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Ocean Acidification: Frequently Asked Questions

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Ocean Acidification: Frequently Asked Questions

SUMMARY

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The ocean absorbs carbon dioxide (CO_2) from the atmosphere. Chemical reactions between CO_2 and water can change the pH of seawater (pH is a measure of water's acidity or basicity). The current shift in the chemistry of seawater is toward a lower pH, commonly referred to as *ocean acidification* (OA). Scientific consensus is that rising CO_2 concentrations in the atmosphere will continue to contribute to OA globally, primarily affecting the ocean's surface waters, over the 21st century. Other factors, such as seawater temperature and freshwater input, also can influence ocean acidification.

Certain U.S. regions are experiencing impacts from OA (e.g., coastal waters of Oregon), and some scientists expect that nearly all U.S. coastlines and open ocean waters will experience impacts of OA by 2100. In addition, some scientists project large freshwater bodies, such as the Great Lakes, may exhibit acidification trends and impacts similar to those in the ocean by 2100. Impacts of OA include inhibiting the ability of some marine organisms to grow their shells and corroding existing carbonate reef structures—a similar pattern is shown in the fossil record from a period of widespread OA approximately 56 million years ago. These impacts to shell-building marine organisms have had consequences for U.S. fisheries and aquaculture. Economic impacts of increased OA going forward may include higher risks of storm damage to coastal communities and loss of tourism revenue from OA-caused degradation of coral reefs.

Congress has authorized federal agencies, such as the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency, to support activities that aim to adapt to and mitigate OA impacts. The Federal Ocean Acidification Research and Monitoring Act (FOARAM; 33 U.S.C. §§3701 et seq.) was enacted in 2009. Among other things, the law established the federal Interagency Working Group on Ocean Acidification (IWGOA) to coordinate OA activities across the federal government. IWGOA's work includes studying OA's potential impact on marine species and ecosystems as well as identifying adaptation and mitigation strategies.

Congress has continued to show interest in OA. For example, in 2022, Congress passed the Coastal and Ocean Acidification Research and Innovation Act of 2021 (P.L. 117-167, Division B, Title VI, Subtitle E), which amended FOARAM. The amendments added acidification of coastal waters as a concern to be addressed; established an advisory board to the IWGOA; emphasized research on OA adaptation and mitigation strategies, the compounding effects of OA with other environmental stressors, and the socioeconomic impacts of OA; and authorized appropriations for NOAA and the National Science Foundation to conduct OA activities. Congress also has provided funding for certain OA activities. For example, Congress specified funding to NOAA for OA activities in the explanatory statement accompanying the Consolidated Appropriations Act, 2023 (P.L. 117-328).

Some Members of Congress have introduced, and congressional committees have considered, additional OA-related legislation. For example, bills introduced during the 117th Congress focused on examining and addressing the impacts of OA, among other activities. As another example, some Members have proposed legislation to increase federal engagement and collaboration with tribes on OA issues in the 118th Congress.

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Introduction

Rising atmospheric carbon dioxide (CO_2) levels impact the ocean in several ways, including by altering its seawater chemistry. The increased uptake of atmospheric CO_2 by the surface of the ocean contributes to ocean acidification (OA).[1] Parts of the ocean currently are experiencing OA, and scientists project that OA will continue over the 21st century.[2] The effects of OA vary geographically, and with ocean depth, due to other factors that influence seawater chemistry. Similarly, not all marine organisms will be impacted by OA in the same way; however, many shell-building organisms are harmed by OA. U.S. ocean and coastal waters, as well as the Great Lakes, are threatened by OA, and Congress has shown and continues to show interest in addressing OA and its impacts. This report answers nine frequently asked questions about OA.

What Is Ocean Acidification?

Atmospheric gases, such as CO_2, continuously diffuse into the surface of the ocean.[3] Dissolved gases in the surface of the ocean are in near equilibrium with gases in the atmosphere. Thus, as more CO_2 is emitted into the atmosphere, the surface of the ocean absorbs more CO_2. **Figure 1** shows the direct relationship between seawater CO_2 concentrations (green data and line) and atmospheric CO_2 concentrations (red points and line). The increased uptake of atmospheric CO_2 by the ocean alters the chemistry of seawater by decreasing its pH in a process referred to as *ocean acidification*, or OA (blue data and line).[4]

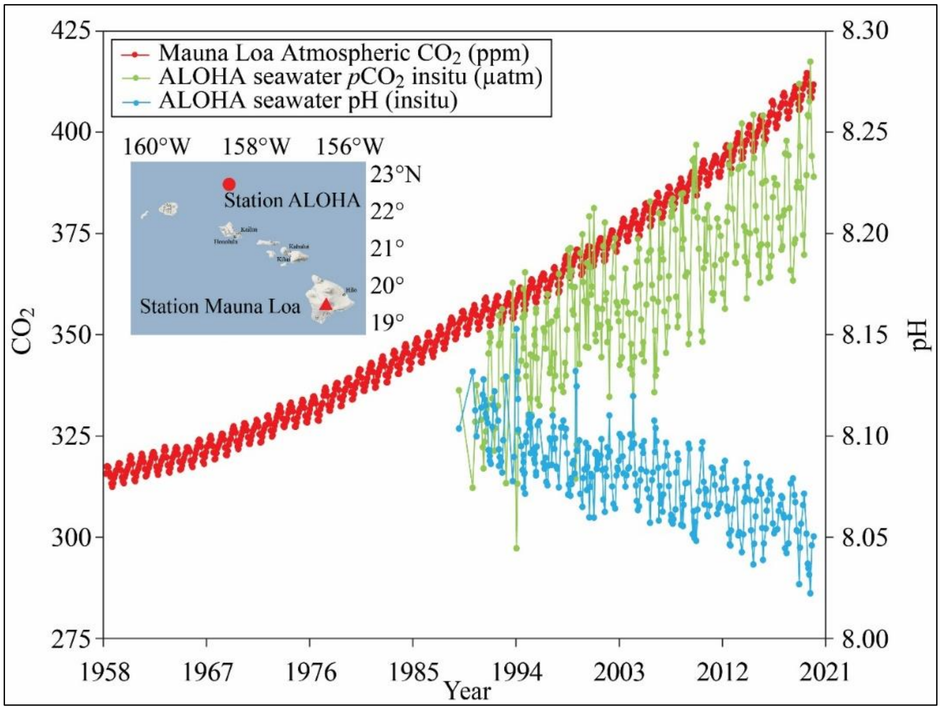
[1] Woods Hole Oceanographic Institution, "Ocean Acidification," at https://www.whoi.edu/know-your-ocean/ocean-topics/how-the-ocean-works/ocean-chemistry/ocean-acidification/.

[2] Josep G. Canadell et al., "Chapter 5: Global Carbon and Other Biogeochemical Cycles and Feedbacks," in *Changing Climate 2021: The Physical Science Basis*, Intergovernmental Panel on Climate Change (IPCC), eds. Valerie Masson-Delmotte et al., 2021, p. 720 (hereinafter referred to as IPCC, *AR6 Physical Science Basis*).

