Supporting Materials For MOCA Action Plan

HOW THIS REPORT WAS CREATED:

The content that follows is summative of a series of stakeholder workshops held in the summer of 2019, and draws from past conferences and research focused on Ocean and Coastal Acidification (OCA) in Maine. The report begins with an account of the current status of OCA activities highlighting research and monitoring. Afterward, subject matter is arranged by topic, as shown in the index on page 3.

This work was generated as a supplemental material to the 2019 Maine Ocean and Coastal Acidification Partnership's Action Plan and to Maine's 2015 Commissioned Report on 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". This work aims to provide a comprehensive list of the activities and personnel involved with Maine's preparedness to and understanding of OCA. The document is to be used as a guide to assist decision-making around partnership activities, research, mitigation and adaptation.

If your work is represented in the following pages and you would like to amend the information shared, please contact parker.gassett@maine.edu. This draft was compiled in 2019 through a group process including many MOCA members and the MOCA Steering Committee. Parker Gassett of the University of Maine is the primary editor.

Special thanks to the MOCA Steering Committee:
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DRAFT JUNE 2020

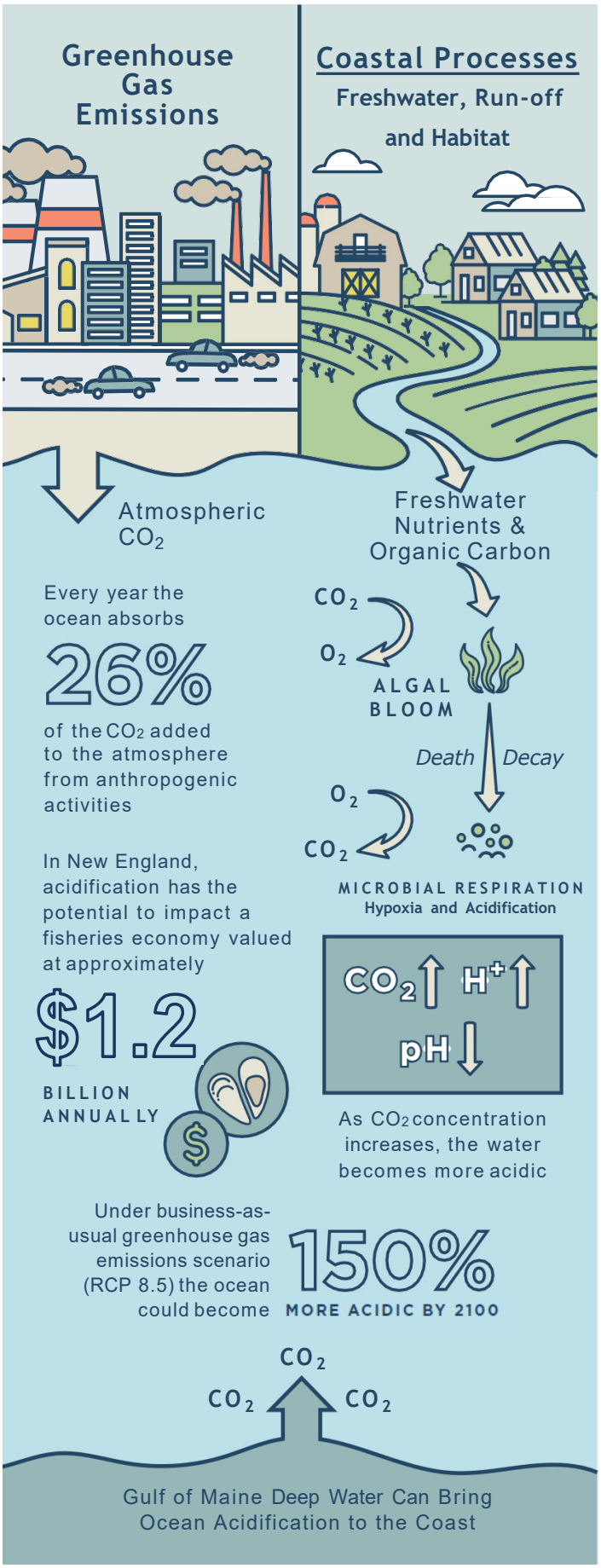
MAINE

OCEAN AND COASTAL ACIDIFICATION

PARTNERSHIP

Supporting Materials For MOCA Action Plan

CONTENTS



Ocean and coastal acidification (OCA) is part of a system of interacting stressors facing marine ecosystems along the Northeast Coast, challenging the ability of natural resource managers and conservationists to protect ocean and coastal ecology. OCA will have important effects on marine organisms, translating into impacts on a $1.2 billion annual fishery, food webs and marine ecosystems, and the ecosystems services provided to society by shellfish and other vulnerable species.

Commission to study the effects of ocean acidification and its existing and potential effects on species that are commercially harvested and grown along the Maine coast.

In 2015, the Maine OA Commission established six overarching goals:

1. Invest in Maine's capacity to monitor and investigate the effects of ocean acidification and determine impacts of ocean acidification on commercially important species and the mechanisms behind the impacts;

2. Reduce emissions of carbon dioxide;

3. Identify and reduce local land-based nutrients and organic carbon that contribute to ocean acidification by strengthening and augmenting existing pollution reduction efforts;

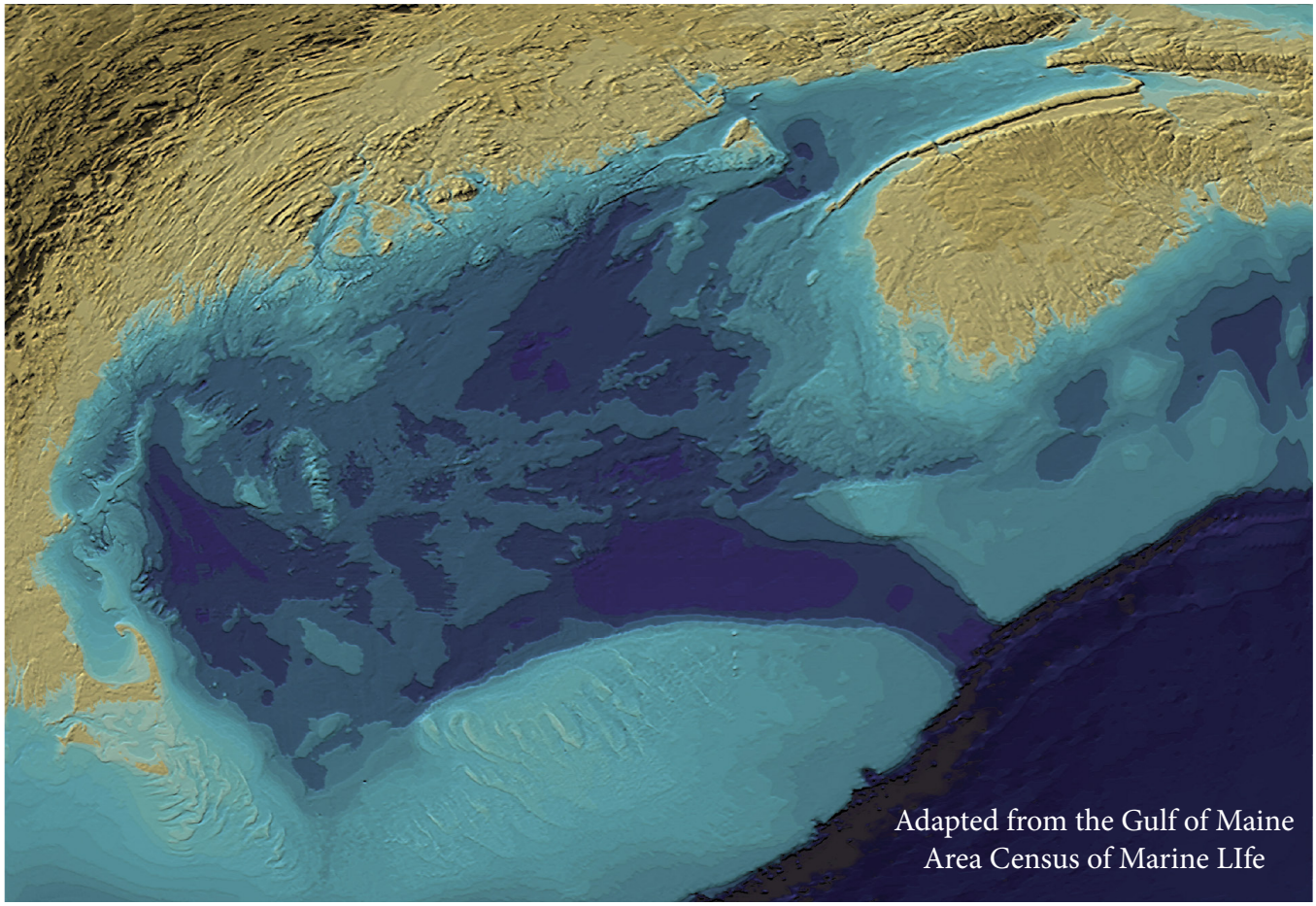
4. Increase Maine's capacity to mitigate, remediate and adapt to the impacts of ocean acidification;

5. Inform stakeholders, the public and decision-makers about ocean acidification in Maine and empower them to take action; and

6. Maintain a sustained and coordinated focus on ocean acidification.

FIGURE SHOWN:
Global carbon emissions are the dominant cause of OA, though local factors including nutrient pollution, river discharge, land use changes and marine habitat loss can exacerbate conditions at local scales.

Figure Adapted from The California OA Action Plan (2018) and The Nature Conservancy "Washington and Ocean Acidification", Washington Marine Resources Advisory Council (2017).
Facts: Gledhill et al. 2015; IPCC, 2018.
Text: Adapted from California OA Action Plan (2018) and Maine OA Commission Report (2015)



OCA IN MAINE

Waters of the Gulf of Maine are among the most vulnerable to Ocean and Coastal Acidification (OCA), and acidification along with temperature regime shifts associated with climate change threaten the livelihoods of Northeast coastal communities through impacts on commercially and culturally important species and ecosystems. Successful adaptation and mitigation options to address these impacts – including actions by municipal, state, and federal water quality managers, marine resource and coastal zone managers, and the aquaculture and fishing industry – depend strongly on developing and implementing best practices for resilience at the community level and on the availability of real-time observations and forecasts that can inform decision-making.

Ongoing Ocean and Coastal Acidification efforts and research in Maine largely coalesce around three themes:

1. Water monitoring, ecosystem modeling, and species level laboratory studies that aim to improve scientific prediction and understanding of oceanographic and ecological patterns of OCA.
2. Work to elevate public and governance awareness of risks, and how we can reduce risk through renovating existing policies and norms for coastal environments and contributing watersheds.
3. Early investigations for potentially adaptive measures and pilot scale mitigation projects that improve conditions for vulnerable species.

REGIONAL PARTNERS FOR MAINE'S WORK

- The National Oceanic and Atmospheric Administration Ocean Acidification Program has been a major sponsor for OA research in the Gulf of Maine. NOAA OAP provides funding for the Northeast Coastal Acidification Network (NECAN) and for the Northeast Regional Association of Coastal Ocean Observing Systems (NERACOOS) and the associated buoy monitoring network (Page 9). Representatives from NOAA OAP including director Dr. Libby Jewett have consistently attended MOCA and NECAN conferences and other activities in Maine relating to OCA research.
- NECAN acts as a collaborative partnership across agencies, NGOs and Research Institutions. It serves as a clearinghouse and organizing framework for region wide progress on OCA. NECAN hosts informational webinars, supports and advises MOCA, facilitates OCA monitoring training programs, and is consistently involved in State progress across commercial, academic, and departmental efforts. NECAN and NERACOOS have recrui substantial resources to investigate the relative strength of Maine's drivers of acidification (terrestrial inputs, near-shore processes, and oceanic water masses).

- The Northeast Regional Ocean Council (NROC) is a state and federal partnership providing a forum for regional initiatives to conserve and use coastal and ocean resources. The 2017 NROC meeting focused on OCA, identifying needs for research and interventions. Priorities included further work to bring together and expand monitoring efforts, research and development for rapid tests and ecologically oriented sampling approaches to see local vulnerability, and the potential for localized remediation through nutrient reduction efforts, buffering estuaries with calcium carbonates and further understanding the role of submerged aquatic vegetation in raising pH and thus also the potential for co-locating seaweed with shellfish operations. http://www.necan.org/sites/default/files/NROC%20NECAN%20OCA%20Monitoring%20Workshop%20synthesis_final.pdf

- The International Alliance to Combat Ocean Acidification established an international framework for developing OA action plans at the state and national level. The Alliance has routinely engaged with work in Maine, inviting Maine researchers to speak on webinars and at conferences, and utilizing the 2015 Maine commissioned report on OA for other audiences. In 2020 the State of Maine became a member of the International Alliance to Combat Ocean Acidification.

