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SECOND REGULAR SESSION

Final Report of the COMMISSION TO STUDY the EFFECTS OF COASTAL and OCEAN ACIDIFICATION and ITS EXISTING and POTENTIAL EFFECTS on SPECIES THAT ARE COMMERCIALLY HARVESTED and GROWN ALONG the MAINE COAST

December 2014

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Executive Summary

In 2014, the 126th Maine Legislature established the Commission to Study the Effects of Coastal and Ocean Acidification and its Existing and Potential Effects on Species That Are Commercially Harvested and Grown along the Maine Coast (the "commission") with the passage of Resolve 2013, Chapter 110. The resolve established the 16 member commission, specified the duties of the commission and directed it to submit its report by December 5, 2014 to the full Legislature. A copy of Resolve 2013, Chapter 110 is included as Appendix A.

The commission's membership includes two State Senators, three State Representatives, two representatives of an environmental or community group, three persons who fish commercially, including at least one aquaculturlist, three scientists who have studied coastal or ocean acidification, the Commissioner of Marine Resources, the Commissioner of Environmental Protection and the Commissioner of Agriculture, Conservation and Forestry or the commissioners' designees. A copy of the membership list of the commission is included as Appendix B.

The commission's duties included, but were not limited to, a review of the scientific literature to identify what is known about ocean acidification and steps that are needed to enhance scientific research and monitoring, developing mitigation strategies and steps that could be taken to increase public awareness of coastal and ocean acidification. Resolve 2013, chapter, 110, directed the commission to submit any legislation needed to implement its recommendations to the joint standing committee of the Legislature having jurisdiction over Marine resource matters.

The commission met on August 1, September 4, September 18, October 10, October 21, November 10 and December 2, 2014. The August 1, 2014 meeting was held at the Darling Marine Center, University of Maine's Marine Laboratory Walpole, Maine. During the July 1 meeting, the commission heard presentations from scientists and other experts on the scientific understanding of ocean acidification and the economic and policy implications for Maine. The remaining meetings were held in the Cross State Office Building in Augusta. Meeting summaries are included in Appendix C.

To facilitate the commission's work, two subcommittees were established: the State of the Science subcommittee, charged with delving into the scientific literature and data pertaining to ocean acidification; and a second subcommittee to review the Washington State Blue Ribbon Panel of Ocean Acidification report to determine the applicability of that panel's recommendations to the conditions in Maine. The State of the Science report is a comprehensive review of the current scientific literature; a synopsis of the report can be found in section III of this report and the full report can be found in Appendix D.

While Maine's marine environment is a complex ecosystem and there is much we don't know about ocean acidification, existing scientific data shows that by far, the greatest contributor of open ocean acidification is atmospheric carbon dioxide (CO_2), and that nutrient and CO_2 runoff from land-based point and nonpoint sources are additional drivers of acidification in Maine's estuary and near shore waters. That data also indicates that the increasing rate of acidification will most heavily impact those marine organisms that produce calcium carbonate hard parts, such

as clams, lobster, shrimp and cold water coral (see State of the Science report, Appendix D). Research and monitoring efforts have already shown that there are mud flats in Casco Bay where shellfish cannot survive because of increasing acidification. This information highlights the fact that ocean acidification is a real threat to Maine's commercially valuable species, including the iconic lobster, and provides a focal point for actions that can and must be taken to prevent, reduce and mitigate the negative impacts of ocean acidification.

Contrary to the widely held belief that ocean acidification cannot be addressed at the state or local levels, Maine's coastal communities need not wait for a global solution to address a local problem that is compromising their marine environment. Municipalities can take concrete steps alone or hand-in-hand with the state to eliminate possible sources of acidification, such as identifying and remediating untreated wastewater discharges that lead to acidification.

The commission arrived at its goals and recommendations based on the current state of the science on ocean acidification and in light of practical, economic and political realities, and after consideration of various viewpoints on the causes, levels and trends of ocean acidification. The commission strongly believes its unanimous(?) recommendations reflect a balance of those considerations.

The commission identified six overarching goals and twenty-six recommendations to achieve those goals. A synopsis of the recommendations can be found in Appendix F. The commission's six goals include:

1. Investing in Maine's ability to monitor and investigate the effects of ocean acidification;

2. Reducing emissions of carbon dioxide and fixed nitrogen;

3. Reducing Local Land-Based Nutrients and Organic Carbon Contributions to Ocean Acidification by Strengthening and Augmenting Existing Pollution Reduction Efforts.

4. Increasing Maine's capacity to mitigate, remediate and adapt to the impacts of ocean acidification;

5. Informing stakeholders, the public and decision makers about ocean acidification in Maine and empowering them to take action; and

6. Maintaining a Sustainable and coordinated focus on ocean acidification.

To implement its goals and recommendations the commission is proposing legislation to create an ongoing ocean acidification commission structured after this commission to identify, study, mitigate and prevent the effects of coastal and ocean acidification on species commercially harvested and grown in Maine's marine environments. The commission would have the authority to advise on matters of ocean acidification and to respond to advances in ocean acidification science and to shifts in the economic and political landscapes. The commission's proposed legislation can be found in Appendix E.

I. Introduction

** A glossary of terms can be found in Appendix H.*

In 2014, the 126th Maine Legislature established the Commission to Study the Effects of Coastal and Ocean Acidification and its Existing and Potential Effects on Species That Are Commercially Harvested and Grown along the Maine Coast with the passage of Resolve 2013, Chapter 110. Ocean acidification is the processes that lower the pH (the measure of the acidity or basicity of water or other aqueous solution) of ocean water. The resolve established the commission, specified the duties of the commission and set December 5, 2014 as the due date for submitting its report to the First Regular Session of the 127th Legislature. A copy of Resolve 2013, Chapter 110 is included as Appendix A.

The President of the Senate, the Speaker of the House of Representatives and the Governor completed their appointments to the commission during the early summer of 2014. The members include two State Senators, three State Representatives, two representatives of an environmental or community group, three persons who fish commercially, including at least one aquaculturlist, three scientists who have studied coastal or ocean acidification, the Commissioner of Marine Resources, the Commissioner of Environmental Protection and the Commissioner of Agriculture, Conservation and Forestry. A copy of the membership list of the commission is included as Appendix B.

The 16 member commission met on August 1, September 4, September 18, October 10, October 21 and November 10, 2014. The August 1, 2014 meeting was held at the Darling Marine Center, University of Maine's Marine Laboratory in Walpole, Maine. The remaining meetings were held in the Cross State Office Building in Augusta. The inaugural meeting of the commission included presentations by scientists and other experts on ocean acidification and the economic and policy implications for Maine. All meetings were open to the public and the meetings held in Augusta were broadcast through the Legislature's public internet system. The meeting summaries are included in Appendix C.

