Northeast Coastal Acidification Network (NECAN) Ocean and Coastal Acidification Stakeholder Workshops: Synthesis Report

February 2016

Executive Summary

The Northeast Coastal Acidification Network (NECAN) organized six one-day workshops between December 2014 and January 2016 to inform and learn from key stakeholder groups regarding Ocean and Coastal Acidification (OCA). The workshops took place in Walpole, Maine; Barnstable, Massachusetts; Narragansett, Rhode Island; Gloucester, Massachusetts; Antigonish, Nova Scotia; and Shelton, Connecticut. Each workshop had a different mix of stakeholders in attendance, and included approximately 35 to 65 participants.

The workshops involved presentations on OCA from scientists, fishermen, aquaculturists, and others (including NECAN members), along with facilitated conversations among participants. Each included presentations on the science behind OCA, local environmental and economic issues linked to OCA, research and monitoring efforts, and communication and outreach. The participants' conversations focused on their questions, observations and concerns related to OCA; their ideas on research needs and focus; and their feedback on communication and outreach needs and opportunities.

<u>Key Takeaways from Participants' Comments</u>

The comments below reflect participants' opinions based on their own observations and knowledge.

Observations and concerns

- There have been substantial changes in water quality linked to nutrient inputs in estuaries, and daily pH fluctuations in nearshore waters.
- There has been a significant increase over time in hypoxic muds in some coastal areas.
- It is difficult to distinguish among the impacts of atmospheric carbon, nutrient loading, stormwater runoff, and other coastal inputs.
- There are many aspects of the impact of OCA on species and ecosystems that we do not yet understand.
- There have been observable geographic changes in the abundance of certain species, such as lobster and a number of fish populations.
- There has been a significant decline in the overall size of many nearshore shellfisheries.

Research needs and focus

- It is important to focus on developing long-term and continuous datasets.
- We need to standardize research approaches and collaborate with multiple actors like monitoring groups, fishermen, and native peoples. Relatedly, there is a desire for guidance and training to ensure the data are uniform and usable.
- We need more monitoring of coastal conditions and of freshwater inputs.
- We need more research on species and food chain impacts and adaptability. We should focus on species that are commercially important, are likely to be impacted by OCA, or serve key ecological functions.
- Priority areas for monitoring include critical and sensitive habitats, and key estuaries.
- We need to improve monitoring technology.
- We should focus on improving our understanding of local mitigation opportunities.

Communication and outreach

- We should use existing networks to reach local community members, schools, and industry.
- The complexity of OCA makes effective communication about it difficult.
- We need to develop a robust, targeted, and simple message.
- It is key to communicate opportunities for community action and not just the problems.
- When communicating OCA, it is important not to focus too much on scientific uncertainty.

I. **Overview and Context**

From December 2014 to January 2016, the Northeast Coastal Acidification Network (NECAN) organized six one-day workshops to inform and learn from key stakeholder groups regarding Ocean and Coastal Acidification (OCA). Each workshop included approximately 35 to 65 participants. Workshop participants spanned a wide variety of stakeholder groups, including fishermen, shellfish harvesters, aquaculturists, researchers, members of coastal water quality volunteer programs, representatives from state and federal agencies, and others. The broad purpose of the workshops was to get input from stakeholders to inform development of a NECAN implementation plan.

The workshops were held in Walpole, Maine on December 10, 2014; Barnstable, Massachusetts on April 27, 2015; Narragansett, Rhode Island on June 5, 2015; Gloucester, Massachusetts on June 23, 2015; Antigonish, Nova Scotia, Canada on October 6, 2015; and Shelton, Connecticut on January 11, 2016. A detailed meeting summary was drafted for each of the workshops. The meeting summaries, agendas, and participant lists from each workshop can be found on the NECAN website at http://www.neracoos.org/necan. This synthesis is intended to summarize the themes heard across the six stakeholder workshops and to flag any substantive differences among the sessions, with a focus on the ideas and feedback put forward by workshop participants.[1]

Workshop Format

While the details of each workshop differed, they followed a similar overall format, touching on the following issues and involving the following activities:

1) *Introduction and overview*: The meeting facilitator and a representative from NECAN began each workshop by welcoming participants, reviewing the agenda for the day and providing an overview of NECAN's formation and purpose.[2]
2) *Scientific background on OCA*: A presenter from the scientific community provided background information on OCA including information on the link between OCA and climate change; changes in water chemistry associated with OCA; and the impact of coastal factors including eutrophication, increased precipitation events, upwelling events (on the West Coast), and species impacts.[3]
3) *Setting the local context:* A speaker or series of speakers discussed local environmental and economic issues linked to OCA, such as the impacts on environmental health, human health, local water quality, and local fisheries including lobster, wild shellfish, and shellfish aquaculture. Participants then broke into small groups to discuss their observations and concerns related to OCA, and whether and how they are measuring pH and other parameters.[4]
4) *Research*: Speakers discussed ongoing research activities on OCA, local monitoring efforts, and research gaps and needs moving forward. Participants then broke into small groups a second time to discuss issues related to research, including where NECAN and others should focus their research, what topics are in need of research, and who should be conducting that research.

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[1] This Synthesis Report was drafted by the Consensus Building Institute (CBI), a not-for profit organization that empowers stakeholders — public and private, government and community — to resolve issues, reach better, more durable agreements and build stronger relationships. For detailed descriptions of the speaker presentations and question and answer sessions, see the individual workshop summaries available on the NECAN website, www.neracoos.org/necan.

[2] At the Nova Scotia workshop, a representative from the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) opened the workshop before handing it off to a representative from NECAN. At the Connecticut workshop, representatives from Connecticut Sea Grant and New York Sea Grant opened the workshop.

[3] The Connecticut workshop included multiple science presentations at the outset, touching on the global implications of OCA on marine species globally, on shellfish aquaculture, and on wild capture fisheries species.

[4] Participants at some of the meetings were asked to self-select into small groups based on the issue or issues their work or interests most closely related to, such as lobster, shellfish, or water quality.

5) *Communication and Outreach:* In the final session, a representative from NECAN presented on the organization's efforts and plans to improve communication and outreach on OCA. Participants provided feedback to NECAN on its outreach efforts and draft materials, how best to reach key audiences, who it should be trying to reach, how it can best communicate with stakeholders, and what stakeholders need from NECAN in order to help them share information on OCA more effectively.[5]

Differences Among the Workshops

Although the workshops addressed the same general topics and followed the same basic format, they included participants from different backgrounds and addressed slightly different issues. For example:

- Speakers at the Walpole workshop focused on the Maine lobster fishery and oyster farming on the Damariscotta River. The Maine workshop included a good number of lobstermen, shellfish aquaculturists and harvesters, and representatives of volunteer water quality groups.
- The Barnstable workshop addressed local issues involving the South Shore and Cape Cod, with speakers focused on Cape Cod fisheries, Massachusetts' shellfish harvesters, a Cape Cod shellfish hatchery, and water quality monitoring on the Cape. The workshop included a number of shellfish harvesters, aquaculturists, and wastewater management experts.
- The Narragansett workshop included speakers focused on monitoring in Narragansett Bay and species impacts in Long Island Sound and elsewhere. Participants included a number of researchers and individuals from conservation organizations.
- The meeting in Gloucester addressed local impacts in the North Shore area with speakers focused on changes in the Atlantic sea scallop fishery, changes in the North Shore lobster fishery, and water quality observations in Salem Sound. The workshop included a number of water quality experts, shellfish aquaculturists and harvesters, and participants from local monitoring groups.
- Speakers at the Nova Scotia workshop discussed field research, aquaculture impacts, adaptation strategies, and impacts on lobster. Participants included researchers, fishermen, aquaculturists, and agency representatives.
- At the Connecticut workshop, speakers discussed the implications of OCA for shellfish aquaculture and wild capture species in Long Island Sound and elsewhere, and monitoring related to shellfish, human health, and the environment. Participants included aquaculturists, shellfish harvesters, and representatives of agencies and organizations working on water quality or marine resources.

