Northeast Coastal Acidification Network (NECAN) Ocean and Coastal Acidification Stakeholder Workshop: Massachusetts North Shore

June 23, 2015

I. Overview and Context

The Northeast Coastal Acidification Network (NECAN) organized this one-day workshop to inform and learn from fishermen, aquaculturists, and coastal water quality groups regarding Ocean and Coastal Acidification (OCA). The workshop was held at The Gloucester House in Gloucester, Massachusetts, and was the fourth in a series of stakeholder engagement workshops on OCA organized by NECAN. The first workshop was held in Walpole, Maine on December 10, 2014; the second was held in Barnstable, Massachusetts on April 27, 2015; and the third was held in Narragansett, Rhode Island on June 5, 2015.

This summary is designed to capture key themes and topics from the day.[1] Presentation slides from the workshop can be found at the NECAN website (www.neracoos.org/necan).

Highlights of the workshop included the following ideas, which emerged from the presentations and group discussions:

- OCA consists of three different issues: global ocean acidification due to climate change, coastal eutrophication and nitrogen loading, and coastal upwelling events.
- The impacts of OCA on fisheries are potentially dramatic but poorly understood. There are many additional research needs, particularly around the impacts of OCA on the lifecycle of shellfish and other organisms like phytoplankton, zooplankton, and lobster.
- There are multiple ongoing monitoring programs, but there is a lot we don't know about the best way to monitor and the most important data to collect.
- Efforts to improve water quality, reduce nitrogen loading, and mitigate OCA have a synergistic relationship with shellfish aquaculture.
- Communication of OCA is a challenge due to the complexity and long time horizon involved, but there are examples of good communication to build on.
- NECAN could embrace a "train the trainer" approach to leverage its impact and energize community and volunteer groups, while working to ensure high quality monitoring and data collection.

[1] This summary was written by Toby Berkman of the Consensus Building Institute, with input from note takers from the workgroups and the oversight of the planning team.

At the start of the meeting, Ona Ferguson, facilitator from the Consensus Building Institute (CBI), welcomed participants and thanked the many people involved in planning the workshop.[2] See Appendix A for a complete list of workshop participants. In addition, a glossary of key terms was distributed to participants, and is attached as Appendix B.

Cassie Stymiest, Program Manager for NERACOOS, the parent organization of NECAN, provided background information on NECAN, how it was formed, and its work to date. In 2010, the California Current Acidification Network was founded to address OCA issues on the West Coast. Then, in 2013 (though first observed in 2007 and 2008), upwelling events on the West Coast devastated hatcheries, bringing renewed attention to OCA issues nationally. East Coast shellfish hatcheries, such as Mook Sea Farms, had also begun to notice slower growth, lower survival rates, and deformed shells. NECAN was formed in September of 2013 with members of industry, academia, and government agencies working together on a range of ocean and coastal acidification topics in coastal waters from Long Island Sound to Nova Scotia.

NECAN's role is to: (1) review and assess the most recent scientific, technical and socio-economic information relevant to the economically important marine organisms potentially impacted by ocean and coastal acidification, (2) communicate critical knowledge gaps identified by stakeholders to relevant state and federal agencies, (3) help to coordinate and set regional priorities for monitoring and research designed to further our understanding of coastal acidification, and (4) respond to user and stakeholder needs.

Since its formation, NECAN has held 16 science-based webinars led by experts on OCA, which are available on the NECAN website. It hosted a two-day State of the Science Workshop in April 2014, and developed an article, "Ocean and Coastal Acidification off New England and Nova Scotia," published in the scientific journal *Oceanography* in June 2015. The scientific synthesis and the sub-regional stakeholder engagement workshops are designed to contribute to the development of an implementation plan, to be written in 2015.

NECAN has come to recognize that the northeast region is highly vulnerable to OCA, but there will be diverse impacts and there are many unanswered questions. Although the science is complicated, NECAN has made a concerted effort to use simple messaging and communication tools to reach stakeholders. So far, its stakeholder engagement workshops have suggested a number of important regional needs related to OCA, including:

- Improved understanding of OCA in the context of climate change and multiple additional environmental stressors;
- Improved understanding of risks and recommendations for each industry group;
- More – and more coordinated – monitoring and research; and
- Improved and expanded monitoring to ensure high quality and long-term data.

To address these and other issues, NECAN plans to set up working groups on science, industry, policy, and outreach and education. For more on NECAN, see the NECAN website.

[2] People involved in workshop planning included Julie Simpson, MIT Sea Grant; Prassede Vella, Massachusetts Bays National Estuary Program; Madeleine Hall-Arber, MIT Sea Grant, Esperanza Stancioff, Maine Sea Grant; Matt Liebman, EPA; Todd Callaghan, MA Office of Coastal Zone Management; Ona Ferguson, Consensus Building Institute; and Cassie Stymiest, NERACOOS.

II. What is Ocean and Coastal Acidification?

Nathan Rebuck, a researcher at the NOAA National Marine Fisheries Service (NMFS), provided scientific background on OCA. Ocean acidification is the continuous trend of increasing acidity in marine waters resulting from increased carbon dioxide. It can be quantified with several chemical parameters, including pH, dissolved inorganic carbon (DIC), partial pressure of carbon dioxide (pCO_2), and calcium carbonate (aragonite) saturation state (represented by the symbol omega, i.e. Ω). Regionally, ocean acidification is also affected by sulfur oxide (SOx) and nitrogen oxide (NOx) emissions from industrial activities. Locally, it is impacted by upstream eutrophication and its impact on biological respiration.

Ocean acidification on a global level is impacted by anthropogenic CO_2 emissions, which total roughly 10 billion tons per year. While about half of this carbon goes into the atmosphere, roughly one quarter of it is absorbed on land and another quarter is absorbed by the oceans. Today, atmospheric CO_2 is higher than it has been for millions of years. The last time atmospheric carbon was this high, however, it took hundreds of thousands of years to reach that level, giving species time to adapt. The analytic record shows a 0.02 decrease in seawater pH over the past decade. This might seem small but, as with global average temperature, small changes can have large impacts.

