Initial Report on Federally Funded Ocean Acidification Research and Monitoring Activities and Progress in Developing a Strategic Plan

Prepared by
Interagency Working Group on Ocean Acidification
Subcommittee on Ocean Science and Technology
Committee on Environment, Natural Resources, and Sustainability
National Science and Technology Council

Report directed by Section 12404(c) of the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act)

Issued March 22, 2011

EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

March 22, 2011

Dear Colleague:

I am pleased to transmit this document, *Initial Report on Federally Funded Ocean Acidification Research and Monitoring Activities and Progress in Developing a Strategic Research Plan*, which summarizes federally funded ocean acidification research and monitoring activities; provides the budgets for these activities; and describes progress toward the development of a strategic research plan for Federal research and monitoring of ocean acidification.

In March 2009, Congress passed the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act). The authorization of the FOARAM Act acknowledged the importance of the observed decrease in pH of the Earth's oceans and the need to address this issue. The FOARAM Act also called for the establishment of an Interagency Working Group on Ocean Acidification, to be chartered through the Joint Subcommittee on Ocean Science and Technology of the National Science and Technology Council. This document constitutes the initial report of the Working Group. It will be followed by a strategic plan for Federal research and monitoring of ocean acidification which will provide a roadmap for assessing the impacts of ocean acidification on marine organisms and marine ecosystems and for developing adaptation and mitigation strategies to conserve those organisms and ecosystems.

As was documented in a recent National Research Council report, *Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean*, the long-term consequences of ocean acidification are not known but are likely to include serious impacts on ecosystems and the services those systems provide to society. Therefore, it is critical that we proceed towards developing a coordinated program to understand ocean acidification and its impacts. This inventory of Federal activities is an important step in this process. I hope Congress and other parties interested in ocean acidification will find its content of great value.

Sincerely,

John P. Holdren

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

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Executive Summary

This document responds to the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act). The FOARAM Act specifies that the Joint Subcommittee on Science and Technology (JSOST) shall transmit an initial 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:

(A) includes a summary of federally funded ocean acidification research and monitoring activities, including the budget for each of these activities; and

(B) describes the progress in developing a strategic research plan required under section 12405 of this subtitle.

In this initial report, Federal agency activities related to ocean acidification are summarized for fiscal years 2008 and 2009 (FY 2008-09). 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 2008 Federal agencies supported approximately $6.8 million of activities with a primary focus on ocean acidification and an additional $22.7 million for contributing studies. In 2009 funding was approximately $10.9 million for primary and $21.3 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, and education/outreach activities. A majority of the activities with a primary focus on ocean acidification were directed at understanding species and ecosystem responses, while the major activities for contributing studies were monitoring, modeling, and studies of species and ecosystem responses. In FY 2008-09 no Federal activities supported the assessment of socioeconomic impacts of ocean acidification.

A Strategic Research Plan for Ocean Acidification, as required by the FOARAM Act, is under development, with delivery anticipated in 2011. JSOST (recently renamed the Subcommittee on Ocean Science and Technology or SOST) is conferring with domestic and international scientific advisory groups concerned with ocean acidification to ensure that the plan is well coordinated with non-government scientists, and is informed by the latest scientific advice.

Introduction

The Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act) directed the Joint Subcommittee on Science and Technology[1] (SOST) 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 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:

(A) includes a summary of federally funded ocean acidification research and monitoring activities, including the budget for each of these activities; and

(B) describes the progress in developing a strategic research plan required under section 12405 of this subtitle.

This constitutes the initial report of the SOST IWG-OA. The IWG-OA was chartered by SOST in October 2009 and includes representatives from the National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), U.S. Geological Survey (USGS), Environmental Protection Agency (EPA), Minerals Management Service (MMS, which has since been renamed the Bureau of Ocean Energy Management, Regulation and Enforcement [BOEMRE]), Department of State (DOS) and U.S. Fish and Wildlife Service (USFWS). This includes two ex officio members representing the former Subcommittee on Integrated Management of Ocean Resources (SIMOR). NOAA chairs the group, with vice-Chairs from NSF and NASA. 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.

The report is organized into six main sections corresponding to the categories of information required in the strategic plan for ocean acidification research and monitoring. Each section contains an overview of the activities conducted within that category by Federal agencies in FY 2008-09. Appendix 1 provides a summary of individual agency ocean acidification research and monitoring activities, including the budget for each of these activities. In Appendix 1, activities are classified as having a primary focus on ocean acidification or as "contributing" activities designed for other purposes but clearly providing information useful for understanding ocean acidification.

Section 1. Monitoring of ocean chemistry and biological impacts associated with ocean acidification at selected coastal and open-ocean monitoring stations, including satellite-based monitoring to characterize marine ecosystems, changes in marine productivity, and changes in ocean chemistry.

In order to understand the progress of ocean acidification in open-ocean and coastal environments and its impacts on marine ecosystems it will be necessary to develop a coordinated multidisciplinary approach to observations and modelling. This approach, in turn, will be fundamental for establishing a successful research strategy relating to ocean acidification and for facilitating our ability to predict and respond to future impacts on marine biota, ecosystem processes, biogeochemistry, and climate feedbacks. In 2008 and 2009 EPA, MMS[2], NASA,

[1] Renamed as the Subcommittee on Ocean Science and Technology (SOST) on Dec. 2, 2010.

[2] Renamed Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) in June 2010.

NOAA, NSF, and USGS all supported studies that were focused on monitoring ocean chemistry or biological impacts associated with ocean acidification, or studies that had a slightly different focus but contributed to these goals. Approximately $1,426K was spent on monitoring directly related to ocean acidification in 2008, and $1,289K in 2009. Approximately $12,501K was spent on activities that were not specifically termed ocean acidification studies but contributed to monitoring ocean acidification in 2008, and $10,164K in 2009.

The existing global oceanic carbon observatory network of repeat hydrographic surveys, time-series stations, and volunteer observing ships in the Atlantic, Pacific, and Indian Oceans supported by NSF and NOAA has documented many aspects of carbonate chemistry central to the process of ocean acidification in open-ocean and coastal waters. Indeed, much of our present understanding of the long-term changes in the carbonate system is derived from such repeat surveys and time series measurements over the past two decades. From these studies it has been determined that the pH of ocean surface waters has already decreased by about 0.1 since the industrial era began, while a decrease of ~ 0.0018 per year has been observed over the last quarter century at several open-ocean time-series sites. In addition, many ecosystem monitoring and assessment studies provide valuable information for examining the impacts of ocean acidification.