[3] The surface mixed layer depth of the ocean varies seasonally and geographically but generally is between 0 and 200 meters beneath the surface of the ocean.

[4] Rising carbon dioxide (CO_2) emissions are the root cause for current surface ocean acidification (OA). In the ocean interior, bacteria break down organic matter during *cellular respiration*, which adds CO_2 to seawater (see "What Factors Influence Ocean Acidification?"). National Oceanic and Atmospheric Administration (NOAA), "Ocean Acidification," at https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification.

Figure 1. Pacific Atmospheric and Seawater Carbon Dioxide Concentrations and Seawater pH



Source: National Oceanic and Atmospheric Administration (NOAA), "Hawaii Carbon Dioxide Time-Series," at https://www.pmel.noaa.gov/co2/file/Hawaii+Carbon+Dioxide+Time-Series.

Notes: ppm = parts-per-million, µatm = microatmosphere. Figure shows the relationship between atmospheric carbon dioxide (CO_2) concentrations (red points and line) and dissolved CO_2 concentrations of seawater in surface ocean (green points and line), as well as the relationship between increasing dissolved CO_2 concentrations in surface ocean (green points and line) and decreasing seawater pH (blue points and line). Atmospheric CO_2 measurements were made at Mauna Loa Baseline Observatory (refer to Station Mauna Loa on the insert map), which has been continuously monitoring and collecting data related to atmospheric change since the 1950s (NOAA, "Mauna Loa Baseline Observatory," at https://gml.noaa.gov/obop/mlo/). Dissolved CO_2 and pH measurements were made at Station ALOHA, a circle of a 6-mile radius in the Pacific Ocean north of Hawaii (refer to Station ALOHA on the insert map), which has been collecting oceanographic data since 1988 (Station ALOHA, at https://aco-ssds.soest.hawaii.edu/ALOHA/).

OA alters seawater chemistry following a series of chemical reactions. When atmospheric CO_2 dissolves into water (H_2O), it forms carbonic acid (H_2CO_3). Some of the carbonic acid breaks up in ocean water, producing free hydrogen ions. As the number of free hydrogen ions increases, the pH of the ocean decreases and the water becomes more acidic. The prevailing global average pH (a measure of hydrogen ion concentration) of water near the ocean surface is around 8.1, with regional variations.[5]

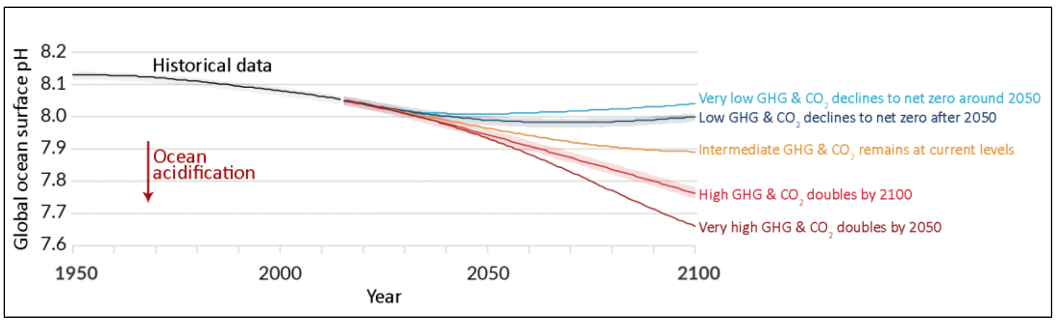
[5] The pH scale is an inverse logarithmic representation of hydrogen ion concentration, indicating the activity of hydrogen ions (or their equivalent) in the solution. A pH of less than 7.0 is considered *acidic*, a pH greater than 7.0 is considered *basic*, and a pH level of 7.0 is defined as *neutral*.

How Might Ocean Acidification Change over the 21st Century?

Over the past two centuries, the average pH of water near the ocean surface has decreased by almost 0.1 unit.[6] That change represents a 26% increase in the concentration of free hydrogen ions dissolved in seawater, because the pH scale is logarithmic (i.e., water with a pH of 8.0 is 10 times less acidic than water with a pH of 7.0 and 100 times less acidic than water with a pH of 6.0).

Modeling studies project that OA will continue over the 21st century, but the rate of OA likely will depend on the rate of atmospheric CO_2 emissions.[7] Under the Intergovernmental Panel on Climate Change's scenario involving a doubling of the concentration of atmospheric CO_2 by 2050 based on no additional climate change policies, models project that average surface ocean pH may decrease by 0.4 units by the year 2100 (see the maroon line in **Figure 2**).[8] However, using a scenario in which CO_2 emissions reach net zero by 2050 or shortly thereafter, models project that average surface ocean pH may decrease by less than 0.1 unit by 2050 and may rise slightly in the second half of the 21st century (see the light and dark blue lines in **Figure 2**).[9] **Figure 2** also shows the projected pathway of ocean surface pH for other CO_2 emissions scenarios in modeling studies.[10]

Figure 2. Scenario Projections of Global Ocean Surface pH



Source: CRS with information from Intergovernmental Panel on Climate Change, "Summary for Policymakers," in *Changing Climate 2021: The Physical Science Basis*, eds. Valerie Masson-Delmotte et al., 2021, p. SMP-22.

Notes: CO_2 = carbon dioxide; GHG = greenhouse gas. Model scenarios with intermediate to very high GHG emissions (yellow, red, and maroon lines) project decreasing ocean surface pH through the 21st century. Other model scenarios with very low to low GHG emissions (light and dark blue lines) project decreasing pH until around 2070 that rises slightly after 2070. The light blue line holds global warming to about 1.5 degrees Celsius (°C), in line with the goals of the Paris Agreement; the dark blue line holds global warming to beneath 2°C.

[6] James Orr et al., "Anthropogenic Ocean Acidification over the Twenty-First Century and Its Impact on Calcifying Organisms," *Nature*, vol. 437 (2005); and NOAA, "Ocean Acidification," at https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification.

[7] IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 720.

[8] Ibid., p. 714.

[9] *Net-zero emissions* means that some greenhouse gases (GHGs) are emitted, but these emissions are offset by removing an equivalent amount of GHGs from the atmosphere and storing it permanently in soil, plants, or materials. Achieving *net-zero emissions* may be considered more feasible than releasing no GHGs to the atmosphere (i.e., *zero emissions*).

[10] IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 720.

Model projections of average global OA changes, such as the projections shown in **Figure 2**, are driven primarily by atmospheric CO_2 simulations.[11] In general, the global trend would reflect surface pH decline with increasing atmospheric CO_2 concentrations. Regional seawater properties may influence the surface pH value, resulting in geographic variations in OA.[12] See "What Factors Influence Ocean Acidification?" for a further discussion on the factors that may amplify regional variations in seawater pH.