- The Environmental Protection Agency and EPA Region 1 supports and funds work affiliated with MOCA and NECAN. In 2018 EPA produced a series of guidelines for measuring coastal acidification in the Eastern United States: http://www.necan.org/epa-guidelines-measuring-changes-seawater-ph-and-associated-carbonate-chemistry-coastal-environments. The authors of these research guidelines supported water monitoring training programs in the summer of 2018 and participated in 2019 regional sampling (Shell Day, page 12). EPA Region 1 representative Matt Liebman has interfaced with OCA work in Maine, provided financial and technical support for Shell Day, and advising Casco Bay efforts to establish shell recycling programs for localized OA mitigation (Page 24).

- The Ocean Conservancy has routinely engaged in events and discussion supporting Maine's research and policy planning to address ocean and coastal acidification. This engagement has supported multiple researchers from the Gulf of Maine to testify for federal legislation (Mook Sea Farm and Salisbury lab, University of New Hampshire), research collaboratives around climate change (Pershing et al. GMRI and the 4th National Climate Assessment), and local interventions (Price et al. Kelp amelioration of OCA) (Political Engagement, page 38). It is widely regarded, and has been enunciated by the Ocean Conservancy, that Maine's social and scientific infrastructure and capacity for addressing OCA is helping to lead efforts on the East Coast.

- The Nature Conservancy has prioritized climate change and OCA through a variety of ventures ranging from scientific research to outreach and policy advising. Bill Mook from Mook SeaFarm and Shellfish Hatchery is a founding member of The Nature Conservancy's Shellfish Growers Climate Coalition. TNC Maine supported Dr. Nichole Price's work with kelp remediation of OA (Page 29). TNC Maine has also been a foundational partner in wild shellfish restoration efforts throughout the East Coast and in New Meadows, Maine for the past several years.

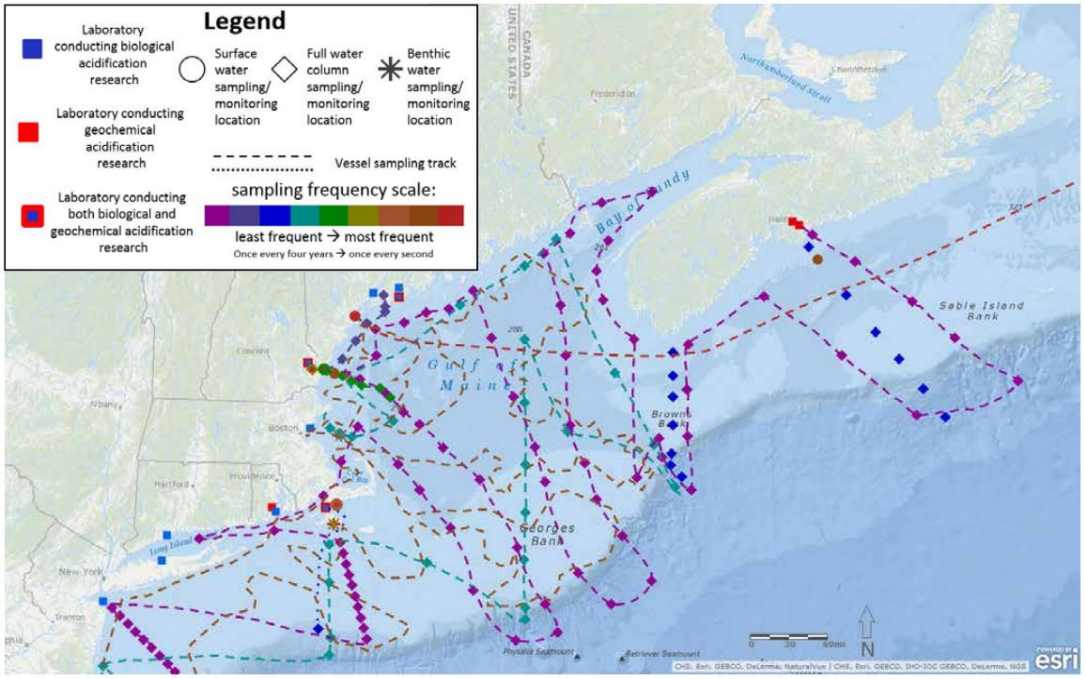
OVERVIEW OF THE REGION

Observing trends in ocean and coastal acidification

Current research

in the Gulf of Maine aims to understand and forecast the oceanographic and ecological consequences of ocean acidification and to discern how coastal ecosystems and coastal acidification are influenced by short term drivers that exacerbate local conditions. These drivers include rainfall events, stormwater and nutrient pollution, the tidal and river flow dynamics that affect estuarine alkalinity and buffering capacity, and habitat quality and ecological resilience to the pressures of acidification. However, we lack comprehensive monitoring at spatial and temporal scales needed to characterize OCA and marine climate change patterns in a way that provides actionable information for managers. Many existing research institutions and water quality monitors in the Northeast United States are already measuring carbonate chemistry and are well positioned to collaboratively investigate coastal acidification processes alongside state environmental and fisheries agencies. These observations can be incorporated with traditional priorities for marine habitat protection, nutrient pollution control and watershed management.

Standardizing OCA measurements, measurement equipment and protocols, facilitating monitoring training programs and providing financial support for data synthesis efforts would likely result in a significant expansion of state monitoring of near-shore conditions. Expanding current water monitoring and environmental stewardship efforts within coastal communities and incorporating new understanding of ocean and coastal acidification into environmental protections and management strategies can help Maine to navigate this complex environmental and economic challenge.



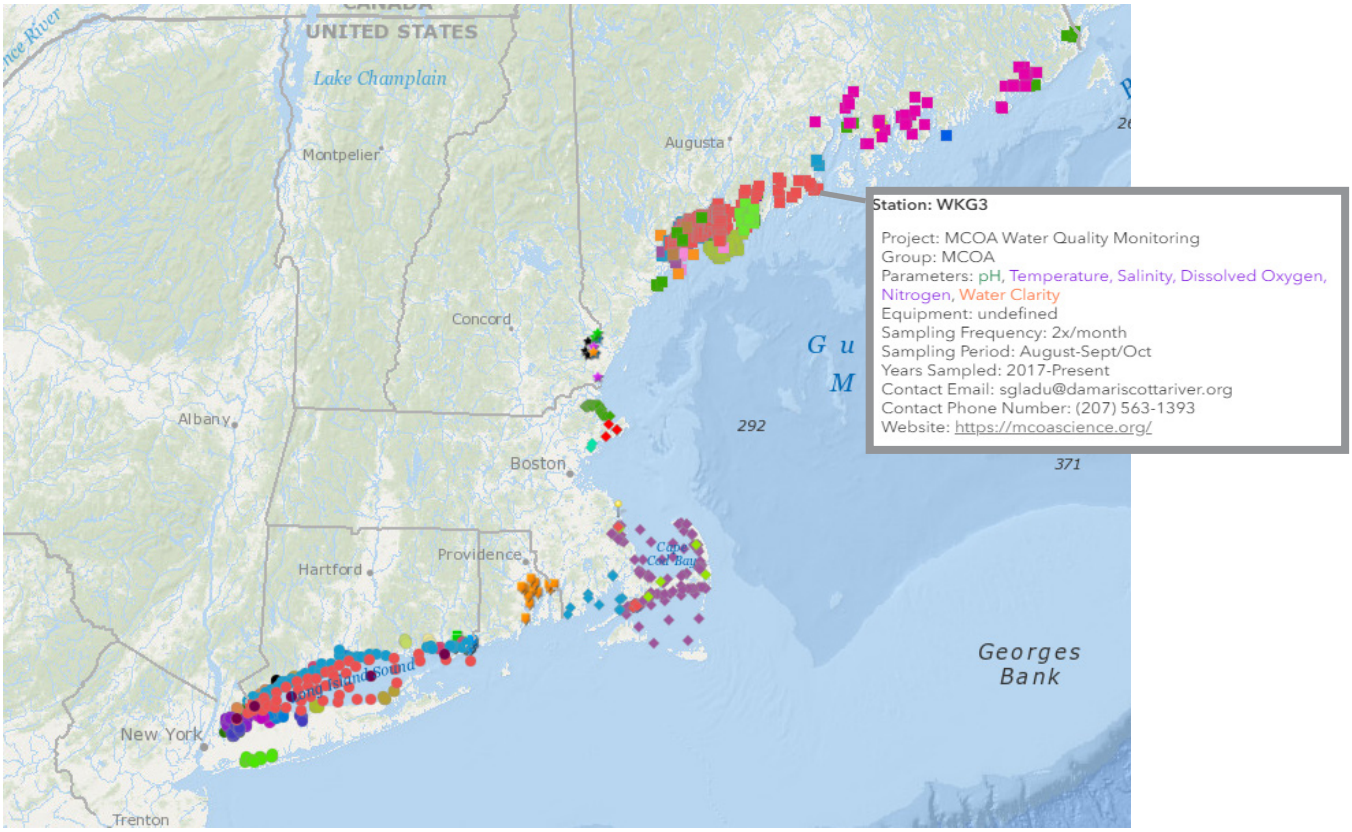
The above figure outlines oceanic carbon system monitoring in the New England/ Nova Scotia region from Gledhil et al. 2015 "Ocean and Coastal Acidification off New England and Nova Scotia". Shown are laboratories researching ocean acidification (red squares) along with its effects on biology (blue squares). Monitoring of carbonate chemistry parameters by buoys and vessels and approximate cruise tracks and sampling waypoints are color coded according to frequency of observation/reoccupation.

Current Monitoring Capacity:

High precision offshore cruise data for conditions of acidification include the NOAA East Coast Ocean Acidification cruise, Wilkinson Basin transect, the GNATS Survey supported by Bigelow, NASA and others, and buoy data from NERACOOS and partners. Many of these data are published or uploaded to public platforms monthly, though further effort is needed to ensure that data are accessible for end users.

In the nearshore environment of Maine, precision monitoring of acidification occurs primarily during a 4-6 month period in the summer and sparsely year round. These efforts are highlighted by extensive and consistent monitoring in locations including the Damariscotta River and Mook Sea Farm Hatchery, Appledore Island, at the Southern Maine Community College pier (UNH Salisbury Lab and Friends of Casco Bay FOCB), at Cousins Island (FOCB), in Harpswell at the Bowdoin Schiller Coastal Studies Center, and as of spring 2020, in West Boothbay via the Department of Marine Resources. One year-round, hourly monitoring station is operated by FOCB in Middle Bay, and two additional year-round stations are to be added to Eastern Casco Bay/Kennebec River and the Fore River. Coast-wide, summertime non-continuous monitoring of pH, dissolved oxygen, temperature, salinity and other parameters pertinent to coastal acidification occurs frequently, upheld by a large community of water quality monitoring organizations, research institutions, and State and Municipal staff.

The figure on the following page is a snapshot from a GIS layer collating coastal water quality monitoring stations. The Monitoring Acidification Project (MAP) encompasses the Northeast Coastal Acidification Network (NECAN) region from Long Island Sound to the Canadian Maritimes. Stations on these GIS layers are tagged online to include metadata about the sampling frequency, equipment used, and contact information to acquire data files.
https://storymaps.arcgis.com/stories/fae30818a6164043a0d368ba0cd7bad3



Maine monitoring efforts:

- Bigelow Laboratory for Ocean Sciences
- Bowdoin College
- Boothbay Region Land Trust
- Casco Bay Estuary Partnership
- Environmental Protection Agency
- Friends of Casco Bay
- Gulf of Maine Research Institute
- Hancock County Soil and Water Conservation District
- Island Institute
- Maine Coastal Observing Alliance
- Maine Department of Marine Resources
- Maine Department of Environmental Protection
- Maine Coastal Program
- Maine Healthy Beaches Program
- Mook Sea Farm/University of New Hampshire
- Rockport Conservation Commission
- Schoodic Institute, Acadia National Park, and Earthwatch International
- Shaw Institute
- University of Maine
- University of New Hampshire
- Wells National Estuarine Research Reserve

GIS information produced by Katie O'Brien Clayton of the Connecticut Department of Energy and Environmental Protection, Parker Gassett of the University of Maine, and the NECAN Outreach and Education working group. Colors represent distinct water monitoring programs. https://storymaps.arcgis.com/stories/fae30818a6164043a0d368ba0cd7bad3

Organizations and monitoring stations not yet included in the MAP include:

- The Downeast Institute
- Hurricane Island Center for Science and Leadership
- Maine Water Foundation
- Maine Maritime Academy
- The Belfast Watershed Association
- Unity College
- University of New England

MONITORING

pH	Total Alkalinity (Potential Salinity Proxy)	Marine organisms are affected by the availability of carbonate ions dissolved in the marine environment. Acidification results in a reduction of those ions. At least two of four carbon measurements, along with temperature and salinity are often needed to evaluate the risk of acidification and subsequently describe the availability of carbonate ions (saturation state).
pCO2	Dissolved Inorganic Carbon	

Research through NECAN in 2017 showed that 91% of water monitoring organizations in Maine are measuring pH, and that nearly all are measuring temperature, salinity, and dissolved oxygen. In general, monitoring organizations specifically investigating Ocean and Coastal Acidification (~20%) have progressively expanded from single carbon system measurement to second and third carbon system parameters needed to calculate and corroborate observations of saturation state. These organizations will likely require sustained technical support and further training in order to provide actionable information on the dynamics of coastal acidification.

