Management Guidance for the Use of Ocean and Coastal Acidification Regional Model Outputs in the Northeast

NERACOOS
NORTHEASTERN REGIONAL ASSOCIATION OF COASTAL OCEAN OBSERVING SYSTEMS

Acknowledgements

This paper is the result of research funded by the National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science Competitive Research Program and the NOAA Ocean Acidification Program under award NA18NOS4780178 to the Northeastern Regional Association of Coastal Ocean Observing Systems.

Special thanks to all the individuals that participated in our focus group discussions.

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Introduction

Engagement Objectives

1. Understand how potential end-users may use a forecast biogeochemical model. The results of this effort would then be used to inform future model development.
2. Understand where the thresholds are that stakeholders worry about when it comes to ocean acidification in order to inform adaptive actions to ocean and coastal acidification.

Stakeholder Engagement Team & Report Authors

The stakeholder engagement team for this project is a diverse group of academics, practitioners, engagement experts, scientists, data experts, industry representatives and individuals who work closely with the aquaculture industry in the Northeast. This team was formulated to support the development of the predictive model through iterative engagement with stakeholder communities.

- Aaron Strong, Hamilton College
- Parker Gassett, Maine Sea Grant
- Jason Goldstein, Wells National Estuarine Research Reserve
- Christine Feurt, Wells National Estuarine Research Reserve
- Stephen Jones, New Hampshire Sea Grant
- Meredith White, Mook Sea Farm
- Riley Young-Morse, Gulf of Maine Research Institute
- Jennifer Brewer, University of New Hampshire
- Jackie Motyka, Northeastern Regional Association for Coastal Ocean Observing Systems
- Joan LeBlanc, Northeast Regional Ocean Council

Methodological Approach

Stakeholder Identification

The original project proposal identified three potential stakeholder groups who might be in a position to use the forecast model being developed for this project in their decision-making: shellfish aquaculture industry, water quality managers, and wild harvest fishers. After initial progress in model development brought the model to a place where its potential future applications could be visualized by stakeholders, the plan was to conduct semi-structured interviews with individual potential end-users about their perceptions of ocean and coastal acidification. Building on discussions at the Gulf of Maine 2050 meeting in November 2019, and through consultation with the Advisory Committee for this project, the stakeholder engagement team identified a revised set of three stakeholder groups.

1. Oyster growers who use upweller systems
2. Mussel growers
3. Water quality specialists who actively monitor nearshore water quality

Each of these groups' day-to-day management decisions is in a position to respond to changing local water chemistry conditions on short-term time scales (hours to days) and across narrow spatial scales (10s of meters). As such, each of these groups is in a position to actively use the model under development.

Focus Group Approach

In 2020, after the start of the COVID-19 pandemic, planned in-person semi-structured interviews with stakeholders to understand their perceptions of ocean acidification in each of these groups was no longer possible to contemplate under social distancing requirements. In late 2020, the Stakeholder Engagement team decided to revise our planned interview-based approach towards a focus-group methodological approach that could be conducted remotely, while still being attentive to the needs of stakeholders. We concluded at that time that Zoom-engagement was now feasible for industry participants because remote engagement had been normalized. We also concluded after extensive discussion that a focus-group approach would be most advantageous, in particular, because focus-group participants would be able to listen to, hear from and inform each other.

We decided to develop a focus group approach that would be able to showcase the model's predictive functionality using the 2017 year hindcast for Massachusetts Bay that had been developed by Chengsheng Chen's group at UMass-Dartmouth. In early 2021, Riley Young Morse and Aaron Strong iteratively worked with Chen's group to understand available hindcast model data from 2017 in order to develop a set of visuals to present to focus group participants.