There are a number of chemical reactions that cause ocean acidification. When atmospheric carbon dissolves in seawater, it combines with the water molecule and converts to carbonic acid. Carbonic acid then dissociates into hydrogen and bicarbonate, which causes the pH to change. Some of the additional hydrogen reacts with carbonate ions to form more bicarbonate. The net result is more CO_2, lower pH, fewer carbonate ions, and a lower saturation state for calcite and aragonite (Ω). These chemical changes make it more difficult for calcifying organisms to produce shells.

There are four major measures of ocean acidification: pH, DIC (dissolved inorganic carbon), pCO_2, and total alkalinity. Because pH is temperature dependent, it is necessary to use at least two of these four measures to fully understand the chemical changes occurring in the water.

The analytic record shows a 0.02 decrease in seawater pH over the past decade. This might seem small but, as with global average temperature, small changes can have large impacts.

-Nathan Rebuck, NMFS

Although there has been a meaningful decrease in ocean pH in recent years, there is also a lot of "noise" that makes it difficult to determine exactly how quickly ocean chemistry is changing globally as a result of CO_2 emissions. For example, while the pH of the ocean has gone down by about 0.1 over the last thirty years, there is also about a 0.1 change in ocean pH seasonally. In coastal waters, the daily fluctuations are even larger. This is because when animals eat, the cellular respiration of sugar molecules puts additional CO_2 into the water. In addition, when phytoplankton die, they release carbon back into the water. Stormwater runoff, sewage, and fertilizer used for farming, each of which contribute to phytoplankton growth, can therefore decrease ocean pH significantly in coastal waters. In addition, because the deep ocean has a lot of built up CO_2, coastal upwelling (as occurred on the West Coast in 2013) can cause a substantial (if temporary) decrease in pH.

Ocean acidification creates multiple stressors for calcifying organisms. For example, low pH correlates with low dissolved oxygen, which means organisms cannot survive in the sediments where shellfish typically embed themselves. In addition, low aragonite saturation will cause clam shells to dissolve or make it more difficult for organisms to grow shell.

We are not yet sure of the overall impact of ocean acidification on marine life. It is likely that different species will be impacted differently. We know OCA is very bad for corals, and it is probably bad for plankton. It will likely be bad for bivalves and other crustaceans, but some studies show it can be good for lobster at warm temperatures (or, at least, that it may result in thicker shells). In order to understand these impacts it is key to track the variety of chemical changes occurring in the water beyond just pH. One research challenge is that it is difficult to mimic the large daily fluctuations in ocean chemistry in lab settings.

In the future, scientists anticipate that CO_2 will increase to 1,000 parts per million, resulting in a 0.2 to 0.4 change in pH globally. It is difficult to predict exactly what changes this will cause in marine life and how organisms will – or will not – be able to adapt. In nearshore coastal regions, local upstream land usage and nutrient inputs will continue to be the primary determinants of acidification.

Participant questions

Participants asked the following questions about Nathan's presentation. *Nathan's responses are in italics.*

- How is it that land usage and nutrient inputs will be the primary determinants of acidification if atmospheric CO_2 keeps increasing? *In most of world's oceans, the water has lower CO_2 than the atmosphere. As a result, on average, the atmosphere feeds CO_2 into the water, which causes global ocean acidification. In areas of high organic inputs with lots of community respiration, however, there is higher CO_2 dissolved in the water than in the atmosphere. In such areas, the CO_2 leaves the water and enters the atmosphere. This is actually the case in many New England coastal regions in the winter, when marine plant life is breaking down.*
- Have we learned anything relevant to our understanding of ocean acidification from our research into freshwater acidification, for example as a result of acid rain? *We learned a number of important lessons from freshwater acidification. For example, once we placed scrubbers on smokestacks and capped emissions from factories, pH in some areas started to go back up. For remediation, limestone can be placed in lakes to increase pH. In estuaries and locally, oyster and eelgrass will have similar impacts. It is also helpful to do mitigation upstream from where shellfish farms are located. Unfortunately, these interventions have limited applicability to ocean acidification globally, given the size of the ocean.*
- How do sulfate and nitrate affect the buffering capacity of seawater? *The increase in nitrate increases the alkalinity. However, if there is an increase in nitrate sufficient to affect buffering capacity, it will cause an algae bloom. The algae is then recycled, which defeats your purpose.*

III. Setting the Local Context

<u>Presentation 1: Changes in the Scallop Fishery</u>

Susan Inglis from the University of Massachusetts Dartmouth discussed the potential impacts of OCA on the wild Atlantic sea scallop fishery. The management areas for the Atlantic sea scallop stretch from Canada to the mid-Atlantic. In the scallop life cycle, settlement occurs about 45 days after fertilization. The pH of the sediment is important for settlement.

Carbonate is important for scallop growth because they are marine calcifiers. They grow both by adding to the open edge of the shell and by gradually thickening the shell. On the outside their shell has calcite, which is less susceptible to pH change, and on the inside they have aragonite, which is stronger but more effected by pH.

The Atlantic sea scallop supports the highest valued commercial fishery in New England. Currently, no significant changes to the fishery have been observed or tied to OCA, but the future impacts are less clear.

Different species have different responses to OCA. Bivalves are negatively impacted because of their large shell mass relative to body mass, the permeable nature of some species periostaca, and their inability to regulate pH at site of calcification. Crustaceans, on the other hand, may be positively impacted because they use bicarbonate to make their shells. There are several ongoing studies on the effect of OCA on Atlantic sea scallops, but we do not yet have the results.

Given the economic importance of marine calcifiers, more research into the potential impacts of OCA is critical.
-Susan Inglis, UMass Dartmouth

Work on species similar to Atlantic sea scallops, like bay scallops, has been completed. The research suggests that the scallops' early life stages are most affected by OCA due to the lower saturation level of aragonite. However, there are preliminary findings of a study suggesting that the response of larval shellfish growth to aragonite under-saturation may be modulated by the availability of food. Typically, however, OCA results in reduced growth, lower meat weights, and thinner shells.

OCA may also have indirect effects on scallops by increasing their susceptibility to disease and certain parasites. However, OCA may also impact the parasites themselves, so the net impact is unclear. OCA may also have a negative impact on scallop predators, like starfish. More research would help clarify the net impact.