To facilitate the commission's work, two subcommittees were created: the State of the Science subcommittee, to delve into the scientific literature and data pertaining to ocean acidification; and another subcommittee to review the Washington State Blue Ribbon Panel of Ocean Acidification report to determine the applicability of panel's recommendations to the conditions in Maine. The State of the Science report is a comprehensive review of the scientific literature and data pertaining to ocean acidification and can be found in Appendix D.

It is well-documented that by far the greatest contributor to open ocean acidification (lowering of pH levels) is atmospheric CO_2[1] and that nutrient and CO_2 runoff from land-based point and nonpoint sources are drivers of acidification in Maine's estuary and near shore waters (see State of the Science report, Appendix D). It is also known that ocean acidification is occurring globally and proceeding at an increasing rate. Scientific data indicates the rate of acidification is at least 100 times faster at present than at any other time in the last 200,000 years and is likely

[1] Atmospheric CO_2 dissolves in water, making it more acidic, for example, carbonated soda water is more acidic than regular tap water.

unprecedented in Earth's history. This rapid rate of change in ocean chemistry is one of the most stressful aspects of ocean acidification on marine life, including Maine's commercially valuable Maine species (see State of the Science report, Appendix D).

The importance of the commission's directive is highlighted by research that demonstrates the cold waters of the Gulf of Maine are more susceptible to ocean acidification than other regions in the United States because carbon dioxide is more soluble in cold water resulting in a faster rate of acidification than in warmer waters.[2] Additionally, Maine's heavy commercial reliance on a single species, the American lobster, that is likely to be negatively impacted by increasing acidification, creates a heightened risk for devastating socio-economic impacts.[3]

While scientific research on the effects of ocean acidification on marine ecosystems and individual organisms is still in its infancy, it does not mean we can wait to take action until there are more robust data, which may be decades away. Contrary to the widely held belief that ocean acidification cannot be addressed at the state or local levels, Maine's coastal communities need not wait for a global solution to address a locally exasperated problem that is compromising their marine environment. The state and its municipalities can take concrete steps alone or hand-in-hand to eliminate possible sources of acidification. For example, state and municipal officials can work together to identify point source discharges that may be contributing to coastal acidification and removing or minimizing these sources through existing regulatory channels or by adopting rules or ordinances to otherwise address the issue. Additionally, municipalities could conduct pilot projects using macroalgae as a buffering "agent" in clam flats to determine if it is effective reducing acidification.

The existing scientific data on ocean acidification is already compelling and the commission strongly urges that steps be taken immediately to implement its recommendations. The commission compiled its goals and recommendations based on the current state of the science and in light of practical, economic and political realities and after consideration of various viewpoints on the causes, levels and trends of ocean acidification. The commission's unanimous (?) recommendation's reflect a balance of those factors.

II. RESOLVE 2013, CHAPTER 110

In addition to establishing that the commission must meet a minimum of four times to review, study and analyze existing scientific literature and data on coastal and ocean acidification and how it has affected or potentially will affect commercially harvested and grown species along the coast of Maine, Resolve 2013, chapter 110 also requires the commission to do the following:

1. Identify mitigation strategies for coastal and ocean acidification;

[2] Zhaohui Aleck Wang et. al., 2013. The marine inorganic carbon system along the Gulf of Mexico and Atlantic coasts of the United States: Insights from a transregional coastal carbon study. Limnol. Oceanogr. 58(1) pp. 325–342.

[3] In 2013, there were 125,953,876 pounds of lobster landed with a value of $364 million representing 69% of the total value of all of Maine's commercially harvested marine species. http://www.maine.gov/dmr/news/2014/2013Landings.htm; http://www.maine.gov/dmr/commercialfishing/documents/2013ValueBySpecies.Pie.Graph.pdf.

2. Identify knowledge gaps in critical scientific data as it pertains to acidification in marine environments, including how coastal and ocean acidification affects commercially harvested and grown species;

3. Review work and studies presented at conferences and workshops held in New England or the Northeast region relating to acidification in marine environments, including but not limited to, coordination with the Northeast Coastal Acidification Network to avoid duplication in efforts;

4. Ascertain ways to strengthen existing scientific monitoring, research and analysis regarding the causes of and trends in coastal and ocean acidification;

5. Determine how to increase public awareness of coastal and ocean acidification; and

6. Identify methods to help Maine mitigate, remediate and adapt to the effects of coastal and ocean acidification.

III. Commission Process

During the enactment of Resolve 1013, c. 110, the Legislative Council approved and budget for four meetings of the commission. On July 25, 2014, the Legislative Council accepted an in-kind contribution from the University of Maine's Darling Marine Center thorough the Maine Sea Grant program to pay facility and meal costs associated with the commission's first meeting on August 1, 2014 at the Darling Marine Center in Walpole, Maine. At that meeting the commission heard presentations from scientists and other experts on the scientific understanding of ocean acidification and the economic and policy implications for Maine. On September 25, 2014, the commission requested and the Legislative Council approved two additional meetings that were held on October 21, and November 10, 2014. On October 21, 2014 the commission requested and received authorization for a final meeting that was held on December 2, 2014.

Summaries of the commission's meetings can be found in Appendix C.

IV. State of the Science report, Executive Summary

Subcommittee members: Susie Arnold, Mark Green, Larry Mayer, Bill Mook, Joe Salisbury and Meredith White

** A glossary of terms can be found in Appendix H.*

To focus the efforts of the commission the State of the Science subcommittee was established to delve into the scientific literature and data pertaining to ocean acidification. This subcommittee produced a report which discusses the processes and impacts of ocean acidification, monitoring needs, mitigation options and a comprehensive review of current scientific literature related to ocean acidification. This executive summary is a broad summary of that report. The full report can be found in Appendix D.

Ocean acidification refers to the decrease in pH of ocean waters. While the science on ocean acidification, especially in the Gulf of Maine, is still in its infancy, it is clear that rapid changes in seawater chemistry related to acidification are occurring on a global scale and are having an effect on marine species, including those that are commercially important to Maine.

Of all the processes that can cause acidification of marine waters, the most documented and best-understood is the uptake of carbon dioxide (CO_2) from the atmosphere by the ocean. The increased uptake of CO_2 in recent decades can be linked to the increasing usage of fossil fuels, and in the cold waters of Maine this uptake is enhanced because CO_2 is more soluble in colder waters. The fact that colder waters acidify more rapidly than warmer waters makes it particularly important for Maine to be proactive in its response to and study of ocean acidification.

Another factor driving the acidification of Maine's ocean waters is inputs from freshwater sources such as rivers and streams. These fresh waters tend to be more acidic than ocean waters due to numerous influences such as acidic rainwater, lag effects in soils, land use activities, and higher intensity storm systems from changing climatic patterns.

In addition to external influences on the acidity of the Gulf of Maine, pH variations within marine ecosystems also occur due to the balance between photosynthesis, which raises pH making water less acidic by taking up CO_2 through the creation of organic matter, and respiration, which lowers pH making water more acidic by producing CO_2 through the conversion of organic matter to energy. This balance is threatened by the addition of nutrients, such as nitrogen and phosphorus, from land use activities. Nutrient loading can also result in eutrophication that can be lethal to marine organisms.