Participant Contributions

The remainder of this Synthesis Report focuses on the insights and feedback provided by participants during workshop discussions. In each workshop, participants discussed:

1) Their questions, observations and concerns related to OCA;
2) Their ideas on research needs and focus; and
3) Their feedback on communication and outreach.[6]

Rather than detailing individual responses, this report seeks to capture the broad themes that were discussed across the workshops, and general observations on the key ideas specific to each workshop. The comments

[5] The exact questions posed to participants during this session varied by workshop, and in some workshops the session occurred in small groups while in others participants remained in the large group. The Connecticut workshop featured a more streamlined agenda without separate sessions on research and communication and outreach. Instead, participants addressed a variety of questions in a single breakout session.

[6] Participants also provided NECAN with information about monitoring efforts they were aware of involving pH and other factors, to help NECAN develop a broader understanding of the nature and extent of monitoring in the northeast region. NECAN collected this information during the workshops and is working to make that information available online.

reflect participants' personal opinions based on their own observations and knowledge; they are anecdotal observations, not scientific facts. A list of the scientific studies on OCA referenced by workshop speakers is included in the Appendix.

II. **Questions, Observations and Concerns Related to OCA**

During the first breakout group session in each workshop, participants discussed their questions, observations and concerns related to OCA.[7] Overall, their unanswered questions touched on a variety of issues, including disentangling the relationship between coastal factors and global ocean acidification, and understanding species and ecosystem impacts. Their observations focused on regional and local changes in water chemistry, decreased water quality, species impacts, and changes to the composition of sediments and benthic habitats. Most observations focused on impacts in coastal areas. Participants also expressed questions and concerns related to understanding and communicating the complex impacts of OCA on ocean chemistry and species life cycles, and predicting and mitigating impacts on shellfish, lobster, and other economically important species. The main points of discussion are recounted below, organized by theme.

Unanswered questions on coastal and species impacts. Participants noted questions about an assortment of issues, including the impact of storms and rainfall on OCA, the relationship between OCA in the water column and anoxic sediments, understanding the impact of OCA on coastal communities and economies, and the relevance of laboratory studies on species impacts to OCA in the wild.

Observations on overall impacts regarding water chemistry, water quality, increase in water temperature and benthic habitats. Participants reported a variety of observations on water chemistry and water quality. Some reported that they had observed an overall downward trend in ocean pH along with increasing variability in pH, especially in coastal waters, while others said that they had not seen observable signs of global ocean acidification to date. However, a consistent theme across the workshops was that participants had observed changes in coastal water quality linked to nutrient inputs in estuaries. Participants in the Maine, South Shore, North Shore, Rhode Island, Nova Scotia, and Connecticut workshops all reported observing increased plant life in coastal waters. Relatedly, they reported observing an increasing number of phytoplankton and macroalgal blooms, causing big daily swings in pH in nearshore waters. In Nova Scotia, participants suggested that the cold 2015 winter, with little runoff, caused an increase in phytoplankton blooms.

A number of shellfish harvesters and aquaculturists reported corresponding impacts on sediments and benthic habitats based on their observations in the field. Whereas the bottom used to be clean and sandy, participants in Massachusetts noted a marked increase over time in algal mats with black mud underneath, or what some participants termed "black mayonnaise," in places such as Wellfleet Harbor. Although no routine monitoring is taking place to document these changes, participants highlighted the devastating impact that these anoxic sediments can have on shellfish, especially during the larval stage, because shellfish cannot settle on them. They noted that very little is understood about the composition of these sediments and how to mitigate their impact. Some participants discussed their observations on additional climate-related impacts, such as an increase in the severity and frequency of intense storms leading to increased nutrient runoff and decreased salinity.

Concerns about complexity and limited knowledge. Participants from all the workshops expressed concerns about the complexity of OCA, our limited understanding of its impact, and the slow pace of scientific progress. They noted that as a chemical process, OCA involves a number of simultaneous changes in water chemistry that result from a variety of inputs, including atmospheric carbon, nutrients, and other elements of the ocean and coastal ecosystem. It is difficult to understand or communicate the interplay of all these different inputs.

[7] As noted, the Connecticut workshop included only one breakout session. The questions addressed in this session differed slightly from those in the other workshops.

Similarly, we still do not understand the complex impacts of OCA on specific species and specific ecosystems (*e.g.*, lobsters and scallops), especially in coastal areas.

Participants highlighted a lack of understanding of how different aspects of the system interact with each other, such as the impact of co-stressors or co-benefits, and synergistic effects among OCA, increased precipitation, coastal eutrophication, and other factors including anoxic sediments. They noted that it is extremely difficult to identify specific drivers among the many environmental and anthropogenic variables and stressors. There are still large gaps in information about critical issues like species' adaptive capacity, genetics, and biological effects. It is unclear how much of the change in ocean chemistry is due to local versus regional or global impacts, and how species and ecosystems might be able to adapt.

Participants had differing ideas about the implications of these observations and unanswered questions. A number of participants expressed concern that our lack of understanding will lead to missed mitigation opportunities, or failure to collect critically important data. Some worried that the complexity of the problem and our lack of scientific understanding or consensus could be used as an excuse for inaction, when immediate action is sorely needed. Others suggested that the main danger is politicians latching on to poor, simplistic or incomplete data and using it to further their own agendas.

Questions and concerns regarding communication challenges. Many participants had questions and expressed concerns over how best to communicate the science of OCA to the public and policymakers. Some observed that despite the importance of OCA, it is not a top priority for most people, and it may be difficult to create a simple, resonant story around OCA given its complexity and the lack of easy, short-term solutions. A number of participants highlighted the urgent need for clear, easily digestible communication tools to take to federal, state and local governments; industry; and the public. Others suggested it could be helpful to improve communication among coastal communities facing similar problems, and asked questions about the level of conversation between communities on the West and East coasts of the U.S. within specific industries. Still others highlighted concerns about communicating and addressing the problems that fishermen are experiencing.

