FEBRUARY 9, 2021

REPORT ON THE OCEAN ACIDIFICATION CRISIS IN MASSACHUSETTS

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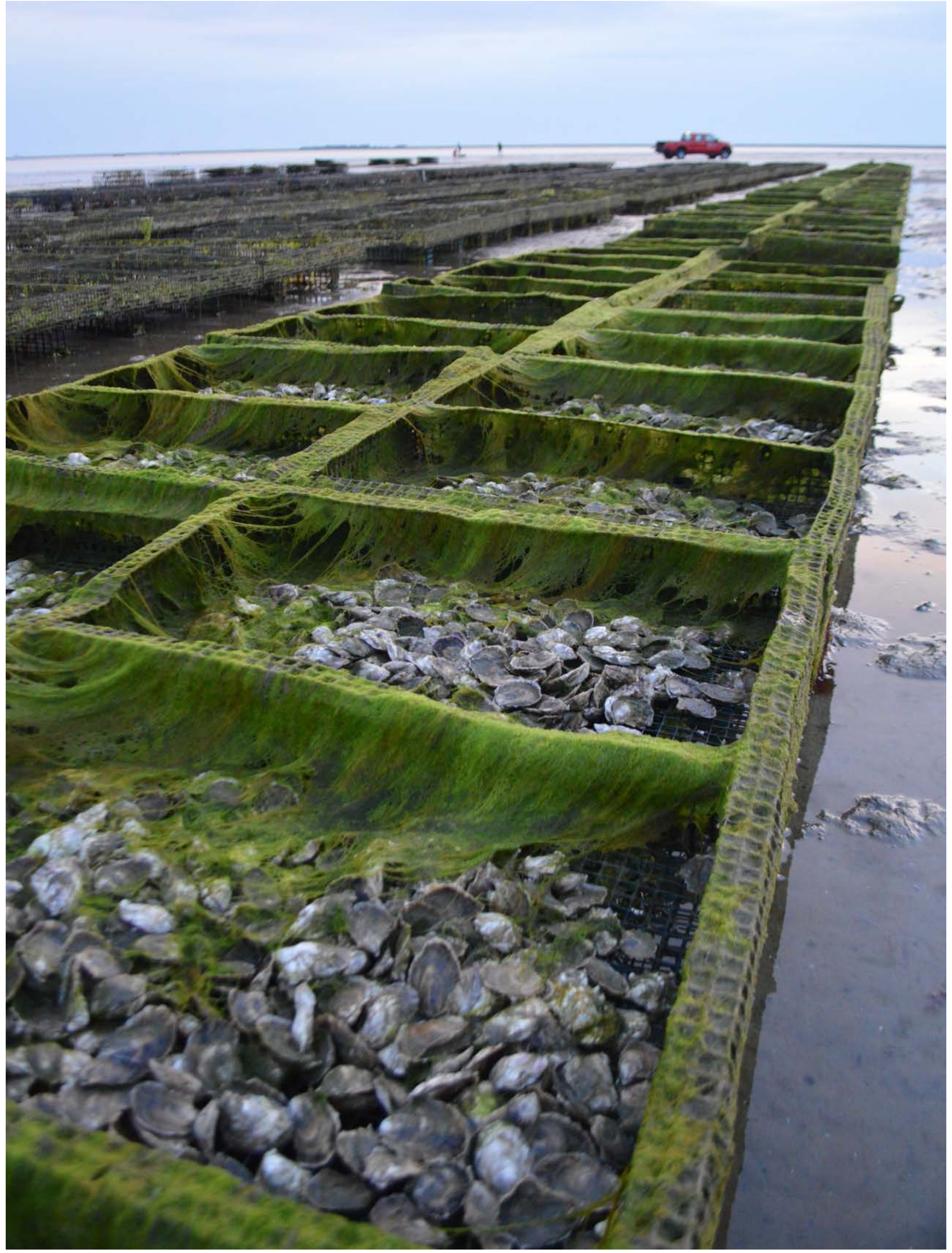
EXECUTIVE SUMMARY

- Since the industrial revolution, the world's oceans have become increasingly acidic. The main drivers of ocean acidification in Massachusetts are (1) global increases in atmospheric carbon dioxide resulting from anthropogenic emissions, and (2) local nutrient pollution leading to the eutrophication of coastal waters.

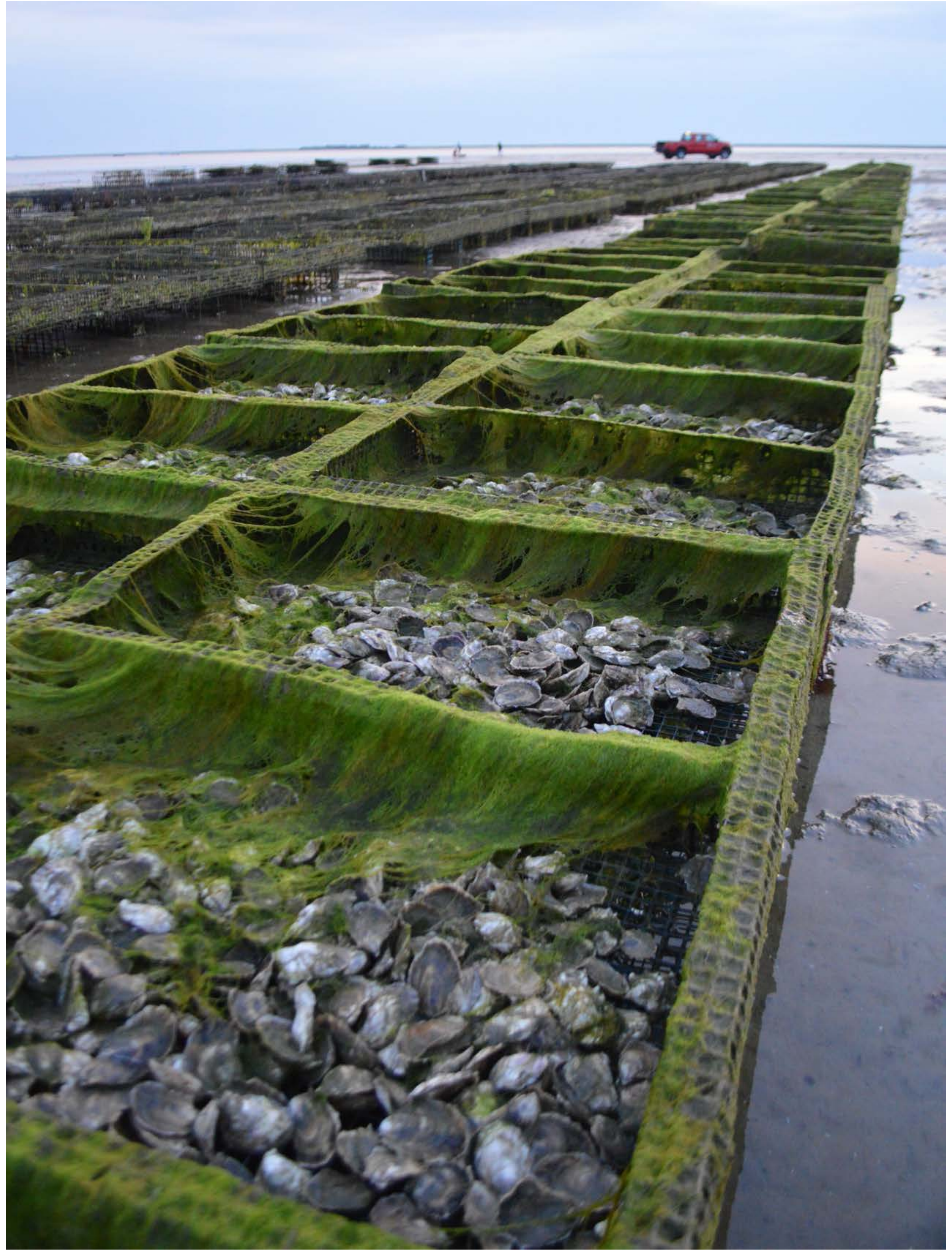
- Many marine species that evolved under less acidic conditions are threatened by ocean acidification, including some that are critical to the Massachusetts economy. Species that are both economically important and vulnerable to acidification include mollusks such as the sea scallop and eastern oyster.

- Massachusetts will be disproportionately affected by ocean acidification due to the relative importance of its coastal economies and environments.



EXECUTIVE SUMMARY

- **In order to mitigate and adapt to ocean acidification, this commission has composed a series of recommendations aiming to:**
    1. Fund research into the economic and ecological effects of acidification.
    2. Develop a set of best practices for shellfishing and marine industries in Massachusetts.
    3. Improve acidification monitoring along the coastline.
    4. Update nutrient pollution regulations to reflect the impact of acidification due to eutrophication.
    5. Implement updated pollution standards through upgrades to publicly-owned treatment works and septic systems, and through the restoration of coastal wetlands.
    6. Further incentivize the adoption of green infrastructure through the creation of the Blue Communities Program.
    7. Update legislative and executive language in order to acknowledge the effects of human activity on ocean acidification.
    8. Engage the general public in ocean acidification mitigation and research efforts, and join the International Alliance to Combat Ocean Acidification.
    9. Create a permanent ocean acidification council and adaptive fund to support the recommendations outlined above.



OVERVIEW OF THE OCEAN ACIDIFICATION CRISIS

AS ATMOSPHERIC CO_2 INCREASES, THE WORLD'S OCEANS BECOME MORE ACIDIC

- The world's oceans have absorbed as much as 30% of the carbon dioxide (CO_2) generated by human activity.
- As dissolved CO_2 increases, oceans become more acidic (pH decreases). Carbonate ions (CO_3^{2-}), which are needed to form shells, also decrease in concentration.
- **Without intervention, average concentrations of hydrogen ions in the world's oceans (indicating acidity) could increase by 114% by the year 2100[1].**
- The ocean's capacity to buffer CO_2 could decrease by 34% by 2100[1].

As atmospheric CO_2 has increased over time, ocean pH has decreased

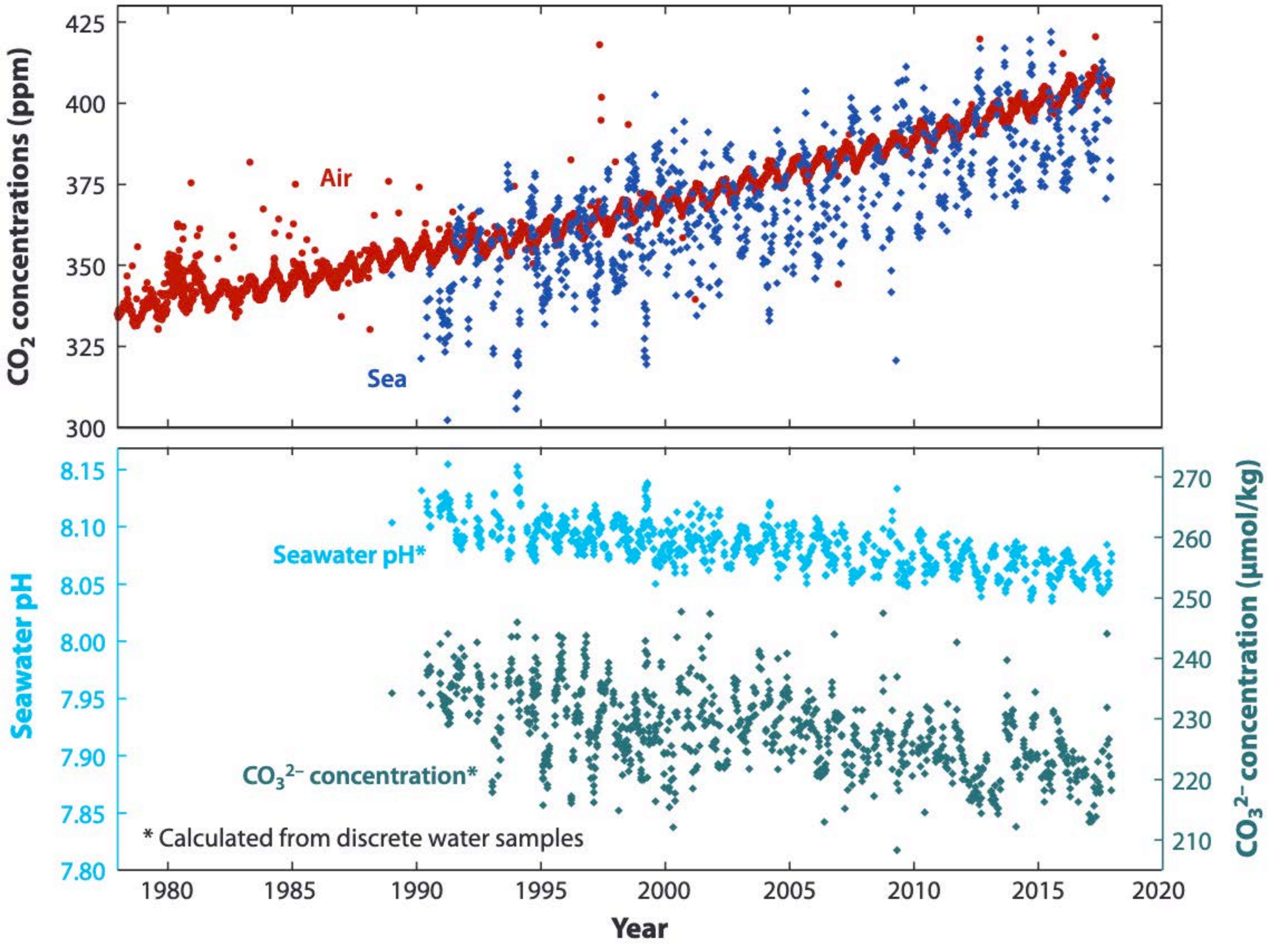
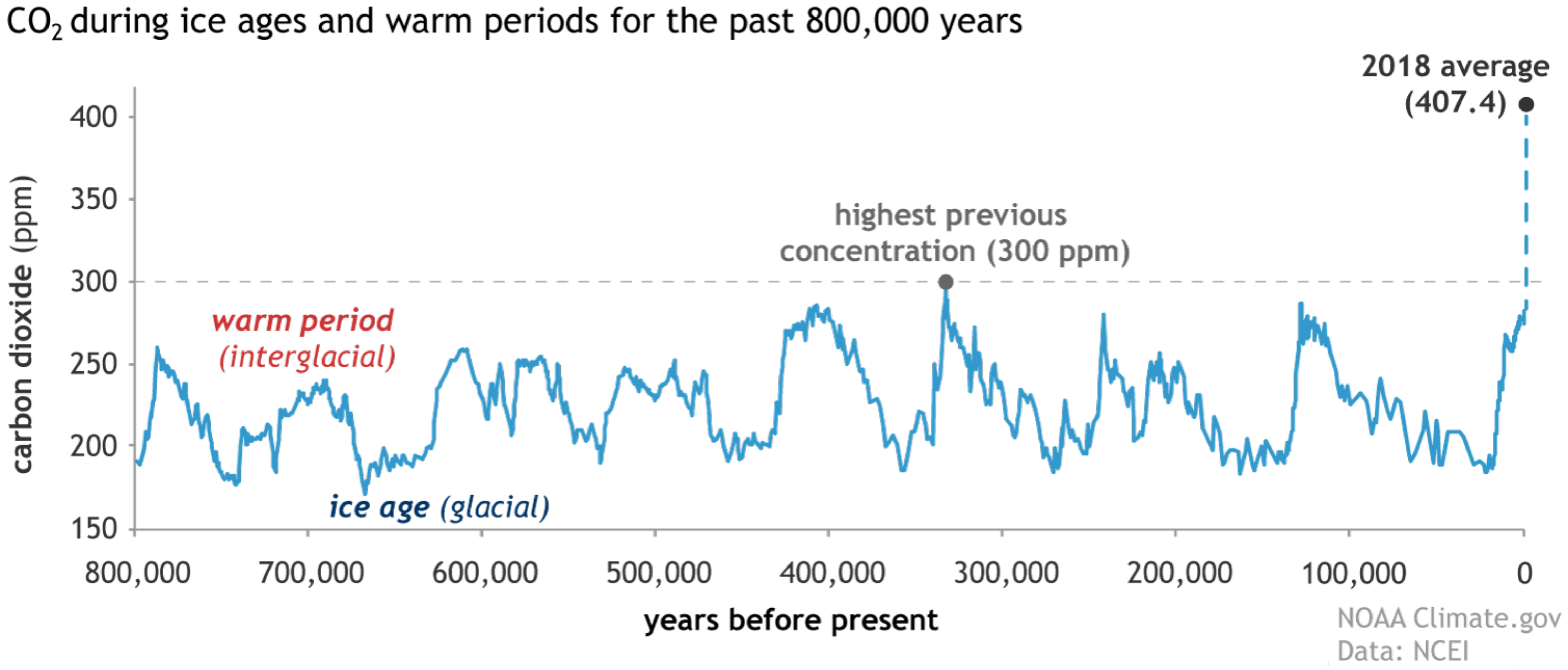


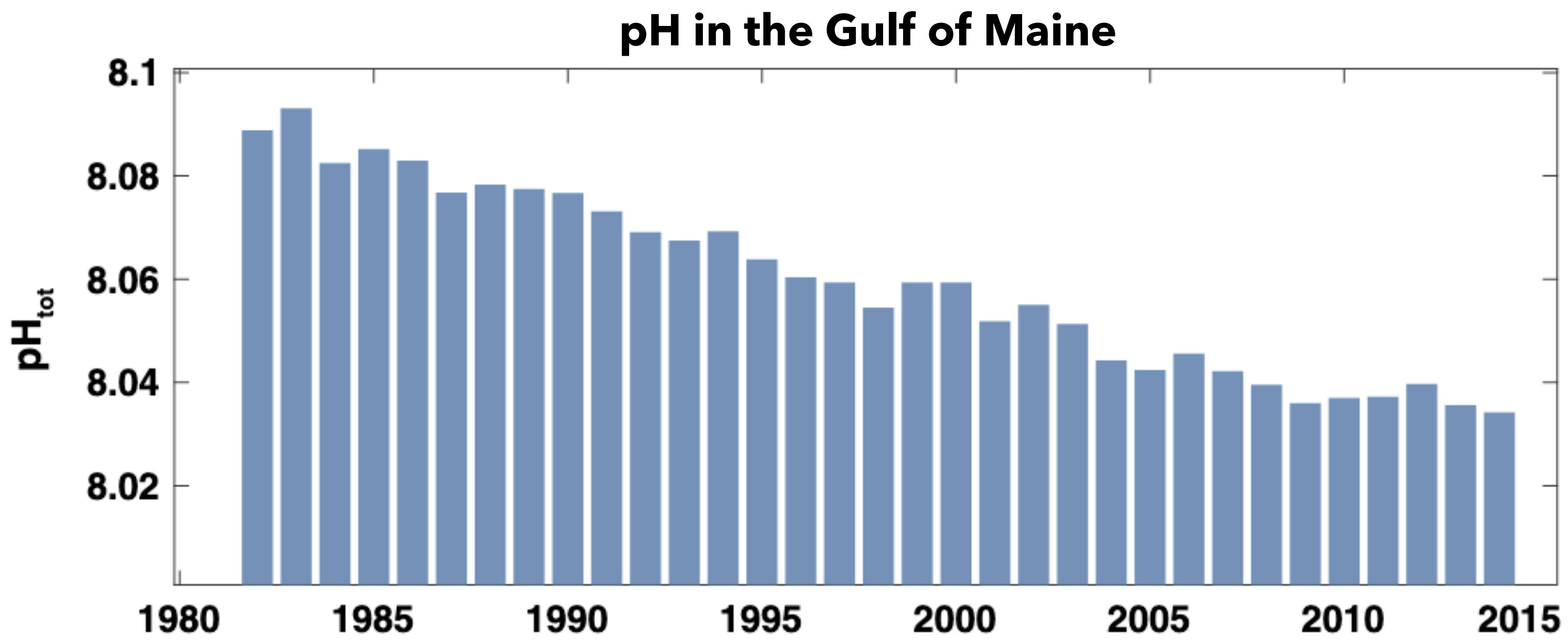
Figure adapted from Doney *et al.*, 2020. Data collected from the Hawaii Ocean Time Series Program.

[1] Jiang *et al.*, 2019. *Surface ocean pH and buffer capacity: past, present, and future.*

THE OCEAN HAS BEEN RAPIDLY ACIDIFYING SINCE THE INDUSTRIAL REVOLUTION

- The increase in atmospheric carbon dioxide that the world is currently experiencing is unprecedented in recent history. In the mid-1700s, the concentration of atmospheric CO_2 was approximately 280 parts per million (ppm). **Today, the concentration of atmospheric CO_2 is 411 ppm. This change represents a 47% increase in CO_2 concentration.**
- The pH of the ocean has been dropping since the industrial revolution. In the mid-1700s, the ocean's average pH is estimated to have been approximately 8.2 pH units. **Today, the ocean's average pH is approximately 8.1 pH units. This change represents a 30% increase in hydrogen ion concentration.**
- In the Gulf of Maine, pH has been steadily declining since measurements began in 1980.





Top figure adapted from NOAA climate.gov.
Bottom figure adapted from Salisbury and Johnson, 2018. *Rapid warming and salinity changes in the Gulf of Maine alter surface ocean carbonate parameters and hide ocean acidification.*

ACIDIFICATION LEADS TO A DEPLETION OF CARBONATE IONS IN THE OCEAN

- When carbon dioxide dissolves in the ocean, it reacts with water to form carbonic acid. Carbonic acid dissociates into bicarbonate and hydrogen ions.
- Hydrogen ions react with carbonate ions to form bicarbonate, which reduces the availability of carbonate ions for shell-forming organisms.
- The protective exteriors of shellfish and lobsters are composed of calcium carbonate. The most soluble form of calcium carbonate is aragonite, which is formed by corals and the early larval stages of mollusks.
- Aragonite saturation state is represented by Ω_{ar}. When Ω_{ar} drops below 1.5, shells are unable to form properly. When Ω_{ar} drops below 1, shells actively dissolve.
- **The more carbon dioxide is dissolved in the ocean, the more carbonate ions are converted into bicarbonate, and the more difficult it is for shells to form.** This process is not uniform and is strongly dependent on temperature and salinity.

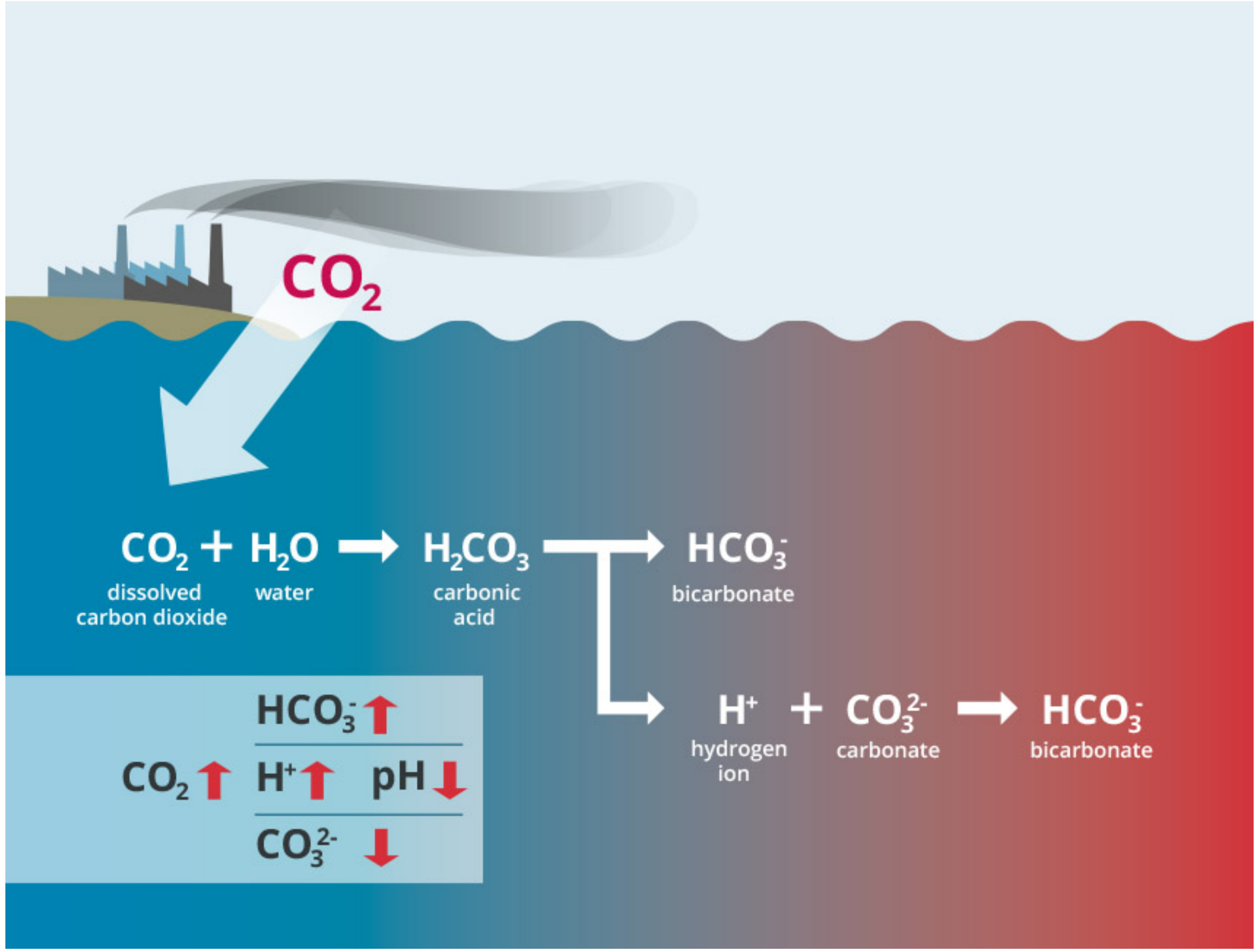


Figure adapted from Biological Impacts of Ocean Acidification (BIOCAD): https://www.oceanacidification.de/ocean-acidification/?lang=en

MARINE SPECIES WITH CALCIUM CARBONATE SHELLS ARE ESPECIALLY SENSITIVE TO ACIDIFICATION

- As carbonate ions become less accessible, the shells of oysters and lobsters become smaller and weaker. These changes reduce larval survival rates and increase risk of predation and shell breakage.
- All other shellfish are similarly affected, including those at the base of the food web such as pteropods.
- Shell formation is also impeded by rising ocean temperatures(1).
- **The shellfishing industry in the United States is expected to lose more than $400 million annually by 2100 as a result of ocean acidification.** Global losses are estimated at $6-100 billion(2).

Eastern Oyster shell size and thickness decrease as CO_2 concentrations increase

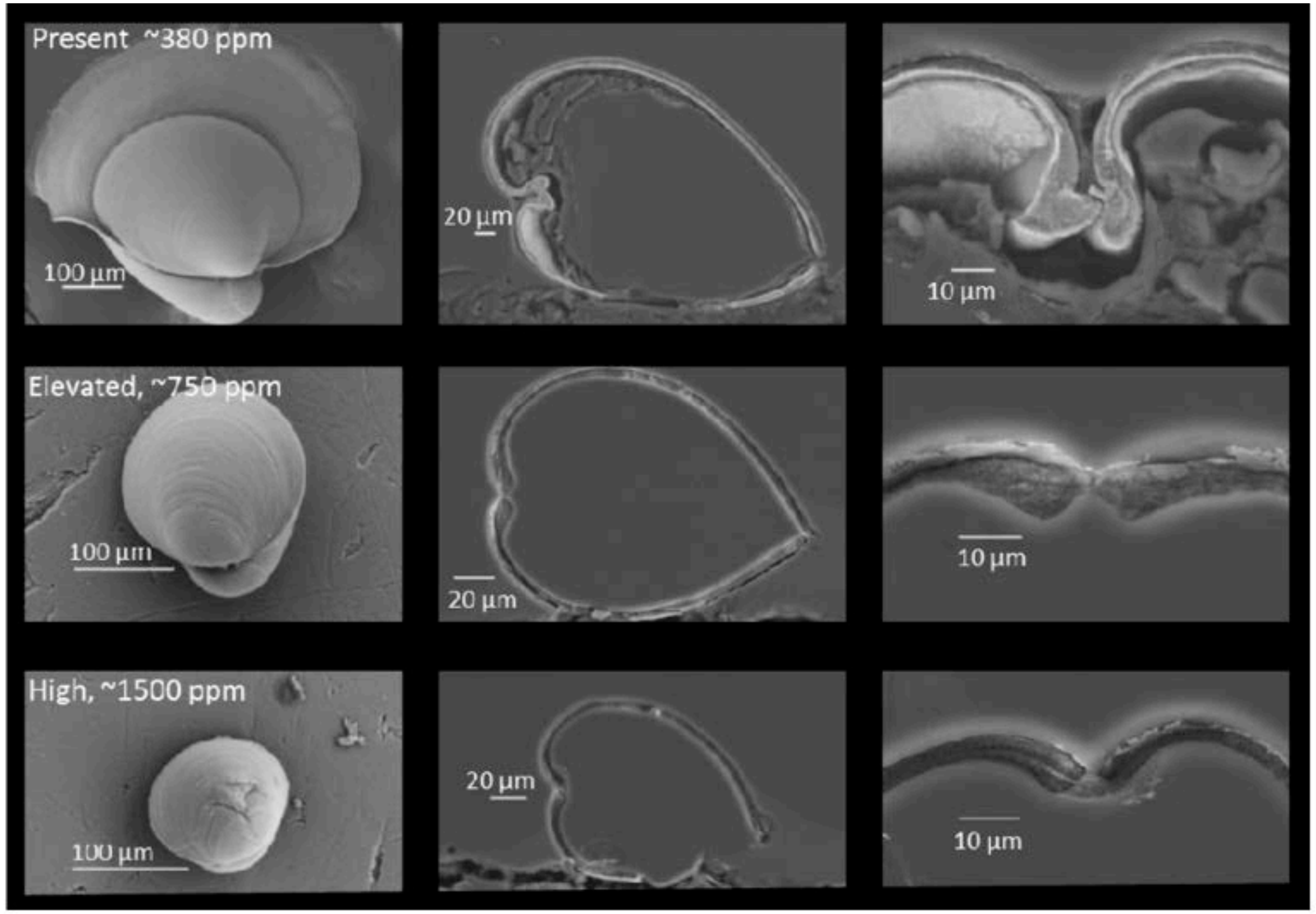


Figure adapted from Gobler and Talmage, 2014. *Physiological response and resilience of early life-stage Eastern oysters (Crassostrea virginica) to past, present and future ocean acidification.*

[1] Mackenzie et al., 2014. *Ocean Warming, More than Acidification, Reduces Shell Strength in a commercial Shellfishing Species During Food Limitation*

[2] Doney et al., 2020. *The Impacts of Ocean Acidification on Marine Ecosystems and Reliant Human Communities*

OCEAN pH FLUCTUATES NATURALLY OVER THE COURSE OF THE YEAR

- pH fluctuates seasonally, with coastal waters becoming more acidic during the winter. This is largely due to CO_2 dissolving more easily in colder water.
- **By 2100, the average temperature of the world's oceans may increase by 1-4° Celsius(1). The ocean's capacity to buffer CO_2 will decrease as water temperature continues to rise.**

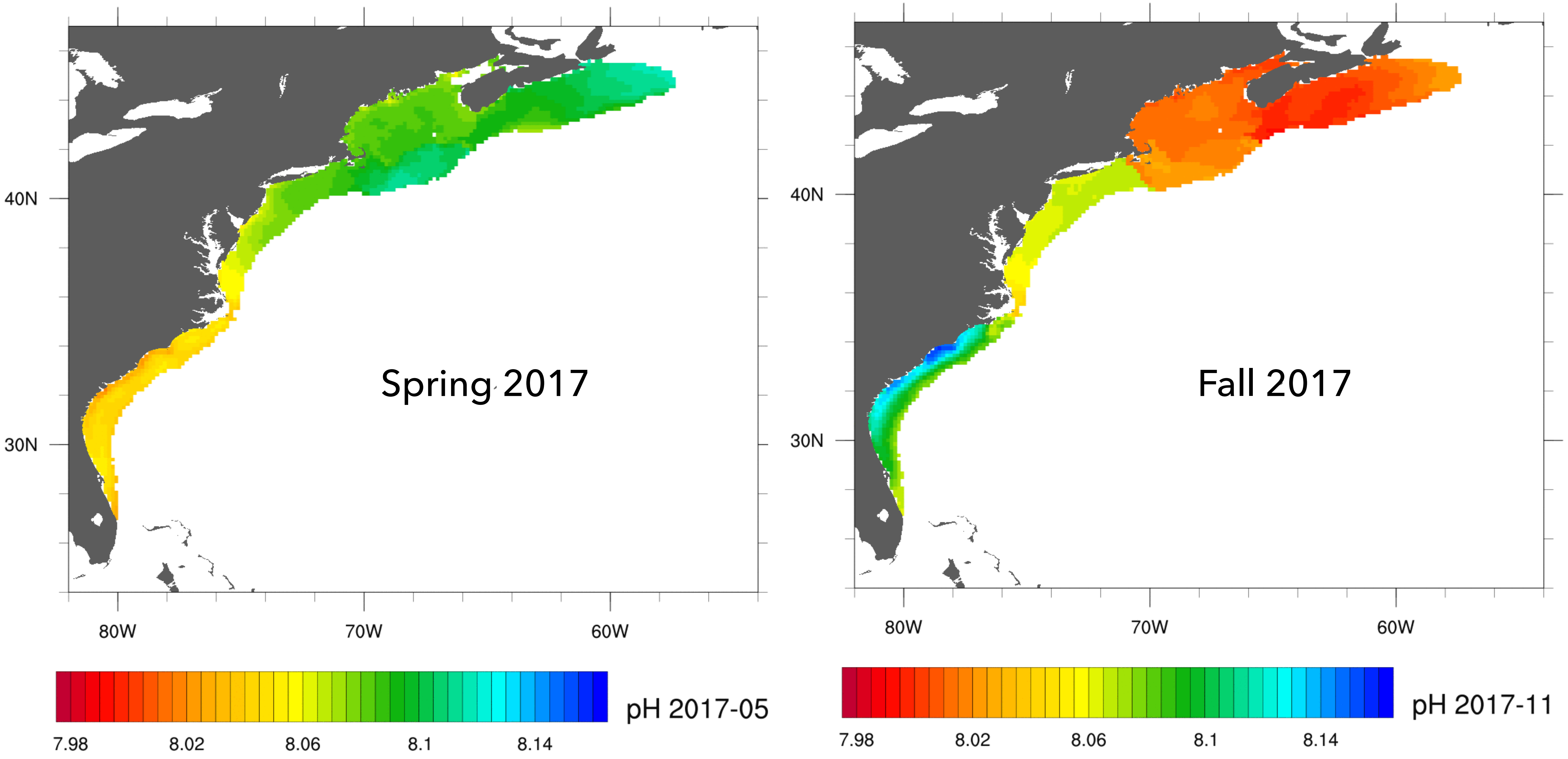


Figure adapted from https://www.coral.noaa.gov/images/research/pH_2017_East_Coast_fulld.gif

[1] Intergovernmental Panel on Climate Change: 2013 Report

[2] https://www.coral.noaa.gov/accrete/east-coast-oaps.html

OCEAN pH FLUCTUATES NATURALLY OVER THE COURSE OF THE YEAR

- New Englands' coastal waters are generally more acidic than waters further south, due to having a lower average temperature.
- Anthropogenic carbon emissions cause the ocean to become more acidic on average, while seasonal pH changes exacerbate this global trend.
- **As the average pH of the ocean decreases, some marine species may be unable to adapt to new oceanographic conditions.**