Marine species that will likely be most impacted by acidified ocean water are those that calcify, or produce calcium carbonate hard parts, including coral reefs, crustaceans, mollusks, echinoderms, calcareous macroalgae and plankton. This result is due to the building of calcium carbonate, which is particularly sensitive to changes in pH; however, the mechanisms of calcification are both species specific and not always well understood.

- **Crustaceans:** Of all the marine species harvested in Maine, the American lobster is the most critical to Maine's commercial marine economy. However, there is very little known about how the lobster will react to a more acidic marine environment. Only two studies have looked at the American lobster, each finding differing effects from increased pCO_2. One study found increased calcification of juvenile lobsters at increased pCO_2, while the other found that the length of the hard upper shell of certain stages of larvae were smaller when exposed to high pCO_2 conditions and that the larvae took longer to molt, likely making them more vulnerable to predation. While these studies provide some information, they were conducted at water temperatures not reflective of Maine, and are insufficient to understand and protect this very valuable species.

Northern shrimp appear to be resilient to increased pCO_2, with the exception of the appearance of an increase in larval development time, which should be viewed as a negative effect of CO_2 exposure because it can result in increased predation.

Of Maine's two commercially important crab species, the rock crab and the Jonah crab, there have been no studies investigating the effects of ocean acidification; however, two studies looking at other crabs of the same genus found one species, the Dungeness crab, to have the ability to compensate for increased exposure to pCO_2, whereas the European edible crab was found to not be able to tolerate warmer temperatures when exposed to high CO_2 conditions.

- **Bivalves:** Bivalves, which are also very important to Maine's economy, include softshell clams, sea scallops, eastern oysters, blue mussels, mahogany quahogs, hard clams and surf clams. Studies have shown that most bivalves are very susceptible to the negative effects of ocean acidification. While adult bivalves in Maine can generally survive in extreme acid conditions, studies have shown that at larval stages bivalves are more sensitive to ocean acidification. This can be largely attributed to the mineralogy of larval shells. The earliest portions of a bivalve's larval shell are formed from amorphous calcium carbonate, which is the most soluble form of calcium carbonate. Studies have also shown that some bivalve larvae exposed acidified ocean conditions are smaller, less fit and slower to develop than larvae exposed to ambient conditions. Other studies have found that the saturation state of sediments can influence the larval settlement behavior of softshell clams, meaning the more acidic the sediments, the more likely the clam will swim back into the water column rather than settle into the substrate.

- **Other species:** Studies have also looked at the effects of ocean acidification on various commercially important species, such as polychaete worms, green sea urchins, Atlantic herring, Atlantic halibut, Atlantic cod, red algae, brown algae, green algae, as well as phytoplankton and zooplankton. The impacts of ocean acidification on various marine species are variable. In species like Atlantic cod sourced from the Norwegian coast, negative effects, such as an increase in tissue damage and a decrease in movement have been observed, whereas species such as macroalgae have responded positively to an increase in acid conditions by showing an increase in productivity.

While the studies thus far are helpful in providing some insight into the effects of ocean acidification, they fail to provide enough information to understand how acidification impacts Maine's commercial species. Furthermore, the vast majority of studies only consider one species, or even one life stage when investigating the effects of ocean acidification. By focusing on only one species at one life stage, studies fail to recognize the interactive effects of ocean acidification on predator-prey relationships. Furthermore, the studies also fail to look at ocean acidification in the context of multiple anthropogenic stressors and look at how ocean acidification affects the structure of marine ecosystems as a whole.

As recognized by the State of the Science subcommittee, Maine needs to establish research and monitoring priorities in order to properly adapt to, mitigate and remediate the impacts of ocean acidification on Maine's commercially important marine species. The better the understanding

of how greater acid conditions impact all species at all stages, as well as the marine ecosystem as whole, the better prepared the state will be to find effective, efficient solutions.

V. Goals and Recommendations[4]

Maine must make hard decisions to effectively address the rapidly increasing rate of acidification of its marine environments. Ocean acidification and its effects are not readily observable by the general public, underscoring the importance of education and outreach efforts to illuminate the seriousness of this issue and its importance amongst other issues that capture the public's attention. Decision makers are often faced with competing economic and political issues and ocean acidification may never enter the equation unless that person is aware of the issue and knows that the public considers acidification to be of significant importance; the gravitas of ocean acidification must hold a prominent place in the mind of the public before a hard decision can be made in favor of addressing ocean acidification. To ensure the long-term stability of Maine's commercially harvested species, which are vital to the State's economy, ocean acidification must be recognized as an issue of statewide significance and, where applicable, the commission's recommendations must be incorporated into state and local short-term and long-term planning.

The commission's unanimous (?) recommendations are the culmination of six months of in depth discussions, involving the review and analysis of highly technical scientific data, federal and state ocean acidification studies and programs, and policy considerations. For Maine and its commercial fisheries, addressing ocean acidification has become an urgent matter and the commission emphatically supports the immediate implementation of its recommendations. While the commission understands that some of its recommendations have significant financial and time implications, preliminary actions can still be taken towards fulfilling those recommendations.

As used in this section, "shellfish" means the American lobster, crabs, oysters, mussels, clams, scallops and periwinkles unless otherwise indicated by the context.

Goal 1: Invest in Maine's Ability to Monitor and Investigate the Effects of Ocean Acidification

To date, most experiments have focused on single species responses to ocean acidification in laboratory settings. Given the current rate of acidification, we must move beyond a single species approach and consider how ocean acidification impacts the structure of marine ecosystems as a whole and over time. This will require expanding monitoring and new experimental tools such as multispecies experiments that bring a small part of the natural environment under controlled condition for study, and multispecies food-web models to obtain a better understanding of the direct and indirect impacts acidification is having on our commercial species.

[4] The commission's recommendations dovetail with many of the recommendations from the 2012 report of the Washington State Blue Ribbon Panel on Ocean Acidification. The Washington State report can be found at http://www.ecy.wa.gov/water/marine/oceanacidification.html.

Recommendations:

1. Expanding monitoring of ocean acidification to establish its natural variability and to detect trends in water chemistry and related biological responses.

It is difficult to adapt to or mitigate acidification if we cannot detect it. Maine requires more "eyes" on its coastal waters to see where and when acidification might occur. These eyes will likely include fixed measurement platforms as well as use of boats to measure more extensive areas. Time series using reproducible methods will be vital to find trends.