What Factors Influence Ocean Acidification?

Not all ocean and coastal regions experience OA in the same way. Increased CO_2 concentrations in the atmosphere contribute to OA, but other factors also influence coastal and ocean acidification. Rates of acidification can vary geographically for numerous reasons, including temperature, ocean circulation, biological activity, coastal upwelling, freshwater input, nutrient runoff, and atmospheric deposition, among other influences.[13]

- **Temperature**. Gases, such as CO_2, are more soluble in colder water than in warmer water. Thus, marine waters near the poles have a much greater capacity to absorb atmospheric CO_2 than do ocean waters in the tropics. As a consequence, polar regions tend to experience greater regional changes due to OA.[14]
- **Ocean Circulation**. Dissolved CO_2 is transported from the ocean surface into deeper ocean water at high latitudes, because cold polar surface waters have a higher density than warm tropical waters. The cold polar surface waters sink to depth (i.e., vertical ocean mixing), and both observations and modeling studies show that the vertical ocean mixing contributes to acidification of the deeper ocean.[15] For example, OA below 2,000 meters has been detected in polar regions in both the North Atlantic and the Southern Ocean.[16]
- **Biological Activity**. The breakdown of organic carbon in the ocean interior by bacteria, via a biological process known as *cellular respiration*, adds CO_2 to seawater. Deep ocean water is enriched in CO_2 due to cellular respiration, in addition to the capacity of colder water in the deep ocean to absorb CO_2. Phytoplankton near the ocean surface and marine plants (i.e., kelp, seaweed, seagrass) take up CO_2 during *photosynthesis*, which may offset some effects of OA.
- **Coastal Upwelling**. *Coastal upwelling* is a process by which coastal winds push warm surface waters offshore, causing cold deep water to rise to the surface. Upwelled ocean waters have high CO_2 concentrations, because deep ocean waters carry dissolved CO_2 from two sources: (1) atmospheric CO_2 from cold polar waters that absorbed CO_2 at the surface and sank to depth and (2) CO_2

[11] IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 719.

[12] Ibid.

[13] IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 720.

[14] IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 677.

[15] IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 717.

[16] Ibid.

respired by bacteria during the decomposition of organic carbon in the ocean interior.[17]

- **Freshwater Input**. Riverine influx associated with high-intensity precipitation events or glacial melt can yield large freshwater inputs that contribute dissolved inorganic carbon, organic carbon, and nutrients to coastal waters. These contributions can alter the chemistry of waters located at the mouths of large rivers or the toes of glaciers. Rivers and streams also can deliver gases and particles deposited within the watershed via *atmospheric deposition* (see below) to freshwater bodies or coastal waters.
- **Nutrient Runoff**. Riverine inputs with high nutrient loads (often nitrogen and phosphorous associated with farming practices) can lead to excessive plant and algae growth in coastal settings, a process known as *eutrophication*.[18] The resulting decomposition of algae and plants in coastal waters produces increased amounts of CO_2 in the water column, which can lead to a lowering of seawater pH.[19]
- **Atmospheric Deposition.** Fossil fuel combustion and biomass burning release sulfur dioxide and nitrogen oxide gases to the atmosphere, where these gases are chemically transformed into sulfuric acid and nitric acid.[20] Wet atmospheric deposition is commonly known as *acid rain*, and it includes any form of precipitation (e.g., sleet, snow) that contains acidic compounds, such as sulfuric and nitric acids.[21] Uncontaminated precipitation (normal rain) is naturally acidic with a pH of 5.6; acid rain generally has a pH between 4.2 and 4.4.[22] Acid rain plays a minor role in making the ocean more acidic on a global scale, but it can have a greater impact on ocean coastal waters and freshwater systems.[23]

How Does Ocean Acidification Impact Marine Life?

The influence of OA on marine life is complicated. A pH of less than the global average of 8.1 may cause some organisms to expend more energy, but organisms may be able to adapt in complex and species-specific ways to OA. OA may affect more marine species when its effects are compounded by the effects of climate change, including warming seawater temperatures and deoxygenation (loss of oxygen).[24] In particular, OA poses physiological stress to invertebrate

[17] U.S. Global Change Research Program (USGCRP), "Chapter 13: Ocean Acidification and Other Ocean Changes," in *Climate Science Special Report: Fourth National Climate Assessment*, vol. I, eds. Donald J. Wuebbles et al., 2017, p. 373 (hereinafter referred to as USGCRP, NCA4 vol. I). For a discussion on coastal upwelling, see CRS Report R47021, *Federal Involvement in Ocean-Based Research and Development*, by Caitlin Keating-Bitonti.

[18] U.S. Environmental Protection Agency (EPA), "The Sources and Solutions: Agriculture," at https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture.

[19] NOAA, "What Is Eutrophication?," at https://oceanservice.noaa.gov/facts/eutrophication.html.

[20] Scott C. Doney et al., "Impact of Anthropogenic Atmospheric Nitrogen and Sulfur Deposition on Ocean Acidification and the Inorganic Carbon System," *Proceedings of the National Academy of Sciences*, vol. 104 (2007), p. 14580 (hereinafter referred to as Scott Doney et al., 2007).

[21] EPA, "What is Acid Rain," at https://www.epa.gov/acidrain/what-acid-rain.

[22] Ibid.

[23] Scott Doney et al., 2007, p. 14580, and EPA, "Effects of Acid Rain," at https://www.epa.gov/acidrain/effects-acid-rain.

[24] IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 721.

organisms that build their hard parts (i.e., shells, skeletons, reef structures) with carbonate minerals.[25]

Marine Invertebrates

For many marine invertebrate organisms, the abundance and availability of carbonate ions (CO_3^{2-}) in seawater are critical for survival. Most marine invertebrates have biochemical mechanisms to regulate internal pH and are able, within limits, to grow and secrete their shells or exoskeletons even when water in their surrounding environment is acidic. At current average ocean pH levels (about 8.1), ocean waters near the surface have ample carbonate ions to support shell formation and coral reef growth. However, as more CO_2 dissolves into the ocean, the resulting chemical reactions decrease the abundance and availability of carbonate ions.[26] A reduction in the availability of carbonate ions in the ocean makes it physiologically challenging for shell-forming marine organisms to grow shells, especially those in early stages of their life cycle (i.e., larval and juvenile stages). If the availability of carbonate ions becomes too low (i.e., undersaturated) in seawater, then shells made with carbonate minerals tend to dissolve.

The following sections expound on current or potential impacts of OA on specific types of invertebrate species, including corals, oysters, lobsters, and crabs.