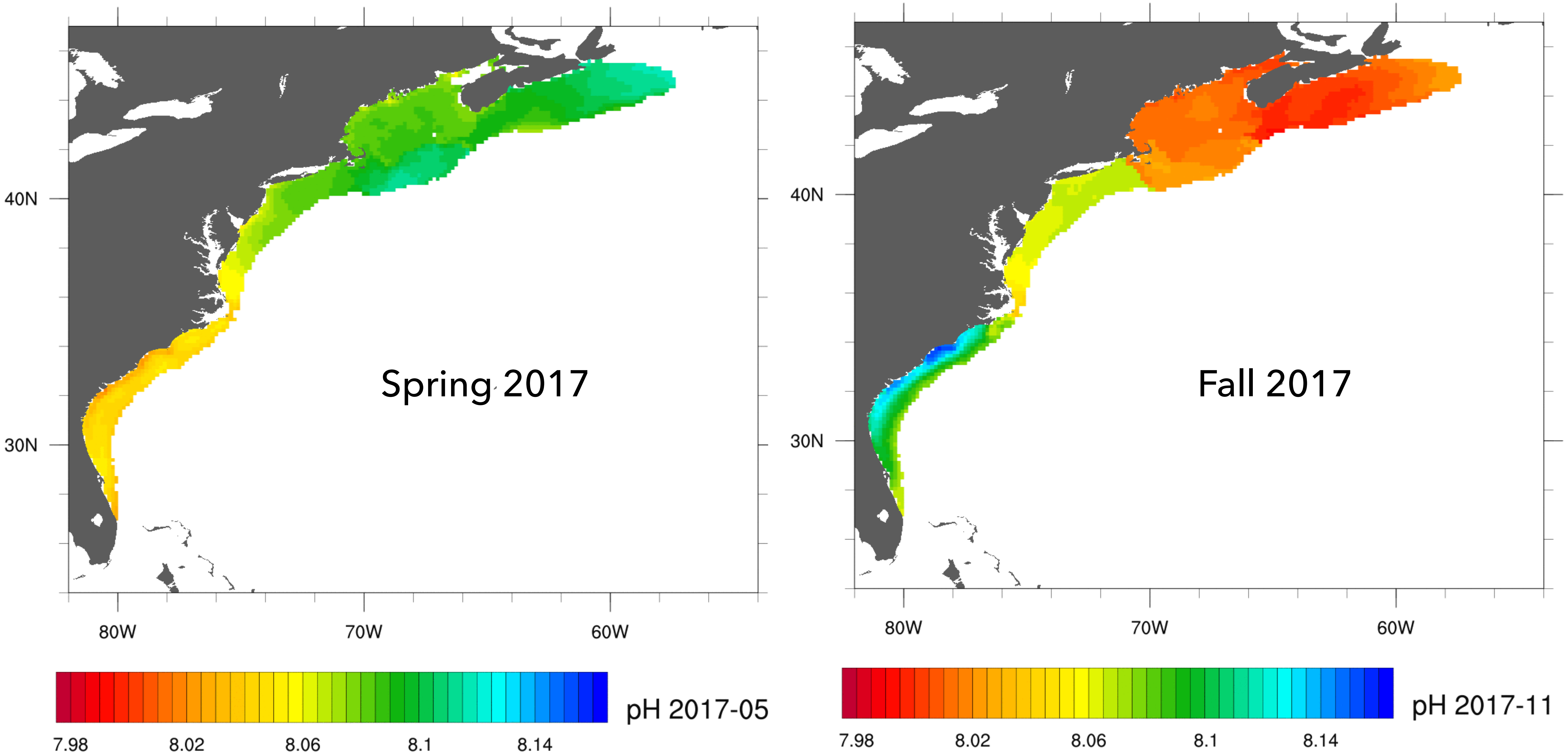
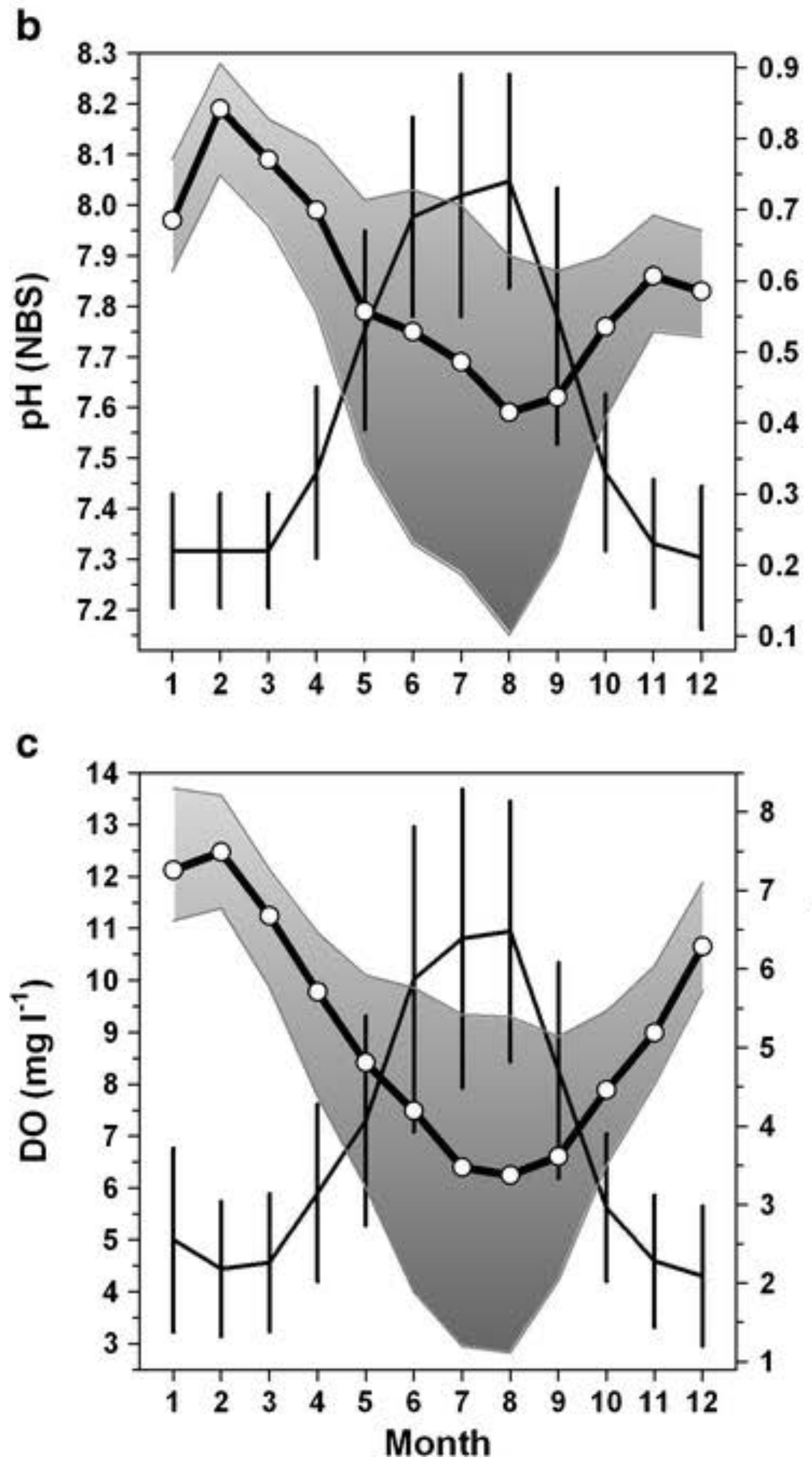


Figure adapted from https://www.coral.noaa.gov/images/research/pH_2017_East_Coast_fulld.gif

[1] Intergovernmental Panel on Climate Change: 2013 Report

ALONG THE COASTLINE, NATURAL pH FLUCTUATIONS CAN BE MUCH LARGER

- **pH fluctuations are often much larger in coastal waters, especially in highly organic environments.**
- Coastal waters that are high in nutrients and organic matter are also highly productive. Biological processes consume oxygen, creating hypoxic or anoxic zones that are also lower in pH.
- In recordings taken over the course of eight years at a tidal salt marsh in the Long Island Sound, pH and dissolved oxygen (DO) were found to covary drastically over the course of the year. pH dropped to a daily average of 7.6 during August and September.



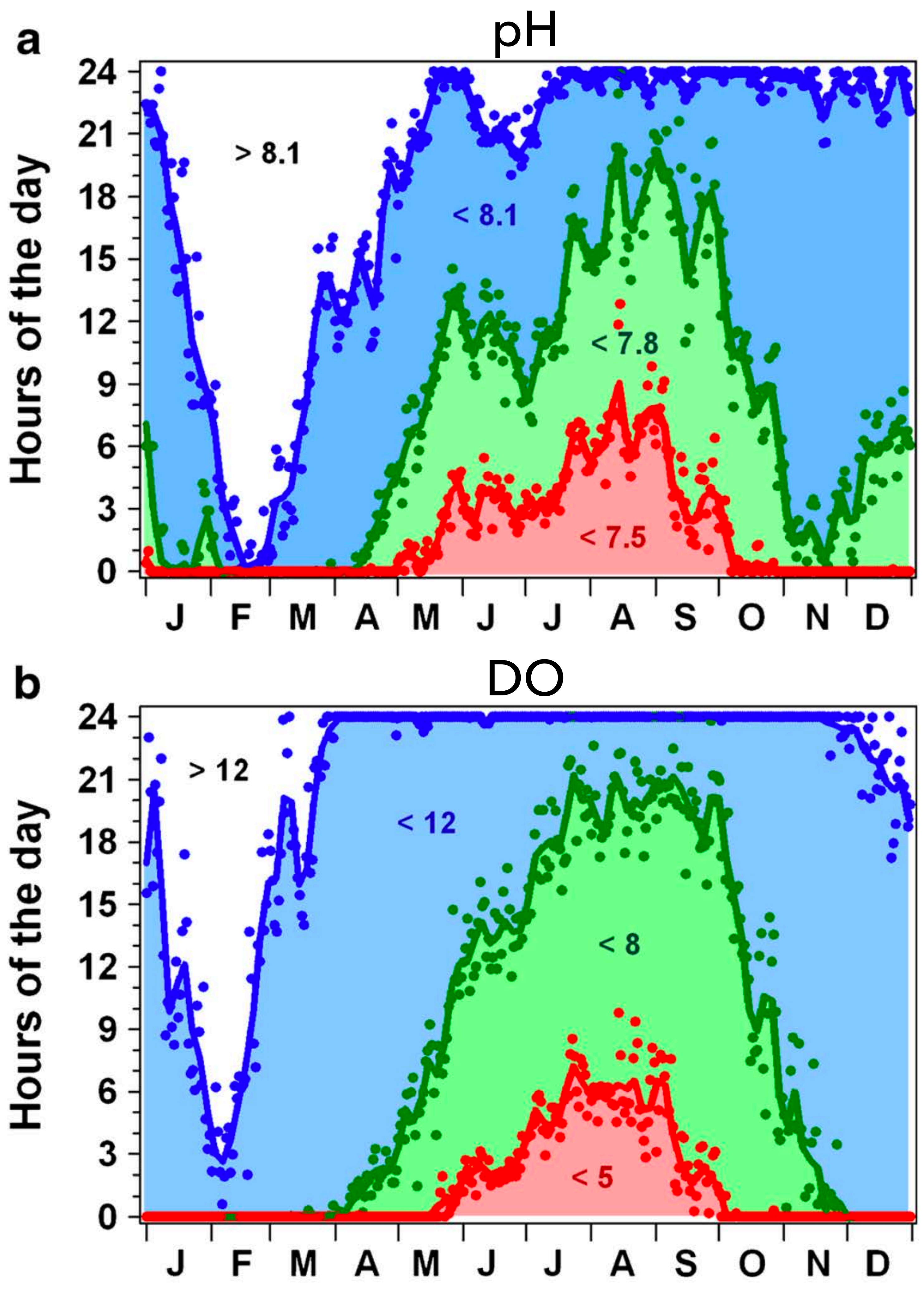


Figure adapted from Baumann *et al.*, 2014. *Large Natural pH, CO_2, and O_2 fluctuations in a temperate tidal salt marsh on Diel, Seasonal, and Interannual Time Scales*

NUTRIENT POLLUTION CAN LEAD TO LOCAL EUTROPHICATION AND ACIDIFICATION

- Nutrient pollution can lead to excessive growth among marine plants and algae, a process known as eutrophication.
- This rapid increase in growth leads to an acute depletion of oxygen (hypoxia) that can suffocate marine organisms in the surrounding area.
- **Marine organisms release carbon dioxide when they decompose, leading to a sharp increase in ocean acidification at the site of the eutrophication event. Respiration also contributes to the increase in CO_2.**
- **Compounds containing nitrogen and phosphorus are specific drivers of eutrophication.** Iron is also an essential nutrient in the process.

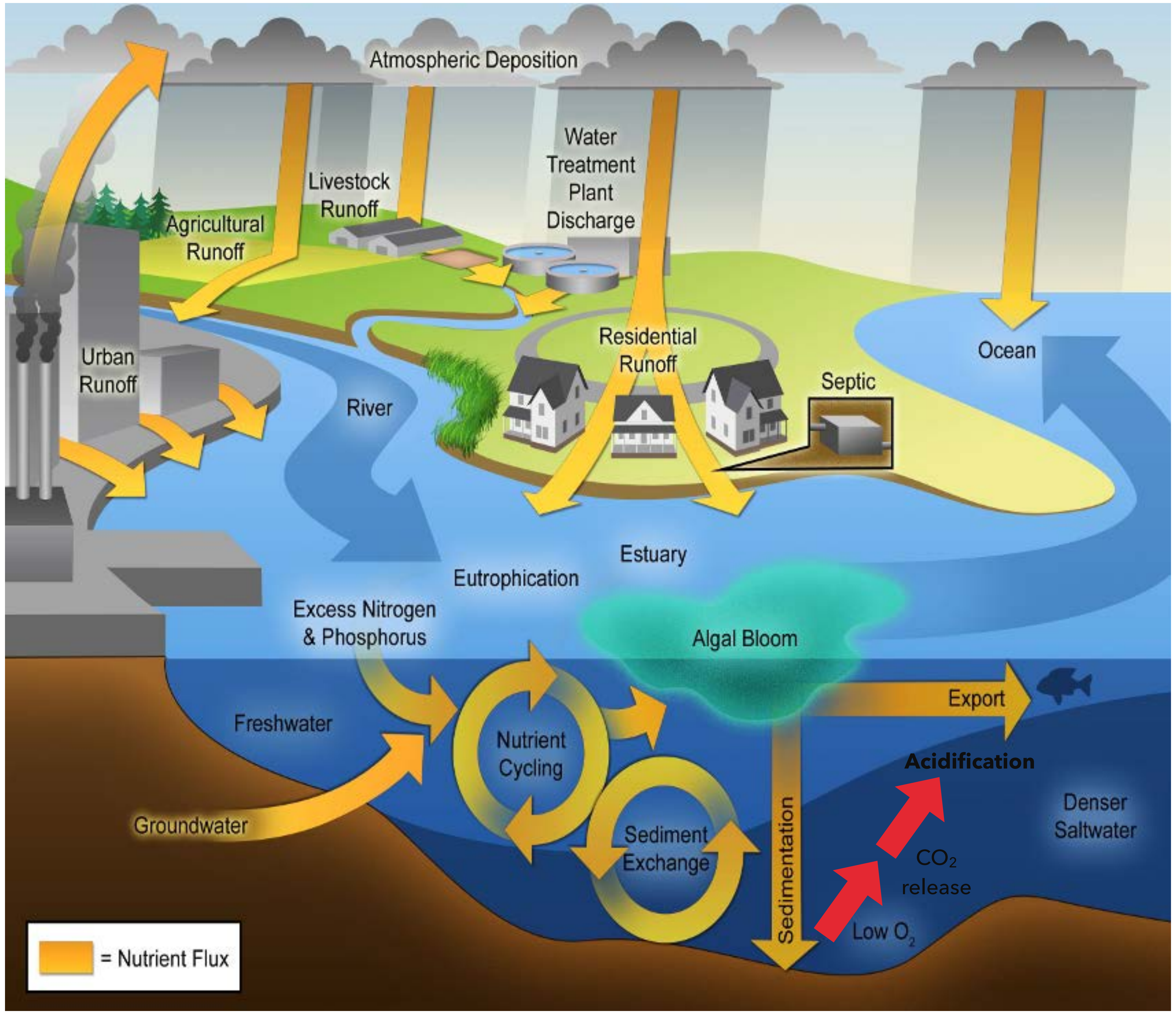


Figure adapted from http://www.vliz.be/projects/iseca/en/science-for-all/what-is-eutrophication.html

NATURAL pH FLUCTUATIONS CAN BE COMPOUNDED BY THE EFFECTS OF NUTRIENT POLLUTION

- **In coastal environments, land-based nutrient pollution amplifies localized differences in pH.** Organisms respond to excess nutrients by drawing down CO_2 through respiration and decay.
- For example: Childs River and Sage Lot Pond are both located in Waquoit Bay, Cape Cod. Childs River receives more nutrient runoff than Sage Lot Pond, and Childs River more frequently drops below pH = 7.5 compared to Sage Lot Pond. However, higher acidity freshwater discharges into Childs River may account for some of these pH differences.
- **In Southeastern Massachusetts, many controllable nutrient discharges into coastal systems derive from septic system discharges into ground and surface waters. Impervious surface runoff, agricultural runoff, golf course runoff, landfill discharges, and other nonpoint source pollution also contribute.**
- Many major cities (including Brockton, Taunton, Fall River, and New Bedford) are served by sewers that discharge to surface waters.

pH measurements across two bodies of water in Cape Cod

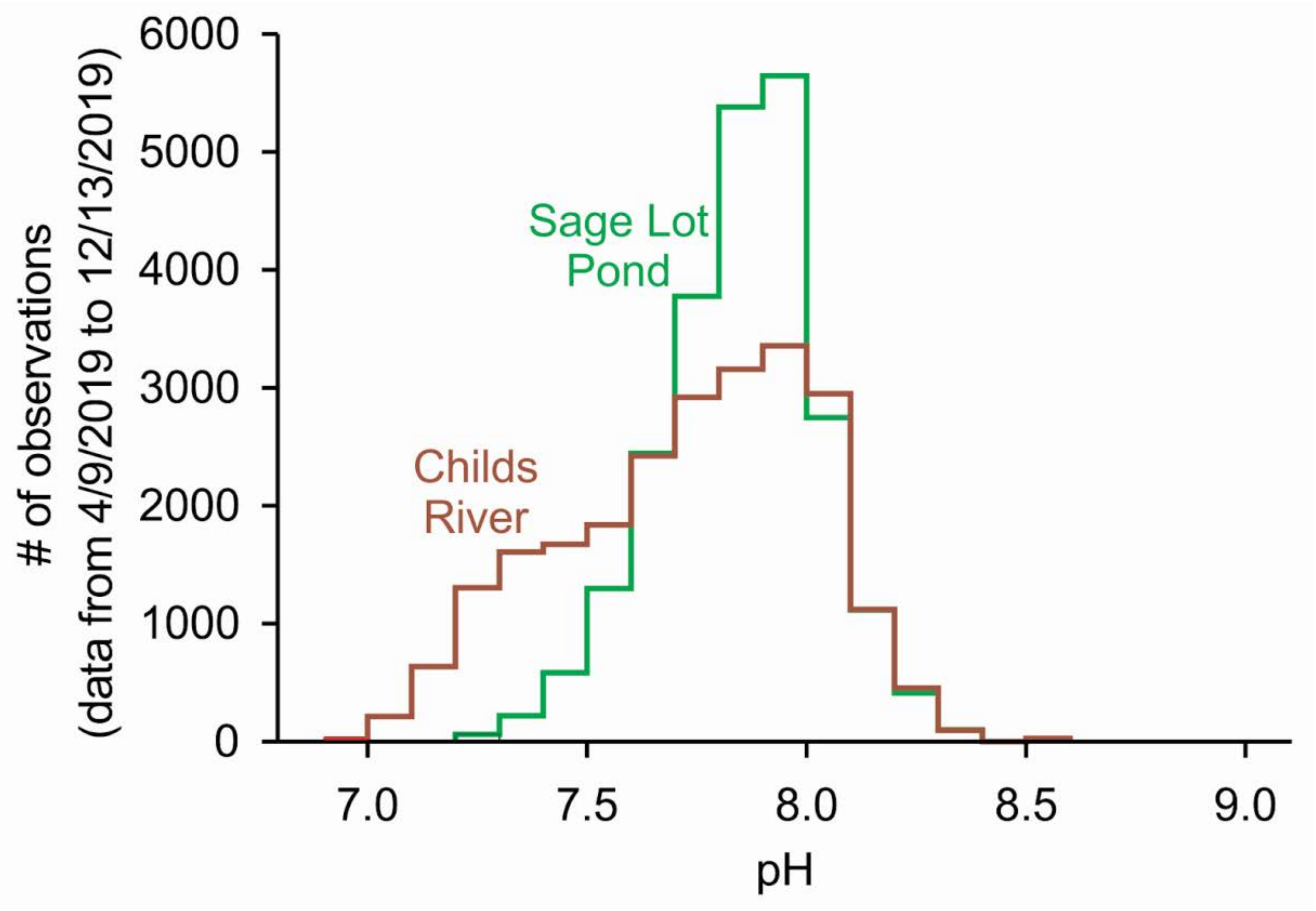


Figure adapted from WBNERR data

EUTROPHICATION ENDANGERS SHELLFISH AND SHELLFISHING COMMUNITIES

- **Localized acidification due to eutrophication and other coastal processes may be more variable than pH changes resulting from increased oceanic uptake of atmospheric carbon.**
- At the mouth of the Kennebec River in Casco Bay, Maine, shells are unable to form due to an extremely low Ω_{ar}. Away from the mouth of the river, Ω_{ar} is high enough for shells to form.
- Low Ω_{ar} at the mouths of rivers primarily results from freshwater discharges with higher acidity. This effect can be amplified by the presence of nutrients, leading to eutrophication and acidification of coastal waters at sites already hostile to shell-forming species.

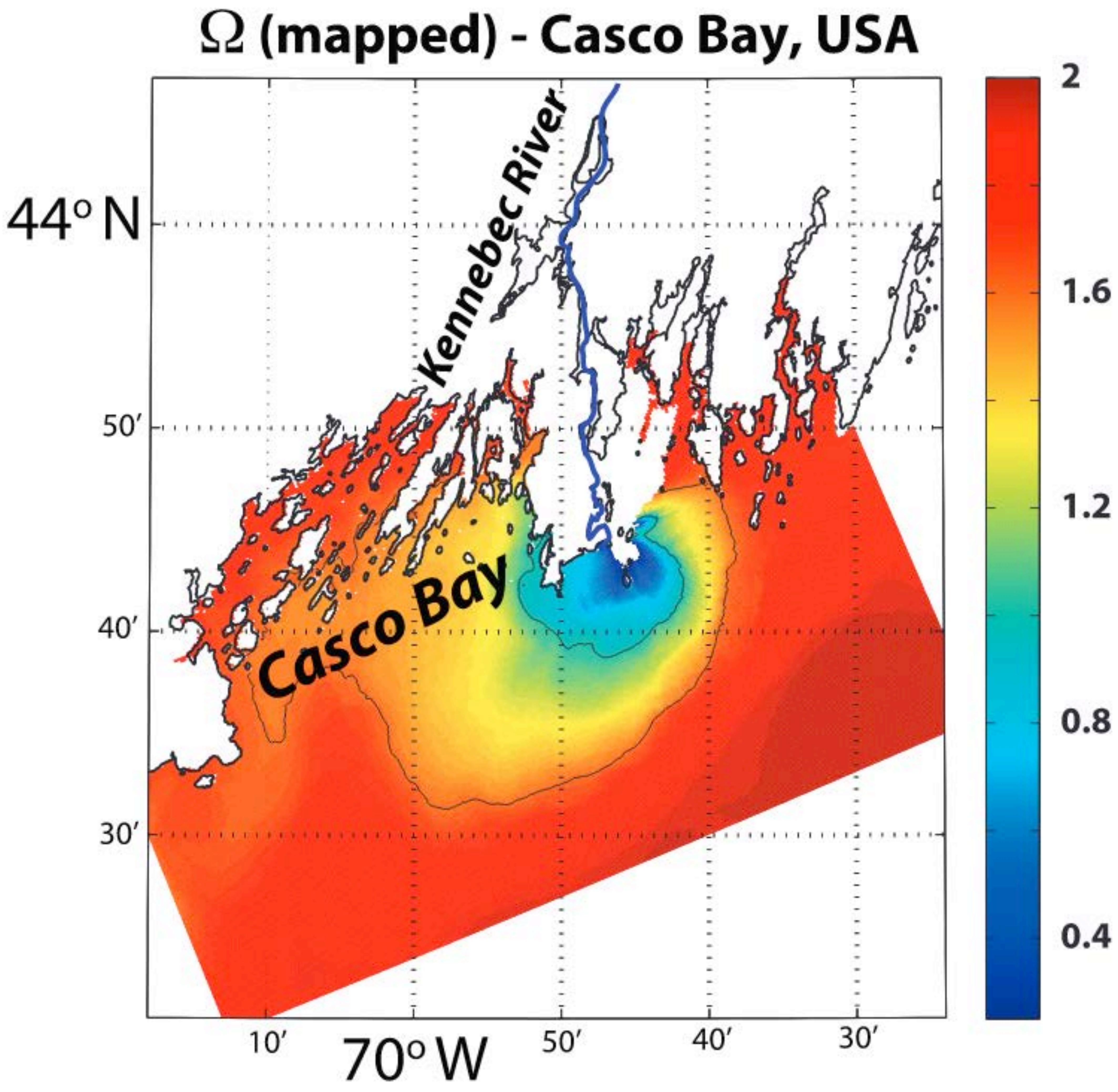
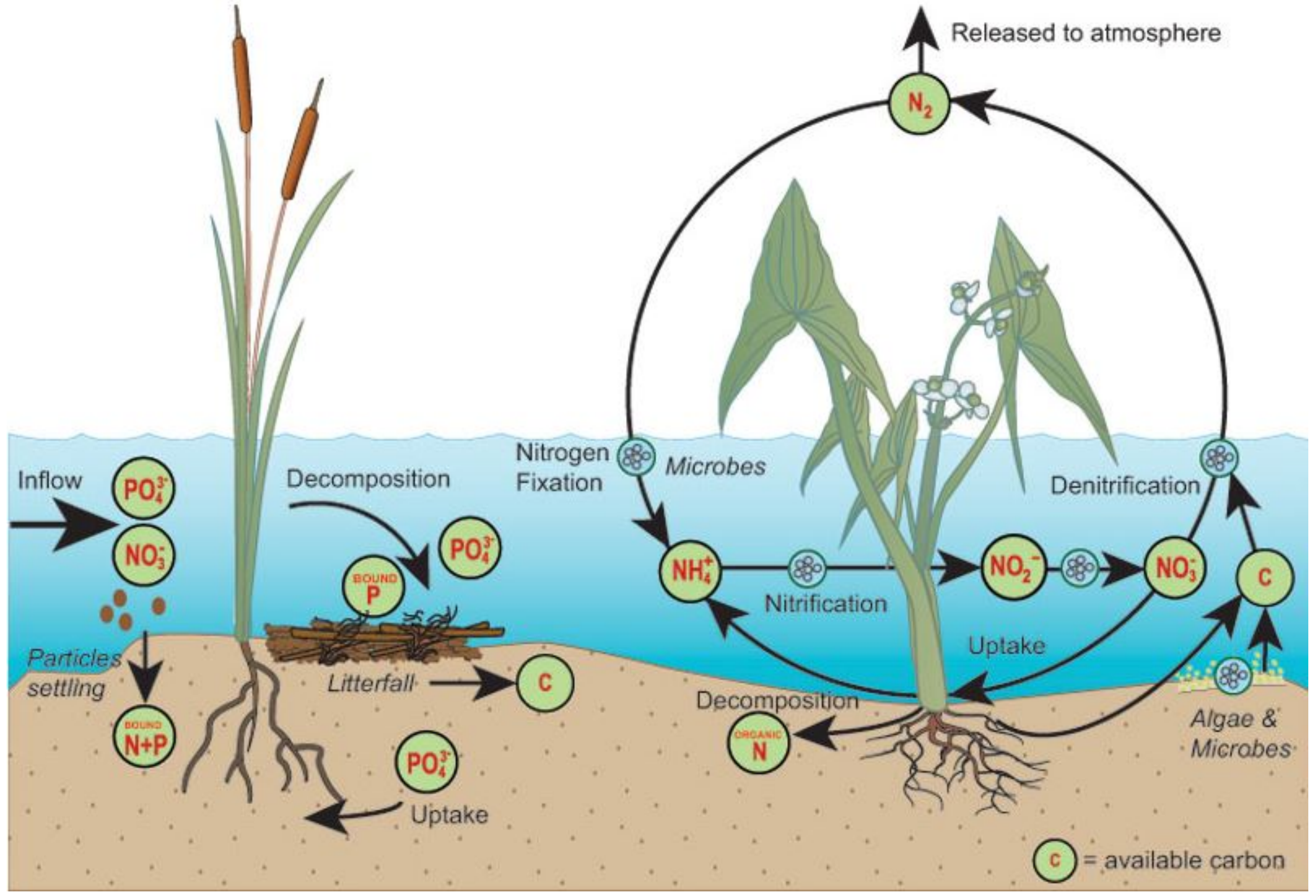


Figure adapted from Salisbury *et al.*, 2008. *Coastal Acidification by Rivers: A Threat to Shellfish?*

COASTAL WETLANDS PREVENT OCEAN ACIDIFICATION BY ABSORBING NUTRIENTS AND CARBON DIOXIDE

- **Salt marshes and other wetlands help to mitigate the effects of ocean acidification by capturing and storing excess nitrogen, phosphorus, and carbon dioxide. This helps to offset lower pH by creating more alkaline conditions.**
- A meta-analysis of studies related to the buffering effects of salt marshes found that increased nitrogen load (N) was correlated with a decrease in seagrass production along the coastline.
- In Massachusetts, wetlands are protected under the Wetlands Protection Act (M.G.L. c.131, § 40). Programs related to wetland conservation are overseen by the Massachusetts Department of Environmental Protection (MassDEP), the Massachusetts Office of Coastal Zone Management (CZM), the Massachusetts Division of Ecological Restoration, the Massachusetts Wildlife's Land Protection Program, and the Department of Fish and Game.



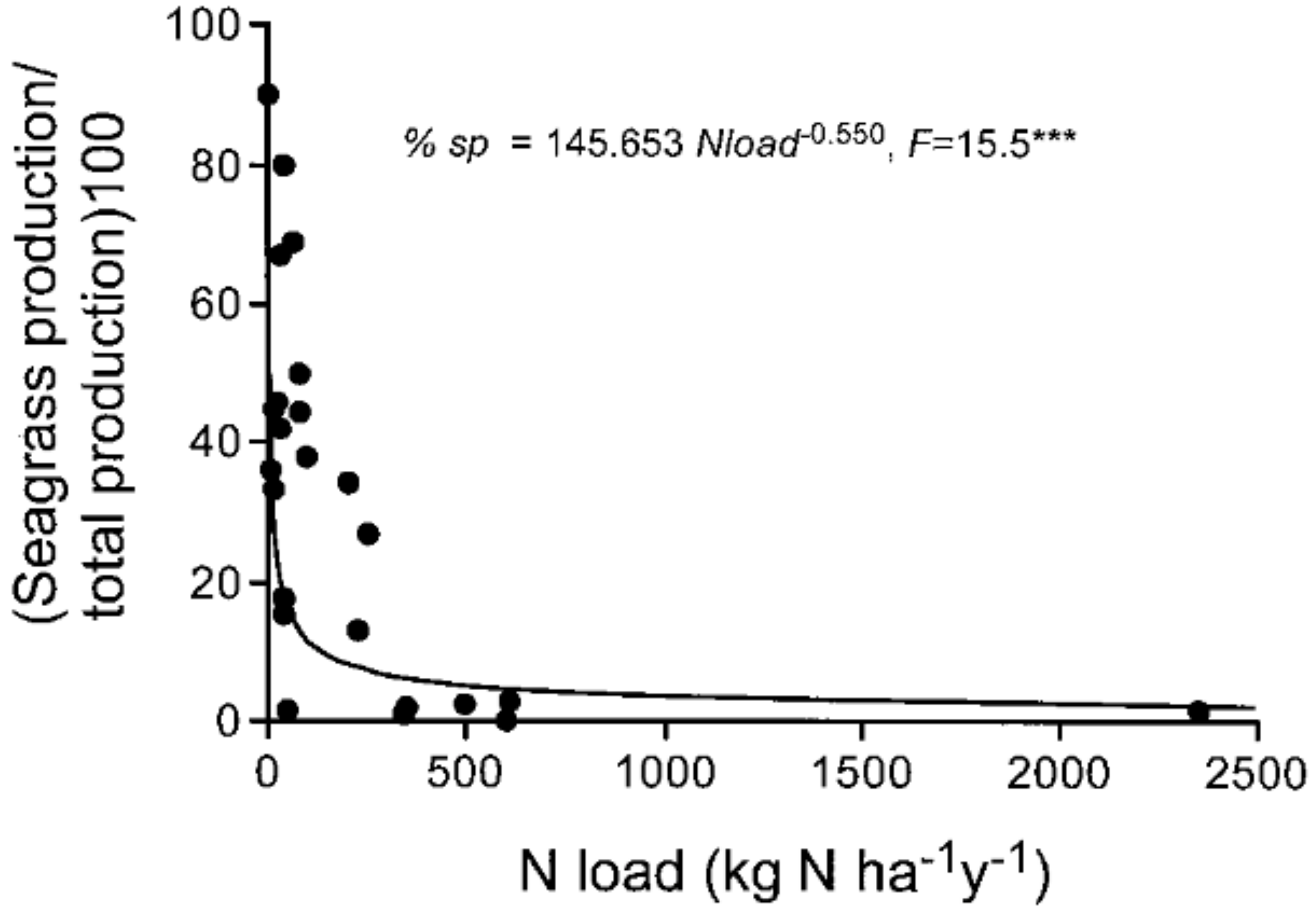
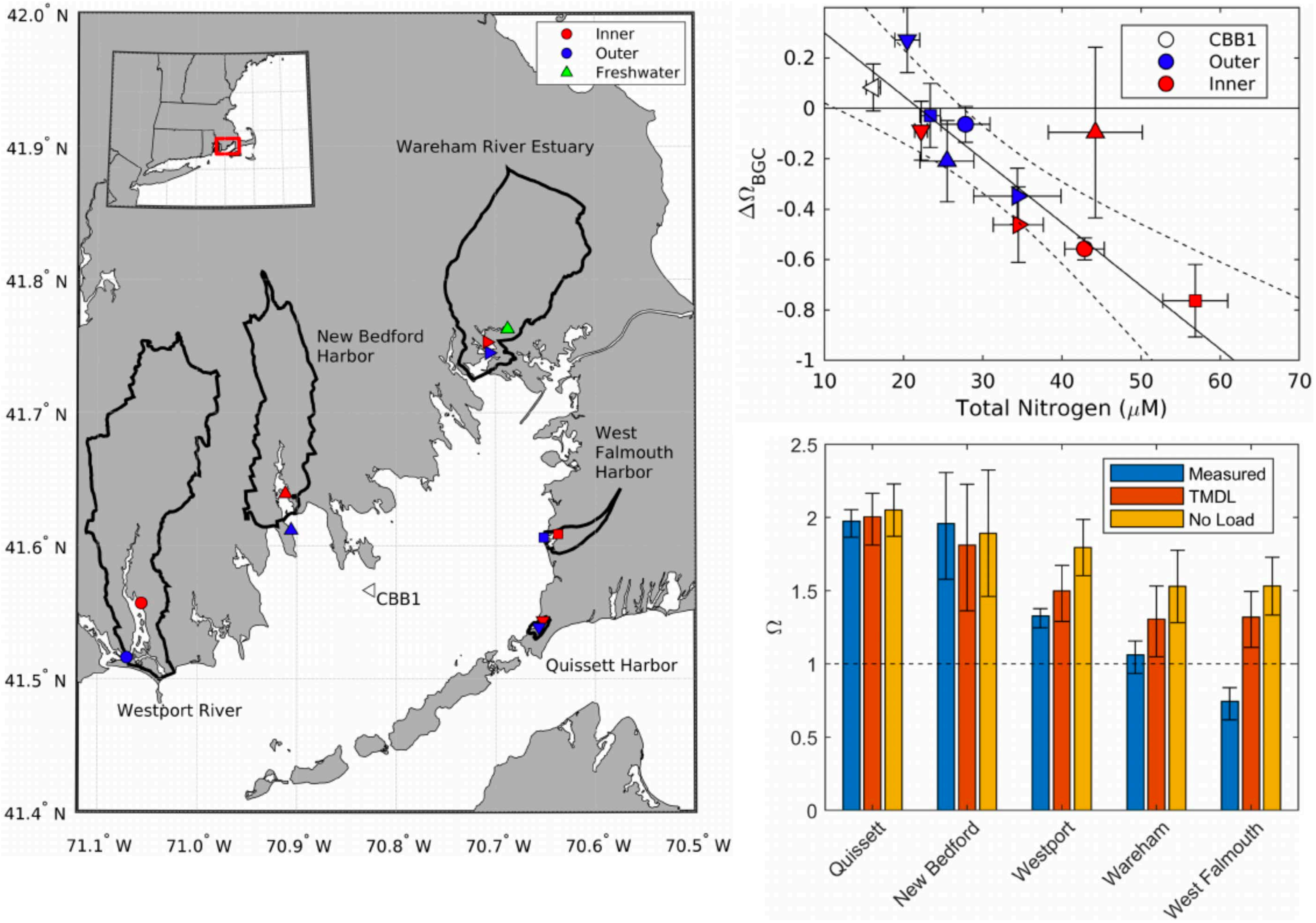


Figure 1 adapted from Kadlec and Knight, 1996. *Treatment Wetlands.*
Figure 2 adapted from Valiela and Cole, 2001. *Comparative Evidence that Salt Marshes and Mangroves May Protect Seagrass Meadows From Land-derived Nitrogen Loads*

LIMITING NUTRIENT POLLUTION CAN REDUCE ACIDIFICATION CAUSED BY EUTROPHICATION

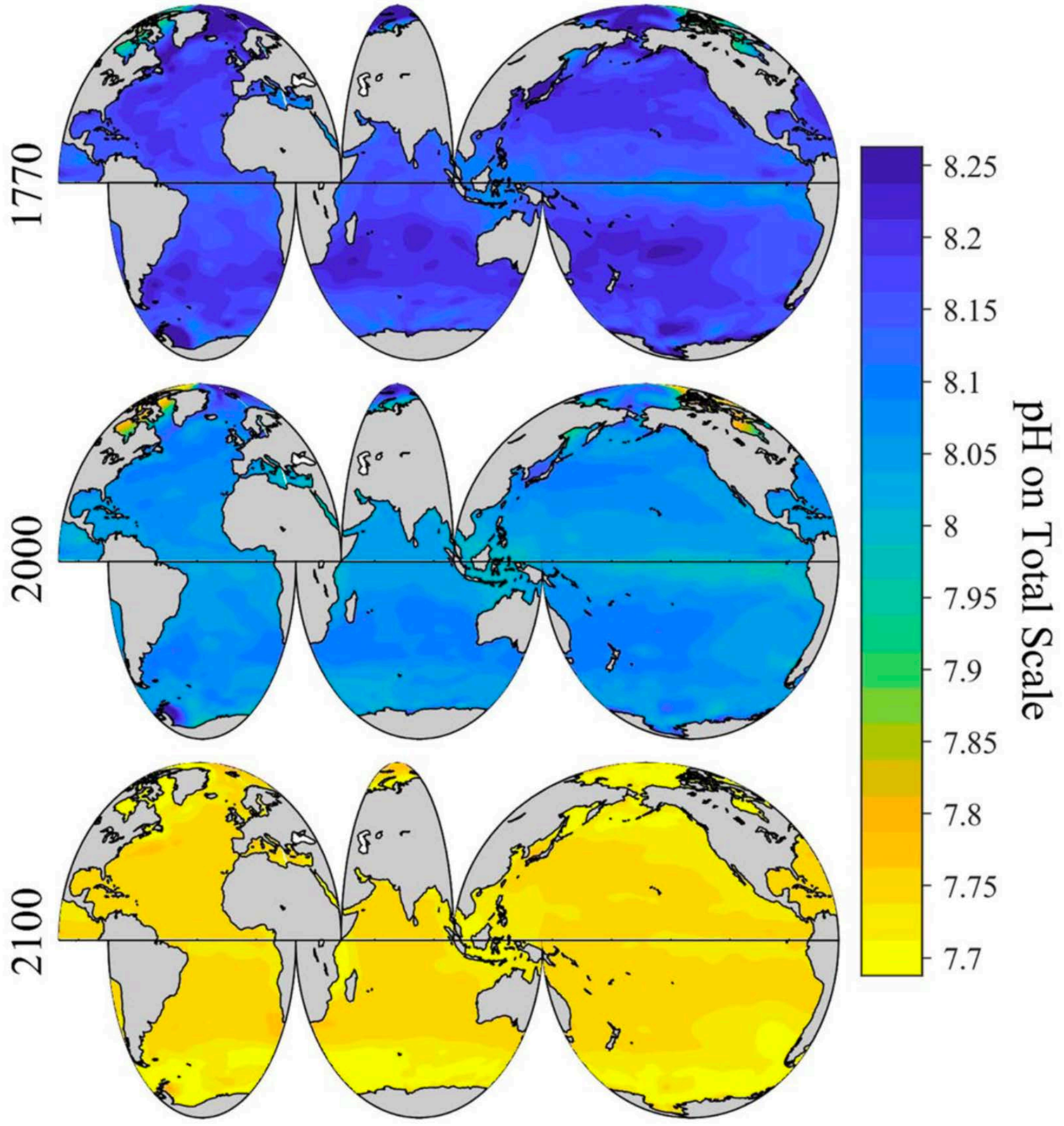
- **State-imposed limits on nutrient pollution help reduce ocean acidification due to eutrophication.**
- A recent study in Buzzard's Bay (Rheuban *et al.*, 2019) tracked the nutrient content of freshwater inputs at five different watersheds, and determined that increased nitrogen content was highly correlated with decreased Ω_{ar} at the interface between the freshwater and the bay.
- The study modeled the potential effects of implementing total maximum daily loads (TMDLs) for nitrogen, and determined that the impact of eutrophication could largely be mitigated by the implementation of nutrient TMDLs.