Measurements of both water quality and biological indications of acidification are difficult and, at present, expensive. The most thorough measurements are affordable on only a limited basis, but need to be made at some selected sites as benchmarks. More extensive measurements need to be made by less expensive means. Three strategies are obvious to extend these measurements:

A. Empower and assist citizens, singly as in fishing vessels or in organized groups such as environmental monitoring groups (e.g., Maine Coastal Observation Alliance) to make measurements as widely as possible. Reliability of data should be assured via practices such as training in, and adoption of, Quality Assurance Project Plans;

B. Support the development, and take advantage, of rapidly evolving technology such as new sensors, to bring down the costs of direct or indirect measures of acidification (or proxies; see Recommendation 2) of waters or sediments; and

C. Take advantage of existing platforms such as hatcheries, shore side laboratories and moorings to deploy sensors.

Likewise, detection of biological impacts is difficult due to the many stressors that might account for biological problems. Considerable research will be needed to develop indices of stress that is due to acidification. ~~Early work suggests that dissolution of shells will be useful.~~

Extensive measurement efforts will need to be in touch with one another, and data compared among places and times. Central data-gathering groups such as the Northeast Regional Association of Observing Systems, coalition groups of citizen monitors (e.g., Maine Coastal Observation Alliance) and state agencies with water quality databases will all be vital to this networking. It is important that scientific data on ocean acidification from various sources be centralized and made readily available to all researchers.

2. Develop new tools with which to assess and understand acidification and its impacts in Maine waters.

The science and technology of assessing acidification impacts is developing rapidly. Maine needs to both keep up with this evolution as well as develop tools appropriate to its local waters and species.

Indicators of acidification at the levels of water quality and biological impact need to be enhanced. Expensive chemical measurements of acidification will need to be supplemented by less expensive ways of measuring the same properties (e.g., pH). Similarly, impacts on organisms will be increasingly measured by automated methods such as genetic and image recognition technologies.

New tools will be developed by assessment of chemical or biological proxies that signal the onset of acidification, such as dissolved oxygen or indicator bacteria. Such indicators need development for not only present and future conditions, but also to allow us to reach into the past so that we can understand how changing water quality has affected commercial species in prior times. Basic oceanographic sensing will enable detection of water masses that set the stage for acidification – whether salinity sensors inside estuaries or offshore buoys/glider systems that sense different water masses entering the Gulf of Maine.

Building models that connect the atmosphere, water masses and their chemistry, impacts on organisms, and linkages to socioeconomic process needs to be done. This modeling extends the results of data gathering into times and places not measured. Modeling should proceed first at the level of individual components and later in linked forms as the components are proven. As understanding improves from experiments, field studies and models, sensing systems will need expansion or reorganization to detect acidification effects in the real ocean.

3. Determine the causes of acidification in waters and sediments of Maine.

The commission recognizes three primary sources of acidification in Maine waters: 1) enrichment of atmospheric CO_2 via fossil fuel combustion; 2) eutrophication via nutrient additions; and 3) increased inputs of low-pH freshwater. The importance of these sources will vary with place and time; for example, freshwater inputs will likely be most important where rivers lower salinity, and nutrient controls will be strongest near sources of nutrients. The separate and combined roles of each should be assessed for a more complete understanding.

Acidification of pelagic waters may show different patterns than acidification at the benthic boundary. Sediments will experience a suite of different processes such as those mediated via biologic activity over a wide range of oxygen concentrations.

Detectable acidification caused by increasing atmospheric CO_2 will be gradual, taking place over decades. However it is very likely that this will lower pH to levels likely to be harmful to Maine's commercial species. Careful time series of appropriate measurements should be enhanced, as well as explorations of past conditions via proxy measurements. Models will be relatively successful at this endeavor, because the physics and chemistry is relatively well understood.

Nutrient-derived acidification will be more variable and increased acidification via this pathway will require studies of nutrient-driven cycles such as photosynthesis and subsequent respiration. Nitrogen is likely to be the principal nutrient of concern, but the role of other nutrients such as phosphorous should also be assessed. The roles of various sources of these nutrients to the

coastal zone including atmospheric, sewage, land use, river, oceanic source waters and others should be determined in order to plan future adaptive and remediative actions.

Changing patterns of freshwater inputs into marine waters should be determined. The resultant salinity distributions in estuarine and coastal waters should be monitored.

4. Identify the impacts of acidified waters and sediments on Maine's commercial species.

Maine must develop better information on the impacts of acidification on its wild and cultured commercial species. These studies should use Maine's environmental conditions. Because acidification is one of many environmental challenges faced by these species, its impacts should be considered both separately and in conjunction with other stressors such as warming, disease, and fishing pressure. Differences between water and sediment ecosystems mean that acidification of water inputs to hatchery bivalves may differ considerably from acidification affecting natural sets of bivalves in adjacent coves.

These impacts may occur in direct and indirect ways. Direct impacts on species should be studied in well-controlled experimental systems capable of evaluating the combined effects of climate change parameters such as dissolved oxygen and temperature. These studies should include impacts on both physiology and behavior, and should assess the ability of various species to adapt to changing conditions. Acidification may also affect ecosystems in ways that indirectly affect commercially important species. For example, plankton that serve as food may change in quality or quantity, or disease-causing organisms may become prevalent. **Anyone provide example of indirect impacts using specific species??**Studies of overall impacts of acidification on commercial species must remain sensitive to these possibilities.

Some studies should address whether the impacts found in experiments appear in organisms in the field, especially in conjunction with water quality measurements. Researchers should develop markers of acidification impact that can be used in subsequent field monitoring.

Goal 2: Reduce Emissions of Carbon Dioxide

While the acidification of the Gulf of Maine is the result of several processes, the most discernable and largest contributor to acidification in the gulf is the uptake of atmospheric carbon dioxide. The Gulf of Maine is colder than most coastal areas in the United States and CO_2 is more soluble in colder water, thereby, facilitating a higher rate of CO_2 uptake causing an accelerated rate of acidification. This is why reducing global atmospheric carbon dioxide levels should be an immediate priority. While ocean acidification from atmospheric carbon dioxide is largely recognized as a result of global activities (of which Maine has a small proportional impact), Maine can still have a discernable impact in reducing atmospheric carbon dioxide by taking the following steps.

Recommendations:

1. Coordinate with international, national, and regional partners and encourage key leaders and policymakers to promote a comprehensive strategy to reduce carbon dioxide emissions.

Maine's legislators, congressional delegation and Governor along with community, academic and business leaders are in a position to serve as ambassadors to promote the reduction of global atmospheric carbon dioxide levels. State delegations and missions to promote trade, development and cooperation, can and should carry the message about the importance of reducing atmospheric carbon dioxide levels to leaders of other states and nations. Elected officials and other key leaders should be periodically briefed on ocean acidification issues to stay current on carbon dioxide levels and trends, ocean acidification science and impacts relevant to Maine's commercial fisheries.