Although we do not yet know the future impact of OCA on sea scallops, studies suggest it is complex and potentially negative. We are likely to see decreased recruitment, increased mortality, lower meat yield, and lower overall biomass. Given the economic importance of marine calcifiers, more research into the potential impacts of OCA is critical.

Participant questions
Participants asked the following questions about Susan's presentation. *Responses are in italics.*

- Have researchers used museum collections to compare the historic thickness of scallop shells to today? *We have a large library of scallop shells and we are doing work with them, but it might also be helpful to look at other museum collections.*

- Ocean quahogs might be a resource because they take so long to grow and they are so old. *There have been some studies done on ocean quahogs.*

Presentation 2: Questioning How Acidification Will Impact Shellfish

Robert Rheault, Executive Director of the East Coast Shellfish Growers Association, presented in his personal capacity on the potential impact of OCA on east coast shellfish fisheries. He suggested there has been a lack of scientific progress on understanding ocean acidification. Although we know ocean acidification is coming, we do not yet know how it will impact shellfish growth or recruitment.

> ***The real world has dramatic daily changes in pH, phytoplankton, and corrosive sediments, which cannot be replicated by bubbling CO_2 in a beaker.***
> **-Robert Rheault, East Coast Shellfish Growers Association**

Laboratory research in its current form is a weak proxy for real world conditions. The real world has dramatic daily changes in pH, phytoplankton, and corrosive sediments, which cannot be replicated by bubbling CO_2 in a beaker. This makes it very difficult to rely on laboratory research to predict how OA will impact organisms. Although the Federal Ocean Acidification Research and Monitoring (FOARAM) Act has resulted in significant funding for research into ocean acidification, it has mostly been spent on oceanographic cruises and monitoring buoys. There has been insufficient funding into research on the impact of OA on organisms like shellfish.

Changes in ocean chemistry involve three separate issues: 1) global ocean acidification, 2) upwelling of corrosive deep water, and 3) eutrophication-induced acidification. The first issue, global ocean acidification, is linked to climate change and is therefore projected to increase. The second issue, upwelling, has been happening for hundreds of years. Deep ocean waters are rich in nutrients due to the bacterial decay of sinking fecal pellets and dead plankton. Upwelling events might become more frequent due to climate change if changing weather patterns cause an increase in northerly breezes on west coast. The third issue, eutrophication, is being observed in estuaries all over the world. During the day, dense algal blooms take up CO_2; at night they respire, giving off CO_2 and causing pH to drop. Nighttime pCO_2 levels as high as 1000-3000 ppm are commonly observed in eutrophic estuaries. These are equivalent to the levels predicted for the ocean as a whole in 50-100 years.

These multiple aspects of OCA have cumulative effects on organisms. For example, the changing ocean chemistry results in acidified sediments. Shellfish larvae are unable to dig into the acidified mud, because it will cause them to dissolve. The larvae are therefore forced to settle on top of the mud and are eaten by predators.

Despite all these challenges, some shellfish sets are still surviving in certain areas. For example, in areas showing aragonite saturation of 0.9, where shells might be expected to dissolve, 20 to 30 million clams are still being harvested. However, we are also seeing areas where clam harvesting is in steep decline, like in Narragansett Bay. More work needs to be done to understand why and how organisms are surviving in certain areas but not others.

Even though they are small in absolute terms, the changes in pH associated with global ocean acidification are important. Because these changes are occurring on a global scale, they will add up and have significant impacts. The last time CO_2 levels were this high, there were mass extinctions. At the same time, shellfish have survived for hundreds of millions of years, and may be able to withstand significant changes in ocean chemistry due to their inherited genetic variation. Notable scientific observations include the following:

- Researchers in Australia looking at the Sydney Rock Oyster have observed adaptation to OCA within two generations, potentially through epigenetics.
- On the West Coast, the offspring of oysters exposed to high pCO_2 levels were more resistant to high CO_2.
- A study from the 1960s suggests there was 90% survival of shellfish embryos and larvae at pH levels ranging from 6.2 to 9.
- Another study suggests that oyster hemocytes maintain internal pH and calcium under acidic conditions, and there is evidence that the carbon isotope ratio of shell is based on diet rather than ambient water CO_2.
- On the West Coast, hatchery production has not returned to normal following the upwelling events in 2013, even though hatcheries buffer their water with carbonate and keep aragonite saturation high. This suggests there may be other causative factors besides OCA.
- Aragonite-based corals are likely headed for extinction, but Palau coral has been surviving despite low pH levels.

Locally, acidified mud due to eutrophication is affecting biomass right now. The loss of soft shell clams in Chesapeake Bay over the last few decades may in fact be related to OCA. Although there are measures we can take to mitigate impacts, such as managing waters in hatcheries or reseeding areas with heartier adults, there is still the potential for mass extinctions. All of this suggests an urgent need for more research to help determine if there will still be a surviving shellfish industry in 50 years.

Participant questions

Participants asked the following questions and made the following statements about Robert's presentation. *Responses are in italics.*

- Based on your intuition, how quickly do we need to have the science to answer the questions you are posing? *We know pH will change and we need to know the impact on species and communities on the coast. We need to know if approaches like selective breeding and mitigation of acidic mud will be effective. Under the FOARAM Act, we are spending only $6-8 million on science, but the scale of the problem is much greater.*
- The Massachusetts Department of Marine Fisheries has been studying whether there is a correlation between OCA and the disappearance of soft shell clam sets, and the answer has been yes. There has also been some work on adding limestone to the water to mitigate OCA on a limited basis. *Mitigation approaches – such as removing "black mayonnaise" from the bottom of the ocean – can help locally, but cannot be done on a broad basis. The other clear need is to reduce runoff.*
- Is there talk of additional funding for upgrading wastewater treatment facilities and dealing with stormwater runoff? *Yes. EPA has mandated total maximum daily loads (TMDLs) for nitrogen and is addressing other sources like agriculture. One challenge is the lobbying power of the farm bureau. In wastewater treatment plants, the first 90% of nitrogen removal is reasonably affordable, but the last 10% is expensive. It would be cheaper to stop putting fertilizer on lawns and cut down on nitrogen emissions from other sources.*

Presentation 3: A Lobsterman Perspective

Sooky Sawyer, a lobsterman for over 40 years and President of the Massachusetts Lobstermen's Association, provided a lobsterman's perspective on OCA. Lobstermen have been seeing an increase in shell disease, which used to be limited to crab, and they are concerned because no one understands the cause. South of Cape Cod, shell disease has caused lobster die offs. 75% of lobstermen in southern New England have left the industry. There are a variety of hypotheses on the potential causes of the shell disease, including water temperature, increased mosquito spraying, and oil spills.