Observations and concerns related to species changes. Participants also discussed their observations on the impacts of OCA on particular species and highlighted concerns over species' and industries' ability to adapt. A number of participants expressed fear that OCA may have significant, unpredictable effects on the ocean food chain, in particular through its impact on organisms at the base of the food chain like plankton. Eventually, these impacts could threaten ecosystem collapse, the loss of key fisheries, and the loss of important food sources. Participants added the following species-specific observations and concerns.

Lobster:

Observations: Participants in multiple workshops had observed spatial changes in lobster distribution and abundance, resulting in a higher abundance of lobsters moving northward and deeper offshore. They also had observed more undersized eggers (sub-legal female lobsters with eggs), higher incidents of shell disease, smaller lobster larvae, and changes in seasonal temperatures causing lobsters to molt earlier in the season.[8]

Concerns and questions: Overall, participants expressed concern over our lack of knowledge about the long-term effects of OCA on lobster. Such concerns were especially prevalent in the Maine workshop. Maine participants suggested that lobstermen now fear that it's possible to experience huge economic changes in the lobster industry in the course of just a few weeks due to seasonal unpredictability in environmental conditions. They also noted significant concern over the effect of OCA and temperature change on lobster immune systems and larvae, and the potential impact of OCA on lobster food sources.

[8] A handful of participants noted a study suggesting that OCA may have some limited benefits for lobster, for example by leading to thicker shells at warmer temperatures.

In Barnstable, participants questioned whether the smaller size of lobster larvae is due to their efforts to fight rusty tide (*i.e.* Cochlodinium). They also questioned whether there are links between OCA and wasting disease in lobster. In Gloucester and Walpole, participants expressed concerns that earlier lobster molting has impacted processing availability, lowered prices, and made it more difficult for lobstermen to rely on a predictable harvest. In Nova Scotia, participants expressed concern over the effects of environmental changes on deep-water hotspots in the Gulf of Lawrence. Connecticut participants reflected on the disappearance of lobster in Long Island Sound, noting that while water temperature changes appeared to be the major cause of the movement northward, OCA and decreased oxygen could be contributing factors. There was relatively little discussion of lobster in the Rhode Island workshop, due to the loss of Rhode Island's inshore fishery.

Shellfish:

Observations: Participants across the workshops noted anecdotal observations of a general decline in wild shellfish production in coastal waters. (Some participants suggested that increased human population density has led to significant pollution problems, which in turn has led to decreased overall shellfish populations.) More specifically, participants suggested that multiple species of shellfish have experienced larval settlement issues, have been developing thinner shells, and have experienced increased incidents of shell disease (potentially linked to higher water temperatures). Some participants noted decreases in scallop populations in eutrophic areas, an overall decrease in abundance of mussels and clams, and changes in the types of surfaces to which mussels are attaching.

Overall, participants reported that some species have been doing well, while others have been suffering. In some cases, populations have simply shifted locations rather than dying off. In Maine, participants observed that clamshells get thinner the further upstream one goes near Phippsburg. Barnstable participants noted that shellfish recruitment and development in Boston Harbor has collapsed since the cleanup, potentially as a result of changes in sediment composition such as increased bacteria. In Rhode Island, they observed larval settlement issues and large biomass declines in estuaries. In Gloucester, participants reported observing more razor clams and quahogs, and noted that the oyster industry has thrived. Some also commented that the overall shellfish population in Gloucester Harbor has reached a crisis point. In Nova Scotia, participants noted that problems with larval oyster sets seem to be linked to heavy rainfall, and noted an increase in "lazy larvae" syndrome where larvae stop feeding after a couple weeks. Participants in Connecticut highlighted concerns over increased incidence of vibrio, bacteria that affect shellfish and human health, but they were careful not suggest a direct linkage between vibrio and OCA. They also noted a significant increase in slipper shell and baby blue mussels.

With respect to shellfish aquaculture and hatcheries, some participants expressed an opinion that OCA has had little direct impact on shellfish aquaculture to date. Others reported that shellfish hatcheries have experienced changes in success possibly linked to seawater pH changes, and that there have been periodic unexplained losses of seed.

Concerns: Generally, a number of participants expressed concern about the future of shellfish fisheries in the region, and organisms' ability to adapt to changing ocean conditions. Specific concerns included fears that there may be poorly understood links between OCA and incidents of Paralytic Shellfish Poisoning (PSP), or that shellfish may be negatively impacted not just by lower pH but also by larger pH fluctuations compared to more constant exposure.

Participants expressed different levels of concern regarding the impact of OCA on shellfish aquaculture and hatcheries. On the one hand, some expressed confidence that the industry would be able to find ways to adapt to any OCA-related challenges in the future. On the other hand, a number of participants highlighted the importance of seed production to the success of the industry, and expressed concerns regarding its fragility and potential vulnerability to OCA. As one participant noted, "If you can't get seed, you can't grow shellfish, but seed production is the least secure piece of bio-production and the most vulnerable to OCA issues. There are only a few companies doing it, and if they are lost, the industry will go off a cliff." Some participants also expressed concern over the lack of knowledge about shellfish species or strains that might be more resilient to changing water chemistry, as well as the lack of attention to marketing more resilient species.

Observations and concerns on other species:

Participants shared the following observations and concerns about additional species:

- Maine participants had observed blooms of salps offshore up to 50 fathoms deep, which clog lobster boat engines, as well as tunicates. The loss of mussel beds has been observed by lobstermen in the mid-coast to the downeast area. In southern Maine, they had observed the disappearance of eelgrass beds.
- Participants in the Maine workshop reported hearing anecdotal observations of affects to finfish, especially in their larval stages, which they suggested may be related to OCA.
- Connecticut participants highlighted increases in blue and horseshoe crabs, and a decrease in starfish.
- There have been observed migrations of a number of species, such as the Atlantic salmon, northward.
- Overall, participants expressed significant concern that there might be more negative impacts on finfish in the future, especially if the overall food chain is affected through a decrease in zooplankton.

III. Research Needs and Focus

During the second small group breakout discussions, participants answered three questions related to research needs and focus:

1. Where should we focus our research efforts?
2. What should we study?
3. Who should participate?

Overall, these questions elicited responses that were broadly consistent across the workshops. Participants made the following points.

Research should be long-term and continuous. There is great value in developing continuous, long-term datasets with high quality data. We should continue such datasets where they exist, and also focus on developing new ones that measure the variables of greatest need and value to marine resources.

There is a need both for collaboration and standardization. In light of our relative lack of scientific knowledge, the trustworthiness and uniformity of scientific data is key. In order to make good policy, we need a trusted source of information and an honest broker of the research. Some participants expressed concern that disjointed efforts in research and community actions may prevent the formulation of a cohesive plan.

Participants stressed the importance of using broad research networks such as local monitoring groups, and of gathering information through collaboration with fishermen. They also noted that the long-term, historical knowledge of native peoples and oral histories could be valuable to understanding the impact of OCA over time. The goal should be to take full advantage of monitoring infrastructure and knowledge where it already exists, and to make sure that lab work can be translated to field ecology. Furthermore, a collaborative and participatory approach to research will both improve the amount of data we can gather, and increase stakeholder buy-in once the data have been gathered and we understand its implications. With respect to fishermen, it is important to manage the exchange of information so that fishermen do not feel that they are being asked to share secrets that give others a competitive advantage. In the Nova Scotia workshop, participants expressed the importance of pooling U.S. and Canadian research efforts.