Maine's leaders should actively coordinate with the federal government, other coastal states, Canadian provinces and territories and other international governments to develop effective strategies including a comprehensive approach to reduce atmospheric levels of carbon dioxide. Effective strategies include, but are not limited to:

A. Sharing knowledge, data, scientific expertise and establishing potential policy initiatives with other governments and partners;

B. Participating in joint actions to protect oceans and other marine waters from acidification;

C. Pursuing agreements with other governments and partners to cooperate in scientific initiatives that will better define the impacts of atmospheric carbon dioxide on marine fisheries, seafood supplies and water quality; and

D. Building public awareness by using intergovernmental compacts and joint outreach and education efforts.

2. Continue coordination and involvement with existing state and regional initiatives regarding the reduction of atmospheric carbon dioxide levels.

Maine is currently involved with several initiatives to help reduce atmospheric carbon dioxide levels and other greenhouse gases at both the regional and state level. At the regional level, Maine is a member of the Regional Greenhouse Gas Initiative. This initiative is the first market-based regulatory program in the United States designed to reduce greenhouse gas emissions and is a cooperative effort among the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont to cap and reduce CO_2 emissions from the power sector. Maine is also a member of the Transportation and Climate Initiative of Northeastern and Mid-Atlantic States. Its mission is to develop the clean energy economy and reduce greenhouse gas emissions in the transportation sector.

At the state level, Maine is currently winding down the Environmental and Energy Resources Working Group created in 2013 with a mission to ensure effective cross-coordination and integration of programming among Maine's agencies relating to reduction of greenhouse gases as well as adaptive measures taken to environmental or climate changes. The results of this group are not yet released, but one of the anticipated outcomes is efficient mechanisms for

collaborating to reduce redundancies and duplication of efforts among state and local agencies. Efforts to work on reducing greenhouse gases (which include CO_2) as part of an ocean acidification mitigation strategy should be coordinated with the Environmental and Energy Resources Working Group and its involved members.

In addition to the Environmental and Energy Resources Working Group, a number of Maine's state agencies are currently working on several aspects of greenhouse gas reductions. These includes the monitoring and reporting of greenhouse gas emissions, regulating greenhouse gas emissions at permitted facilities, encouraging both energy efficiency and investments into renewable energy, managing a "cleaner" fleet of state cars and promoting new technologies to capture greenhouse gas emissions. Some of these state agencies include: the Department of Environmental Protection; the Public Utilities Commission; the Department of Transportation; The Efficiency Maine Trust; and the Governor's Energy Office.

Other organizations and academic institutions throughout Maine are also focusing on the reduction of atmospheric carbon dioxide levels, and may also serve to be useful resources in determining any additional strategies.

3. Implement actions at the state and local level that may help in reducing CO_2 emissions.

While Maine acting on its own will lessen only a small proportion of the overall levels of atmospheric carbon dioxide (as compared to the global contribution), Maine can still help to increase public awareness and set a good example for others to follow. If Maine were to adopt the following actions, and if other states were to follow suit, the aggregate impacts might be more considerable.

Initially, it is recommended that Maine continue efforts begun by the 2004 Climate Action Plan, and the 2010 Climate Adaptation Plan in identifying and implementing measures to reduce greenhouse gases. As a lot of thought and effort have already been conducted on how to reduce greenhouse gases, it is therefore recommended to draw on the work that has already been completed and to integrate it with other related ongoing efforts including the state's Comprehensive Energy Plan.

Specific actions at the state and local levels should also include:

A. Providing additional funding to existing air quality emissions, monitoring and climate change mitigation and adaptation programs;

B. Creating new incentive programs to encourage more point of use energy generation, energy conservation and efficiency, and use of renewable energy sources as well as clean technologies;

C. Enhancing existing and promoting new transportation fuel efficiency, fuel substitution and enhanced vehicle inspection programs;

D. Setting policies and establishing programs that will encourage the creation and expansion of new technologies and innovations to reduce greenhouse gas emissions (for example, anaerobic methane digesters); and

E. Providing educational and outreach materials to demonstrate the benefits of reducing greenhouse gases.

Goal 3: Reduce Local Land-Based Nutrients and Organic Carbon Contributions to Ocean Acidification by Strengthening and Augmenting Existing Pollution Reduction Efforts.

Maine's numerous rivers and streams provide an influx of freshwater that has a lower pH than ocean waters (contributing to acidification) and is a major source of nitrogen and phosphorus that can be detrimental to commercially valuable species. While an increase in nutrients boosts biological productivity, in larger amounts these nutrients can lead to oxygen depleted waters, toxic algae blooms and the acidification of marine waters putting significant stress on marine species. Given an increase in the frequency and severity of storms and anticipated trends in precipitation, these contributions may become even more significant in the future.

Should there be discussion here about fixed nitrogen and phosphorus?

Recommendations:

1. Reduce nutrient loading and organic carbon from point source and nonpoint discharges causing or contributing to water quality problems ~~affecting commercial species if supported by scientific data and technically feasible~~.

Nutrient and organic carbon originating from point sources (including municipal wastewater treatment facilities or publicly owned treatment works (POTWs); industrial point source discharges industrial, municipal, agricultural, or construction storm water discharges; and on-site sewage discharges; like overboard discharges and septic failures) as well as nonpoint source discharges (runoff) likely account for the majority of local nutrient inputs into Maine's marine waters. Discharges from most point sources are regulated by individual or general permits issued by the Maine Department of Environmental Protection under the Maine Pollutant Discharge Elimination System program.

These permits impose specific effluent limits, monitoring and reporting requirements and other conditions on permitted discharges. However, at this time, specific nutrient criteria (i.e., nitrogen and phosphorus) are typically not included in permits as these criteria are not yet developed in Maine. As compared to point sources, nonpoint source discharges are typically not permitted but the Department of Environmental Protection and the Department of Agriculture, Conservation and Forestry have programs to help landowners with reducing runoff and restoring impacted areas to improved environmental health.

Numeric nutrient criteria provide the basis for regulations to reduce nutrient loading to water bodies from licensed point source discharges. In 2004, Environmental Protection Agency directed states to develop numeric nutrient criteria for nitrogen and phosphorous to protect

aquaculture, shellfish harvesting/propagation and habitats for aquatic marine life. For marine waters, the Resolve 2007, chapter 49, required the Department of Environmental Protection to create a work plan and timeline leading to approved nutrient standards and a report on technological innovations to (total nitrogen) nutrient reduction/wastewater treatment. Subsequently, significant point and non-point sources of nutrients flowing into Casco Bay were inventoried. The Department of Environmental Protection's report was published in June 2008, and can be found at http://www.maine.gov/dep/water/nutrient-criteria/nutrient_criteria_report_2008.pdf. The department's deadline for completing this work is currently 2015 (extended from 2012 by the Legislature).

When properly designed and installed, POTWs provide a high level of treatment for bacteria and other pollutants. However, nutrients are not removed unless nitrogen-reducing technologies are used. If shown to be effective and reliable, appropriate steps should be taken to require these nitrogen-removal technologies in areas where it is determined that nutrients from these systems are contributing significantly to ocean acidification.