Numerous studies were conducted in FY 2008-09 in which one of the primary goals was associated with monitoring ocean acidification. Large-scale studies of carbonate chemistry in the Pacific and Indian Oceans, supported by NOAA and NSF, revealed basin-wide changes in carbon chemistry and pH. MMS supported a biogeochemical assessment of the North Aleutian Basin ecosystem while joint work by NOAA and USGS is providing an experimental ocean acidification product that provides regional maps of a variety of ocean acidification-relevant chemical parameters for the Greater Caribbean region. In addition, USGS studies are providing information regarding ocean acidification impacts on marine ecosystems, productivity, and changes in ocean chemistry in coral reef communities and Florida shelf ecosystems.

Contributing activities included various monitoring and assessment studies, as well as basic research, such as: studies of coral reefs where the results of studies will contribute to the understanding of the affects of ocean acidification on these ecosystems (EPA, MMS, USFWS, NSF); examining the food web and chemical parameters in the Chukchi Sea (MMS); global scale assessments of primary production and its controls, air-sea gas exchange, and carbon cycling (NASA); ocean carbon inventory, global ocean carbon dioxide (CO_2) flux, world ocean circulation experiment, and joint global ocean flux study analysis/reanalysis, quantification of air-sea CO_2 fluxes, and coastal CO_2 measurements for the North American Carbon Program (NOAA); and monitoring of species, ecosystem productivity, and carbon system measurements (NSF).

Section 2. Research to understand the species-specific physiological responses of marine organisms to ocean acidification, impacts on marine food webs of ocean acidification, and to develop environmental and ecological indices that track marine ecosystem responses to ocean acidification.

Marine biological processes can be directly impacted by ocean acidification because of changes in pH, or changes in the concentrations of dissolved CO_2, bicarbonate ion, or carbonate ion. Virtually every major biological function has been shown to respond to these chemical

changes in seawater, including rates of photosynthesis, respiration, growth, calcification, reproduction, and recruitment. In FY 2008-09, NSF, NOAA, USGS, NASA, and EPA were beginning to address some of the pressing issues of organism response to ocean acidification. Approximately $4,260K was spent on activities directly related to ocean acidification impacts research in 2008, and $6,366K in 2009. Approximately $4,991K was spent on activities that were not specifically termed ocean acidification studies, but contributed to ocean acidification impacts research in 2008, and $4,366K in 2009.

Biology of impacted species

Federal agency activities for FY 2008-09 concerning how ocean acidification affects calcification and other physiological processes were diverse, spanning molecular to physiological functions, including impacts on growth, reproduction, and survival.

Diverse scientific studies supported by NSF measured the effects of changing seawater pH on coral and algal/anemone symbioses, pteropod physiology and gene expression, and shell dissolution in mollusks; gene expression under pH stress, with and without added temperature stress; evolution and pH changes in coccolithophorids; pH impacts on benthic and planktonic foraminifera; and physiology of coral reef larvae with changing pH.

NOAA supported preliminary laboratory and *in situ* experiments using king crab species, shellfish, and krill to test hypotheses related to the direct effects of decreased pH and undersaturation of calcium carbonate in seawater. EPA also supported studies in 2008 that examined the impacts of ocean acidification on individual species.

USGS supported studies involving 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. Preliminary studies on the effects of lowered pH and higher carbon dioxide values in seawater on photosynthesis and respiration of different tropical and subtropical benthic organisms were also started. Collaborative research between MMS, NOAA, and USGS focused on deep-water coral communities, their ecology, and the microbial communities associated with them.

Ecosystems and Foodwebs

Marine food webs can be complex, and changes in one or more key species can have serious repercussions. Because ocean acidification has the potential to affect key species, it has the potential to alter marine foodwebs in fundamental ways. Further, in some communities, particularly those populated by bottom dwellers, decreases in calcium carbonate production alter the structural fabric of the ecosystem by affecting hard-bottom habitats. Many marine plants and animals depend on the structural habitat provided by corals and other associated organisms in both tropical and cold-water systems. Oyster banks, clam beds, etc. may also be affected by substrate changes associated with decreased carbonate production.

NSF sponsored ocean acidification research in differing physical and geographic environments, comparing open ocean and estuarine "foundation" species in upwelling environments; studying the ecological dynamics of coccolithophorids in the South Atlantic; documenting effects of ocean acidification on nutrient availability and requirements by phytoplankton; and investigating the primary production of coral reefs. Research projects on population dynamics of viruses and coccolithophorids in changing pH; aquatic plant-induced changes in pH, and invertebrate responses and disease resistance in corals in decreased pH environments were also supported.

NOAA scientists have adapted food web models from Puget Sound and the California Current to predict how these ecosystems may respond to future ocean acidification.

NASA studies using remote sensing to identify algal functional groups and their global phenology and to link them to biogeographic provinces were ongoing in 2009. In addition, the identification and development of proxies from satellite data—i.e., indicators of ocean acidification—and improved interpretation of fluorescence signals observable from space or from *in situ* platforms such as underwater gliders, were supported. 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.

Calcification processes

Changes in the carbonate ion 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 carbonate ion concentration decreases dramatically with ocean acidification – by 30 percent once the atmospheric CO_2 concentration is twice the preindustrial level. This decreased availability of carbonate ions will limit shell and skeletal formation of many organisms, including corals, shellfish, sea urchins, and some algae.

NSF supported fundamental research to evaluate the solubility of calcite produced by living organisms. Both precipitation and dissolution processes were being evaluated based on solubility. NSF also supported research on coral reef and foraminifera calcification rates and productivity, as well as developing geochemically novel ways to estimate coral reef calcification rates. The BEACON project (BErmuda ocean Acidification and COral reef iNvestigation) seeks understanding of the consequences of ocean acidification on the process of calcification and calcium carbonate production at three different spatial scales, including: (1) individual coral colonies; (2) local reef communities; and (3) regional coral reef ecosystems.

In FY 2008-09 ocean acidification process studies within the USGS included monitoring tropical coral reef calcification and dissolution rates, from the community level to the individual organism level. Support was also provided to study the effects of lowered pH and higher CO_2 values on a group of shell-forming, bottom-dwelling organisms in the tropics and subtropics known as sediment producers.