There is a desire for standardized protocols, guidance, and training to ensure the data are uniform and usable. Regional coordination and a common repository to manage and share the data are also critical. In the Gloucester and Walpole workshops, participants suggested that EPA, with NECAN support, should create Quality Assurance Project Plans (QAPP) to provide standardized protocols and methods to help ensure data compatibility and quality. NECAN should develop a “train the trainer” program on OCA, and NECAN should assist its trainees and key organizations in doing their own outreach to constituents. Participants further suggested that the types of monitoring should be tailored to the needs of the organization.

There is a need for more coastal monitoring. Participants across the workshops stressed the need for more monitoring of estuaries and rivers where freshwater flows have an impact, as well as more monitoring near shore and close to bays. They stressed that it is key to better understand what is coming out of rivers and off the land, and how water quality may be impacting OCA. Some participants suggested it is also important to monitor the areas between the coast and offshore, since such areas are often overlooked, while others emphasized the need for more monitoring in federal waters and in aquaculture areas.

Despite their overall support for more and better coastal monitoring, some participants expressed concern over the costliness of such measures. Still others suggested that monitoring may be overvalued since, according to these participants, OCA is going to happen and there is no way to mitigate it completely. These participants suggested that we should increase our focus on understanding biological impacts and impacts on the food chain.

We should be strategic about our research priorities. Regardless of where exactly participants suggested research and monitoring is most needed, there was an emphasis across the workshops on the need to be strategic, systematic, and thoughtful about monitoring and other research priorities in light of limited resources. Participants suggested that the region should focus its research on priority areas, such as critical and sensitive habitats for commercially important species and key estuaries (*e.g.*; Penobscot Bay off the Maine coast; north of Prudence Island off the coast of Rhode Island; North Shore, Massachusetts areas where the rivers empty into Gloucester Harbor, Ipswich Bay, and the Merrimack River; and shellfish seedbed areas in the Quinnipiac and Housatonic Rivers in Connecticut).

The broader goal should be thoughtful and purposeful design of research programs in terms of the amount of monitoring, the scale, the level of precision, and the geographic locations. For example, the region could identify a few strategic sites for in-depth research based on their economic importance. Alternatively, it could select sites in order to show the contrast between protected and impacted areas, or try to target research towards important policy hinge points. Every effort should be made to predict what data will be important in the future to make sure we are collecting the right information now.

A participant in the Gloucester workshop laid out an example of a systematic approach to research design. He suggested we first identify “known unknowns,” *e.g.*, the cause of the lobster collapse in Rhode Island, or how soft-shell clam landings connect to OCA impacts. Next, we should identify the most important questions to answer, *e.g.*, the ability to forecast times of increased acidity versus biological or economic studies. *Then* we should decide where to spend money. The goal should be to try to find critical ecosystem and industry “tipping points,” and link research funding to areas of greatest need.

Participants identified specific issues that may be critical to ecosystem, species, and industry survival, which they suggested should be the focus of experimental and monitoring research. These included the interactions and potential impacts of OCA on bio-fouling, sediment composition, water column pH, shell dissolution, and mollusk and bivalve settlement variability. Other reported research needs included improving our understanding of why shellfish hatchery seed has been failing, the impacts of multiple stressors on major shellfish growing areas, the impact of OCA and temperature changes on lobster, and the interactions among OCA and other chemicals or molecules, such as oxygen. Participants suggested that field studies should be an important piece of the research strategy, even if it can be difficult to obtain permits for them.

We should develop more affordable and higher quality monitoring technology and equipment. A number of participants stressed the importance of improving OCA monitoring protocols and quality-assured instruments to increase their accuracy and reduce costs for citizen scientist groups. They suggested industry would be eager to incorporate more monitoring in their work if it was affordable. Relatedly, participants suggested it is key for organizations like Massachusetts Water Resource Authority and citizen water quality programs to use quality-assured equipment and standardized methods. There should be an effort to develop equipment that is sufficiently accurate to provide good measurements but also affordable enough to allow for broad usage.

We should focus on local mitigation options. Participants across the workshops noted the importance of improving our understanding of local mitigation options such as adding lime to sediments, adding crushed clam or mussel shells to clamflats, integrating macroalgae into shellfish growing systems, and using incoming tidal water to buffer the influence of high pH in shellfish hatcheries. They suggested it is key to provide communities with solutions based in sound research so that stakeholders can come together around OCA issues and feel like they have support to address the problem. Given the enormity and complexity of OCA, participants stressed the importance of looking at manageable factors and dealing with the problem on a local level. The goal should be to find community-based solutions that address the key local issues of water quality, species and economic impacts, with an emphasis on practical, economic solutions.

IV. Feedback on Communication Needs and Outreach

The final discussion in each workshop focused on communication needs and outreach. Participants provided feedback to NECAN on the following questions:

1. How should we reach out and share what we have learned?
2. How and with whom will you share this information?
3. What is the best way to communicate with stakeholders? What is the best way for scientists and stakeholders to communicate with each other?
4. What do you need from NECAN to help you share the information?[9]

Participants made the suggestions below.

Use existing networks to reach key stakeholders at the local level. Participants had different suggestions on the individual groups that NECAN should target in its outreach efforts, but they were consistent in encouraging NECAN to take advantage of existing networks as much as possible, and to target its outreach to the state and local levels. Key groups mentioned include the Northeast Regional Ocean Council (NROC), the National Estuarine Research Reserves (NERRS), EPA's Region 1 National Estuary Programs, Mass Audubon, the Marine Environmental Observation Prediction and Response Network (MEOPAR) and Fishermen's Science Research Society (FSRS) in Canada, the East Coast Shellfish Growers Association, and the New York Sea Grant program on OCA. However, participants were clear that NECAN should not just reach out to "the usual suspects," and should engage in targeted outreach to key stakeholders like recreational fishers and shellfish farmers, and special interests like wastewater groups. Participants in multiple workshops suggested that the fishing industry and its regional and local organizations could be powerful allies, but there is not yet widespread agreement in the fishing industry that OCA is a topic of concern. To engage effectively with these groups, participants suggested that NECAN focus on educating and recruiting trusted individuals from within the groups themselves, and not try to do all the work itself.

Participants also suggested that NECAN should work through schools to educate students about OCA. They noted that students often bring home messages they learn from school and explain them to their parents. NECAN could consider setting up school contests about OCA to spread awareness and interest.

Develop a robust, targeted, and simple message. A large number of comments focused on effective messaging. Participants suggested that messaging around OCA should be accessible and robust. It should communicate the

[9] The precise wording of the questions varied by workshop.

seriousness of OCA without overwhelming people or making them feel hopeless. It is therefore important to frame the message around the audience's values, and discuss specific, implementable opportunities for positive community action. It is also important to use everyday, simple language that non-scientists can understand, for example through the use of metaphor and stories. Some participants suggested that academics are not always the most effective at communicating clearly, so may not be the best ones to tackle this problem. They noted that industry representatives may respond best to stories and best practices relayed by others in industry.