Focus Group Participants

Lists of potential stakeholder participants were developed by the Stakeholder Engagement team in Spring 2021. Parker Gassett and Meredith White identified oyster upweller operators, operating between Cape Cod Bay and Maine. Stephen Jones identified mussel growers operating in Massachusetts and New Hampshire. Aaron Strong and Jason Goldstein identified state and federal government, NGO, and volunteer water quality specialists operating between Massachusetts, New Hampshire, and Maine. Invitations were sent in June 2021. We identified an ideal range of participants as 5-10, for maximal engagement with stakeholders present.

Focus groups lasted for 90 minutes and were conducted in late July and early August 2021. All focus groups were recorded for later analysis. Each focus group proceeded in an identical fashion. The first question for all participants was about the COVID-19 pandemic and how participants had pivoted to respond to it. The second question was a chat-based question (so all participants could provide answers without being affected by others' answers). The prompt asked participants to discuss their perceptions of "when or how might ocean acidification impact your business (or your work)?" After this, the model's objectives and structure were briefly introduced and a metaphoric example of wave forecasting was used to explain the ultimate goal of model development and an explanation of the observation-based model validation. After this, a unique set of scenarios for model usage was presented and stakeholders were asked for reactions to the scenarios. This approach was used so that the model's potential applications could be showcased and stakeholders could respond to, correct, and discuss these scenarios, rather than relying on elicited brainstormed scenarios from stakeholder participants. The development and presentation of scenarios are explained in the next section.

Scenario Development

Focus-group-specific scenarios for model usage were developed by the Stakeholder Engagement team in June and July 2021. Riley Young-Morse used the descriptions of these scenarios to develop visuals that were presented to focus group participants. In each case, the participants were informed that these were modeled data from 2016 and intended to be illustrative of the model's potential capabilities once it has been fully developed.

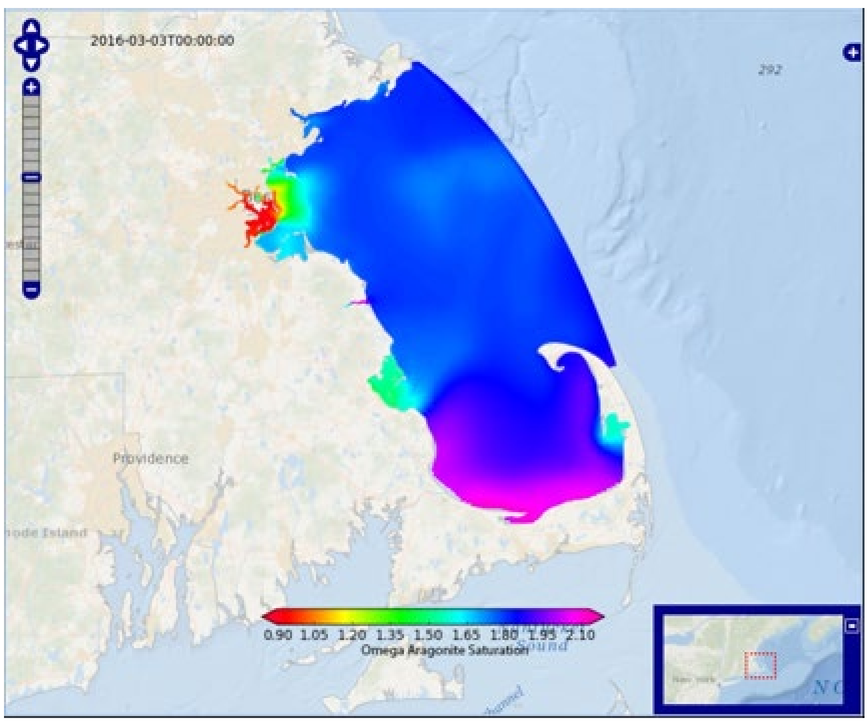

Fig.1. Above is a screen grab from a video showing omega-aragonite saturation state for a series of days in March 2016 for Massachusetts Bay. This video was shown to the Water Quality Specialist focus groups.

The table below shows the scenarios used with each stakeholder group.