Other marine chemical and physical attributes

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 CO_2 from the atmosphere. Ocean acidification has the potential to alter both chemical and biological processes that will affect nutrient and carbon cycles, such as by altering the rate of nitrogen fixation by certain marine cyanobacteria.

In 2009 NSF supported the documentation and understanding of how ocean acidification may affect the formation and sinking of organic and inorganic particles within the water column.

USGS supported studies that evaluated coastal carbon fluxes and submarine groundwater discharges to coral reefs and provided an understanding of related dynamics, which would be additional to the stresses of ocean acidification.

The record of the Earth system history regarding ocean acidification

USGS supported studies in FY 2008-09 that compared historic calcification rates with current rates, with the goal of modeling future biogenic calcification rates. In 2009, USGS

initiated synthesis of historical physical and chemical records at shellfish bed sites within Florida to provide regional view of ocean acidification, while NSF sponsored studies to examine ocean acidification in the geologic record.

NSF and USGS supported development of the use of boron isotopes and their ratio to calcium as a proxy for determining seawater pH, which can then be applied to samples from marine sediments, drill sections from coral reefs, and preserved exoskeletons of gastropods to ascertain environmental conditions in Earth system history. The method has the potential to reflect glacial/interglacial changes of surface seawater pH and atmospheric CO_2 levels.

Section 3. Modeling to predict changes in the ocean carbon cycle as a function of carbon dioxide and atmosphere-induced changes in temperature, ocean circulation, biogeochemistry, ecosystem and terrestrial input, and modeling to determine impacts on marine ecosystems and individual marine organisms.

There were a wide variety of activities during FY 2008-09 within the USGS and NASA that were associated with modeling the marine carbon cycle, although most were not explicitly directed towards ocean acidification. Approximately $457K was spent on activities directly related to ocean acidification modeling in 2008, and $162K in 2009. Approximately $4,658K was spent on activities that were not specifically termed ocean acidification studies but contributed to ocean acidification modeling in 2008, and $5,205K in 2009.

These latter modeling efforts could likely support ocean acidification understanding through the improved depiction of land-air-sea carbon coupling, understanding carbon fluxes in hydrologic and geologic processes, and defining spatial distributions and fluxes of carbon (i.e., sources and sinks of carbon), production of CO_2 from photosynthesis and respiration, and oceanic carbon cycling. Further, modeling linkages between solubility of nutrients, and carbon sources and sinks, will likely assist in improving future modeling efforts of ocean acidification.

In FY 2008-09, NASA supported modeling of ocean acidification within the greater Caribbean in which seawater carbonate system data acquired from ships of opportunity were used to refine algorithms derived from satellite data. These algorithms are being used to compute saturation state and other carbon parameters. USGS is supporting modeling of historical and future changes in ocean carbon cycle, through the use of boron as a proxy on coral cores. These data are being used to model ecosystem change over historic and geologic time. EPA also supported modeling efforts in 2008, with a focus on addressing the ecological and biological impacts of ocean acidification.

Section 4. Technology development and standardization of carbonate chemistry measurements on moorings and autonomous floats.

Research needs and priorities stated in the FOARAM Act, in agency planning, and in the 2010 National Research Council report, *Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean*, point to the necessity of improved instrumentation, sensors, and methods to support long-term observations, systematic ocean surveys, and the development of experimental systems to investigate organism and ecosystem responses to ocean acidification. Approximately $480K was spent on activities directly related to technology development for ocean acidification in 2008, and $1,245K in 2009. Approximately $419K was spent on activities

that were not specifically termed ocean acidification studies but contributed to ocean acidification technology development in 2008, and $745K in 2009.

USGS, cooperating with NOAA and universities, supported the refinement and standardization of methods measuring carbon parameters and calcification in coral reef systems as part of efforts to understand the metabolic function of reef systems. USGS has also supported the development of flow-through systems for the rapid measurement of CO_2 levels in water, which will serve both marine and freshwater uses.

NOAA ocean acidification technology developments in FY 2008-09 were focused on coral reef and open ocean systems. La Parguera, Puerto Rico, is the primary site for the coral reef technology development as it is the location of the Atlantic Ocean Acidification Test-bed. This work involves the Atlantic Meteorological and Oceanographic Laboratory, the University of Miami, Pacific Marine Environmental Laboratory and the University of Puerto Rico. Specific technology developments have included a moored autonomous buoy deployed on the fore-reef, providing continuous measurements of near-reef CO_2 levels (both air and sea surface), temperature, and salinity. This test-bed serves as a nexus of Federal agency and academic monitoring and research activities related to ocean acidification and coral reefs within the region. It complements continuous meteorological and oceanographic measurements (e.g., from NOAA's Integrated Coral Observing Network/Coral Reef Early Warning System); weekly geochemical surveys on the reef; and the NOAA, University of Miami, Columbia University, and USGS testing of a unique benthic flux instrument capable of rapidly determining reef metabolic activity.

A small-craft CO_2 analyzer prototype has been developed and deployed to test the value of rapid spatial surveys across the broader reef system. A successful and robust mobile system will be used to establish the broader carbonate system chemistry dynamics across reef systems, and also will assist in identifying sites for future mooring deployments.

With regard to open ocean systems, NOAA and NSF collaborated to develop a deep water mooring in the Gulf of Alaska (Station Papa; 50°N, 145°W) capable of making high frequency measurements of both CO_2 and pH in surface waters. The measurement of two carbon parameters is required to fully understand the chemical changes of ocean acidification. The Papa mooring was the first long-term mooring to transmit two carbon measurements (CO_2 and pH) back to the laboratory in near realtime. It was the prototype mooring for NOAA's proposed Ocean Acidification monitoring system.

NSF technology and methods development has been multifold. An exploratory research grant to California State University, San Marcos, supported the rapid development of a new method to quantify calcification rates in planktonic foraminifera. Planktonic foraminifera comprise a major group of biogenic carbonate producers in the world's oceans, contributing an estimated 25 percent to 65 percent of the total deep-marine calcite budget. Direct quantitative measurement of calcification rates in planktonic foraminifera is necessary for determination of calcium carbonate production rates—a key component of the global ocean calcium carbonate budget.