Other participants said it is often helpful to frame issues around their economic impact, because people can be inspired to act if they see the issue affecting their individual or community financial resources. Still others suggested creating a message centered on our need to protect our food supply from being lost forever. Regardless of the particular frame, participants agreed that the broader goal should be to communicate with the public in a way that causes or inspires them to change behavior and spend money on solutions.

Participants also noted the importance of tailoring the message to specific audiences. For example, although a positive, hopeful message that stresses opportunities for action may be most appropriate for general audiences, a participant suggested that lobstermen respond best to "doomsday scenarios."

Participants offered a variety of ideas on specific messaging techniques, including the use of video, social media, info-graphics, and fact sheets. One participant suggested that a useful video could involve members of the fishing community discussing the changes to their industry, while another suggested showing images of shellfish larvae refusing to settle on anoxic sediments. Participants noted the importance of specific tools and fact sheets targeting members of Congress and state legislators, much like those created years ago by environmental advocates on acid rain. They also brainstormed a number of creative and innovative marketing techniques, including having people stand in the "black mayonnaise" (*i.e.*, anoxic sediments) on the bottom in coastal areas, appealing to tradition through slogans like "bring back the scallops," having an open house/tour program at the Aquacultural Research Corporation (ARC) shellfish hatchery in Dennis, Massachusetts, or developing a "traveling show" to present at fishermen's association meetings.

Message effectively around uncertainty. As noted above, one difficult challenge about communicating OCA is balancing the uncertainty of future OCA impacts with the need for immediate and robust action. Some participants commented that there may be cultural differences between how scientists and the public view uncertainty, which get in the way of effective communication. Generally, participants suggested, scientists are careful about hedging their findings and emphasizing uncertainty even when large negative impacts are highly likely, while the public is interested in knowing what to do right now. A number of participants recommended that scientists focus less on things like "*p values*" and "95% significance," and talk about uncertainty at the *end* of presentations not at the beginning. Scientists should focus on recommending positive action steps *now* despite what we don't know.

V. Final Discussion and Next Steps

Each workshop concluded with a final summary from the facilitator and a brief discussion of next steps. In some cases, participants took part in a keypad polling exercise, which demonstrated their learning about OCA over the course of the workshop. (In each case, the polling exercise showed improved knowledge of OCA and related issues.) Participants' final comments focused on the need to build a broader political constituency around addressing OCA, the need to work together more effectively across groups and networks, and the need to engage with policymakers. Participants in a number of the workshops reflected on their intention to reach out to other stakeholder groups not at the meeting to spread the message about OCA.

Appendix:

List of Scientific Studies Related to OCA Referenced by Workshop Presenters

Walpole, ME

Mark Green, St. Joseph's College

- Peters et al. 2013 (observed CO_2 emissions and emissions scenarios to 2100)
- Le Quéré et al. 2012; Global Carbon Project 2012 (fate of anthropogenic CO_2 emissions)
- cmore.soest.hawaii.edu (changes in ocean chemistry due to OA)
- Bopp *et al*., 2013 (ocean surface pH projections to 2100)
- Turley *et al.,* 2006 (rapid ocean acidification graphic)
- O. Hoegh-Guldberg et al, Science 14 December 2007: Vol. 318. no. 5857, pp. 1737 - 1742 (Coral Reefs Under Rapid Climate Change and Ocean Acidification)
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- Gobler and Talmage, 2013 (Calcification rates for *Argopecten irradians*, veligers)
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- Salisbury et al. 2008; Waldbusser et al. in prep (examples of coastal and estuarine acidification)
- Green et al., 2011 (percentage of settling clams burrowing in acidic mud)
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Bill Mook, Mook Sea Farms

- Groisman et al. 2004 (fresh water from increasing runoff; updated)

Ru Morrison, NERACOOS

- National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, et al. (map of ocean acidification research and monitoring in the NECAN region)

Barnstable, MA

Scott Doney, WHOI:

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- Wolf-Gladrow et al. 1999 (chemistry of ocean acidification)
- IPCC 2014 WG1, Chapter 3; Doney et al. Ann. Rev. Mar. Sci. 2009; Dore et al. PNAS 2009 (changing seawater chemistry)
- Doney et al. PNAS 2007; Doney Science 2010; Kelly et al. Science 2011 (other sources of coastal acidification)
- D. McCorkle, WHOI (ocean biological pump, acidification & low oxygen)
- Feely et al. Nature 2005; Bednaršek Nature Geosci. 2012 (calcium carbonate saturation state)
- Wang & Lawson, in prep (seasonally corrosive waters in deep Gulf of Maine)
- Gledhill et al. Oceanography 2015 (in press); http://www.pmel.noaa.gov/co2/story/GOM (regional spatial patterns & seasonal variability)
- Kroecker et al. Global Change Biology (2013) (synthesis of biological impacts)
- Talmage et al. PNAS 2010 (negative impacts of C02 on mollusks)

- Hall-Spenser et al. Nature 2008; Fabricius et al, Nature Clim. Change 2011 (natural high C02 laboratories)
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Mo Bancroft, Fishermens Alliance:
- MA Fisheries Landing Data (2013), NOAA, http://www.st.nmfs.noaa.gov/commercial-fisheries/index

Josh Reitsma, Cape Cod Cooperative Extension:
- Cape Cod Cooperative Extension, Marine Water Quality Monitoring Program (Real time data, http://wqdatalive.com/public/103; Archived data, http://www.capecodextension.org/marine-programs/water-quality-monitoring-2/archived-data/)
- Hawaii Ocean Time-Series Program (calculated mean seawater pH)

Narragansett, RI

Nathan Rebuck, NOAA/NMFS (duplicate citations to Doney presentation and second Rebuck presentation omitted)
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- Prell, W., Saarman, E., Murray, D., Deacutis, C., 2004. Summer-Season, Nighttime Surveys of Dissolved Oxygen in Upper Narragansett Bay (1999-2003). Data available at http://www.geo.brown.edu/georesearch/insomniacs

Heather Stoffel, University of Rhode Island- Graduate School of Oceanography
- NBFSMN data collection

