THIRD REPORT ON FEDERALLY FUNDED OCEAN ACIDIFICATION RESEARCH AND MONITORING ACTIVITIES

PRODUCT OF THE

Committee on Environment, Natural Resources, and Sustainability of the
National Science and Technology Council

April 2015

EXECUTIVE OFFICE OF THE PRESIDENT

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

WASHINGTON, D.C. 20502

April 23, 2015

Dear Colleagues:

I am pleased to transmit to you the *Third Report on Federally Funded Ocean Acidification Research and Monitoring Activities*, a biennial report to Congress for Fiscal Years 2012 and 2013 that responds to the Federal Ocean Acidification Research and Monitoring (FOARAM) Act. This report was produced by the Interagency Working Group on Ocean Acidification of the Subcommittee on Ocean Science and Technology, under the auspices of the National Science and Technology Council's Committee on Environment, Natural Resources, and Sustainability.

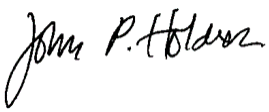
This report summarizes federally funded ocean-acidification research and monitoring activities; provides expenditures for these activities; and describes the recent release of a strategic research plan for Federal research and monitoring of ocean acidification.

Ocean acidification refers to a reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere but can also be caused by other chemical additions or subtractions from the ocean. The long-term consequences of ocean acidification are still being determined, but likely include serious impacts on marine ecosystems and the services those systems provide to society.

The *Strategic Plan for Federal Research and Monitoring of Ocean Acidification*, another requirement of the FOARAM Act, was released in March 2014 to help guide Federal agency activities on ocean acidification into the future. This strategic plan aims to increase coordination among Federal agencies and assist a wide variety of stakeholders seeking to collaborate with and build upon Federal activities.

The Obama administration is deeply concerned about ocean acidification and committed to better understanding and addressing its impacts on America's communities, economy, and environment. Many members of Congress share this concern and commitment and have supported Federal activities on ocean acidification. I look forward to continued partnership in this domain going forward.

Sincerely,



John P. Holdren
Assistant to the President for Science and Technology
Director Office of Science and Technology Policy

About the National Science and Technology Council

The National Science and Technology Council (NSTC) is the principal means by which the Executive Branch coordinates science and technology policy across the diverse entities that make up the Federal research and development (R&D) enterprise. One of the NSTC's primary objectives is establishing clear national goals for Federal science and technology investments. NSTC prepares R&D packages aimed at accomplishing multiple national goals. The NSTC's work is organized under five committees: Environment, Natural Resources, and Sustainability; Homeland and National Security; Science, Technology, Engineering, and Mathematics (STEM) Education; Science; and Technology. Each of these committees oversees subcommittees and working groups that are focused on different aspects of science and technology. More information is available at www.whitehouse.gov/ostp/nstc.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on questions in which science and technology are important elements; articulating the President's science and technology policy and programs; and fostering strong partnerships among Federal, state, and local governments, and the scientific communities in industry and academia. The Director of OSTP also serves as Assistant to the President for Science and Technology and manages the NSTC. More information is available at www.whitehouse.gov/ostp.

About the Subcommittee on Ocean Science and Technology

The purpose of the Subcommittee on Ocean Science and Technology (SOST) is to advise and assist on national issues of ocean science and technology. The SOST contributes to the goals for Federal ocean science and technology, including developing coordinated interagency strategies, and fosters national ocean science and technology priorities, including implementation of the National Ocean Policy.

About this Document

This document was developed by the Interagency Working Group on Ocean Acidification, which advises, assists, and makes recommendations on matters related to ocean acidification, including coordination of Federal activities on ocean acidification and other interagency activities as outlined in the Federal Ocean Acidification Research and Monitoring Act of 2009. The document was published by OSTP.

Acknowledgements

We thank Drs. Shallin Busch, Dwight Gledhill, and Erica Ombres from the National Oceanic and Atmospheric Administration's Ocean Acidification Program for their contributions to the drafting of this document.

Copyright Information

Printed in the United States of America, 2015

National Science and Technology Council

Chair
John P. Holdren
Assistant to the President for Science and Technology and Director, Office of Science and Technology Policy

Staff
Jayne B. Morrow
Executive Director

Committee on Environment, Natural Resources, and Sustainability

Co-Chairs
Tamara Dickinson
Principal Assistant Director for Environment and Energy
Office of Science and Technology Policy

Glenn Paulson
Science Advisor
Environmental Protection Agency

Kathryn Sullivan
Acting Undersecretary for Oceans and Atmosphere; Administrator of the National Oceanic and Atmospheric Administration
Department of Commerce

Staff
Lisa Matthews
Executive Secretary
Environmental Protection Agency

Subcommittee on Ocean Science and Technology

Co-Chairs
Debbie Bronk
National Science Foundation

Fabien Laurier
Office of Science and Technology Policy

Richard Merrick
National Oceanic and Atmospheric Administration

Staff
Hilary Goodwin
National Oceanic and Atmospheric Administration

Roxanne Nikolaus
National Science Foundation

Interagency Working Group on Ocean Acidification

Chair
Libby Jewett
National Oceanic and Atmospheric Administration

Co-Vice Chairs

Dave Garrison
National Science Foundation

Paula Bontempi
National Aeronautics and Space Administration

Members

Krisa Arzayus
National Oceanic and Atmospheric Administration

Jill Brandenberger
Department of Energy

Jennifer Culbertson
Bureau of Ocean Energy Management

Ned Cyr
National Oceanic and Atmospheric Administration

Richard Feely
National Oceanic and Atmospheric Administration

Steve Gittings
National Oceanic and Atmospheric Administration

Jason Grear
Environmental Protection Agency

Kenli Kim
Department of State

Justine Kimball
United States Navy

Pete Leary
United States Fish and Wildlife Service

Max Mayeaux
United States Department of Agriculture

Chris Moore
Environmental Protection Agency

Kenric Osgood
National Oceanic and Atmospheric Administration

David Redford
Environmental Protection Agency

Lisa Robbins
United States Geological Survey

Chris Sabine
National Oceanic and Atmospheric Administration

Kim Yates
United States Geological Survey

Table of Contents

Executive Summary

This document is the third biennial summary and progress report submitted under the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act). The FOARAM Act specifies that the Subcommittee on Ocean Science and Technology (SOST) shall transmit a biennial report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science and Technology and the Committee on Natural Resources of the House of Representatives that includes:

1. A summary of federally funded ocean acidification research and monitoring activities, including the budget for each of these activities; and
2. An analysis of the progress made toward achieving the goals and priorities for the interagency research plan developed by the Subcommittee under section 12405.

Federal agency activities related to ocean acidification are summarized for fiscal years (FY) 2012 and 2013. Activities are classified as having either a primary focus on ocean acidification or being contributing activities in that they were designed for other purposes but clearly provide information useful for understanding ocean acidification. In FY2012, federal agencies supported approximately $20 million of activities with a primary focus on ocean acidification and an additional $6 million for contributing studies.

In FY2013 funding was approximately $22 million for primary and $6 million for contributing studies. Activities included monitoring of ocean chemistry and biological impacts, research to understand species-specific and ecosystem responses to ocean acidification, biogeochemical and ecosystem modeling, technology development for improved measurement, assessment of socioeconomic impacts from ocean acidification, education/outreach activities, data management and integration, and other activities. A Strategic Plan for Federal Research and Monitoring of Ocean Acidification Act was released March 26, 2014.

Introduction

The Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act, Public Law 111-11, Subtitle D) directed the Subcommittee on Ocean Science and Technology (SOST), which is governed by the National Ocean Council, to create an Interagency Working Group on Ocean Acidification (IWG-OA). Section 12404(c) of the FOARAM Act further specifies that the SOST will transmit a biennial report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science and Technology and the Committee on Natural Resources of the House of Representatives that includes:

1. A summary of federally funded ocean acidification research and monitoring activities, including the budget for each of these activities; and
2. An analysis of the progress made toward achieving the goals and priorities for the interagency research plan developed by the Subcommittee under section 12405.

This document constitutes the third biennial summary and progress report of the SOST IWG-OA. The IWG-OA was chartered by SOST in October 2009, is chaired by the National Oceanic and Atmospheric Administration (NOAA), and includes additional representatives from National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), U.S. Geological Survey (USGS), Environmental Protection Agency (EPA), Bureau of Ocean Energy Management (BOEM), Department of State (DOS), U.S. Navy, and the U.S. Fish and Wildlife Service (FWS). In 2013, a representative from the U.S. Department of Agriculture (USDA) was included in the working group. The group meets regularly to coordinate ocean acidification activities across the federal government and has made significant progress toward meeting the goals of the FOARAM Act.

This report is organized into sections corresponding to the thematic areas as outlined within the Strategic Plan for Federal Research and Monitoring of Ocean Acidification. An additional category is used for those items not adequately captured by those themes. Each section contains an overview of the activities advanced within a given thematic area by federal agencies in fiscal years (FY) 2012 and 2013. Appendix 1 provides a summary of funding amounts for individual agency ocean acidification research and monitoring activities. In Appendix 1, activities are classified as having either a primary focus on ocean acidification or being contributing activities, in that they were designed for other purposes but clearly provide information useful for understanding ocean acidification.