Focus Group	Scenarios	Modeled Animations Presented
Oyster Upwellers	1. Siting of upweller operations 2. Management of upweller operations	1. Dissolved Oxygen – Mass Bay 2. Dissolved Oxygen – Duxbury Harbor
Water Quality Specialists	1. Siting of new monitoring infrastructure 2. Identification of hotspots 3. Management decision	1. Omega Aragonite Saturation – Mass Bay 2. Omega Aragonite Saturation – Boston Harbor
Mussel Growers	1. Siting of aquaculture operation 2. Management of aquaculture operation	1. Dissolved Oxygen – Mass Bay 2. Dissolved Oxygen – Duxbury Harbor

Table 1. Presented scenarios and model animations. Animations for dissolved oxygen at the surface were presented for June-July 2016. Omega aragonite animations were presented for March 2016, based on available hindcast data.

Below we summarize the results of each of those focus groups and then synthesize the key take-aways from the focus groups both for model development and for our understanding of stakeholder perceptions of ocean and coastal acidification in this region.

Focus Group 1: Upwellers for Oyster Aquaculture

Key Takeaways

- Predictive model is of interest as a diagnostic tool for mortality events and for growth prediction.
- Predictive model is unlikely to be helpful in siting decisions, due to other logistical constraints for site selection.
- Predictive model is unlikely to be helpful in day-to-day management of upwellers, as little can be done when conditions are bad.
- Most important parameters are chlorophyll, temperature and dissolved oxygen, with little interest in carbonate chemistry parameters.
- Strong interest in potential inclusion of phytoplankton parameters and food availability information in model development.
- Apps, maps and easy to access data interfaces with visual summaries, simple binaries of 'good/bad' and user-selectability of geography and temporal dimensions are appreciated.

Focus Group Synthesis

Ocean Acidification Perspectives

Focus group participants specifically highlighted their understanding that larvae and juveniles are more vulnerable to ocean acidification (OA), and that growth and strength of adults could be slowed by OA. They uniformly regarded OA as a future threat to be considered and planned for, rather than a clear and present immediate danger.

Reaction to Scenarios

Oyster aquaculture stakeholders operating upweller systems expressed great interest in the model as a diagnostic tool to further understand the environmental causes of occasional mortality events and to correlate conditions with observations of oyster growth. They collectively expressed a strong interest in understanding the relationships between water quality parameters and oyster growth rates. A better understanding of growth patterns would allow farmers to better predict timing and product availability for juveniles sold to other grow-out operations and for mature organisms to be sold among markets. They fully acknowledged that growth models based on phytoplankton availability and basic water chemistry parameters already exist, though are not widely an operational tool among growers and they expressed interest in connecting the predictive model's functionality with these existing oyster growth models. In discussing the importance of growth projections, temperature and chlorophyll were unanimously regarded as the most important parameters of interest. Dissolved oxygen (DO) was expressed as a more important parameter of study by aquaculture representatives in Massachusetts, while growers in New Hampshire and Maine stated that they've not seen problems of low DO nor impacts from hypoxia to their business. Stakeholders are well equipped to partner directly with the model development team, as stakeholders discussed ongoing efforts with academic teams, including collaborations with Woods Hole Oceanographic Institution to use an in-water flow-cytometer for plankton research and referencing data streams from University of Maine LOBO buoys.

