aquatic life impacts. OA may be able to be incorporated into habitat suitability designations to help in this regard. Most regulators need a quality assurance plan, certified labs, and technical assistance for data literacy: where to find it, how to download it, what methodology to use, and an integrated product with access to all the data that goes into the informed decision. There was an identified need to promote co-development of indicators that could be produced and delivered by the state entities versus a product delivered to them from outside. This would require technical assistance. State partners may in some instances have a preference for raw data versus prepackaged tailored products. Data visualization is an important tool that is needed for all of the above themes, along with an inventory of integrated data platforms and education for these tools. Ready access to an existing model could provide visualizations of current conditions and project future ones.

<u>Modeling</u>

Models are built on data, and several types of data are needed for further model development. These include:

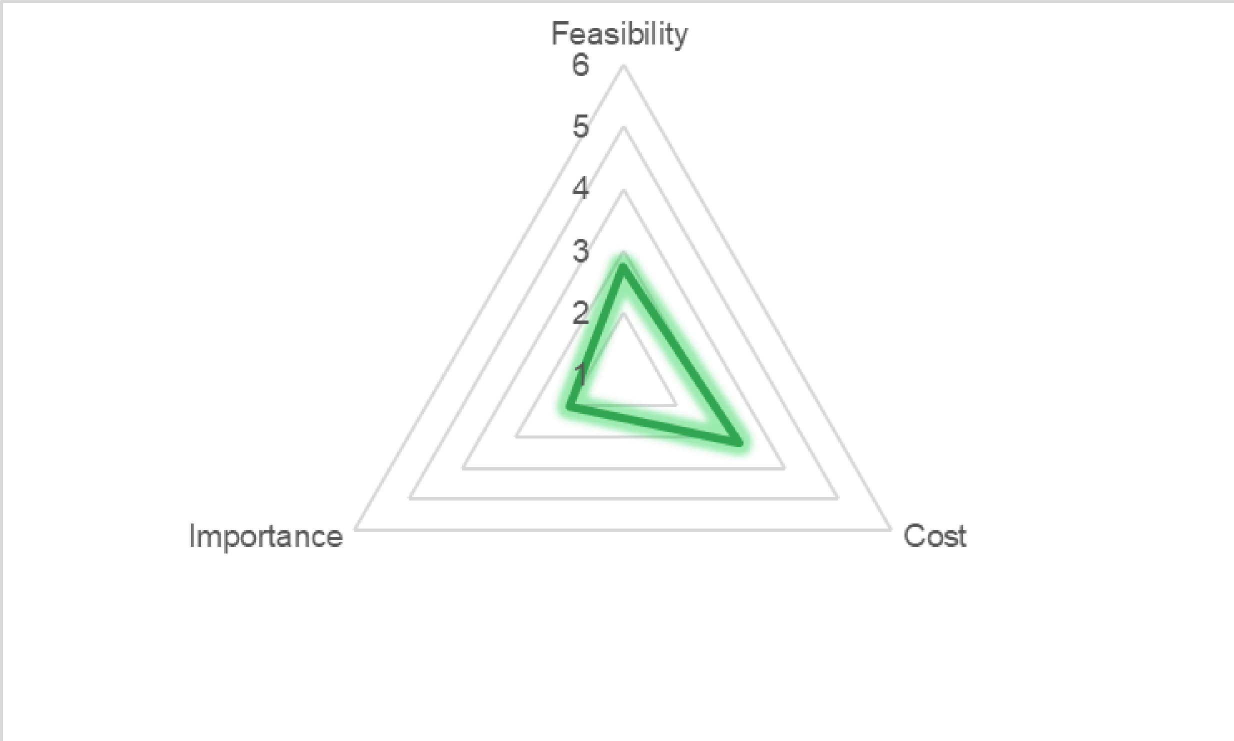
- More TA observations and/or better constrained relationships between temperature, salinity and other proxies and TA. THis is more feasible in offshore/open ocean regions,
- Fluxes between water column and benthos,
- Boundary conditions for northern water mass input,
- Rates (e.g., Net Community Productivity, calcification, dissolution),
- River sources to parameterize land input, and
- $CaCO_3$ cycling.

It is important to have real time observations for model validation and to build trust with model users. There must be user-friendly interfaces to link models to end-users and ecosystem-based management.

IWG monitoring needs:

Implementing a monitoring plan cannot be done all at once for every monitoring need. Thus it is helpful to know which needs have the most importance, which are more feasible and what are the costs of addressing the need. Breakout groups at the workshop endeavored to rank the IWG-OA needs along axes of importance to user groups (1 = most number of user groups, 6 = fewest user groups), feasibility (1 = most feasible with existing technology, 6 = least feasible), and cost (1 = least expensive, 6 = most expensive). A post-workshop web survey also asked participants for their individual rankings. The survey forced participants to use only one rank per need (so that not all needs could be #1 importance, for example). There was variability in the rankings, but general rankings emerged. These are discussed below in order of importance to user groups.