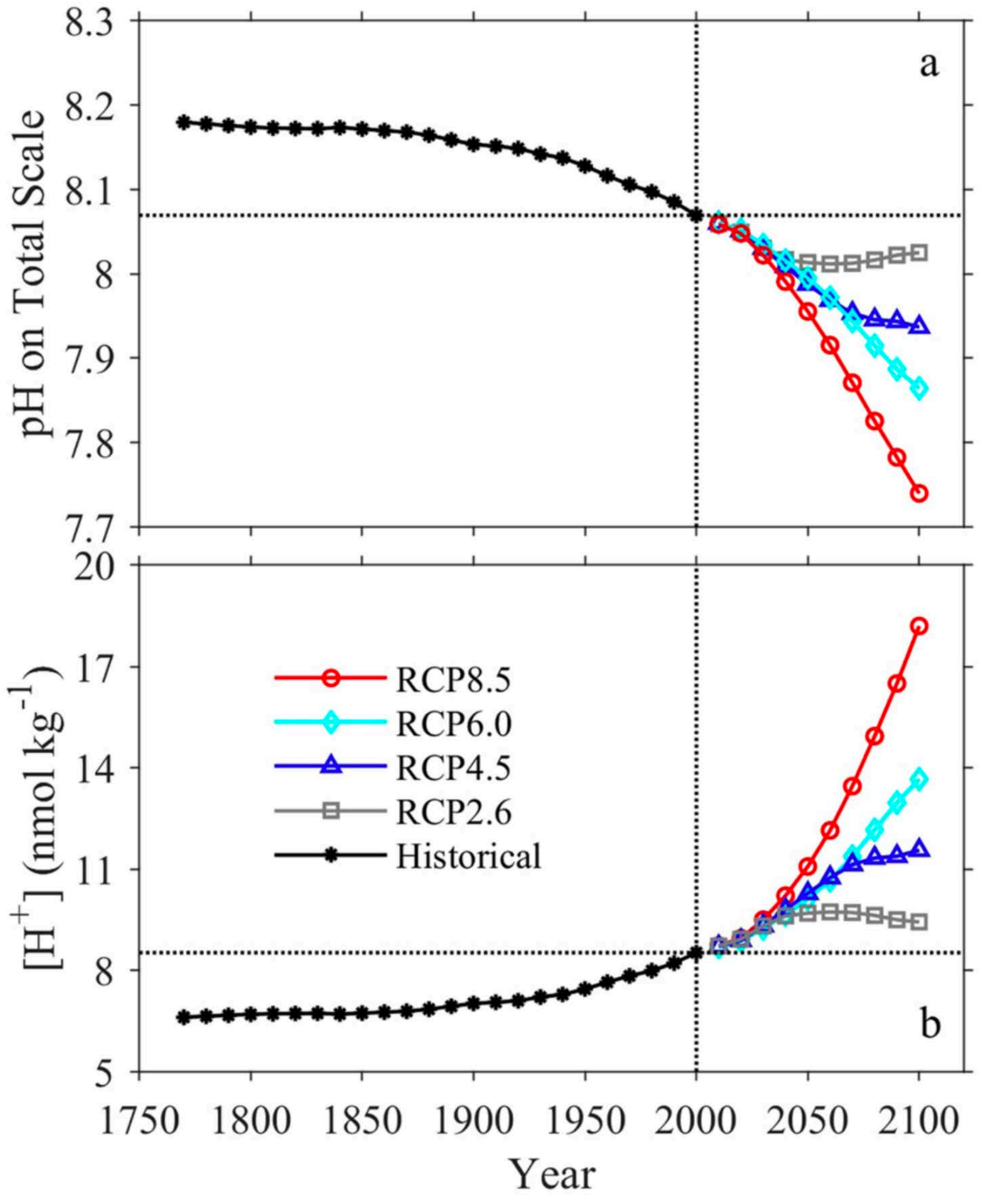


Figures adapted from Rheuban *et al.*, 2019. *Quantifying the Effects of Nutrient Enrichment and Freshwater Mixing on Coastal Ocean Acidification.*

THE OCEAN WILL CONTINUE TO ACIDIFY WITHOUT COORDINATED GLOBAL ACTION

- **In the absence of significant interventions, models predict that average ocean surface pH could fall below 8.0 this century.**
- Average ocean surface pH has not fallen below 8.0 in over 20 million years[(1)].
- A Representative Concentration Pathway (RCP in Figure 2) is a projection of future atmospheric greenhouse gas concentrations that has been adopted by the Intergovernmental Panel on Climate Change. "RCP8.5" assumes no attempt at controlling greenhouse gas emissions, while "RCP2.6" assumes significant global efforts to curtail the effects of ocean acidification.
- **The extent to which the Commonwealth can mitigate ocean acidification will depend on the magnitude of actions taken now.**





Figures adapted from Jiang *et al.*, 2019. *Surface ocean pH and buffer capacity: past, present and future.*

[1] Honisch *et al.*, 2012. *The Geological Record of Ocean Acidification.*

SHELLFISHING AND MARINE INDUSTRIES IN MASSACHUSETTS

SHELLFISH WILL BE INCREASINGLY AFFECTED BY OCEAN ACIDIFICATION

- **As the ocean continues to acidify the aragonite saturation state (Ω_{ar}) is anticipated to decrease below 1.5, making it more difficult for shellfish to develop properly.**
- In the Gulf of Maine, three models suggest that bottom waters have already reached $\Omega_{ar} < 1.5$.
- These models suggest that by 2060, surface waters will reach $\Omega_{ar} < 1.5$ and bottom waters will approach an $\Omega_{ar} < 1$. At this point, shells at the bottom of the gulf will begin to dissolve.

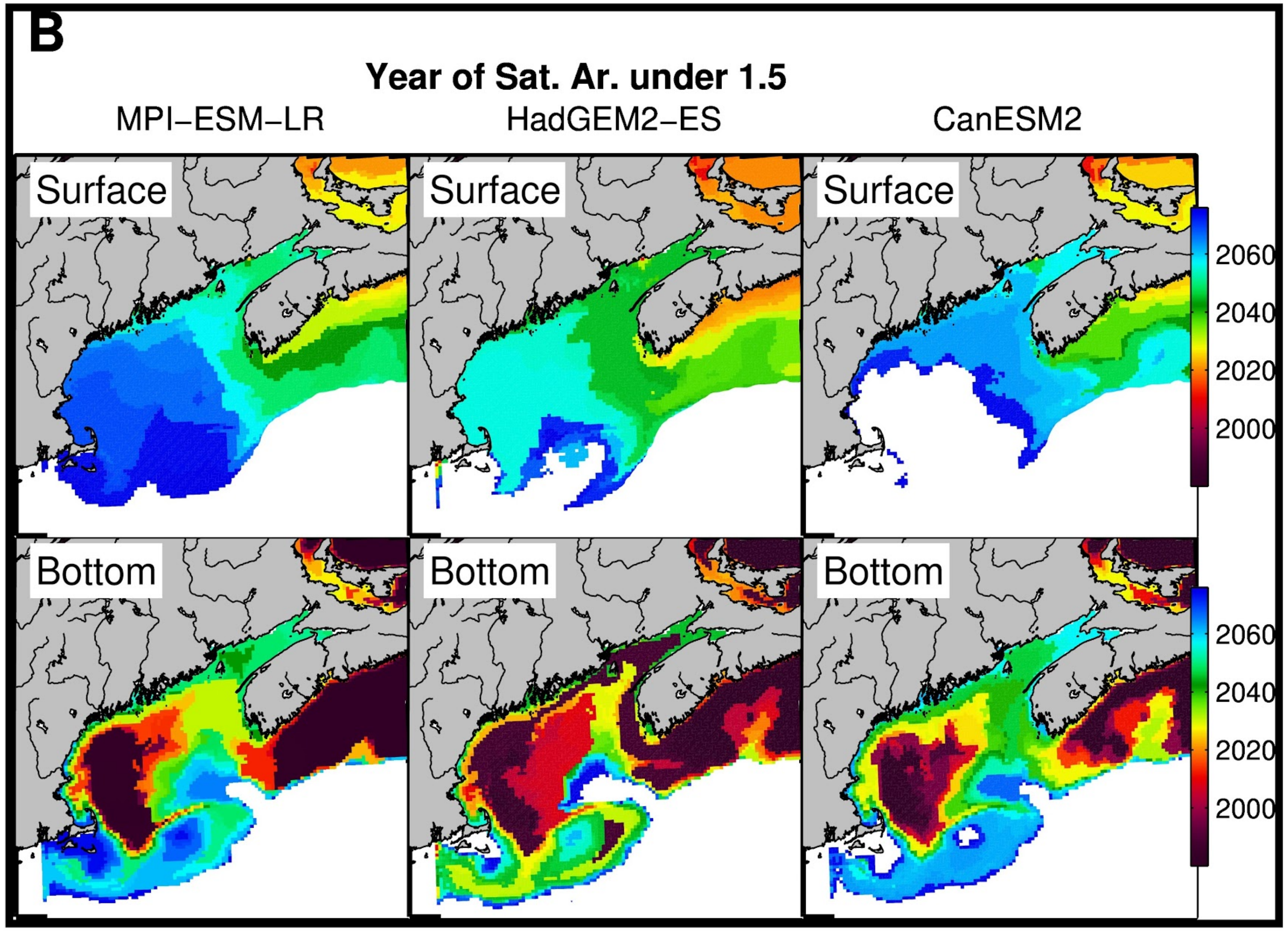
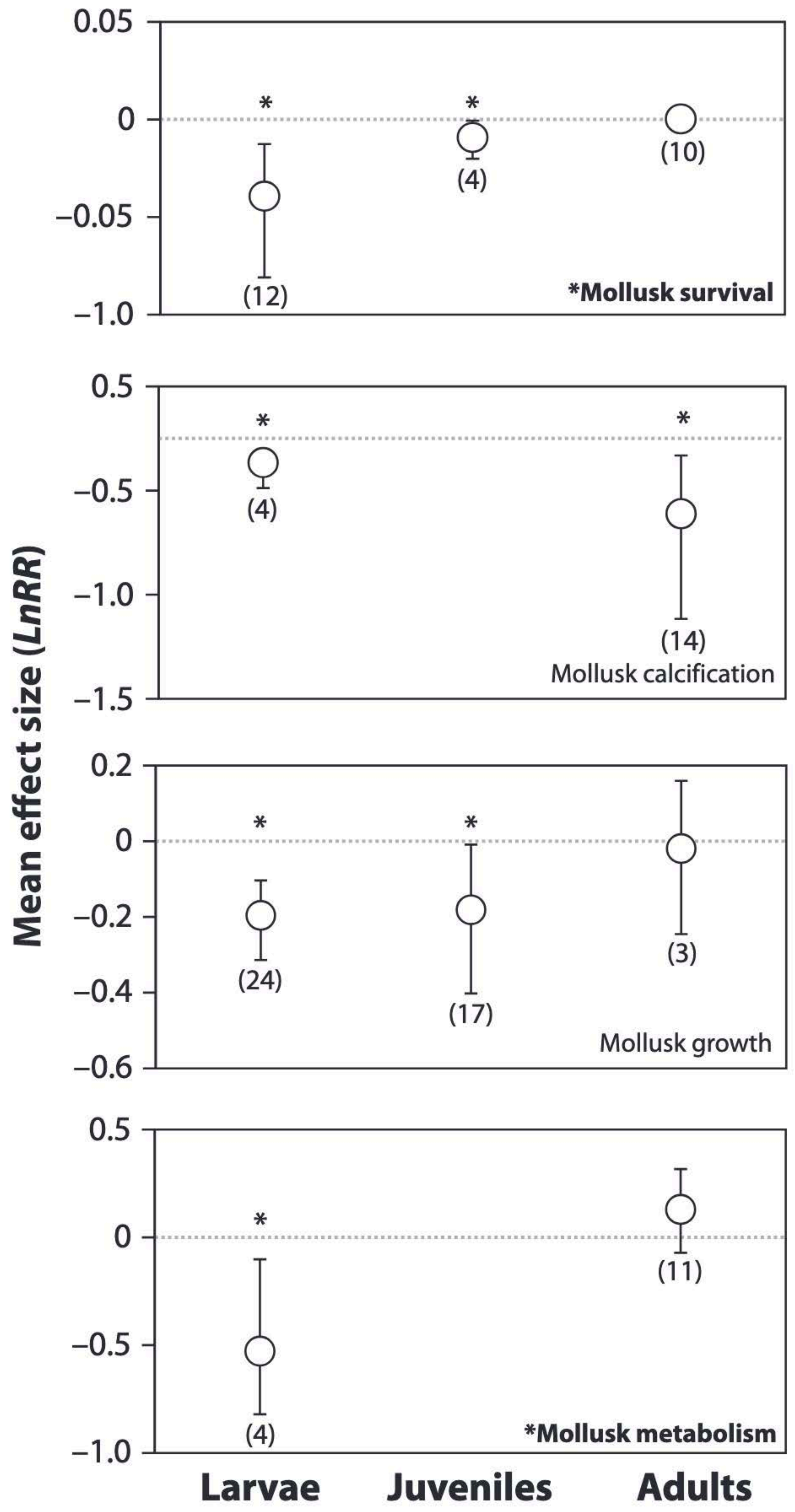


Figure adapted from Siedlecki *et al.*, 2020. *Projecting ocean acidification impacts for the Gulf of Maine to 2050: New tools and expectations*

MOLLUSKS ARE PARTICULARLY VULNERABLE TO OCEAN ACIDIFICATION

- **Mollusks such as the eastern oyster, sea scallop, and Atlantic surf clam are extremely vulnerable to ocean acidification.**
- Acidification can reduce mollusk survival rates by 34%. Surviving mollusks can be 17% smaller.
- Adult mollusks experience reduced calcification under acidic conditions, but are generally less susceptible to acidification than larvae.
- Some species, including certain fleshy algae and diatoms, may thrive under more acidic conditions. Understanding which Massachusetts species are more or less susceptible to acidification, and why, is an important focus for future research.

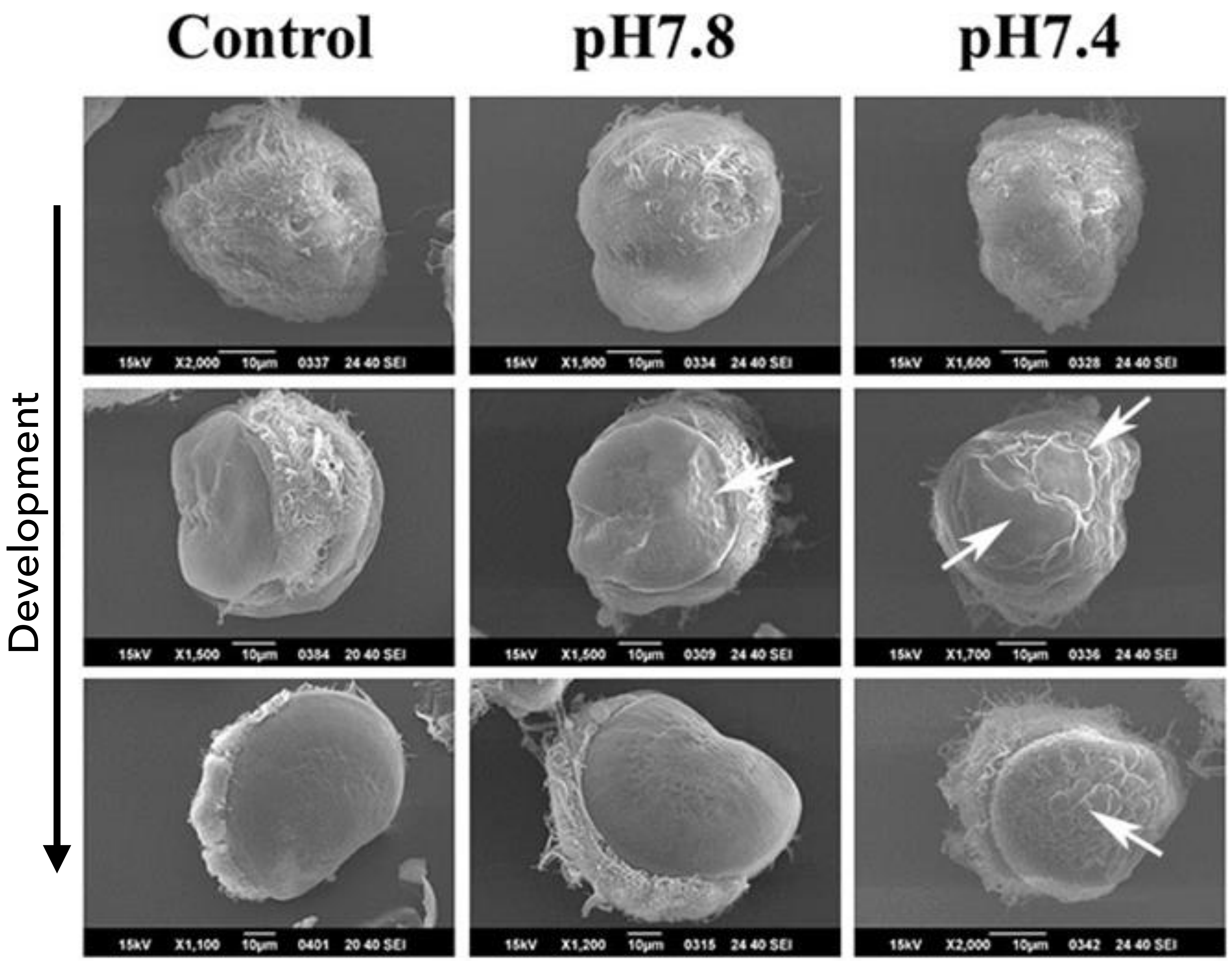
Taxa	Response	Mean Effect
Mollusks	Survival	−34%
	Calcification	−40%
	Growth	−17%
	Development	−25%
	Abundance	
Echinoderms	Survival	
	Calcification	
	Growth	−10%
	Development	−11%
	Abundance	
Crustaceans	Survival	
	Calcification	
	Growth	
	Development	
	Abundance	
Fish	Survival	
	Calcification	
	Growth	
	Development	
	Abundance	
Fleshy algae	Survival	
	Calcification	
	Growth	+22%
	Photosynthesis	
	Abundance	
Seagrasses	Survival	
	Calcification	
	Growth	
	Photosynthesis	
	Abundance	
Diatoms	Survival	
	Calcification	
	Growth	+17%
	Photosynthesis	+12%
	Abundance	



Figures adapted from Kroeker *et al.*, 2013. *Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming*

MOLLUSKS ARE MOST VULNERABLE TO OCEAN ACIDIFICATION IN THEIR LARVAL STAGES

- The initial shells of mollusk larvae deform under acidic conditions.
- Across species, larval length and survival rate decrease as concentration of dissolved CO_2 increases.
- **Because acidification is most detrimental in the larval stage, mitigation efforts can be conducted in collaboration with shellfish hatcheries.**



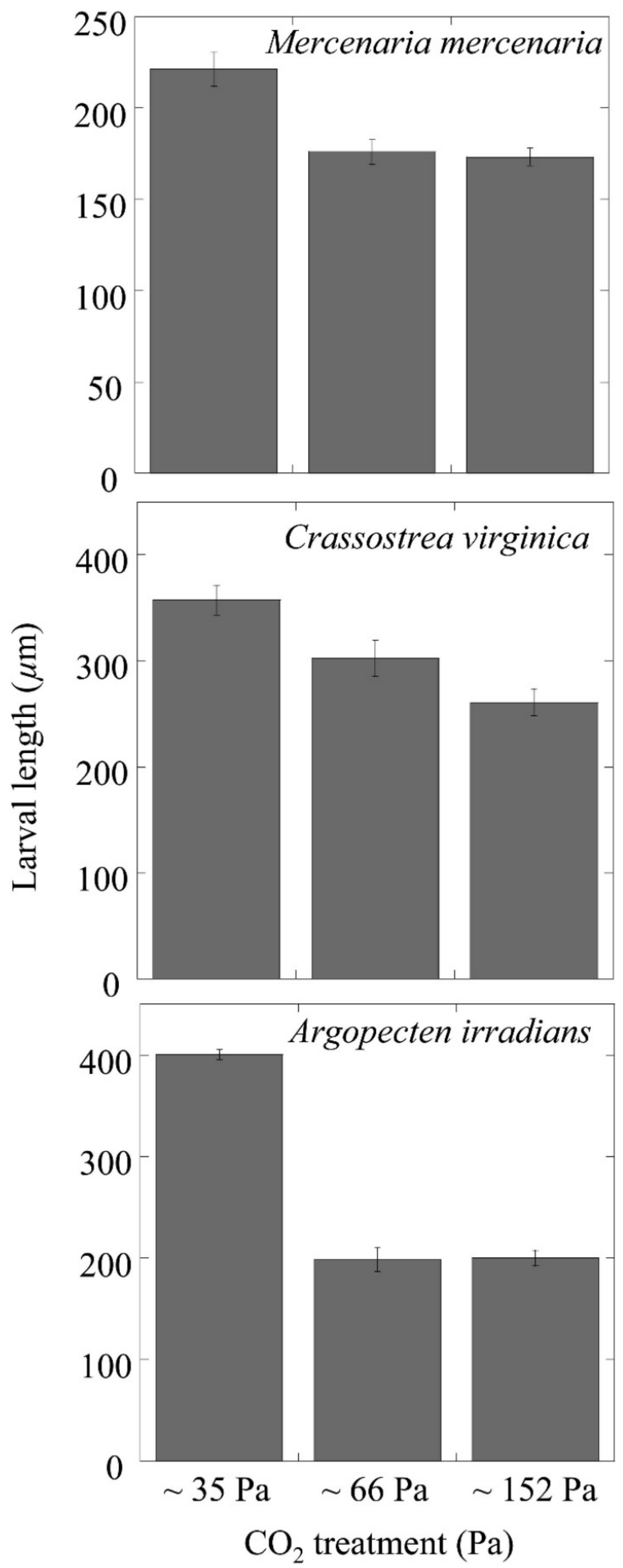


Figure 1 adapted from Zhang *et al.*, 2019. *The Inhibition of Ocean Acidification on the Formation of Oyster Calcified Shell by Regulating the Expression of Cgchs1 and Cgchit4*
Figure 2 adapted from Talmage and Gobler, 2009. *The effects of elevated carbon dioxide concentrations on the metamorphosis, size, and survival of larval hard clams, bay scallops, and Eastern oysters.*

MULTIMODAL STRESS CAN AFFECT MOLLUSKS MORE THAN ACIDIFICATION ALONE

- A study into the effects of multimodal stress on quahogs (Talmage and Gobler, 2011) suggests that quahogs are less likely to survive and grow under acidic and warm conditions compared to acidic and temperate conditions.

- **The effects of multimodal stress are species-specific.** While quahog and bay scallop juveniles were observed to be negatively affected by the combination of warmer waters and acidification, Eastern oyster juveniles were unaffected.

- As the climate continues to change, multimodal stress is unavoidable. When greenhouse gases enter the atmosphere, they trap heat that is subsequently absorbed by the ocean. Anthropogenic carbon emissions therefore result in both ocean acidification and ocean warming.

Effects of multimodal stress on quahogs

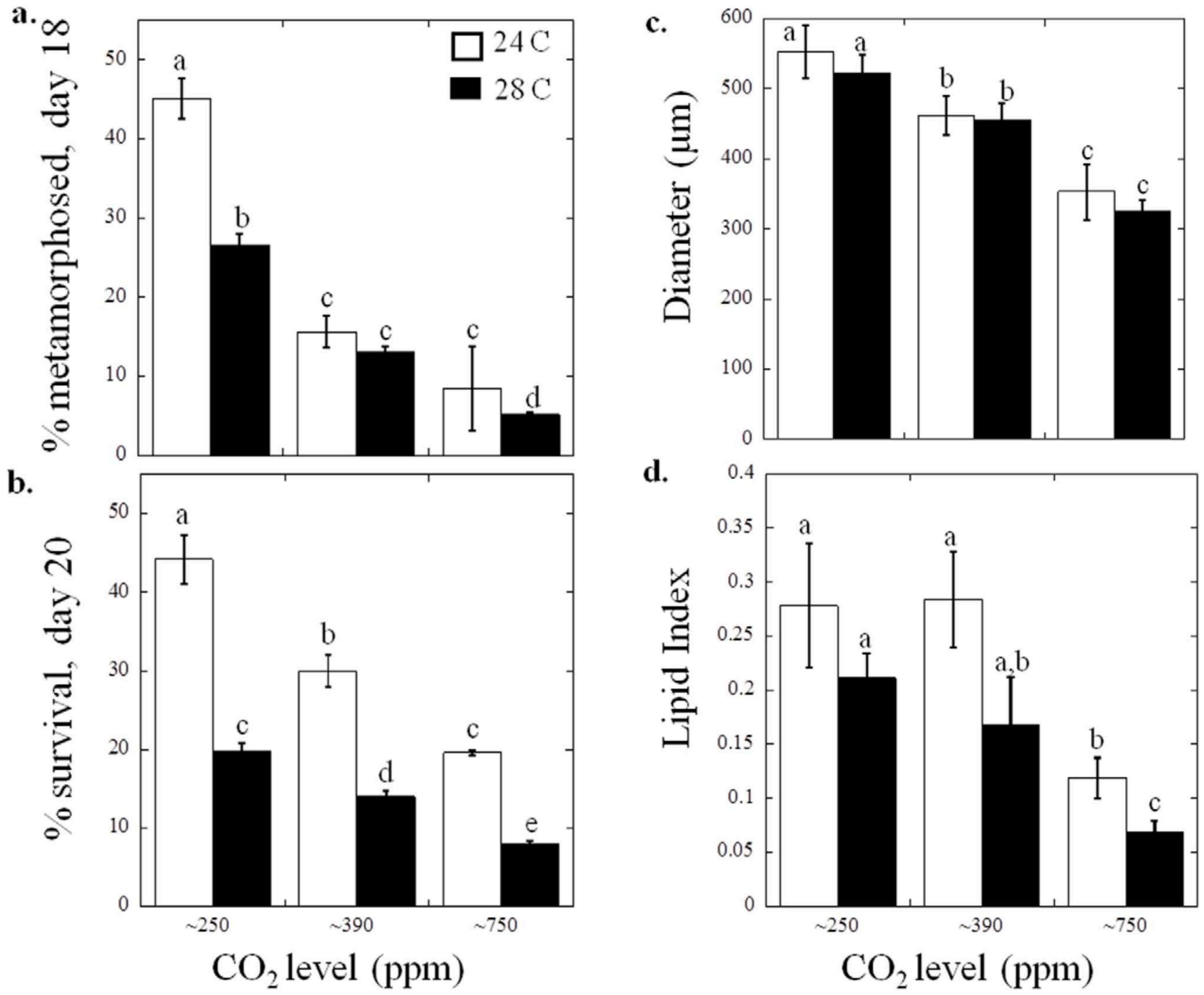


Figure adapted from Talmage and Gobler, 2011. *Effects of Elevated Temperature and Carbon Dioxide on the Growth and Survival of Larvae and Juveniles of Three Species of Northwest Atlantic Bivalves.*

MULTIMODAL STRESS MAY ALSO INFLUENCE THE HEALTH OF CRUSTACEANS

- In general, crustaceans such as lobsters and crabs appear to be more resistant to ocean acidification than mollusks[1].
- **However, the effects of multimodal stress have not been thoroughly studied in most economically-relevant crustacean species.**
- In spider crabs, exposure to dissolved carbon dioxide leads to a decrease in thermal tolerance. Testing thermal tolerance or acidification tolerance alone does not reveal this relationship.

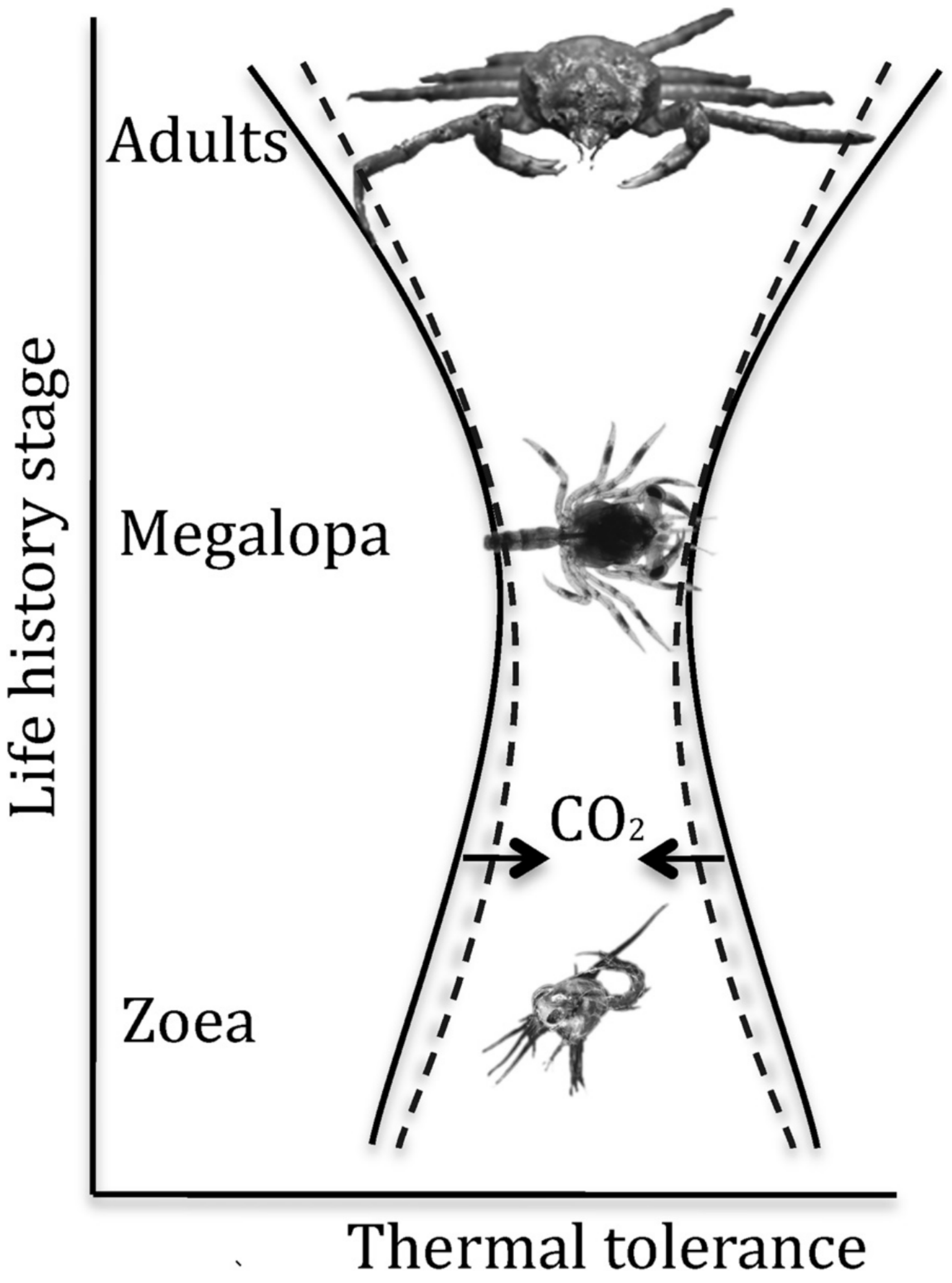


Figure adapted from Schiffer et al., 2014. *Temperature tolerance of different larval stages of the spider crab exposed to elevated seawater pCO2.*

[1] Kroeker *et al.*, 2013. *Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming*

RELATIVELY FEW STUDIES HAVE EXPLORED THE EFFECTS OF MULTIMODAL STRESS

- Studies that have examined the effects of multimodal stress on shellfish have primarily focused on eastern oysters and northern quahogs.
- There have been few studies into the effects of multimodal stress on crustaceans or finfish.
- Zero studies have been conducted into the effects of multimodal stress on: Atlantic surf clams, horseshoe crabs, Jonah crabs, or Atlantic deep-sea red crabs.