Corals

OA reduces corals' ability to build and maintain reefs, the majority of which are located in tropical and subtropical shallow waters. Most corals are colonial organisms, comprising hundreds to hundreds of thousands of individual animals, called *polyps*.[27] Some polyps secrete carbonate skeletons that can grow into very large reef structures, called *coral reefs*. Modeling studies employing an emissions scenario in which very little climate change mitigation is undertaken this century project seawater pH conditions by 2100 that are less favorable to the growth of coral reefs (refer to the maroon line in **Figure 2**).[28]

Coral reefs are biodiverse, productive ecosystems that can provide socioeconomic benefits to coastal communities. For example, studies show that reefs provide protection against erosion by, and flooding from, waves comparable to that provided by artificial structures such as *breakwaters*.[29] Coral reef recreation and tourism also provide economic benefits for coastal communities. For example, in 2015, reef-related tourism generated an estimated $217 million for Puerto Rico and $108 million for the U.S. Virgin Islands.[30] In addition to potential impacts on tourism, declines in coral reef cover may reduce fisheries' maximum catch potential in the

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[25] Carbonate minerals include aragonite, calcite, and high-magnesium calcite.

[26] As more CO_2 dissolves into the ocean, bicarbonate ions (HCO_3^{1-}) form at the expense of carbonate ions (CO_3^{2-}), which is described by the following reaction: $CO_2 + CO_3^{2-} + H_2O = 2HCO_3^{1-}$.

[27] NOAA, "What Are Corals?," at https://oceanservice.noaa.gov/education/tutorial_corals/coral01_intro.html.

[28] USGCRP, "Chapter 27: Hawai'i and U.S.-Affiliated Pacific Islands," in *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, vol. II, eds. David R. Reidmiller et al., 2018, p. 1264 (hereinafter referred to as USGCRP, NCA4 vol. II); and K.L. Ricke et al., "Risks to Coral Reefs from Ocean Carbonate Chemistry Changes in Recent Earth System Model Projections," Environmental Research Letters, vol. 8 (2013), p. 5.

[29] Filippo Ferrario et al., "The Effectiveness of Coral Reefs for Coastal Hazard Risk Reduction and Adaptation," *Nature Communications*, vol. 5 (2014); and U.S. National Park Service, "Breakwaters, Headlands, Sills, and Reefs," at https://www.nps.gov/articles/breakwaters-headlands-sills-and-reefs.htm.

[30] USGCRP, NCA4 vol. II, Chapter 20, p. 829.

exclusive economic zones of most central and western Pacific islands and in the Caribbean region.[31]

Shellfish

OA's effects on certain shellfish has impacted shellfish fishery revenues and may continue to do so should OA expand to new regions and greater water depths.[32] Of particular relevance to shellfish hatcheries, relatively acidic ocean conditions caused by OA may impair the ability of larval shellfish to build shells. For example, in the mid-2000s, oyster growers from Washington to California experienced financial hardships from widespread death of larval shellfish (seed) at hatcheries.[33] In 2008, scientists from the National Oceanic and Atmospheric Administration (NOAA) and various universities linked the oyster seed losses to OA; in turn, oyster hatcheries shifted their operations to adapt to the OA conditions (see "What Are Federal Agencies Doing About Ocean Acidification?").[34] An additional consideration regarding OA's impact on oysters is potential reductions in shell thickness and hardness, which could devalue oysters commercially because shells that are easily shucked and do not break or chip (i.e., thick and hard shells) are a sought-after characteristic of oysters on the half shell.[35]

OA also may affect other economically valuable shellfish, including the American lobster and Dungeness crab. In 2021, the most recent year reported by NOAA Fisheries, the American lobster found along the coast of New England was the highest-valued shellfish species in North America.[36] The Gulf of Maine, an area with record high stock abundance of American lobster,[37] has experienced changing oceanographic conditions.[38] Ocean warming has influenced lobster fisheries in the region,[39] and some research studies project the Gulf of Maine will experience OA conditions by 2050.[40] In the laboratory, researchers have shown that OA impacts both juvenile and adult lobsters by causing erratic heart rates and fewer infection-fighting blood cells; should these laboratory conditions occur in nature, they may impact lobsters' survival.[41]

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[31] USGCRP, NCA4 vol. II, Chapter 27, p. 1264; and USGCRP, NCA4 vol. II, Chapter 20, p. 853.

[32] Sarah Cooley and Scott Doney, "Anticipating Ocean Acidification's Economic Consequences for Commercial Fisheries," *Environmental Research Letters*, vol. 4 (2009).

[33] Ryan Kelly, "Narratives Can Motivate Environmental Action: The Whiskey Creek Ocean Acidification Story," *Ambio*, vol. 43 (2014), pp. 592-599.

[34] Ibid. and NOAA, "Improving an Ocean Acidification Observation System in Support of Pacific Coast Shellfish Growers," at https://ioos.noaa.gov/project/turning-headlights-high/.

[35] Catherine Liberti et al., "The Impact of Oyster Aquaculture on the Estuarine Carbonate System," *Elementa: Science of the Anthropocene*, vol. 10 (2022).

[36] NOAA Fisheries reported a total commercial catch of nearly 134.7 million pounds of American lobster, yielding over $924.7 million dollars, in 2021 (NOAA Fisheries, "Landings," at https://www.fisheries.noaa.gov/foss/f?p=215:200:14333709901427:Mail:NO, hereinafter referred to as NOAA Fisheries, Landings Database).

[37] NOAA, "American Lobster," at https://www.fisheries.noaa.gov/species/american-lobster.

[38] Samantha Siedlecki et al., "Projecting Ocean Acidification Impacts for the Gulf of Maine into 2050: New Tools and Expectations," *Elementa: Science of the Anthropocene*, vol. 9 (2021).

[39] Katherine Mills et al., "Fisheries Management in a Changing Climate: Lessons from the 2012 Ocean Heat Wave in the Northwest Atlantic," *Oceanography*, vol. 26 (2013), pp. 191-195.

[40] Samantha Siedlecki et al., "Projecting Ocean Acidification Impacts for the Gulf of Maine into 2050: New Tools and Expectations," *Elementa: Science of the Anthropocene*, vol. 9 (2021).

[41] Amalia Harrington and Heather Hamlin, "Ocean Acidification Alters Thermal Cardiac Performance, Hemocyte Abundance, and Hemolymph Chemistry in Subadult American Lobsters *Homarus americanus* H. Milne Edwards, 1837 (Decapoda: Malcostraca: Nephropidae)," *Journal of Crustacean Biology*, vol. 39, no. 4 (2019), pp. 468-476.

On the U.S. West Coast, Dungeness crabs are a valuable shellfish.[42] Thus far, Dungeness crabs have shown no change in natural population dynamics due to changing oceanographic conditions. However, laboratory experiments have found decreased survival rates in Dungeness crabs hatched in waters with a pH of 7.5 (a level that has been observed in upwelled waters along the Washington coast) compared with those hatched in laboratory waters with a global average pH of 8.1.[43]

Marine Vertebrates

Whereas invertebrate organisms primarily build their hard parts (e.g., shells, carapace) with carbonate minerals, vertebrate bones, including those of fish, are composed of a phosphate mineral. OA does not affect the chemical structure of phosphate. Some studies, however, show that the durability and robustness of some fish bones and shark teeth increase under OA conditions.[44] Other studies have claimed that OA can alter the behaviors of certain fish species, but the research methodology behind these studies is debated.[45]

How Might U.S. Regions Be Affected by Ocean Acidification?