The Maine Department of Environmental Protection's Marine Unit conducts water quality monitoring under the Marine Environmental Monitoring Program on an ongoing basis which includes some OA parameters. However, resource constraints limit where, how often, and for how long monitoring can occur. Department focus is usually on areas with wastewater discharge licenses coming up for renewal to determine if there is reasonable potential for discharge to cause a water quality standards impairment and or issues of coastal acidification. Casco Bay has been a focus for monitoring in recent years (Casco Bay Subsection, page 17). All DEP monitoring data are publicly accessible and water quality data are kept in the Department's Environmental and Geographic Analysis Database. https://www.maine.gov/dep/gis/datamaps/index.html#egad

The DEP Marine Unit has proposed a more comprehensive and sustainable monitoring program that annually rotates through five coastal regions for assessing eelgrass and the benthic infaunal community as well as water quality parameters that would include OA indicators. An additional four staff positions at DEP have been suggested to implement such a monitoring and data management effort.

The Environmental Protection Agency has been involved with a variety of training, research grants, and meetings surrounding OCA in Maine. Every five years, the EPA facilitates a National Coastal Condition Assessment, which entails physical, chemical and biological monitoring at probabilistically selected sites throughout Maine's coastal waters. In 2020, these assessments will, for the first time, include total alkalinity.

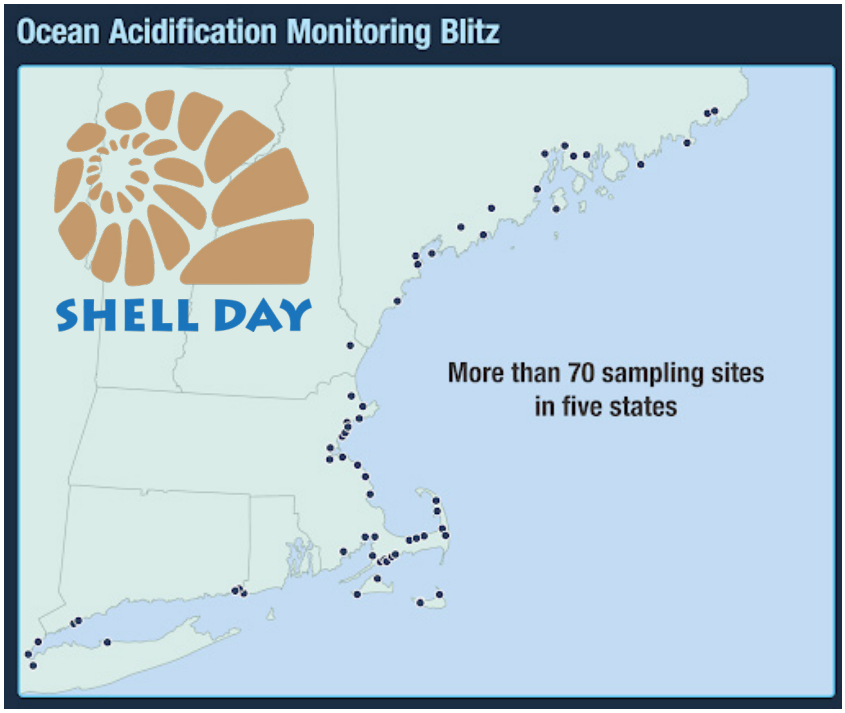
91% of monitoring organizations in Maine are measuring pH, and nearly all organizations are measuring temperature, salinity, and dissolved oxygen.

The Maine Coastal Observing Alliance (MCOA) has been operating and growing for five years and has built a citizen science network of monitoring programs in estuaries from Casco Bay to Penobscot Bay. The Alliance operates under the Quality Assurance Project Plan (QAPP) of the Friends of Casco Bay and generates a variety of water quality observations that locally inform understanding of nutrient patterns and coastal acidification processes. The Maine Coastal Observing Alliance has also helped to improve community based water monitoring programs by serving as a hub for calibration of monitoring equipment and helping to ensure that consistent and high quality data is generated. This work has been made possible alongside the Darling Marine Center with key personnel including Kathleen Thornton, Damian Brady, Larry Mayer, and Kate Liberti.

MCOA has made progress in sampling occurrences of acidification that seem to result from freshwater dilution, estuarine eutrophication, and the import of deep, acidified, open ocean waters from offshore. While some incidents of acidification have clear origins, others are difficult to interpret. MCOA's data show that certain estuaries in certain years are prone to nutrient-driven acidification. These findings have motivated MCOA to plan for future monitoring strategies for high-priority sites to measure at least three of the four carbon system parameters simultaneously (pH, alkalinity, total dissolved inorganic carbon, and pCO_2).

Funding for monitoring work has ranged from Federal, State, private and Non-Government sources. Over the past six years, the Northeast Coastal Acidification Network (NECAN) has prioritized connectivity among a broad audience of water quality stakeholders in coastal acidification research. These efforts have included a workshop training series sharing EPA guidelines for measuring carbonate chemistry. Training materials, videos and reports can be found at http://www.necan.org/OCACitizenScienceWorkshops.

The first ever Shell Day was orchestrated in the summer of 2019 as a regional effort in the Northeast to simultaneously sample for ocean and coastal acidification. From Long Island sound to Downeast Maine 57 research organizations and an additional 7 chemical oceanography laboratories joined to measure total alkalinity, salinity, and temperature, along with a variety of other parameters pertinent to coastal acidification. More information can be found at http://necan.org/shellday.



Few long term water quality monitoring programs have been directly linked with biological indices or research on settlement for shellfish or lobsters. Future monitoring is planned for commercial docks at lobster buying stations (Lobster, Page 32). Monitoring via on-board commercial lobster boats has been discussed by the Lobster Institute. Discussion at conferences and meetings has frequently acknowledged the potential to further link research with industry by co-locating monitoring with the growing scale and distribution of aquaculture operations. Additionally, utilizing other vessels such as ferries or commercial boats with continuous monitoring equipment has been suggested as an important opportunity for better understanding conditions over time and among locations.

Multiple organizations have undergone an organic process to share data and equipment and to co-develop best practices as new instruments and monitoring approaches for acidification and climate change become available. Significant collaboration has occurred in Casco Bay and Mid Coast Maine.

DATA MANAGEMENT

The need to create adequate and user friendly databases for OCA and coastal water quality data has been routinely emphasized at strategic meetings including the Northeast Region Ocean Council (NROC) and the Regional Association For Research on the Gulf of Maine.

In general, coastal water quality data from the Gulf of Maine reside in disparate locations; some reaching the Department of Environmental Protection, the National ERDDAP System, and community science data portals like “Anecdata”, while still other programs have their information on individual organization websites or private computer spreadsheets.

The NOAA Ocean Acidification Program now supports a three year data synthesis effort under the leadership of the University of Maine’s School of Marine Sciences Director, Dr. Dave Townsend, to synthesize nearly 40 years of available OCA data within the region to address water quality changes over time and the patterns of coastal and offshore drivers. There are multiple data originators and this data synthesis effort has engaged a wide community of researchers that are also involved with the Maine Ocean and Coastal Acidification Partnership and the Northeast Coastal Acidification Network.

The Northeast Regional Association for Coastal Ocean Observing Systems (NERACOOS) presently acts as a clearinghouse for buoy data from Long Island Sound to the Canadian Maritimes. NERACOOS has long been considered as a potential, continued avenue for publicly accessible OA and water quality information. Modeling efforts through NERACOOS aim to generate forecasting for acidification/ saturation state within the next two to five years and the process has prioritized working with model “end-users” so that forecasting tools are created to be most useful for resource managers and fisheries stakeholders.

NERACOOS is additionally working with EPA to provide a series of recommendations around quality assurance for OCA data with a special focus on National Estuary Programs and community science programs. The strategic plan for the Bigelow Laboratory for Ocean Sciences includes a “Big Data Discovery Initiative”, to encompass geospatial datasets on ocean water quality and work to integrate new data types (e.g., copepod distribution, harmful algal blooms (HABs), nutrients, etc.). Bigelow currently hosts a high performance computing facility and data warehouse capable of storing over 200TB of data. The Gulf of Maine Research Institute also has staff and capacity to create and maintain database infrastructure.

HOT SPOTS

A reasonable approach identified by multiple organizations is to assess and target hot-spots for acidification. Maine Coast Observing Alliance data has identified zones of Mid Coast estuaries that have experienced relatively acidified conditions based on low pH excursions. Hotspots have included deeper waters at the mouths of several estuaries in 2014, and the Medomak estuary in 2017. These areas include estuaries that are both dominated by the influx of open ocean water as well as estuaries primarily driven by watershed processes. Friends of Casco Bay has observed seasonal patterns of acidification at their continuous monitoring station. Through observations, and with the help of modeling, the strategy of identifying hotspots can generate a series of high priority areas for management and interventions. The Casco Bay Estuary Partnership has worked with University of Maine to facilitate hydrodynamic and ecosystem-based models to better understand system metabolism, pollutant transport, and near-shore carbonate chemistry in Casco Bay. Mapping of CO_2 hot and cool spots in coastal waters was recently performed by UNH and Bigelow Laboratories. NERACOOS is currently involved with regional modeling effort aimed to further characterize acidification using Northeast Coastal Ocean Forecast System (NECOFS). NECAN's work to orchestrate Shell Day further aligns with priorities to identify hot-spot locations within a coastline of heterogeneous conditions.

BASE LINES

Having baseline information about water chemistry and ecology of species vulnerable to ocean and coastal acidification is particularly important for establishing environmental impairment criteria. Baselines allow managers to compare environmental status to a target state. Baselines can also be critical for assessing narrative and numerical criteria for acidification within existing legislation; namely the Clean Water Act Section 303. Conversations with the Maine Department of Environmental Protection have highlighted the potential for both numeric and narrative bio-criteria for marine environments similar to those used in freshwater environments. Numeric criteria for ocean and coastal acidification is challenging because of the natural dynamics and ranges of pH observed in coastal ecosystems. Using existing laws and legislation to confront acidification has often been regarded as preferable to developing new protections.

Dr. Michèle LaVigne, research collaborators and Maine Sea Grant, are working to assess historical chemical baselines for acidification and carbonate chemistry using crustose algae and *Arctica islandica* clams to develop paleoceanographic isotope proxies for reconstructing past pH changes in the Gulf of Maine. Historical ecological information about population size and distribution of shellfish along the Maine coast is sparse. The distribution of vast shell middens throughout Maine estuaries from Native American populations indicate a historic abundance of wild American Oysters thought to be naturally extirpated by past climatic stress.

Eutrophication, Hypoxia and Acidification

NUTRIENT POLLUTION

Research on coastal acidification over the past decade has highlighted the role of point and non-point nutrient pollution in the eutrophication processes that can lead to discrete coastal acidification and hypoxia events. Warming water in the Gulf of Maine, population growth and coastal development aggravate the risk of nutrient pollution leading to eutrophication, hypoxia and acidification. Multiple-stressors for coastal ecology contextualize a need for developing model ordinances and best practices for nutrient management.

Large tidal flows flush coastal nutrients away from the near-shore environment in Maine's embayments. Furthermore, coastal food webs have specific capacities to uptake nutrients without eutrophication or nuisance algae blooming. These dynamics are unique among locations coast-wide.

Understanding if and where nutrient reduction actions can support real and lasting improvements to the conditions of acidification is critical. Therefore, as coastal nutrient pollution reduction programs are put in place, it is important to study how these interventions affect acidification processes.

DEP's Division of Environmental Assessment's Engineering Unit has conducted preliminary modeling of nutrient inputs (point and non-point) as part of its review of point source license applications. Several permittees have implemented nitrogen reduction measures voluntarily and/or are monitoring effluent nitrogen. DEP's Stormwater Rules focus on reducing impacts of runoff through the use of best management practices (BMPs) that often promote infiltration of water on the ground's surface to enter into soils. Recent concerns for chlorides in urban stream watersheds have, however, caused some projects to advocate against infiltration due to high chloride levels measured in base flow.