Improve spatial and temporal scale of monitoring co-located OA variables and biological measurements to better resolve variability of acidification dynamics in concert with biological processes

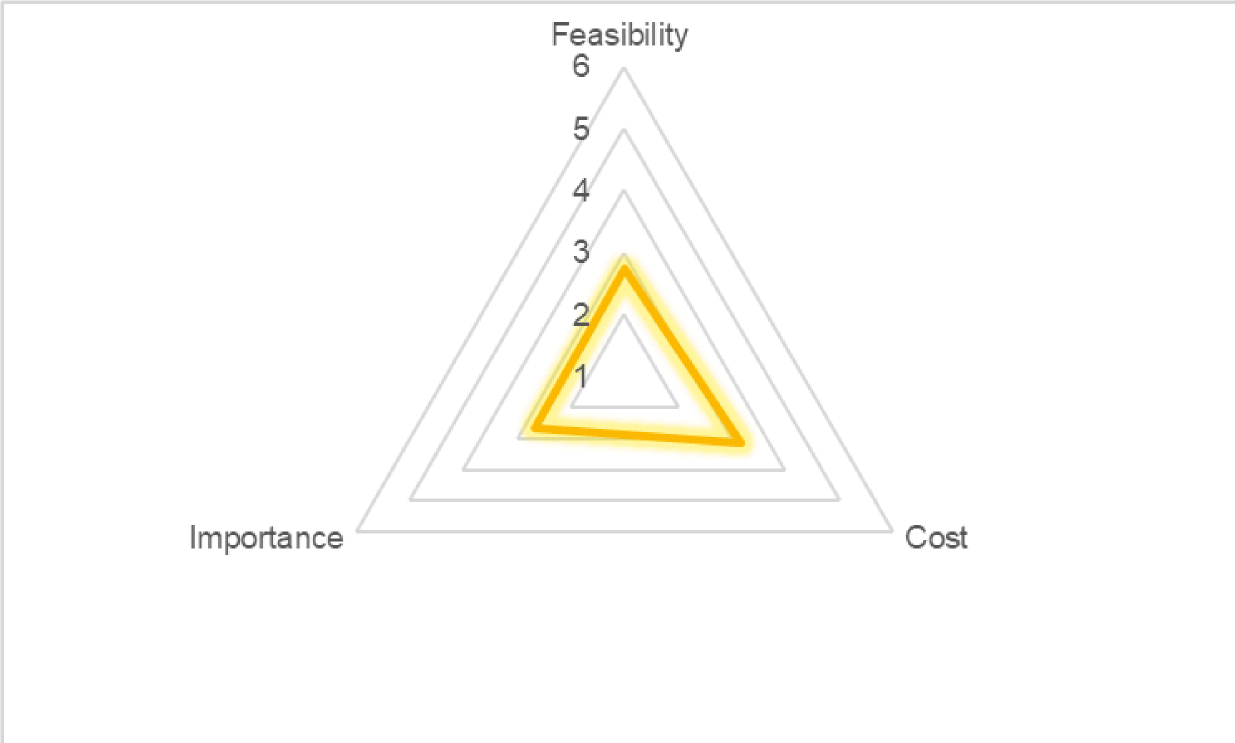


This was judged to be important to the most number of user groups (average ranking = 2). It was deemed feasible if resources were available (average ranking = 2.7), and could start from a relatively low cost, but would require higher costs as the number of sites increased (average ranking = 3.2).

Recommendations for actions under this need are

- Mapping of existing biological monitoring assets with an overlay of where OA parameters are already taken. This will help to identify potential study sites and opportunities for augmenting OA measurements where biological monitoring is already taking place. Collaboration with the Integrated Sentinel Monitoring Network should be explored. The NROC Northeast Ocean Data Portal (NEDP) will be helpful in this, and addition of a layer for carbonate chemistry measurements in the portal would be useful.
- Augment existing programs where appropriate to utilize long time series of data and ancillary observations.
- Map or identify sites where recruitment or settlement is monitored, similar to the Maine Shellfish Settlement Network (Description Here). Add settlement monitoring to sentinel sites that already measure other parameters.
- Facilitate best practice exchange and validation efforts between OA labs and biological monitoring.