Robert Rheault, East Coast Shellfish Growers Association
- Anthony Calabrese & Harry Davis (1966) Biol. Bull 131:427-436 (pH tolerance of embryos and larvae of *Mercenaria mercenaria* and *Crassostrea virginica*)
- Gary Wikfors, Carsten Krome, & Shannon Mesec, In prep (internal pH and calcium under acidic conditions)
- McConnaughy, T. & D.P. Gilligan (2008) Geol-Mar Lett 28:287-299 (Carbon isotopes in mollusk shell carbonates)
- Ullman, D. S., and D. L. Codiga http://www.crmc.ri.gov/samp (maps of oxygen (mg/l) at different seasons)
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Jason Grear, EPA Office of Research and Development
- Wa. Blue Ribbon Panel (S. Alin, R.A. Feely) (algal decomposition releasing carbon dioxide)
- Pilson, An Introduction to the Chemistry of the Sea
- Wallace et al., Estuarine Coastal and Shelf Science 2014 (pH and shell mineral availability in upper bay)
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- Talmage and Gobler, PNAS, Effects of past, present, and future ocean carbon dioxide concentrations on the growth and survival of larval shellfish
- Gobler et al, in prep (Meta-analysis showing declines in survival under high CO_2 (~1,500ppm) for Eastern oysters, hard clams, and bay scallops)
- Salisbury et al. 2008 (Ω values for surface waters for Casco Bay, Gulf of Maine)
- Data from Kraeuter & Castagna 2001; Shumway & Parsons 2006; Kennedy et al. 1996 (salinity tolerance of bivalves)
- Gazaeu et al 2013 (meta-analysis of OA effects on bivalve larvae)
- Baumann, Talmage, and Gobler, Nature Climate Change, 2011, Reduced early life growth and survival in a fish in a direct response to increased carbon dioxide
- Wallace, Baumann, Grear, Aller, and Gobler, Estuarine, Coastal and Shelf Science 148 (2014) 1-13, Coastal ocean acidification: The other eutrophication problem
- Wallace et al, 2014, ECCS; CTDEEP data set (seasonality of acidification and hypoxia in Long Island Sound; Co-occurrence of low oxygen and acidification in Narragansett Bay)
- Gobler et al 2014, PLOS One (Effects of hypoxia and acidification on survival of bay scallop larvae; Effects of hypoxia and acidification on the size of bay scallops; Growth of juvenile hard clams (4 months old) exposed to low oxygen and acidification; Low pH is depressing the survival of finfish and shellfish in the Forge River)
- Depasquale et al, 2015, MEPS (Survival of larval silversides exposed to low oxygen and low pH (acidification))
- Clark and Gobler, in prep (Experimental patterns in hypoxia and acidification; Survival of larval scallops exposed to chronic and diel fluctuations in hypoxia and acidification; Experimental 'diurnal' pH exposure)
- Talmage and Gobler, 2012, Mar Ecol Prog Ser (Effects of *Aureococcus* and elevated CO_2 on bay scallop (*Argopecten irradians)* larvae)

Cassie Stymiest, NERACOOS/NECAN

- Gledhill et al. 2015, in press (map of acidification sampling in the Northeast)

Gloucester, MA

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- Talmadge and Gobler PNAS 2010 (impacts of OCA on marine life)
- Mook Sea Farm and Casco Bay shore stations (OCA measures)

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- Tans et al., 2010; updated 2014 (rising atmospheric CO2 at Mauna Loa Observatory)
- IPCC AR4 WG1 Chap. 6 (rising atmospheric CO2)
- Feely 2008, BAMS (data from Tans et al., and Karl et al., updated online) (atmospheric CO2, seawater pCO2, and seawater pH)
- Zoebe & Walf-Gladrow, 2001 (OA chemistry)
- Wallace et al., Estuarine, Coastal & Shelf Science, 2014 (excess nutrients, low oxygen and coastal acidification)
- UNH/PMEL Buoy Data, http://www.pmel.noaa.gov/co2/story/GOM
- Salisbury et al., 2001 (local hydrographic and riverine inputs)
- Wes Pratt, NMFS (OA biological consequences)

- Meehl et al. (2007) (future CO2 projections)
- NASA ESM2M Forecast (50- and 100-year pH changes)

Susan Ingliss, UMass Dartmouth

- Marin and Luquet 2004 (molluscan shell calcification process)
- Voorhees and Pritchard, 2014 (value of Atlantic sea scallop fishery)
- 59th SAW Assessment Summary Report (Atlantic sea scallop landings by region 1975 – 2013)
- John Harding - Parksville Qualicum Beach News (Island Scallops losses and layoffs)
- Ries 2010 (species responses to OA)
- Ries et al 2009 impact of OA on bivalves)
- McCorkle 2013 (response of larval shellfish growth to aragonite saturation modulated by availability of food)
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- Mackenzie et al . 2014 doi:10.1371/journal.pone.0099712.g004 (Prevalence of parasites in *Mytilus edulis*)
- Cooley & Doney, Environment Research Letters, 2009 (economic impacts of OA)

Chris Hunt, UNH

- Doney et al. 2009 (biological impact of OA)
- Gledhill et al. 2015 (map of acidification sampling in the Northeast)
- PC 1405 ECOMON Nov 4-19, 2014 Statin Positions
- Salisbury, Vandemark (UNH); Pilskaln, Hayashi (SMAST); Cowie-Haskell and Hatch (SBNMS) (Sellwagen bank benthic OA deployment, Jan-June 2012)
- Mook Sea Farm Hatchery salinity and omega measurements
- Casco Bay 2015 measurements
- Skogafoss near real-time measurements

Barbara Warren, Salem Sound Coastwatch

- CDM 1978; CDM 1987; CDM 1991; Dallarie and Halterman 1991 and SESD 1998 (background on Salem Sound)
- The Marine Resources of Salem Sound, 1997, Technical Report TR-6, MA DMF, DFWELE, EOEA, Bradford C. Chase, Jeffrey H. Plouff, and Wayne M. Castonguay (report on Salem Sound measurements)
- Salem Sound Water Quality 2010-2011, Salem Sound Coastwatch & Salem State University, Barbara Warren, Dr. Brad Hubeny (report on Salem Sound measurements)

Antigonish, Nova Scotia

Joe Salisbury, University of New Hampshire (duplicate citations omitted)

- IPCC AR5 WG1 Chap. 6 (rising atmospheric CO2)
- Barton et al, 2012; Salisbury et al, 2008 (Ω threshold for optimal larval growth in clams and oysters)
- DFO, Canada (fresher water can be more sensitive to acidification than saltier water; colder water tends to be more acidic and lower omega than warmer)
- Signorini et al, 2014 (min annual pH in the NECAN region)
- W-J Cai and the UDEL team (data from this year's ECOA cruise)
- Wallace et al., Estuarine, Coastal & Shelf Science, 2014 (excess nutrients, low oxygen & coastal acidification)
- Waldbusser et al. 2012 (Chesapeake Bay pH Summer, Salinity >20)
- Britburg et al, 2015 (coping with OA in the midst of many stressors)
- Kalnejas (unpublished) (sediment profiles in Stellwagen Bank (5/7/13))

- J. Marra (OPAL NPP model)
- Waldbusser and Salisbury, 2014 (omega in the Kennebec Plume)