Primary interest is in causes of mortality events or low-growth conditions, with a principal focus on poor quality phytoplankton food available for larval oyster growth. Growers referenced their concerned awareness for large rain events, described monitoring salinity, and their own stress and anticipation of periods of environmental pressure on their oysters after heavy rainfall events. Yet, ubiquitously, growers shared a sentiment that little can be done during periods of environmental stress or organismal sensitivity to conditions. “Logistically you get your million [oyster] seed, you put them in the upweller, and then you are basically at the mercy of nature.” There is not a practice of moving oysters among locations to avoid environmental stressors and growers did not anticipate making such decisions even with a fully functional predictive model. One grower commented that they’ve thought to, but not attempted to bring oysters out of the water during major rain events when they perceive salinity and pH to drop dangerously low. Throughout the discussion that focused on how the model could be used in operations, stakeholders frequently reiterated the importance of logistical constraints in operations and emphasized that observational and modeled data are primarily used in retrospective diagnosis of past poor conditions or in anticipation of upcoming poor conditions rather than in operational decision-making. It would be difficult to move stock among grow out locations; grow out locations are selected with a suite of factors beyond environmental conditions (e.g. social acceptance, access to docks and shore-power, and proximity to on-land company facilities). Ultimately, industry representatives do extensively explore environmental conditions for siting their operations, the community is adept in accessing available data on temperature, salinity and chlorophyll in siting considerations, and growers communicate among themselves about the growth rates and conditions among farms in a sub region.

Upweller: Specific Requests for Model Development and Presentation

- Embedding a growth estimate, phytoplankton food availability estimates or any information about phytoplankton along with other parameters is important.
- Principal interest in chlorophyll and temperature, rather than acidification parameters.
- Visualizations of data at different time scales: growers commented that seeing overview data is helpful in existing (NERACOOS) data streams, allowing them to assess important trends before deciding if they need to look more closely at numeric values. These visual overviews are always appreciated.
    - Being able to select the time horizon of interest e.g. daily, weekly, monthly, and being able to toggle between these forecasts.

- To be able to access data and past conditions as a diagnostic tool is vitally important, with lots of interest in availability of near-term past modeled conditions within the last week or two before present.
- For alerts to be an option:
    - When thresholds (potentially user-defined) are crossed
    - When trends point to a threshold being crossed in the future
    - With the option of the user setting their own threshold values among parameters
    - With email, text message, or phone call alerts as optional
- For red light, green light simplifications for unfavorable and favorable conditions for larval oyster growth. The desire is for a “bad conditions” flag to be available.
- For model parameters of size class of phytoplankton to be viewable.
- For uncertainty values and information to be shown in visualizations and data.

Focus Group 2: Water Quality Specialists

Key Takeaways

- Water quality specialists see this model as an exciting and welcome addition to the toolsets available for professionals working on coastal monitoring in the Northeast.
- Water quality specialists are primarily interested in using the model to corroborate their own datasets and in using the model to identify hotspots and locations for future monitoring infrastructure.
- The forecast capabilities of the model could be used for one-off targeted monitoring efforts during unusual events.
- Water quality specialists believe that the model could assist in developing OA budgets that allocate changes in carbonate chemistry to particular drivers.
- Water quality specialists believe that the model's near real-time capabilities would be helpful for identifying areas that may pass regulatory thresholds (not specifically for OA but for other coastal nutrient issues).
- Water quality specialists believe that the short-term forecasts can help develop assessments of uniquely vulnerable areas.
- Water quality specialists believe that the model may be beneficial in elucidating interesting mechanisms that are in play in relatively understudied coastal areas with minimal existing observational data.

Focus Group Synthesis

Ocean Acidification Perspectives

Water quality specialists indicated that OA would affect their work through its impacts on shellfish growers and through its impacts on general water quality degradation. Several of the participants indicated that OA had 'already' affected their work, highlighting that the phenomenon of OA had changed the water quality parameters they had been monitoring, specifically noting that pCO2 data were now being collected and that their work now involved trying to help communities prepare for OA.

Reaction to Scenarios

Cumulatively, this focus group identified three intersecting uses for model outputs:

1. Corroborating and informing real-time observations, as well as decision for site selection among various activities.
2. Using the model to help interpret the patterns and drivers of OA and interrelated environmental phenomenon/events, including helping to build an OA budget.
3. Using model patterns and predictions to develop plausible future scenarios for scenario planning exercises.