Because POTWs are considered to be permanent infrastructure, they are costly to construct, maintain and operate. Reducing nutrients from these sources will require technology that must be tailored to location conditions and the actual facility design to work properly. The cost of the advanced treatment of nutrients will generally fall on individuals as POTWs are managed and funded at the municipal level.

In addition to POTWs, other smaller on-site sewage systems are in operation around the state. These include residential sewage and septic systems. Provided that funding is available, Maine offers several programs to assist qualifying homeowners with replacement of failing on-site septic systems and overboard discharge systems. The contributions to nutrient loading from these types of systems is insignificant in comparison to the larger permitted systems, but continued efforts to improve technologies and mitigate these localized sources where opportunities are available is still worthwhile.

The commission recommends additional research and monitoring to determine the extent to which point sources of nutrients and organic carbon are significant causes of acidification. From that research, we recommend that more clarity be provided on nutrient criteria and how they might be incorporated into both regulations and/or the permitting process. Concurrently, sources that are determined to be contributing significantly to nutrient loading should be required to reduce their contributions when feasible by instituting new technologies.

Additionally, state agencies should enhance their efforts to remediate sources of pollution, especially in the watersheds of shellfish growing areas and in pilot ocean acidification watersheds (see Recommendation 4), emulating successful efforts such as the Department of Agriculture, Conservation and Forestry and the Department of Environmental Protection memorandum of agreement that outlines the responsibilities of both agencies to assist with agricultural runoff.

2. Assess the need for water quality criteria relevant to ocean acidification.

Currently, pH is the only water quality criteria that can be readily associated with ocean acidification. It is conceivable that changing existing regulatory limits could have an effect on pH in the near coastal waters depending on the volume of effluent being discharged and the diluting characteristics of the receiving water. The allowable limits of pH in wastewater discharges are governed by statute and legislation would be required to change those limits.

Other parameters associated with acidification include dissolved oxygen. Recent scientific research suggests that other ocean chemistry parameters and biological indicators may be relevant to local acidification.

We recommend that the Environmental Protection Agency and other federal agencies take the lead on evaluating the relevance of existing standards to ocean acidification. If it is determined that existing standards are insufficient to control the impacts of local sources, the Environmental Protection Agency should evaluate the applicability of other water quality criteria identified by recent research or recommended by scientific experts in the fields of ocean acidification and water quality.

3. Enhance monitoring and create a database sufficient to support the development of regulatory and non-regulatory approaches to reduce and limit nutrients and organic carbon from sources that are contributing significantly to acidification of Maine's marine waters. Enhanced monitoring should begin in one or more pilot estuaries where impacts are presently occurring.

To support new or strengthened pollution reduction efforts, Maine industries, landowners and policy makers need to understand if and how public and private investment in pollution controls will deliver the desired reduction in nutrients in coastal waters. Inputs from land-based sources (wastewater treatment plants, industrial point sources, urban runoff and agricultural and silvicultural practices) need to be better understood in the state. Maine does not currently monitor nitrogen production or its biological impact.

The Department of Environmental Protection generally assumes nitrogen is a factor in drawing down inorganic carbon to raise pH but what happens before it gets into the bay/harbor is the unknown variable. The Department of Environmental Protection lacks data with which to establish a valid database, although much effort has been invested to improve/ensure/establish the quality of data from other sources such as non-profit volunteer networks, and more recently a volunteer survey from industrial point sources. Ample ambient nitrogen data points are available (mostly from Casco Bay), but major data gaps include biological response to nitrogen loads where there are concentrations. It is a challenge to tie the status of aquatic life to ambient nitrogen. It is a further challenge to prioritize where in Maine this research is most needed to determine that the aquatic life present in coastal waters is appropriate. Looking at the effects over very short time periods would shed light on understanding biological responses.

We recommend instituting a few pilot projects to include monitoring key estuaries around Maine to learn more about how specific pollutants and sources are contributing to ocean acidification. While much work has been done in Casco Bay, more data is needed in that location as well as in several other significant locations along the Maine coast.

4. Establish public/private partnerships for additional data collection.

We recommend that the Department of Environmental Protection continue efforts to work with regulated (permitted) entities to obtain additional monitoring data regarding nutrient loading, specifically phosphorus, nitrogen and fixed nitrogen. As this information is collected, the Department of Environmental Protection will be able to continue compiling data to better understand the impacts of nutrient loading.

In addition to efforts by the Department of Environmental Protection and permit holders, the commission recommends that community groups continue efforts structured like those in Casco Bay to collect data and enhance monitoring in areas around the state. Such monitoring would need to be aligned with protocols approved by the Department of Environmental Protection, and likely would follow those set up by the Casco Bay Estuary Partnership.

5. Ensure that state staff and other practitioners are working with the latest and best information and technology.

To ensure that Maine's state agencies and other cooperating partners are working with the best and newest technologies, especially in light of the increased frequency and severity of storms, the commission recommends a Best Management Practices workshop to provide information about the most effective existing and emerging tools that remove or reduce nutrients, organic carbon and help minimize land use changes that increase freshwater dilution of seawater.

There is a critical need for better technologies to address nutrient loading, especially from nonpoint sources. New septic system technologies that more effectively treat nutrients are one example. The state should seek private partnerships to identify, promote and support new and improved technologies that remove or reduce nitrogen and organic carbon from both point and nonpoint sources.

Maine should increase the monitoring of best management practices to ensure that practices are installed and effective with demonstrated reductions in nutrient loading.

6. Investigate and implement incentive programs for pollution reduction.

The design of best management practices is often site specific and existing financial incentives are often insufficient to warrant landowner participation. Maine should investigate the use of effective incentives for landowners to participate in activities that will contribute toward water quality improvements.

Maine should also investigate nutrient trading programs such as those adopted in Virginia, Pennsylvania, Maryland, West Virginia, Indiana, Ohio, New York, Connecticut and Kentucky. In a nutrient trading market, individuals that reduce their nutrient runoff or discharges below allowable levels can sell their surplus reductions or "credits" to other individuals (for example, wastewater treatment facilities). This approach allows those that can reduce nutrients at low cost

to sell credits to those facing higher-cost nutrient reduction options. The "sellers" would need to go beyond their baseline target by the amount of credits the seller wants to sell.

7. Support and reinforce current planning efforts and programs that address the impacts of nutrients and organic carbon and variations in freshwater inputs into coastal areas.

Local, state, and federal programs in the area of storm water management, land use planning and land conservation work to protect and improve water quality. For example, land conservation programs conserve forests, marshes and agricultural lands, all of which can function as natural filters to remove nutrients and sequester carbon and help minimize fluctuations in seawater dilution (lowers pH levels) from freshwater runoff in estuaries.