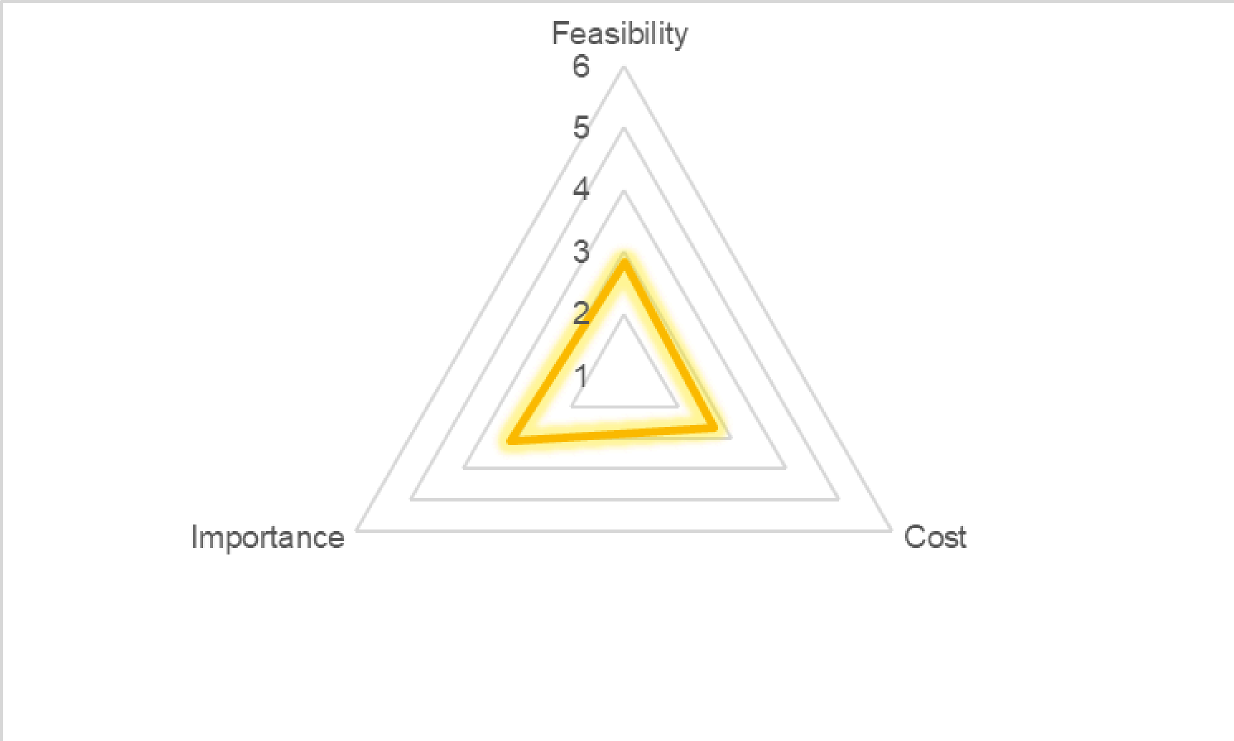
Increase subsurface monitoring to understand how conditions vary at depth



This monitoring need had an average ranking of 2.7 for importance, 2.7 for feasibility and 3.2 for cost. Recommendations under this need are:

- Understanding how close to the bottom monitoring needs to occur in order to characterize the benthic environment. This may require more intense measurements to determine the gradient from the sediment surface into the water column.
- Support integration of pH (and possibly other variables) into existing programs (e.g., eMOLT), and expand spatial coverage of programs that already have carbonate and biological measurements (e.g., HABCAM).
- Explore using new technologies (gliders, benthic rovers and landers).
- As subsurface carbon observations can be challenging with the current sensors available, it is recommended to consider the utilization of locally derived empirical or machine learning algorithm techniques to extend more readily observed quantities like oxygen, temperature, and salinity observations.

Increase the number of high-frequency monitoring assets that measure at least two of four carbon parameters.