On the North Shore in Massachusetts, there is a modest-sized lobster fishery – about one-tenth the size of the lobster fishery in the whole Gulf of Maine. Most of the issues on the North Shore seem to be temperature related. In Woods Hole, temperature probes have been put in lobster traps for the last twenty years. These probes have shown a gradual increase in water temperature. The temperature varies a lot by year, and this appears to impact the size of the catch and the timing of molting. For example, this year the temperature on the bottom in this area was low compared to the past ten years, and the catch has been okay. Two to three years ago there was a mild winter and a warm spring and molting took place in May. As a result, there was a big catch in June, which resulted in depressed prices. The traditional time to catch lobsters is July through August.

Although OCA is probably an issue for lobstermen, there has not been much done about it. The industry needs to pay attention. There have been obvious changes to the ocean over the last few decades. For example, at night you used to be able to observe phosphorus glowing in the water, but that does not happen any more. There used to be schools of mackerel in June and July on the surface, but they have been gone for 20 to 30 years.

> ***Although OCA is probably an issue for lobstermen, there has not been much done about it. The industry needs to pay attention.***
> **-Sooky Sawyer, MA Lobstermen's Association**

Participant questions

Participants asked the following questions about Sooky's presentation. *Responses are in italics.*

- Have you noticed improvements in water clarity in Gloucester Harbor? *Yes, the water has become a lot clearer. It used to be that there was a lot of life in the water, you just could not see it. Today, you cannot catch lobster near sewage treatment plants that use chlorine. The Massachusetts Water Resources Authority (MWRA) has done sampling to show that the chlorine is dissolved by the time it leaves the pipe, but fishermen report that it is impossible to catch anything close to the plants,*
- Is the next generation in your family planning to fish? *No, I don't think there will be a next generation of fishermen in my family.*

IV. Participants' Questions, Observations and Concerns about Ocean Coastal Acidification

Participants worked in small groups to discuss three questions:

1. What are your unanswered questions about OCA?
2. What are you seeing that could be related to OCA?
3. What's of most concern to you?

This section synthesizes participants' comments and ideas, organized by question and loosely grouped by theme.

<u>What are your unanswered questions about OCA?</u>
Participants noted the following questions and puzzles related to OCA:

Fisheries and industry:

- What will be the impact of OCA on phytoplankton and zooplankton, and what will be the consequences? If it impacts these organisms lower in the food chain, there is the potential for ecosystem collapse.
- What will be the impact of OCA on finfish? Given that finfish eat zooplankton, there might be significant negative impacts in the future. Already, studies have shown negative impacts on flounder larvae, and negative impacts on ear bone development in clownfish, which causes them to be unable to hear predators.
- There is a need to learn more about how to optimize the impact of shellfish aquaculture, which can be used to offset nitrogen loading. There has been substantial success in Duxbury Bay. There is a need to learn how to quantify the benefits.
- To what extent might temperature increases serve as a catalyst for many of the negative impacts of OCA on organisms and fisheries?
- Is there an opportunity for industry to explore the prospects for kelp and seaweed farming, and perhaps combine them with shellfish?

Messaging and action:

- How do we message OCA clearly and simply, given how complex the topic is?
- How do we best message to members of the industry, who may hold relatively unfavorable opinions of government or anti-science views?
- How do we create a resonant story around OCA for lobstermen? Because lobsters settle on gravel not mud, the story about acidified mud is unlikely to have the desired impact.
- How do we deliver a message about the need for planning for a long-term issue like OCA in a world where people want short-term fixes?
- What would go in a useful toolkit for mitigation?
- Can we slow down OCA in a meaningful sense?
- Can water bodies be "listed" as impaired for acidification?

Research needs and research design

- What is the impact of OCA on acidified mud, and what is the impact of the mud on organisms? What is the pH in the microhabitat where organisms grow?
- How can we best take advantage of tribal knowledge and oral history to provide new insights?
- How can we better partner with fishermen on research? There is a need to manage the exchange of information so that fishermen do not feel like they are being asked to share secrets that give others a competitive advantage.
- How do we optimize the design of our monitoring programs? For example, how much monitoring do we need, at what scale, and where?
- Should we identify a few strategic sites for in-depth research (e.g., acidification on the surface vs. the bottom, offshore inputs, tidal forcing, etc.). We could choose key sites based on their economic importance, or to show the contrast between protected and

impacted areas. It will be key to identify and target our research towards the important policy hinge points.

- How can we best try to predict what data will be important in the future, to make sure we are collecting the right information today? What are the key gaps in our current knowledge?
- How much of the change in ocean chemistry is due to local impacts, and how much is due to global or regional impact? How much variation is there at these different scales?
- What technology might help us improve our water measurement capacity?
- How did shellfish survive 300 million years ago?
- What should we be measuring besides pH and at what level of precision?
- What is the baseline from which we should measure improvement or deterioration with respect to OCA?

<u>What are you seeing that could be related to OCA?</u>

Participants discussed the following observations.

Fisheries

- More "paper" shells among shellfish.
- More razor clams and quahogs.
- Possible links between increased shell disease and higher temperature.
- Multiple stressors impacting shellfish beyond just OCA and acidic sediment, such as neoplasia.
- Migration of species to the north, such as the Atlantic salmon.
- Dead mud in previously productive areas.
- Little direct impact on shellfish aquaculture to date.
- Apparent benefits to oysters from nutrient loading and algal blooms. The industry has doubled or tripled in value in the last 15 years.
- There are no longer abundant shellfish at the shore in Gloucester Harbor and Annisquam River. In Gloucester the population is at a crisis point.
- Some populations (e.g., mussels in Salem Sound) are not necessarily "gone," they have just shifted in location.