NSF is supporting the University of South Florida to develop a new method to directly determine carbonate ion concentrations in the laboratory, shipboard, or *in situ*. The method, if successful, will obtain carbonate ion concentrations with ultraviolet spectroscopic observations of lead absorbance spectra by comparing the relative concentrations of lead carbonate and an ensemble of lead chloride complexes, which change in response to varying concentrations of dissolved carbonate.

The standard method for measuring coral reef calcification requires knowledge of the alkalinity differences between reef water and the offshore source water, and the residence time of water over the reef. This is expensive and time-consuming. With NSF support, two researchers at the University of Miami are testing a novel method that uses a simple set of inexpensive instruments and an isotope of beryllium to estimate the residence time. The team will use the method to determine how calcification rates vary spatially and temporally at three well-studied reef systems in the Caribbean and Western Atlantic.

A new approach to measure calcification at the reef scale rather than by small scale incubations with individual organisms is being developed by researchers at Stanford University. During four field seasons at Heron Island Marine Station, located on the Great Barrier Reef, the NSF-funded researchers are making the first simultaneous and *in situ* measurements of Net Community Production/Respiration and Net Community Calcification/Dissolution on a large intact coral reef tract by determining water-column inorganic carbon-system properties along the boundaries of a 3-dimensional control volume.

NASA has supported the development, assessment, and commercialization of a biogeochemical profiling float for ocean carbon studies. The float is designed to incorporate a suite of instruments to remotely quantify components of the carbon cycle, such as primary production, and should serve as a platform for new sensors of the dissolved-carbonate system.

Section 5. Assessment of socioeconomic impacts of ocean acidification and development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems.

There were no agency activities addressing these issues in 2008 or 2009.

Section 6. Education/Outreach on ocean acidification.

One important aspect of tackling the problem of ocean acidification is the engagement and education of stakeholders and the public through such methods as websites, workshops, and publications. Workshops and special sessions at professional meetings have been conducted to engage the scientific community and provide input for planning strategies over the past several years. Approximately $200K was spent on activities directly related to ocean acidification outreach in 2008, and $1,846K in 2009. Approximately $100K was spent on activities that were not specifically termed ocean acidification studies but contributed to ocean acidification outreach in 2008, and $809K in 2009.

The State Department has supported various international activities relevant to ocean acidification. These include the development and adoption of the Manado Ocean Declaration, which focuses on the critical linkages between oceans and climate changes and addresses the effects of climate change, including ocean acidification, on marine ecosystems and living resources. In order to promote greater understanding of the impacts of ocean acidification on the marine environment, the United States hosted side events at the United Nations Climate Change Conference in Copenhagen and the 2009 Pacific Regional Environment Program meeting. The United States also supported language recognizing the importance of improving understanding of the impact of climate change on the oceans in the 2009 United Nations resolution 64/71 on oceans and the law of the sea.

NSF, NASA, and NOAA have jointly supported the Ocean Biology and Biogeochemistry project office that has actively engaged the U.S. science community via workshops, acidification courses and preparation of laboratory outreach kits for teachers. The project's ocean acidification website tracks worldwide research activities and publications. The three agencies, along with USGS, also jointly supported a National Research Council study that produced the 2010 report, *Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean*. In addition, NSF, NASA, and NOAA recently sponsored a special issue of Oceanography, the flagship magazine of the Oceanography Society, which included 16 articles on ocean acidification written by leading scientists from around the world.

NOAA has prepared a fact sheet for the public and is hosting a website that serves as an information resource for research activities occurring both in the United States and throughout the world. In 2009 NOAA's National Ocean Service education team and the NOAA Coral Reef Conservation Program developed and implemented a symposium at the National Science Teachers Association National Conference in New Orleans, as well as a follow up Web Seminar that focused on coral ecosystems, climate change, and ocean acidification. The National Marine Educators Association published a special issue on ocean acidification that included a lesson plan for teachers about ocean acidification based on a study jointly sponsored by MMS and NOAA on deepwater corals. The same MMS/NOAA joint study, *Lophelia II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks*, and outreach materials are available on NOAA's Ocean Exploration website. NOAA's Office of Ocean Exploration also features other outreach materials including a keynote address by a NOAA senior scientist, leader's guide, and lesson plans.

The USGS presents research activities and findings through its website, particularly the site's Sound Waves newsletter, and other outreach mechanisms.

NSF/NASA/NOAA funded website: http://www.whoi.edu/OCB-OA/

NOAA Pacific Marine Environmental Laboratory website: http://www.pmel.noaa.gov/co2/OA/

MMS/NOAA Office of Ocean Exploration project website:
http://oceanexplorer.noaa.gov/explorations/09lophelia/welcome.html

NASA website: http://www.nasa.gov/topics/earth/features/climate_acidocean_prt.htm

NOAA Office of Ocean Exploration activities:

Keynote Address by Steve Hammond for online workshop, focus-Ocean Acidification
http://ps.connect230.com/coexploration/hammondwithclips/f.htm

To Boldy Go...Lesson
http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09toboldlygo.pdf

Off Base Lesson
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/09offbase.pdf

NOAA's Coral Reef Conservation Program:

NOAA/NSTA Symposium: The Heat is On: Climate Change and Coral Reef Ecosystems Saturday, March 21, 2009

http://learningcenter.nsta.org/products/symposia_seminars/NewOrleans09/NOAA/symposium_post.aspx

NOAA/NSTA Web Seminar: The Heat is On: Climate Change and Coral Reef Ecosystems, April 2, 2009
http://learningcenter.nsta.org/products/symposia_seminars/NewOrleans09/NOAA/webseminarI.aspx

Progress in Developing the Strategic Research Plan for Ocean Acidification

The IWG-OA is in the process of developing the Strategic Research Plan for Ocean Acidification as required by the FOARAM Act. A comprehensive outline has been developed that addresses the contents of the plan specified in Sec. 12405 (Appendix 2). Federal agencies, along with academic and international partners, are conducting work in almost every topical area identified in Section 12405. The IWG-OA has identified all ongoing ocean acidification activities (Appendix 1) and is working with agency scientists and managers to coordinate future work. The IWG-OA is also working with domestic and international scientific advisory groups concerned with ocean acidification to ensure that the plan is well coordinated with non-government scientists and is informed by the latest scientific advice on ocean acidification. The IWG-OA anticipates delivering the plan in 2011.