Some U.S. regions have experienced measurable impacts from OA. Scientists expect that nearly all U.S. coastlines will experience the impacts of OA by 2100.[46] As shown in **Figure 2**, models project a decrease in global ocean surface pH ranging from about 0.05 to 0.10 units by 2050. As discussed above in "What Factors Influence Ocean Acidification?," regional seawater properties may affect the surface pH value, resulting in geographic variations of OA.

For example, Pacific waters along the U.S. West Coast are influenced by coastal upwelling.[47] Observations and models project the California Current System may experience an expansion and intensification of low-pH water due to upwelling.[48] OA has impacted some oyster hatcheries along the West Coast. In particular, in 2007, the Oregon-based Whiskey Creek Shellfish Hatchery was unable to provide shellfish growers with late-stage oyster larvae because the low-pH

[42] NOAA Fisheries reported a total commercial catch of nearly 69.3 million pounds of Dungeness crab in 2021, yielding a total revenue of over $332.2 million for the Pacific Coast (NOAA Fisheries, Landings Database).

[43] Nina Bednarŝek et al., "Exoskeleton Dissolution with Mechanoreceptor Damage in Larval Dungeness Crab Related to Severity of Present-Day Ocean Acidification Vertical Gradients," *Science of the Total Environment*, vol. 716 (2020); and NOAA, "Dungeness Crab Larvae Already Showing Effects of Coastal Acidification," January 23, 2020, at https://research.noaa.gov/article/ArtMID/587/ArticleID/2581.

[44] Jonathan Leung et al., "Shark Teeth Can Resist Ocean Acidification," *Global Change Biology*, vol. 28, no. 7 (2022); Valentina Di Santo, "Ocean Acidification and Warming Affect Skeletal Mineralization in a Marine Fish," *Proceedings of the Royal Society B: Biological Sciences*, vol. 268 (2019); and Alice Mirasole et al., "Evidences On Alterations in Skeleton Composition and Mineralization in a Site-Attached Fish Under Naturally Acidified Conditions in a Shallow CO_2 Vent," *Science of the Total Environment*, vol. 761 (2021).

[45] See Martin Enserink, "Sea of Doubts," *Science* (2021), at https://www.science.org/content/article/does-ocean-acidification-alter-fish-behavior-fraud-allegations-create-sea-doubt.

[46] USGCRP, NCA4 vol. I; and USGCRP, NCA4 vol. II.

[47] For more information about ocean upwelling, see CRS Report R47021, *Federal Involvement in Ocean-Based Research and Development*, by Caitlin Keating-Bitonti.

[48] See "What Factors Influence Ocean Acidification" for more information about coastal upwelling. IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 721.

seawater corroded the shells of early stage larvae.[49] Waters circulating around Alaska's Pacific coastline also are derived from upwelled cold waters and may be impacted by OA.[50] Moreover, glacial runoff may further amplify OA along the Alaskan coast (e.g., Gulf of Alaska).[51]

U.S. coastal regions near agricultural watersheds and urbanized estuaries may be susceptible to OA due to eutrophication.[52] For example, the Mississippi River delivers riverine inputs of nutrients (nitrogen and phosphorus) to the Gulf of Mexico, contributing to eutrophication of coastal waters and a decrease in pH along the Gulf coast.[53] Similarly, runoff into the Chesapeake Bay is contributing to eutrophication and a decrease in pH in the Bay's waters.[54] In addition, coastal waters of the East Coast are influenced by freshwater inputs from riverine and estuarine sources, which may contribute to OA.[55]

Tropical oceans are expected to experience the greatest change in seawater chemistry associated with rising atmospheric CO_2 concentrations.[56] The seawater pH off the Hawaiian Island of Oahu has declined from an annual average of about 8.11 in 1988 to 8.07 (roughly an 8.7% increase in acidity), according to 35 years of ocean data collection at Station ALOHA (**Figure 1**).[57] Although oceanic pH varies geographically, scientists consider the conditions at Station ALOHA to be broadly representative of those across the western and central Pacific Ocean.[58] The tropical and subtropical Pacific Ocean also is projected to experience the highest levels of thermal stress from climate change, which could exacerbate the effects of increasing OA.[59]

Big freshwater systems, such as the Great Lakes, may be susceptible to acidification.[60] The Great Lakes are projected to experience acidification at a similar rate to the oceans by 2100 as a result of atmospheric CO_2 emissions.[61] Currently, there are no long-term monitoring programs in the Great Lakes that are designed to detect acidification.[62]

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[49] NOAA, "Improving an Ocean Acidification Observation System in Support of Pacific Coast Shellfish Growers," at https://ioos.noaa.gov/project/turning-headlights-high/; and R. Kelly, "Narratives Can Motivate Environmental Action: The Whiskey Creek Ocean Acidification Story," *Ambio*, vol. 43 (2014).

[50] Jeremy Mathis, "Ocean Acidification Risk Assessment for Alaska's Fishery Sector," *Progress in Oceanography*, vol. 136 (2015).

[51] Ibid; IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 720.

[52] NOAA, "What Is Eutrophication?," at https://oceanservice.noaa.gov/facts/eutrophication.html.

[53] IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 721.

[54] NOAA, "OPA Projects in the Southeast U.S.," at https://oceanacidification.noaa.gov/CurrentProjects/Southeast.aspx#.

[55] USGCRP, NCA4 vol. I, Chapter 13, p. 373.

[56] OA generally occurs in shallow ocean waters in tropical regions because there is little to no vertical ocean mixing to transport the atmospheric CO_2 absorbed by the surface ocean into the deep ocean.

[57] Data collection and observations began at the Station ALOHA in October 1988.

[58] John Marra and Michael Kruk, "State of Environmental Conditions in Hawaii and the U.S. Affiliated Pacific Islands und a Changing Climate: 2017," NOAA National Centers for Environmental Information, 2017, p. 74, at https://coralreefwatch.noaa.gov/satellite/publications/state_of_the_environment_2017_hawaii-usapi_noaa-nesdis-ncei_oct2017.pdf.

[59] Ibid.

[60] See, for example, Linda Weiss et al., "Rising pCO_2 in Freshwater Ecosystems Has the Potential to Negatively Affect Predator-Induced Defenses in Daphnia," *Current Biology*, vol. 28 (2018).

[61] Mark Rowe et al., "Great Lakes Region Acidification Research," *NOAA Ocean, Coastal, and Great Lakes Acidification Research Plan: 2020-2029*, 2020, p. 102 (hereinafter referred to as NOAA, *Acidification Research Plan*, 2020).

[62] Ibid, p. 104. In 2022, NOAA's Great Lakes Environmental Research Laboratory placed an instrumentation buoy in the Thunder Bay National Marine Sanctuary to monitor Lake Huron's water column carbon dioxide pressure and pH

Has Ocean Acidification Happened in the Past?