Legislation and outreach around nutrient pollution, fertilizer use, and waste-water and septic ordinances have been incrementally and successfully pursued state-wide. It will be advantageous to develop comprehensive nutrient control ordinances or legislation and criteria (numeric or narrative) that can be easily shared and implemented across coastal municipalities.

Using ecologically responsive permit procedures has been widely suggested as an opportunity for improved hypoxia and OCA management. Nature-based solutions include promoting populations of shellfish to reduce water column particulate matter and filter blooms of micro-algae, and encouraging and protecting submerged aquatic vegetation that can metabolize excess nutrient loads, sequester CO_2, and improve habitat for filter feeders and other marine life (Submerged aquatic vegetation, page 29).

CASCO BAY


Photograph from Friends of Casco Bay

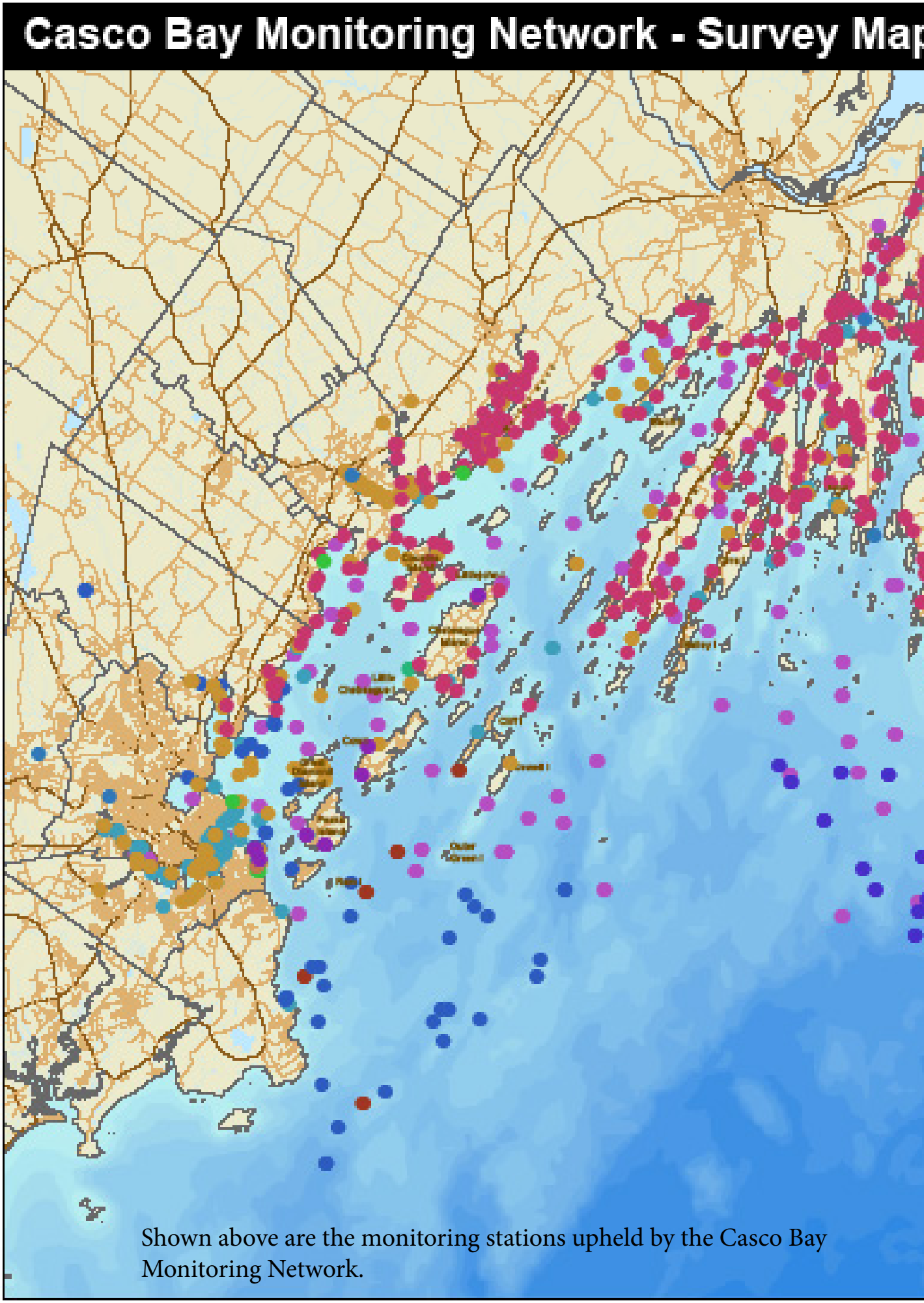
Research on nutrients and practical nutrient reduction programs have been highly prioritized in Casco Bay. This work positions the embayment as an important case study for further statewide action. The Department of Environmental Protection is working with partners, including the University of Maine, Casco Bay Estuary Partnership and Friends of Casco Bay to assess high resolution observations of nitrogen concentrations and other nutrients. GMRI has piloted a stable nitrogen isotope monitoring study in Casco Bay to trace impacts of human-derived nitrogen on blue mussels.

Casco Bay hosts an extensive catalogue of collaborative research characterizing seasonal risks of eutrophication and duly observing and documenting local acidification events. These data, syntheses and models have informed the Casco Bay Nutrient Council.

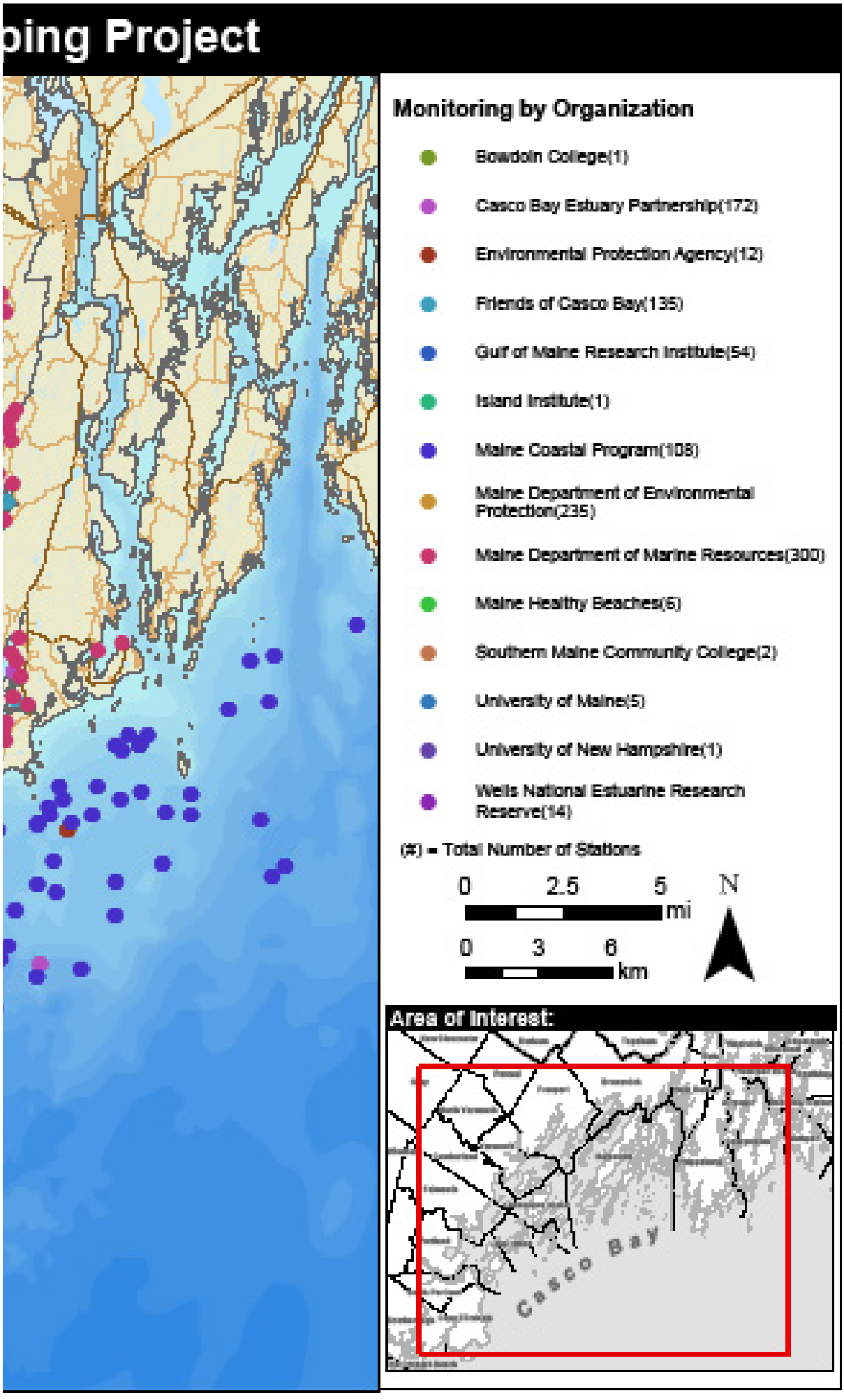
Multiple monitoring initiatives and the ongoing technical work to synthesize data among collaborators (including the work performed by DEP) are beholden to competitive grant funding.

Consistency and utility of monitoring in Casco Bay and beyond would be made more effective by ensuring long term funding and by advancing opportunities to further equip monitoring efforts to include parameters for acidification along with biological indices for climate change stressors. Enhancing the capacity for monitoring to include necessary parameters to accurately characterize acidification, linking these observations with harmful and nuisance algae blooms, and supporting programs to conduct year-round monitoring are each critical steps.

"The Town of Brunswick now supports expanding shellfish programs, stating that for every 20 thousand oysters harvested, one coastal household's annual nitrogen production is removed."



Shown above are the monitoring stations upheld by the Casco Bay Monitoring Network.


ping Project
Monitoring by Organization
Bowdoin College(1)
Casco Bay Estuary Partnership(172)
Environmental Protection Agency(12)
Friends of Casco Bay(135)
Gulf of Maine Research Institute(54)
Island Institute(1)
Maine Coastal Program(108)
Maine Department of Environmental Protection(235)
Maine Department of Marine Resources(300)
Maine Healthy Beaches(6)
Southern Maine Community College(2)
University of Maine(5)
University of New Hampshire(1)
Wells National Estuarine Research Reserve(14)
(#) = Total Number of Stations
0 2.5 5 mi
0 3 6 km
N
Area of Interest:
Casco Bay