Summary of studies conducted in mid-Atlantic species

Group	Common name	Scientific name	# Acidification-only studies	# Multi-stressor studies (Acidification + other)	Response to acidification		
					+	-	none
Crustaceans	American lobster[b]	*Homarus americanus*	2	1		2	
	Blue crab[d]	*Callinectes sapidus*	3	1		2	2
	Northern shrimp[b]	*Pandalus borealis*	2	1		2	2
Mollusks	Eastern oyster	*Crassostrea virginica*	9	5	2	11	1
	Northern quahog/Hard clam	*Mercenaria mercenaria*	4	7		9	1
	Bay scallop[d]	*Argopecten irradians*	4	3		7	
	Ocean quahog[a]	*Arctica islandica*	1	1			2
	Sea scallop[c]	*Placopecten magellanicus*	2	0		2	
	Longfin squid[a]	*Doryteuthis pealeii*	2	0		1	1
Finfish	Atlantic herring[b]	*Clupea harengus*	3	2	1	4	4
	Atlantic striped bass[b]	*Morone saxatilis*	0	1			1
	Cobia[b]	*Rachycentron canadum*	2	1		2	3
	Red drum[b]	*Sciaenops ocellatus*	4	1	1	1	3
	Scup[a,b]	*Stenotomus chrysops*	1	0			1
	Summer flounder[a]	*Paralichthys dentatus*	1	1		2	
	Weakfish[b]	*Cynoscion regalis*	0	1			1
Elasmobranchs	Coastal sharks[b]	Various	1	0		1	
	Little skate[c]	*Leucoraja erinacea*		2		2	
SAV	Eelgrass	*Zostera marina*	>15	2	>15		
	Widgeongrass	*Ruppia spp.*	1		1		
	Wild celery	*Vallisneria americana*	1		1		
	Pomatogeton	*Potamogeton spp.*	1		1		

Blue = 5 or more studies conducted; Yellow = between 1 and 4 studies conducted

Figure adapted from Saba et al., 2019. *Recommended priorities for research on ecological impacts of ocean and coastal acidification in the US Mid-Atlantic.*

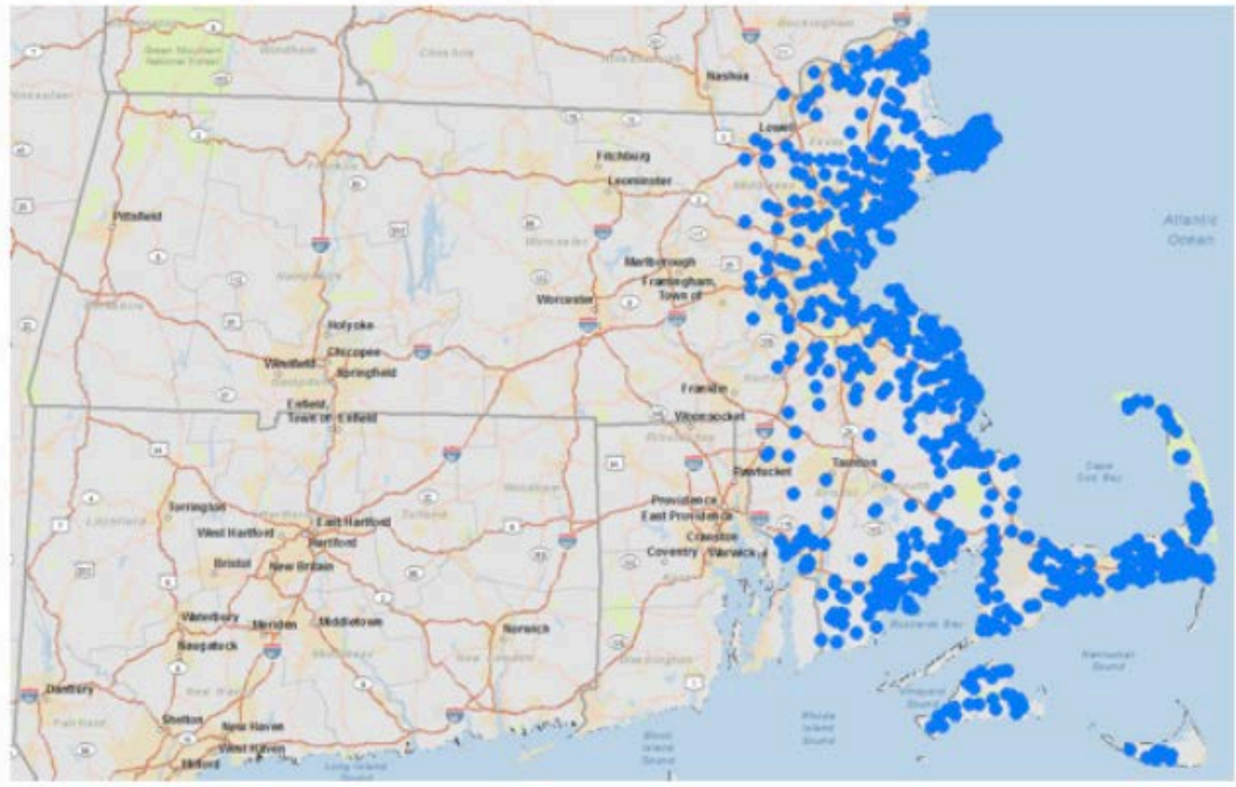
THE MASSACHUSETTS FISHING ECONOMY IS IMPORTANT TO COASTAL COMMUNITIES

- The "living resources" sector of the Massachusetts marine economy, which includes fisheries as well as seafood processors and vendors, is more valuable in Massachusetts than in geographically similar states.
- **This sector generates more than $600 million Gross State Product (GSP),** compared to $200 million in Maine and less than $100 million in either Connecticut, New Hampshire, or Rhode Island.
- **This sector employs more than 5700 individuals across more than 500 establishments and generates over $300 million in annual wages.**

Figure 11
Establishments, Employment, Total Wages, and GSP

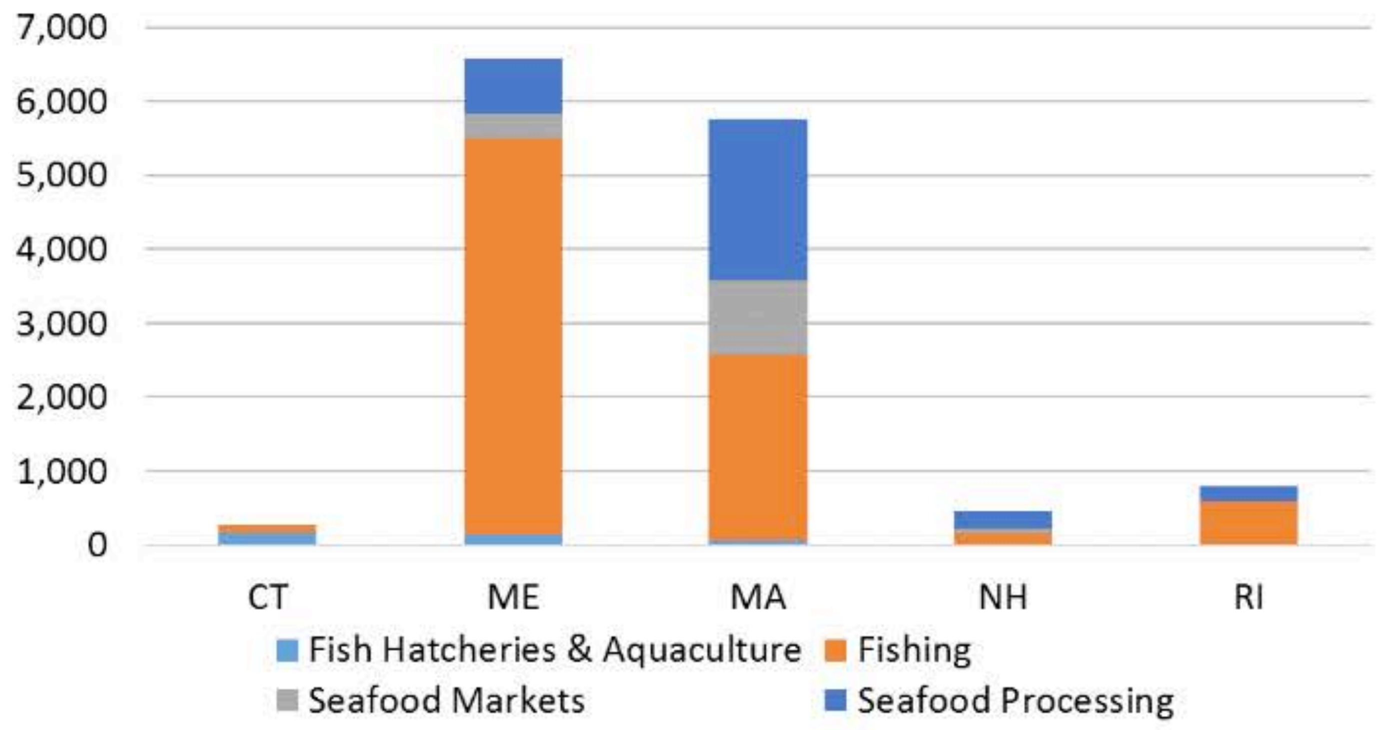
Source: ENOW; NOEP; Authors' calculations.

Figure 13
Massachusetts' Living Resources Businesses [43]



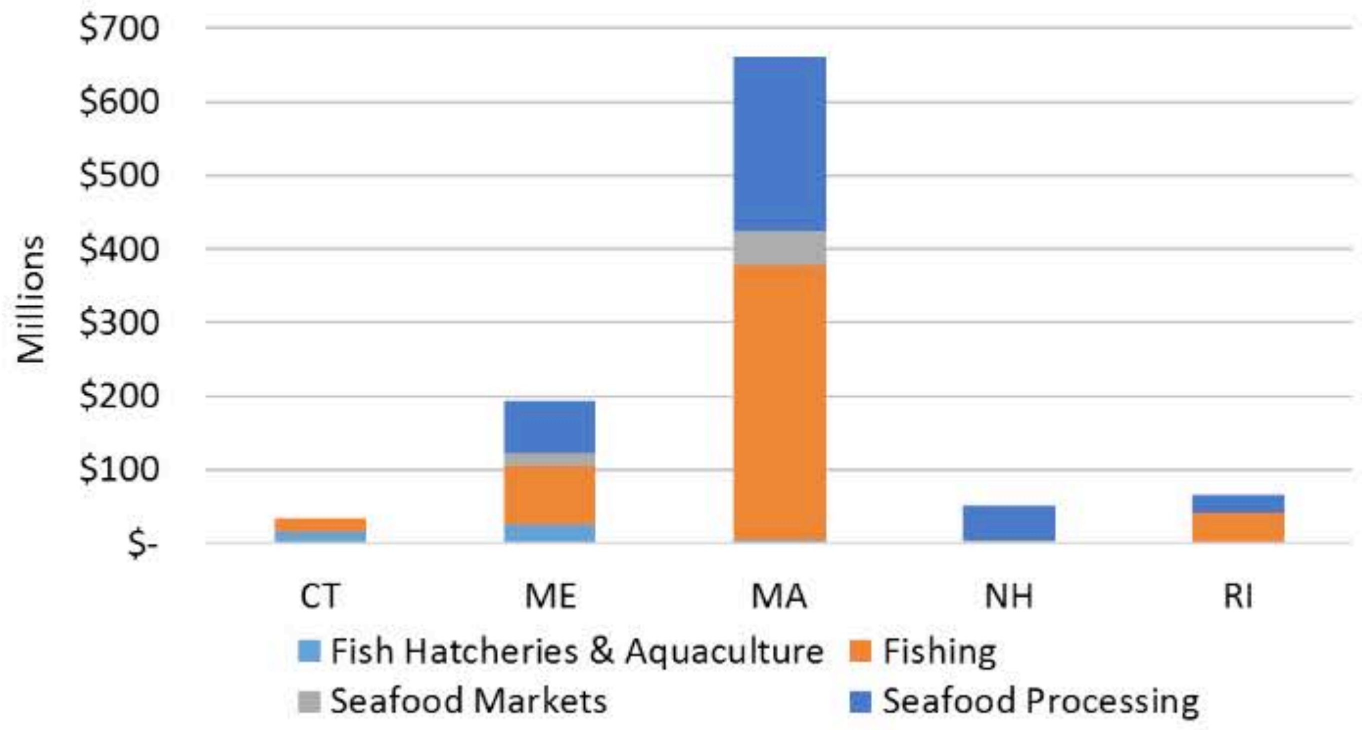
Source: Public Policy Center.

Figure 18
Subsector Employment by State, Living Resources, 2013



Source: ENOW; NOEP; Authors' calculations.

Figure 19
Subsector GSP by State, Living Resources, 2013



Source: ENOW; NOEP; Authors' calculations.

Figures from the UMass Dartmouth Public Policy Center 2017 Report: *Navigating the Global Economy: A Comprehensive Analysis of the Massachusetts Maritime Economy*

MASSACHUSETTS CONTAINS SOME OF THE MOST ACIDIFICATION-VULNERABLE COMMUNITIES IN THE UNITED STATES

- **The dependence of the Massachusetts marine economy on shellfish makes it particularly vulnerable to the effects of ocean acidification,** according to a study that examined the relative vulnerability of coastal communities across the United States[1].
- This study based the relative "sensitivity" of communities on several factors, including landed value of mollusks, percentage of total fishery revenues derived from mollusks, and number of shellfishing licenses administered.

Economic vulnerability of US coastal communities to changes in mollusk fisheries

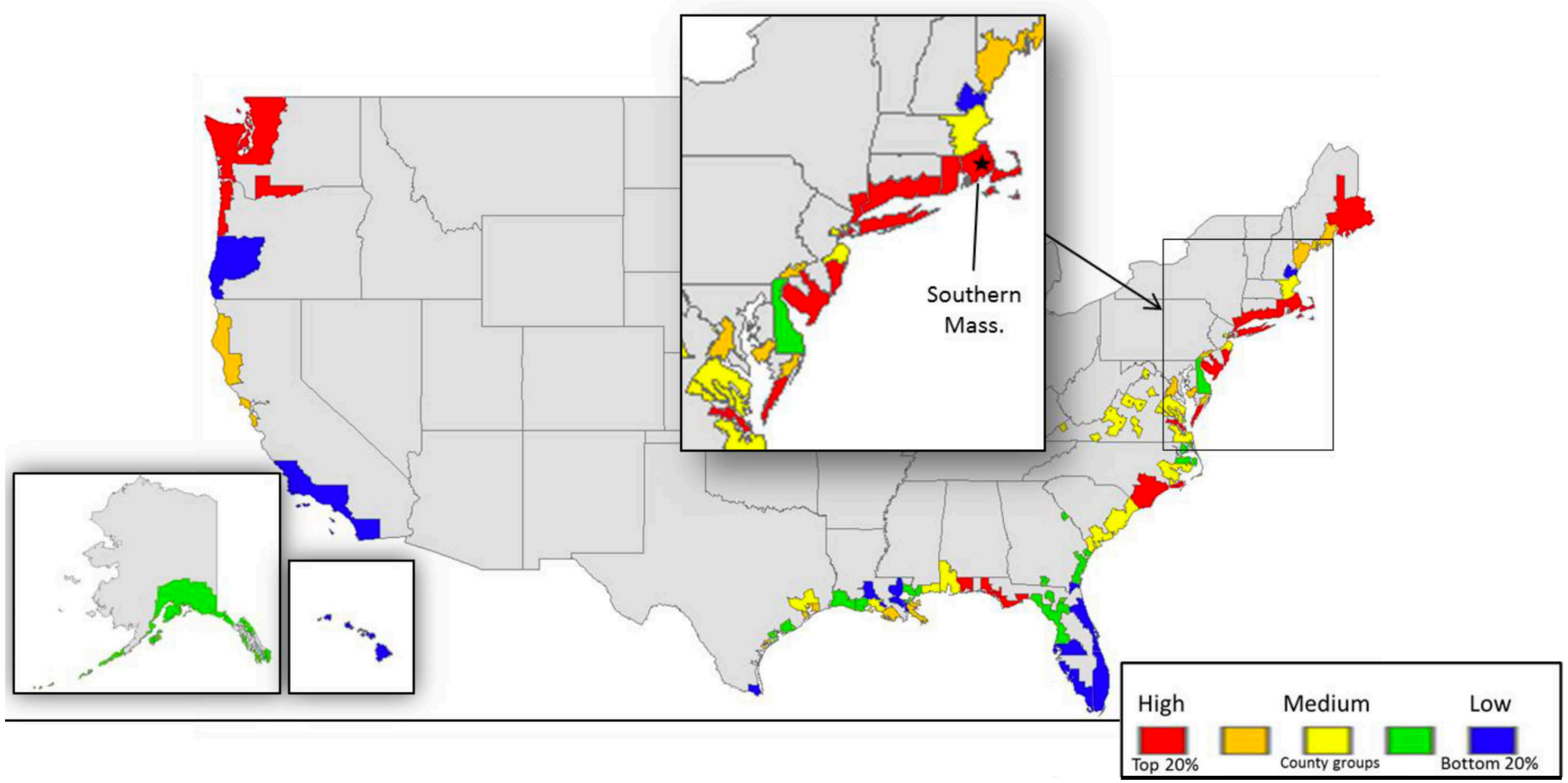


Figure from Ekstrom et al., 2015. *Vulnerability and adaptation of US shellfisheries to ocean acidification.*

[1] Ekstrom et al., 2015. *Vulnerability and adaptation of US shellfisheries to ocean acidification.*

[2] https://www.fisheries.noaa.gov/national/sustainable-fisheries/fisheries-united-states&sa=D&ust=1609917709745000&usg=AFQjCNGgSlhGSrlTUhZef_K9qCp8rUJkKA

MASSACHUSETTS CONTAINS SOME OF THE MOST ACIDIFICATION-VULNERABLE COMMUNITIES IN THE UNITED STATES

- Southeastern Massachusetts has the highest mollusk harvest revenues of any coastal area in the United States[2]. Southeastern Massachusetts has the second highest number of licenses and highest number of licenses and fourth highest proportion of seafood revenues from mollusks in the United States[1].
- **The adaptive capacity of Massachusetts coastal communities is among the highest in the United States[1].** Factors used to assess adaptive capacity included access to scientific knowledge, employment alternatives, and potential for political action.

Economic vulnerability of US coastal communities to changes in mollusk fisheries

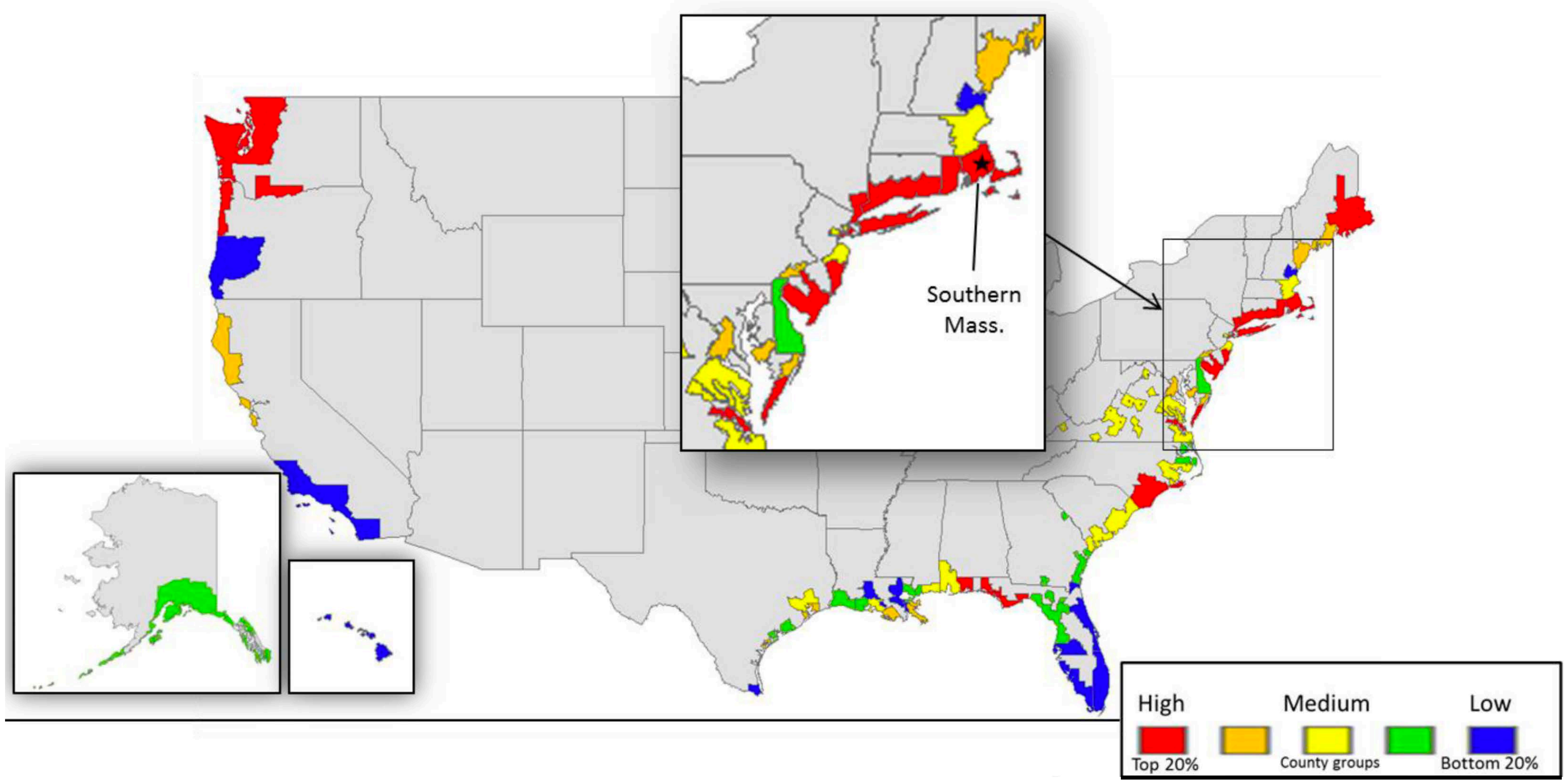


Figure from Ekstrom et al., 2015. *Vulnerability and adaptation of US shellfisheries to ocean acidification.*

[1] Ekstrom et al., 2015. *Vulnerability and adaptation of US shellfisheries to ocean acidification.*

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SHELLFISH HAVE BECOME INCREASINGLY IMPORTANT TO NEW ENGLAND FISHERIES

- Over the past six decades, shellfish landing value has increased continuously compared to finfish. **As shellfish become a more prominent feature of the marine economy, the economy as a whole becomes more susceptible to ocean acidification.**
- Between 1958 and 1968, American Lobsters and Sea Scallops constituted roughly 40% of total landing value.
- Between 2008 and 2018, American Lobsters and Sea Scallops constituted roughly 70% of total landing value.

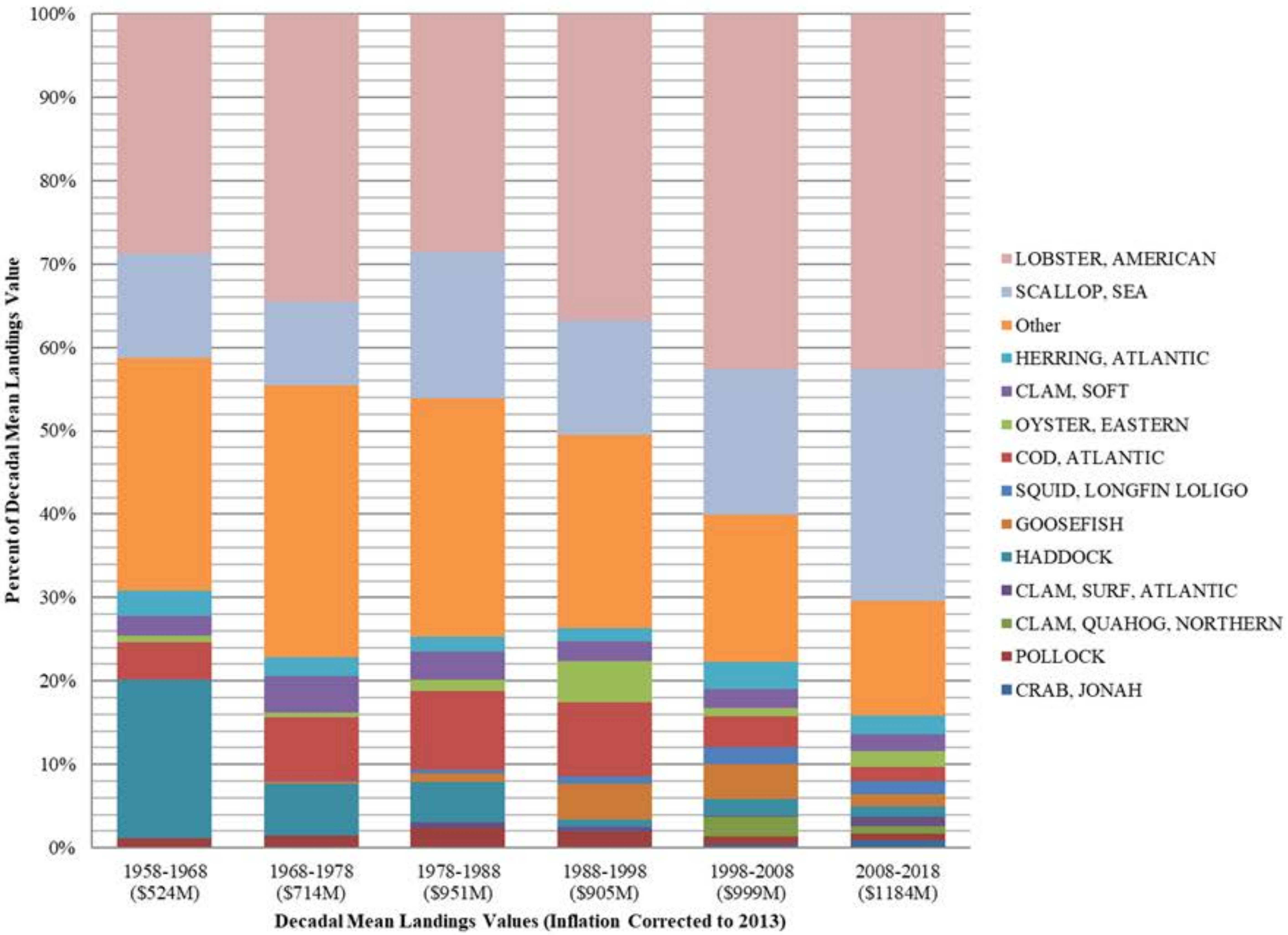
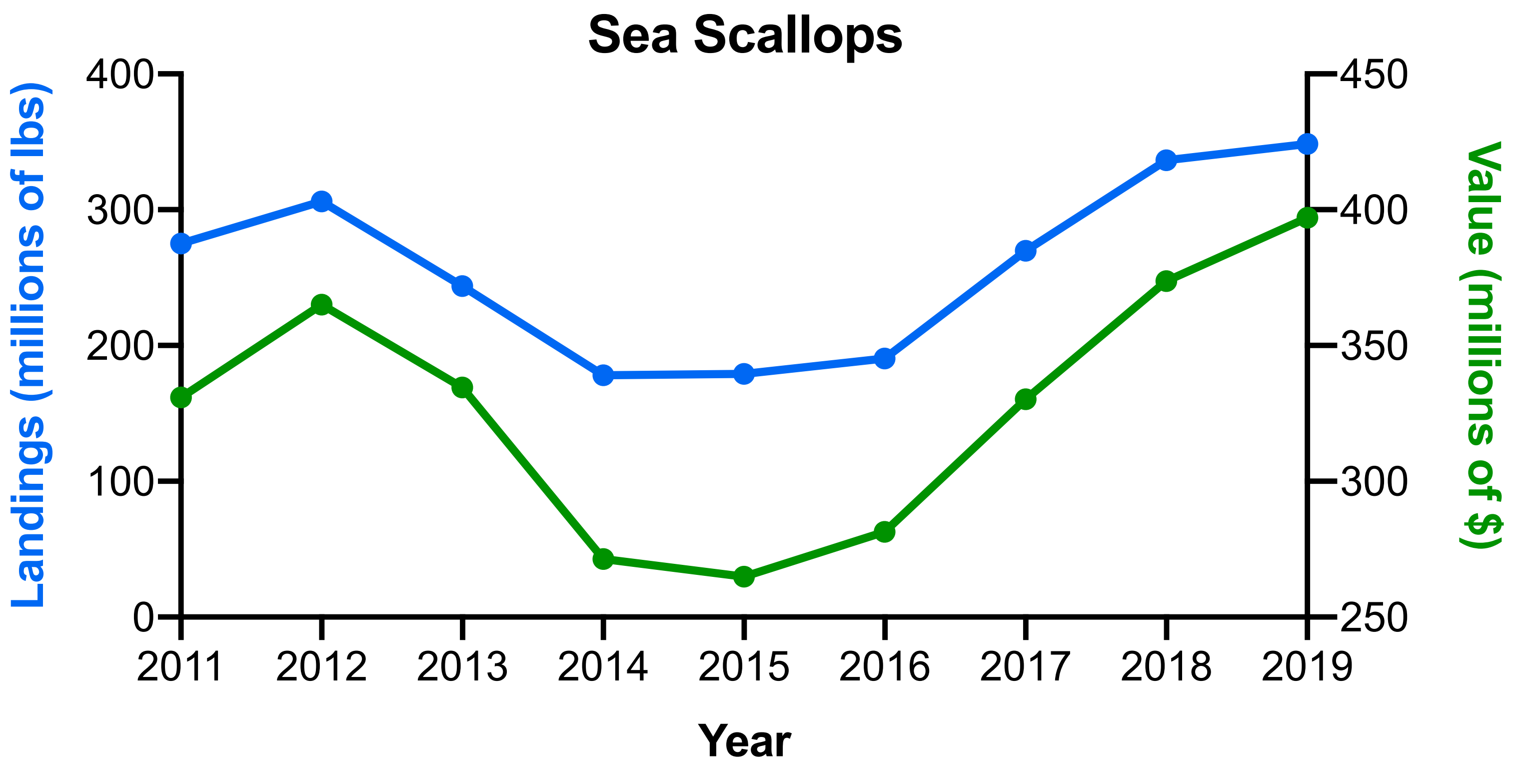


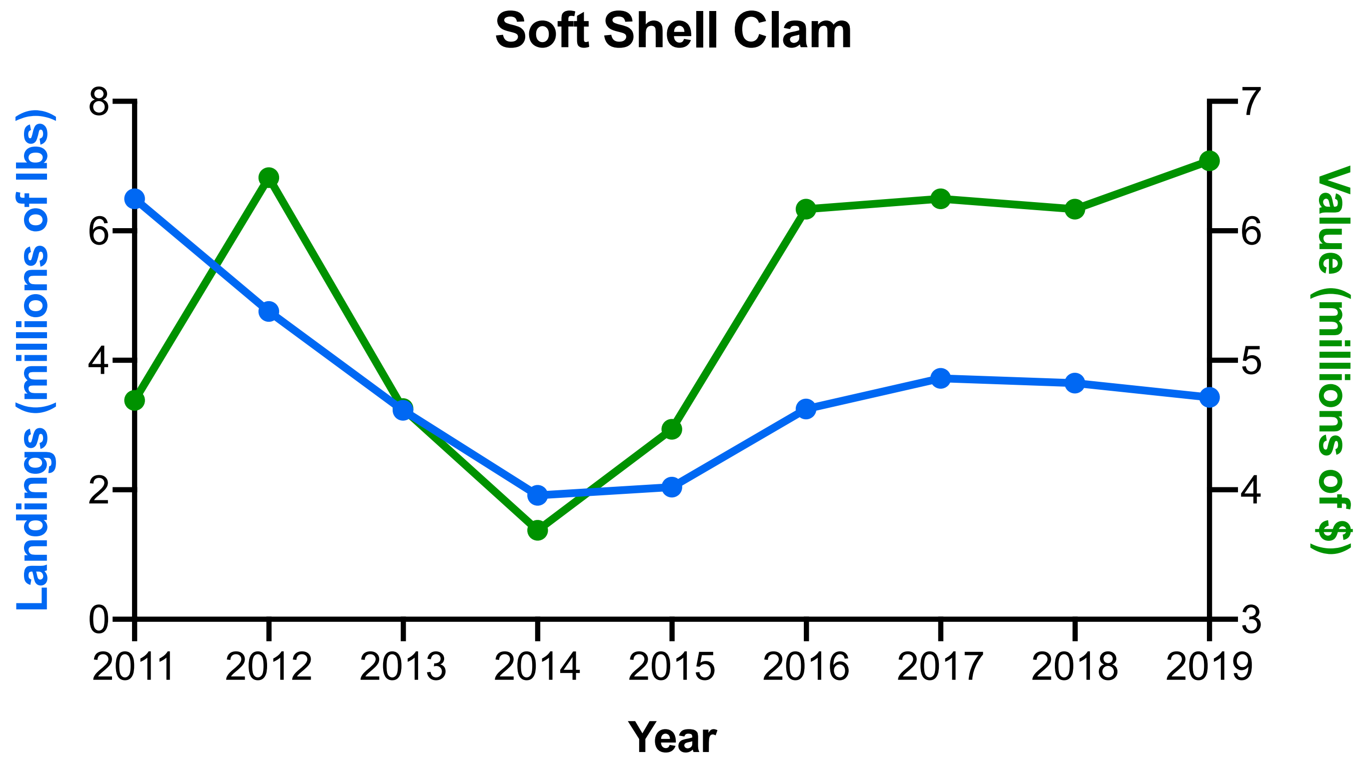
Figure adapted from Siedlecki *et al.*, 2020. *Projecting ocean acidification impacts for the Gulf of Maine to 2050: New tools and expectations*

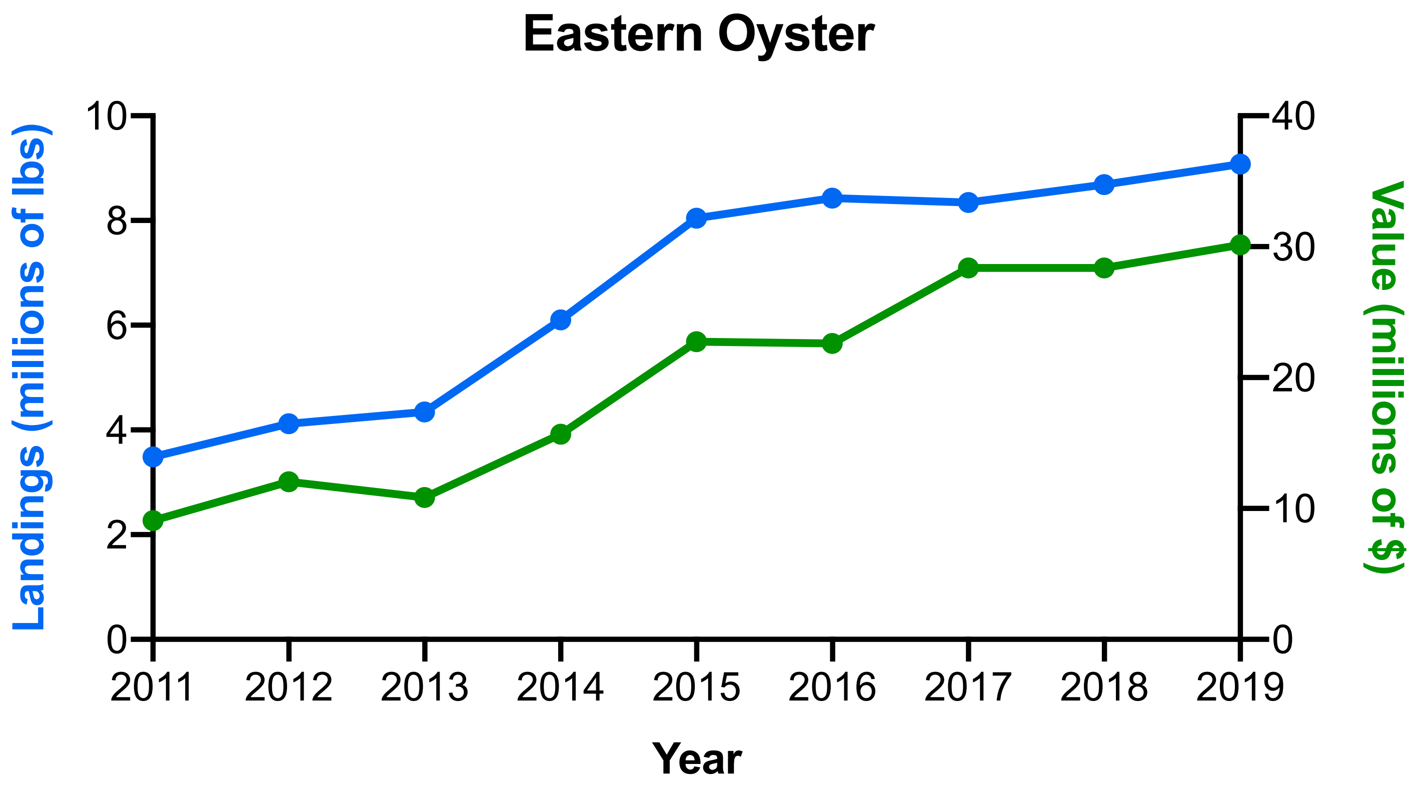
MOLLUSKS IN MASSACHUSETTS

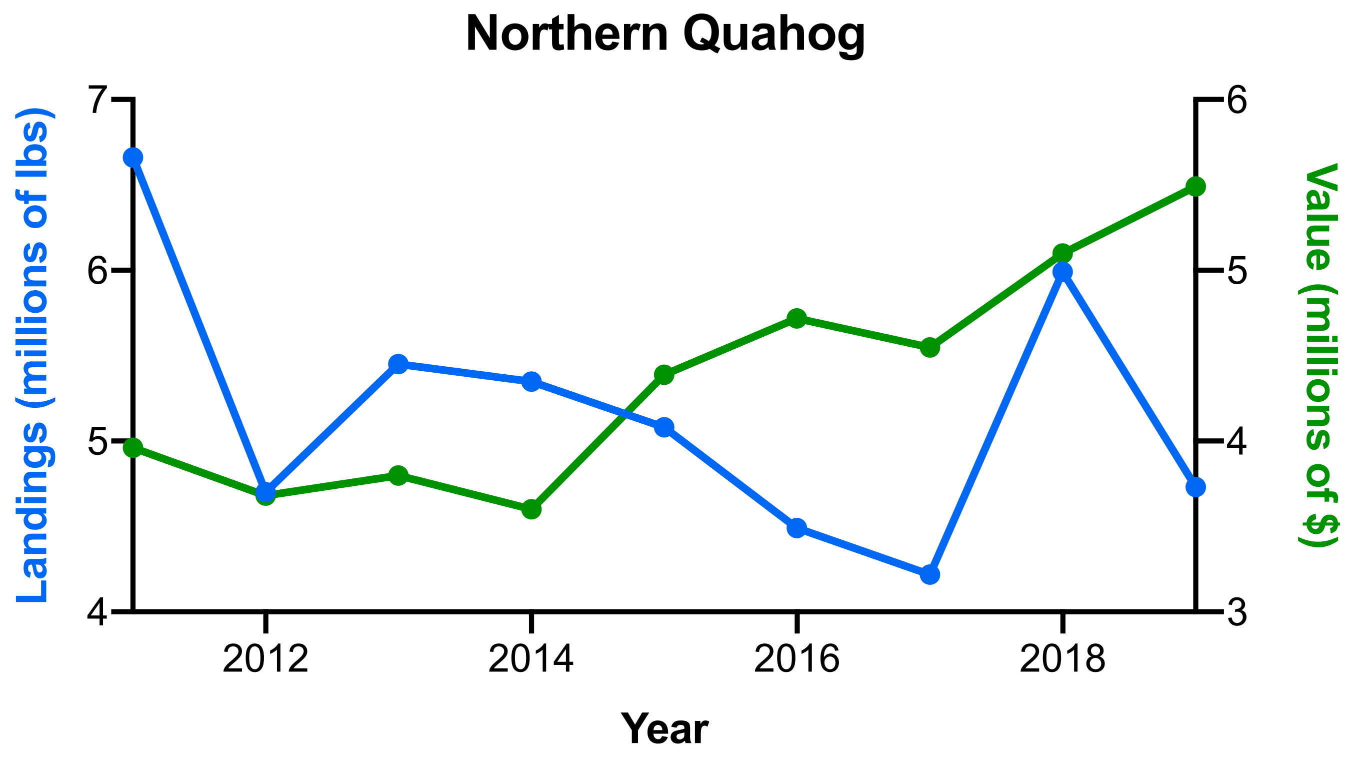
- The values of several acidification-sensitive mollusk species have increased over the past decade.