Appendix 1

Summary of Federally Funded Ocean Acidification Research and Monitoring Activities

All agencies combined

Summary of funded ocean acidification research and monitoring activities			
Agency: IWG-OA agencies combined			
Program Elements	FY 2008 Budget ($K)	FY 2009 Budget ($K)	Activity Classification
1. Monitoring of ocean chemistry and biological impacts associated with ocean acidification at selected coastal and open-ocean monitoring stations, including satellite-based monitoring to characterize - marine ecosystems, changes in marine productivity, and changes in ocean chemistry.	$12,501	$10,164	Contributing
	$1,426	$1,289	Primary
	$13,927	$11,453	Total
2. Research to understand the species specific physiological responses of marine organisms to ocean acidification, impacts on marine food webs of ocean acidification, and to develop environmental and ecological indices that track marine ecosystem responses to ocean acidification.	$4,991	$4,366	Contributing
	$4,260	$6,366	Primary
	$9,251	$10,731	Total
3. Modeling to predict changes in the ocean carbon cycle as a function of carbon dioxide and atmosphere-induced changes in temperature, ocean circulation, biogeochemistry, ecosystem and terrestrial input, and modeling to determine impacts on marine ecosystems and individual marine organisms.	$4,658	$5,205	Contributing
	$457	$162	Primary
	$5,115	$5,367	Total
4. Technology development and standardization of carbonate chemistry measurements on moorings and autonomous floats.	$419	$745	Contributing
	$480	$1,245	Primary
	$899	$1,990	Total
5. Assessment of socioeconomic impacts of ocean acidification and development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems.	$0	$0	Contributing
	$0	$0	Primary
	$0	$0	Total
6. Education/Outreach on ocean acidification.	$100	$809	Contributing
	$200	$1,846	Primary
	$300	$2,655	Total
	$22,669	$21,288	Total Contributing
	$6,823	$10,908	Total Primary
	$29,492	$32,196	Grand Total

Environmental Protection Agency

Summary of funded ocean acidification research and monitoring activities								
Agency:	EPA							
Division:								
Program Elements							FY 2008 Budget ($K)	FY 2009 Budget ($K)	Activity Classification
1. Monitoring of ocean chemistry and biological impacts associated with ocean acidification at selected coastal and open-ocean monitoring stations, including satellite-based monitoring to characterize -									
A) marine ecosystems							$2,000	$2,000	Contributing
	Stony coral assessments conducted in U.S. Virgin Islands to document regional distribution and to test reef indicators for sensitivity to human disturbance								
B) changes in marine productivity									
C) changes in ocean chemistry									
2. Research to understand the species specific physiological responses of marine organisms to ocean acidification, impacts on marine food webs of ocean acidification, and to develop environmental and ecological indices that track marine ecosystem responses to ocean acidification.									
A) Biology of impacted species							$300	$0	Primary
	Evaluation of affects of elevated carbon dioxide in flow-through systems on recruitment of crustose coralline algae and growth rate of stony coral.								
B) Ecosystems and foodwebs									
C) Calcification processes and Carbonate chemistry of the oceans									
D) Other marine chemical and physical attributes									
E) The record of Earth system history re: ocean acidification									
3. Modeling to predict changes in the ocean carbon cycle as a function of carbon dioxide and atmosphere-induced changes in temperature, ocean circulation, biogeochemistry, ecosystem and terrestrial input, and modeling to determine impacts on marine ecosystems and individual marine organisms.									
A) Physico-chemical change									
B) Ecological/Biological Impacts							$250	$0	Primary
	Development of model to forecast changes in coral condition related to elevated temperature and carbon dioxide.								
4. Technology development and standardization of carbonate chemistry measurements on moorings and autonomous floats.									
5. Assessment of socioeconomic impacts of ocean acidification and development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems.									
6. Education/Outreach on ocean acidification.									
							$2,000	$2,000	Total Contributing
							$550	$0	Total Primary
							$2,550	$2,000	Grand Total

Minerals Management Service

Summary of funded ocean acidification research and monitoring activities								
Agency:	Minerals Management Service							
Division:	Environmental Studies Program							
Program Elements						FY 2008 Budget ($K)	FY 2009 Budget ($K)	Activity Classification
1. Monitoring of ocean chemistry and biological impacts associated with ocean acidification at selected coastal and open-ocean monitoring stations, including satellite-based monitoring to characterize -								
A) marine ecosystems								
	Chukchi Sea: Chemistry and Benthos - Examined the foodweb of the Chukchi Sea as well as chemical parameters, inlcuding measurements of pH.					$2,887		Contributing
	Long-term Monitoring at the East and West Flower Garden Banks in the Gulf of Mexico - Part of a 30-year effort to monitor the health of the coral reef, includes measurements of pH as a water quality parameter.					$125	$125	Contributing
B) changes in marine productivity								
C) changes in ocean chemistry								
	Biogeochemical Assessment of the North Aleutian Basin Ecosystem: Current Status & Vulnerability to Climate Change - Results from the study are being used in publications about ocean acidification.					$490		Primary
						$3,012	$125	total Contributing
						$490	$0	total Primary
						$3,502	$125	total
2. Research to understand the species specific physiological responses of marine organisms to ocean acidification, impacts on marine food webs of ocean acidification, and to develop environmental and ecological indices that track marine ecosystem responses to ocean acidification.								
3. Modeling to predict changes in the ocean carbon cycle as a function of carbon dioxide and atmosphere-induced changes in temperature, ocean circulation, biogeochemistry, ecosystem and terrestrial input, and modeling to determine impacts on marine ecosystems and individual marine organisms.								
4. Technology development and standardization of carbonate chemistry measurements on moorings and autonomous floats.								
5. Assessment of socioeconomic impacts of ocean acidification and development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems.								
6. Education/Outreach on ocean acidification.								
						$3,012	$125	Total Contributing
						$490	$0	Total Primary
						$3,502	$125	Grand Total