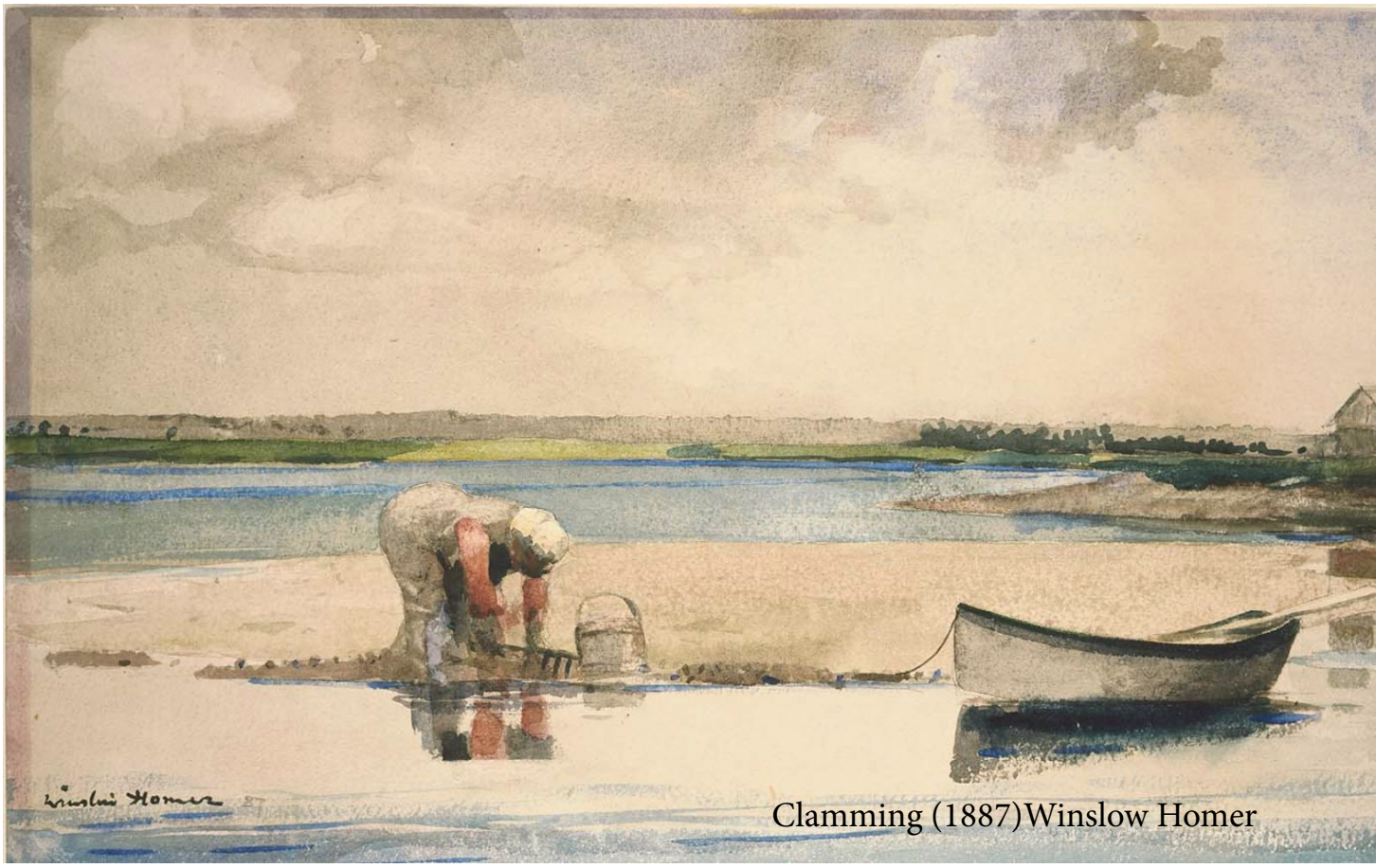
NUTRIENT REDUCTIONS IN CASCO BAY

The Casco Bay Nutrient Council, Casco Bay Estuary Partnership, and Friends of Casco Bay (FOCB) have reviewed and cataloged existing governance and policy tools to reduce nutrient pollution in one of the most densely populated regions along Maine's coast. http://www.cascobayestuary.org/wp-content/uploads/2019/06/Casco-Bay-Nutrient-Council-Report-Final-6-12-19.pdf This group published a comprehensive report in June 2019 and no longer actively meets. The effort interfaced with the Portland's "Blue Portland" water quality planning efforts and South Portland City Council's interest in fertilizer ordinances as they relate to eutrophication and coastal acidification. The town of Falmouth is also working on a fertilizer ordinance and a draft MS4 permit which would allow municipalities to adopt fertilizer ordinances as a nonstructural means to reduce pollution in urban impaired streams. Such approaches aim to work with local governments to identify local strategies to reduce nutrient pollution and address municipal permit obligations.

For example, having observed nuisance macroalgal blooms correlated with nitrogen sources, FOCB commented on Maine Pollutant Discharge Elimination System (MEPDES) permits for wastewater treatment facilities (WWTFs) that discharge into Casco Bay. Their comments urged permits to ensure treatment plants monitor effluent to determine seasonal nitrogen loads and that major facilities optimize treatment to reduce nitrogen loading. Such engagement contributed to the East End WWTF in Portland reconfiguring aeration basins, now achieving over a 70% seasonal reduction in nitrogen since 2018.

Friends of Casco Bay and others further recommend the following approaches, ordinances and legislation be considered:

- Conduct policy reviews of existing laws to strengthen them in addressing OCA and climate change, for example:
    - Identify means to improve water quality in nutrient and urban impaired waters.
    - Review 2007 Resolve and stalled work to develop numeric nutrient criteria.
    - Review whether to recommend revision of water quality standards to consider signs of OCA as an impairment.
    - Advocate for delegated authority to regulate cooling waters in MEPDES permits.
    - Consider if temperature and pH regulations need to be modified for climate change.
- Use the work in Casco Bay as a model for other coastal WWTFs.
- Advocate for enhanced funding for upgrades to WWTFs, septic systems and overboard discharge systems (OBDs).
- In areas where nitrogen has been identified to contribute to poor water quality or algae blooming; eliminate the use of lawn fertilizer on adjacent property, ask town to investigate septic systems, or seek nitrogen optimization in MEPDES permits.
- Develop model fertilizer ordinance that can be adapted and tailored at local level or as a state fertilizer statute.
- Advocate for expanded septic inspections to all properties.
- Enhance repair and replacement of failed septic systems.
- Explore where to expand sewer lines.
- Advocate for revised Chapter 500 storm-water rules to be more proactive and require LID and green infrastructure.
- Review expired Maine Construction General Permit to advocate for tightening requirements to prevent runoff from construction sites and consider tightening post construction requirements.
- Advocate for implementation of policies designed to disconnect impacts of impervious cover and treatment of storm-water before it reaches receiving waters.
- Taking action to improve water quality of urban impaired streams, including those that show signs of degradation from excess nutrient loading.
- Make entire coast a no discharge zone.



Clamming (1887)Winslow Homer

Laboratory and in-situ research has shown acidification to decrease the survival of juvenile clams, slow their growth rates, and weaken their shells. However, research from the Downeast Institute shows that predation from the invasive green crab is a far more direct threat to wild populations at this time. Multiple-stresses are likely the cause of recent and steep declines in soft shell clam populations. Excluding predatory green crabs from juvenile clams appears possible through screened protections on boxes of hatchery reared clams, but this method will be challenged to match the ecological scale of decline for wild and self seeded populations.

MONITORING ON CLAM FLATS

In many states, there are established programs that rear young clams in hatcheries and then spread the clam seed over clam flats to supplement wild populations. In Massachusetts these programs are supported by the revenue from recreational clamming licenses.

Acidification monitoring on Maine Clam flats has been conducted by multiple municipalities and research programs, often in coordination with testing for bacterial closures.

The Downeast Institute (DEI), the Hancock County Soil and Water Conservation District, Bowdoin College and Professor Mark Green from St. Josephs College have each published work and data around their monitoring programs and seasonal research.

The Downeast Institute conducted multiple manipulative experiments on soft shell clam recruitment from 2017 through 2018 in Freeport, Machiasport and Cutler. Each site showed the hardiness of clams to low pH environments and that predation was the most direct challenge for populations. There is now a 2 year post doctoral research position at DEI to further evaluate the impacts of acidification in sediments on commercial species. DEI has submitted a proposal to establish a statewide clam settlement monitoring network using recruitment boxes. This would be similar to the post larval collection that is part of the American Lobster Settlement Index (ASLI).

The Town of Brunswick in partnership with Fair Winds Inc monitored pH levels in several clam flats consistently over the course of 2019, and aim to include monitoring in the town's municipal plan. This work seeks to identify environments that are suitable for re-seeding wild populations.

Dr. Michèle LaVigne at Bowdoin College, in collaboration with Kennebec Estuary Land Trust and Manomet, has surveyed both spatial and temporal variability in carbonate chemistry throughout different clam flats in the Kennebec Estuary, and has performed experiments investigating the impacts of shell buffering on sediment carbonate chemistry in the laboratory. This work has shown that sediment texture, organic matter content, and evaporation play a large role in setting pH, alkalinity, and saturation state in sediment pore-waters.

SHELLS AND CALCIUM CARBONATE BUFFERING

Ocean alkalizing, ocean liming, and buffering with shells have been often considered but sparsely researched approaches to mitigating acidification in both marine and freshwater environments. Because estuaries are home to immense flows of water on daily timescales, it is a challenge to envision local buffering programs that match the scale and residence time of marine waters so as to be effective in actually reducing acidification. Yet, it is known that at geographic scales, and decadal time-frames, alkalinity in watershed substrates plays an integral role in the ability for buffered coastal marine systems to resist acidification. Natural buffering can already be observed within high alkalinity watersheds. The interaction between acidification and natural limestone deposits, historic piles of shell known as shell middens from Native American populations, and modern piles of shells constructed as artificial oyster reefs in many other coastal U.S. States remains largely understudied.

Establishing marine refugia for shellfish populations through artificial reefs is an emerging conservation approach addressing coastal acidification, and a well explored technique for traditional restoration efforts.

Such ventures can align with green infrastructure and living shorelines approaches to coastal resilience aimed to protect communities from storm surge and erosion while enhancing ecosystem functioning and biodiversity. In Maine, some shellfish conservation commissions have informally engaged in supplanting low yield clam flats with “shell hash” (shell chips and fragments) from nearby areas that have naturally abundant shell debris.

Hundreds of thousands of tons of shells from restaurants and processing plants are sent to land fills in Maine each year.

THE MAINE MOLLUSK SHELL RECYCLING PROGRAM

FOR COASTAL ACIDIFICATION REMEDIATION

As recommended in 2015 by Maine's Commissioned report on Ocean Acidification, the Casco Bay Estuary Partnership (CBEP) and Maine Coastal Program have initiated a pilot scale shell recycling program "The Maine Mollusk Shell Recycling Program for Coastal Acidification Remediation." EPA's Climate Ready Estuaries Program financed the work, and project seeks to gain practical experience and document lessons learned that can facilitate scaling up statewide shell recycling programs.

The pilot project is currently collecting oyster shells from 10 restaurants in downtown Portland, and storing and "compost sterilizing" them in freight containers at Portland's EcoMaine facility. Implementation for "living shorelines", erosion control and research on buffering of acidification is proposed to begin in the summer of 2020 in Maquoit Bay.

The project aims to produce a white paper about the effectiveness of remediation at a study site and the ability to scale up state-wide initiatives.

This project is operating on short-term grant funding. In order to pay for the costs associated with collecting and transporting shells from restaurants, the program will need to explore a model for revenue or continued grant support.

Furthermore, conversations within the research and management community engaged through the Maine Ocean and Coastal Acidifcation Partnership have highlighted the opportunity for shells as a value added product for harvesters and the importance of diverting shells from Maine's waste-stream and landfills.

Artificial reef and reef-structures for erosion control and shellfish habitat are common in the Mid-Atlantic and Southern Coast.

L.D. 1286 "An Act To Allow the Deposition of Oyster Shell Cultch To Ameliorate Ocean and Coastal Acidification" (HP0928) Proposed for future sessions.

The survival rate and settlement of shellfish among Maine's estuaries and coastal regions remains understudied. It is also difficult to isolate the effect of acidification among multiple stressors on shellfish populations and larval survival. However, it is not unlikely that the larvae of wild shellfish in the Gulf of Maine are exposed to harmful conditions of acidification. Routinely, conditions in Gulf of Maine estuaries cross thresholds for shellfish health identified in laboratory studies.

In 2019 the Department of Marine Resources and the Marine Resources committee heard L.D. 1286 "An Act To Allow the Deposition of Oyster Shell Cultch To Ameliorate Ocean and Coastal Acidification" (HP0928). The Bill was crafted by Representatives Mick Devin and Lydia Blume and by Parker Gassett from the Maine Ocean and Coastal Acidification Partnership.

The bill did not pass. However, the Marine Resources Committee voiced support for the concept of the legislation, stated that such activities are possible within the aquaculture leasing system and requested one additional year to consider the biohazard risk of introducing composted shell material into marine waters through the Maine Municipal Shell Recycling Program.

Research is being conducted by the Downeast Institute and by Bowdoin College, where investigations of the buffering effects of depositing shell into marine substrate is now incorporated into annual classroom curriculum. Michèle LaVigne and Elizabeth Halliday Walker have also collaborated with Manomet to incorporate shell buffering experiments into annual marine bio-geochemistry curriculum.

LARVAL SHELLFISH AND HATCHERIES

Shellfish hatcheries are major stakeholders for OCA and climate change. Larval shellfish, which are the focus of hatcheries, are significantly more vulnerable to OCA than juveniles or adults. There is a well established body of literature showing the detrimental and lethal effects of acidification on larval shellfish. It is increasingly common for hatcheries to monitor the seawater entering into their tank systems, and to avoid acidification by adding alkaline buffering material when the acidity of local seawater threatens the survival and health of juvenile shellfish. Thus, hatchery operations may be uniquely resilient to acidification once they are equipped with the ability to measure and augment water quality within hatchery flow-through water systems. Preventing the deleterious and lethal effects of acidification in this way is a critical adaptation.

Additionally, research by Bigelow Laboratory for Ocean Sciences, Casco Bay Estuary Partnership, Mook Sea Farm and EPA is exploring buffering within post hatchery oyster nursery upweller systems. These systems are designed for young oysters before being moved to baskets or bottom planting sites. Ground and crushed shell within these systems may act as an antacid for acidified coastal seawater. Because upweller systems pump seawater at a rate of many gallons per minute, buffering an open system may be unrealistic. Nonetheless, post hatchery upwellers are a method currently utilized by 22 commercial shellfish operations throughout the state, and further research and development supporting this emerging propagation technique is warranted.