Thomas Helmuth, Dalhousie University

- Canadian Ocean Acidification Research Partnership (COARp) observation sites (pCO2, tide height, and sunlight intensity)
- Thomas, Tyedmers, Greenan, Miller, Salisbury (spatio-temporal variability of ocean pH, relationship between shelf and inshore observations Scotian Shelf region)
- Mucci, Starr, Thomas, Noyes-Hull (GAMS), spatio-temporal variability of ocean pH, relationship between Gulf and inshore observations GSL region)
- Kuzyk, Thomas, Mucci, Miller, Heath (AES) (variability of the oceanic CO2 system from water column observations in Hudson Bay)
- Else, Thomas (variability of the CO2 system and atmosphere-ocean coupling in Cambridge Bay (J. Whitehead))
- Klenast, Thomas Kuzyk, Mucci, Garbary (sedimentary records from Hudson Bay and the GSL to hint-cast ocean pH/CO2 conditions; using the seaweed *Ascophyllum nodusum* as environmental proxy for CO2 system conditions (S. Mellon))
- Cheung, Sumaila, Tyedmers (potential chance in economic value of Canadian shellfish fisheries due to OA)
- Tyedmers, Sumaila, Cheung (biochemical-economic-social risk assessment of communities and regions dependent on shellfish production due to OA)
- Thomas, Kienast, Greenan, Fennel (shelf-scale drivers of ocean acidification from the seasonality of 13C (MEOPAR initial project 2.2, J. Lemay))
- Fennel, Thomas, Greenan (biogeochemical modeling of shelfscale drivers of ocean acidification (MEOPAR initial project 2.2, Dr. C. Brennan))
- Mucci, Starr (ocean acidification and ecosystem structure in the GSL (Chloe Martias/McGill))
- Thomas, Kienast, Garbary (establishing seaweed *Ascophyllum nodusum* as environmental proxy for CO2 system conditions; CO2 system variability in the Grand Passage area (Gulf of Maine))

Tony Charles

- Helen Gurney-Smith and Sarah Dudas (doing biodiversity and recruitment studies at a suite of locations along an anthropogenic gradient (Quadra, Calvert and Baynes Sound))
- Fisheries and Oceans Canada 2013. Commercial fisheries. http://www.dfo-mpo.gc.ca/stats/commercial-eng.htm

Bill Mook, Mook Sea Farms

- U.S. EPA, IPCC AR5 Report (visualizing CO2 emissions)
- http://ncdc.noaa.gov/cag (average annual precipitation in Portland Maine 1930-2013)
- Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014: Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT (Change in Precipitation Patterns: Intense precipitation events (the heaviest 1 percent) in the continental U.S. from 1958 to 2012)
- Maine Department of Marine Resources (number of shellfish harvest flood closures in Maine 2000-2014)

Dwight Gledhill, NOAA

- Strategic Plan for Federal Research & Monitoring of Ocean Acidification (2014)

- Directed investment on monitoring OA:
    - NANOOS FY2014 Marine Sensor and Other Advanced Observing Technologies Transition Project: "Turning the headlights on 'high': Improving an ocean acidification observation system in support of Pacific coast shell fish growers" (Newton)
    - CIMEC Moored Carbon, Biogeochemical, and Ecosystem Observations in the Southern California Current (Send)
    - AFSC FY2015-FY2017 Alaska Ocean Acidification Research: Physiological response of commercially important crab species to predicted increases in pCO2 (Foy)
    - AFSC FY2015-FY2017 Alaska Ocean Acidification Research: Autonomous Observations of Ocean Acidification in Alaska Coastal Seas (LOI)
    - (Mathis) NWFSC FY2015-FY2017 Northwest Fisheries Science Center Sustained Investment Workplan: NWFSC OA Facility (McElhany)
    - NWFSC FY2015-FY2017 Northwest Fisheries Science Center Sustained Investment Workplan: NWFSC OA Experiments (McElhany)
    - AFSC FY2015-FY2017 Alaska Ocean Acidification Research: Effects of OA on Alaskan gadids: sensitivity to variation in prey quality and behavioral responses (Hurst)
    - NANOOS (Formaly CIMRS) Ocean Acidification Monitoring and Prediction in Oregon Coastal Waters (Hales)
    - PMEL FY2015–FY2017 NOAA Ocean Acidification Observing Network (NOA-ON) Sustained Investment Workplan: PMEL Sustained Ocean Acidification Large-Scale Survey Observations. (Feely)
    - PMEL FY2015–FY2017 NOAA Ocean Acidification Observing Network (NOA-ON) Sustained Investment Workplan: PMEL Sustained Coastal Ocean Acidification Underway Observations (Alin)
    - NANOOS UW OA observatories (Newton) NANOOS Westcoast Coastal Ocean Acidification (WECOA)
    - Cruise Analytical Support (Hales)
    - NWFSC FY2015-FY2017 Northwest Fisheries Science Center Sustained Investment Workplan: NWFSC OA Zooplankton Exposure Modeling (McElhany)
    - NWFSC FY2015-FY2017 Northwest Fisheries Science Center Sustained Investment Workplan: NWFSC OA West Coast Vulnerability Assessment
    - AFSC FY2015-FY2017 Alaska Ocean Acidification Research: Forecast effects of ocean acidification on Alaska crabs and pollock abundance (Dalton)
- **Contributing Investment**
    - PMEL FY2015–FY2017 NOAA Ocean Acidification Observing Network (NOA-ON) Sustained Investment Workplan: PMEL Sustained Ocean Acidification Mooring Observations (Sutton)
    - PMEL FY2015–FY2017 NOAA Ocean Acidification Observing Network (NOA-ON) Sustained Investment Workplan: Data Management, Quality Control, Access, and Products (Sutton)
    - NODC FY2015-FY2017 Ocean Acidification Data Stewardship (OADS) Project: Ocean Acidification Data Stewardship(OADS) Project (Jiang)
    - PMEL FY2015–FY2017 NOAA Ocean Acidification Observing Network (NOA-ON) Sustained Investment Workplan: TMAP (Burger)
    - CIMEC CalCOFI OA Monitoring and QA/QC Analytical Support (Dickson) CINAR - In support of Special Issue of Oceanography (Benway)
- Feely, Alin, Chan, Hill et al (in prep) (location of the corrosive water from spring 2007 to summer 2013)
- Directed investment on marine life:
    - AFSC FY2015-FY2017 Alaska Ocean Acidification Research: Physiological response of commercially important crab species to predicted increases in pCO2 (Foy)
    - NWFSC FY2015-FY2017 Northwest Fisheries Science Center Sustained Investment Workplan: NWFSC OA Facility (McElhany)