Theme 1. Research to Understand Responses to Ocean Acidification

Marine biological processes can be affected by ocean acidification due to changes in pH, or in the concentrations of dissolved CO2, bicarbonate ion, or carbonate ion. OA research to date has revealed a broad range of biological sensitivities to OA across a diverse group of marine taxa. Effects observed have included changes in rates of photosynthesis, respiration, growth, calcification, reproduction, and recruitment. Agencies invested $11,837 K on research directly related to the effects of ocean acidification on marine organisms and ocean chemistry in FY2012, and $13,665 K in FY2013. NSF issued solicitations in FY2012 (NSF solicitation 12-500) and FY2013 (NSF solicitation 12-600) with funding levels of approximately $10,000 K and $10,000-$11,000 K for research primarily focused on ocean acidification in FY2012 and FY2013, respectively. In addition, NSF supported a significant amount of research that contributed to understanding ocean acidification but was focused on related topics, such as carbon cycling and ocean chemistry.

Across all agencies, roughly $393 K was spent in FY2012 on activities not specifically termed ocean acidification studies, but that substantially contributed ocean acidification relevant information (e.g., ocean carbon inventory surveys). Expenditures on contributing activities in FY2013 were $409 K.

Species-specific Physiological Responses and Adaptation Potential, Food Webs, and Ecosystems

In FY2012 and FY2013, federal agency activities to study species' response to ocean acidification were diverse, spanning molecular and physiological functions including impacts on growth, reproduction, and survival. Results from these studies have afforded the science community an opportunity to begin addressing the adaptive potential of living marine resources to ocean acidification. They also provided foundational information for predicting the response of food webs and ecosystems to future acidification.

Predictions of the ecological effects of ocean acidification are essential for the development of effective adaptation, mitigation, and prevention strategies. Marine food webs are complex, and changes in one or more key species may have serious repercussions for ecosystem structure and function. Because ocean acidification has the potential to affect key species at the base of marine food webs, it could alter marine food webs up to and including commercial and recreational fishery species. Further, decreases in calcium carbonate production may alter the structural fabric of some seafloor ecosystems by reducing hard-bottom habitats. Many marine plants and animals depend on the complex habitat provided by corals and other associated organisms in both tropical and cold-water systems. Oyster and clam beds, which provide critical habitat in temperate waters, may also be affected by decreased carbonate production and calcium carbonate dissolution as well as increased occurrence of or susceptibility to disease organisms. Because large-scale ocean acidification experiments on intact marine ecosystems are generally impractical, ecological prediction commonly relies on extrapolating results from small-scale laboratory studies on individual species to modeled effects on entire populations in the context of complex food webs (Theme 3).

NSF supported research focused on organism responses to changing seawater pH at about $6,000 K and $9,000 K in FY2012 and FY2013 respectively. Organisms targeted included phytoplankton, benthic invertebrates (including corals), fishes, and pelagic zooplankton. Research included both calcifying and non-calcifying forms. Some projects focused on the combined effect of other stressors, in addition to lowered pH and increased CO2. A few studies were focused on the ability of organisms to adapt or evolve in response to increasing CO2 and decreasing pH.

NSF-funded projects focused on how ocean acidification will affect food webs, communities, and ecosystems (~ $1,000 K in both FY2012 and FY2013) included studies on how copepods might be affected by changing food quality of phytoplankton, understanding the patterns of coral reef systems to ocean acidification, and assessing whether biogeochemical cycling in future oceans may result in the formation of "refugia" in some coral reef locations.

NOAA conducted a number of research studies directed towards assessing how ocean acidification may affect the life history and physiology of living marine resources, including commercially harvested species and their prey. These studies investigated survival, growth, physiology, nutritional quality (phytoplankton), genomics, and/or proteomics. The Alaska Fisheries Science Center (AFSC) has published results on walleye pollock and red king and tanner crabs, and conducted studies on golden crab and northern rock sole. In addition, the AFSC has worked to characterize the calcium carbonate mineralogy of 44 cold-water corals and a sponge that inhabit Alaskan waters, which may be useful as a proxy for their susceptibility to effects of acidification. The Northeast Fisheries Science Center studied the response to ocean acidification in two shellfish species (surf clam and scallop), four fish species (scup, black sea bass, winter flounder, summer flounder), and multiple species of phytoplankton, including assemblages of

phytoplankton species collected from the wild. The Northwest Fisheries Science Center has studied the response to ocean acidification in the china rockfish, two crab species (Dungeness and pygmy rock), three zooplankton species (a Pacific krill, a Pacific copepod, and a pteropod), and five shellfish species (Pacific oyster, geoduck, bay and Mediterranean mussels, manila clam). Pilot experiments on other species have also been conducted to assess the feasibility of future work. The Atlantic Oceanographic and Meteorological Laboratory (AOML) has applied the use of an advanced micro-CT technology to investigate the effects of high CO2 on the otoliths of pantropical fish species.

Some key findings from NOAA investigations have included:

- The growth potential of early life stages of walleye pollock appears resilient to the direct physiological effects of ocean acidification.
- Ocean acidification affects the otoliths of larval cobia, which may alter the perception of auditory information and could influence the dispersal, survival, and recruitment of this pelagic fish species.
- Red king crab may maintain calcification rates under ocean acidification, but at a high energetic cost. Both red king crab and tanner crab have decreased larval survival and growth under ocean acidification conditions, indicating potential declines in abundance over the coming decades, barring any evolutionary adaptation or acclimatization.
- High CO2 has negative physiological impacts on bivalve larvae, with the greatest sensitivity to ocean acidification being the first days of development.

USGS supported studies on the effects of ocean acidification on coral health and coral reef degradation, as well as monitoring of coralline algae that form crusts of calcium carbonate and interactions between corals and their algal symbionts. Calcification rates measured on field specimens are now focused on two species of coral that are listed as endangered under the Endangered Species Act. Laboratory studies on the effects of lowered pH and higher CO2 values in seawater on photosynthesis and respiration of different tropical and subtropical benthic organisms, foraminifera, and aragonitic green algae, were continued. Additionally, collaborative research between BOEM, NOAA, and USGS that focused on deep-water coral communities, related ecology, and the associated microbial communities was conducted.

In FY2012, EPA used seawater pH manipulations (CO2 bubbling) as a generic stressor to develop quantitative ecological methods for detecting and modeling demographic responses of marine crustaceans to human stressors. In FY2013, EPA began a study of coastal acidification impacts on shellfish in Narragansett Bay. To improve ecological interpretation, this was intentionally synchronized with the current NOAA-funded study by State University of New York-Stony Brook, with which EPA scientists are collaborating. The added EPA component focuses on experiments using field deployments of early life stage shellfish that have been pre-conditioned in EPA's CO2 control system. Concurrently, EPA is collaborating with the University of Rhode Island on studies of plankton community and macroalgal responses to acidification via CO2 bubbling. Since nutrient-stimulated marine production can both affect and be affected by acidification, these EPA activities are partly motivated by nutrient priorities in EPA's Safe and Sustainable Water Resources research program. Through these collaborations, EPA scientists are improving the basic ocean acidification literacy of research planning efforts intended to support Clean Water Act and Clean Air Act activities.

Environmental and Ecological Responses and Indices

The major nutrient cycles in the ocean, which include geological, chemical, physical, and biological processes determine the availability of nutrients that support all ocean life, as well as the ability of the

oceans to sequester CO2 from the atmosphere. Ocean acidification has the potential to alter both chemical and biological processes that will affect both nutrient and carbon cycles. Changes in the carbonate ion ($CO_3^=$) concentration in seawater affect the "saturation state" of the various calcium carbonate minerals that are used by marine organisms to produce their shells or skeletons. The $CO_3^=$ concentration decreases dramatically with ocean acidification and the resulting decrease in availability of carbonate ions may impact shell and skeletal formation of many organisms, including corals, shellfish, sea urchins, and some algae.

In FY2012 and FY2013, NSF supported approximately $2,500 K and $2,000 K, respectively, of research focused on how ocean acidification will influence the chemistry of sea water. The research topics include carbon and nutrient cycling processes, experimental work on calcium carbonate dissolution rates and CO2 thermodynamics, the role of sea ice in determining ocean chemistry, trace-metal availability to phytoplankton, ocean acidification effects on dimethylsulfide production, and processes modifying seawater CO2 chemistry in near-shore environments.

NOAA's Coral Reef Conservation and Ocean Acidification Programs explored the local biogeochemical feedbacks to ocean acidification within coral reef environments. NOAA also sponsored studies to determine the effects of and controls on seasonal hypoxia and acidification in coastal estuaries on the east coast and Gulf of Mexico. Laboratory experiments were conducted to quantify changes in calcification and organic and inorganic carbon production in West Coast pteropods; data on these processes in pteropods can be used to better parameterize projections in ocean carbon models. NOAA's Coral Reef Conservation Program, in partnership with NOAA's Ocean Acidification Program, has begun the implementation of long-term status and trends monitoring within U.S. coral reef ecosystems, which includes chemical and ecological monitoring specific to ocean acidification. The Pacific Marine Environmental Laboratory works closely with academic partners to maintain a network of coral reef ecosystem monitoring stations within these systems to track ocean acidification and reef responses. These studies have found that, while the net calcification of a reef system does show strong correlation with changes in carbonate mineral saturation state, ocean acidification will not affect coral reefs uniformly, with some being more sensitive to increasing partial pressure of CO2 (pCO2) than others.