Augmenting marine conditions for wild populations of shellfish is clearly a far greater challenge. If and when wild shellfish populations in certain locations are no longer self sustaining due to lethal effects of acidification, anoxia, or others stressors on larvae, hatcheries may play an increasingly important role in rearing shellfish species for both commercial and ecological applications. Habitat restoration and conservation may increasingly incorporate hatchery bred juveniles in re-establishing and supporting shellfish populations. As hatcheries in Maine are largely for-profit companies, it will be important to consider incentives and governance structures that can help operations further interface with conservation goals.

The Downeast Institute has been a public research hatchery since 2003, raising 10 species: soft- shell clam, razor clams, European and American oysters, quahogs, Arctic surf clams, Atlantic surf clams, sea scallops, mussels and lobsters. Mook Sea Farm on the Damariscotta River is the largest oyster hatchery in Maine, and is now experimenting with other bivalve species for aquaculture. Muscongus Bay Aquaculture rears oysters, hard clams (quahogs), and bay scallops. Running Tide Hatchery in Harpswell will soon produce oyster seed and may work with other species in the future. Facilities at the University of Maine's Darling Marine Center also include a hatchery for shellfish.

In many states there are established programs that rear young clams or other shellfish in hatcheries and then seed those shellfish in the wild to supplement natural populations. In Massachusetts these programs are supported by the revenue from recreational harvesting licenses.

Maine Sea Farms, Photo: Jaclyn Robidoux, Maine Sea Grant

SUBMERGED AQUATIC VEGETATION

There is growing interest in the ability of submerged aquatic vegetation (SAV) to locally ameliorate conditions of acidification and absorb nutrient pollution. Ongoing state priorities include mapping and protecting eelgrass habitat, and programs that support and provide education for seaweed aquaculture and growing seaweed with shellfish (multi-trophic aquaculture).

Research by Bigelow Laboratory, the Island Institute, and the University of New Hampshire, along with industry partner Atlantic Sea Farms (formerly Ocean Approved), observed a halo of less acidified ocean water within and nearby to kelp aquaculture in Casco Bay. Here, and also in the Damariscotta River, researchers deployed high-frequency OA monitoring sensors and collected nutrient water quality samples inside and outside of natural and aquaculture kelp beds. High resolution OA monitoring has also been conducted within eelgrass beds by Bigelow, the Nature Conservancy, and USGS.

Most seaweed species and eelgrass show accelerated growth in acidified conditions, as the CO_2 causing acidification fuels photosynthesis.

Studies conducted with the company Bangs Island Mussels also showed a measurable improvement in the health and hardness of mussel shells grown with kelp, translating to a more valuable product and more efficient commercial practice. This research, alongside an established archive of other studies and modeling, show the positive impact of photosynthesis on local conditions of acidification and measurable benefits of co-locating shellfish and macro-algae or seagrasses.

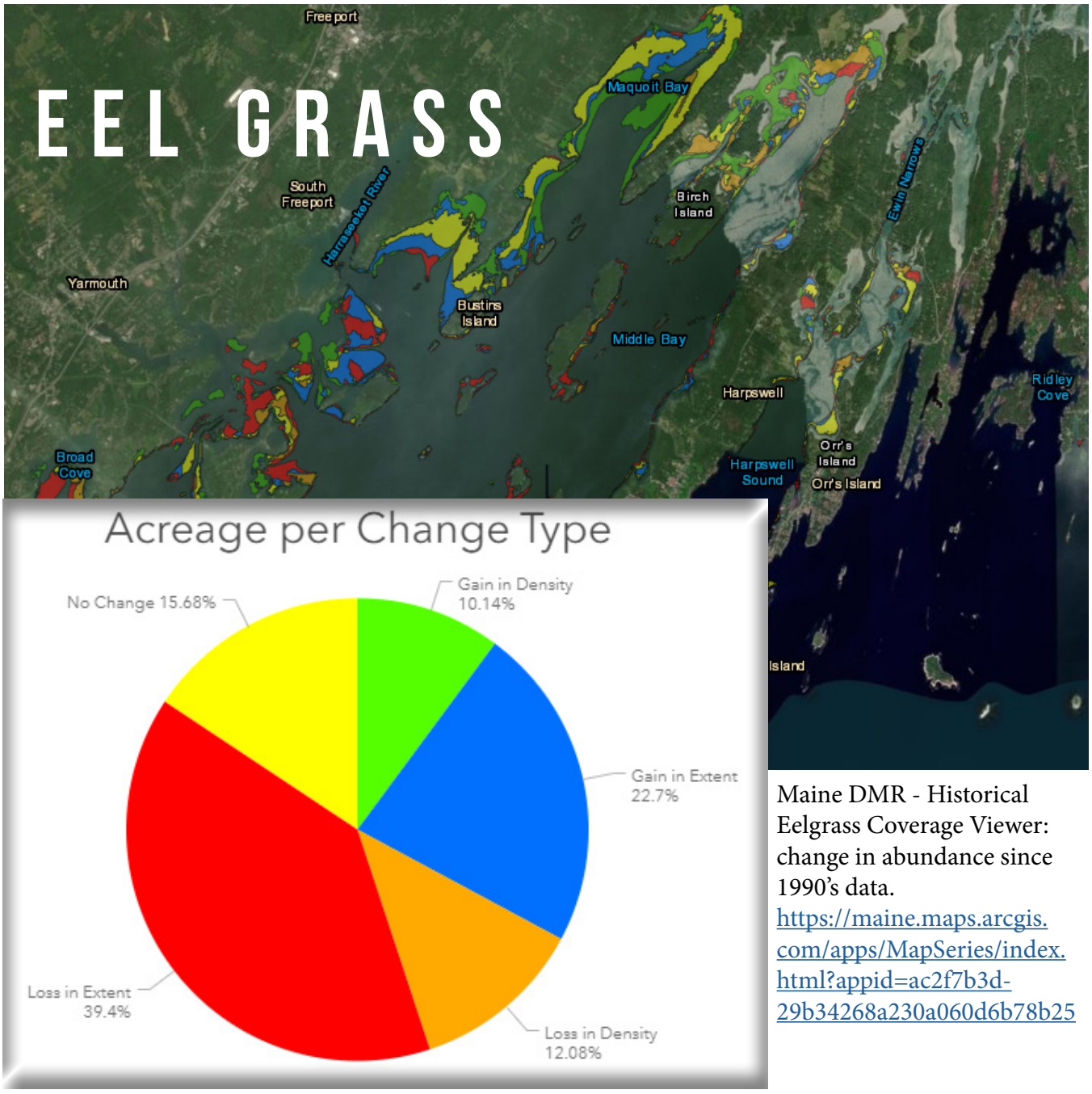
Further research is needed, along with strategic planning at the intersection of commercial activities, conservation, and strategies for carbon sequestration / "Blue Carbon".

SEAWEED INDUSTRY

Seaweed species are expected to thrive in the Gulf of Maine's predicted oceanographic changes and are a commercial product with growing market attention. Seaweed farms stand as a complementary strategy for improving water quality conditions for other organisms.

The seaweed industry has a growing market value, and there is a growing number of farmers and harvesters throughout the state. Commercial operations for wild harvested and aquaculture seaweeds are positioned to complement Maine's strategy for resilience to acidification. The Aquaculture Workforce Development Committee and a Seaweed Fisheries Advisory Council are positioned to consider and advise on this topic. Wild harvest and aquaculture seaweeds may function as additional tools for improving water quality. Incentives and training initiatives can help shellfish growers to explore growing seaweed, thereby improving environmental resilience through "multi-trophic" practices.

Educational programs and business development trainings for seaweed operations exist, linking partners including Maine Sea Grant, GMRI, Bigelow Laboratory, Island Institute and other organizations. Maine Sea Grant continues to expand the Aquaculture in Shared Waters training program. Bigelow Laboratories is developing a seaweed nursery and cryo-preservation services to support a heightened need from growers. GMRI provides support for aquaculture including the Farmed Shellfish Market Analysis, Aquaculture Top Gun Accelerator Program, the South Portland Pier Aquaculture & Fishing Needs Assessment, a commercial oyster demonstration-farm partnership, and are in the process of creating a workforce development strategy and a Maine Aquaculture Knowledge Portal.



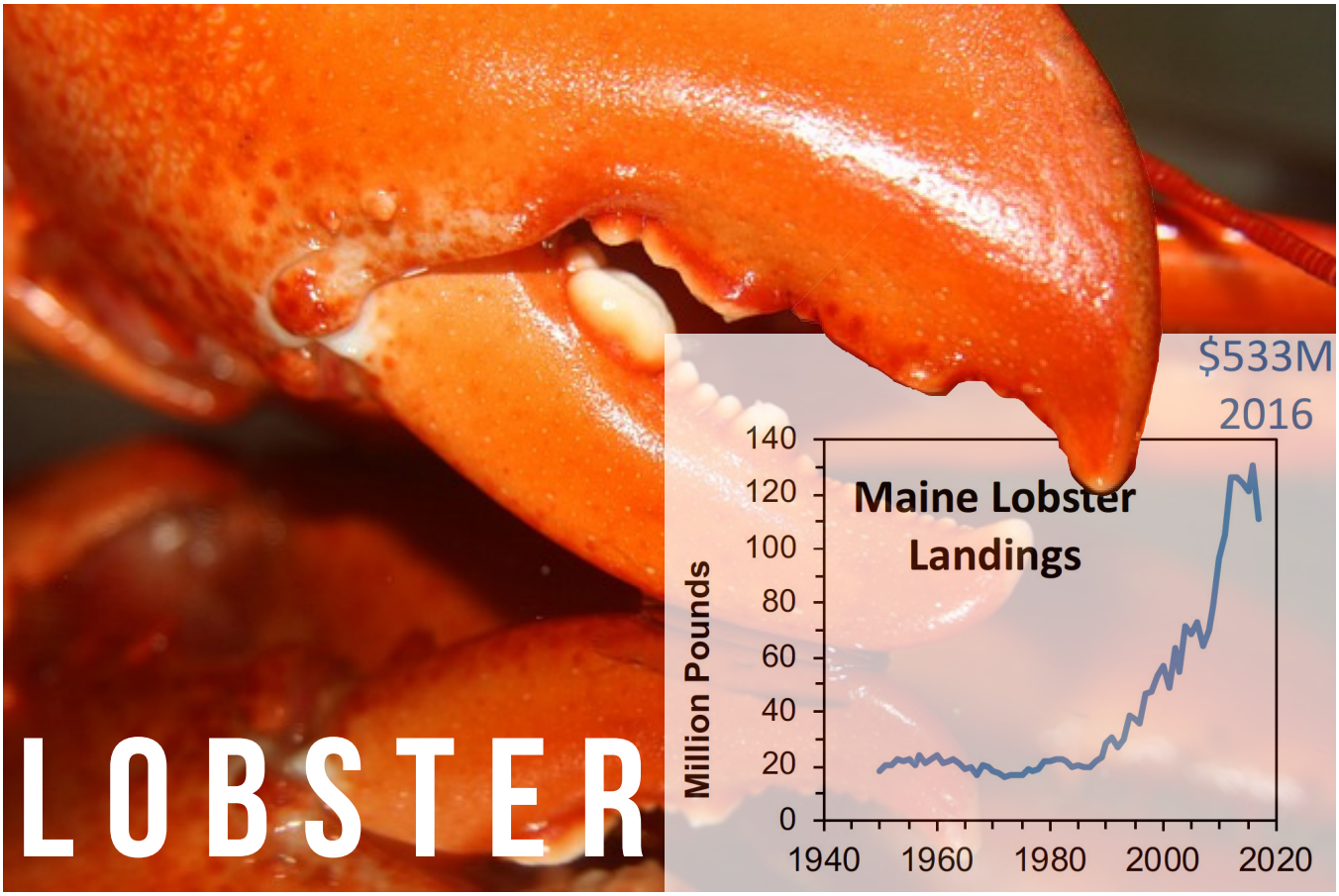
Maine DMR - Historical Eelgrass Coverage Viewer: change in abundance since 1990's data. https://maine.maps.arcgis.com/apps/MapSeries/index.html?appid=ac2f7b3d-29b34268a230a060d6b78b25

Eelgrass is a functional indicator for eutrophication and can be utilized to identify impairments and set nutrient permit limits. Eelgrass can augment benthic habitat and support rehabilitation of wild shellfish populations.

The Department of Environmental Protection has conducted mapping efforts focused on eelgrass distribution along areas of Maine's coast since 2013. DEP began long term monitoring in 2018 of three eelgrass beds in the vicinity of East End in Portland. DEP also assisted in 2019 with establishing a long term monitoring site in Portsmouth Harbor. The DEP seeks ongoing funding and support for monitoring of eelgrass in five coastal regions proposed on an annual, rotating basis (LD 559 in Maine Legislature carried over).