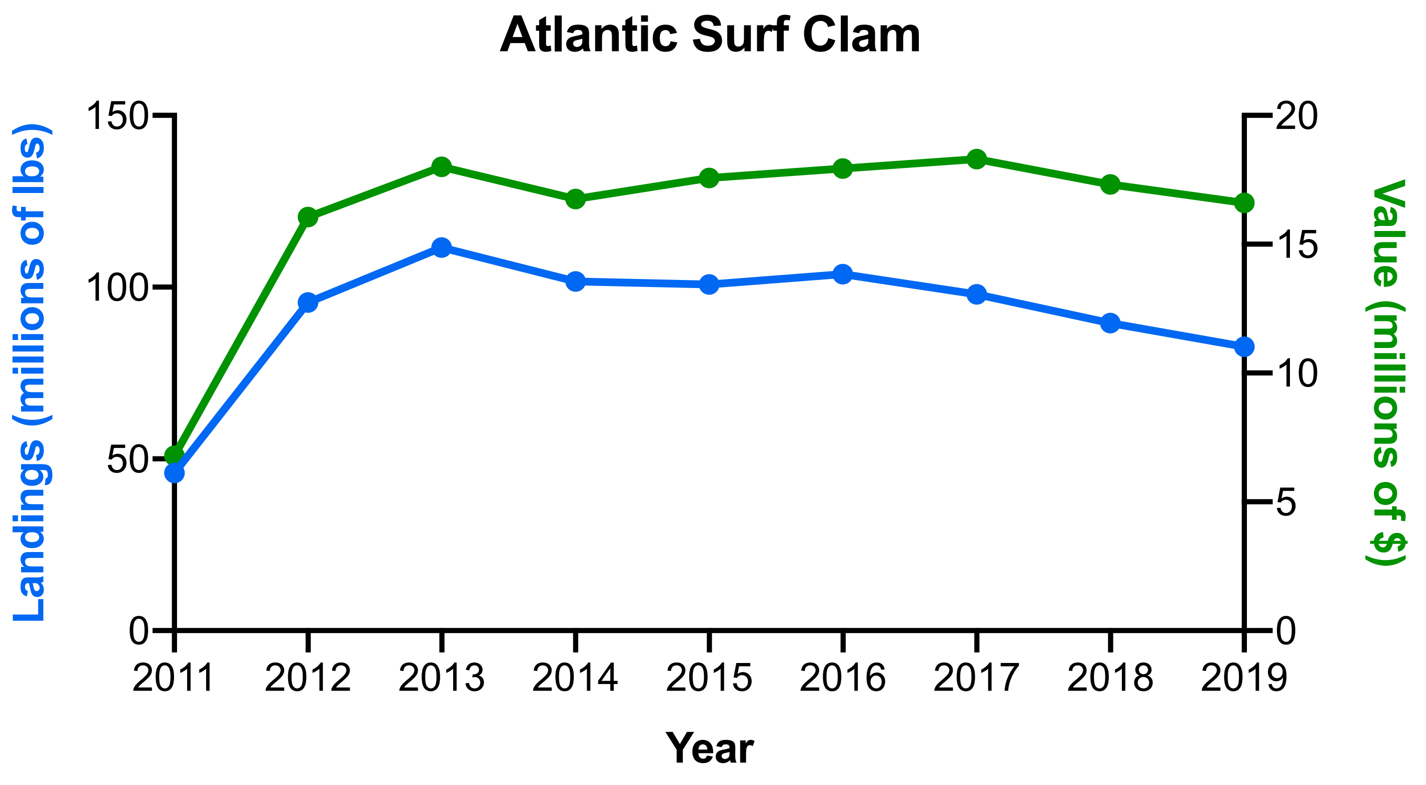
- **The total value of all mollusks harvested in Massachusetts now exceeds $459 million annually**, with the majority derived from sea scallop landings.

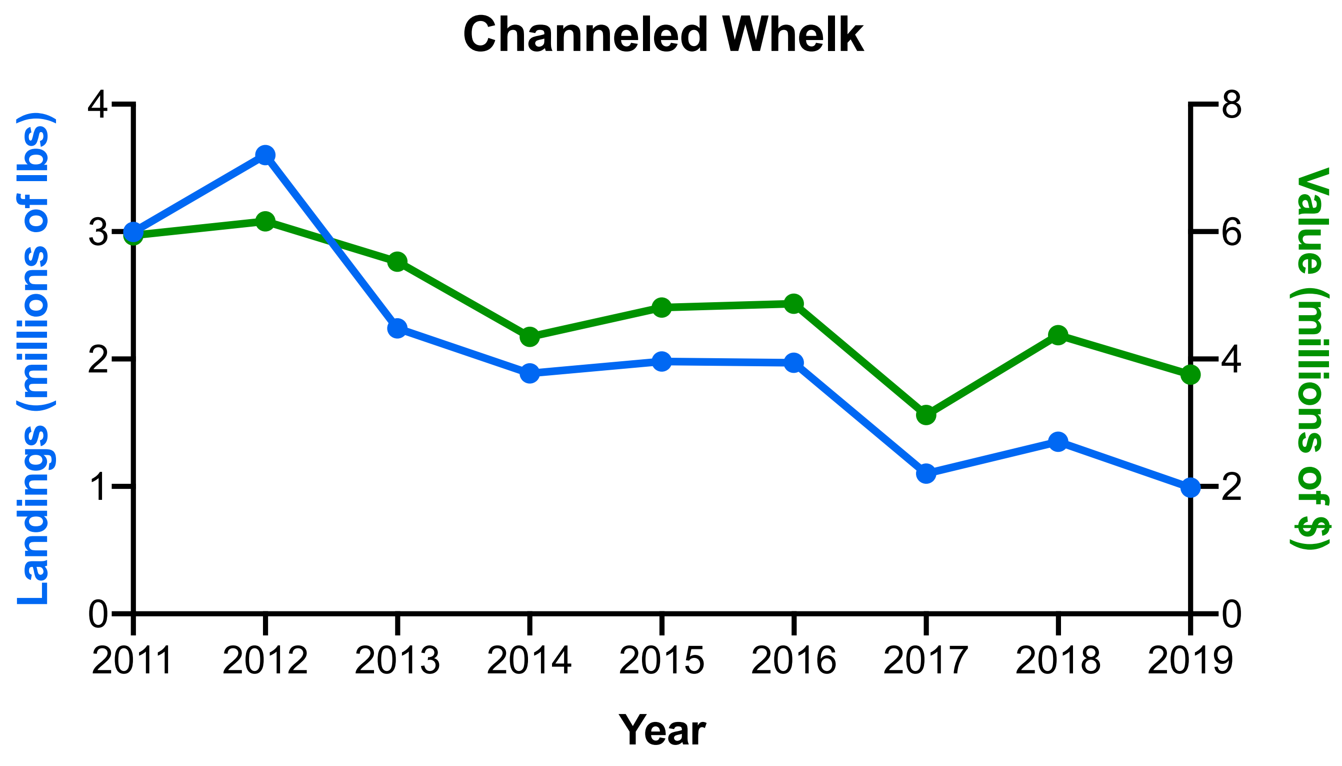








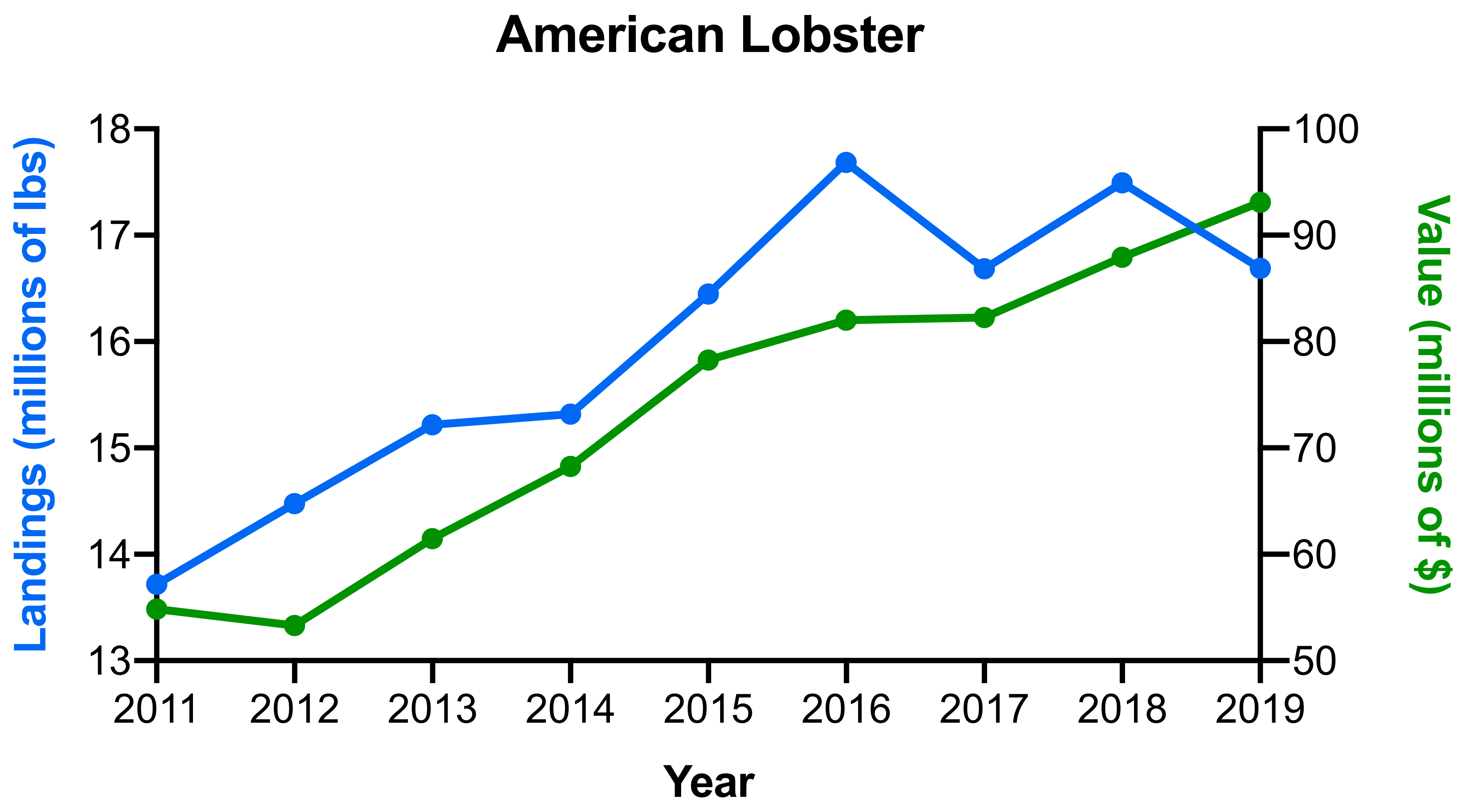


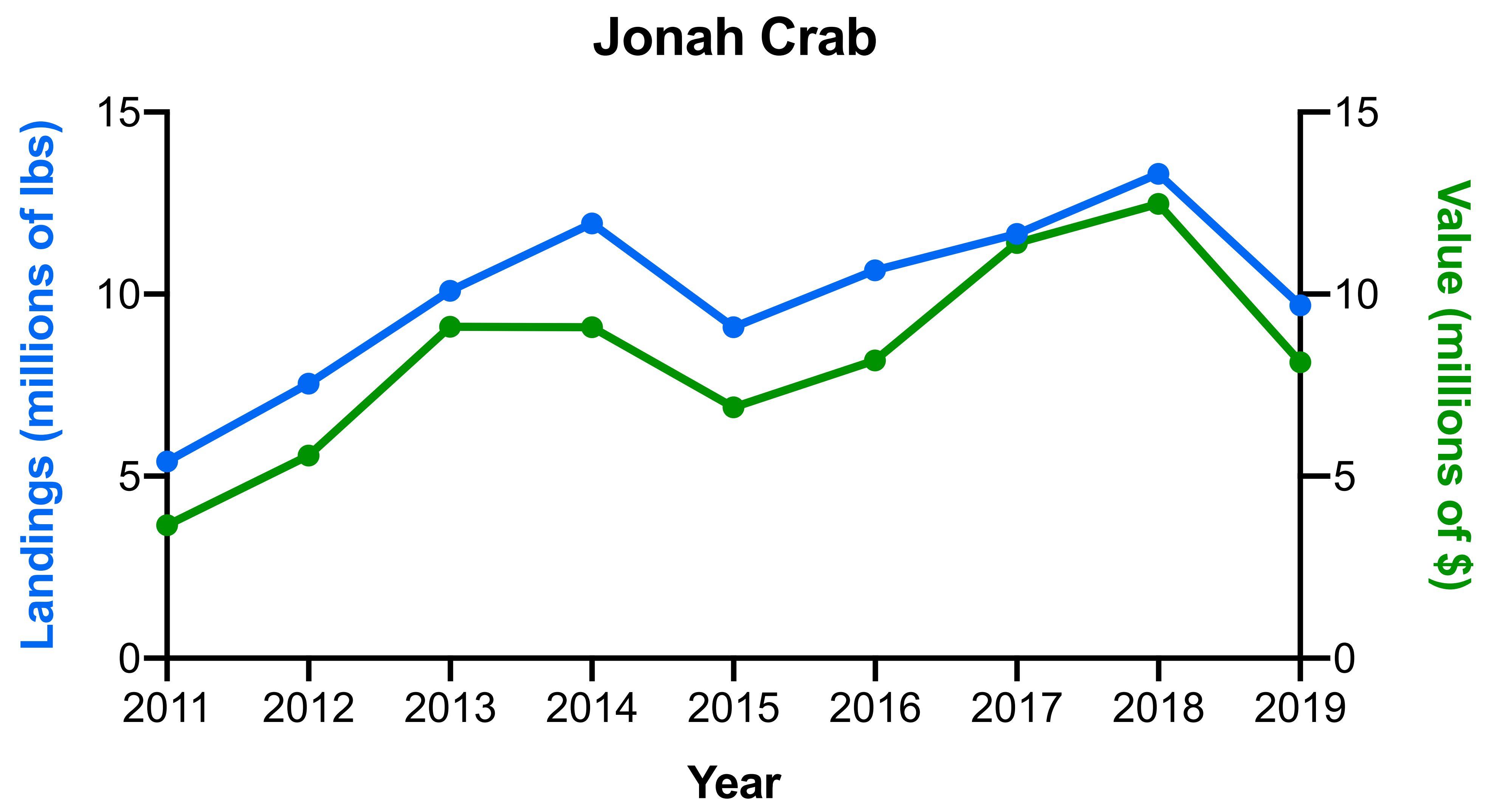


Data from the Massachusetts Division of Marine Fisheries Annual Reports

CRUSTACEANS IN MASSACHUSETTS

- The total value of American lobsters caught in Massachusetts has increased by nearly 67% over the past nine years.
- While these species are expected to be somewhat less susceptible to ocean acidification than mollusks, their contribution to the marine economy makes certain research subjects (such as the effects of multimodal stress) worth investing in.

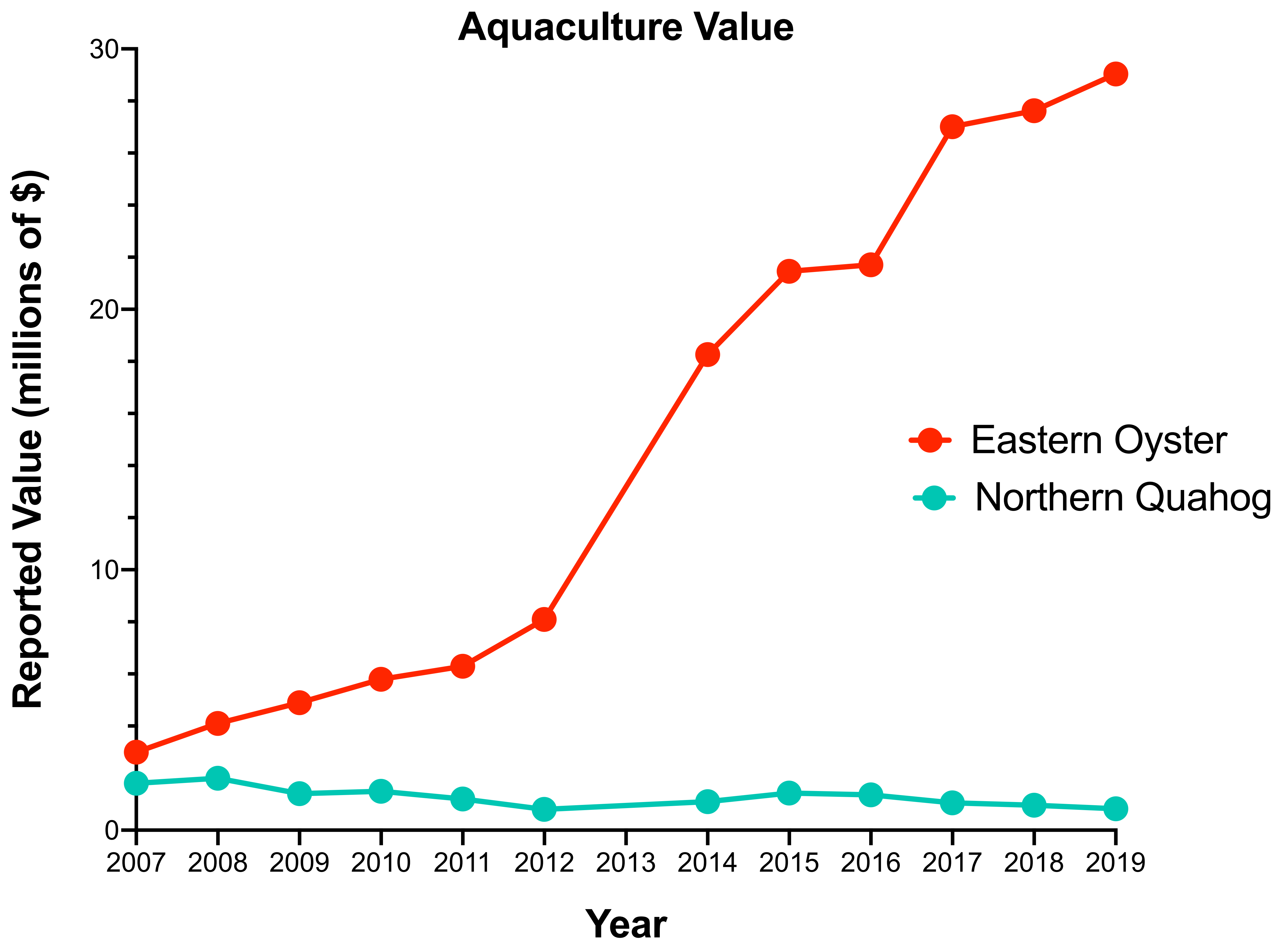




Data from the Massachusetts Division of Marine Fisheries Annual Reports

AQUACULTURE IN MASSACHUSETTS

- Massachusetts defines aquaculture as “the rearing of aquatic animals or the cultivation of aquatic plants for food.”(1)
- In 2018, DMF issued 391 private and 32 municipal shellfish propagation permits. There are currently 586 lease sites covering 1202 acres across 30 coastal municipalities. The average size of a private shellfish aquaculture grant site is 2.6 acres and 89% of permit holders have less than a 5 acre grant site.(2)
- **The degree of environmental control that aquaculture offers relative to wild harvesting may make it more adaptable to ocean acidification.**

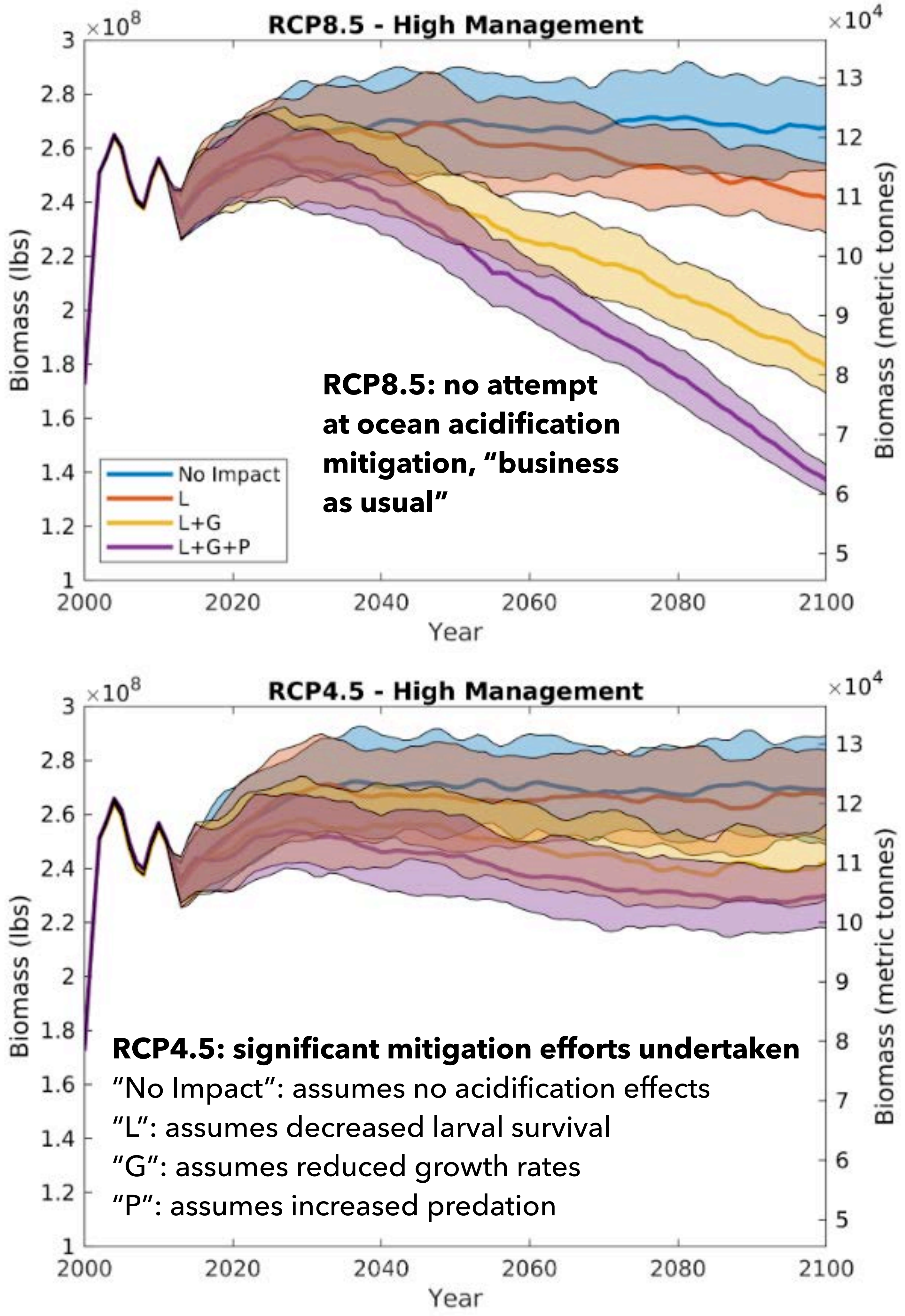


[1] https://www.mass.gov/service-details/aquaculture
[2] Massachusetts Shellfish Initiative: 2020 Assessment Report
Figure data from the Massachusetts Division of Marine Fisheries Annual Reports

THE LONG-TERM ECONOMIC EFFECTS OF OCEAN ACIDIFICATION WILL VARY BASED ON ACTIONS TAKEN NOW

- Economic forecasts attempt to model shellfish yields based on assumptions about future acidification rates, including policies aimed at mitigating acidification. Certain models also consider secondary effects of acidification, such as increased rates of predation resulting from decreases in shell thickness.
- **All models agree that shellfishing economies will suffer as a result of ocean acidification. The degree of harm that occurs will depend on the extent of mitigation efforts undertaken now.**
- The U.S. shellfishing industry is expected to lose more than $400 million annually by 2100 as a result of ocean acidification(1).

Effects of ocean acidification on scallop biomass



Effects of ocean acidification on mollusk biomass in the United States

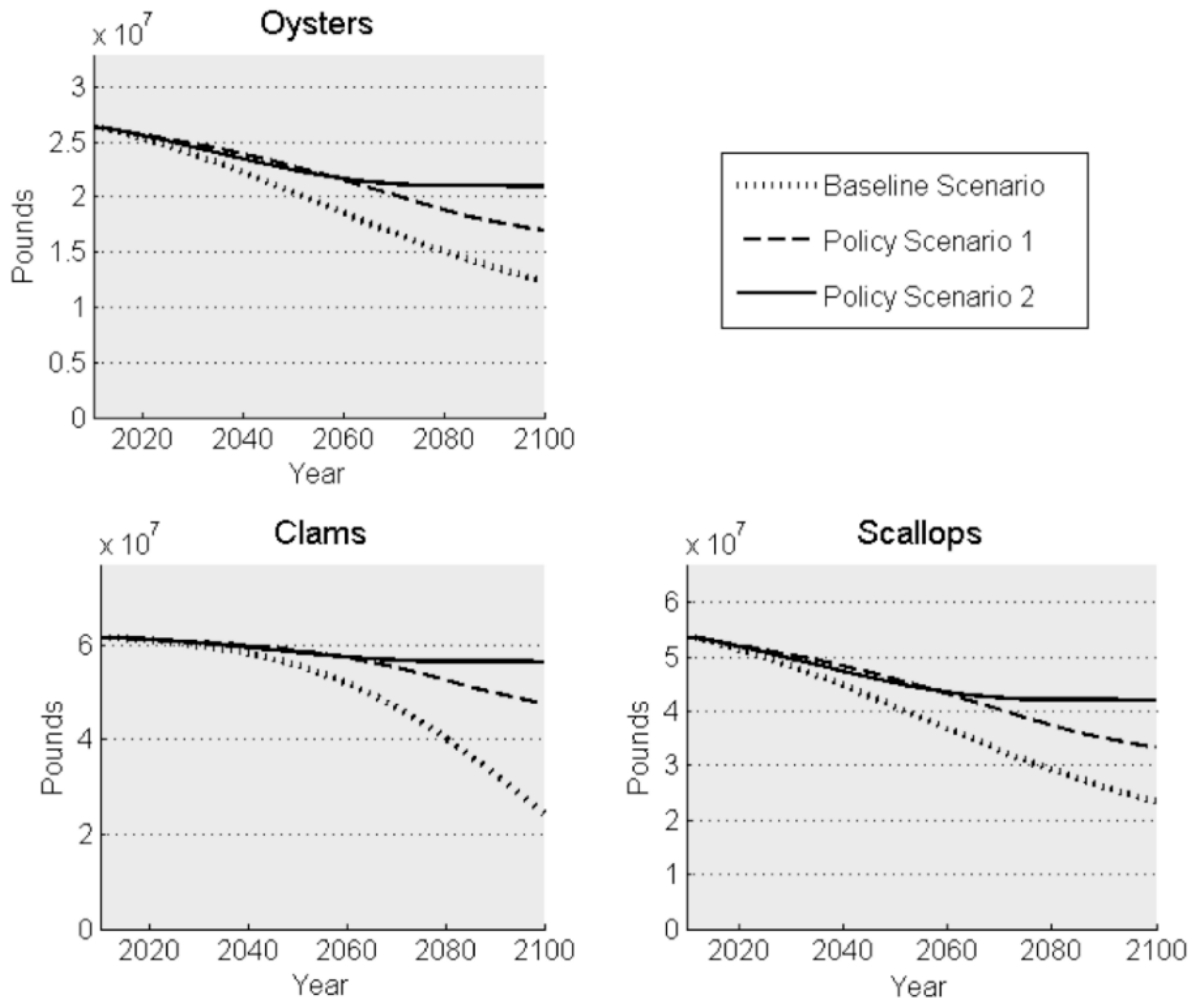


Figure 1 adapted from Rheuban *et al.*, 2018. *Projected impacts of future climate change, ocean acidification, and management on the US Atlantic sea scallop.*
Figure 2 adapted from Moore 2015. *Welfare Estimates of Avoided Ocean Acidification in the US Mollusk Market.*
[1] Doney *et al.*, 2020. *The Impacts of Ocean Acidification on Marine Ecosystems and Reliant Human Communities*

CERTAIN SHELLFISHING PRACTICES MAY HELP MITIGATE THE EFFECTS OF OCEAN ACIDIFICATION

- Planting marine algae (kelp, gracilaria, ulva) at shellfishing sites may reduce acidification by absorbing CO_2. These plants can be harvested and sold if a relevant market exists. However, planting algae requires balancing these benefits with potential negative effects associated with uncontrolled algae growth, and should be done primarily in open areas.
- Spreading waste shell around the beds of shellfishing sites can increase carbonate concentrations locally, potentially buffering against the effects of pH changes. Waste shell also introduces substrate for setting larval shellfish.
- Adopting or developing more acidification-resistant shellfish species can protect the industry against long-term trends towards ocean acidification.
- Individual hatcheries can monitor water quality and adjust pH accordingly, in order to avoid exposing larvae to acidic conditions.
- It is not clear which subset of these practices is best suited for use along the Massachusetts coastline. **Developing a set of best practices for the shellfishing industry in Massachusetts will provide some protection against the effects of ocean acidification.**

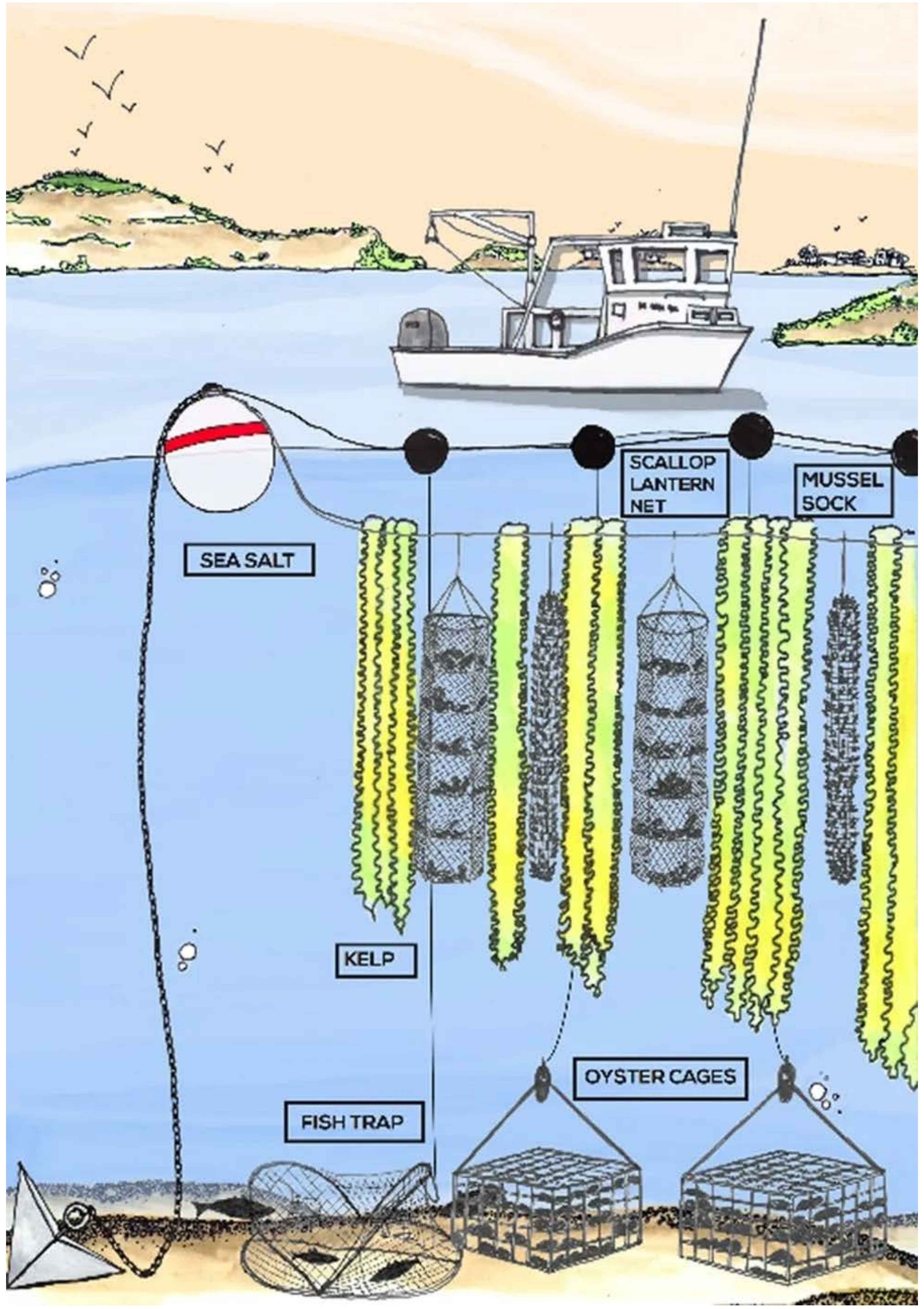


Figure adapted from Morrissey and Heidkamp, 2018. *A transition perspective on coastal sustainability.*

OCEAN STEWARDSHIP IN MASSACHUSETTS

EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS (EOEEA)

- **Massachusetts Department of Environmental Protection (MASSDEP)**
- MassDEP is the lead state agency for administering and enforcing environmental laws and reducing pollution in Massachusetts' natural environments.
- MassDEP has already promulgated regulations and developed programs targeting nutrient pollution, the most stringent of which have been nutrient "diets" (total maximum daily loads, or TMDLs) in estuaries.
- The Massachusetts Estuary Project (MEP) is a collaborative effort between MassDEP, the School for Marine Science and Technology at the University of Massachusetts-Dartmouth (SMAST), local communities, and regional and federal agencies. Since 2001, MEP has studied the problem of nutrient buildup in estuaries on the southeastern coast of the state. Research from this project helps MassDEP develop TMDLs.
- MassDEP does not evaluate the effect that nutrient pollution has on ocean pH. The department does not seek to determine how coastal ocean acidification will impact coastal activities.
- MassDEP's role in resisting ocean acidification should be to require that communities undertake appropriate measures to control land-based nutrient sources to affected water bodies, in order to decelerate pH changes due to eutrophication.
- Several ongoing programs are aimed at addressing nutrient pollution. These include the Surface and Groundwater Discharge Programs, Stormwater Standards, and the Municipal Separate Storm Sewer System (MS4) Program. These programs act to mitigate ocean acidification by controlling nutrient discharges, and will seek to continue to modify permits and implement new permit requirements to reduce nutrient pollution.