USGS supported studies that evaluated coastal carbon fluxes and submarine groundwater discharges, which act as an additional cause of stress on coral reefs. USGS developed numerical modeling systems for the flow patterns and discharge rates to Biscayne Bay in Florida, which may provide insight into causes of ecosystem degradation. From 2010-2013, USGS participated in collection of baseline data to address ocean acidification in the Canadian Basin of the Arctic Ocean. The goal of this research was to document the carbon and isotopic chemistry and biological characteristics of the upper water column to determine the role of sea ice in ocean acidification of the different basins. Carbon data from the Gulf of Mexico are being analyzed by USGS in collaboration with researchers from NOAA and academia and as part of a NASA-lead effort on carbon synthesis in the ocean. USGS measured carbon chemistry of the West Florida Shelf as a cooperator in this project and to address ocean acidification in the Gulf of Mexico.

NASA funded the final stages of the Impacts of Climate change on the Eco-Systems and Chemistry of the Arctic Pacific Environment (ICESCAPE) field campaign. The goal of ICESCAPE was to determine the impact of climate change on the biogeochemistry and ecology of the Chukchi and Beaufort seas. ICESCAPE utilized an interdisciplinary, cross cutting approach integrating field expeditions, modeling, and satellite remote sensing. ICESCAPE analyzed observations and research to specifically address ocean acidification and its impacts on the ecology of the Arctic.

In addition, NASA supported projects investigating ocean acidification in the Arctic Ocean. One study used biological and bio-optical observations to address the role of calcifiers in the Chukchi and Beaufort Seas. This region is expected to undergo fundamental changes as the ice cap melts, affecting both the biota,

resulting in increased abundance of coccolithophores, and the bio-optical properties of the water mass. This is due to increased abundance of highly-scattering calcium carbonate coccoliths.

A field and modeling project was funded in this region and will comprise high-quality sampling of discrete water column dissolved inorganic carbon (DIC) and surface underway pCO2 and DIC observations. The project addresses the impact of natural and anthropogenic factors such as sea-ice loss, shelf-basin physical dynamics, net phytoplankton primary production on the marine inorganic carbon cycle, and air-sea CO2 fluxes.

NASA continued funding satellite research investigating ocean color. Ocean color can be used to measure particulate inorganic carbon, biogenic silica, and pCO2. NASA also funded efforts to reduce uncertainty when measuring phytoplankton chlorophyll in the ocean. These efforts provide the foundation to observe physiological processes such as photosynthesis, evaluate phytoplankton health, and provide global datasets for modeling efforts that include ocean acidification. Much of this work is also in support of NASA's Earth Science carbon cycle science program.

Research and monitoring efforts funded by USDA targeted the anthropogenic atmospheric deposition of nitrogen, sulfur, and other compounds. Although the monitoring stations for this program were primarily land-based, these data can be used to extrapolate deposition of nitrogen and sulfur oxides that will make it into the oceans. Atmospheric deposition of nitrogen and sulfur oxides has a direct effect on pH, but also provides essential nutrients effecting primary productivity in the oceans and Great Lakes ecosystems. Additionally, USDA has several programs aimed at the reduction of nutrients going into our Nation's waterways which eventually end up in the oceans causing algal blooms and creating dead zones. USDA programs also focused on carbon sequestration, reduced emissions of greenhouse gasses, and the production of agriculture-based biofuels. Agriculture-based biofuels, such as woody biomass and algae, may reduce reliance upon fossil fuels. USDA has many other programs addressing indirect effects on ocean acidification.

Understanding Earth History to Inform Ocean Acidification Predictions

Studies supported by USGS and NSF in FY2012 and FY2013 compared historic calcification rates with current rates, with the goal of modeling future rates. USGS continued supporting work initiated in 2009 that focuses on the synthesis of historical, physical, and chemical records at shellfish bed sites within Florida to provide a regional view of ocean acidification.

NSF sponsored research to examine ocean acidification in the geologic record with studies that focused on the ancient, Paleocene-Eocene Thermal Maximum, and recent century-scale changes in Aleutian kelp beds. NSF also supported studies to develop and test new paleo-proxies and to examine the kinetics of calcium carbonate dissolution. Approximately $1,000 K was spent to support work on this theme in FY2012 and FY2013.

USGS supported the development of the use of boron isotopes and their ratio to calcium as a proxy for determining seawater pH. This technique can be applied to samples from marine sediments, drill sections from coral reefs, and preserved exoskeletons of gastropods to ascertain environmental conditions in Earth's history. The method has further potential to reflect glacial/interglacial changes of surface seawater pH and atmospheric CO2 levels.

NOAA supported an historical analysis of calcification rates within select coral reef environments, primarily in the Pacific, through extraction of cores from coral reefs as a part of NOAA's Coral Reef Conservation Program status and trend monitoring program. NOAA engaged in nitrogen-isotope dynamics studies as recorded in the sedimentary record in order to learn about the dynamics of the marine nutrient

cycle in the Quaternary period and the present. These studies are useful for building ocean nutrient models that feed into projection models for future ocean conditions.

Laboratories and Field Sites

Modifications at some research facilities have allowed advancement in the study of ocean acidification. NOAA invested in facilities for shared-user species response studies at research laboratories in Kodiak, Alaska; Seattle, Washington; Newport, Oregon; Highlands, New Jersey; and Milford, Connecticut. NOAA funded inter-comparison studies across NOAA and affiliated laboratories to determine uncertainty in the measurement of ocean acidification-related parameters and the likely root causes of the uncertainties.

USGS established a new time-series field site on a reef in the Florida Keys. The USGS St. Petersburg Carbon Analytical Laboratory participated in inter-comparison quality control projects with other federal laboratories and academia.

Support for Data Synthesis

As information on ocean acidification increases, synthesis activities are needed to capture and summarize the current state of knowledge. These summaries are useful for research endeavors in a variety of ways, but also for resource management decisions and communication activities.

NOAA scientists engaged in vulnerability analyses of Washington and Alaskan marine resources to ocean acidification. Through a competitive grant program, NOAA supported a meta-analysis of the responses of temperate species to ocean acidification, which will be completed in 2014. NOAA funds the Ocean Acidification Data Stewardship (OADS) project to serve the broader ocean acidification community by providing dedicated online data discovery; access to NOAA Ocean Data Center-hosted and distributed authoritative data sources; and long-term archival, data-flow, and scientific stewardship for a diverse range of ocean acidification and other chemical, physical, and biological oceanographic data.

Theme 2. Monitoring of Ocean Chemistry and Biological Impacts

To understand the progress of ocean acidification in open-ocean and coastal environments and the impacts on marine ecosystems, it is necessary to employ a coordinated, multidisciplinary approach to observations and modelling. In FY2012 and FY2013, EPA, BOEM, NOAA, NSF, and USGS supported studies that addressed monitoring ocean chemistry or biological impacts associated with ocean acidification. $4,418 K was spent on monitoring related to ocean acidification in FY2012, and $3,208 K in FY2013. $5,183 K was spent on activities that were not specifically termed ocean acidification studies, but contributed to monitoring ocean acidification in FY2012, and $5,199 K in FY2013.

Marine Ecosystems

NOAA supported research and monitoring programs focused primarily on the effects of ocean acidification on corals and associated ecosystems. NOAA's National Coral Reef Conservation Program is now monitoring the status and trends of the nation's coral reef ecosystems including key chemical and ecological indicators specific to ocean acidification. There are three main elements to effectively monitor ocean acidification in a coral reef environment: monitoring the spatial and temporal trends in ocean carbonate chemistry; monitoring the ecosystem response to the changes in carbonate chemistry; and modelling change in both ocean chemistry and ecosystem response. The coral reef observation network has proposed six sentinel sites for ocean acidification, three in the Pacific Ocean basin and three in the Atlantic Ocean basin. Currently, two are established in the Atlantic (Puerto Rico and the Florida Keys) and one in the Pacific (Oahu). At each, autonomous measurements of air and seawater pCO2 and pH are taken

every three hours, and discrete samples are collected biweekly for laboratory analysis of ocean carbon. To assess ecosystem response to carbon chemistry, the following are monitored at each site: community composition; net community productivity; benthic rugosity; bioeroder abundance; ecosystem and coral calcification; and coral bioerosion. Specific taxa are also targeted for monitoring based upon the current state-of-the-science anticipated effects of ocean acidification to coral reef ecosystems.

NOAA is also supporting work related to ocean acidification in temperate ecosystems. NOAA's Northwest Fisheries Science Center continued to support a zooplankton time-series off of Newport, Oregon, and, with the Pacific Marine Environmental Laboratory, has done initial work to relate species abundance with carbon chemistry. NOAA has also supported work at the Northwest Fisheries Science Center to correlate species abundance with carbon chemistry in Puget Sound, Washington. NOAA's Northeast Fisheries Science Center conducts several different surveys off the northeast continental shelf each year, which provide complete coverage of the shelf (Cape Hatteras to the Gulf of Maine) during the spring and fall. The primary objectives of these surveys include assessing change in biological and physical properties which influence production of living marine resources in the Georges Bank and Gulf of Maine portions of the northeast continental shelf ecosystem. Key parameters measured during these surveys include ichthyoplankton and zooplankton composition, abundance, and distribution. Water column temperature, salinity, chlorophyll-a fluorescence, and carbonate chemistry are also measured.