Participants shared a strong interest in the model's ability to interface with existing monitoring platforms and initiatives, and the flexibility for the model to incorporate new data streams as climate-specific monitoring programs expand in the near future. The scarcity of resources for monitoring networks was consistently raised as a theme for consideration. As such, a successful model would help managers decide where and when to allocate scarce monitoring resources. Furthermore, patterns within model outputs can help oceanographers to interpret which drivers most influence conditions of OA and water quality. Subsequently, the model can help along with other science to constrain indicators of OA and water quality which can be used in smaller embayment's that are routinely unobserved. More generally, this approach would be helpful for related conditions/processes of nutrient cycling. Beyond the utility of a model corroborating and forecasting present/near-future conditions, the development of future scenarios, and thus scenario planning exercises for managers would be helpful and would fill a current gap in the policy and management context of OA in our region.

A successful model interface depends on the target audience. Depending on the circumstance it will be helpful for the model to, like a weather forecast, provide quick overview information that is site-specific (parameters, trends, and high/low condition forecasts). Alternatively, some users would benefit from the option to query data for investigative uses and cross-location comparisons. In either format, careful consideration should be made to visual communication approaches, selecting colors and ways of portraying information in ways that intuitively communicate target information. As voiced in previous focus groups, having an 'alarm setting" which sends a message to email/phone will be helpful for those who do not routinely visit the platform site. Generally, it will be helpful to allow users to set their own thresholds in querying data and in setting alarms. Subsequently, the meta-data from users can continue to help the modeling team in understanding the needs/interests of end-users.

Water Quality Specialists: Specific Requests for Model Development & Presentation

- Unlike the two industry groups, there was very little discussion of any additional parameters.
- Access to metadata and an interface that could allow user-generated observations to be compared with model-generated outputs.
- Ease of generating data outputs for use in other applications, such as scenario planning.
- Incorporation of existing legal and regulatory numeric criteria or targets, where available so that passage of thresholds could be identified.
- Flagging outliers or unusual areas/hotspots visually would be beneficial.
- Other than ease of access to the data and a customizable, user-driven interface for selection of both temporal and spatial windows, there was relatively little discussion about additional specific end-user interface components.

Focus Group 3: Mussel Aquaculture

Key takeaways

- Predictive model is of interest as a diagnostic tool for mortality events and for growth prediction.
- Predictive model could be helpful for site selection by matching hindcast model data to observations of good growth conditions and using predictions of future ocean conditions to select and permit future sites.
- Predictive model is unlikely to be helpful in day-to-day management of mussel farms, except in highly specific situations where raising or lowering the depth of the farm could be helpful.
- Most important parameters are chlorophyll, temperature, and dissolved oxygen, with little interest in carbonate chemistry parameters.
- Strong interest in potential inclusion of phytoplankton parameters and food availability information in model development.
- Apps, maps, and easy to access data interfaces and user-selectability of geography and temporal dimensions are appreciated. Compared to upwellers, there was less interest in threshold-based 'good/bad', 'red light/green light' style visualizations.

Focus Group Synthesis

Ocean Acidification Thresholds Perspectives

Stakeholders highlighted that OA creates a need for vigilance among mussel growers. Specifically, they highlighted that natural recruitment is important to the industry and that OA could affect larval mussel recruitment and that OA might interact with other stressors (temperature, most notably) to create multi-stressor negative impacts on future growth. In all cases, stakeholders highlighted that they regard OA as a future potential threat.

Reactions to Scenarios

Monitoring water quality conditions is underway at mussel farms and all data is informative for both the original siting of grow-out locations and ongoing operations at farms. Observational data is currently widely used for these decisions and modeled forecast data would be appreciated as another source of data.

The parameters of greatest interest to mussel growers include: temperature, dissolved oxygen, and food availability. Because mussels can die off with increasing warm temperatures, there is a strong interest in water temperature forecasting generally. As mussel farming practices include both surface rafts as well as submerged methods and vertical lines through the water column, depth-specific values for model parameters are important to these growers. Tracking harmful algal blooms and PSP toxins are also deterministic for harvesting routines, and at times growers are able to see deteriorating trends and opt to harvest animals before toxins pass safety thresholds, thus any information that can help inform future predictions of HABs and shutdowns due to toxins would be invaluable. As some mussel farms are equipped with extensive monitoring instrumentation, and in some cases have collected environmental data for decades, these data streams could be used as model inputs and growers were willing and interested in partnering to help improve the model and to corroborate their own on-site data.