OA has occurred in the past when geologic events (e.g., volcanic eruptions) emitted large quantities of CO_2 and other gases to the atmosphere. The fossil record suggests that some mass extinction events of marine organisms that have occurred in geologic history may have been related to changes in ocean pH. For example, approximately 56 million years ago, a large pulse of methane locked in ocean sediments was released into the ocean-atmosphere system over a 3,000-20,000 year period.[63] Methane released into the ocean-atmosphere undergoes a chemical reaction to become CO_2 within about 10 years. Chemical analyses of marine sediments suggest this methane release was associated with a global surface ocean pH decline ranging from 0.15 to 0.30 units. However, this change in pH occurred more slowly than the current rate of OA and continued over a long time interval.[64]

What Actions or Interventions Might Limit or Reduce Ocean Acidification?

Some stakeholders may be interested in limiting or reducing OA and its impacts. Mitigating OA involves decreasing the availability of CO_2 in the ocean by removing it from either the atmosphere or the ocean. The ocean's rate of uptake of atmospheric CO_2 would start to decrease if the concentration of atmospheric CO_2 decreased.

Some shellfish industries have implemented approaches to mitigate CO_2 concentrations in the water. Some shellfish farmers on the Pacific and Atlantic coasts of the United States grow marine plants (e.g., kelp, seaweed, seagrass) as a nature-based approach to offset the effects of OA.[65] Researchers also are exploring an approach that involves placing bags of oyster shells near oyster farms to improve the health of the living oysters.[66] These researchers are testing the hypothesis that, over time, the shells in the bags will dissolve and provide a natural buffer to OA. The placement of oyster shells, or pulverized silicate or carbonate rocks, in seawater can alter the water chemistry by fixing the CO_2 dissolved in the seawater to the added material (i.e., shell,

level—both measurements are needed to study acidification. NOAA aims to expand the monitoring network in Lake Huron and establish monitoring stations in Lakes Erie, Michigan, Ontario, and Superior. (John Flesher, "Scientists: Atmospheric Carbon Might Turn Great Lakes More Acidic," Associated Press, December 19, 2022, at https://apnews.com/article/science-us-news-fish-plants-oceans-4db7ea795573e9d9260f6432b3e9b9f6, and NOAA, *Acidification Research Plan*, 2020, p. 104).

[63] Miriam Katz et al., "Uncorking the Bottle: What Triggered the Paleocene/Eocene Thermal Maximum Methane Release?," *Paleoceanography*, vol. 16 (2001); James Zachos et al., "Rapid Acidification of the Ocean During the Paleocene-Eocene Thermal Maximum," *Science*, vol. 308 (2005); and IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 714.

[64] IPCC, *AR6 Physical Science Basis*, Chapter 5, p. 714.

[65] Marine plants remove CO_2 from the surface waters of the ocean via photosynthesis. See, for example, World Wildlife Foundation, "Exploring the Benefits of Kelp Farming in Maine," 2021, at https://www.worldwildlife.org/magazine/issues/winter-2021/articles/exploring-the-benefits-of-kelp-farming-in-maine; and Marketplace, "Could Kelp Help Mitigate Ocean Acidification?," February 22, 2018, at https://www.marketplace.org/2018/02/22/could-kelp-help-oyster-industry-mitigate-effects-ocean-acidification/.

[66] NOAA, "Researchers Explore Using Empty Oyster Shells to Decrease Acidic Seawater," October 13, 2017, at https://seagrant.noaa.gov/News/Article/ArtMID/1660/ArticleID/1661/Researchers-Explore-Using-Empty-Oyster-Shells-to-Decrease-Acidic-Seawater.

pulverized rock or mineral). This approach for removing dissolved CO_2 from the water is known as *ocean alkalinity enhancement* or *enhanced weathering*.[67]

What Are Federal Agencies Doing About Ocean Acidification?

Congress has shown interest in OA and its impacts over the past few decades and has directed federal agencies to take certain actions to address OA.

Federal Agency Research and Monitoring Activities

In 2022, Congress amended the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM; P.L. 111-11).[68] As amended, FOARAM

- Established and assigned responsibilities to the federal Interagency Working Group on Ocean Acidification (IWGOA) and a nonfederal advisory board;
- Directed the Secretary of Commerce to establish an OA program within NOAA and defined the program's activities;[69]
- Instructed the National Science Foundation (NSF) to continue its OA research activities, supporting competitive proposals for OA research, observation, and monitoring;
- Charged the National Aeronautics and Space Administration with ensuring space-based monitoring of OA and its impacts; and
- Authorized appropriations for NOAA and NSF to carry out these activities from FY2023 through FY2027.[70]

The IWGOA released a strategic federal research and monitoring plan in 2014.[71] In that plan, the working group listed seven thematic areas of federal research and monitoring activities.[72]

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[67] National Academies of Sciences, Engineering, and Medicine, *A Research Strategy for Ocean-Based Carbon Dioxide Removal and Sequestration* (Washington, DC: National Academies Press, 2022), p. 181. For more information on ocean-based CO_2 removal technologies, see CRS Report R47172, *Geoengineering: Ocean Iron Fertilization*, by Caitlin Keating-Bitonti.

[68] 33 U.S.C. §§3701 et seq. See "What Are Recent Congressional Actions Addressing Ocean Acidification" for information on the 2022 amendments.

[69] Under statute, the federal Interagency Working Group on Ocean Acidification (IWGOA) is chaired by a representative from NOAA and includes representatives from the National Science Foundation; National Aeronautic and Space Administration; Smithsonian Institution; National Institute of Standards and Technology of the Department of Commerce; EPA; Bureau of Indian Affairs, Bureau of Ocean Energy Management, National Park Service, U.S. Fish and Wildlife Service, and U.S. Geological Survey of the Department of the Interior; U.S. Department of Agriculture; Department of State; Department of Energy; Department of the Navy; and other agencies as appropriate.

[70] The Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM; P.L. 111-11), as amended, did not specify an authorization of appropriations for the National Aeronautics and Space Administration.

[71] IWGOA was charged with developing a strategic research and monitoring plan to guide federal research on OA and overseeing the plan's implementation (33 U.S.C. §§3703(a)(2)). IWGOA is to submit an updated plan to Congress at least once every five years (33 U.S.C. §§3703(c)(3)). According to NOAA, a revised plan is forthcoming (email correspondence with NOAA Office of Legislative and Intergovernmental Affairs, April 12, 2023).

[72] IWGOA, *Strategic Plan for Federal Research and Monitoring of Ocean Acidification*, March 2014, at https://oceanacidification.noaa.gov/Portals/42/Images/IWGOA Strategic Plan.pdf.