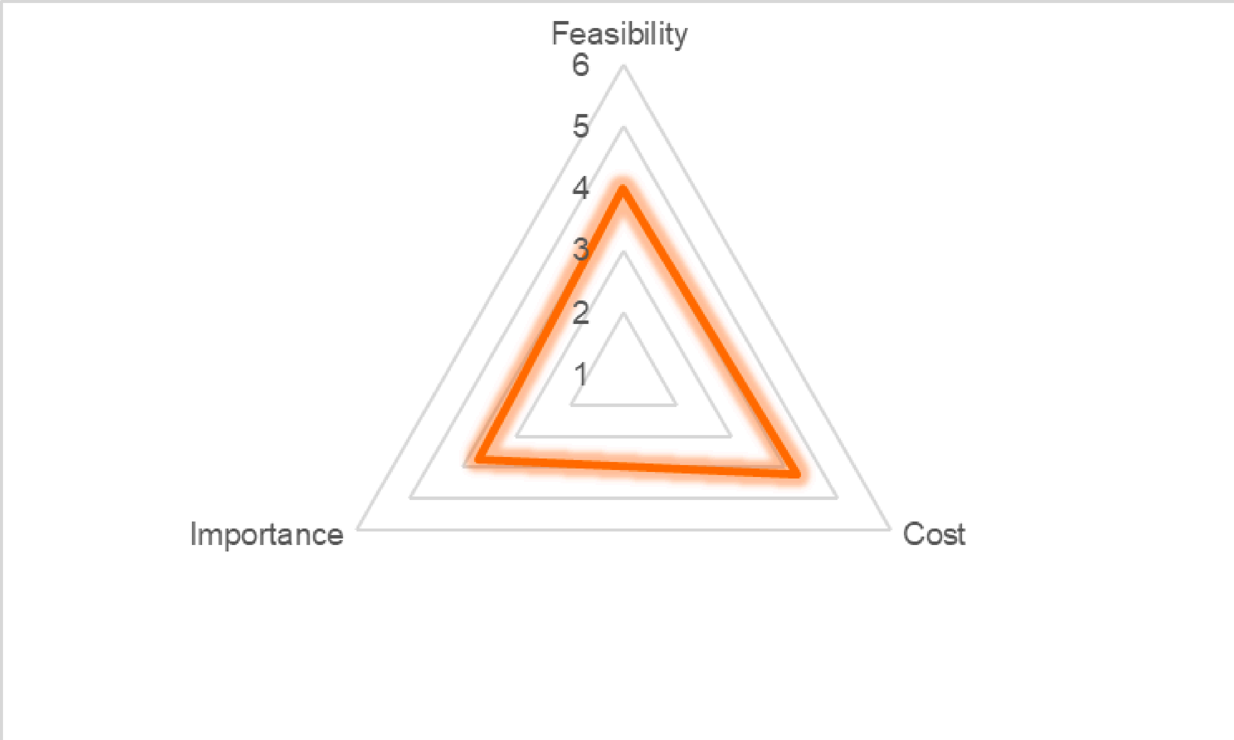


This monitoring need had an average ranking of 3.1 for importance, 2.8 for feasibility and 2.7 for cost. The feasibility ranking may need to be interpreted with care, because although it is feasible to measure pH and pCO_2 with commercially-available sensors on most platforms (including remotely), this pair of measurements is highly intercorrelated and has the highest uncertainty in calculating the rest of the carbonate system. In near-coastal areas, DIC and TA can be obtained through bottle samples and lab analyses, which are feasible with support and expertise.

Recommendations for actions under this need are:

- Work with existing groups (watershed organizations that monitor water quality, buoy operators, etc.) to determine where carbonate chemistry parameters can be added to existing platforms.
- Explore the use of new sampling and analysis capabilities such as
  - https://www.aoml.noaa.gov/advanced-manufacturing-lab/
  - https://techtransfer.whoi.edu/chanos-marine-carbonate-detection-instrument/.
- Develop site-specific models of carbonate chemistry parameters (i.e. TA) from easily obtained environmental data such as salinity, temperature, oxygen, and others.
- Prioritize sites where one parameter is already measured to add others. This would be another use for a carbonate chemistry layer on the NEDP.

Increase near real time and rapid response observing capacity to capture episodic events

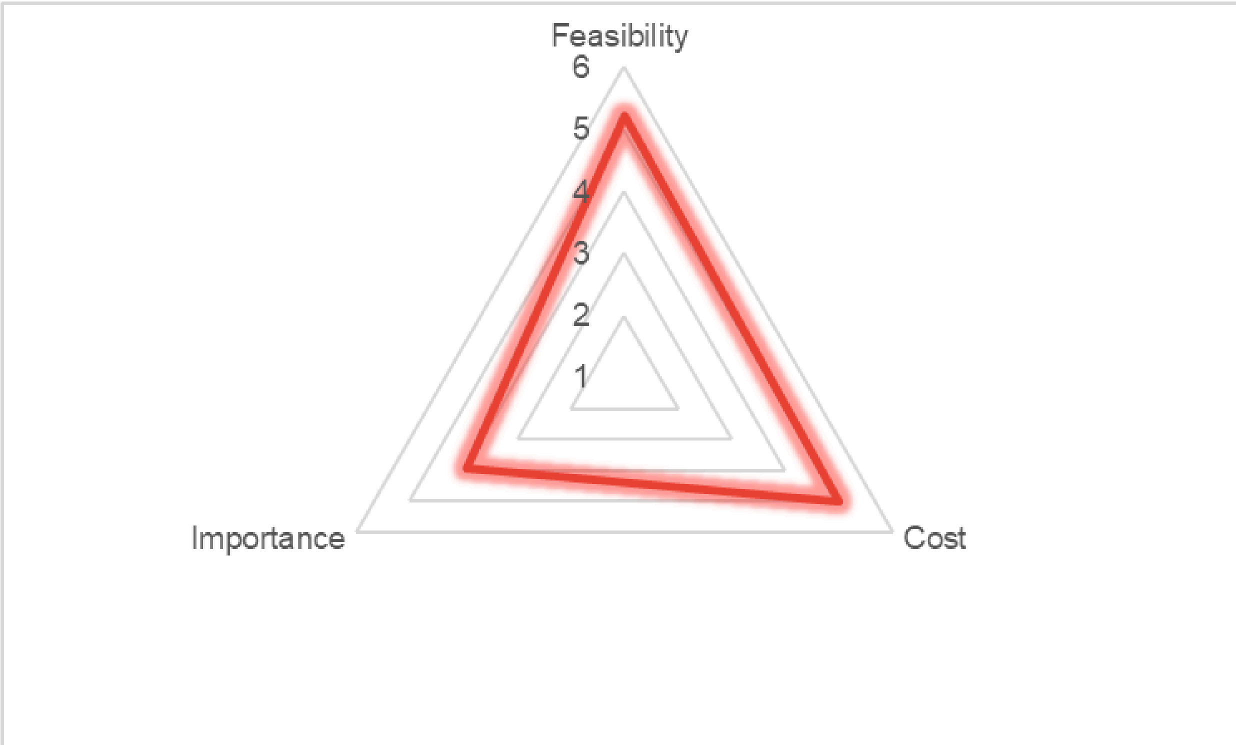


This monitoring need ranked at 3.7 for importance, 4.0 for feasibility and 4.2 for cost. It should be recognized that as a monitoring system increases in coverage and extent, the need for specialized rapid response monitoring decreases.