Land use planning that encourages the use of "green infrastructure" practices reduces the amount of impervious surface and assists in groundwater recharge.[5] Maine and its local governments should advance the use of incentives and other non-regulatory tools to promote and conserve forest and agricultural land uses, promote reduction in impervious surfaces and encourage use of green infrastructure and other sustainable practices.

Maine state agencies, county soil and water conservation districts, watershed groups and other qualified organizations should continue existing planning, technical and financial assistance programs to help rural and urban landowners, farmers and others properly manage nutrients and reduce organic carbon.

8. Enhance education and outreach programs that provide landowners with information about best practices for reduction of nutrient pollution.

The contribution of residential lawn fertilizers to nutrient pollution may be noteworthy based on the characteristics of individual coastal watersheds. Other states have lead successful outreach and education programs encouraging homeowners to perform simple soil tests and apply only the type and quantity of fertilizer needed for uptake by lawns and gardens. In the aggregate, the possibility of communities and individuals lessening their use of certain fertilizers and pesticides may help reduce nutrient loading in their watersheds.

Goal 4: Increase Maine's Capacity to Mitigate, Remediate and Adapt to the Impacts of Ocean Acidification

Ocean acidification is occurring in our ocean and coastal waters. Scientific data suggests that the rate of acidification will continue to increase and further alter ocean chemistry. The rate of change to ocean chemistry represents the most stressful impact of ocean acidification on marine species. In light of this data, we make the following recommendations to mitigate the current effects of ocean acidification and to begin to research mechanisms and methods that may

[5] Per the U.S. Environmental Protection Agency, at the lot or neighborhood level, green infrastructure refers to storm water management systems that mimic nature by soaking up and storing water. At the municipal or regional scale green infrastructure refers to the patchwork of natural areas that collectively provide habitat, flood protection, cleaner air and cleaner water.

enhance the adaptability of commercial species and those industries that depend upon them, thereby improving their resilience to changes in ocean chemistry.

Recommendations:

1. Preserve and enhance marine vegetation including eelgrass beds, kelp and all native vegetation in bivalve areas and adjacent shorelines.

Because plants absorb carbon dioxide through photosynthesis, they have the potential to locally remediate acidification by drawing down carbon dioxide in the surrounding seawater. This concept is called "phytoremediation". Acquisition of CO_2 by marine macrophytes represents an important sink for anthropogenic CO_2 emissions. The remediation benefits are likely to be more apparent in areas of slower circulation. Growing and harvesting macroalgae could play a considerable role in carbon sequestration. The benefits of co-culturing macroalgae, like kelp, and shellfish, should be a research priority.

Currently, the process for obtaining a permit for new or expanded aquaculture sites can be quite lengthy. We recommend that the Departments of Environmental Protection and Marine Resources work together to identify ways to streamline the permit and leasing processes to facilitate and promote the development and use of vegetation-based remediation efforts. Many eelgrass restoration efforts are already underway and the state can build off of these existing efforts.

2. Encourage bivalve production to support healthy marine waters.

Sustaining shellfish production in Maine is a component of a sound plan to protect healthy seawater chemistry and marine ecosystems from acidification. Productive shellfish beds provide natural treatment of some water quality conditions. By the very act of feeding, shellfish organisms filter nutrients out of the water, cleaning and clarifying it. Clearer water allows more sunlight to penetrate, which aids in the growth of crucial seagrasses, including eelgrass. Seagrasses, in turn, take up carbon dioxide and sequester it deep in their root systems, reducing carbon dioxide levels in the water. Different mechanisms exist for maintaining and expanding shellfish beds, including monetary incentives. For example, the State of Maryland offers a $500 tax credit ($1,000 per household) to residents who raise oysters because of the ecosystem services they provide. We recommend that the State of Maine promote shellfish production in a similar manner.

3. Spread shells in bivalve areas to remediate impacts of local acidification.

Redepositing pulverized bivalve shell hash on mudflats can effectively buffer mudflats, reducing corrosive conditions and improving chances for shellfish recruitment.

The spreading of shell material in intertidal zones would require certain permits through the Department of Environmental Protection and Department of Marine Resources. These departments should adopt rules to provide a streamlined permitting process for such remediation measures. The vast majority of shells from thousands of oysters consumed at restaurants

throughout Maine currently go to landfills. With appropriate handling protocols, a shell collection and deposition program could help protect cultivated and native oysters and clams from acidification and engage citizens and businesses in mitigating local impacts of acidification.

The commission strongly encourages the creation and promotion of shell collection programs and best management practices for carrying them out safely and effectively. To properly process shell material, centralized stockpiling locations should be identified, likely in association with shellfish growing operations, to season the shells sufficiently to meet state standards for prevention of disease and exotic organisms. Furthermore, such programs should be carried out on a 'pilot study' scale initially to identify any unforeseen negative impacts of spreading crushed shells on mudflats.

4. Increase the capacity of the fishing and aquaculture industries to adapt to ocean acidification.

As acidification worsens, hatcheries may become refuges where huge quantities of larvae can be raised in a controlled environment. The creation of this capacity would be an economic development opportunity for the private sector. The commission encourages work looking at the feasibility of growing species in this controlled environment until they reach a point at which they are less vulnerable to acidification. In order to do this, better information about the tolerances of individual species in combination with rigorous monitoring and maintenance of hatchery water will be essential. Hatcheries may require technical support for monitoring and buffering methodology. Also, sharing results of models of future carbonate chemistry scenarios with industry will give business owners some predictive capacity when it comes to making investments.

5. Identify refuges and acidification hotspots in order to prioritize protection and remediation efforts.

Vulnerability assessments identify assets in the path of disturbance as well as those less likely to be affected, and can help develop site specific adaptation strategies within the priority areas that are identified. In order to more effectively protect Maine's marine ecosystems and resources, we can start by locating areas of refuge – areas less at risk from ocean acidification because of physical features, less proximity to sources of acidification, or because of biological activity utilizing CO_2. When locales are identified as being at high risk from increased CO_2, we can take steps to mitigate the impacts through habitat restoration, phytoremediation, or other measures.

In order to identify refuges or acidification hotspots, monitoring of critical locations must be a priority. A set of criteria should be developed with which to rank different areas. The rankings will guide management efforts by providing a framework with which to focus on the most vulnerable regions first.

6. Encourage the creation of research hatcheries.

Hatcheries with a focus on research can both maintain and improve our current understanding of the genomes of commercially valuable shellfish (including crustaceans, mollusks, and

echinoderms. The development and testing of technology to improve large scale commercial hatchery production should be supported. A high priority of these hatcheries should be to explore the genetic adaptive capacity within these populations and selectively breed for resistance to ocean acidification and maintenance of these selected lines.