BOEM contributed to knowledge about ocean acidification through research taking place in the Pacific Ocean and the Gulf of Mexico under its Environmental Studies Program. This program conducts ocean research to provide science in support of decisions regarding oil and gas, marine-mineral, and renewable-energy leasing of the outer continental shelf. The Pacific Regional Intertidal Sampling and Monitoring team (a group of biologists within the BOEM Pacific Region) partnered with the Channel Islands National Park to maintain an ocean monitoring station within the Park's boundaries. Monitoring of ocean pH, temperature, and salinity at this site is a partnership with a broader network of agencies and university groups aiming to track ocean acidification on the Pacific coast. Furthermore, BOEM partnered with NOAA and the USGS in the Gulf of Mexico to examine ocean acidification impacts on coral metabolism, calcification rates, and interactions between corals and their algal symbionts.

Changes in Marine Productivity

USGS programs were aimed at determining the baselines and thresholds of various coral reef communities to changes in pCO2, calcium carbonate saturation state, and ocean acidification by measuring coral metabolic and calcification rates. Furthermore, studies on endangered species prompted the establishment of five monitoring sites within Biscayne and Tortugas National Parks and the Florida Keys National Marine Sanctuary. These studies aim to provide information on calcification rates of corals and the potential relationship with climate change and ocean acidification.

EPA's nutrient research includes work in the coastal zone, where acidification is strongly influenced by production and organic loading. Collaborative research in FY2013 led to an increased interest in integrating carbonate chemistry into coastal ecosystem and water quality models that are also used to support nitrogen management decisions.

NSF supported observations at the Hawaii Ocean Time-Series and Bermuda Atlantic Time-Series that included measurements of ocean primary productivity, changes in the ocean biota, and changes in nutrients, pH, and carbonate chemistry. These time series now provide a more than 25 year record of changing productivity, biology, and chemistry at these mid-ocean sites in the Pacific and Atlantic Oceans. NSF also supported CO2 balance measurements as part of the US Climate Variability and Predictability program (US CLIVAR) repeat hydrography survey program. Measurements of primary productivity and ocean chemistry in coastal waters are routine at the NSF coastal Long Term Ecological Research (LTER)

sites (Plum Island Ecosystems LTER, Virginia Coast Reserve LTER, Georgia Coastal Ecosystems LTER, Santa Barbara Coastal LTER, California Current Ecosystem LTER, Moorea Coral Reef Long-Term Ecological Research site, and Palmer Antarctica LTER). These ongoing projects are "contributing" research to understand ocean acidification and were supported at about $2,000 K per year. Significant ship support provided for ocean-acidification-related oceanographic sampling, primarily at the Ocean Time Series stations mentioned above, with University-National Oceanographic Laboratory System vessels was not included in the NSF contributing research totals for FY2012 and FY2013. NSF also supported the Ocean Margin Ecosystems Group for Acidification Studies in FY2012 that provided coastal and intertidal records of pH along the Oregon and California coastal region.

Changes in Ocean Chemistry

Monitoring efforts related to ocean acidification were advanced through many NOAA programs including the Ocean Acidification Program, Climate Program Office, National Marine Fisheries Service, Coral Reef Conservation Program and Coastal Hypoxia Research Program. Collectively, these efforts constitute the establishment of the long-term ocean acidification monitoring program called for under the FOARAM Act. The existing global and national ocean observing assets have been augmented as necessary to meet the biogeochemical requirements for ocean acidification monitoring.

NOAA's ocean acidification monitoring portfolio comprises a suite of observations ranging from repeated large-scale synoptic surveys of the major ocean basins to sustained fixed time-series stations. A variety of assets are used for monitoring, including fixed-site observing platforms (e.g., moorings and piers), ships of opportunity, dedicated geochemical cruises, remote sensing, wave gliders, and profiling floats. The large-scale oceanic observations are primarily led through the NOAA Climate Program Office while NOAA's Ocean Acidification Program has placed a larger emphasis on tracking ocean acidification dynamics within waters along the U.S. coastal shelf, continental slope, and rise. These efforts work to characterize the rate and magnitude of acidification and discern the primary biogeochemical controls of variability. Observations include pCO2, pH, oxygen, temperature, and salinity, and permit the determination of carbonate mineral saturation state (a key indicator of ocean acidification). The data and information obtained from the observing network is increasingly applied in devising and interpreting experimental studies and process investigations to improve our understanding of ecosystem responses to ocean acidification and to validate regional and global models of ocean acidification. FY2012 and FY2013 efforts focused on monitoring of ocean acidification included:

- Ocean Moorings: Throughout FY2012 and FY2013, the ocean acidification mooring programs advanced by NOAA Pacific Marine Environmental Laboratory continued to collect data, build capacity, and collaborate with academic and agency partners to bolster the capabilities of the network. The first high-latitude, Pacific and Atlantic, ocean-acidification moorings were established. Existing carbon observing systems were augmented in the outer reef of Kaneohe Bay, Hawaii, to achieve ocean acidification monitoring capabilities. This augmentation provided a critical capability necessary for establishing this location as a long-term, coral reef-monitoring site where ecological measures of change are tracked in coordination with NOAA Coral Reef Conservation Program's status and trends monitoring efforts.
- Volunteer Observing Ships: During FY2012, the CO2 group at the Pacific Marine Environmental Laboratory collected measurements of pH, O2, and pCO2 on 11 cruises along the North American West coast, 5 cruises in coastal Alaskan waters and the Bering Sea, and 9 open-ocean cruises. These measurements contribute to the NOAA objective to provide accurate and reliable data from sustained observing systems and long-term data sets. The Pacific Marine Environmental Laboratory installed an underway pCO2 system, Durafet pH probes, and Aanderaa oxygen

optodes on the container ship Cap Vilano and the RV Ka'imikai-O-Kanoloa. These new measurements will add to the long time series of pCO2 measurements in this dynamic equatorial region. The Atlantic Oceanographic and Meteorological Laboratory sustained surface measurements using autonomous systems aboard seven ships of opportunity.

- Hydrographic/Geochemical Surveys: During the summer of FY2012, the Pacific Marine Environmental Laboratory led a dedicated geochemical survey along the Washington-Oregon-California continental shelf region to investigate the extent of acidification conditions. The dedicated survey employed the use of shipboard cruises and profiling gliders. In addition, the Atlantic Oceanographic and Meteorological Laboratory led a dedicated research cruise aboard the NOAA ship Ronald H. Brown along the Gulf of Mexico and East Coast margins (GOMECC-2, the second Gulf of Mexico and East Coast Carbon cruise) with surface and subsurface ocean acidification measurements. These surveys sought to better understand the relationships among natural and human-induced processes that lead to acidification of the water column and their effects on marine resources.
- Advanced Technology Development: A series of testing and validation studies were carried out by the Pacific Marine Environmental Laboratory to evaluate the use of autonomous Wave Gliders for ocean acidification monitoring.

Key Findings:

- Open-ocean cruises consistently find strong upwelling along the equator, biological uptake in the subtropics, and seasonal warming in some portions of both hemispheres.
- Members of the Pacific Marine Environmental Laboratory CO2 group were involved in the most recent release of the Surface Ocean Carbon Atlas, adding data to the atlas.
- Survey results along the U.S. west coast showed that in upwelled waters, 14-28 percent of the overall acidification experienced over the continental shelf during the summer upwelling season is derived from anthropogenic CO2. Corrosive, undersaturated waters were observed at depths ranging from 20 to 200 m over most of the continental shelf region during the late summer months. These corrosive waters can have significant negative implications for local hatchery facilities and adaptive strategies are being developed to better prepare impacted industries to these episodic events.
- Data collected in Alaskan waters indicated a similar pattern of upwelling around the Aleutian Islands.
- The GOMECC-2 cruise revealed that waters of the Gulf of Maine may be more susceptible to ocean acidification as a consequence of significant freshwater input and cold water temperatures. Given the importance of the Gulf of Maine to East coast fisheries, this is a region of increased focus.

The NOAA Ocean Acidification Program was actively involved in the development and adoption of standardized monitoring methods that are accurate and precise. Internal activities include an inter-comparison project to evaluate consistency of laboratory carbon chemistry measurements and development of the Coral Reef Ocean Acidification Monitoring Program. International activities included leadership of the Global Ocean Acidification Observing Network.

USGS ocean acidification projects focused on regional studies of carbon chemistry off the west coast of Florida and in the Arctic Ocean. Both provided baseline data in areas that have little or no prior information. These projects have resulted from collaboration with other non-related projects on ships of opportunity.

EPA's sampling efforts focused on long-term observations in coastal waters. EPA collaborated with SUNY Stony Brook on a project that includes NOAA funding for laboratory studies of ocean acidification effects on resource shellfish species. Within the NOAA-funded project, EPA is providing in-kind ecological modeling and vessel support through joint sampling in Narragansett Bay. To leverage and capitalize on the timing of this project, EPA is also funding a separate but coordinated field experiment to examine in situ shellfish responses to ocean acidification based on results from the laboratory studies. In a separate collaboration, EPA obtained carbonate chemistry samples from the mid-Atlantic bight using contracted time aboard NOAA ship Nancy Foster.