Water quality issues

- MWRA has observed changes in Boston Harbor. It has conducted sediment metabolism studies and some DIC measurements for primary productivity. The Harbor is on a good trajectory with less sulfurous mud.
- EPA has observed positive feedback loops through the use of shellfish aquaculture to "polish" water. Removing the shell through harvesting removes the carbon from the system.
- Water at the mouth of Gloucester Harbor is clear, but there are no animals there.
- There is a phytoplankton "problem" increasing turbidity in Salem Harbor/Sound.
- There has been no change in CO_2, on average, at Isle of Shoals buoy since 2006.
- In June, a large pulse of rain went through a culvert onto Brackenberry Beach in Beverly. Mud flats covered with *Mya* (soft shell) clams were poking out of the sediment with their valves open.

<u>What's of most concern to you?</u>

Participants highlighted the concerns below.

Effective communication

- Communication to non-scientists is key to getting more funding, but there are significant challenges related to industry shortsightedness and the complexity of the OCA narrative
- Communication is especially challenging when there's no simple fix or "magic bullet" to the problem, and when there is no perceived immediate crisis.
- There is an urgent need to create something easily digestible to take to Congress and to the public.

Industry or ecosystem collapse

- In the years or decades to come, there could be a hatchery failure and a lack of preparation to address it through adaptation or mitigation.
- We could see a collapse of finfish or scallops fishery.
- Among lobsters, increasing ocean temperature might be compromising their immune systems.
- The West Coast could be the canary in the coal mine, suggesting a bleak future for shellfish.
- We do not know the resilience of the ocean ecosystem without plankton.
- Fisheries are not just "industry," they are a critical food source. We need to protect them.

Science

- There is a lack of progress on the science, especially on issues of genetics, adaptive capacity and biological effects.
- On the one hand, we need to be careful about the use of questionable scientific data. It can be used by politicians with an agenda.
- On the other hand, we cannot wait for scientists to be "sure" about issues before making strides toward new policies.
- There's a concern that water quality impacts generated near the coast will move offshore to affect fisheries. We may need more monitoring offshore.
- We need to collect data in a more uniform way in order to make good policy.

Missed opportunities

- There may be critical mitigation opportunities we could be starting now but are missing due to lack of knowledge.
- We may be failing to collect data that will be critically important in the future.

V. Research

<u>Presentation 1: Our capacity for research and what is being done here and in our region</u>
Chris Hunt from the Ocean Process Analysis Laboratory at the University of New Hampshire (UNH) discussed research and monitoring capacity in the NECAN region. He focused his remarks on UNH research assets, which include ships, facilities, and buoys monitoring pH and other factors. His team at UNH is focused on measuring geochemical and biochemical factors, and he is especially interested in carbonate system measurements.

There are four different carbonate system measurements: pH, total alkalinity, DIC, and pCO_2. Getting an accurate reading of the ocean chemistry ideally involves obtaining at least two of these measurements. Another important measurement might be calcium.

Chris made the following observations about regional monitoring and monitoring at UNH:

- There is a lot of interest regionally in monitoring OCA.
- UNH is expanding its monitoring facilities, and recently installed new sensors in Casco Bay in Maine, supported by EPA, the Casco Bay Estuary Partnership and Southern Maine Community College. It has measures for pCO_2 and pH; the sensors sit on bottom of the ocean and are brought up once a month. Researchers are excited about it.
- UNH has built a monitoring system in collaboration with Bill Mook. This system can measure CO_2 levels of both the intake water and the treatment tanks, where Bill is modifying the water to make it more hospitable for organisms.
- The ECOA 2015 Cruise, an oceanographic survey of the East Coast, is another important UNH asset. The history of measurements taken during such cruises provides a way to measure pH through time. The goal is to revisit the lines every two years to build a time series of data.
- In the Gulf of Maine, research suggests there is a lot of sampling activity but much of it happens only sporadically.
- UNH has been working with NOAA and NMFS on ECOMON cruises, which take measurements twice a year at stations throughout the region.
- UNH has installed sensors on a new cargo container ship called the Skogafoss. It measures pCO_2 and salinity, and will be adding a new alkalinity sensor, and will operate between Portland and Reykjavik.
- UNH is hoping to add new alkalinity sensors to its monitoring assets at the Mook Hatchery and the Coastal Marine Lab in New Hampshire.
- Results of the monitoring efforts show different pCO_2 results at the surface and at the bottom, which is important because for organisms a lot of what is important is occurring at the bottom and in the mud.
- Chris has been working to build a floating sensor made from cheap, off-the-shelf components, which would be accurate enough to provide useful measurements in estuaries, rivers, or hatcheries.
- It would be very useful to have more data on what is coming into the region from up the coast, around Nova Scotia, and flowing down the coast. This could be a buoy.

Participant questions
Participants asked the following questions about Chris's presentation. *Responses are in italics.*

- What is the floating sensor made out of and how does it work? *It involves a K-30 sensor, a non-dispersed infrared detector on a chip, which was developed for mining industry. It costs about $100. A normal infrared detector costs $4000. I partnered the detector with a small pump that will recirculate air, so that the* CO_2 *in the air matches what is in the water. I tested the new device against our more expensive existing device and am writing up the findings. It performed relatively well. The goal is for people to be able to build it themselves. It could be used by watershed groups, hatcheries, or anyone else who wants to know how much* CO_2 *is in water.*

- Why are researchers so excited about the new Casco Bay facility? *It provides measures of* pCO_2 *and pH at the same time and in the same place, which are not easy to get. The sensors exist in a dynamic system that we can access pretty easily.*
- A lot of greenhouses pump in CO_2. Do they have CO_2 monitors? *Yes. The technology is becoming pretty cheap and marketable. The question is can you use it and make sense of the data.*
- The Casco Bay 2015 data show some large spikes in pCO_2 and pH. Can you tell what these are by looking at the data? *No, although they could be tidal signals.*

<u>Presentation 2: Changes observed in Salem Sound</u>
Barbara Warren, Executive Director of Salem Sound Coastwatch (SSCW) and Lower North Shore Regional Coordinator of the MassBays National Estuary Program presented on data monitoring and collection efforts in Salem Sound.