Goal 5: Inform Stakeholders, the Public, and Decision Makers about Ocean Acidification in Maine and Empower them to Take Action

The effects of acidification on marine organisms have only been a topic of scientific inquiry for a little more than 10 years. Calcifiers (e.g., organisms that produce shells) account for about 80% of Maine's commercial fisheries and the research conducted so far suggests that these marine resources are at risk. Mainers, including the general public, leaders at all levels of government and those whose livelihoods depend on marine species need information. They need to know what is known and what research is needed to answer key questions, and they need to be kept up to date as answers become available. Information is a crucial requirement for empowerment to take action. A sustained, coordinated, and publically supported effort by all branches and levels of Maine government will be necessary in order to understand the risks and address the causes and effects of ocean acidification. Given the high stakes associated with the changes in ocean chemistry, stakeholders, managers, water quality monitoring groups, conservation organizations and scientists must work together to develop a roadmap that will guide Maine's efforts to cope with an uncertain future.

Recommendations:

1. In addition to providing the Commission's report, the commission's key findings should be communicated to the Governor, Maine's legislative leaders, and Maine's Congressional delegation and the general public (including the press) in a series of briefings.

2. Continue efforts to increase the understanding of ocean acidification among key stakeholders, targeted audiences and local communities to help implement the commission's recommendations.

Encourage leadership amongst nongovernmental organizations and community networks, such as the Maine Coastal Observing Alliance. Build on existing nongovernmental organizations' outreach and education efforts, such as workshops, multi-media tools and informational mailings. Improve educational material targeted at key stakeholders, including but not limited to, the Maine Lobstermen's Association, the Maine Lobstermen's Union, the Maine Coast Fishermen's Association, the Maine Aquaculture Association, the Maine Soil and Water Conservation Districts, the Maine Farm Bureau and the Agricultural Council of Maine. Information regarding ocean acidification science, remediation and adaptation strategies should be shared at existing conferences, including but not limited to the Maine Fishermen's Forum, the Maine Water and Sustainability Conference, Northeast Coastal Acidification Network's stakeholder workshops and the Northeast Aquaculture Conference.

3. Enhance the existing communication network of engaged stakeholders, state agency representatives and the research community.

Currently an online group exists called the Maine Ocean Acidification google group. This is a group of over 110 individuals who have joined to stay informed about ocean acidification. It is currently managed by the Island Institute. The commission encourages broader and more active participation in this group to share information about the latest educational opportunities, research findings, mitigation, remediation, and adaptation strategies related to ocean acidification. Continued Maine representation within the Northeast Coastal Acidification Network is essential.

4. Develop, adapt and use curricula on ocean acidification in K-12 schools and higher education, and increase interdisciplinary university programs to equip young leaders with the skills to find solutions to complex multidisciplinary problems such as ocean acidification.

Maine educators should be encouraged to include curricula related to ocean acidification in their K-12 classrooms and college level courses. This topic lends itself towards hands-on experimentation and exploration at all age levels, making the subject more engaging. Where possible, students should be encouraged to participate in Maine's volunteer monitoring efforts. Students could join citizen volunteer groups to learn about this issue first-hand. For example, students could be involved in remediation pilot projects where they plant eel grass in clam flats and monitor the area to see if there has been an effect to pH levels.

There are existing ocean acidification materials available from multiple sources on the internet. In order for these materials to be used most efficiently and effectively, they should be compiled into one database where they will be readily available to teachers who will be able to select materials suitable to their class. Prior to inclusion in the central database, the materials should be evaluated and revised if necessary to make sure they are aligned with the *National Next Generation Science and Common Core Standards.* The easier it is for educators to incorporate ocean acidification materials into their required curricula, the more likely they are to do so.

Educational, research and non-profit organizations (including the Gulf of Maine Research Institute, Gulf of Maine Marine Education Association, Bigelow Laboratory for Ocean Sciences and the Island Institute) around Maine could hold symposia for educators to learn more about ocean acidification and how they can incorporate ocean acidification lessons into their curricula. Such events could also serve to connect students directly with researchers. Maine Sea Grant may provide funding to support low-cost, big-impact school and community partnerships. University programs such as the University of Maine's School for Marine Sciences Dual Masters Degree program that link marine policy and marine science education should be encouraged.

Goal 6: Maintain a Sustainable and Coordinated Focus on Ocean Acidification

The state's effectiveness in addressing the impacts of changing ocean chemistry on our marine ecosystems and coastal communities requires sustained leadership and support by the Governor and other state officials and a coordinating mechanism to facilitate implementation of the commission's recommendations.

Effective responses to the risk of ocean acidification require ongoing collaboration, well-coordinated strategies and actions, and efficient implementation of the recommended actions.

The problem should not be divorced from other ocean and coastal actions and priorities. The commission's recommendations touch on a wide range of ocean and coastal activities involving multiple entities. Coordinating all actions related to ocean health and coastal resources, including collaboration among scientists and decision makers, should reduce redundancies and inefficiencies.

Recommendations:

1. Create an on-going ocean acidification commission.

The creation of an on-going ocean acidification commission to facilitate the recommendations of this commission and to do the following:

A. Establish partnerships with state agencies involved with ocean acidification matters;

B. Coordinate the implementation of the commission's recommendations with other ocean and coastal actions;

C. Incorporate refinements and updates to the recommendations according to the latest science on ocean acidification;

D. Bridge ocean acidification-related science and policy needs by supporting continued productive interaction between scientists and policymakers;

E. Coordinate with key federal agencies, including the National Oceanographic and Atmospheric Administration, the Environmental Protection Agency, and the Department of the Interior, and work within the framework of the National Ocean Policy, and with the National Ocean Council, the Northeast Regional Planning Body, the Northeast Regional Ocean Council and the Northeast Coastal Acidification Network, while sharing data with the Northeast Ocean Data Portal. This can be done by developing memoranda of understanding or other mechanisms among partners to support data sharing, collaboration, and leveraging and prioritizing of funding;

F. Identify and promote economic development opportunities afforded by ocean acidification through development and commercialization of new technologies and businesses; and

G. Build public awareness, support and engagement to advance public understanding of the importance of a healthy ocean and of the most pressing challenges facing the ocean, and to engage citizens and various stakeholders in the development of and support for actions and solutions needed to address those challenges.

VI. PROPOSED LEGISLATION

The commission strongly believes that an ongoing entity must be created to continue the work of this commission. Ocean acidification is a long-term issue that will evolve in ways this

commission cannot foresee or have the ability to address during its limited existence. The creation of a permanent ocean acidification commission is paramount to protecting our commercially valuable species from the deleterious effects of acidification. The proposed legislation can be found in Appendix E.

APPENDIX A

Resolve 2013, Chapter 110

APPENDIX B

Membership list, Commission To Study The Effects Of Coastal And Ocean Acidification And Its Existing And Potential Effects On Species That Are Commercially Harvested And Grown Along The Maine Coast

APPENDIX C

Summaries of Meetings

APPENDIX D

State of the Science Subcommittee Report

APPENDIX E

Figures and Tables

APPENDIX F

Synopsis of Goals and Recommendations

APPENDIX G

Proposed legislation

APPENDIX H

Glossary of Terms