Related Programs:

- Watershed Planning Program
- Massachusetts Estuaries Project (MEP)
- Combined Sewer Overflow Control Program
- Wetlands Program
- State Capital Improvement Revolving Fund
- Surface Water Discharge Program
- Stormwater Standards
- Municipal Separate Storm Sewer System Program

EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS (EOEEA)

- **Massachusetts Office of Coastal Zone Management (CZM)**
- CZM is the lead policy and planning agency for coastal and ocean issues in Massachusetts.
- CZM works to balance the impact of human activities with the protection of coastal and marine resources.
- CZM's role in resisting coastal ocean acidification should be to support agencies and institutions as they incorporate pH variation into their existing monitoring efforts, conduct research on coastal acidification's effects, and improve wetland conservation to combat nutrient pollution.

Related Programs:

- Coastal Pollution Remediation Program
- Coastal Wetland Monitoring and Assessment

STATE PROGRAMS

- **Resilient Massachusetts Action Team**
  - Implements the State Hazard Mitigation and Climate Adaptation Plan. This plan projects effects for four climate-related impacts – precipitation, sea level rise, rising temperatures, and extreme weather – and fourteen natural hazards. This plan does not include ocean acidification as a natural hazard or project its effects.
- **Ocean Advisory Commission**
  - Permanent legislative body charged with aiding EOEEA with development of the Ocean Management Plan. The Ocean Management Plan protects critical marine habitat and important water-dependent uses and sets standards for new ocean-based projects in Massachusetts ocean waters.
- **Environmental Trust Fund**
  - Provides grant money for municipal water quality improvement projects through environmental license plate revenues. The vast majority of funds do not cover coastal uses or nutrient abatement, and no funding has ever been allocated to the study of ocean acidification.

STATE PROGRAMS

- **Massachusetts Bays National Estuary Partnership (MassBays)**
  - The program is administered by the Massachusetts Bays National Estuary Partnership (funded by EPA). Since 2011, an average of $100,000 is made available every 1-2 years for projects that address coastal water quality conditions including monitoring and assessment. These projects provide data to inform management decisions to reduce coastal pollution. Projects funded under this grant have received subsequent funding by other grants (e.g. Section 319 Nonpoint Source Grant) to conduct feasibility assessments, construct stormwater best management practices, and carry out other implementation efforts. Ocean acidification is not a priority item for this organization, though it has been identified by MassBays as a worrying trend.
- **Buzzards Bay National Estuary Program**
  - An advisory and planning unit of the Massachusetts Office of Coastal Zone Management that principally works with non-governmental organizations and fifteen municipalities in the Buzzards Bay watershed. The program's mission is to protect and restore water quality and living resources in Buzzards Bay and its surrounding watershed through the implementation of the Buzzards Bay Comprehensive Conservation and Management Plan (CCMP). In the Buzzards Bay CCMP, adaptation to climate change is a high priority, and how shifts in precipitation, water temperatures, and ocean acidification caused by greenhouse gas emissions alter coastal ecosystem structure and function, including populations of non-natives, is called out as an important research priority. Two ongoing monitoring programs the NEP supports (embayment waters and stormwater discharges) track pH in samples collected.

OTHER PROGRAMS

- **National Oceanic and Atmospheric Administration (NOAA)**
  - NOAA's mission is to understand and predict changes in climate, weather, oceans, and coasts, and to share that information with others to aid in the conservation and management of coastal and marine resources. NOAA provides some funding to states for research as well as for coastal and monitoring programs.
- **Northeastern Coastal Acidification Network (NECAN)**
  - NECAN is the leading group in the region for the synthesis and dissemination of ocean and coastal acidification information. Created by the Northeastern Regional Association of Coastal Ocean Observing Systems in 2013, NECAN is a partnership among governmental agencies, industry members, and the scientific community. NECAN serves as a conduit through which decision makers and stakeholders are able to provide guidance for regional research and monitoring.

STATE GRANT PROGRAMS REDUCING COASTAL NUTRIENT POLLUTION

Massachusetts has existing programs and infrastructure that can be leveraged to limit coastal acidification caused by eutrophication:

- **CZM's Coastal Pollutant Remediation Program:** Established in 1994 to help communities identify and improve water quality impaired by non-point source pollution.
- **DEP’s Section 319 grant program:** Program under the federal Clean Water Act. Provides funding for implementation of projects that address the prevention, control, and abatement of nonpoint source (NPS) pollution.
- **DEP's Section 604b grant programs:** Program for water quality assessment and watershed management planning.
- **MassBays's Healthy Estuaries grant program:** EPA funds projects that address coastal water quality conditions including monitoring and assessment.
- **Buzzards Bay NEP municipal mini-grant program:** EPA funds projects in Buzzards Bay ranging from water quality monitoring and assessment to stormwater management planning and Best Management Practices design.
- **Southern New England Program (SNEP):** SNEP Watershed Grants provide financial support to address water pollution, habitat degradation, nutrient pollution and other high-priority environmental issues in the region.

EXISTING WATER QUALITY MONITORING NETWORKS WERE NOT ESTABLISHED TO COLLECT ACIDIFICATION PARAMETERS

- Several local water quality monitoring programs are currently in operation. Water quality monitoring has historically focused on nutrients and bacteria, and has more recently focused on ocean acidification.
- Existing programs that capture pH generally do not sample frequently enough to provide insight into daily fluctuations, however the Cape Cod Cooperative Extension is one program that does record pH continuously in several embayments.

Organization	Geographic Area	Start of Monitoring	Frequency of Monitoring	Parameters Monitored	Monitoring sufficient for OA?
MWRA	Boston Harbor & Mass Bay	1992 (updated in 1997, 2004, 2009)	Monthly	temp, salinity, DO, turbidity, nutrients, chl-A, bacteria, plankton, pH	no
MWRA	Boston Harbor & Mass Bay	2018	Monthly	DIC, pH (4 stations)	yes
Buzzards Bay Coalition (Baywatchers)	Buzzards Bay	1992	Weekly & biweekly May - Sept (volunteers)	DO, temp, salinity, water clarity, TDN/TPN. orthoPhosphate, C/N ratios, Phytoplankton,	no (no pH monitoring)
Center for Coastal Studies	Cape Cod Bay (12 sites)	2006	Weekly or bi-weekly May - Oct	temperature, salinity, turbidity, dissolved oxygen, pH, and nutrients	no
Center for Coastal Studies	Cape Cod Bay and Nantucket Sound (120 sites)	2006	offshore data are collected once a month, year round	DO, temp, salinity, water clarity, nutrients, silicates, chlorophyll	no
Center for Coastal Studies	Duxbury Bay, Wellfleet Harbor, Provincetown Harbor	2020	twice a month May-Oct, monthly Nov-April	pH, total alkalinity (water samples)	yes
Cape Cod Cooperative Extension	Cape Cod Bay and Nantucket Sound	2004	Continuous (every 15 mins)	temp, salinity,conductivity, TDS, pH, DO, turbidity, chlorophyll A	no
Cape Cod Cooperative Extension	Near shellfish growing areas - exact locations TBD	2021	Continuous	pH, total alkalinity (sensors)	yes
MassBays National Estuary Partnership	Duxbury Harbor	2020	Continuous	pH, pCO2, temp, salinity, CDOM, DO (sensors)	yes
MassBays National Estuary Partnership	Duxbury Harbor	2021	Biweekly Jan-Dec (volunteers & staff)	DIC, total alkalinity (water samples)	yes
Salem Sound Coastwatch	Gloucester, Manchester, Beverly, Salem	2017	Monthly (July-Sept) (not in 2020)	temp, salinity, pH (porewater in mudflats)	yes
MassBays National Estuary Partnership	Salem Sound	2019	Monthly (July-Sept)	temp, salinity, pH, DO, turbidity, water clarity, nutrients, chl-A, isotopes (Salem Harbor) benthic	no
MA Division of Marine Fisheries (Shellfish Sanitation Program)	Statewide	mid-1980s	9000 samples per year	bacteria, temperature, pH	no
MA Division of Marine Fisheries	Statewide	1986	hourly at 52 fixed stations	temperature (bottom) in addition to fish metrics	no

EXISTING WATER QUALITY MONITORING NETWORKS WERE NOT ESTABLISHED TO COLLECT ACIDIFICATION PARAMETERS

- Accurately measuring ocean acidification requires measurement of a number of parameters. Calculating Ω_{ar} requires measuring any two of: alkalinity (A_T), pH, dissolved inorganic carbon (DIC) concentration, and pCO_2.
- **Many monitoring programs currently lack the capacity to measure Ω_{ar}, but modifications to expand parameters and update protocols could adapt existing programs to collect ocean acidification-specific data. New ocean acidification-specific monitoring is currently being planned.**

Organization	Geographic Area	Start of Monitoring	Frequency of Monitoring	Parameters Monitored	Monitoring sufficient for OA?
MWRA	Boston Harbor & Mass Bay	1992 (updated in 1997, 2004, 2009)	Monthly	temp, salinity, DO, turbidity, nutrients, chl-A, bacteria, plankton, pH	no
MWRA	Boston Harbor & Mass Bay	2018	Monthly	DIC, pH (4 stations)	yes
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Center for Coastal Studies	Cape Cod Bay and Nantucket Sound (120 sites)	2006	offshore data are collected once a month, year round	DO, temp, salinity, water clarity, nutrients, silicates, chlorophyll	no
Center for Coastal Studies	Duxbury Bay, Wellfleet Harbor, Provincetown Harbor	2020	twice a month May-Oct, monthly Nov-April	pH, total alkalinity (water samples)	yes
Cape Cod Cooperative Extension	Cape Cod Bay and Nantucket Sound	2004	Continuous (every 15 mins)	temp, salinity,conductivity, TDS, pH, DO, turbidity, chlorophyll A	no
Cape Cod Cooperative Extension	Near shellfish growing areas - exact locations TBD	2021	Continuous	pH, total alkalinity (sensors)	yes
MassBays National Estuary Partnership	Duxbury Harbor	2020	Continuous	pH, pCO2, temp, salinity, CDOM, DO (sensors)	yes
MassBays National Estuary Partnership	Duxbury Harbor	2021	Biweekly Jan-Dec (volunteers & staff)	DIC, total alkalinity (water samples)	yes
Salem Sound Coastwatch	Gloucester, Manchester, Beverly, Salem	2017	Monthly (July-Sept) (not in 2020)	temp, salinity, pH (porewater in mudflats)	yes
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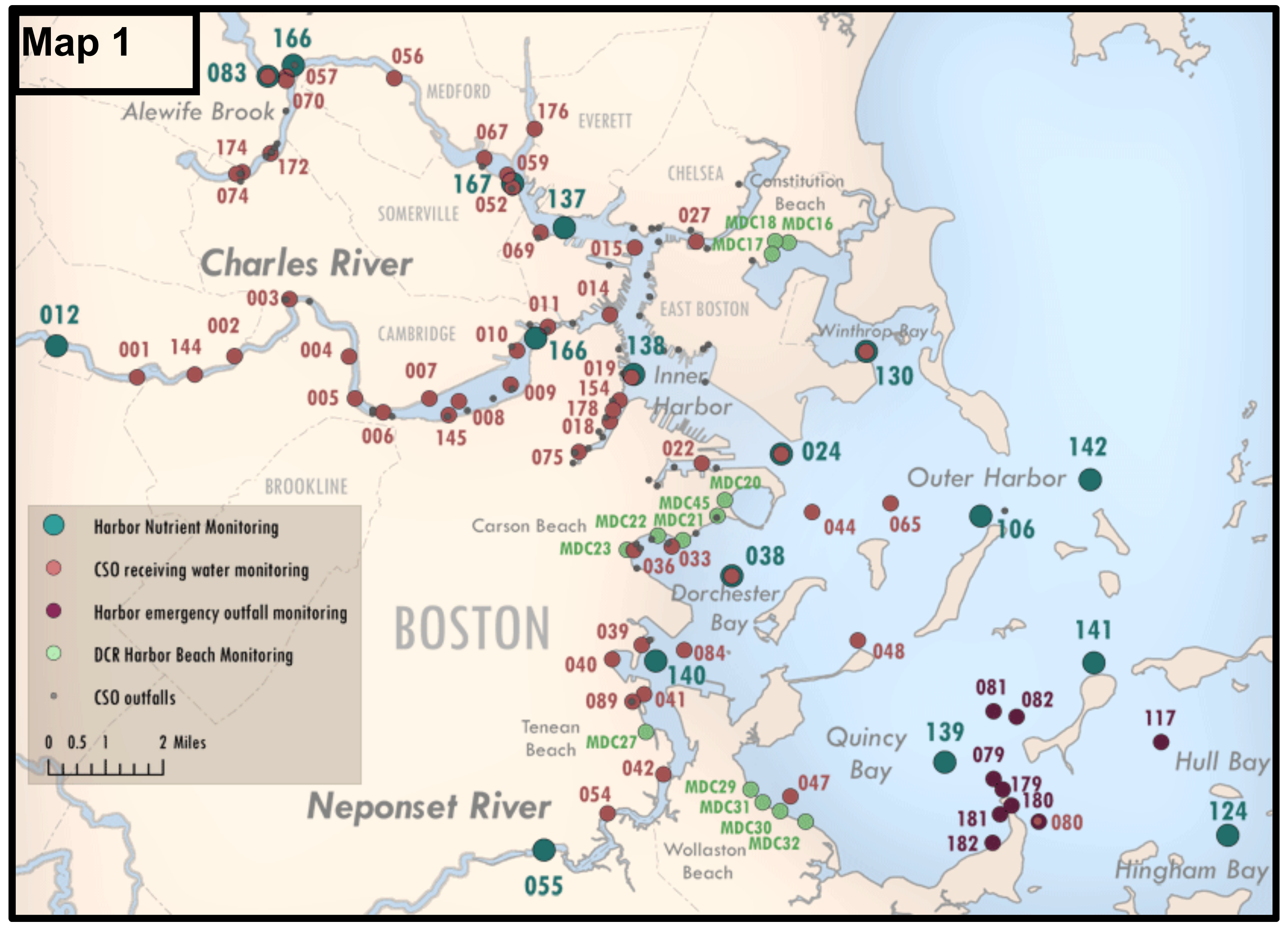
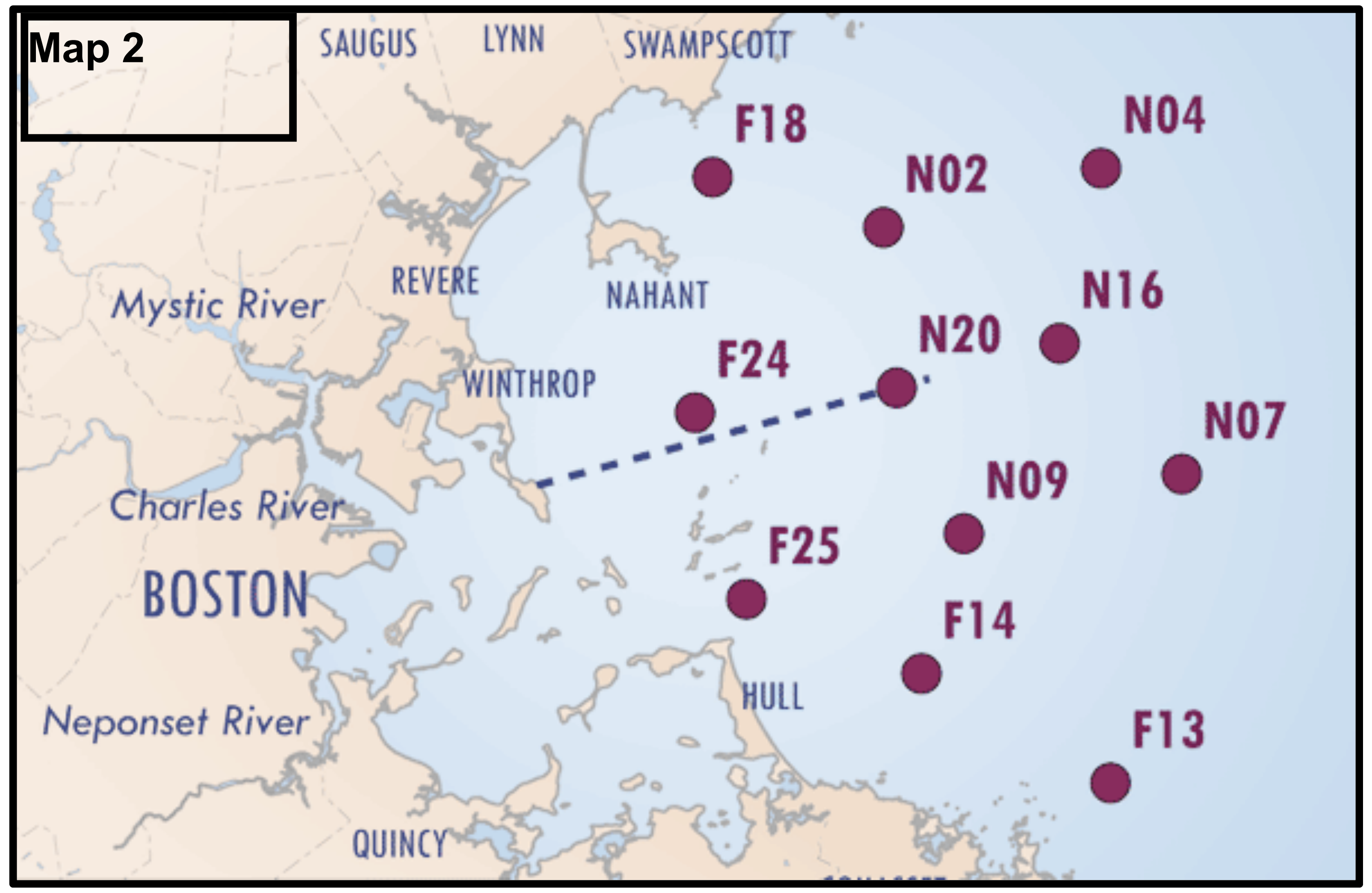
MA Division of Marine Fisheries (Shellfish Sanitation Program)	Statewide	mid-1980s	9000 samples per year	bacteria, temperature, pH	no
MA Division of Marine Fisheries	Statewide	1986	hourly at 52 fixed stations	temperature (bottom) in addition to fish metrics	no

MWRA: BOSTON HARBOR AND MASSACHUSETTS BAY MONITORING PROGRAM

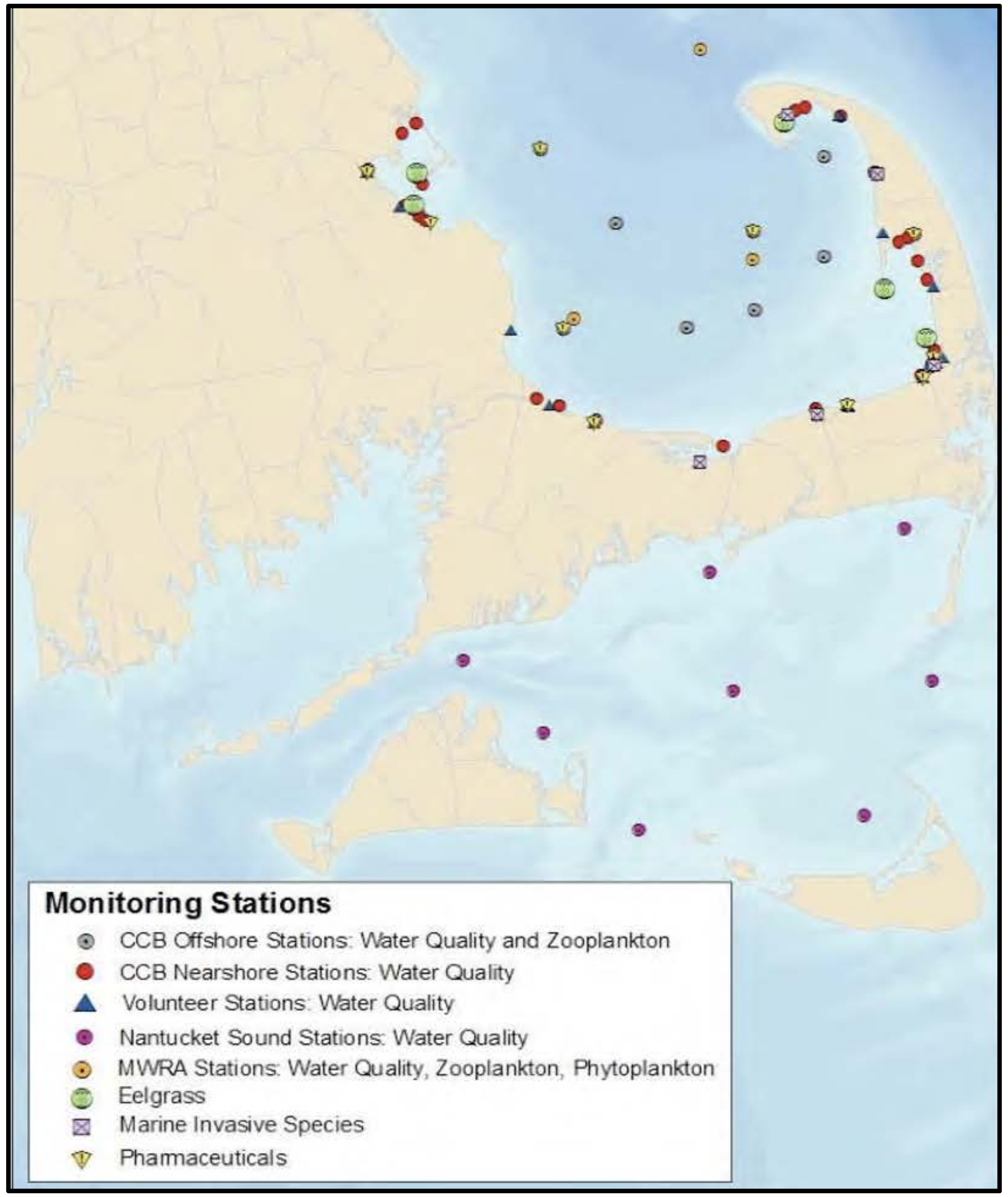
- 1995 – present.
- Water quality monitoring for temperature, salinity, DO, turbidity, nutrients, chl-A, bacteria, plankton for many stations all year round.
- pH measured at two stations: Boston Harbor (Map 1, green indicates monitoring since 1995) and Mass Bay (Map 2, monitoring since 2006).
- This monitoring did not seek to measure long-term acidification trends, so data methods and quality are not appropriate for understanding ocean acidification.
- More recently, some of these sites collect pH and DIC as part of an ongoing ocean acidification project with MIT Sea Grant.





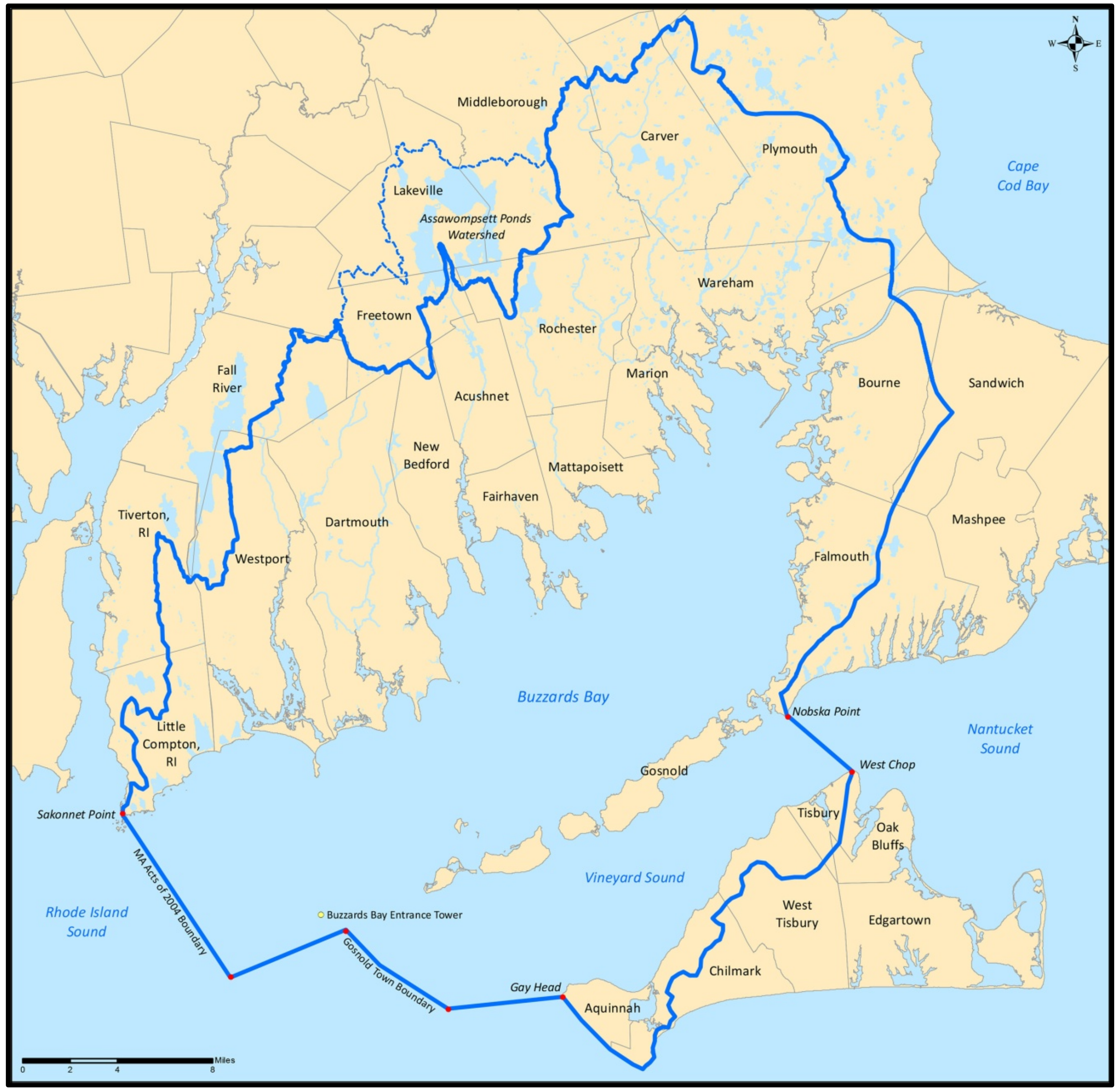
CENTER FOR COASTAL STUDIES: CAPE COD BAY AND NANTUCKET SOUND MONITORING PROGRAM

- 2006 – present.
- Regular monitoring year-round in Cape Cod and Nantucket Sound.
- Measures several water quality parameters at more than 120 sites.
- Collects pH data only at nearshore stations using sensors and test kits.
- Methods are not sensitive enough to measure ocean acidification.



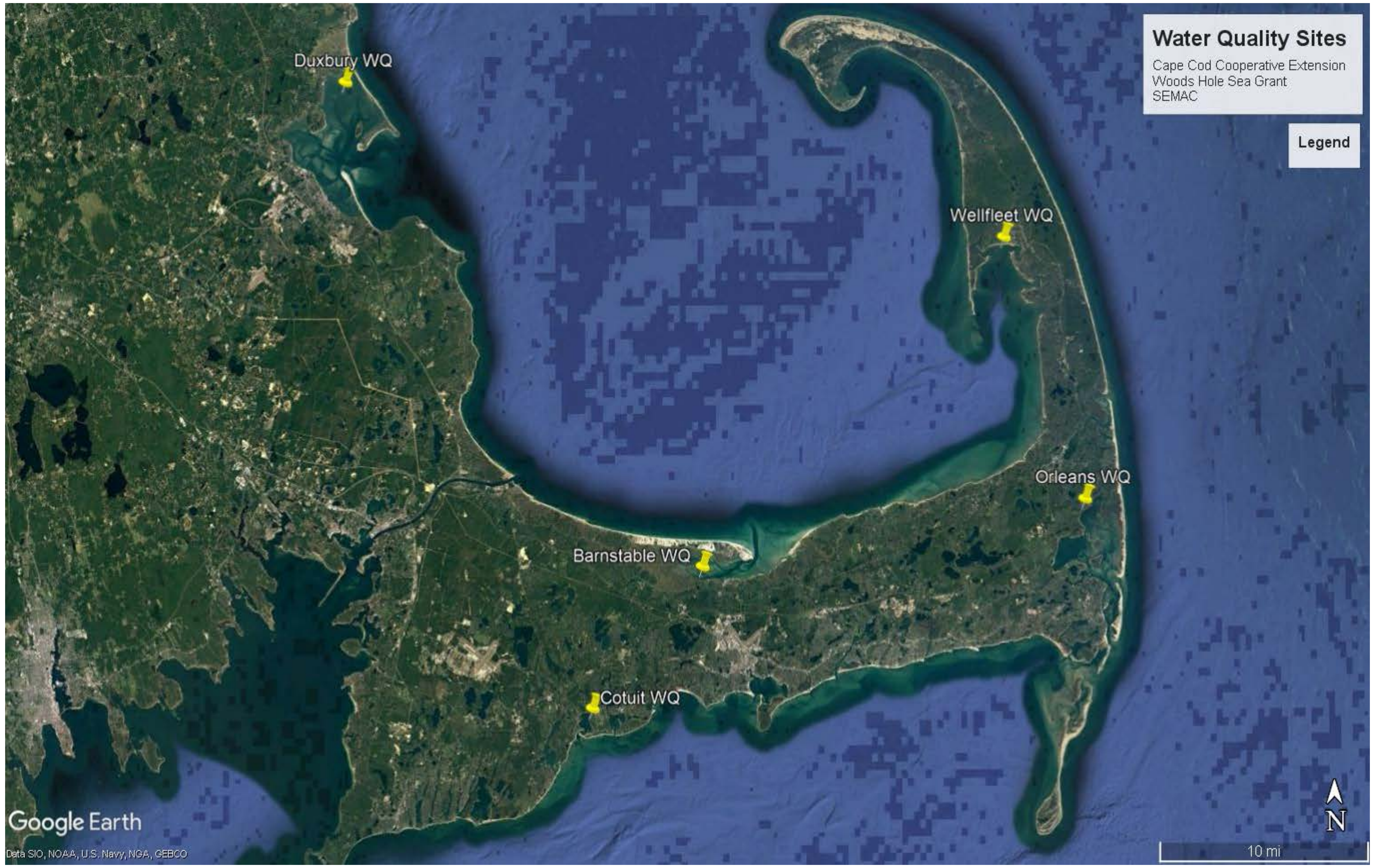
BUZZARDS BAY COALITION: BAYWATCHERS

- Active for nearly 30 years.
- Measures DO, salinity, water clarity weekly. Does not measure pH.
- Measures nutrients and phytoplankton four times per year.
- Reports on the nutrient-related health of more than 100 harbors, coves, salt ponds, and rivers throughout Buzzard Bay and Vineyard Sound via the Bay Health Index.



CAPE COD COOPERATIVE EXTENSION

- 2004 – present.
- 5 long-term water monitoring stations (YSIs).
- Measures DO, temperature, salinity, pH, turbidity, chl-A.
- Data collected March/April through October/November.
- Collaborates with shellfishermen and aquaculture initiatives.



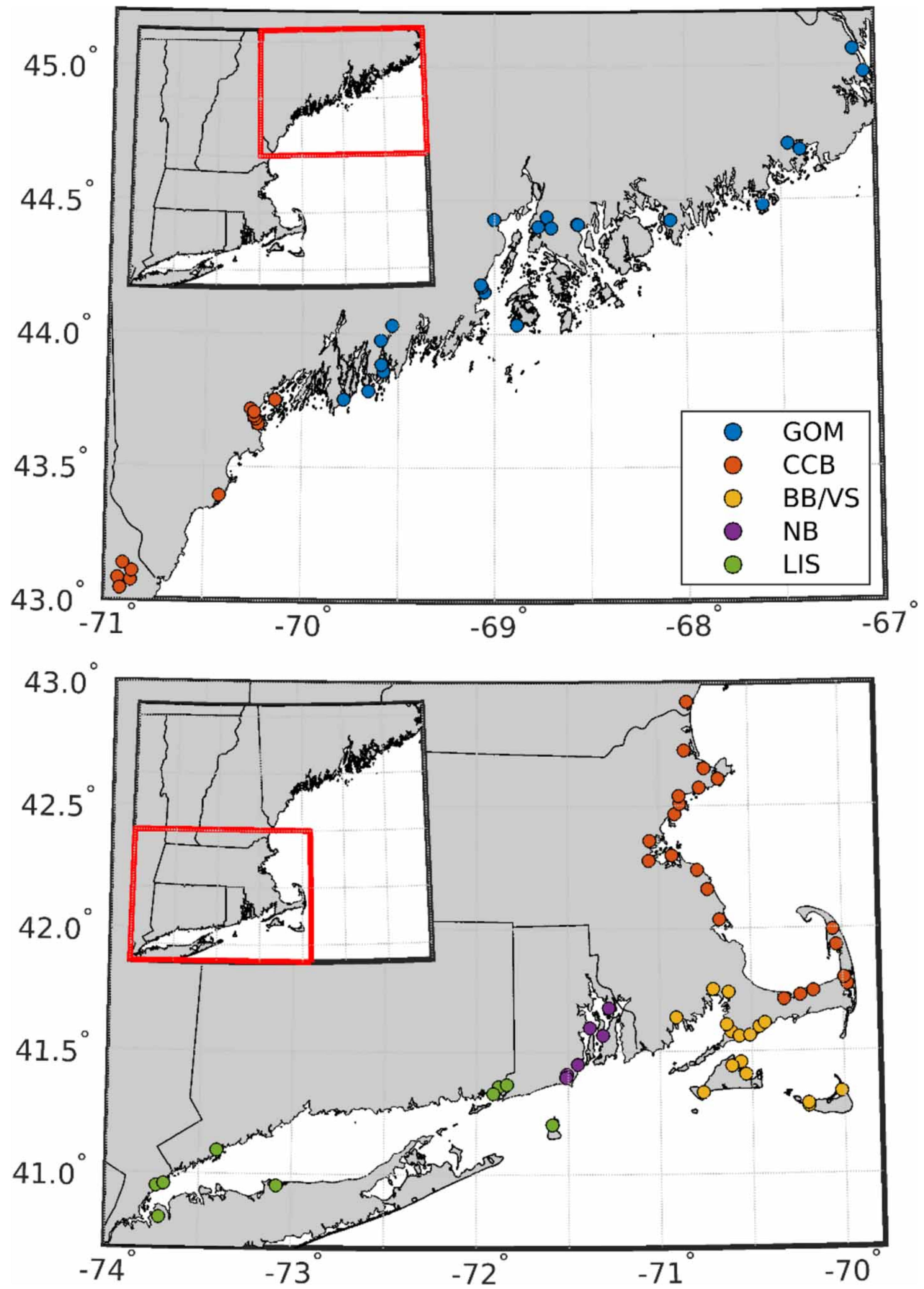
OCEAN ACIDIFICATION–SPECIFIC MONITORING PROGRAMS

- **MassBays' Coastal Acidification Observing System (CAOS)**
  - Studies variability of coastal acidification and potential long-term impacts on the oyster aquaculture industry.
  - Part of EPA's network deployed in 10 NEPs around the United States.
  - Continuous monitoring in Duxbury Bay.
  - Characterizes variability in pH and pCO_2.
  - Works with stakeholders to determine potential impacts of acidification, and to determine adaptation strategies.

- **Monitoring Alkalinity and pH in the Coastal Waters of Cape Cod Bay**
  - Funded by MassBays 2020 Healthy Estuary Grant.
  - Grantee: Center for Coastal Studies.
  - Measures pH and total alkalinity.
  - Covers Duxbury Bay, Wellfleet Harbor, and Provincetown Harbor.
  - Collects discrete water samples and analyzes aragonite saturation values in lab.
  - Although not continuous, the program generates data on conditions in nearshore hotspots.

VOLUNTEER OCEAN ACIDIFICATION MONITORING EFFORTS

- **Shell Day**
  - Organized by NECAN
  - Annual
  - 410 alkalinity samples collected from 86 stations (temperature, salinity, pH, water samples). Field duplicates were collected at both low and high tide at most stations
  - 59 community science programs
  - 8 labs analyzing samples



"Groupings are the northern Gulf of Maine (GOM, blue), central Gulf of Maine/Cape Cod Bay (orange, CCB), Buzzards Bay/Vineyard Sound (BB/VS, yellow), Narragansett Bay (NB, purple), and Long Island Sound (LIS, green)."