Salem Sound is a well-flushed embayment in Salem, Massachusetts. There was a water quality study of the sound in 1997, with samples taken every month from January to December, and a resulting dataset. SSCW decided to update it from 2010 to 2011, with help from Dr. Brad Hubeny at Salem State University. In 2010 and 2011, SSCW collected water quality samples at six stations from May 2010 to May 2011, using a pontoon boat. They were unable to take samples from December through March. They used a YSI 6820 multi-parameter water quality monitor, measuring from the surface down to 1 meter from the bottom

The 1997 report showed a mean pH for marine samples of 7.88, a mean pH of 8.15 for coastal intertidal samples, and a mean pH of 7.14 for all river stations. In 2010 to 2011, the mean pH for marine stations was much higher, at 8.2. This difference could have resulted from the accuracy of the YSI, or due to the time of year that measurements took place, which excluded winter months.

Barbara raised several questions suggested by this research, including:
- Are we interested in pH from river sources?
- Is there a way we could learn to take measures of acidified mud?
- What kind of data set do we need in order to observe trends in ocean acidification?
- Should we have a Quality Assurance Project Plan (QAPP) that all coastal monitors can follow?
- Is there something else besides pH that we should be measuring?

As a watershed group, SSCW would be wiling to receive and implement guidance on these questions, but they need help along the way.

Participant questions
Participants asked the following questions and made the following comments about Barbara's presentation. *Responses are in italics.*

- Was there effort to get a baseline for your pH measurements? *We used Division of Marine Fisheries data as a baseline. While their measures were in the sevens, we were in an open ocean area that is tidally flushed and got a measure of 8.2.*

- pH varies significantly depending on the time of day you measure it and the tides. You can get a factor of 10 change. *This raises the important questions of how frequently you need to monitor and at what time of day, and what factors you need to monitor. We went out ten times total. If we know that we need more frequent measurements, we can try to do that. We might need a permanently-installed data logger. It is hard as an organization to work to obtain data and then be told it cannot be used because you did not do something. A quality assurance plan would be helpful so we're all on the same page.*

It is hard as an organization to work to obtain data and then be told it cannot be used because you did not do something. A quality assurance plan would be helpful so we're all on the same page.
-Barbara Warren, Salem Sound Coast Watch

- EPA hopes to create a practical monitoring guidance plan that will include this sort of information next year.

Small group discussions

In small groups, participants discussed ongoing and future research. They addressed the following three questions:

1. Are you measuring pH or other parameters?
2. What monitoring efforts should we be aware of?
3. Where and what do we need to focus future research efforts?

Participants remained in the same small groups, divided according to their interest in shellfish or water quality issues. The themes and comments from the small group discussions are captured below.

<u>Are you measuring pH or other parameters?</u>
Participants noted the following specific measurement efforts, or issues related to measurement:

- It would be helpful to follow up with Dave Sargent or Joe Buttner on monitoring efforts or their relevant connections.
- There are 6 NEPs in the northeast conducting some degree of measurement that cover the northeast region.
- It is important to work with EPA to see what is being collected in order to respond to information requirements for permits and to see if pH is being collected.
- SMAST has a lot of access and a convenient location in Buzzards Bay. At SMAST, seawater is routinely pumped into the lab so it would easy measure relevant parameters. UNH should connect with EPA to get its recommendations on technologies to use.
- MA Department of Agricultural Resources helps fund the Southeast Aquaculture Center, which has real-time data in Cotuit and Wellfleet with money through Woods Hole Oceanographic Institution and the Cape Cod Cooperative Extension.
- In 2005 there was a big red tide outbreak, and Don Anderson conducted a series of transects in the Gulf of Maine for toxic algae.

- MWRA has additional data available (e.g., DIC) that was not reported, but could be used and might help identify gaps.

What monitoring efforts should we be aware of?
Examples mentioned included: the Gloucester outfall monitoring, the MWRA outfall, the Harvard Study of the Charles River, and the HabCam used for scallop surveys by NMFS.

Where and what do we need to focus future research efforts?
Participants made the following suggestions:

- We should focus on benthic areas and muds.
- There should be more monitoring in shore and close to bays (e.g., the rivers that empty into Gloucester Harbor, Ipswich Bay, Merrimack River), to get a better sense of what is coming out of rivers and off the land, as well as more monitoring out in federal waters and in aquaculture areas.
- We should focus on research within the fishing industry, e.g. cod grunts, or looking at productive shellfish habitat acres and how these change over time in size and location.
- We should engage in a systematic research approach around key issues: First, identify "known unknowns," e.g., the cause of the lobster collapse in the U.S., or and how soft-shell clam landings connect to OCA impacts. Next, identify the most important questions to answer (e.g., the ability to forecast times of increased acidity versus biological or economic studies). *Then* decide where to spend money.
- We should speak with shellfish constables.
- We need to focus on biological impacts through multiple, duplicate studies.
- We need to focus on determining if the monitoring equipment used by MWRA and others is the best equipment, and if it is being used at the right frequency and time.
- We should look for the most cost effective solutions to reach the targets, e.g., for TMDLs.
- We should focus on identifying critical tipping points and actions to avoid reaching them.
- There should be a QAPP created to make sure that measurements are useful, and an effort to engage communities, volunteers, and groups to do work in accordance with the QAPP. There is a huge potential upside to leveraging these kinds of efforts.
- There should be a focus on ensuring good data management.
- NECAN would best serve the community by training the trainers on OCA and letting those trusted individuals and organizations go out to their constituents.

VI. Communications and Outreach

Cassie from NERACOOS provided background on communication challenges and opportunities relevant to OCA. She made the following points:

- It is essential to know your audience and target your message so that they can hear it.
- You also need to listen to what your audience is saying.
- You want to explain your message in a way that the general population will be able to understand it. This means watching your language, sticking to your main message, being careful in your use of figures and numbers, and trying multiple strategies.
- You need to boil down your message so it is short and simple.
- NECAN has attempted to follow these principles in developing a graphic on OCA.