Recommendations under this need are:

- Establish an instrument “lending library” paired with a technical support team for opportunistic or event-driven sampling.
- Conduct scenario planning that focuses on what is needed to detect anomalies, what would be appropriate actions, how prior responses to events could be improved.
- Develop a "playbook" of approaches to anomalous events.
- Open communication channels among affected parties and establish a rapid response email list.
- Review rapid response protocols/experiences for other issues (harmful algal blooms, oil spills, marine heat waves, fish kills, etc.). Identify ways to connect with those in the Northeast toward a unified rapid response system.
- Explore how the near-real-time NERACOOS/NECAN data system could be enhanced to detect and alert when anomalous readings are seen.

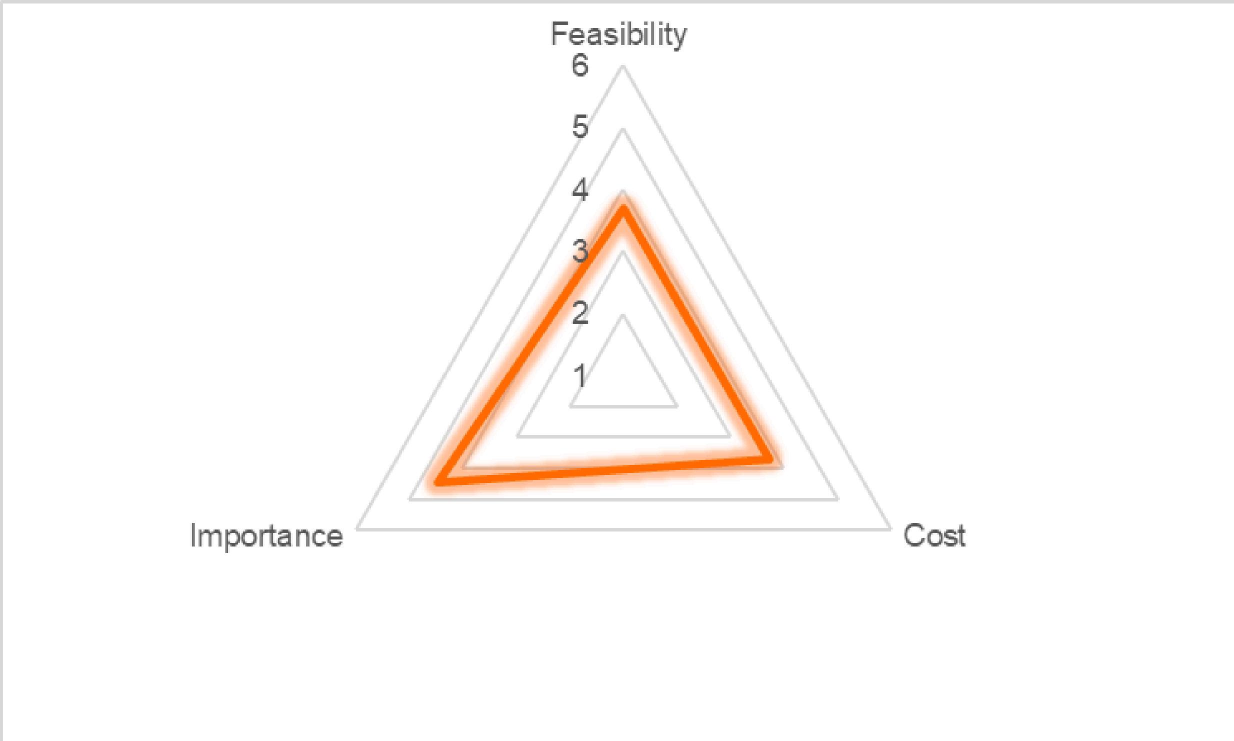
Fluxes and rates that would help parameterize and constrain regional modeling efforts to understand past conditions and project future trends.



This monitoring need ranked at 3.94 for importance, 5.2 for feasibility and 5.0 for cost. Although deemed relatively important, the feasibility and cost of addressing this need is daunting. Recommendations under this need include:

- Prioritize which fluxes are most important to pursue and direct research towards obtaining them.
- Continue to refine methods on the East Coast Ocean Acidification cruises to secure benthic sampling. Prioritize sites based on model estimates of contributing forcing by benthic exchange.
- Refine and standardize net community rate measures (plus gross respiration) for inclusion on regional biogeochemical surveys.

Better spatial coverage of climate-quality observations



This monitoring need ranked at 4.4 in importance, 3.7 in feasibility and 3.7 in cost. While the importance of these measurements are recognized, the need to increase these measurements was seen as less important and the user base was judged to be potentially smaller. Recommendations under this need are:

- Establish community best practices for data inter-comparisons between existing climate capable observing assets to allow for a more diverse portfolio of sensor options.
- Define “climate quality” for coastal regions.
- Identify priority locations for sentinel stations that have esp. high oceanographic, ecological, management value, including Marine Protected Areas.
- Provide an inventory and overview of climate quality instrumentation and techniques.
- Coordination/support for discrete sample collection between groups throughout the region and labs.