1. Research to understand responses to OA
2. Monitoring of ocean chemistry and biological impacts
3. Modeling to predict changes in the ocean carbon cycle and impacts on marine ecosystems and organisms
4. Technology development and standardization of measurements
5. Assessment of socioeconomic impacts and development of strategies to conserve marine organisms and ecosystems
6. Education, outreach, and engagement strategy on OA
7. Data management and integration

The IWGOA's 2016 report on implementation of the strategic plan identified multiple OA-related activities across most of the IWGOA agencies.[73] Of the seven thematic areas outlined in the 2014 strategic plan, most OA activities reported in 2016 were related to (1) research to understand responses to OA and (2) monitoring of ocean chemistry and biological impacts.[74] As of 2016 (the latest update on implementation of the strategic plan), strategic plan actions remaining to be addressed were (7) data management and integration.[75]

The IWGOA's summary report for FY2018 and FY2019 (the most recent available) identified funding levels by agency and research and monitoring activities by geographic area, with a focus on locations of interest to the United States (**Figure 3**).[76] Over the FY2012-FY2019 period, NSF and NOAA reported the highest amount of OA activity funding in FY2019, with totals of $67.9 million and $29.3 million, respectively.[77]

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[73] According to the report, the Smithsonian Institution and the Department of Energy were not members of IWGOA in 2014, so their activities were not included in the 2016 implementation plan. In addition, the U.S. Navy did not contribute to the document because its work on OA is "limited." Activities of the Bureau of Indian Affairs also were not included in the 2016 implementation plan. (National Science and Technology Council [NSTC] Subcommittee on Ocean Science and Technology, *Implementation of the Strategic Plan for Federal Research and Monitoring of Ocean Acidification*, December 2016, p. 33, at https://oceanacidification.noaa.gov/sites/oap-redesign/Documents/IWGOA/OA%20Implementation%20Plan%20FINAL.pdf [hereinafter referred to as NSTC, *Implementation Report*, December 2016]).

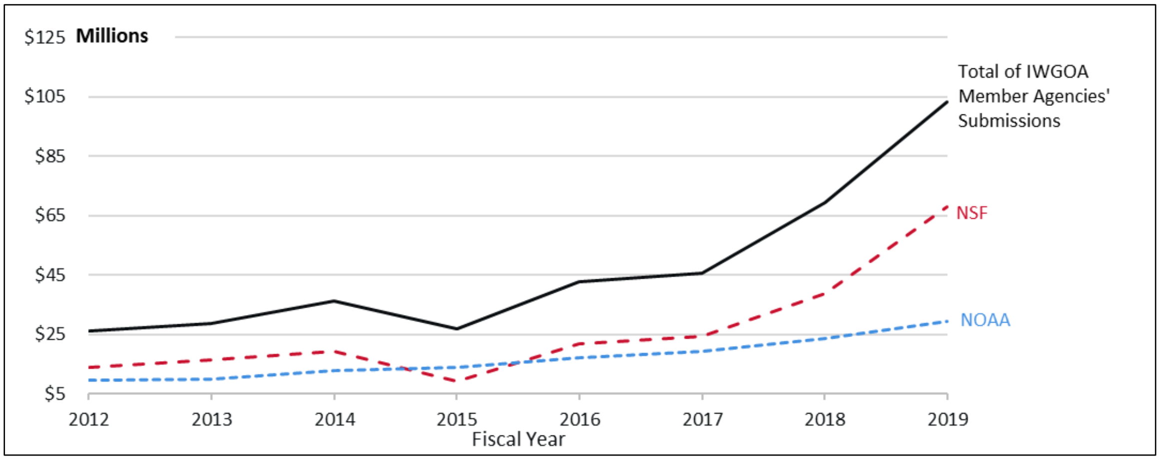
[74] NSTC, *Implementation Report*, December 2016, p. 3.

[75] Ibid.

[76] IWGOA, *Sixth Report on Federally Funded Ocean Acidification Research and Monitoring Activities*, October 28, 2022, pp. 27-28, 36, and 38 (hereinafter referred to as IWGOA, *Sixth Report*, October 2022). IWGOA is to submit updated reports on implementation and funding to Congress every two years (33 U.S.C. §3703(c)(2)). According to NOAA, revised reports are forthcoming (email correspondence with NOAA Office of Legislative and Intergovernmental Affairs, April 12, 2023).

[77] IWGOA, *Sixth Report*, October 2023, pp. 36, 38.

Figure 3. Trends in Federal Funding of Ocean Acidification Research and Monitoring Activities, FY2012-FY2019



Source: CRS, using Interagency Working Group on Ocean Acidification (IWGOA), *Third Report on Federally Funded Ocean Acidification Research and Monitoring Activities*, April 23, 2015, pp. 20 and 25-26; IWGOA, *Fourth Report on Federally Funded Ocean Acidification Research and Monitoring Activities*, December 20, 2016, pp. 43, 48, and 50; IWGOA, *Fifth Report on Federally Funded Ocean Acidification Research and Monitoring Activities: Fiscal Years 2016 and 2017*, January 28, 2020, p. 29; and IWGOA, *Sixth Report on Federally Funded Ocean Acidification Research and Monitoring Activities*, October 28, 2022, pp. 27-28, 36, and 38.

Notes: Fiscal year total funding for ocean acidification research and monitoring for all IWGOA member agencies that submitted information in that year, including the Bureau of Indian Affairs, Bureau of Ocean Energy Management, Environmental Protection Agency, Department of State, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration (NOAA), National Park Service, National Science Foundation (NSF), Smithsonian Institution, U.S. Fish and Wildlife Service, and U.S. Geological Survey, (solid black line); and for the two agencies with the most funding, NSF (dashed red line) and NOAA (dashed blue line).

The IWGOA's (sixth) summary report for FY2018 and FY2019 provides the most recent publicly available funding levels. The IWGOA's (fifth) summary report for FY2016 and FY2017 notes that the NSF contributions are underreported. For example, ship support for NSF research activities is provided by NSF-funded University National Oceanographic Laboratory System and is a major expense for OA activities; this expense was not included in data used by CRS to create this figure.

NOAA is working on the summary report for FY2020 and FY2021 (email correspondence with NOAA Office of Legislative Affairs, April 12, 2023).

Federal Agency Adaptation and Mitigation Activities

Federal agencies also support activities to adapt to and mitigate OA impacts.[78] For example, following the drop in oyster production levels at the Whiskey Creek Shellfish Hatchery in 2007, NOAA deployed a network of sensors off the Northwest Pacific Coast to act as an early warning system for shellfish hatcheries.[79] The early warning system alerts hatchery managers when

[78] For example, see NOAA Ocean Acidification Program, "Adaptation Strategies," at https://oceanacidification.noaa.gov/WhatWeDo/EducationOutreach/SOARCEWebinars/TabId/3463/PID/16157/evl/0/CategoryID/207/CategoryName/adaptation-strategies/Default.aspx; and EPA, "What EPA Is Doing to Address Ocean and Coastal Acidification," at https://www.epa.gov/ocean-acidification/what-epa-doing-address-ocean-and-coastal-acidification.