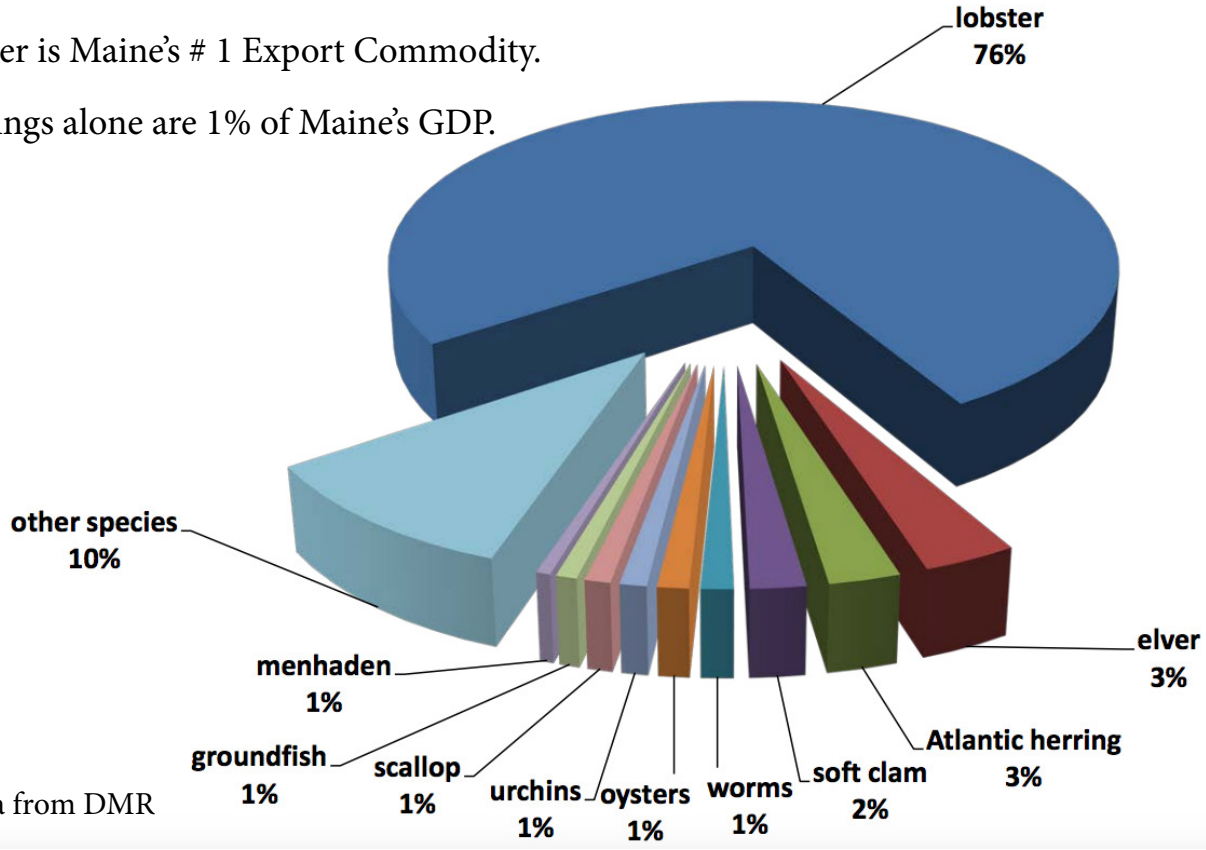
Dr. Hilary Neckles at USGS has researched eelgrass within Maquoit Bay and has studied restoration potential among planting methods.

Extensive research and habitat protection for eelgrass has also been carried out in Frenchmans Bay by the Mount Desert Island Biological Laboratory and their partners. This work includes the platform "Anecdata" for community scientists to contribute to eelgrass mapping efforts.



ME DMR

- Lobster is the most valuable single species fishery in U.S. & Canada.
- 90% of the US share from the Gulf of Maine.
- 80% of U.S. share from Maine.
- Lobster is Maine's # 1 Export Commodity.
- Landings alone are 1% of Maine's GDP.



2018 Data from DMR

CLIMATE CHANGE AND EFFECTS ON LOBSTER

Lobster demographics appear to be largely temperature driven, correlating with Gulf of Maine lobster's shift to deeper and more northerly waters. This transition has had and will continue to have profound effects on fisheries and ports-of-sale along Maine's Coast. The connectivity between deep water habitats and near shore reproductivity is not yet well understood within the context of changing environmental conditions in the Gulf of Maine. The reliance of Maine's fisheries portfolio on lobster stresses the importance of understanding population dynamics and responses to environmental change.

Experts appear to agree that Maine's Lobster population is not significantly effected by acidification at present conditions. However, there exists only preliminary research on the combined effects of acidification and warming temperatures on lobsters among their multiple life stages. This research includes rates of survival, performance and gene expression among various common and predicted oceanic conditions. Waller et al. (2016) showed that higher temperature and higher partial pressure of CO_2 (pCO_2) stressed larvae and post-larvae American Lobsters (*Homarus americanus*), elevating respiration rate and expediting growth for some larvae while limiting overall survival. A study on the European Lobster (*Homarus gammarus*) showed that temperature and pCO_2 levels predicted for mid-century, caused deformities in juveniles. Keppel et al. (2012) showed that oceanic conditions predicted for 2100 led to significantly slowed American lobster development through all stages of molting, stunted growth rates, shortened overall size, and increased mortality. A relationship between acidification and shell disease has been posited and remains understudied.

Dr. Rick Wahle is now the director for the Lobster Institute, which is the University of Maine's center for information and opportunities for lobster research. The institute is positioned to contribute to our understanding of lobster and environmental change, and works with a variety of partners from industry associations, the management sector and research scientists. The Department of Marine Resources furthermore has prioritized positions for lobster biology for 15 years, and staff scientist Jessica Waller has research experience on the impacts of climate change and OCA on lobster.

Near future priorities include equipping lobster boats or lobster ports-of-sale with monitoring equipment for acidification and marine climate change (initiated by the Lobster Institute); to further investigate the ecological pressures of environmental change (near-shore and offshore) on lobster populations; and work to diversify Maine's fisheries landing values to ensure economic prosperity if lobster landings subside.

Climate change assessments have documented species range shifts, including lobsters, and forecasting work is underway to anticipate transitions in the available fisheries among Gulf of Maine fishing ports. GMRI has conducted work to analyze how species available to fishing ports may change as waters warm. This research evaluates the vulnerability of fishing communities to these changes and identifies effective adaptation strategies for responding to species shifts. Many researchers have focused on the opportunities to diversify landings and fisheries revenue, improve permitting and licensing processes, and provide training and support for the industry.

2014-2018
CLIMATE/LOBSTER RESEARCH
(UNIVERSITY OF MAINE)

FY	UM Investigators	Climate Related Projects	Sponsor	Award Amt
2014	Anderson	Collaborative Research: Strengthening the scientific basis for decision-making: Advancing knowledge-action capacities in a coupled coastal-inland system	NSF	$120,000
	Chen, Thomas, Wahle	Coastal SEES (Track 2), Collaborative Research: resilience and adaptation of a coastal ecological-economic system in response to increasing temperature	NSF	$139,713
	Hamlin, Bricknell, Bayer, Bouchard	The effects of regional temperature cycles on the development and disease susceptibility of the American lobster (Homarus americanus)	NOAA-SK	$249,516
2015	Anderson, Brady, Bricknell, Hamlin, Bouchard	Maine EPSCoR: The Nexus of Coastal Marine Social8Environmental Systems and Sustainable Ecological Aquaculture	NSF	$600,000
	Wahle	Using the American Lobster Settlement Index and Environmental Indicators in Fishery Forecasting and Stock Assessment	NOAA-FATE	$134,827
2016	Bouchard, Hamlin, MacRae, Bayer	Understanding the effects of changing ocean ecosystems on lobster health and susceptible to disease in the context of rising water temperatures	ME DMR	$127,482
2017	Wahle	Assessing the impact of environmental change on the recruitment of lobsters off southeastern New England	NOAA-SK	$48,356
	Leslie, Stoll, Anderson, Wilson	Assessing the potential for sustainability of fishing-dependent communities in coastal Maine in the face of environmental and socioeconomic change	NOAA	$275,308
	Wahle	Genetic and phenotypic response of larval American lobster to ocean warming and acidification across New England's steep thermal gradient	NOAA-OA Program & Sea Grant	$153,099
	Wahle	Revealing deepwater lobster settlement across thermal gradients in the Gulf of Maine	NOAA-Sea Grant	$82,337
	Wahle	Supporting decision-making under climate variability and change: multi-scale forecasts and analyses for the Maine lobster fishery	NOAA - SK	$58,053
2018	Chen	Incorporating Environmental Variables to Improve Assessment and Predictive Capacity for American Lobster in a Changing Gulf of Maine and Southern New England	NOAA	$173,287
	Wahle	Do small female lobsters produce low quality eggs?	NOAA-SK	$59,711
	Wahle	Bridging the spawner-recruit disconnect: Investigating linkages between larval lobster and the pelagic food web.	ME DMR	$40,000
			Total	**$2,261,689**

EDUCATION AND OUTREACH

There is now a decade of developed curriculum and outreach for schools, the public, and decision-maker audiences regarding OCA. The majority of these materials, graphics, and data visualizations concern the global phenomena of ocean acidification. To a lesser degree there are education and outreach materials and efforts that target coastal processes and local resilience.

Most outreach content focuses on:

- The global rise of CO_2, its chemical interaction with seawater, and ocean current driven sources of acidified ocean water;
- The role of eutrophication in causing short term coastal acidification events linked with hypoxia;
- The influence of low alkalinity river water and groundwater and of precipitation events that reduce the buffering capacity of a marine environment to resist acidification;
- The influence of tides in estuarine chemistry and the balance of photosynthesis and respiration on pH and alkalinity in estuaries and embayments.

These biogeochemical processes then link to education and outreach surrounding

- Ecosystem responses to acidification;
- The impact on commercial species and the delivery of ecosystem services from coastal and open ocean environments;
- Opportunities for decision-making, civic engagement, and adaptation to face these challenges.

The Northeast Coastal Acidification Network is the most developed clearinghouse of information and activities surrounding outreach and education for ocean and coastal acidification in the Gulf of Maine. The NECAN.org web-page has a considerable collection of publications and reference materials arranged by topic. NECAN facilitates an outreach and education working group that has curated the best available outreach materials for non-scientist audiences. NECAN's effort and related training series for Shell Day engaged water quality monitoring programs and stakeholders. Resources from this outreach effort can be found at NECAN.org/OCACitizenScienceWorkshops and NECAN.org/shellday.

The Ocean Acidification Information Exchange (oainfoexchange.org) is an online hub for discussion and information sharing around ocean and coastal acidification. This forum has established topic specific dialogue involving scientists, resource managers and educators from around the world.

Most member organizations with the Maine Ocean and Coastal Acidification Partnership are involved with marine climate change and ocean and coastal acidification education and outreach.

- MOCA has held 6 symposia, disseminated seasonal newsletters and email updates to a community of over 200 subscribers in Maine. MOCA supported outreach to legislators in Nov. 2019 which led to Representative Lydia Blume's Marine Advisory Council Bill incorporated into the passage of the Governor's Climate Council Bill.

- At Bigelow Laboratory for Ocean Sciences Ocean Acidification is a focus of the Bigelow Research Experience for Undergraduates program, the Keller Bigelow Orders Of Magnitude (BLOOM) high school program, the BLOOM middle school teacher education program, and the Colby Semester Program. The Boothbay Sea and Science Center and Edgecomb Eddy School both visit Bigelow to learn about ocean acidification, grow seaweed and test the Seaweed OA remediation 'halo' theory in classrooms.

- The Island Institute and Bigelow are engaged in regular outreach efforts sharing findings from their OA remediation research to audiences including the Island Institute's Aquaculture Business Development program, decision-makers, students and the public.

- The Down East Institute has been providing experiential, hands-on science and math education to kindergarten-12th grade students since 2011. Many local schools attend Marine Science Days on an ongoing basis. DEI also hosts a Coastal Science Academy for teachers and Marine Science Summer Camps. This program has generated data on clam growth and survival 2010 in Downeast ME.

- Meredith White from Mook Sea Farm and MOCA joined "Maine Calling" on Maine Public radio on July 15, 2019 to discuss the impacts of climate change on marine industries.

- The Town of Brunswick Marine Resources Officers present on OA annually to students at the Junior High School.

- The Casco Bay Nutrient Council has reviewed existing outreach and education programs, including programs specifically targeting behavior change for coastal landowners.