National Aeronautics and Space Administration

Summary of funded ocean acidification research and monitoring activities			
Agency:	NASA		
Division:	Earth Sciences		
Program Elements	FY 2008 Budget ($K)	FY 2009 Budget ($K)	Activity Classification
1. Monitoring of ocean chemistry and biological impacts associated with ocean acidification at			
Global scale assessments of primary production and its controls, air-sea gas exchange, carbon cycling in Great Lakes, coastal and ocean habitats.	$3,080	$2,800	Contributing
2. Research to understand the species specific physiological responses of marine organisms to ocean acidification, impacts on marine food webs of ocean acidification, and to develop environmental and ecological indices that track marine ecosystem responses to ocean acidification.			
Remote sensing and field studies of algal functional groups, phenology, size structure and fluorescence.	$765	$651	Contributing
3. Modeling to predict changes in the ocean carbon cycle as a function of carbon dioxide and atmosphere-induced changes in temperature, ocean circulation, biogeochemistry, ecosystem and terrestrial input, and modeling to determine impacts on marine ecosystems and individual marine organisms.			
Modeling activities including air-sea gas exchange, spring phytoplankton bloom formation, production of carbon dioxide from photosynthesis and respiration, and oceanic carbon cycling	$937	$741	Contributing
Ocean Acidification of the Greater Caribbean Region 1999 - 2009	$207	$162	Primary
4. Technology development and standardization of carbonate chemistry measurements on moorings and autonomous floats.			
Development, assessment and commercializtion of a biogeochemical profiling float for ocean carbon studies.	$0	$326	Contributing
5. Assessment of socioeconomic impacts of ocean acidification and development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems.	$0	$0	
6. Education/Outreach on ocean acidification.			
Program and interagency offices, and National Research Council studies	$100	$136	Contributing
National Research Council study to develop an integrated science strategy for ocean acidification monitoring, research, and impacts assessment.	$0	$30	Primary
	$4,882	$4,654	Total Contributing
	$207	$192	Total Primary
	$5,089	$4,846	Grand total

National Oceanic and Atmospheric Administration

Summary of funded ocean acidification research and monitoring activities			
Agency:	NOAA		
Division:			
Program Elements	FY 2008 Budget ($K)	FY 2009 Budget ($K)	Activity Classification
1. Monitoring of ocean chemistry and biological impacts associated with ocean acidification at selected coastal and open-ocean monitoring stations, including satellite-based monitoring to characterize -			
A) marine ecosystems			
B) changes in marine productivity			
C) changes in ocean chemistry			
Coral Reef Watch experimental product - regional maps of ocean acidification relevant chemical parameters for the greater Caribbean region	$22	$14	Primary
Coral Reef Conservation Program - Coral Reef Ecosytem Division remote Pacific Islands carbonate chemistry survey	$20	$52	Primary
Ocean carbon inventory (Repeat Hydrodrography transects)	$1,389	$1,389	Contributing
Global ocean carbon dioxide flux (Volunteer Observing Ship Program)	$1,339	$1,341	Contributing
World Ocean Circulation Experiment/Joint Global Ocean Flux Study Analysis/Reanalysis	$652	$652	Contributing
Observation-based quantification of seasonal to interannual changes in air-sea carbon dioxide fluxes	$174	$181	Contributing
Coastal carbon dioxide measurements and databases for the North American Carbon Program	$255	$0	Contributing
	$3,809	$3,668	total Contributing
	$42	$68	total Primary
	$3,851	$3,628	total
2. Research to understand the species specific physiological responses of marine organisms to ocean acidification, impacts on marine food webs of ocean acidification, and to develop environmental and ecological indices that track marine ecosystem responses to ocean acidification.			
A) Biology of impacted species			
Preliminary ocean acidification research on Alaska king crab species.	$50	$50	Primary
Development of an acidification treatment system for examining organism response preliminary experiments on Puget Sound geoduck and krill.	$25	$55	Primary
B) Ecosystems and foodwebs			
Adaptation of foodweb models of Puget Sound and the California Current to predict how these ecosystems will respond to future ocean acidification		$15	Primary
C) Calcification processes and Carbonate chemistry of the oceans			
D) Other marine chemical and physical attributes			
E) The record of Earth system history re: ocean acidification			
	$75	$120	total Primary
	$75	$120	total
3. Modeling to predict changes in the ocean carbon cycle as a function of carbon dioxide and atmosphere-induced changes in temperature, ocean circulation, biogeochemistry, ecosystem and terrestrial input, and modeling to determine impacts on marine ecosystems and individual marine organisms.			
A) Physico-chemical change			
B) Ecological/Biological impacts			
4. Technology development and standardization of carbonate chemistry measurements on moorings and autonomous floats.			
Atlantic Ocean acidification test-bed (La Parguera, Puerto Rico) - development and deployment of instruments on a coral reef to measure ocean acidification parameters and aquire related meteorological and oceanographic observations	$83	$169	Primary
Carbon dioxide moored buoy systems	$419	$419	Contributing
	$419	$419	total Contributing
	$83	$188	total Primary
	$502	$588	total
5. Assessment of socioeconomic impacts of ocean acidification and development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems.			
6. Education/Outreach on ocean acidification.			
National Research Council study to develop an integrated science strategy for ocean acidification monitoring, research, and impacts assessment	$200	$197	Primary
	$200	$197	total Primary
	$200	$197	total
	$4,228	$3,982	Total Contributing
	$400	$662	Total Primary
	$4,628	$4,634	Grand Total