Recommendations:

An OA monitoring network will need to have more than sensors and observations. The inherent value in a monitoring network is the connective tissue that surrounds the observations. Several suggestions for this were put forward.

It is beneficial to have more data, but there must also be strong attention to data management. The EPA National Estuary Programs published a 2022 report, “Using Data Repositories for Ocean and Coastal Acidification Monitoring Data” that examined the suitability of several Federal databases for OA data in terms of having a common format, metadata, data preparation and submission, accessibility and archiving. Two databases were found to be most suitable, the CUAHSI HydroShare site and the NOAA NCEI OCADS site.

Technical assistance should be made available for monitoring programs. A list of willing partners and labs that can provide guidance and/or analysis would help new programs. Cross-calibration exercises among labs and monitoring programs should be supported. It would be helpful to have an overview of climate quality carbonate chemistry instrumentation similar to that found in Riebsell et al. 2010.

Data visualization should be developed that can help link users with the data. This could take a variety of forms from maps to climatologies. Examples already exist for other types of data and could be modified for carbonate data. Communication products should be developed, both for OA information itself and also integration of OA into a larger ecosystem context. A regional network could provide common templates for partners to display and communicate their data.

More specific recommendations fell into a few categories: mapping, sensor deployment and support, and developing better understanding.

Targeted maps would advance long-term OA research, planning, and increase understanding throughout the region. Understanding the current spatial extent of monitoring would allow for planning for future OA monitoring sites and underpin key recommendations with the NECAN OA Plan. This may involve adding data layers to the Northeast Ocean Data portal.
Spatial map(s) should include

- Long-term climate monitoring sites,
- Ongoing biological monitoring,
- NERACOOS buoys that currently include carbonate monitoring,
- State and watershed programs that measure at least one carbonate parameter

Sensor deployment and support will always be the foundation of monitoring. It must be recognized that there are costs beyond sensor deployment associated with long-term maintenance and upkeep. Entities must be willing to invest long-term in operations and maintenance of equipment. Several opportunities were identified for increasing sensor deployment. These include:

- Funding sensor deployment in coordination with National Estuarine Research Reserves and National Estuary Programs
- Funding sensor deployment and supporting technical assistance with potentially interested Tribes
- Identifying potentially interested industries for sensor deployment
- Partnering with commercial fishermen to advance winter ocean acidification monitoring to gain additional seasonal data (most collection is in spring/summer)
- Supporting a portable OA monitoring suite of assets that could be relocated and deployed on relatively short notice to areas of concern

For some monitoring questions, we need to develop more understanding before we know what to monitor. These may be addressed through workshops or other group activities, or could be addressed in a research mode. Suggestions for these include:

- Conducting a gaps analysis of ocean acidification data being collected (this will be greatly facilitated by the mapping activity above)
- Defining sentinel sites for OA monitoring (this will also be facilitated by mapping biological monitoring sites as mentioned above)
- Developing multiple stressor indices for important particular species that includes OA among other ecosystem variables (e.g. T, S, O_2, Ω, pCO_2, HABs)
- Develop a broader understanding of biogeochemistry and biology, and incorporate this understanding into models.

Conclusions:
A region-wide OA monitoring plan will help to set priorities, provide context for individual measurements, and compare conditions across locations. It will avoid duplication of effort, promote communication with stakeholders at various levels (municipal, state, regional, national), and leverage funding. Having a plan in one place with clear guidance for monitoring will make it easier for new programs to be added. NECAN is committed to developing a plan that will serve monitoring programs, managers, stakeholders and community members with the OA information they need to make informed decisions.

APPENDIX I

Webinar Presenters by Theme

Current Assessments

Holly Galavotti- *Expanding the LISWQMP: Coastal Acidification Monitoring*
Katie Clayton- *O'Brien- Coastal Acidification Monitoring in the US*
Ivy Frignoca- *Maine Ocean Climate Collaborative*
Tammy Silva- *Stellwagen Bank National Marine Sanctuary Ocean Acidification Monitoring*
Sarah Gaichas- *Ocean Acidification in the Northeast US: State of the Ecosystem Reporting*
Jason Goldstein & Jeremey Miller- *Monitoring Coastal Acidification: Using Existing Infrastructure and Local Collaboration to Increase our Ability to Accurately Monitor Carbonate Chemistry in Coastal Systems*

Climate

Wiley Evans- *Coastal CO_2 Monitoring from Volunteer Observing Ships*
Xinyu Li- *Anthropogenic Carbon Estimation from the US East Coast Ocean Acidification*
Brendan Carter- *Climate in the Pelagic Ocean with a focus on Anthropogenic Carbon and Marine Carbon Dioxide Removal*
Rob Holmburg- *Monitoring and Mitigation Sediment Pore Water Acidification on Marine Tidal Mudflats*