[79] NOAA, "Improving an Ocean Acidification Observation System in Support of Pacific Coast Shellfish Growers," at https://ioos.noaa.gov/project/turning-headlights-high/; and R. Kelly, "Narratives Can Motivate Environmental Action: The Whiskey Creek Ocean Acidification Story," *Ambio*, vol. 43 (2014).

upwelling produces relatively colder and lower pH seawater; these alerts allow hatchery managers to time when coastal waters are pumped into the hatchery's oyster larvae tanks or treat the waters to avoid harming the oysters. Such early warning systems can help buffer the shellfish industry against OA, as larvae grown at the hatchery are sold to commercial shellfish growers.

In another example, at the 2023 Our Ocean Conference in Panama, the United States (via the Department of State) joined the International Alliance to Combat Ocean Acidification (OA Alliance) and committed to drafting its national OA action plan. Members of the OA Alliance committed to take individual actions that address the environmental, cultural, and economic threat posed by OA by creating an action plan.[80]

In addition to the areas identified by the IWGOA in its 2014 strategic plan, the Ocean Policy Committee (OPC) has noted other actions to address OA, such as engaging with vulnerable communities, especially tribal communities, and ensuring that OA and its impacts are included in discussions of potential solar geoengineering and carbon dioxide removal approaches.[81] OPC also identified other federal entities that may have a role in addressing OA, in addition to agencies in the IWGOA, including the National Science and Technology Council Subcommittee on Ocean Science and Technology and the National Security Council.[82]

What Are Recent Congressional Actions Addressing Ocean Acidification?

In 2022, Congress passed the Coastal and Ocean Acidification Research and Innovation Act of 2021 (P.L. 117-167, Division B, Title VI, Subtitle E), which amended FOARAM. The amendments included

- the addition of a definition for coastal acidification;[83]
- the addition of several federal agencies and departments to IWGOA;
- the establishment of an advisory board to IWGOA;
- a greater research focus on OA adaptation and mitigation strategies, on how OA may interact with other environmental stressors, and on the socioeconomic impacts of OA; and
- authorization of appropriations for FY2023 through FY2027.

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[80] U.S. Department of State, "United States Announces $800 Million in International Commitments for Protecting Our Ocean," press release, March 8, 2023, at https://www.state.gov/united-states-announces-800-million-in-international-commitments-for-protecting-our-ocean/. In addition to the United States as a whole, nine U.S. states are members of the OA Alliance and, of these nine states, California, Oregon, Maine, Washington, Maryland, and Hawaii have completed their respective action plans. New Jersey, New York, and Virginia are the remaining alliance members. OA Alliance, "Current Members," at https://www.oaalliance.org/current-members, and OA Alliance, "Action Plans," at https://www.oaalliance.org/action-plans.

[81] The Ocean Policy Committee coordinates federal actions on ocean-related matters and was codified by the National Defense Authorization Act for Fiscal Year 2021 (P.L. 116-283, Title X, Subtitle E, §1055).

[82] Ocean Policy Committee, *Ocean Climate Action Plan*, March 2023, p. 44, at https://www.whitehouse.gov/wp-content/uploads/2023/03/Ocean-Climate-Action-Plan_Final.pdf.

[83] The Coastal and Ocean Acidification Research and Innovation Act of 2021 (P.L. 117-167) amended the ocean acidification definition in FOARAM and defined *coastal acidification* as "the decrease in pH and changes in the water chemistry of coastal oceans, estuaries, and Great Lakes from atmospheric pollutions, freshwater inputs, and excess nutrient run-off from land."

Congress also has provided direction to federal agencies regarding OA via the appropriations process. For example, in FY2023, Congress appropriated $17 million to NOAA for the Integrated Ocean Acidification Program.[84] Language accompanying the FY2023 appropriations act directed the agency to continue to work with state, local, territorial, and tribal governments on ocean and coastal acidification research to complete vulnerability assessments required by FOARAM,[85] and to work with the White House Office of Science and Technology Policy to competitively award prizes for innovation to understand, research, or monitor OA or its impacts, or to develop management or adaptation options to respond to OA.[86]

Some Members of Congress have introduced additional legislation regarding OA in recent years. For example, some bills in the 117th Congress would have directed the Secretary of Commerce or NOAA to work with the National Academies of Sciences, Engineering, and Medicine to examine the impact of OA and other environmental stressors on estuarine environments.[87] One of these bills also would have directed NOAA to support state and local OA vulnerability assessments and strategic research planning related to OA and its impacts on coastal communities, among other OA activities.[88] Other bills would have included OA and its impacts as part of broader climate change impacts or physical risks to be addressed in certain ways.[89] As another example, in the 118th Congress, the proposed Coastal Communities Ocean Acidification Act of 2023 (H.R. 676) would amend FOARAM to require federal engagement and collaboration with tribes.[90]

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[84] "Explanatory Statement Submitted by Mr. Leahy, Chair of the Senate Committee on Appropriations, Regarding H.R. 2617, Division B—Commerce, Justice, Science, and Relate Agencies Appropriations Act, 2023, Consolidated Appropriations Act, 2023," *Congressional Record*, daily edition, vol. 168 (December 20, 2022), p. S7911. Hereinafter, 2023 Explanatory Statement Accompanying P.L. 117-328, Division B.

[85] Ibid.

[86] U.S. Congress, House Committee on Appropriations, *Commerce, Justice, Science, and Related Agencies Appropriations Bill, 2023*, Report Together with Minority Views to Accompany H.R. 8256, 117th Cong., 2nd sess., June 30, 2022, H.Rept. 117-395, p. 43. The explanatory statement accompanying the 2023 Consolidated Appropriations Act states that "Unless otherwise noted, the language set forth in House Report 117-395 ('the House report') carries the same weight as language included in this joint explanatory statement and should be complied with unless specifically addressed to the contrary in this joint explanatory statement or the act. The explanatory statement, while repeating some language for emphasis, is not intended to negate the language referred to above unless expressly provided herein" (2023 Explanatory Statement Accompanying P.L. 117-328, Division B, p. S7898).

[87] For example, in the 117th Congress see H.R. 2533 (passed by the House on May 18, 2021) and H.R. 3764, Section 1011 (placed on the Union Calendar on December 30, 2022).

[88] In the 117th Congress, H.R. 3764, Section 1011 (placed on the Union Calendar on December 30, 2022).

[89] For example, in the 117th Congress, see H.R. 1187, Title IV (passed by the House on June 16, 2021), H.R. 2570 (placed on the Union Calendar on May 20, 2021), H.R. 2780, Section 301 (placed on the Union Calendar on December 30, 2022), H.R. 2872 (placed on the Union Calendar on November 16, 2022), and S. 1217 (hearings held by the Senate Committee on Banking, Housing, and Urban Affairs on September 14, 2021).

[90] In the 118th Congress, H.R. 676 was ordered to be reported by the House Committee on Science, Space, and Technology on March 29, 2023.

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