National Science Foundation

Summary of funded ocean acidification research and monitoring activities			
Agency: NSF			
Division: Geosci -Oceans; Biological Sci - Molecular, Cellular and Organismal; Polar Prog - Arctic and Antarctic			
Program Elements	**FY 2008 Budget ($K)**	**FY 2009 Budget ($K)**	**Activity Classification**
1. Monitoring of ocean chemistry and biological impacts associated with ocean acidification at selected coastal and open-ocean monitoring stations, including satellite-based monitoring to characterize -			
A) marine ecosystems	$200	$200	Contributing
ocean time series monitoring - species			
B) changes in marine productivity	$200	$200	Contributing
ocean time series monotoring - productivity			
C) changes in ocean chemistry	$200	$1,276	Contributing
coral reef system monitoring; ocean time series monitoring - carbonate system, pH monitoring; California Current System monitoring			
carbon system measurements (dissolved inorganic carbon, acidity, alkalinity) in global survey transects			
	$600	**$1,676**	**total Contributing**
2. Research to understand the species specific physiological responses of marine organisms to ocean acidification, impacts on marine food webs of ocean acidification, and to develop environmental and ecological indices that track marine ecosystem responses to ocean acidification.			
A) Biology of impacted species	$1,583	$4,015	10% Contributing
effects of seawater pH on coral symbiosis; algal/anemone symbioses; pteropod physiology and gene expression; shell dissolution in molluscs			
gene expression in pH stress with temperature; evolution and pH changes in coccolithophorids; pH impacts on bentic foraminiferans; pH impacts on planktonic foraminiferans			
physiology of coral reef larve in changing pH;			
B) Ecosystems and foodwebs	$512	$370	30% Contributing
ecological dynamics of coccolithphorids in the South Atlantic; population dynamics of viruses and coccolitthophorids			
aquatic plant induced changes in pH and invertebrate responses; disease resistance in corals in decreased pH environments			
effects of ocean acidification on nutrient availability and requirements in phytoplankton			
C) Calcification processes and Carbonate chemistry of the oceans	$1,768	$851	Primary
methods development for calcification rates; coral reef calcification and productivity; investigating yttrium and rare earth elements co-precipitation with phosphate and biogenic aragonite as indicators of ocean acidification; calcification rates in foraminifera			
D) Other marine chemical and physical attributes	$0	$547	Primary
effects of ocean acidification on the formation and sinking of particles			
E) The record of Earth system history re: ocean acidification	$0	$652	Primary
examination of ocean acidification in the geologic record; validation of the Boron/Calcium ratio proxy for surface seawater pH and application to measure anthropogenic ocean acidification			
	$312	**$513**	**total Contributing**
	$3,551	**$5,923**	**total Primary**
	$3,863	**$6,435**	**total**
3. Modeling to predict changes in the ocean carbon cycle as a function of carbon dioxide and atmosphere-induced changes in temperature, ocean circulation, biogeochemistry, ecosystem and terrestrial input, and modeling to determine impacts on marine ecosystems and individual marine organisms.			
A) Physico-chemical change	$0	$0	
B)Ecological/Biological Impacts	$0	$0	
4. Technology development and standardization of carbonate chemistry measurements on moorings and autonomous floats.			
development of methods for: quantifying calcification rates of plankton; infering past pH levels; direct determinations of carbonate ion concentrations; and for determination of coral reef calcification	$372	$1,076	Primary
	$372	**$1,076**	**total Primary**
5. Assessment of socioeconomic impacts of ocean acidification and development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems.	$0	$0	
6. Education/Outreach on ocean acidification.			
Ocean Acidification volume of Oceanography Magazine	$0	$50	Primary
Ocean Carbon and Biogeochemistry community science and best-practices workshops.	$0	$2,242	30% Contributing
	$0	**$673**	**total Contributing**
	$0	**$1,619**	**total Primary**
	$912	**$2,861**	**Total Contributing**
	$3,923	**$8,618**	**Total Primary**
	$4,835	**$11,479**	**Grand Total**

U.S. Geological Survey - x, y, z indicate applicability of projects listed within 1. A) to other elements

Summary of funded ocean acidification research and monitoring activities			
Agency:	USGS		
Division:			
Program Elements	FY 2008 Budget ($K)	FY 2009 Budget ($K)	Activity Classification
1. Monitoring of ocean chemistry and biological impacts associated with ocean acidification at selected coastal and open-ocean monitoring stations, including satellite-based monitoring to characterize -			
A) marine ecosystems			
Coral Reef Communites - In situ measurement of community metabolism and calcification baselines and thresholds of CO2 levels, pH and saturation state for calcification and dissolution. Applicable to other elements in the table as indicated by an "x" in the budget columns.	$267	$377	Primary
Coral Reefs and algae - Provides baseline information on the latitudinal and seasonal variability in calcification rates for a species of reef-building coral and encrusting coralline algal communities thorughout the Florida Keys. Applicable to other elements in the table as indicated by a "y" in the budget columns.	$71	$254	Primary
Shelf Ecosystems - This project utilizes historical information, field work and satellite data to understand the response of Florida shelf ecosystems to climate change. Applicable to other elements in the table as indicated by a "z" in the budget columns.	$440	$492	Primary
B) changes in marine productivity			
Coral Reef Community Metabolism and Calcification - In situ measurement of community metabolism and calcification baselines and thresholds of CO2 levels, pH and sataturation state for calcification and dissolution	x	x	Primary
C) changes in ocean chemistry			
Mapping the Florida shelf CO2 levels and saturation state - Key baseline data on CO2 concentrations, total carbon, pH, Dissolved Inorganic Carbon (DIC), temperature and salinity in near shore coastal waters of the west Florida Shelf.	$116		Primary
Coastal and shelf Florida waters - This project utilizes historical information, field work and satellite data to understand the response of Florida Shelf Ecosystems to Climate Change.	z	$100	Primary
Links between water chemistry, geology, and biologic communities - Synthesis of collected west Florida shelf data including, CO2 concentrations (seawater and atmosphere), total carbon, pH, dissolved inorganic carbon, temperature and salinity.	z	z	Primary
Diurnal changes in coastal carbonate chemistry - measuring diurnal changes in coastal and reef ecosystems	x	x	Primary
	$894	**$1,223**	**total Primary**
2. Research to understand the species specific physiological responses of marine organisms to ocean acidification, impacts on marine food webs of ocean acidification, and to develop environmental and ecological indices that track marine ecosystem responses to ocean acidification.			
A) Biology of impacted species			
Coral Reef degradation including coralline algae - Manipulative study on encrusting coralline algal communities on coral reefs.	$182	$103	Primary
Lophelia (coral) communities - Identifying and characterizing microbial communities associated with the cold-water coral Lophelia pertusa as a baseline for biology and ecology of this deep-reef habitat builder.	$2,434	$1,505	Contributing
Deep water habitats of corals - This research is examining benthic community structure and trophic function in deep-coral ecosystems in the Gulf of Mexico - response to change	$192	$192	Contributing
Foraminiferans and calcareous green algae from Florida's west coast: This task involves laboratory experiments to evaluate the effects of lower pH and carbonate saturation state on calcifying organisms and is part of dissertation research of a University of South Florida student	z	z	Primary
B) Ecosystems and foodwebs			
C) Calcification processes and Carbonate chemistry of the oceans			
Coral Reef Landscape - Numerical modeling of flow patterns and discharge rates to Biscayne Bay, FL to provide insight into causes of ecosystem degradation	$75	y	Primary
Chronic effects on the growth rates of coral & macroalgae - Effects on algal growth rates & coral growth & recruitment	$77	y	Primary
D) Other marine chemical and physical attributes			