Theme 3. Modeling to Predict Changes in the Ocean Carbon Cycle and Impacts on Marine Ecosystems and Organisms

A wide variety of activities in FY2012 and FY2013 were associated with modelling ocean acidification and its impacts on marine ecosystems and organisms. $994 K was spent on activities directly related to modelling in FY2012, and $1,695 K in FY2013. $399 K in FY2012 and $310 K in FY2013 was spent on activities that were not specifically termed ocean acidification studies but contributed to ocean acidification modelling. These contributing efforts increase our understanding of ocean acidification through improved: 1) depiction of land-air-sea carbon coupling; 2) understanding of carbon fluxes in hydrologic and geologic processes; and 3) definition of spatial distributions and fluxes of carbon (i.e., sources and sinks of carbon). Further, modelling linkages between nutrients and carbon sources and sinks will assist in improving future modelling efforts of ocean acidification.

Physico-Chemical Change

In FY2013, NSF and NOAA (Geophysical Fluid Dynamics Laboratory) supported a modeling study focused on using coupled climate-carbon models to predict the large-scale pattern of future ocean calcite and aragonite saturation states. USGS supported modeling of historical and future changes in the ocean carbon cycle through the use of boron as a proxy from coral cores. These data are being used to model ecosystem change over historic and geologic time scales.

NOAA supported a number of regional modeling exercises on ocean carbon chemistry. NOAA developed the Ocean Acidification Product Suite model for the Greater Caribbean Region which maps out the distribution and dynamics of ocean acidification using synoptic environmental datasets (e.g., satellite, Hybrid Coordinate Ocean Model) applied to regionally specific algorithms developed from in situ data. It has also supported models investigating effects of hypoxia and associated day-night swings in pH in shallow waters. These accompanying swings in pH may exacerbate the effects of hypoxia on marine organisms. In the California Current region, NOAA funded the development of algorithms based upon temperature and oxygen measurements to derive estimates of seasonal dynamics in ocean acidification. These algorithms are intended for application to legacy data sets, such as those collected by the National Marine Fisheries Service in their annual transects, and could expand historical knowledge of ocean acidification in certain regions. NOAA also funded development of projections of ocean acidification using a California Current Regional Ocean Model. NOAA-collected observations of ocean carbon chemistry are contributing to this effort and development of a Pacific Northwest Regional Ocean Model. NOAA initiated development of a climatology of ocean acidification in the Northeast U.S. shelf region using data from the 1980s to the present. The climatology characterizes seasonal and regional variability, which can then be used to track whether current changes in ocean carbon chemistry are within the normal range of variability for the region or if they are outliers.

Ecological/Biological Impacts

In FY2013, NSF funded a collaborative project on the biogeochemical effects of plankton evolution to ocean acidification. For this project, experimental work on the ability of key planktonic organisms to adapt and evolve to increasing CO2 levels was paired with a biogeochemical model to predict how some species might respond to future oceans if beneficial mutations occur over time. Other NSF-supported research included a component of modeling as part of the research; the investment in the modeling efforts could not easily be separated from the overall research investment.

NOAA supported and completed a number of modeling exercises on the ecological implications of ocean acidification. Many of these projects merged regional biogeochemical models with ecological models. In the Pacific Northwest, NOAA scientists imposed various scenarios of ocean acidification on a food web model of the Puget Sound to understand how acidification impacts may ripple through the food web and how they may compare to impacts of climate change and other human uses of the marine environment. NOAA funded a similar effort to project impacts of ocean acidification on the California Current food web using a sophisticated model that incorporates geophysical data and is linked to a fisheries economics model. NOAA scientists started a project to investigate how the diel movements of zooplankton in the Puget Sound influence their CO2 exposure under current and projected future conditions, information that is important for properly parameterizing laboratory experiments. NOAA developed a model to forecast abundance of Alaskan crab that incorporates the impacts of ocean acidification, and began building a species life-cycle model to investigate Dungeness crab population dynamics under various ocean acidification scenarios. NOAA continued funding two projects that assess and predict the impacts of ocean acidification on hard clams and scallops in the U.S. Northeast. NOAA-funded modeling work used global and regional models to search for potential refugia for coral reef ecosystems to acidification and climate change, and explored the impacts of short-term, event-based impacts, like cyclones, on coral reef biogeochemistry. NOAA also investigated which treatment levels should be employed in experiments on biological impacts of ocean acidification by conducting an ecoregion-scale analysis of global carbon chemistry datasets and identifying the range of pCO2 levels of contemporary marine habitats.

NASA supported research to better constrain the magnitude of ocean acidification and climate change impacts on marine inorganic carbon dynamics, ocean carbon storage, and atmospheric CO2 levels over the next several decades to centuries using the new Community Earth System Model, which includes fully interactive marine ecosystem and global carbon modules. Satellite observations will be integral to the project in terms of both model parameterization development and model-data evaluation. The results will provide quantification of projected changes over the 21st century in the patterns and strength of marine biological calcification in a warmer, higher CO2 world and the resulting feedbacks on ocean carbon storage.

Theme 4. Technology Development and Standardization of Carbonate Chemistry Measurements on Moorings and Autonomous Floats

Improved instrumentation, sensors, and methods to support long-term observations, systematic ocean surveys, and laboratory systems are highlighted in the FOARAM Act, the IWG-OA's Strategic Plan for Federal Research and Monitoring of Ocean Acidification, agency plans for ocean acidification research, and the 2010 National Research Council report Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. Approximately $1,075 K was spent on activities directly related to technology development for ocean acidification in FY2012, and $1,367 K in FY2013.

USGS, cooperating with NOAA and universities, supported the refinement and standardization of methods for measuring carbon parameters and calcification in coral reef systems. These methods will help build

understanding of the metabolic function of reef systems. USGS also supported the development, testing, and improvement of flow-through systems for the rapid measurement of carbonate parameters in water. These systems can operate in both marine and freshwater conditions.

NOAA's technology activities in FY2012-13 focused on development of observing gliders, development of a dissolved inorganic carbon sensor, and methods for determining variation in ocean acidification and ecosystem response in coral reefs. NOAA expanded its efforts into alternative measurements for pH and laboratory systems to study species' response to ocean acidification. Wave gliders combine wave-powered, autonomous surface vehicles with instruments to take pCO2 (air and water), pH, temperature, and salinity measurements. The technology used in wave gliders was refined, and wave gliders were deployed to assess the temporal variability of upwelling and hypoxia between research cruises on the west coast. Glider data has been applied with algorithms to predict pH and aragonite saturation, and has assisted in identifying sites for future mooring deployments. Given the limitations inherent in using pH and pCO2 to constrain the carbonate system and limitations on using current technology at depth, it is critically important to develop additional, robust sensors for measuring dissolved inorganic carbon, pH, and pCO2 in surface and sub-surface waters. NOAA invested in development of next-generation technology for measuring pH and dissolved inorganic carbon using spectrophotometry and infrared sensors, and supported work inside and outside of NOAA.

NOAA supported the development of advanced technologies to quantify net community rates (calcification, productivity) within coral reef environments at the Atlantic Ocean Acidification Test-beds (Puerto Rico and Florida). The test-bed project investigates the physical and biogeochemical processes controlling temporal variability in ocean acidification. This technology work advanced the development of an integrated set of high-precision, in situ measurements using state-of-the-art cabled instrumentation that can examine, in real time, the influence of benthic processes on local carbonate chemistry.

NOAA activities have advanced the state-of-the-art for laboratory systems to study species response to ocean acidification. NOAA laboratories have built a number of experimental systems capable of manipulating and controlling pH and pCO2 with the accuracy and precision needed to conduct experiments relevant to addressing the impacts of ocean acidification on living marine resources. Building these laboratories required properly addressing demands related to engineering, chemistry, and biology, which can be highly challenging. NOAA staff acts as a resource in laboratory design for much of the ocean acidification community.

NOAA's Ocean Acidification Program supported an internal QA/QC project, led by Scripps Institution of Oceanography, to evaluate carbon chemistry analyses across NOAA and affiliated labs that conduct ocean acidification research and monitoring. In doing so, NOAA helped refine best practices for conducting carbon chemistry analyses and evaluated the performance of the equipment used to do so. While NOAA itself does not explicitly fund the certification of reference materials, it does purchase a considerable amount thereby providing supporting resources for the on-going production of standard reference materials.

NSF continued to support the production of CO2 reference standards to support the national research effort. Funding allocated in FY2013 will continue the production and distribution of reference standards for an additional three years. In FY2013, NSF also funded a study that would use a novel, isotope-labeling, experimental approach to measure the kinetics of calcium carbonate dissolution in sea water.

The standard method for measuring coral reef calcification requires knowledge of the alkalinity differences between reef and the offshore source water and the residence time of the water over the reef. Gathering this information is expensive and time-consuming, but boron isotope research has helped

to develop a useful and inexpensive method. The use of boron isotopes as a proxy for seawater pH was supported by USGS and NSF.

Because many of the Clean Water Act implications of ocean acidification are within state waters where high frequency/high resolution measurements of carbon chemistry are needed, EPA scientists stay engaged with sensing technology developments. Where possible, EPA has integrated low-cost sensor technologies into existing observation programs in order to identify potential limitations for state-level and consumer-level applications.