Figure adapted from Rheuban et al., 2021. *Synoptic assessment of coastal total alkalinity through community science.*

FEDERAL FUNDING FOR OCEAN ACIDIFICATION RESEARCH

- **National Sea Grant Program**
  - NOAA program aimed at supporting research and conservation of coasts, Great Lakes, and other marine areas.
  - Charged with understanding, conserving, and improving the U.S. coastal and ocean resources.
  - Massachusetts is one of only two states to have both a Sea Grant College Program (MIT) and a Sea Grant Institutional Program (WHOI).

- **MIT and WHOI Sea Grants**
  - Provide competitive funding opportunities for research scientists seeking to address marine issues in ways that benefit the Commonwealth.
  - Support research, education, and extension projects that encourage environmental stewardship, long-term economic development, and responsible use of the nation's coastal and ocean resources.
  - Fund up to $200,000 for projects lasting up to 2 years. 50% of funding must be matched by the investigator, as stipulated by NOAA.
  - Focus areas that relate to ocean acidification: Healthy Coastal Ecosystems, Sustainable Fisheries and Aquaculture, Resilient Communities and Economies.

STATE FUNDING FOR OCEAN ACIDIFICATION RESEARCH

- In Oregon, ocean-related research is funded by the Oregon Ocean Science Fund (OOSF) and administered by the Oregon Ocean Science Trust.
- In California, research is funded by the California Ocean Protection Trust Fund (COPTF) – part of a larger, multi-purpose, which focuses on a suite of environmental and climate-change-oriented goals.
  - Trusts like COPTF and OOSF raise funds through a combination of general fund appropriation, popular ballot funding measures, environmental license plate revenue, grants/donations, and in the case of Oregon, funding from the Outer Continental Shelf Lands Act. Such trusts generally retain the interest they accrue.
- In Maine, the Maine Climate Council is tasked by law with identifying and monitoring factors contributing to the effects of climate change. This council both funds and maintains research projects related to ocean acidification.
  - The Maine Climate Council raises money through general appropriations and support from public, private, and non-profit organizations.

COMMON RESEARCH FOCUSES

- **States that have addressed ocean acidification usually include research priorities for the following areas of study:**
  - Monitoring
  - Ecosystem modeling
  - Developing management practices for shellfish cultivation
  - Studying life cycle impacts of ocean acidification and hypoxia
  - Developing ocean acidification action plans
  - Developing communications plans for outreach

COMMISSION RECOMMENDATIONS

ESTABLISH A BROAD, SENSITIVE OCEAN ACIDIFICATION MONITORING SYSTEM

Massachusetts should establish a comprehensive ocean acidification monitoring program.

- This program should enable sensitive industries and coastal communities to understand and react to ocean acidification.
  - Broadly, the resolution of this system should be focused on allowing shellfishing operations to respond to long-term pH changes along the Massachusetts coastline. The baseline resolution of this system should not be so fine that maintenance becomes impractical.
  - In particularly variable and sensitive regions, this system should be tuned to allow shellfishing operations to respond quickly to short-term acidification events.
- Funding should be appropriated in order to conduct a gap analysis, examining where and to what extent ocean acidification monitoring should be implemented along the coastline. This study should also determine which technologies are appropriate for ocean acidification monitoring, and should provide several options along with cost estimates.

CONDUCT STUDIES TO UNDERSTAND THE EFFECTS OF OCEAN ACIDIFICATION – 1/2

A. Study the effects of ocean acidification on commercially-relevant marine species.

- Massachusetts should study the effects of ocean acidification on species that are ecologically important, economically important, and/or understudied.
- This study should emphasize the impact of multimodal stress on marine species.
- Recommended species to study include sea scallops, American lobster, eastern oyster, quahogs, and fin fish.

B. Develop a set of best adaptive practices for shellfishing and marine industries.

- An agreed-upon set of best practices for ocean acidification has not been established in Massachusetts. It is not clear which practices are both effective and economically viable. Practices such as seeding calcium carbonate or planting kelp buffers may not be practical for individual businesses, but may become viable at scale. Massachusetts should examine all options in order to provide the shellfishing and marine industries with a clear path forward.
- Testimony from members of the shellfishing and marine industries in Massachusetts indicates a willingness to adopt ocean acidification-resistant practices.
- Upon the conclusion of this study, Massachusetts should seek to make the adoption of best practices feasible for members of the shellfishing and marine communities through grants and/or tax credits.
- Massachusetts Department of Agricultural Resources should set the study parameters and solicit requests for proposal. The Southeastern Massachusetts Aquaculture Center has experience developing best management practices for the shellfishing and marine industry.

CONDUCT STUDIES TO UNDERSTAND THE EFFECTS OF OCEAN ACIDIFICATION – 1/2

C. Project coastal acidification trends and make recommendations for efficiently limiting coastal stressors.

- Massachusetts should model coastal ocean acidification trends in coastal waters and clarify the relationship between nutrient loading, eutrophication, and coastal ocean acidification.
- The study should determine where interventions addressing atmospheric deposition or nutrient pollution would be most effective in limiting coastal acidification within a pH range protective of near-shore habitats along Massachusetts coasts.
- The study should also propose revisions to Total Maximum Daily Loads (TMDLs) under the Massachusetts Estuaries Program (MEP) if needed to further protect against projected coastal acidification.

D. Study the economic impacts of ocean acidification.

- The effects of ocean acidification on local economies will vary depending on the regional drivers of ocean acidification, the susceptibility of species that are important to local economies, and the adaptability of affected communities.
- A cost benefit analysis should be conducted for a variety of intervention strategies, comparing mitigation costs against avoided economic losses and associated health benefits from nutrient pollution reductions.
- This study should attempt to identify which communities within Massachusetts will be most affected.

ADDRESS ACIDIFICATION'S COASTAL STRESSORS BY INCREASING FUNDING TO EXISTING PROGRAMS

By providing existing programs with additional support and clarifying their role in combatting ocean acidification, Massachusetts can quickly begin to address the causes of coastal acidification.

The studies outlined in the preceding recommendations should clarify which interventions will have the greatest and most cost-effective impact; once known, the Commonwealth should move swiftly to fund efficient interventions to address coastal stressors by:

- Enhancing funding for the protection and restoration of wetlands, eelgrass, and salt marshes.
- Developing and implementing nutrient total maximum daily loads as quickly as possible.
- Reducing septic system discharges in nutrient sensitive coastal areas within coastal watersheds.
- Reducing nitrogen discharges from publicly owned-treatment works in coastal watersheds.

ESTABLISH AN OCEAN ACIDIFICATION COUNCIL AND TRUST TO COORDINATE EFFORTS

Coastal and ocean acidification implicates numerous agencies and programs. Massachusetts should pass ocean acidification legislation that focuses on coordinating adaptation efforts in the near shore zone.

Ocean Acidification Council

- An Ocean Acidification Council should be formed of the relevant agencies, including representatives from CZM, DEP, MEPA, DMF, and the Division of Ecological Restoration. Legislative and public members should be appointed.

- Similar councils or commissions have been created in California (Ocean Protection Council and Ocean Acidification and Hypoxia Task Force), Oregon (Coordinating Council on Ocean Acidification and Hypoxia), and Maine (Maine Climate Council).

Ocean Acidification Adaptive Trust

- Massachusetts does not have a fund dedicated to coastal and ocean acidification priorities. Legislation should establish a permanent fund administered by the Council, prioritizing mitigation and adaptation to ocean acidification. It should include funding for OA monitoring, research, adaptive technologies for aquaculture, and remedial action for coastal stressors, especially prioritizing nature-based solutions to manage stormwater and reduce nutrient pollution. These funds may target existing programs or novel approaches to restore and buffer marine habitats and resources impacted by ocean acidification.

- Legislation should establish guidelines to direct the administration and management of the Trust. The guidelines will describe the sources from which the Trust is eligible to receive funding and the criteria for expenditure of the funds for specific projects that will advance the Commonwealth's goals to address ocean acidification.

ENHANCE COASTAL ACIDIFICATION FUNDING

Massachusetts should appropriate or authorize funds to capitalize the Trust and maintain support for the Trust in the coming years as ocean acidification worsens. Massachusetts can obtain funding through:

- A water use fee. Fashioned similar to Maryland's 'flush tax,' this fee can be assessed on water and sewer bills throughout Massachusetts. This fee may be greater in coastal communities. In Maryland, the $5.00/month fee raised $117,136,760 in 2018.
- A gasoline tax. In Maryland, The Chesapeake and Atlantic Coastal Bays Trust Fund has generated $506,530,000 through gasoline and rental car tax revenues since its inception.
- A shellfish preservation license plate through the Massachusetts Environmental Trust Fund. Proceeds from sales of four specialty plates has contributed an average of $469,202 annually since 2013 for water quality improvement projects. In California, a significant amount of ocean trust contributions is derived from license plate revenues.
- Small fee increases on commercial fishing licenses and annual shellfishing leases.
- A request for funding from the Secretary of Energy and Environmental Affairs pursuant to the spending authority of the 2018 bond bill for establishing coastal monitoring and conducting gap analyses.
- Permitting private donations to the Trust.

ESTABLISH A BLUE COMMUNITIES PROGRAM

A Blue Communities Program would incentivize communities to implement cost-effective green infrastructure projects, and incorporate conservation principles into local ordinance and zoning laws.

- The Green Communities Division is an effective decentralized strategy for incentivizing solar generation and promoting energy efficiency. Municipalities, in exchange for implementing low-cost, high impact bylaws and ordinances, and committing to annual reporting requirements, receive “green” designations and access to competitive efficiency grants.

- In the same way, a Blue Communities Program could:

    1. Provide “Blue” designation and access to a pool of green infrastructure competitive grants.

    2. Require municipalities to adopt zoning changes for future development, reducing stormwater or agricultural runoff. These “Blue community” criteria should be developed in coordination with the relevant agencies to fill gaps and identify potential reductions.

INCORPORATE OCEAN ACIDIFICATION INTO ADAPTATION PRIORITIES OF CHAPTER 21N

Massachusetts should amend Chapter 21N, Section 10, making reference to ocean acidification. In doing so, ocean acidification will be included alongside other climate change risks and strategies.

- Pursuant to Chapter 21N, Section 10, the Resilient MA Action Team develops the 5-year Massachusetts State Hazard Mitigation & Climate Adaptation Plan (SHMCAP). Currently, the SHMCAP attempts to project the effects of four climate changes: changes in precipitation, sea level rise, rising temperatures, and extreme weather. It further subdivides these changes into 14 natural hazards for study, none of which address ocean acidification.

REVISE AGENCY IMPACT STATUTES

C. 30, Section 61

- Impact statutes require any state agency to consider environmental effects before approving a major agency action. Massachusetts should include ocean acidification in its environmental impact statute.

- The impact statute contained in chapter 30 should be amended to read "In considering and issuing permits, licenses and other administrative approvals and decisions, the respective agency, department, board, commission or authority shall also consider reasonably foreseeable climate change impacts, including additional greenhouse gas emissions, and effects, such as predicted sea level rise *and ocean acidification*."

C. 21, Section 26A

- Massachusetts should amend its state Clean Waters Act to include ocean acidification projects as a type of green infrastructure improvement project.

- The definition of "green infrastructure project" should include projects related to "the mitigation of ocean acidification from coastal and background stressors, using nutrient or carbon reducing green infrastructure in coastal watersheds and coastal waters."

EDUCATE THE PUBLIC ABOUT OCEAN ACIDIFICATION AND THE HEALTH OF COASTAL WATERS

Massachusetts can promote awareness of coastal zones and impacts by borrowing from similar efforts in the Chesapeake Bay region.

- Appropriate funding for signage that clarifies the boundaries between coastal and inland water sheds.
- Create a Bay Awareness Week. The goal of Bay Awareness Week is to provide an opportunity to conduct citizen science. Citizen science initiatives allow members of the general public to become directly involved in preserving the health of the Massachusetts coastline, while generating valuable scientific data for the Commonwealth. NECAN's "Shell Day" is one model of a successful citizen science initiative that relates to ocean acidification.

Massachusetts should join the International Alliance to Combat Ocean Acidification.

- "By joining the OA Alliance, member governments endorse the Call to Action and commit to broadly support the five goals within the Call. This includes building sustained local, regional and international support for tackling this global problem."
- Joining the OA Alliance is free, and membership could open the door to future inter-state or public/private collaborations.

Image by Flickr user: Nicholas A. Tonelli

COMMISSION RECOMMENDATIONS: PRIORITIES AND TIMELINES

A. Immediately:

1. Introduce legislation establishing an Ocean Acidification Council and permanent trust for priorities to address ocean and coastal acidification, and amend existing law to recognize ocean acidification causes and impacts.
2. Perform gap analysis for ocean monitoring.
3. Educate the public about ocean acidification and the health of coastal waters.

B. Within 2 years:

4. Establish a sensitive ocean monitoring program informed by the preceding gap analysis, coordinated by the Office of Coastal Zone Management.

C. Within 5 years:

5. Conduct a series of studies:
   - Assessing the effects of ocean acidification on commercially-important marine species.
   - Estimating the economic impact of ocean acidification.
   - Developing a set of best practices for the shellfishing and marine industries.
6. Finalize Total Maximum Daily Loads (TMDLs) development for the Massachusetts Estuaries project. Revise previously developed TMDLs, if needed, taking into account coastal acidification as a particularized stressor. Revise state water quality standards, if needed.
7. Establish a Blue Communities Program to incentivize local action to reduce nutrient pollution.

D. Within 10-15 years:

8. Implement nutrient TMDLs that have been adjusted for ocean acidification impacts in coastal watersheds. Provide funding for necessary improvements in the most efficient manner to meet nutrient targets through strategies including, but not limited to:
   - Necessary nutrient-reducing upgrades to publicly-owned treatment works (POTWs) in coastal watersheds.
   - Septic system connections in nutrient sensitive coastal watersheds to new or existing POTWs.
   - Upgrades to existing tanks to nutrient-reducing systems.
   - Other nutrient-reducing strategies in coastal watersheds and coastal waters, such as permeable reactive barriers, salt marsh restoration, green infrastructure and living structures.

CONCLUSIONS

- Ocean acidification poses a serious threat to the Massachusetts state economy, and a potentially existential threat to coastal economies that rely heavily on shellfishing.
- Two forms of acidification particularly endanger Massachusetts: acidification as a result of anthropogenic carbon emissions and acidification as a result of coastal eutrophication caused by nutrient discharges from land.
- The threat posed by eutrophication can be addressed by implementing policies that reduce nutrient pollution, restore coastal wetlands, and improve coastal monitoring.
- Several studies should be conducted to quantify the effects of acidification on local shellfishing communities, on the state economy, and on commercially valuable marine species.
- A set of best practices should be developed for the shellfishing and lobster industries.
- Massachusetts should promote public awareness of ocean acidification and join the International Alliance to Combat Ocean Acidification.
- Legislative and executive language should be updated in order to acknowledge the risks posed by ocean acidification.
- A Blue Communities Program should be created in order to further incentivize the adoption of green infrastructure.
- An Ocean Acidification Council and fund should be established in order to support the recommendations outlined above.
- Massachusetts should act to combat ocean acidification now, rather than later. Ocean acidification is expected to worsen significantly before the end of the century. Actions taken now will ultimately be more cost-effective and valuable than actions taken when significant damage has already occurred.

APPENDICES

LIST OF APPENDICES

COMMISSION MEMBERS

State Representative Smitty Pignatelli

- 4th Berkshire district. Representative Pignatelli is a Co-Chair of the Joint Committee on the Environment, Natural Resources and Agriculture. Co- Chair, Joint Committee on the Environment, Natural Resources and Agriculture. Representative Pignatelli is a member of the Berkshire County Deputy Sheriff's Association, a past board member of the Berkshire County Arc, is on the Board of Directors of the Berkshire Visitors Bureau and the Berkshire County Red Cross, and is a former President of the Lenox Historical Society.

State Senator Anne Gobi

- Worcester, Hampden, Hampshire & Middlesex district. Senator Gobi is a Co-Chair, Joint Committee on the Environment, Natural Resources and Agriculture. Senator Gobi previously served in the Massachusetts House of Representatives. She was first elected to the state House in an October 2001 special election.

State Senator Julian Cyr

- Cape and Islands district. Senator Cyr is a native of Truro, Massachusetts. Prior to his election to the senate he worked on policy and regulatory affairs for the Massachusetts Department of Public Health and served as chair of the Massachusetts Commission on LGBTQ Youth. Senator Cyr is the Senate Chair of the Joint Committee on Mental Health, Substance Abuse, and Recovery.

State Representative Dylan Fernandes

- Barnstable, Dukes & Nantucket district. Representative Fernandes has served in the state legislature since 2017. In office he has focused on combating climate change, advancing affordable housing, addressing the opioid epidemic, and promoting access to health care. Prior to serving in the House, Rep. Fernandes worked in the Attorney General's Office in the Civil Rights Division and later served as digital director for the office.

State Senator Joan Lovely

- 2nd Essex district. Senator Joan Lovely is in her fourth term as State Senator for the Second Essex District, comprised of Beverly, Danvers, Peabody, Salem and Topsfield. Senator Lovely has been serving in the Massachusetts Senate since January 2013. Senate Committee on Ways and Means.

State Senator Patrick O'Connor

- Plymouth & Norfolk district. As a State Senator, Patrick has geared his efforts toward economic growth, substance abuse treatment, veteran services, environmental protection, and advocating for individuals with physical and developmental disabilities. His office puts special emphasis on constituent services as he advocates for the residents of his district through state agencies as well as the Legislature.

State Representative Sarah Peake

- 4th Barnstable district. Representative Sarah Peake is currently serving her sixth term representing the 4th Barnstable District on Cape Cod. In 2015, she was named Third Division Floor Leader, a member of the Speaker's team who serves a resource to other members for guidance and discussion on legislation priorities and concerns. She also currently serves as the Chair of the RTA caucus and helped to create the rural caucus.

State Representative Mathew Muratore

- 1st Plymouth district. Matt is active in various community organizations including Plymouth County Drug Abuse Task Force, Sunrise Rotary, the Plymouth Youth Development Collaborative, the Plymouth Area Chamber of Commerce and the Plymouth Networking Group for Seniors. Matt serves on the PACTV Board of Directors, The Plymouth Economic Development Foundation Board of Directors, and is a member of the BID-Plymouth Hospital Advisory Board.

COMMISSION MEMBERS

Steve Kirk, The Nature Conservancy

- Steve's responsibilities include developing, implementing and monitoring state-wide and regional coastal conservation strategies. His current work is focused on advancing the policy and practice of nearshore habitat restoration and shellfish aquaculture through collaborative research efforts. He has supported the deployment of TNC's global aquaculture strategy and brings on the ground experience as a former oyster farm owner/ operator. Before joining TNC, Steve spent his professional life working on the water as a fisheries researcher and captain of tugboats and tall ships.

Director Lisa Berry-Engler, Office of Coastal Zone Management

- Lisa Berry-Engler is the Director of the Massachusetts Office of Coastal Zone Management (CZM). CZM is the lead policy, planning, and technical assistance agency on coastal and ocean issues within the Executive Office of Energy and Environmental Affairs (EEA) and implements the state's coastal program under the federal Coastal Zone Management Act.

Dr. Sara Grady, North and South Rivers Watershed Association

- Dr. Sara Grady is an ecologist and the South Shore Regional Coordinator for MassBays (Massachusetts Bays National Estuary Partnership).

Beth Casoni, Executive Director, Massachusetts Lobstermen's Association

- Beth is a pro-active participant in many areas involving the commercial fishing industry with her primary focus on the commercial lobster industry. As the Executive Director for the Massachusetts Lobstermen's Association, Beth is the boots on the ground representative for the commercial fishermen and will give them the shore side support needed to ensure their continued success on the water.

Dr. Kelly Kryc, Director of Ocean Policy, New England Aquarium

- Dr. Kelly Kryc is the Director of Ocean Policy at the New England Aquarium, and is focused on transforming science into action that protects the blue planet. Dr. Kryc is an energy and environment policy professional who formerly held positions with the U.S. Senate Committee on Energy and Natural Resources, the U.S. State Department, The White House Office of Science and Technology Policy, and the U.S. Department of the Interior. Prior to working in the public sector, she spent a decade working for the non-profit sector advancing science priorities in the United States and abroad. Her doctoral and post-doctoral research focused on understanding extreme climate variability in Antarctica during the past 10,000 years. Dr. Kryc maintains an appointment as an adjunct faculty member of Georgetown University's Science in Public Interest Program where she taught "Science and Society: Global Challenges" and "Shaping National Science Policy."

Dan Martino, Co-Owner, Cottage City Oysters

- Brothers Dan and Greg Martino got into the oyster farming business after taking a tour of an oyster farm. Back home, they promptly jumped to work on a local farm, Sweet Neck Oysters in world famous Katama Bay with proprietor Jack Blake. After learning from the best, the Martino brothers set out to get a farm of their own. Three and a half years later, in 2014, they were granted the first oyster farm in Oak Bluffs history, and the first open ocean oyster farm in New England. Named after the original town name for Oak Bluffs (The Cottage City), Cottage City Oysters was created with the hope of ..."growing the best damn oysters that we can in the most environmentally positive way possible".

COMMISSION MEMBERS

Dr. Anne Giblin, Marine Biological Laboratory

- Marine biologist who researches the cycling of elements nitrogen, sulfur, iron and phosphorus. She is a Senior Scientist and Acting Director of the Ecosystem Center at the Marine Biological. Giblin's research primarily focuses on the cycling of elements such as nitrogen, sulfur, iron, and phosphorus in the environment. The majority of Giblin's research is focused around the circulation of these elements in different redox (reduction-oxidation) conditions in soils and sediments. Another dominant theme in her work is to comprehend if sediment processes act as a buffer or act to exacerbate anthropogenic inputs of nutrients to the environment.

Emiley Lockhart, Government Relations, WHOI

- Ms. Lockhart advises on legal and government relations matters and assists WHOI in building policy engagement programs with government, industry and other key stakeholders in Massachusetts and the surrounding region. Before joining WHOI, Lockhart served as the General Counsel and Policy Director for the Chair of Steering and Policy in the Massachusetts State Senate. Prior to her Beacon Hill work, Lockhart served in various vice president, general counsel, and leadership advisory roles for non-profit and governmental entities. Lockhart began her career as an attorney at Ropes & Gray LLP, after graduating summa cum laude from Boston College and cum laude from Georgetown University Law Center.

Mark Rousseau, Climate & Artificial Reef Specialist, DMF Habitat Program

- Mr. Rousseau is the Climate & Artificial Reef Specialist for the Massachusetts Division of Marine Fisheries, and has been working for the DMF for 21 years. He has worked on coastal protection and classification projects in the past, and is a member of the Mousam Lake Region Association and Lone Tree Spirit Foundation. For undergraduate education, he graduated from University of Massachusetts Dartmouth with a double major in Marine Biology and Biology. Mr. Rousseau then received his Master of Science in Resource Admin and Management from University of New Hampshire.

Stephanie Moura, Director, Division of Wetlands and Waterways at Massachusetts Department of Environmental Protection

- Ms. Moura started her government work in the Massachusetts Water Resources Authority, where she was project manager of the Combined Sewer Overflow Program. She went on to become director of the Massachusetts Ocean Partnership, then executive director of SeaPlan, a non-aligned ocean science and policy group. Currently, Ms. Moura heads the Division of Wetlands and Waterways. She has been in this position for little over a year. Ms. Moura graduated from Occidental College in 1981 with a double major in Marine Biology and Biological Oceanography. She then received her BA in Environmental Studies from UC Santa Cruz and Masters in Urban and Environmental Policy from Tufts University.

COMMISSION CHARGE AND ENABLING LEGISLATION

Legal Authority: Chapter 209 of the Acts of 2018

Purpose: Review relevant scientific data and information related to coastal and ocean acidification, conduct public hearings, and create a report of findings and policy recommendations

Members:

- The house and senate chairs of the joint committee on environment, natural resources and agriculture who shall be co-chairs of the commission;
- 3 members of the senate, 1 of whom shall be appointed by the minority leader; 3 members of the house of representatives, 1 of whom shall be appointed by the minority leader;
- The director of marine fisheries or a designee;
- The commissioner of environmental protection or a designee;
- The director of coastal zone management or a designee
- 8 persons to be appointed by the governor,
    - 2 of whom shall be representatives of an environmental or community group,
    - 3 of whom shall be commercial fishermen, including 1 who shall be a holder of a shellfish aquaculture license, 1 who shall be a holder of a commercial fisherman lobster permit and 1 who shall be a holder of a commercial fisherman shellfish permit and
    - 3 of whom shall be scientists who have studied coastal or ocean acidification.

The commission shall meet at least four times and will address:

- The actual and potential effects of coastal and ocean acidification (COA) on commercially valuable marine species
- Strategies to mitigate coastal and ocean acidification
- Critical scientific data and knowledge gaps pertaining to COA and its effects on species commercially harvested and grown along the commonwealth's coast
- Steps to strengthen existing scientific monitoring, research and analysis related to causes of and trends of COA
- The effect of acidification on great ponds that lie inland of coastal barrier beaches
- Steps to take to provide recommendations to general court and to increase public awareness of coastal and COA

WORKING GROUPS

Scientific Literature Review Working Group

- Members: Anne Giblin, Sara Grady, Kelly Kryc
- Responsibilities: Collect and summarize scientific literature regarding current levels of ocean acidification; Collect and summarize scientific literature regarding ocean acidification mitigation efforts; Collect and summarize scientific literature regarding the causes of ocean acidification; Identify knowledge gaps that may hinder the Commonwealth's ability to craft policy and other responses to ocean acidification.

Shellfish and Marine Industries Working Group

- Members: Beth Casoni, Steve Kirk, Dan Martino, Mark Rousseau
- Responsibilities: Identify critical scientific data and knowledge gaps pertaining to ocean acidification's effects on Massachusetts' shellfishing industry; identify current and potential future effects of ocean acidification on the shellfishing industry; identify solutions and make recommendations for policies and tools to respond to the adverse effects of ocean acidification in the shellfishing industry.

Monitoring and Barrier Beaches Working Group

- Members: Lisa Engler, Sara Grady, Stephanie Moura
- Responsibilities: Identify measures that will strengthen existing monitoring and research efforts related to the causes of and trends of ocean acidification; Identify the effects of ocean acidification on great ponds that lie inland of coastal barrier beaches; compile the locations of great ponds and identify the owners of barrier beaches separating great ponds from the ocean.

Policy and Outreach Working Group

- Members: Sen. O'Connor, Rep. Pignatelli, Sen. Cyr, Rep. Fernandes, Sen. Gobi, Sen. Lovely, Rep. Peake, Rep. Muratore, Emiley Lockhart, Kelly Kryc
- Responsibilities: Identify and compile relevant ocean acidification reports by other states & commissions and highlight relevant policy proposals; Reach out to the Northeast Coastal Acidification Network, the National Caucus of Environmental Legislators, and other groups to gather ocean acidification resources.

RECORD OF COMMISSION VOTE TO ADOPT REPORT

Recommendation → Commissioner ↓	[Vote to adopt full report]	Establish a broad, sensitive ocean acidification monitoring system	Conduct studies to understand the effects of ocean acidification	Address acidification coastal stressors by increasing funding to existing programs	Establish an ocean acidification council and trust to coordinate efforts	Enhance coastal acidification funding	Establish a Blue Communities program	Incorporate ocean acidification into adaptation priorities of Chapter 21N	Revise Agency impact statutes	Educate the public about ocean acidification and the Health of Coastal waters
Anne Giblin, Marine Biological Laboratory	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Beth Casoni, Massachusetts Lobstermen's Association	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Senator Julian Cyr	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dan Martino, Cottage City Oysters	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Representative Dylan Fernandes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Emiley Lockhart, WHOI	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lisa Berry Engler, Massachusetts Office of Coastal Zone Management	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
Kelly Kryc, New England Aquarium	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Senator Joan Lovely	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stephanie Moura, Massachusetts Department of Environmental Protection	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
Senator Patrick O'Connor	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mark Rousseau, Massachusetts Department of Marine Fisheries	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
Sara Grady, North and South Rivers Watershed Association	Present	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Representative Sarah Peake	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stephen Kirk, The Nature Conservancy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Representative Mathew Muratore	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

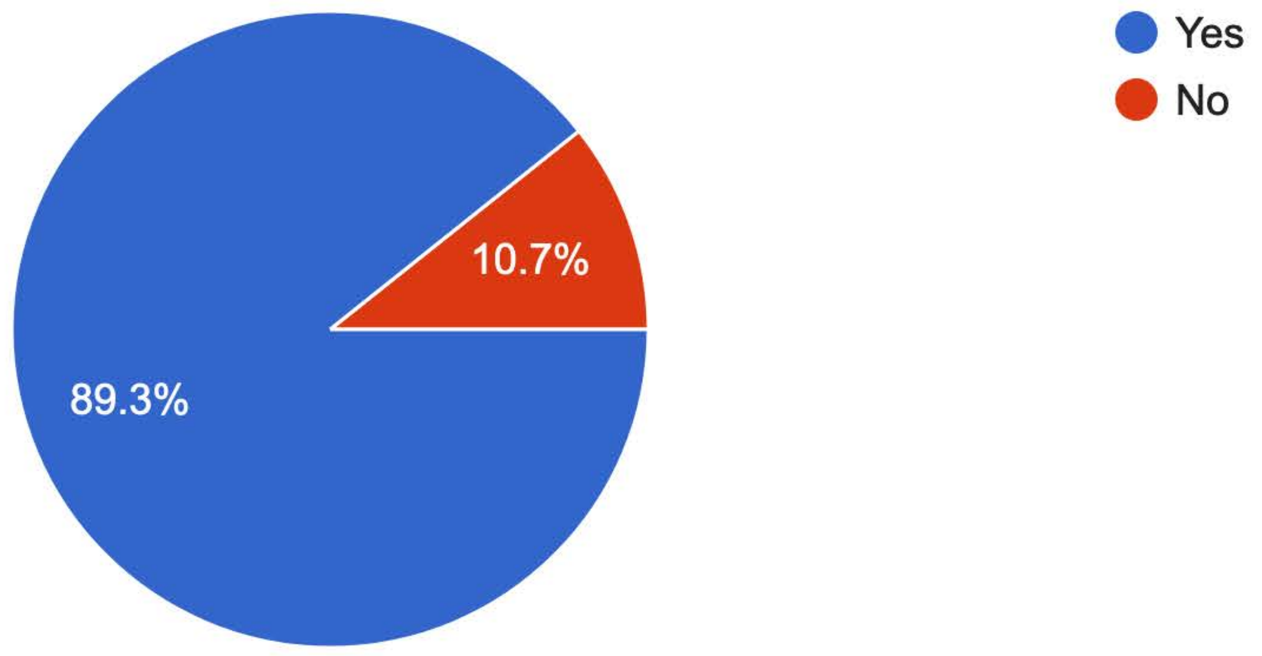
RESOURCE LINKS

- Commission meetings, minutes, and recordings
- Working group materials
- Draft reports and comments
- Ocean Acidification Commission Report: general notes
- Great Ponds within 50 meters of barrier beaches
- Overview of Massachusetts shellfish hatcheries
- Shellfish and Marine Industry Survey results
- Scientific literature and resources spreadsheet
- Ocean Acidification: scientific summary with graphics
- Map of coastal sites that experience low oxygen
- How does Massachusetts monitor freshwater inputs?

INDUSTRY SURVEY: KEY QUESTIONS

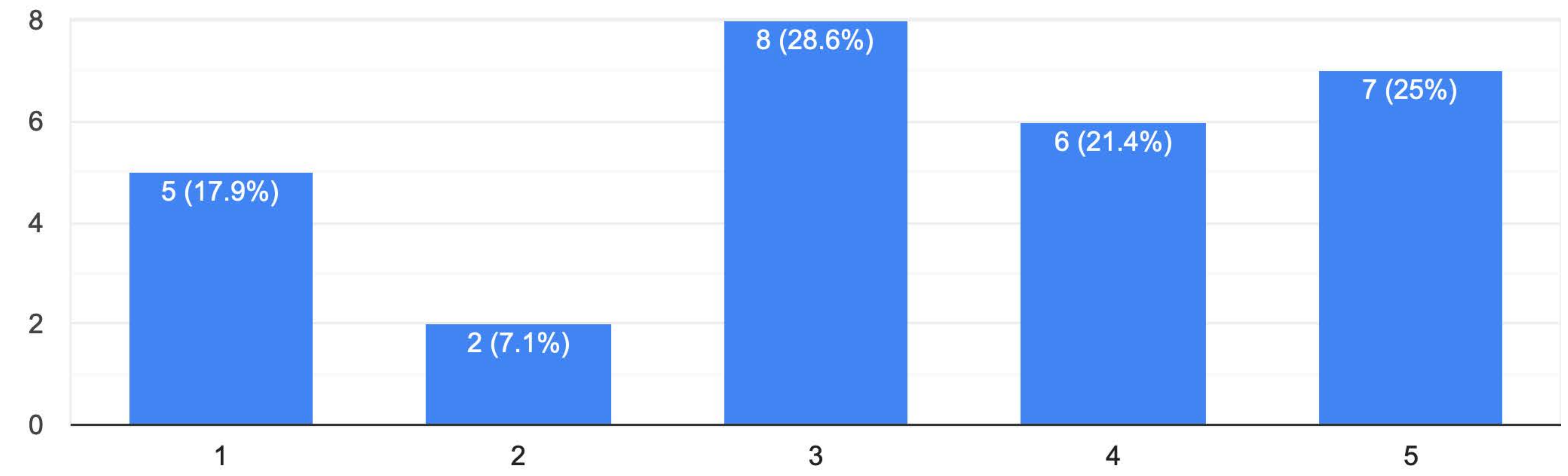
Are you familiar with the term "ocean acidification" (OA)?

28 responses



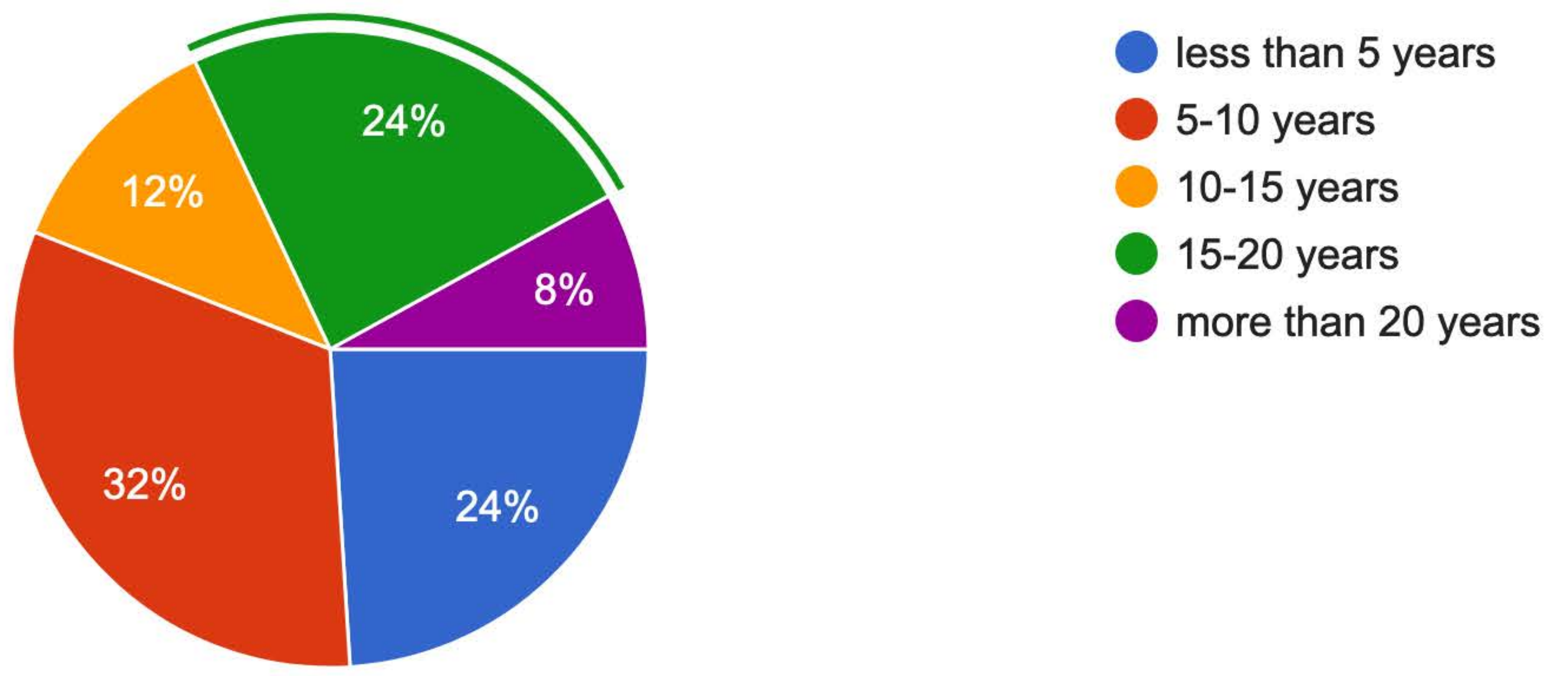
How would you rate your level of understanding regarding the CAUSES of OA? (1 indicates no understanding whatsoever, 5 indicates complete understanding)

28 responses



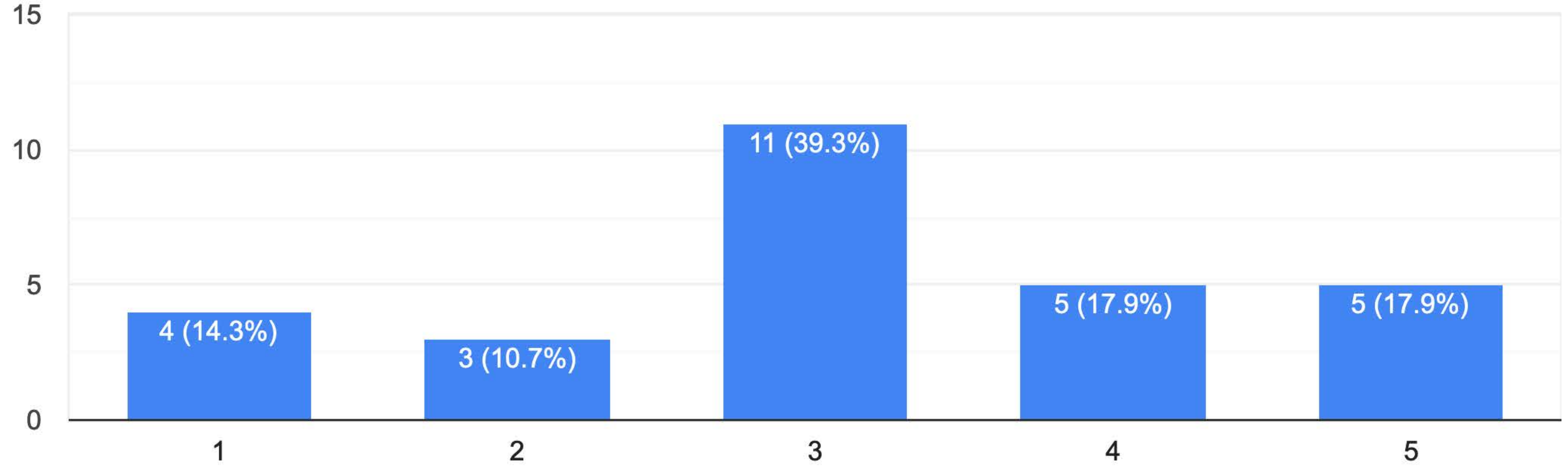
How long have you been aware of OA?