Growers rely on wild-set and settlement, yielding 2-3 sets per year. Stakeholders shared their understanding that spat and juveniles may be more vulnerable to OA and other stressors, implicating the model as a predictive tool for unsuccessful spawning, and the contingent transition to using hatchery-reared seed. Generally, however, wild spawning and recruitment has been especially successful in recent years, showing no sign of environmental stress, and further improved by limited predation from sea stars whose populations have suffered from a wasting disease.

Growers did suggest that they can envision using the model for site selection, but primarily by comparing hindcasted model outputs with observational data at existing farms where there is data on growth success and then using modeled outputs (both hindcast and forecast) to identify sites that might permit similar successful growth at other locations.

Mussel Growers: Specific Requests for Model Development and Presentation

- Embedding a growth estimate, phytoplankton food availability estimates or any information about phytoplankton along with other parameters is important.
- Principal interest in chlorophyll and temperature, rather than acidification parameters.
- While they recognized that these were likely beyond the capability of this model, primary forecasting interest is in warnings of conditions likely to lead to closures due to HABs, *Alexandrium* or PSP events.
- Interest in developing larger ecological components of the model, such as eider duck populations and right whale populations, although this was expressed in a joking manner.
- Easy to access, customizable interface where hindcasted modeled outputs could be linked to observations at the farm when conditions were good and modeled outputs could then be used to help inform site selection (particularly as farms predict they will be moving offshore in future).
- Modeled data could help with permit applications.

Synthesis of Key Takeaways and Key Points for Model and Tool Development

Across all three focus groups, several key themes emerged, which may have direct bearing on model development and the development of visualizations and decision-support tools. Overall, there was general excitement and enthusiasm about the model's future development, without any stakeholders regarding the model as potentially uniquely transformative. Nearly all stakeholders expressed sentiments that they thought that the model would be 'cool' and 'neat'. The Gulf of Maine has a rapidly growing aquaculture sector. While both upwellers and mussel growers occupy slightly different geography they are often faced with similar environmental risks to their products, including: harmful algae blooms and intense weather events affecting salinity and dissolved oxygen in the water column. Due to logistical challenges, it's unrealistic that either type of grower could remove their product from the water in response to a given environmental event. It is therefore critically important that an initial site is selected that historically has fared well under these conditions. Ideally, historical data from a coastal monitoring station would be accessible, but this is currently limited and further complicated by the heterogeneity of the complex coastal landscape. An oceanographic model provides a unique opportunity for growers to consider past environmental events and the associated risks to their businesses. Similarly, a model also provides them with information once in operation to better understand changes in their product. For instance, if a change in growth or mortality occurs they can reference the hindcast model to better understand the cause of such an event.

Overall, stakeholders did not believe that the model's forecasting capabilities would play a key role in day-to-day operations of aquaculture operations in the Gulf of Maine region. That said, stakeholders highlighted specific ways in which modeled data, and in particular, hind-case modeled data could be effectively used to help inform growth modeling, future

Parameters

- For both aquaculture focus groups, primary interest is in **chlorophyll**, **phytoplankton size class parameters** or any other information about food availability.
- Strong interest in **temperature**, especially temperature profiles and temperature at depth.
- In areas already affected by low oxygen, there was stronger interest in dissolved oxygen.
- Little direct interest in carbonate chemistry parameters, except among water quality specialists, though there is a stronger interest in salinity forecasting.
- Water quality specialists expressed strong interest in **spatial variability of carbonate chemistry parameters.**

Model Capabilities

- Strong and near universal interest in the availability of **near-term hindcasting** (past few days to weeks) to help with diagnoses of problematic or unusual events and the conditions present in those events is of uniform interest. Thus, an ability to assess "how bad it got" during a previous storm or set of unusual water conditions is a key feature for stakeholders.
- At the same time, there was some interest among stakeholders in **longer-range seasonal forecasts** (1-6 months into the future), which are not likely to be possible in the current modeled framework.