Theme 5. Assessment of Socioeconomic Impacts and Development of Strategies to Conserve Marine Organisms and Ecosystems

Coastal and marine ecosystems provide a variety of ecosystem services that may be altered by ocean acidification. For example, coastal and marine ecosystems provide provisioning resources of fish, shellfish, and seaweeds that are harvested for food and other consumer products. These ecosystems influence carbon cycling and sequestration, maintain biodiversity, and provide means for commercial and recreational activities. The human activities that rely on these goods and services are often intertwined with the social fabric of coastal communities and tribal groups. Understanding the interactions between the oceans and human systems is critical to protection of environmental public health. In FY2012 and FY2013, NOAA and EPA allocated funding toward socioeconomic studies related to ocean acidification; all funding was for primary research programs. Approximately $245 K was spent on activities directly related to the development of integrated assessment models in FY2012, and $158 K in FY2013.

NOAA made a large advance in addressing the socioeconomic impacts of ocean acidification in FY2012 and FY2013, mostly focusing on assessment of the impacts of ocean acidification on fisheries and fishery-based economies. NOAA's investments in this avenue of research were made primarily through competitive grants awarded in FY2012. Two projects use food web models, and three use population models. NOAA funded two projects that use results from laboratory studies on species sensitivity to ocean acidification and an understanding of local carbon chemistry conditions to project future population dynamics of species that are the target of wild fisheries (hard clams and bay scallops in the U.S. Northeast and red king and tanner crab in Alaska). Both efforts address potential future changes in fisheries, the latter using a bioeconomic model for the Bristol Bay red king crab fishery. An Integrated Assessment Model was developed to project landings by the U.S. sea scallop fishery under different carbon emissions scenarios. The model includes submodels on the basic biology of the sea scallop, regional biogeochemisty, and socioeconomics. Researchers are now developing a web-based decision-support dashboard that allows interactive exploration of model output under various scenarios. A similar effort is assessing the vulnerability of the California Current food web, fisheries, and regional economies to ocean acidification. This project links a regional ocean model forced by scenarios for carbon dioxide emission, a highly explicit food web model that includes scenarios of species response to ocean acidification, and a spatially explicit economic model that translates seafood landings into economic impacts on the broader West Coast economy. Researchers will use various outputs from this project to explore the implications of ocean acidification on fisheries management reference points and the consequences of harvest policies, and will inform managers about the results of this study via engagement with the Pacific Fishery Management Council. NOAA researchers also explored the potential impacts of ocean acidification on Puget Sound fisheries using scenarios of ocean acidification with a relatively simple food web model.

EPA supported the development of biophysical models and new methodologies to determine the economic and intrinsic value of coral reefs and shellfish. The Coral Mortality and Bleaching Output model is used by managers, conservationists, and biologists to predict the effects of climate change and ocean

acidification on coral reefs at local-to-regional scales, and new economic valuation approaches have been applied to estimate damages. The EPA's National Center for Environmental Economics conducted research to assess the economic impacts of ocean acidification on U.S. mollusk fisheries for the purpose of inclusion in monetary estimates of damages from greenhouse gas emissions.

Theme 6. Education, Outreach, and Engagement Strategy on Ocean Acidification

Engaging stakeholders and the public is an important component of addressing the implications of ocean acidification. Information exchange, education, and outreach can occur through several different types of media, including websites, workshops, and publications. Workshops and special sessions at professional meetings engage the scientific community and have provided content for planning strategies. $633 K was spent on activities directly related to ocean acidification outreach in FY2012, and $269 K was spent in FY2013. Roughly $50 K in FY2012 and $50 K in FY2013 was spent by NSF on activities that were not specifically termed ocean acidification outreach, but contributed to ocean acidification outreach.

In June 2012 at the United Nations Conference on Sustainable Development (Rio+20), the U.S. announced its contribution of $320,000 to the Ocean Acidification International Coordination Center (OA-ICC) at the International Atomic Energy Agency's (IAEA) Environment Laboratories in Monaco. The announcement took place at a U.S.-hosted side event on ocean acidification during the Rio+20 meeting. Funding for the OA-ICC was made available through U.S. support for the IAEA Peaceful Uses Initiative. The U.S. viewed this commitment to the establishment of the OA-ICC at the IAEA Laboratory as an important step towards enhanced global cooperation on ocean acidification research, including towards implementation of a global ocean acidification observing network. The U.S. made an additional contribution of $70,000 to the OA-ICC later in FY2012. In FY2013, the U.S., led by the Department of State, participated in the United Nations Informal Consultative Process on Oceans and the Law of the Sea, the topic of which was ocean acidification. This meeting provided a useful opportunity for information exchange and raising awareness on ocean acidification.

NOAA engaged in a variety of education, outreach, and engagement activities in FY2012 and FY2013. The strategy behind NOAA's education and outreach work was formalized in a NOAA Education Implementation Plan, which will likely be released in 2014. NOAA worked with non-governmental experiential learning facilities, such as the Seattle Aquarium and the Exploratorium, to educate the public about ocean acidification and its impacts. NOAA staff also participated in efforts of local, state, and regional policy makers, managers, and stakeholders to educate and inform decision makers about ocean acidification science (e.g., Washington Blue Ribbon Panel on Ocean Acidification). The West Coast National Marine Sanctuaries hosted the workshop entitled "Effective Practices for Communicating Ocean Acidification" in FY2012, which was attended by 90 participants from aquariums, universities, state and federal agencies, teachers, and non-governmental organizations.

NOAA developed a variety of educational and outreach resources. For example, the west coast National Marine Sanctuaries developed outreach kits on ocean acidification that include lesson plans and other materials. A number of NOAA websites include educational information about ocean acidification and links to resources, including presentations, scientific data, and links to other resources. These include websites developed by the Ocean Acidification Program, Pacific Marine Environmental Laboratory, Coral Reef Conservation Program, and the Channel Islands National Marine Sanctuary. A variety of NOAA offices developed summaries and explanations of ocean acidification and the science conducted to understand its progression and potential impacts on living marine resources internationally, nationally, and regionally. Additionally, NOAA created an online forum with the purpose of refining messages and case studies about

ocean acidification. This forum allows the communication and education community to stay abreast of the ocean acidification research, which is rapidly expanding, and helps educators share educational activities and projects as they are being created, including information about their success and implementation. Finally, NOAA trained many undergraduate students in ocean acidification research methodologies through internship programs, as well as the NOAA Hollings Scholar Program.

In FY2013, NOAA helped initiate the Northeast Coastal Acidification Network (NECAN), which will serve as the leading organization for the synthesis and dissemination of regional ocean acidification data and information products. NECAN works to provide rigorous and balanced scientific information to regional decision makers and user groups regarding the current state of knowledge of ocean acidification and its potential environmental and socioeconomic impacts to the northeast region. NECAN is a joint federal agency, academic, and industry partnership established under the Northeast Regional Association of Coastal and Ocean Observing Systems. NECAN also works to coordinate and set regional priorities for science observing and research investments designed to further our understanding of ocean acidification in a way most responsive to user requirements.

USGS presented research activities and findings through: 1) websites; 2) a monthly newsletter titled Sound Waves that is distributed to the public, stakeholders, and State cooperators; 3) presentations; and 4) social media, such as Twitter and Facebook. The USGS also supported the Ocean Acidification International Coordination Centre's efforts in capacity building by taking the lead in coordination and facilitation of ocean acidification workshops.

NSF supported a wide range of education, training, and outreach efforts as part of broader impacts in regular research awards. Some of the outreach efforts included providing the fundamental science needed for formulating management and policy. NSF and NASA provided support for the Ocean Carbon and Biogeochemistry Project Office and its Ocean Acidification Subcommittee. The Ocean Carbon and Biogeochemistry Project supports community-planning activities for ocean acidification and carbon cycling and engages in public outreach activities. The Ocean Carbon and Biogeochemistry Project provided support for the 2nd U.S. Ocean Acidification Principal Investigator Meeting in September FY2013. NSF continued to support international ocean acidification and carbon cycling planning and coordinating activities through the Scientific Committee on Oceanic Research.

NASA continued to support scientific research awards for projects that sought to enhance the public and educational outreach on subjects related to carbon cycle science, interdisciplinary science, and ocean acidification.

USDA-funded Cooperative Extension natural resource and aquaculture field agents work closely with their Sea Grant Marine Advisory Service partners in providing science-based information on climate change and other factors that affect ocean acidification to their joint clientele in the aquaculture industry. Workshops such as those conducted in Maine, Delaware, Louisiana, and other marine coastal and Great Lakes states educate U.S. citizens about sea level rise, ocean acidification, and other effects of climate change on the oceans.

USDA also informs the U.S. public on the results of research on new technologies geared toward reducing greenhouse gas emissions, nutrient runoff, and other programs aimed at reducing atmospheric CO2 through carbon sequestration by agricultural soil conservation practices and best management practices via workshops, on-farm extension programs, and the extension initiative via the Internet.

Theme 7. Data Management and Integration

Data management and integration is critical to the success and impact of any research program. Data must be shared and integrated across disciplinary boundaries to provide intelligible information to managers, planners, educators, other scientists, and the general public.