- OCA is difficult to communicate because it involves complex terms and it may suggest doomsday scenarios
- It is key to discuss OCA within the broader context of climate change, make it relevant to the local context, provide a more focused timescale, and use simple language and graphics.
- NECAN has faced communication challenges due to the multiple causative factors of OCA, its spatial and temporal variability, its different local impacts, and the large number of unknowns.
- For members of the research community, it is key not just to publish our work, but also translate it for general audiences, and provide readers with opportunities to act on what they learn.

NECAN has had a number of important communications successes, including membership growth and substantial readership for its monthly updates. It has been a model for other regions, such as the South where a “SOCAN” recently started up.

Discussion

Ona Ferguson from CBI facilitated a group discussion on outreach and communication challenges and opportunities, with the goal of helping NECAN design an effective engagement strategy. She posed 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?

Participants offered these comments and suggestions. *Where applicable, responses from NECAN are in italics*:

- There is a lecture series called “Underwater” in Salem Sound. Barbara Warren could present on OCA using some of the materials shown today, adapting them for our local stakeholders. We used to get over 100 people at these meetings, all of whom are citizens not scientists. We also record them and create short videos using the recorded material.
- We are trying to encourage society to cut down on carbon emissions. We have been told that the changes are too expensive, but companies that have invested through regional GHG initiatives have both saved money *and* cut down on emissions. This story is not getting out to businesses and the public. It should be part of what we’re talking about.

> ***The most important message is the need to protect our food. If we kill it, we will lose it forever.***
> **-Stakeholder comment**

- NECAN should be more specific about the opportunities for action it suggests. Just saying “do something” is not sufficient, and will leave people feeling depressed because the problem seems so big. *NECAN has developed climate change interpretation work, which focuses on specific things people can do.*
- A lot of the suggested actions will actually help people save money, which is yet another reason they

should want to do it.

- Global ocean acidification has been pitched as the "other" climate problem. We need to continue funding research to help encourage mitigation efforts.
- It may be helpful to tie our message on OCA to issues of public health, safety, and food.
- The most important message is the need to protect our food. If we kill it, we will lose it forever.
- We can use OCA as one more reason to improve water quality. For example, in Duxbury Bay, stormwater and wastewater management measures allowed them to reopen shellfish aquaculture beds, which help clean the water even more. When this shell is removed from the water, it is removing carbon from the system. Unlike eelgrass that dies and then reenters the system, shell is taken out of the system.
- It is important to use a positive form for the narrative, but for some of stakeholders like lobstermen the only way to get them to respond is to show them concrete, doomsday scenarios, like what happened on Long Island Sound. This will get them to respond.
- We need to have some simple, resonant film clips. Video is the new tool to reach the masses. For example, we could have clips of shellfish larvae choosing not to settle on acidic mud, or dissolving in the microscope.
- A one-page, easy to use fact sheet would help. We at this meeting could then make our own presentations to the audiences we can access. *There are fact sheets from different regions that NECAN can share. NECAN will also be creating a simplified version of the* Oceanography *article that discusses what OCA means here in the northeast.*
- We need tools to target Congress in order to get more money for this work. Back when acid rain was a more prominent issue, there were excellent, short publications with very clear diagrams on the science, created by Hubbard Brook. These were very effective with legislators.
- We need to educate state legislators about this issue. There are bills pending in Maine, Massachusetts, and Rhode Island dealing with acidification.

VII. Final Discussion and Next Steps

Cassie concluded the workshop by asking participants how many of them planned to share information that they heard over the course of the day with colleagues or other audiences. A large majority of participants indicated they planned to do so. Ona and Cassie thanked the participants and organizers, and brought the workshop to a close.

Appendix A: Participant List

Kathryn Baltes	MIT Sea Grant
Carolina Bastidas	MIT Sea Grant
Toby Berkman	Consensus Building Institute
Sean Bowen	Dept. Ag Resources - State Aquaculture Coordinator
Priscilla Brooks	Conservation Law Foundation
Joe Buttner	Salem State aquaculture facility
Todd Callaghan	MA Coastal Zone Management
Ona Ferguson	Consensus Building Institute
Ivy Frignoca	Conservation Law Foundation
Kathryn Glenn	MA Coastal Zone Management
Madeleine Hall-Arber	MIT Sea Grant
Jen Halstead	NERACOOS/NECAN
Chris Hunt	University of New Hampshire
Susan Inglis	UMASSD/SMAST
Ken Keay	MWRA
Kevin Madley	NOAA NMFS
Matt Liebman	EPA
Steve Lohrenz	SMAST/UMASS Dartmouth
Regina Lyons	EPA
Ivy Mlsna	EPA
Ru Morrison	NERACOOS/NECAN
Becca Newhall	NOAA
Steve Parkes	Fish Locally Collaborative
Judy Pederson	MIT Sea Grant
Peter Phippen	Merrimack Valley Planning Commission
Nathan Rebuck	NOAA NMFS
Betsy Reilly	MWRA
Bob Rheault	ECSGA
Mark Rousseau	Mass Div Marine Fisheries
Angela Sanfilippo	Gloucester Fishermen's Wives Association, Mass Fishermen's Partnership
Dave Sargent	Gloucester Shellfish Constable
Sooky Sawyer	Mass. Lobstermens Association
Jack Schwartz	Annisquam River Marine Fisheries Station, Division of Marine Fisheries
Julie Simpson	MIT Sea Grant
Esperanza Stancioff	Maine Sea Grant
Colles Stowell	Cape Ann Fresh Catch/One Fish Foundation
Cassie Stymiest	NERACOOS/NECAN
Prassede Vella	Massachusetts Bays National Estuary Program
Barbara Warren	Salem Sound Coastwatch

Appendix B: Glossary

Themes

Ocean acidification: An increase in the global ocean's acidity occurring over years and decades, resulting primarily from the rapid burning of fossil fuels, a subsequent increase in atmospheric carbon dioxide concentration, and absorption of the carbon dioxide into the oceans.