End-User Interface

- In all cases, users want to be able to select the time frames and geographies that they want to view (customizable and selectable).
- Users want to be able to access data to match with observational data that they have generated at specific sites.
- All users would welcome alerts for forecasts for unusual water conditions.
- Some users – especially upweller operators – would welcome an app-based interface with guides to whether conditions are favorable/unfavorable for growth.

Broader Implications

Regional Implications

Ocean acidification, increases in storm intensity, and new HAB species are all concerns for shellfish growers and others working on the water in the Northeast. Ecosystem function will be impacted by these evolving conditions, but to what degree remains unknown. Stakeholders working under these complex conditions present us with an opportunity to better understand emerging issues and establish priorities. Forecast models represent one tool in this toolbox and this sentiment was strongly shared by all of our stakeholder focus groups. Additionally, we highlight that, as climate change progresses and as the composition (temperature and salinity) of the waters entering the Gulf of Maine continues to change its oceanography, a regional oceanographic model that resolves biogeochemistry provides coastal stakeholders an opportunity to understand these shifts and adapt accordingly to minimize impact.

Near-Term Future Policy Frameworks Likely to Utilize Model Outputs

The outreach conducted through focus groups pertained to individual target audiences with interest in oceanic conditions and trends. There is also important political context for this modeling process and outcomes pertinent to novel State-level action for climate change preparedness across the region. States (ME, NH, MA, CT, NY) have, through various legislative or gubernatorial mechanisms, established priorities that call for better understanding ocean conditions as they relate to climate change and subsequently needs to understand and prepare for likely impacts on ocean environments and marine industries. Maine's Climate Council Action plan calls for a comprehensive coastwide monitoring strategy to commence by 2024. New Hampshire's *Coastal Marine Natural Resources and Environment Commission (COMNARE)* highlights the need for a defined research agenda and specific efforts to develop a monitoring plan to improve our understanding of Omega variability in N.H. waters. Massachusetts' Ocean Acidification Commission upheld a central recommendation to improve acidification monitoring along the coastline. In Connecticut, the Governors issued Executive Order No 3. reinstituted the Governor's Council on Climate Change*;* in which a priority was established to *"Evaluate approaches to research, monitor, and address coastal acidification impacts to natural resources including shellfish, crustaceans, and fish, including a monitoring system for water quality parameters critical to the shell-fishing industry in real-time to forecast potentially high-risk events."* The New York Ocean Action Plan for 2017-2027 2027 elevated guidance from the NY OA task force in stating fundamental objectives to understand and evaluate ecological conditions.

Oceanographic biogeochemical modeling, and forecasting tools specifically for carbonate chemistry, are clearly positioned as a critical and compatible component for state level interest and action in evaluating environmental conditions, change, and risk. Our outreach among stakeholder audiences highlighted opportunities for modeling tools to corroborate in-situ information, assist in identifying appropriate locations for various activities, and synthesize oceanographic patterns which emerge from complex, interacting drivers, thus improving environmental literacy of OA and water quality as is essential for resource managers and marine industries. These themes similarly relate to the needs and likely actions pursued at the State level for societal, economic, and environmental preparedness for climate change.

However, despite universal interest from the stakeholders in our focus groups, the development of this OA forecasting model is not inherently likely to be endorsed nor used by State and agency actors. The Stakeholder Engagement Team for this project wants to emphasize that there exists an important window of opportunity to engage policymakers and both federal and state agency representatives as this model is finalized, to explore how data should be communicated, and to support scenario planning among decision-maker audiences.