Data must also be shared and integrated across organizational boundaries, blending data from diverse systems that were created to address distinct mission goals. For example, integrating data collected by regional and sub-regional observing associations into the national U.S. Integrated Ocean Observing System provides easier and better access to this information by end users. Data sharing for oceanographic studies is especially important in that global models and many research investigations and analyses require data from the world's oceans. NOAA and USGS allocated $529 K in FY2012 and approximately $545 K in FY2013 for activities directly related to the development of ocean acidification data management systems and data integration processes. Roughly $100 K in FY2012 and $100 K in FY2013 was spent by NSF on activities that were not specifically termed development of ocean acidification data management systems and data integration processes but contributed to development of ocean acidification data management systems and data integration processes.

NOAA developed metadata content standards in the format of ISO 19115-2 for observing system and biological response studies by working with the ocean acidification scientific community. The ocean acidification data management system currently accommodates ocean acidification data from moorings, research cruises, and laboratory or mesocosm studies on species' response to ocean acidification. This system leverages current data systems that support the World Ocean Database, which brings together, in a common format, all publicly available vertical profile data from the global oceans. It also shares data with many ocean centers including the Department of Energy's Carbon Dioxide Information Analysis Center and NSF's Biological and Chemical Oceanography Data Management Office (BCO-DMO), and coordinates with other groups nationally and internationally.

NSF supported BCO-DMO at approximately $100 K per year in FY2012 and FY2013 to provide data management services for NSF-funded research projects.

Theme 8. Other Ocean Acidification Activities

In addition to the specific activities discussed above, funding has been allocated to develop and support programs, processes, and infrastructure to enable these core activities. $713 K in FY2012 and $1,022 K in FY2013 was spent to support the NOAA Ocean Acidification Program Office (OAP), which was established in 2011 as directed by the FOARAM Act of 2009, and to cover administrative costs for NOAA ocean acidification research and outreach efforts within NOAA's Office of Oceanic and Atmospheric Research and the various laboratories and science centers to which the OAP allocates funding. The OAP, together with the agency and interagency research efforts mentioned above, works to foster, coordinate, and direct: 1) interdisciplinary research among the ocean and atmospheric sciences, and coordinates research and activities to improve understanding of ocean acidification; 2) establishment of a long-term monitoring program of ocean acidification utilizing existing global and national ocean observing assets, and adding instrumentation and sampling stations as appropriate to the aims of the research program; 3) research to identify and develop adaptation strategies and techniques for effectively conserving marine ecosystems as they cope with increased ocean acidification; 4) educational opportunities that encourage an interdisciplinary and international approach to exploring the impacts of ocean acidification; 5) national public outreach activities to improve the understanding of current scientific knowledge of ocean acidification and its impacts on marine resources; and 6) coordination of ocean acidification monitoring

and impacts research with other appropriate international ocean science bodies such as the International Oceanographic Commission, the International Council for the Exploration of the Sea, the North Pacific Marine Science Organization, and others. A key part of the OAP's responsibility is to provide grants for research projects that explore the effects of ocean acidification on ecosystems and the socioeconomic impacts of increased ocean acidification. The OAP incorporates a competitive, merit-based process for awarding grants that has been conducted jointly with other participating agencies or under the National Oceanographic Partnership Program. Scientists funded by the OAP through base and competitive funds have published many peer-reviewed articles in FY2012 and FY2013, and participated in a large number of education, outreach, and policy efforts (e.g., the Washington Blue Ribbon Panel on Ocean Acidification).

Under the Energy Independence and Security Act of 2007, USGS has significant responsibilities to develop scientifically-based methods for assessment of biologic and geologic carbon-sequestration capacities, and to perform a comprehensive, nationwide resource assessment examining the full range of geothermal resources. As part of efforts to fulfill this responsibility, USGS chairs an interdisciplinary carbon committee of scientists and managers. The committee is developing a long-term strategy for comprehensive assessment of carbon-sequestration resources, including the potential for new carbon sequestration and for conservation and enhancement of existing carbon-storage systems.

USDA was not included in the initial list of federal entities involved with the IWG-OA as listed in the FOARAM Act. Although USDA has no programs specific to ocean acidification and the department does not have a primary role in the research and monitoring of ocean acidification as outlined in the Strategic Plan for Federal Research and Monitoring of Ocean Acidification, USDA-funded programs do address ocean acidification indirectly through programs addressing climate change and run-off of excess nutrients into the Nation's waterways. USDA provides for a few research, education, and extension activities and projects that are directly related to ocean acidification such as effects of pH on the larvae of commercially produced shellfish and the production of new genetic lines of commercial shellfish that are resistant to pH changes.

USDA programs that indirectly affect ocean acidification include programs directed at improving air quality such as reducing atmospheric deposition of nitrogen and sulfur oxide compounds as the result of burning fossil fuels and industrial processes, climate variability and climate change, reduction of nutrient runoff and emissions from concentrated animal feeding operations, watershed management, reduction in fuel use in agriculture via improved agricultural practices, carbon sequestration, and many other program aimed at maintaining and improving natural resources.

The USDA is implementing on-farm energy efficiency outreach and technology transfer programs which help farmers and ranch owners reduce input costs and their dependence on fossil fuels by using newly developed conservation and agricultural practices such as no-till and GPS-guided precision agriculture systems, drip irrigation systems, and nutrient management plans for livestock producers that reduce water loss and nutrient runoff. USDA also released a Carbon Management Evaluation Tool to help producers calculate how much carbon their land's soil and vegetation can remove and sequester from the atmosphere.

USDA does not have explicit programs or a funding authority for ocean acidification. Funding of directly or indirectly related projects depends on proposals submitted to core competitive programs, which provide an umbrella for this topical area. Other funding comes from core mission mandates but is subject to the budgets of the agencies implementing those programs.

Strategic Research Plan for Ocean Acidification Released

The IWG-OA developed a Strategic Plan for Federal Research and Monitoring of Ocean Acidification as required by the FOARAM Act. Released in March 2014, this Plan completed the review process indicated in the FOARAM Act. Federal agencies, along with academic and international partners, have increased the scope of work being conducted on ocean acidification since the last report and are doing work in almost every topical area identified in Section 12405 of the FOARAM Act and Strategic Research Plan. The IWG-OA is working with agency scientists and managers to coordinate current and future federal work and with domestic and international scientific advisory groups to ensure coordination with non-government scientists.

Appendix: Summary of Federally-funded Ocean Acidification Research and Monitoring Activities

All IWG-OA Member Agencies

Table 1. Summary of all IWG-OA member agency-funded ocean acidification research and monitoring activities

	FY 2012 Budget ($K)	FY 2013 Budget ($K)	Activity Classification
1. Research to understand responses to ocean acidification	11,837	13,665	**Contributing**
	393	409	**Primary**
	12,230	**14,074**	**Total**
2. Monitoring of ocean chemistry and biological impacts	4,418	3,208	**Contributing**
	5,183	5,199	**Primary**
	9,601	**8,407**	**Total**
3. Modeling to predict changes in the ocean carbon cycle and impacts on marine ecosystems and organisms	994	1,695	**Contributing**
	399	310	**Primary**
	1,393	**2,005**	**Total**
4. Technology development and standardization of measurements	1,075	1,971	**Contributing**
	0	0	**Primary**
	1,075	**1,971**	**Total**
5. Assessment of socioeconomic impacts and development of strategies to conserve marine organisms and ecosystems	245	158	**Contributing**
	0	0	**Primary**
	245	**158**	**Total**
6. Education, outreach, and engagement on ocean acidification	333	269	**Contributing**
	50	50	**Primary**
	383	**319**	**Total**
7. Data management and integration	529	545	**Contributing**
	100	100	**Primary**
	629	**645**	**Total**
8. Other ocean acidification research and monitoring activities	738	1,047	**Contributing**
	0	0	**Primary**
	738	**1,047**	**Total**
	20,169	22,558	**Total Contributing**
	6,125	6,068	**Total Primary**
	26,294	**28,626**	**Grand Total**

Bureau of Ocean Energy Management

Table 2. Summary of BOEM-funded ocean acidification research and monitoring activities

	FY 2012 Budget ($K)	FY 2013 Budget ($K)	Activity Classification
1. Research to understand responses to ocean acidification	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
2. Monitoring of ocean chemistry and biological impacts	0	0	**Contributing**
	162	10	**Primary**
	162	**10**	**Total**
3. Modeling to predict changes in the ocean carbon cycle and impacts on marine ecosystems and organisms	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
4. Technology development and standardization of measurements	0	0	**Contributing**
	2	0	**Primary**
	2	0	**Total**
5. Assessment of socioeconomic impacts and development of strategies to conserve marine organisms and ecosystems	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
6. Education, outreach, and engagement on ocean acidification	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
7. Data management and integration	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
8. Other ocean acidification research and monitoring activities	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
	164	10	**Total Contributing**
	0	0	**Total Primary**
	164	**10**	**Grand Total**

Environmental Protection Agency

Table 3. Summary of EPA-funded ocean acidification research and monitoring activities