Coastal acidification: A term used to describe regional and local impacts in nearshore areas which can be affected by runoff, changes in land use, changes in nutrient inputs, or upwelling of acidic deep waters. While the effects of acidification are similar regardless of the cause, coastal acidification occurs on much shorter timescales, in more localized regions, and often has more attainable mitigation strategies.

Processes

Anthropogenic influence: A longer way to say "human-caused."

Calcification: The biologically mediated process of removing calcium ions and carbonate ions from the water and depositing them in a hard shell or other bodily structure. The most common calcifying organisms globally are small plankton coccolithophores and tropical corals, but other calcifiers are economically valuable such as crustacean and molluscan shellfish (oysters, clams, mussels, lobsters, crabs, and anything with a hard shell).

Carbonate system: All of the forms of inorganic carbon compounds in the water, and the dynamics between them. These compounds include: carbon dioxide, carbonic acid, carbonate and bicarbonate ions. The quantities of these ions can be determined by measuring any two of the four quantities: pH, DIC, pCO_2, and alkalinity.

Ecosystem or community respiration: The sum of all biological processes in a loosely defined system that convert organic materials (such as sugars, fats, and carbohydrates) into energy and release carbon dioxide. This includes everything from bacteria to fungus to fish to people.

Eutrophication: The process of a waterbody increasing in nutrients, and therefore, increasing in phytoplankton and algal growth. While minor or natural amounts of eutrophication can lead to a more robust ecosystem, an oversupply of nutrients can lead to harmful algal blooms, hypoxic waters, and acidified conditions in the water and sediments.

Multiple stressors: A catch-all term for the influence of several expected changes. For example when projecting the effects of climate change on fish and shellfish populations in the future, the effects of warming temperatures, lower pH, decreased dissolved oxygen, and potentially higher variability in these parameters must be considered acting not just separately, but in concert. Assessing the effects of these changes individually and combined makes experimental design difficult and complex.

Photosynthesis: The conversion of light, carbon dioxide, and water into organic compounds, accomplished by vascular plants, phytoplankton, and most green living organisms. High rates of photosynthesis extract carbon dioxide from the air or water, and in turn can reduce acidity (raise pH).

Productivity: The rate at which something is produced. Primary productivity in an ecosystem refers to the amount of inorganic carbon fixed into organic carbon (via photosynthesis) per some unit of time. Areas with high nutrients and high sunlight are typically higher in productivity, such as estuaries and small farm ponds, whereas lower primary productivity areas would be open ocean areas. Fisheries biologists also use the term to describe the rate of recruitment of juveniles into a fishery, e.g. anchovies and sardines are high productivity fisheries whereas Atlantic Halibut are low productivity fisheries.

Respiration: The chemical reaction of combining a carbon containing molecule with an oxygen molecule, with results in usable energy and produces carbon dioxide as a waster product. The reverse reaction of photosynthesis.

Upwelling: The physical process of bringing deep, usually high nutrient and higher acidity (lower pH) waters from deep, offshore sources to the surface where it can impact biological activity.

<u>Measurable Quantities</u>

Alkalinity: An operationally defined quantity that describes a liquid's ability to neutralize an acid, or the sum of proton acceptors over the sum of proton donors. In effect, it is the 'buffering capacity' or a measure of how much acid is needed to change the pH significantly. Since it is a measure of ionic concentration, it scales directly to salinity, whereas freshwaters have lower alkalinity values and saltier waters have higher.

Anoxia and hypoxia: Anoxia means having no oxygen present, as usually happens in deep buried sediments. Hypoxia refers to an area with low oxygen concentrations, inhibitive to most multi-cellular life and occurs at concentrations of <2-3ppm, although exact thresholds may vary.

Aragonite (and calcite) saturation state: Mathematically represented by the Greek letter omega (Ω), the saturation state is the amount of calcium and carbonate ions in a solution normalized by how readily aragonite (or calcite) is dissolved. These ions are used by calcifying organisms to make their hard shells, which are composed of both forms of the calcium carbonate mineral. The typical range for aragonite saturation state in Gulf of Maine surface waters is ~2-3, whereas deep waters (100-200m) can approach Ω values near 1. At values $\Omega<1$, the mineral structure is not thermodynamically stable and will dissolve back into solution, however values $\Omega<1.5$ have been shown to have detrimental metabolic impacts to some shellfish species.

Atmospheric carbon dioxide: The amount of carbon dioxide in the air. Pre-industrial levels were near 280ppm, we are currently at 403+-10ppm, and model projections suggest we could see as high as 1000ppm or 2000ppm over the next 50-100 years.

DIC or TCO2: **D**issolved **I**norganic **C**arbon, or **T**otal carbon dioxide. A measure of the sum total of all inorganic carbon species in solution (aqueous CO_2, carbonic acid, carbonate, and bicarbonate). In general, a more precise measurement than pH or pCO_2 although can only be evaluated in sophisticated laboratories.

pCO_2: The partial pressure of carbon dioxide, typically expressed as µatm, however numerically this measurement is similar to parts per million (ppm, and sometimes erroneously used interchangeably). In the surface oceans, carbon dioxide is exchanged with the atmosphere and in general has values that are relatively similar (+-30% depending on hydrography and biology). Deep waters and areas 'downstream' of highly productive regions can see pCO_2 values up to 1,000-2,000 µatm or higher.

pH: A measure of the free hydrogen ions in a solution, expressed on a scale from 0 to 14. pH is reported as the negative logarithm, therefore the pH of 7 for pure water means hydrogen ions are abundant at a concentration of 10^-7 mol/L. The surface global ocean average pH is ~8.14, whereas the Gulf of Maine is ~8.00 in the summer and ~8.06 in the winter. Rivers and shallow groundwater are typically between 6.5 and 7.5, although this can vary with changes in bedrock and pollution sources. Measuring pH with a high degree of precision (to 0.01 or 0.001 units) is difficult, but necessary to evaluate changes due to atmospheric CO_2. Less precise measurements (to 0.1 units) can be readily made to evaluate the large fluctuations that occur in nearshore and estuarine areas.