25 responses



How would you rate your understanding regarding the EFFECTS of OA?

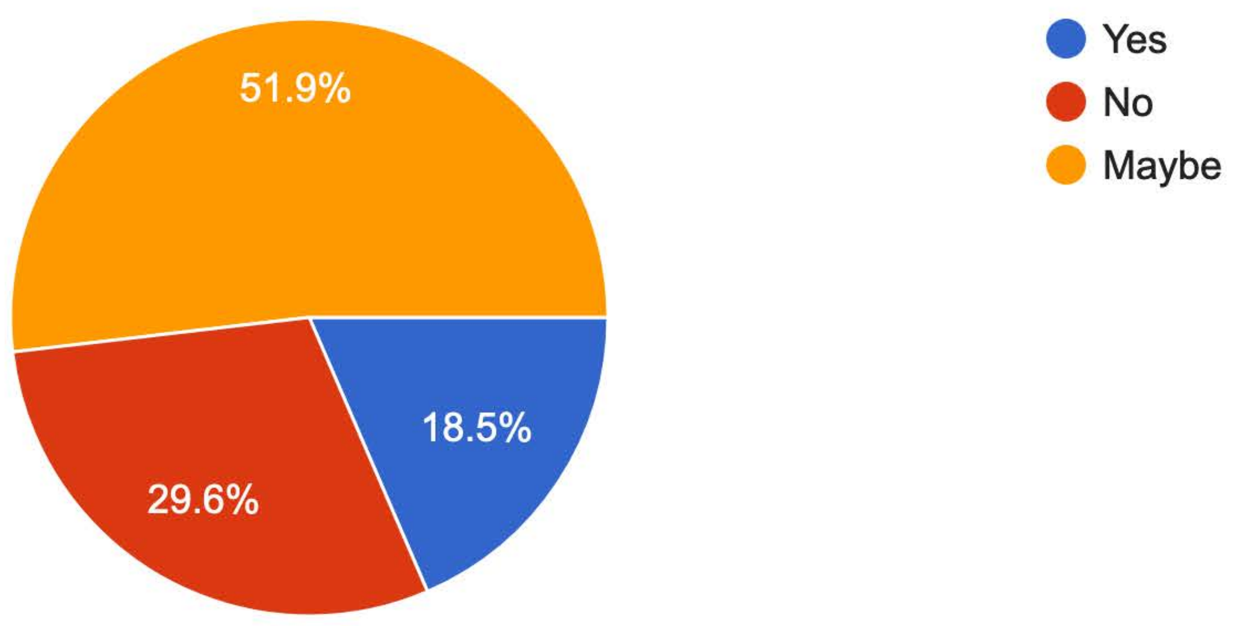
28 responses



INDUSTRY SURVEY: KEY QUESTIONS

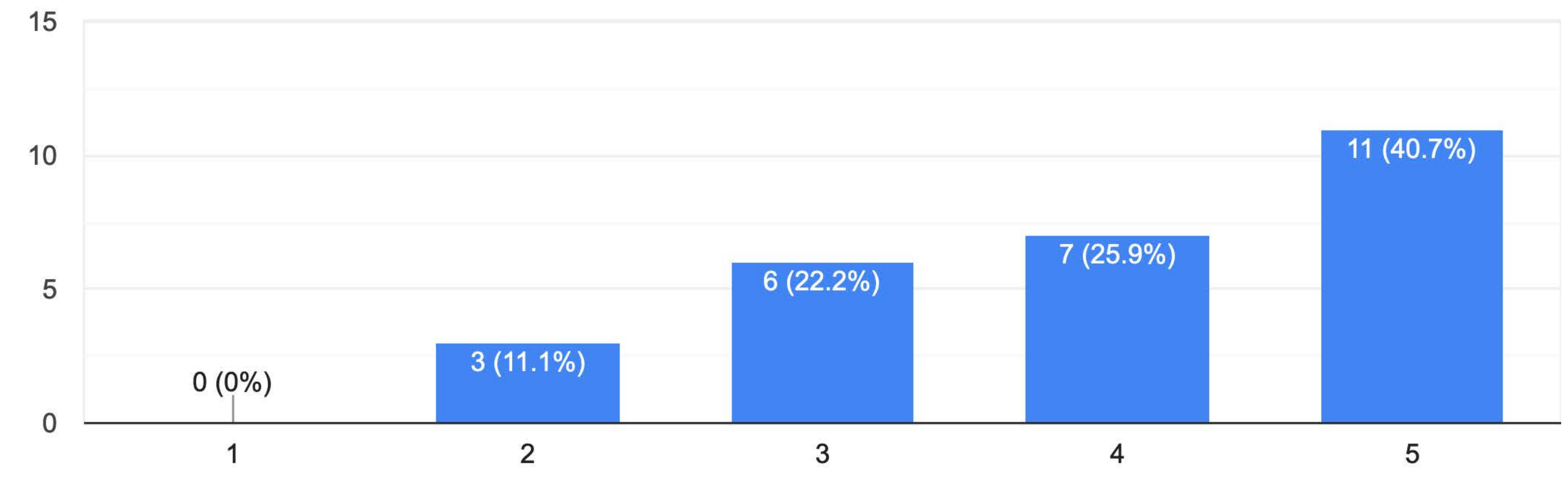
Have you identified OA-related effects in your work?

27 responses



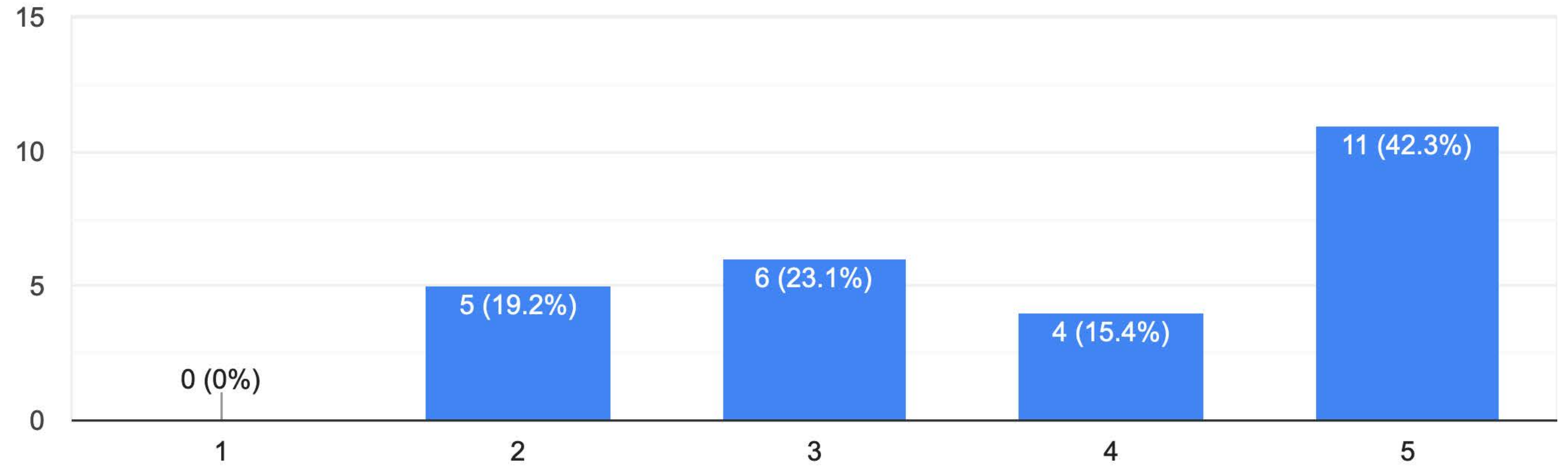
How concerned are you about the future effects of OA on your industry?

27 responses



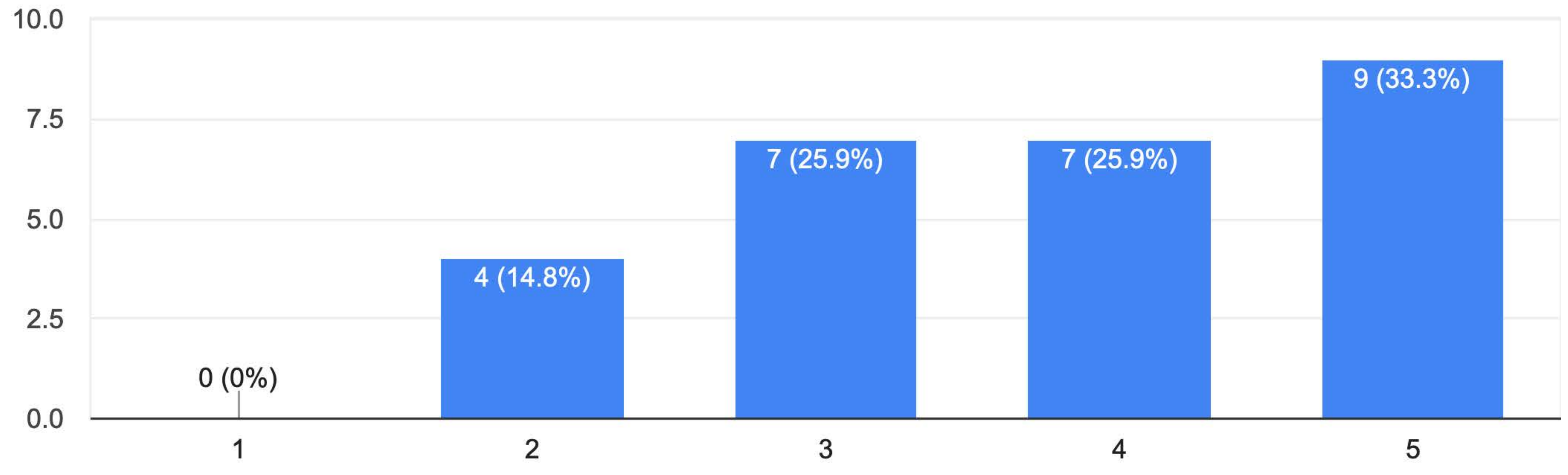
How concerned are you about the future effects of OA on your business? (1 indicates not concerned at all, 5 indicates extremely concerned)

26 responses



How concerned are you about the future effects of OA on the Massachusetts state economy?

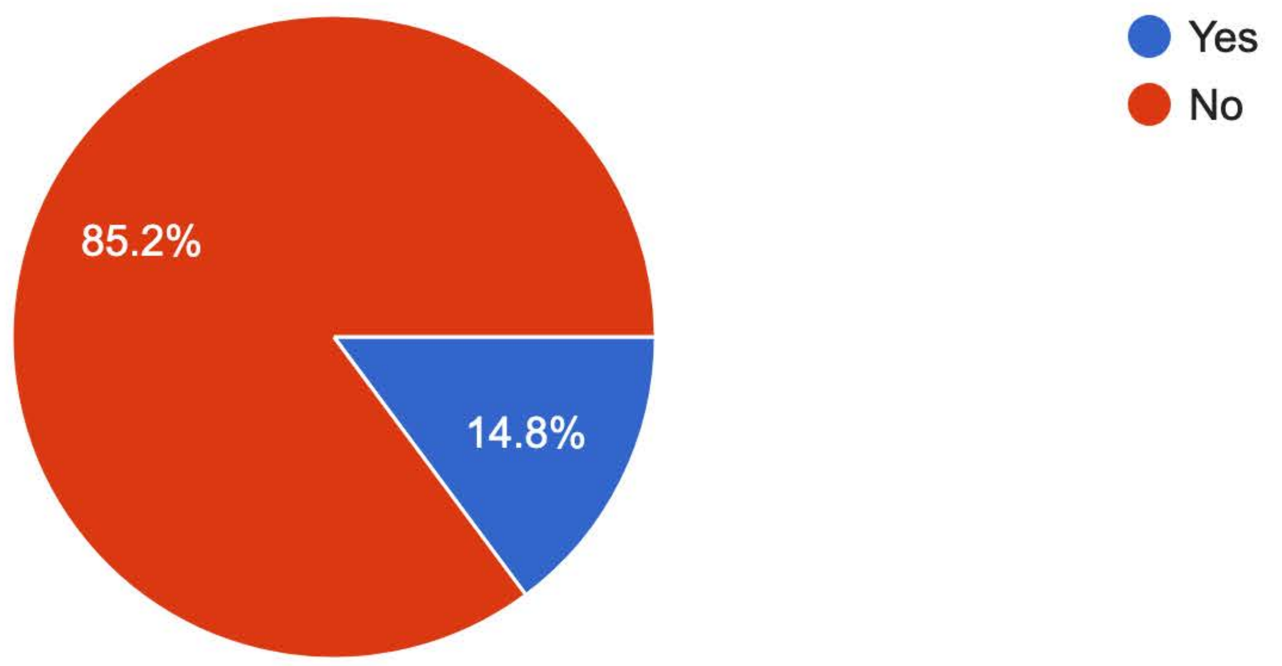
27 responses



INDUSTRY SURVEY: KEY QUESTIONS

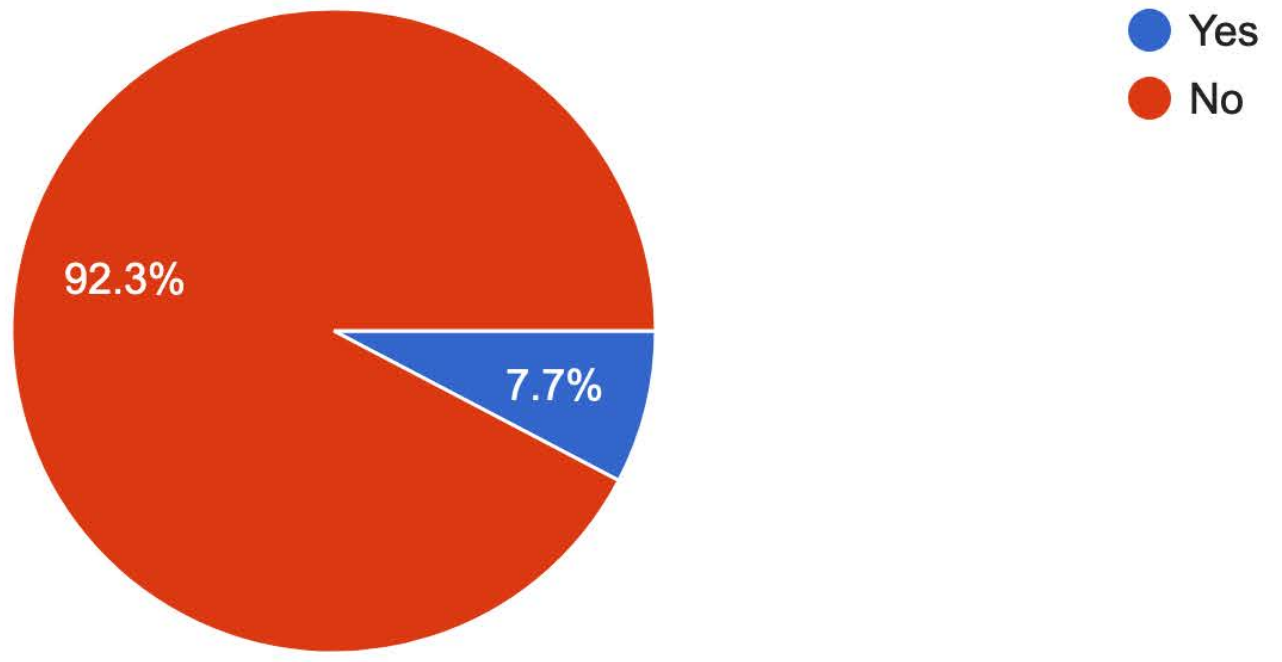
Has your business taken any action to mitigate the effects of OA?

27 responses

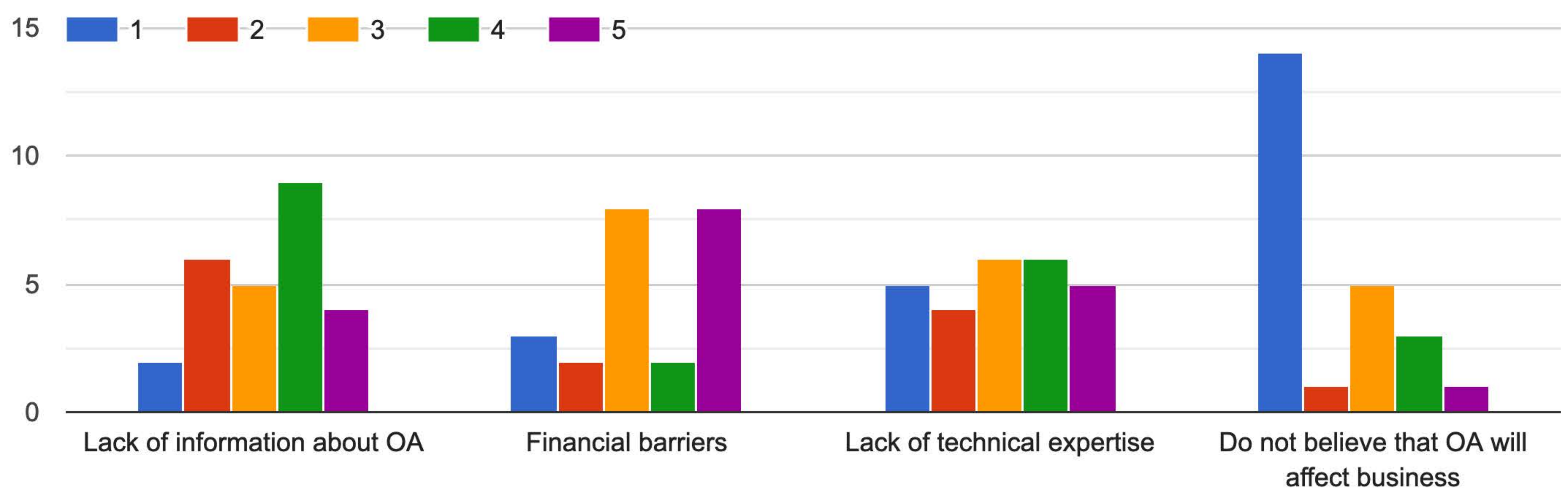


Do you know of any additional actions that your business can take to protect itself from OA?

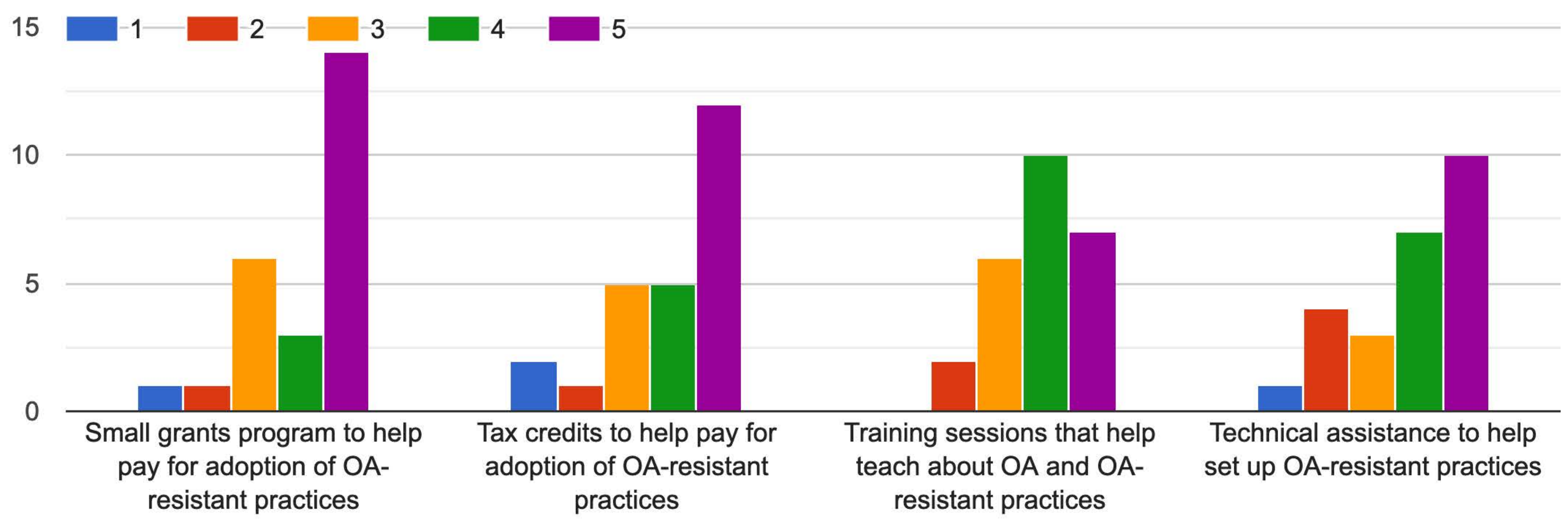
26 responses



How significant is each of the following barriers in preventing your business from preparing for OA? (1 indicates not at all significant, 5 indicates extremely significant)

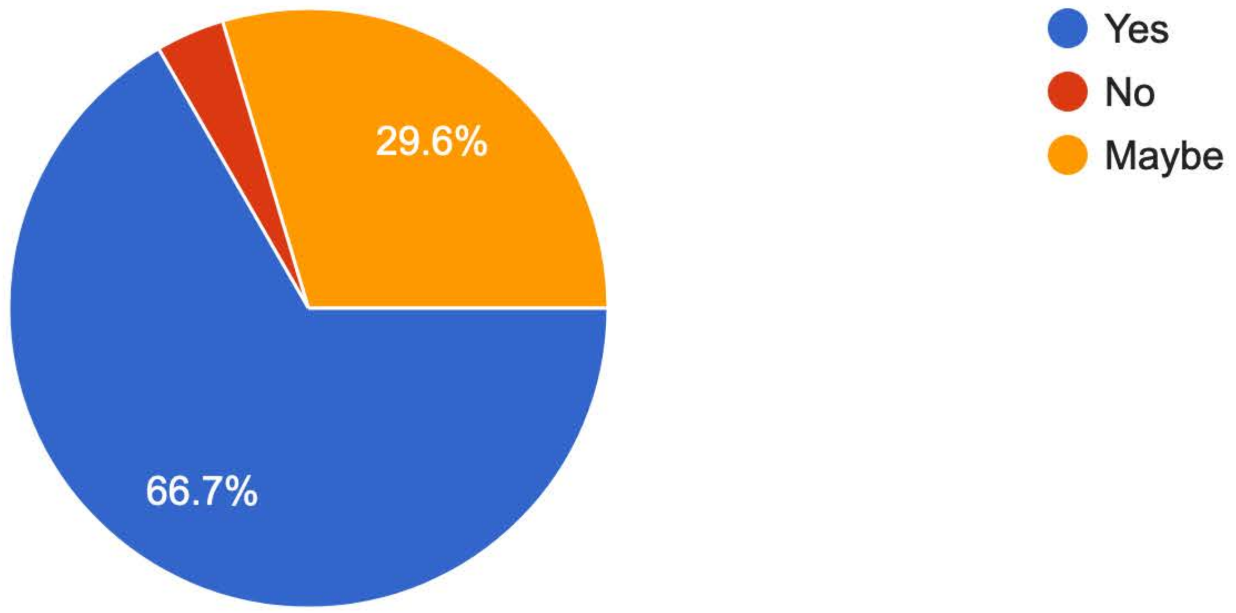


How likely would you be to take advantage of each of the following programs, if Massachusetts were to implement them? (1 indicates not at all likely, 5 indicates extremely likely)

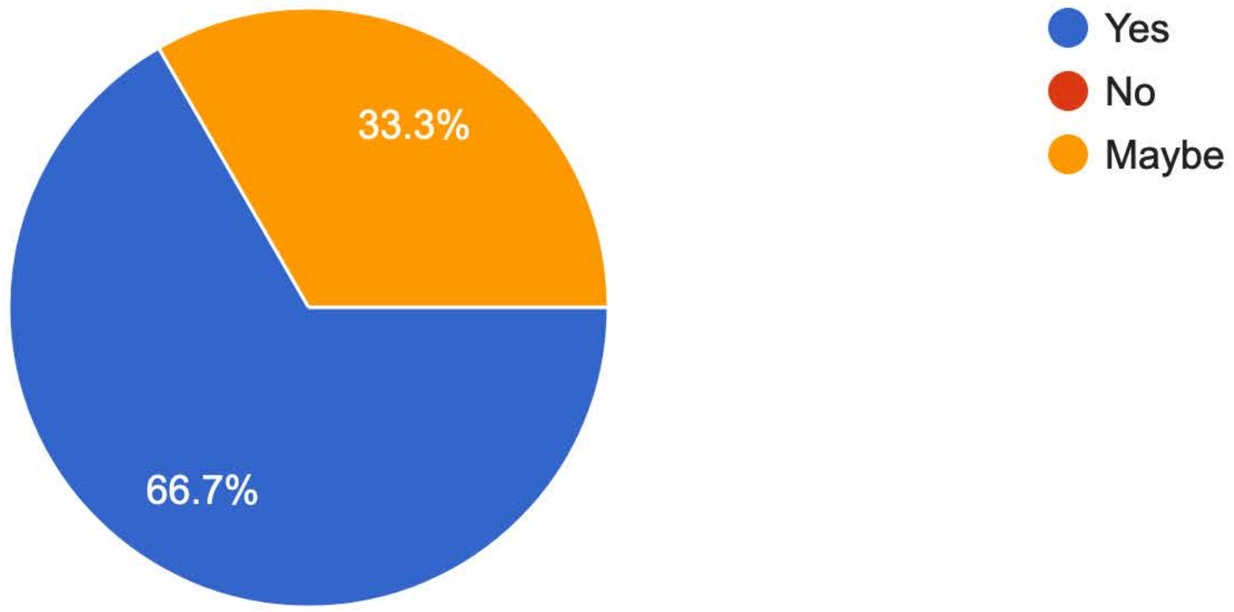


INDUSTRY SURVEY: KEY QUESTIONS

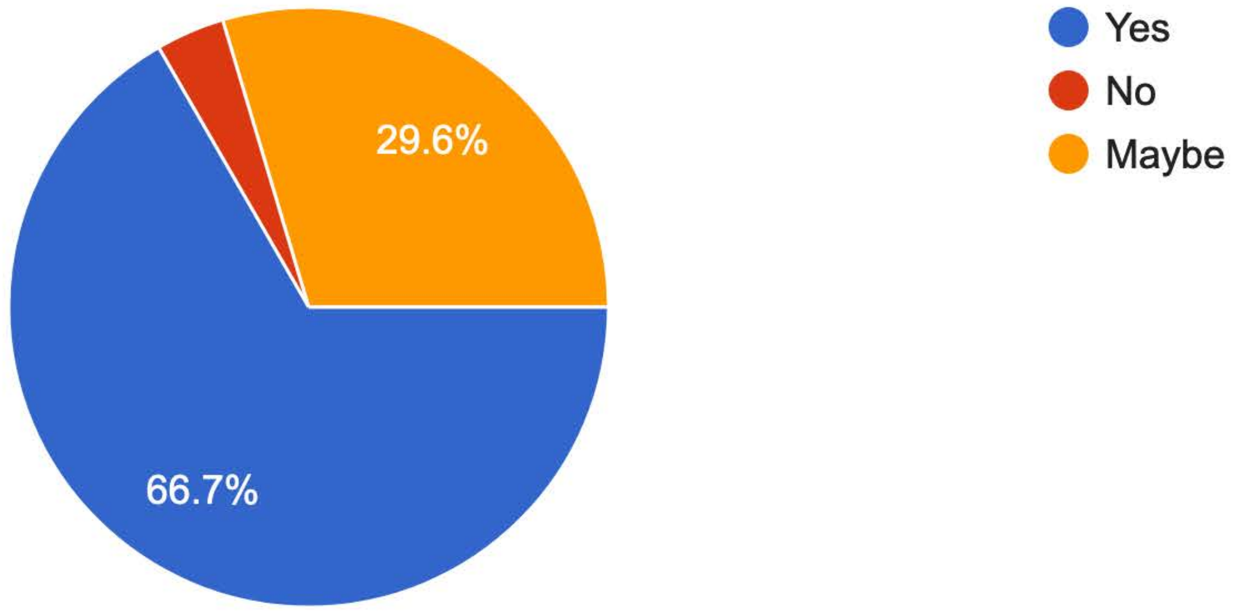
If the water quality monitoring network in Massachusetts was upgraded to include OA monitoring, would you personally find this useful?
27 responses



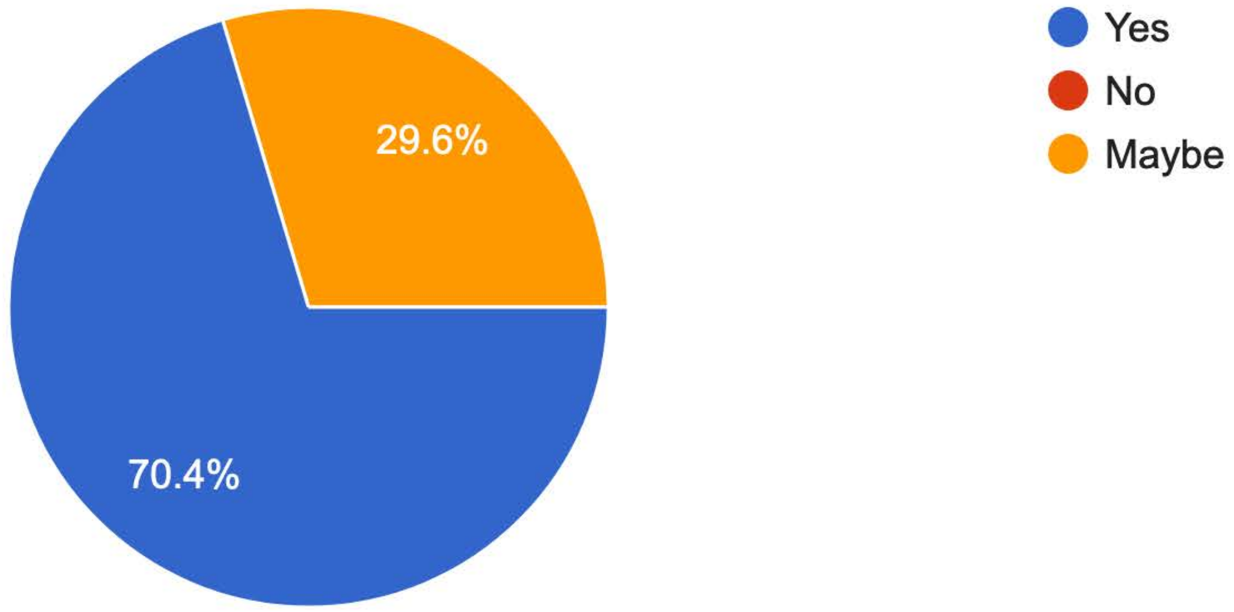
Would you support legislation aimed at addressing the causes of OA?
27 responses



Would you support legislation aimed at funding research into the effects of OA on commercially valuable species?
27 responses



Would you support legislation aimed at improving OA monitoring along the Massachusetts coastline?
27 responses



GREAT PONDS WITHIN 50 METERS OF BARRIER BEACHES

Great Ponds within 50 m of Barrier Beaches (MassGIS Wetlands layer 2017)

SOURCE	NAME	TOWN	AREA (acres)
USGS/MGIS	Chilmark Pond	Chilmark	33.17
USGS/MGIS	Cockeast Pond	Westport	100.51
USGS/MGIS	Coskata Pond	Nantucket	40.44
USGS/MGIS	Crystal Lake	Oak Bluffs	13.39
USGS/MGIS	Edgartown Great Pond	Edgartown	884.26
USGS/MGIS	Farm Pond	Oak Bluffs	34.70
USGS/MGIS	Flat Pond	Mashpee	39.96
USGS/MGIS	Flume Pond	Falmouth	12.63
USGS/MGIS	Hamblin Pond	Mashpee/Falmouth	129.94
USGS/MGIS	Homer Pond	West Tisbury	33.82
USGS/MGIS	Hummock Pond	Nantucket	156.34
USGS/MGIS	James Pond	West Tisbury	47.14
USGS/MGIS	Jobs Neck Pond	Edgartown	66.11
USGS/MGIS	Long Cove	West Tisbury	82.88
USGS/MGIS	Long Pond	Nantucket	65.88
USGS/MGIS	Miacomet Pond	Nantucket	37.47
USGS/MGIS	Musquashcut Pond	Scituate	75.66
USGS/MGIS	Niles Pond	Gloucester	35.82
USGS/MGIS	Oak Bluffs Harbor	Oak Bluffs	29.87
USGS/MGIS	Oyster Pond	Falmouth	63.87
USGS/MGIS	Oyster Pond	Edgartown	156.35
USGS/MGIS	Paqua Pond	Edgartown	10.03
USGS/MGIS	Perch Pond	Falmouth	18.08
USGS/MGIS	Pilgrim Lake	Truro	318.93
USGS/MGIS	Quicks Hole Pond	Gosnold	79.92
USGS/MGIS	Rushy Marsh Pond	Barnstable	15.95
USGS/MGIS	Salt Pond	Falmouth	62.19
USGS/MGIS	Sesachacha Pond	Nantucket	278.14
USGS/MGIS	Ship Pond	Plymouth	12.34
USGS/MGIS	Squibnocket Pond	Chilmark/Gay Head	628.42
USGS/MGIS	Tisbury Great Pond	West Tisbury	811.02
USGS/MGIS	Tom Nevers Pond	Nantucket	10.01
USGS/MGIS	Trapps Pond	Edgartown	30.28
USGS/MGIS	Watcha Pond	West Tisbury	68.58
USGS/MGIS	Westend Pond	Gosnold	37.17

This commission was charged to “include in its investigation and study, the effect of acidification on great ponds that lie inland of coastal barrier beaches, where such beaches are breached allowing seawater into the pond, or where such beaches are prone to breaching or flooding from storm surge that would allow seawater to enter such ponds; and shall report on the locations of these great ponds and the owners of record of such barrier beaches that separate such great ponds from the ocean.” This commission was unable to fulfill the mandate of listing ownership of these barrier beaches as defined in its charge due to lack of clarity on their ownership.

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- **Augustus Judd:** Student Intern – Boston College 2021
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- **Jennie Rheuban:** Woods Hole Sea Grant and Woods Hole Oceanographic Institution
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- **Theo Karplus:** Student Intern – Knox College 2022
- **Todd Callaghan:** MA Office of Coastal Zone Management
- **Zach Contini:** Student Intern – Boston College 2021

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- Senator Julian Cyr: *p. 65, 68*


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