	FY 2012 Budget ($K)	FY 2013 Budget ($K)	Activity Classification
1. Research to understand responses to ocean acidification	0	0	**Contributing**
	0	62	**Primary**
	0	**62**	**Total**
2. Monitoring of ocean chemistry and biological impacts	70	100	**Contributing**
	0	0	**Primary**
	70	**100**	**Total**
3. Modeling to predict changes in the ocean carbon cycle and impacts on marine ecosystems and organisms	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
4. Technology development and standardization of measurements	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
5. Assessment of socioeconomic impacts and development of strategies to conserve marine organisms and ecosystems	0	0	**Contributing**
	111	13	**Primary**
	111	**13**	**Total**
6. Education, outreach, and engagement on ocean acidification	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
7. Data management and integration	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
8. Other ocean acidification research and monitoring activities	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
	70	100	**Total Contributing**
	111	75	**Total Primary**
	181	**175**	**Grand Total**

Department of State

Table 4. Summary of Department of State-funded ocean acidification research and monitoring activities

	FY 2012 Budget ($K)	FY 2013 Budget ($K)	Activity Classification
1. Research to understand responses to ocean acidification	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
2. Monitoring of ocean chemistry and biological impacts	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
3. Modeling to predict changes in the ocean carbon cycle and impacts on marine ecosystems and organisms	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
4. Technology development and standardization of measurements	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
5. Assessment of socioeconomic impacts and development of strategies to conserve marine organisms and ecosystems	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
6. Education, outreach, and engagement on ocean acidification	0	0	**Contributing**
	70	0	**Primary**
	70	**0**	**Total**
7. Data management and integration	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
8. Other ocean acidification research and monitoring activities	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
	0	0	**Total Contributing**
	70	0	**Total Primary**
	70	**0**	**Grand Total**

National Aeronautics and Space Administration

Table 5. Summary of NASA-funded ocean acidification research and monitoring activities

	FY 2012 Budget ($K)	FY 2013 Budget ($K)	Activity Classification
1. Research to understand responses to ocean acidification	323	309	**Contributing**
	0	0	**Primary**
	323	**309**	**Total**
2. Monitoring of ocean chemistry and biological impacts	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
3. Modeling to predict changes in the ocean carbon cycle and impacts on marine ecosystems and organisms	324	235	**Contributing**
	0	0	**Primary**
	324	**235**	**Total**
4. Technology development and standardization of measurements	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
5. Assessment of socioeconomic impacts and development of strategies to conserve marine organisms and ecosystems	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
6. Education, outreach, and engagement on ocean acidification	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
7. Data management and integration	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
8. Other ocean acidification research and monitoring activities	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
	647	544	**Total Contributing**
	0	0	**Total Primary**
	647	**544**	**Grand Total**

National Oceanic and Atmospheric Administration

Table 6. Summary of NOAA-funded ocean acidification research and monitoring activities

	FY 2012 Budget ($K)	FY 2013 Budget ($K)	Activity Classification
1. Research to understand responses to ocean acidification	0	0	**Contributing**
	601	615	**Primary**
	601	**615**	**Total**
2. Monitoring of ocean chemistry and biological impacts	3,260	3,171	**Contributing**
	2,493	2,117	**Primary**
	5,753	**5,288**	**Total**
3. Modeling to predict changes in the ocean carbon cycle and impacts on marine ecosystems and organisms	0	0	**Contributing**
	994	801	**Primary**
	994	**801**	**Total**
4. Technology development and standardization of measurements	0	0	**Contributing**
	877	1,419	**Primary**
	877	**1,419**	**Total**
5. Assessment of socioeconomic impacts and development of strategies to conserve marine organisms and ecosystems	0	0	**Contributing**
	134	145	**Primary**
	134	**145**	**Total**
6. Education, outreach, and engagement on ocean acidification	0	0	**Contributing**
	148	154	**Primary**
	148	**154**	**Total**
7. Data management and integration	0	0	**Contributing**
	504	520	**Primary**
	504	**520**	**Total**
8. Other ocean acidification research and monitoring activities	0	0	**Contributing**
	713	1,022	**Primary**
	713	**1,022**	**Total**
	3,260	3,171	**Total Contributing**
	6,464	6,793	**Total Primary**
	9,724	**9,964**	**Grand Total**

National Science Foundation

Table 7. Summary of NSF-funded ocean acidification research and monitoring activities

	FY 2012 Budget ($K)	FY 2013 Budget ($K)	Activity Classification
Research to understand responses to ocean acidification	0	0	**Contributing**
• Species-specific Physiological Responses and Adaptation Potential	6,111	9,040	**Primary**
• Food Webs and Ecosystems	1,403	956	**Primary**
• Environmental and Ecological Responses and Indices	2,505	1,956	**Primary**
• Understanding Earth History to Inform Ocean Acidification Predictions	1,144	1,098	**Primary**
	0	**0**	**Total Contributing**
	11,162	**13,050**	**Total Primary**
	11,162	**13,050**	**Total**
2. Monitoring of ocean chemistry and biological impacts	1,853	1,928	**Contributing**
	487	0	**Primary**
	1,853	**1,928**	**Total Contributing**
	487	**0**	**Total Primary**
	2,340	**1,928**	**Total**
3. Modeling to predict changes in the ocean carbon cycle and impacts on marine ecosystems and organisms	0	0	**Contributing**
• Physicochemical change	0	427	**Primary**
• Ecological/Biological Impacts	0	467	**Primary**
	0	**0**	**Total Contributing**
	0	**894**	**Total Primary**
	0	**894**	**Total**
4. Technology development and standardization of measurements	0	412	**Primary**
	0	**0**	**Total Contributing**
	0	**412**	**Total Primary**
	0	**412**	**Total**
5. Assessment of socioeconomic impacts and development of strategies to conserve marine organisms and ecosystems	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total Contributing**
	0	**0**	**Total Primary**
	0	**0**	**Total**

6. Education, outreach, and engagement on ocean acidification	50	50	**Contributing**
	100	100	**Primary**
	50	**50**	**Total Contributing**
	100	**100**	**Total Primary**
	150	**150**	**Total**
7. Data management and integration	100	100	**Contributing**
	0	0	**Primary**
	100	**100**	**Total Contributing**
	0	**0**	**Total Primary**
	100	**100**	**Total**
8. Other ocean acidification research and monitoring activities	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total Contributing**
	0	**0**	**Total Primary**
	0	**0**	**Total**
	2,003	2,078	**Total Contributing**
	11,749	14,356	**Total Primary**
	13,752	**16,534**	**Grand Total**

United States Geological Service

Table 8. Summary of USGS-funded ocean acidification research and monitoring activities

	FY 2012 Budget ($K)	FY 2013 Budget ($K)	Activity Classification
1. Research to understand responses to ocean acidification	0	0	**Contributing**
	74	0	**Primary**
	74	**0**	**Total**
2. Monitoring of ocean chemistry and biological impacts	0	0	**Contributing**
	1,276	1,081	**Primary**
	1,276	**1,081**	**Total**
3. Modeling to predict changes in the ocean carbon cycle and impacts on marine ecosystems and organisms	75	75	**Contributing**
	0	0	**Primary**
	75	**75**	**Total**
4. Technology development and standardization of measurements	0	0	**Contributing**
	196	140	**Primary**
	196	**140**	**Total**
5. Assessment of socioeconomic impacts and development of strategies to conserve marine organisms and ecosystems	0	0	**Contributing**
	0	0	**Primary**
	0	**0**	**Total**
6. Education, outreach, and engagement on ocean acidification	0	0	**Contributing**
	15	**15**	**Primary**
	15	**15**	**Total**
7. Data management and integration	0	0	**Contributing**
	25	25	**Primary**
	25	**25**	**Total**
8. Other ocean acidification research and monitoring activities	0	0	**Contributing**
	25	**25**	**Primary**
	25	**25**	**Total**
	75	75	**Total Contributing**
	1,586	1,286	**Total Primary**
	1,661	**1,361**	**Grand Total**

Note: USDA funds many programs and projects not directly related to ocean acidification but have the effect of assisting in the reduction of the causes of the ocean acidification issue: climate change. Federal funding cannot easily be accounted for as directed at ocean acidification since USDA has no direct budget lines to address this important issue.

Abbreviations

AFSC	Alaska Fisheries Science Center
AOML	Atlantic Oceanographic Meteorological Laboratory
BCO-DMO	Biological and Chemical Oceanography Data Management Office
BOEM	Bureau of Ocean Energy Management
DIC	Dissolved Inorganic Carbon
DOS	Department of State
EPA	Environmental Protection Agency
FOARAM Act	Federal Ocean Acidification Research and Monitoring Act
FWS	U.S. Fish and Wildlife Service
FY	Fiscal Year
IAEA	International Atomic Energy Agency
ICESCAPE	Impacts of Climate on the Eco-Systems and Chemistry of the Arctic Pacific Environment
IWG-OA	Interagency Working Group-Ocean Acidification
LTER	Long Term Ecological Research
NASA	National Aeronautics and Space Administration
NECAN	Northeast Coastal Acidification Network
NOAA	National Oceanic Atmospheric Administration
NSF	National Science Foundation
NSTC	National Science and Technology Council
OA	Ocean Acidification
OADS	Ocean Acidification Scientific Data Stewardship
OA-ICC	Ocean Acidification International Coordination Center
OAP	Ocean Acidification Program
OSTP	Office of Science and Technology Policy
R&D	Research and Development
SOST	Subcommittee on Ocean Science and Technology
STEM	Science, Technology, Engineering, and Mathematics
US CLIVAR	United States Climate Variability and Predictability Program
USDA	United States Department of Agriculture
USGS	United States Geological Survey