Modeling

Changsheng Chen & Lu Wang- *Simulating Ocean Acidification in the Northeast US Region Using a Fully Coupled Three-dimensional Biogeochemistry and Ecosystem Model*
Damian Brady & Kate Liberti- *What do we Need to Know to Model Ocean Acidification in Estuaries*
Sam Siedlecki- *Observational needs for regional Oa modeling*

Biological Impacts

Brittany Jellison- *Variability of carbonate chemistry in the nearshore/intertidal environment*
Jaoquim Goes- *Assessing the Potential Impacts of Ocean Acidification on Phytoplankton Communities in River influence Coastal Ecosystems*
Hannes Baumann- *Untitled*
Shannon Messeck- *Benthic organisms respond to a changing environment: Laboratory experiments, field experiments, and monitoring?*
Justin Ries- *Priorities for Ocean Acidification Research*
Chris Algar- *Monitoring sediment impacts on carbonate chemistry in a coastal estuary*

New Tech/Sensors/Methods

Grace Saba- *The application of novel, autonomous profiling gliders for high resolution observations of coastal and ocean acidification in the US Northeast Shelf*
Luke Thompson- *Environmental DNA methods for assessing ecosystem responses of Gulf of Mexico prokaryotic and eukaryotic communities to ocean acidification*

Jamie Palter- *Autonomous platforms for studying biogeochemistry (for the Northeast Coastal Acidification Network)*
Mike Brosnahan- *Changing HAB threats in the rapidly warming Gulf of Maine*
Adam Subhas- *Calcium Carbonate and Alkalinity Cycling in the Gulf of Maine and Beyond*
Aleck Wang- *Towards high-frequency, low-cost in situ sensing of the seawater carbonate system*

User Needs/Products
Anne Giblin- *Report on the Ocean Acidification Crisis in Massachusetts*
Frederic Cyr- *Spatiotemporal variability of ocean carbonate parameters on the Canadian Atlantic Continental Shelf*
Janet Nye- *Ocean acidification and ecosystem monitoring in the New York Bight*

Indigenous Interests, Concerns, and Perspectives
Sharri Venno- *Maliseets & Ocean Acidification*

Rapid Response
Doug Vandemark- *2023 Gulf of Maine Tripos event*
Dave Wu- *MWRA Response Monitoring*

APPENDIX II

NECAN Monitoring Priorities in the Northeast Workshop
Dates: November 1,2, &3
Location: Massachusetts Maritime Academy
101 Academy Dr, Buzzards Bay, MA 02532

Day 1 (Nov 1st): IWG-OA Review

Time / Who	Activity
12:45 PM (30min)	**Registration**
1:15 PM (5min)	**Welcome and Introductions** **NERACOOS: Welcome and interests in OA Monitoring - Jake Kritzer**
1:20 PM (5min)	**Welcome and Introduction** **NROC: Welcome and NROC interests- Amy Trice**
1:25 PM (5min)	**Welcome and Introduction** **OAP Welcome/Introduction- Dwight Gledhill**
1:30 PM (15min)	**Presentation: Context of Workshop Goals- Sam Siedlecki**
1:45 PM (45 min)	**Webinar Recap Presentation:** **Beth Turner (Current Assessments)** **Shannon Meseck (x2) (Climate) (Biological Impacts)** **Jake (Indigenous Perspectives Interests and Concerns)** **Chris Hunt (New Technologies, Sensors, and Methods)** **Dwight Gledhill (User Needs and Products)** **Parker Gassett (Rapid Response)** **Sam Siedlecki (Modeling)**
2:30 PM (15min)	**Break with light refreshments**

Time / Who	Activity
2:45 PM (60min)	**Breakout Groups #1: IWG OA Report Prioritization** **Introduction to activity (main room)** **In breakout groups workshop participants will prioritize the list of recommendations that NECAN submitted to the IWG-OA Vulnerability Report**
3:45 PM (60min)	**Report Out & Discussion Breakout #1** **Group Discussion** Breakout group facilitators will report out to full group (5 min each) Full group discussion based around breakout group subject matter
5:00 PM	**Adjourn**

Day 2 (Nov 2nd): Webinar Topics

Time / Who	Activity
8:30 AM (30min)	**Arrival and Refreshments**
9:00 AM (30min)	**Welcome and Introductions/Review of Day #1** **Welcome** **Review Agenda** **Main takeaways of yesterday's conversation presentation**
9:30 AM (75min)	**Breakout Group #2: Webinar Topics P.t 1** **Introduction to activity** **Breakout group topics:** Current Assessments *How can we integrate/enhance OA measurements into existing assessments? Which assessments are most amenable to including OA*