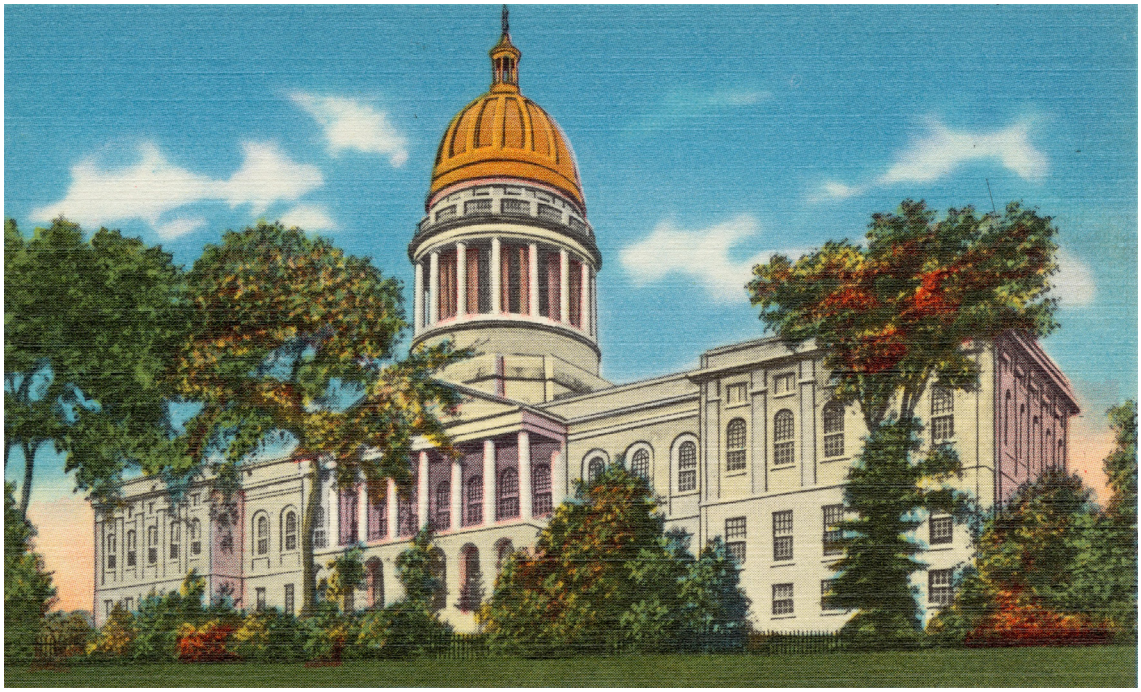
- Friends of Casco Bay upholds a variety of education and outreach efforts for ocean and Coastal Acidification. These include:
    - Revamped BayScaping program to better educate the public regarding how nitrogen fertilizers impact OCA and ocean health.

    - Web pages to share OCA data that are updated on a monthly basis.

    - Hosted the Casco Bay Matters lecture series on impacts of climate change.

    - Revised curricula on the impacts of climate change for grades 3-8 and hosted a teacher training on OCA and climate change.

    - Launched Water Reporter observing network in 2018 to engage the public in reporting algal blooms, sea level rise, storm surge, and other indices of climate change and began using the Water Reporter to develop a volunteer network of observers documenting impacts of climate change.



POLITICAL ENGAGEMENT

Climatic condition assessments and forecasts from the Gulf of Maine Research Institute were included as evidence in the most recent National Climate Assessment report to demonstrate the ecological benefits of reducing CO_2 emissions. Many scientists and industry representatives engaging with the Maine Ocean and Coastal Acidification Partnership are actively involved in state and federal policy around OA and climate change. GMRI, Bigelow Labs, Mook SeaFarm, University of Maine, University of New Hampshire, The Ocean Conservancy, The Nature Conservancy, and others have each been involved with proceedings on Capitol Hill on behalf of legislation for ocean acidification and climate change in the Gulf of Maine. Focus areas include support for NOAA and EPA budgets for work on acidification and climate change, support for legislation that funds and informs state and local efforts to address OCA and climate change in marine environments, and opposition to roll backs in federal environmental laws. For example, the Casco Bay Estuary Partnership holds annual meetings with congressional delegation, which have highlighted work on coastal acidification and nutrient pollution.

Legislators Mick Devin and Lydia Blume sit on the MOCA advisory committee as well as the director of the Environmental Assessment Division at the Department of Environmental Protection, Don Witherill. Many other MOCA partners routinely interface with State government and have been involved in crafting prior legislation including Representative Lydia Blume's bill that was enveloped by the Governors Climate Council Bill.

ENERGY POLICY AND EMISSIONS REDUCTIONS

Many of the individual stakeholders involved with MOCA as well as the organizations interacting with state level preparedness for OCA are also strong supporters of smart growth and clean energy for Maine and the region. Multiple environmental stewardship organizations joining MOCA because of their involvement in water quality monitoring have also acted as guiding institutions for local solar energy efforts and other clean energy work within their communities. A subset of MOCA participants and fishermen working with the Island Institute have actively supported pursuits including the Regional Greenhouse Gas Initiative (RGGI) and the Energy Pathway for Maine. It is clear that comprehensive national and global progress for OCA envelopes broad pursuits for carbon emissions reductions, increased carbon sequestration and blue carbon initiatives. Because the Maine Climate Council is ambitiously preparing for these steps, it is not a primary focus of this report.

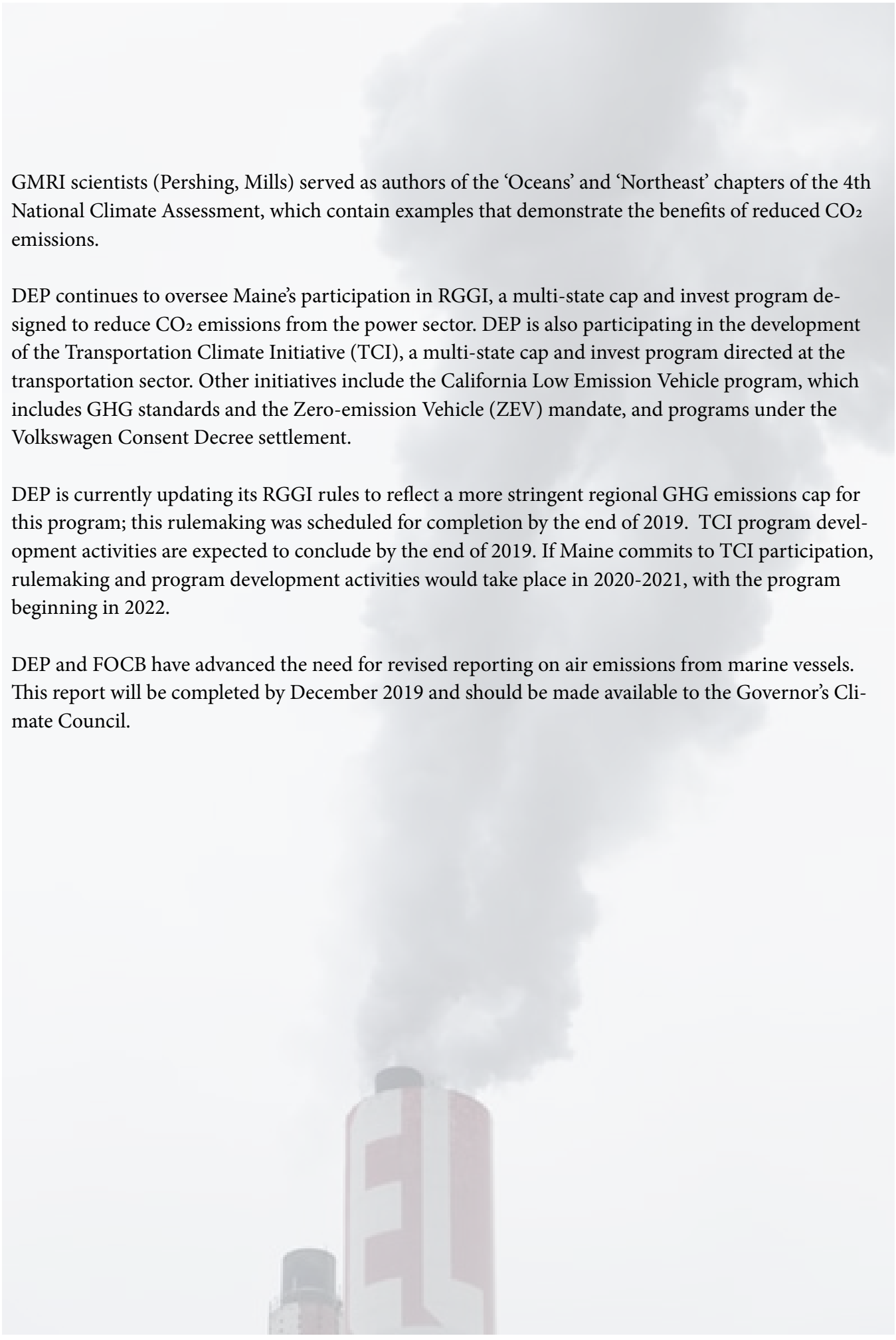
Maine meteorological assessments do identify consistent seasonal patterns of atmospheric CO_2 levels that affect the level of dissolved CO_2 and acidification in marine waters. Though emissions reductions remain imperative, the effect of reducing Maine's CO_2 emissions on localized acidification processes has not yet been well studied. The past impact of airborne acidic pollution from coal burning states to the southwest of Maine and the funneling atmospheric pattern of North America's Jet Stream has been well documented leading to acidification in Northeast freshwater lakes and streams. These stressors may continue to contribute to the acidity of water that runs out of Maine's tributaries. Sulfur dioxide and nitrogen oxides are the components of acid rain that combine in Maine with the effects of rainwater's natural acidity and the predominantly acidic nature of Maine's granitic watershed geology and prevailing conifer forests.

GMRI scientists (Pershing, Mills) served as authors of the 'Oceans' and 'Northeast' chapters of the 4th National Climate Assessment, which contain examples that demonstrate the benefits of reduced CO_2 emissions.

DEP continues to oversee Maine's participation in RGGI, a multi-state cap and invest program designed to reduce CO_2 emissions from the power sector. DEP is also participating in the development of the Transportation Climate Initiative (TCI), a multi-state cap and invest program directed at the transportation sector. Other initiatives include the California Low Emission Vehicle program, which includes GHG standards and the Zero-emission Vehicle (ZEV) mandate, and programs under the Volkswagen Consent Decree settlement.

DEP is currently updating its RGGI rules to reflect a more stringent regional GHG emissions cap for this program; this rulemaking was scheduled for completion by the end of 2019. TCI program development activities are expected to conclude by the end of 2019. If Maine commits to TCI participation, rulemaking and program development activities would take place in 2020-2021, with the program beginning in 2022.

DEP and FOCB have advanced the need for revised reporting on air emissions from marine vessels. This report will be completed by December 2019 and should be made available to the Governor's Climate Council.



PERTINENT FEDERAL LEGISLATION

- Following the widespread death of larval shellfish that nearly bankrupted hatcheries in the Pacific Northwest in the mid-2000s because of ocean acidification, Congress took action to better understand the impact of ocean acidification on people and marine resources by passing the Federal Ocean Acidification Research and Monitoring Act. This federal law created the NOAA Ocean Acidification Program and provides for a coordinated response by federal agencies to understand, track, and address ocean acidification.

- H.R. 1237, the "COAST Research Act of 2019." The Coast Research Act reauthorizes this federal law and broadens the scope of work on ocean acidification to better understand the effects of acidification not only in the open ocean but also in the coastal zone.

- H.R. 1921, the "Ocean Acidification Innovation Act of 2019" The Ocean Acidification Innovation Act of 2019 would allow several federal agencies to establish competitions to award prizes for innovations that would advance our nation's ability to understand, research, monitor or adapt to ocean acidification.

- H.R. 1716, the "Coastal Communities Ocean Acidification Act of 2019". HR 1716 directs NOAA to examine the socioeconomic impacts of acidification on coastal communities. Coastal communities are on the frontlines of experiencing the effects of ocean acidification, and many are already seeing the impacts. As a result, it is important that federal research and monitoring respond to the needs of these communities. This bill codifies that the federal government should assess the needs of coastal communities vulnerable to ocean acidification and ensure that federal research and monitoring plans are influenced by those needs assessments.

- H.R. 988, the "NEAR Act of 2019" Healthy estuaries are a critical economic and recreational driver in coastal communities across the country. However, because acidification often interacts with other coastal processes, like runoff, erosion and upwelled water from the ocean, it is difficult to measure its individual impact in estuarine environments. The NEAR Act of 2019 would authorize the National Academies of Science to examine the impact of ocean acidification and other stressors on American estuaries and near-shore waters.