- NWFSC FY2015-FY2017 Northwest Fisheries Science Center Sustained Investment Workplan: NWFSC OA Experiments (McElhany)
    - AFSC FY2015-FY2017 Alaska Ocean Acidification Research: Effects of OA on Alaskan gadids: sensitivity to variation in prey quality and behavioral responses (Hurst)
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- Manzello, D. P., I. C. Enochs, A. Bruckner, P. G. Renaud, G. Kolodziej, D. A. Budd, R. Carlton, and P. W. Glynn (2014), Galápagos coral reef persistence after ENSO warming across an acidification gradient, Geophys. Res. Lett., 41, 9001–9008, doi:10.1002/2014GL062501.
- Cooley et al. 2015. PLOS One (socioeconomic vulnerability and sea scallops)
- Directed Investment on adaptive strategies:
    - NANOOS FY2014 Marine Sensor and Other Advanced Observing Technologies Transition Project: "Turning the headlights on 'high': Improving an ocean acidification observation system in support of Pacific coast shell fish growers" (Newton)
    - CIMEC Moored Carbon, Biogeochemical, and Ecosystem Observations in the Southern California Current (Send)
    - AFSC FY2015-FY2017 Alaska Ocean Acidification Research: Physiological response of commercially important crab species to predicted increases in pCO2 (Foy)
    - AFSC FY2015-FY2017 Alaska Ocean Acidification Research: Autonomous Observations of Ocean Acidification in Alaska Coastal Seas (LOI)
    - (Mathis) NWFSC FY2015-FY2017 Northwest Fisheries Science Center Sustained Investment Workplan: NWFSC OA Facility (McElhany)
    - NWFSC FY2015-FY2017 Northwest Fisheries Science Center Sustained Investment Workplan: NWFSC OA Experiments (McElhany)
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    - NANOOS (Formaly CIMRS) Ocean Acidification Monitoring and Prediction in Oregon Coastal Waters (Hales)
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    - PMEL FY2015–FY2017 NOAA Ocean Acidification Observing Network (NOA-ON) Sustained Investment Workplan: PMEL Sustained Coastal Ocean Acidification Underway Observations (Alin)
    - NANOOS UW OA observatories (Newton) NANOOS Westcoast Coastal Ocean Acidification (WECOA)
    - Cruise Analytical Support (Hales)
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    - NWFSC FY2015-FY2017 Northwest Fisheries Science Center Sustained Investment Workplan: NWFSC OA West Coast Vulnerability Assessment
    - AFSC FY2015-FY2017 Alaska Ocean Acidification Research: Forecast effects of ocean acidification on Alaska crabs and pollock abundance (Dalton)
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- CIMEC CalCOFI OA Monitoring and QA/QC Analytical Support (Dickson) CINAR - In support of Special Issue of Oceanography (Benway)

Shelton, Connecticut

Chris Gobler, SUNY Stony Brook (duplicate citations omitted)

- Pieter Tans and Thomas Conway, 2010, NOAA/ESRL (CO_2 change, 1960 – present)
- Pearson and Palmer, *Nature,* 2000 (Changes in atmospheric CO_2 during the past 25 million years)
- Ken Caldeira and Michael E. Wickett, Nature, 25 September 2003 (anthropogenic carbon and ocean pH)
- Hönisch et al. 2012 (Atmospheric Carbon Dioxide (CO_2), Ocean pH, and calcium carbonate ($CaCO_3$))
- Chris Roberts (projected surface ocean pH and projected atmospheric CO_2)
- Feely et al. 2009 (carbonate levels projected to drop as ocean acidifies)
- NMFS data (top fisheries in New York, 2012)
- Food and Agriculture Organization of the United Nations; Deming et al. 1998; Helm and Bourne 2004; Abraham and Dillon 1986 (life cycle of bivalves)
- Stephanie C. Talmage and Christopher J. Gobler, PNAS (effects of past, present and future ocean carbon dioxide concentrations on the growth and survival of larval shellfish
- Talmage & Gobler PNAS 2010 (cross-section of juvenile clams)
- Gazeau et al. (2007) (Reduced calcification in blue mussels (*Mytilus edulis*) and Pacific oyster (*Crassostrea gigas*))
- Barton et al. (2015) (Impaired larval shell formation of Pacific oyster (*Crassostrea gigas*))
- Barnhart and McMahon 1988; Kwast and Hand 1996; Guppy and Withers 1999; Langenbuch and Pörtner 2002; Pörtner et al. 2005; Fabry et al. 2008; Sokolova 2013; Waldbusser et al. 2015 (Some generalities about OA and bivalves)
- Kroecker et al. Global Change Biology (2013) (Biological Impacts of OA)
- Hannes Beaumann, Stephanie C. Talmage and Christopher J. Gobler, Nature Climate Change (Reduced early life growth and survival in a fish in direct response to increased carbon dioxide)
- Wang et al 2013 (Acidification vulnerability across the eastern US)
- NASA model 2010, ESM2M
- Carlos M. Duarte, Iris E. Hendriks, Tommy S. Moore, Yiva S. Olsen, Alexandra Steckbauer, Laura Ramajo, Jacob Cartensen, Julie A. Trotter, Malcolm McCulluch, Estuaries and Coasts, March 2013 (Is Ocean Acidification an Open-Ocean Syndrome? Understanding Anthropogenic Impacts on Seawater pH)
- Feely et al. 2008 (US West Coast upwelling linked to the collapse of the Pacific oyster fishery
- Barton et al 2012 (relative larval production versus omega in initial water)
- Median USGS stream data since 2000 (pH levels in US rivers)
- Wallace et al, 2014, ECCS (Co-occurrence of low oxygen and acidification in Long Island Sound)
- William G. Sunda and Wei-Jun Cai, Environmental Science and Technology 2012 (Eutrophication Induced CO_2-Acidification of Subsurface Coastal Waters)
- Wei-Jun Cai, Xinping Hu, Wei-Jen Huang, Michael C. Murrell, John C. Lehrter, Steven E. Lohrenz, Wen-Chen Chou, Weidong Zhai, James T. Hollibaugh, Yongchen Wang, Pingsan Zhao, Xianghui Guo, Kjell Gundersen, inhan Dai and Gwo-Ching Gong, Nature Geoscience, 23 October 2011, Letters (Acidification of subsurface coastal waters enhanced by eutrophication)
- Ringwood and Keppler 2002 (Diurnal changes in pH and DO driven by metabolism)
- Baumann et al 2015, E&C (Diurnal patterns in acidification, oxygen; Flax Pond, NY)

Mark Green, Oyster Farmer and St Joseph College Professor/Researcher

- Media Matters for America (The Kardashians vs. Ocean Acidification)
- After Bopp *et al*., 2013 (Ocean surface pH projections to 2100)

- Turley *et al.,* 2006 (Rapid ocean acidification)
- SEMs by Elizabeth Brunner and George Waldbusser, OSU (Pacific oyster larvae spawned in favorable and unfavorable seawater conditions at Taylor shellfish hatchery on Dabob Bay)
- htpp://ncdc.noaa.gov/cag (Average Annual Precipitation in Portland Maine 1930 -2013)
- Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014: Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT (Change in Precipitation Patterns: Intense precipitation events (the heaviest 1 percent) in the continental U.S. from 1958 to 2012)
- Dr. Joe Salisbury, UNH, data from seawater monitoring system at Mook Sea Farm (estimated change in aragonite saturation at MSF)
- Susie Arnold, Island Institute/Bigelow ("phytoremediation" as an adaptation strategy)
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Lisa Milke, NOAA NMFS Milford Laboratory

- NOAA Fisheries (Wild Capture Fisheries Species)
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- Mark Nelson, Wendy Morrison, Roger Griffis, Jennifer Howard, Jon Hare, Eric Teeter, Megan Stachura, Mike Alexander, Jamie Scott (Assessing the Vulnerability of Fish Stocks to Climate Change, http://www.st.nmfs.noaa.gov/ecosystems/climate/activities/assessing-vulnerability-of-fish-stocks)
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