Time / Who	Activity
	information? What OA measurements are optimal for the most number of existing assessments? Biological Impacts *What species should we focus on initially? Are there particular habitats of most concern? What measurements will tell us the most about impacts?* Indigenous Perspectives, Interests, and Concerns *How can we build a monitoring system with Indigenous concerns in mind? Can we integrate Indigenous communities into a monitoring system? (example from west coast?)* Climate *What observations will best characterize trends, attribute habitat shifts, and allow for robust projections of future OA? What type of observations are needed to properly inform MCDR and biological impact mitigation? Where are these?*
10:45 AM (15min)	**Break**
11:00 AM (45min) Austin	**Report Out & Discussion Breakout #2** **Group Discussion** Breakout group facilitators will report out to full group (5 min each) Full group discussion based around breakout group subject matter
11:45 AM (75min)	**Lunch**
1:00 (60 min)	**Breakout Group #3: Webinar Topics P.t 2** User Needs/Products *Are there specific products that would be useful to stakeholders? Do they vary by stakeholder group or can we develop tools and products that serve multiple communities?* Rapid Response

Time / Who	Activity
	How does OA fit into a rapidly changing ecosystem? What should we be monitoring to detect/attribute rapid changes? Modeling *What monitoring will be most useful to modeling efforts? How can OA be included in existing regional models? What new models need to be developed (and for what purposes)?* New Tech *What sensors and technology are available to implement monitoring priorities? What new technology needs to be developed?*
2:00 PM (45 min)	**Report out and Discussion Breakout #3** **Group Discussion** Breakout group facilitators will report out to full group (5 min each) Full group discussion based around breakout group subject matter
2:45 PM (20 min)	**Break**
3:05 PM (60-70min)	**Full Group Discussion** Reflection on the 3 breakout group outcomes
4:15 PM	**Adjourn**
4:30 (90 min)	**Cocktail Hour/Posters**
6:00	**End of: Cocktail Hour**

Day 3: Conclusions

Time / Who	Activity
8:30 AM	**Arrival and Refreshments**

Time / Who	Activity
(30min)	
9:00 AM (15 min)	**Welcome and Introductions/Review of Previous Days Takeaways** **Welcome** **Review Agenda**
9:15 AM (45min)	**AM Plenary: Mapping Breakout takeaways onto IWG-OA Recommendations- Beth Turner** What barriers exist in the region to implementation? What actions can we take to overcome these barriers? And further build capacity?
10:00 AM (45min)	**Full Group Discussion (Themes Identified)** Reflection on the mapping of the IWG-OA report (previous presentation) Continuation of the previous days full group discussion
10:45 AM (15min)	**Break**
11:00 AM (60 min)	**Final Thoughts and recap of monitoring plan and next steps for the regional monitoring plan -NECAN Steering Committee panel discussion** First look at early SC thoughts on the major takeaways of the breakout groups Next steps for the outcomes of the workshop (Exit survey circulated)
12:00 PM	**Adjourn**

APPENDIX III

Workshop Registered Participants

The following is a list of those who responded that they will be attending the NECAN Monitoring Priorities in the Northeast workshop on the google form (virtual or in person).

Parker Gassett Maine Climate Science Information Exchange Maine Sea Grant
Prassede Vella, MassBays NEP

Adam Pimenta EPA Atlantic Coastal Environmental Sciences Division
Jake Kritzer, NERACOOS
Beth Turner, NECAN Steering Committee
Department of Biological Sciences, UNH
Associate Scientist, Woods Hole Oceanographic Institution
Z. Aleck Wang, Woods Hole Oceanographic Institution
Dwight K. Gledhill, Ph.D, NOAA Ocean Acidification Program, Acting Director, Silver Spring, MD
Chris Hunt, University of New Hampshire
Xinyu Li; University of Delaware
Katie O'Brien-Clayton, CT Dept. of Energy & Environmental Protection
Mike Doan, Friends of Casco Bay
Emily Silva, NERACOOS
Kumiko Azetsu-Scott, Bedford Institute of Oceanography, DFO, Canada
Northeast Regional Ocean Council
Chris Williams - New Hampshire Coastal Program
Natalie Lord, NOAA OAP
Carolina Bastidas - MIT Sea Grant
Liza Wright-Fairbanks, NOAA Ocean Acidification Program
Jeremy Miller - Wells NERR (NOAA)
Samantha Siedlecki (she/hers), UConn
Shannon Meseck NOAA/NMFS
Fisheries and Oceans Canada
Brady K. Quinn, Fisheries and Oceans Canada
Erin Miller DFO
David Capelle - DFO
Alexandra Puritz, NOAA OAP
Joseph Salisbury, University of New Hampshire
Grace Saba, Rutgers University
Jaime Palter (she/her), URI
Jackie Motyka, NERACOOS
Katy Bland, NERACOOS & NH Sea Grant
Cameron Thompson - NERACOOS
Prof. Justin Ries, Northeastern University
Ivy Mlsna, US EPA Region 1
Doug Vandemark, Univ. of New Hampshire
Baoshan Chen, Stony Brook University
Damian Brady University of Maine
Rob Holmberg - Roger Williams University
Courtney Witkowski, NOAA Ocean Acidification Program
Ken Edwardson (NHDES)
Beckie Finn, Environmental Programs Coordinator, Wampanoag Tribe of Gay Head (Aquinnah)
Shavonne F. Smith, Shinnecock Indian Nation
Bianca Champenois / MIT Sea Grant