U.S. Geological Survey - continued

	Coastal fluxes of dissolved iron to northeast Pacific surface waters: A driver of the marine ecosystem and carbon cycle				$36	Contributing
	Submarine Groundwater Discharge and Coral Reefs - Quantifying groundwater to the coastal ocean and coral reef settings in Hawaii, characterize the flux of nutrients, generate data to compare to regional groundwater models, and develop predictions of how groundwater flux and dependent coastal ecosystems may change with expected climate change.				$1,252	$1,505	Contributing
E) The record of Earth system history re: ocean acidification							
	Development of Boron isotope measurements as a proxy for seawater pH					$69	Primary
	Past, Current, and Future Biogenic Calcification Rates - Baseline data on the seasonal variability in calcification rates for a species of reef-building coral and encrusting coralline algal communities in the Dry Tortugas National Park.					$151	Primary
	Historical pH, temperature and salinity data from Florida shellfish beds - Synthesis of Historical data from Florida shellfish beds to document ocean acidification and climate change				z	z	Primary
	Coral Reef Community Calcification - examines past, current, and future calcification rates relative to changes in ocean chemistry				x	x	Primary
					$334	**$323**	**total Primary**
					$3,914	**$3,202**	**total Contributing**
					$4,248	**$3,525**	**total**
3. Modeling to predict changes in the ocean carbon cycle as a function of carbon dioxide and atmosphere-induced changes in temperature, ocean circulation, biogeochemistry, ecosystem and terrestrial input, and modeling to determine impacts on marine ecosystems and individual marine organisms.							
A) Physico-chemical change							
	Land-Sea Carbon Coupling - Annual and seasonal riverine fluxes of dissolved organic carbon in selected rivers in Maine				$73	$73	Contributing
	Modeling carbon fluxes (ocean and aquatic) - Integrating existing information; Carbon fluxes in hydrologic and geologic processes				$574	$282	Contributing
	Modeling historical and future changes in ocean carbon cycle - Using boron proxy on coral cores and data from present day reefs, modeling ecosystem change					$69	Contributing
	Climate Change Impacts on North Slope - Defining the spatial distributions and fluxes of carbon stocks in various biological and chemical forms and the biogeochemical mechanisms controlling these carbon fluxes over both short terms and long terms.						Contributing
	Marine gas hydrates and links to climate change - The fundamental objective of this research is to determine whether Arctic gas hydrates are currently contributing or can reasonably be expected to contribute (under accepted climate change scenarios) to methane seepage offshore of Alaska or in areas of continuous permafrost on the Alaskan North Slope.				$3,039	$4,040	Contributing
	Speciation in bioavailability of iron in Gulf of Alaska - Examines the link between iron solubility and speciation in particulate sources of Alaskan waters, and the connection to marine productivity, carbon sequestration and global change (ocean acidification).				$35		Contributing
B) Ecological/Biological Impacts							
	Ecosystem performance - Quantify Ecosystem Performance anomalies for the Alaskan North Slope						Contributing
					$3,721	**$4,464**	**total Contributing**
4. Technology development and standardization of carbonate chemistry measurements on moorings and autonomous floats.							
	Technology development for flow through systems for measuring pCO2 and total CO2 for ocean and river studies				$25		Primary
	Methods for measuring Coral Reef Community metabolism and calcification - Standarization of methods measuring carbon parameters and calcification; partnering with NOAA, University of South Florida, and University of Miami				x	x	Primary
					$25	**$0**	**total Primary**
5. Assessment of socioeconomic impacts of ocean acidification and development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems.							
6. Education/Outreach on ocean acidification.							
	Various outreach associated with projects; Soundwaves articles				x,y,z	x,y,z	
	USGS Carbon committee				z	z	
	membership on internal and external committees for ocean acidification				x,y,z	x,y,z	
					$7,635	**$7,666**	**Total Contributing**
					$1,253	**$1,546**	**Total Primary**
					$8,888	**$9,212**	**Grand Total**

Appendix 2

Outline for Strategic Research Plan for Ocean Acidification

Executive Summary

Introduction and Background
- What is ocean acidification
- Overview of themes in the strategic research plan
- Existing reports that inform this strategy
  - Ocean Carbon and Biogeochemistry report - 2009
  - National Research Council report – 2010
  - USGS/NSF/NOAA Coral Reef Report – 2008
  - Royal Society Report – 2005
  - 2nd High CO_2 World Symposium
  - OceanOBS'09 community white papers

Legislative Mandate and Report Process
- FOARAM Act details. Plan for next 10 years of research.
- Process – publish in the Federal Register

Monitoring of Ocean Chemistry and Biological Impacts (Theme 1)
- Existing monitoring and gap analysis
  - Measurement requirements
  - Strategy for an observational network for ocean acidification
  - Repeat surveys of chemical and biological properties
  - Time-series measurements at fixed stations and on floats and gliders
  - Remote sensing

Research to Understand Responses to Ocean Acidification (Theme 2)
- Experimental best practices for assessing species specific impacts in the laboratory and field
- Effects on calcification and other physiological processes
- Impacts on growth, reproduction, survival
- Cumulative or synergistic effects of ocean acidification with other stressors

Modeling to Predict Changes in the Ocean Carbon Cycle and Impacts on Marine Ecosystems and Organisms (Theme 3)
- General circulation models incorporating carbonate system parameters and carbon cycling
- Capacity for regional downscaling, e.g. Arctic
- Modeling ecosystem effects of ocean acidification, including habitat shifts and invasions

Technology Development and Standardization of Measurements (Theme 4)
- Sensors: current status and future needs
- Sustained calibration and validation activities
- Best practices

Assessment of Socioeconomic Impacts and Development of Strategies to conserve Marine Organisms and Ecosystems (Theme 5)

Socio-economic or integrated assessment models
Impact on food security
Mitigation and adaptation strategies

Education/Outreach and Engagement Strategy on Ocean Acidification (Theme 6)

Education, outreach, and communications
International engagement strategy

Synthesis of Data and Information Products (Theme 7)

Integration across climate, biogeochemical, and biological datasets
Workshops and synthesis meetings

Budget Requirements by Agency

Appendix I: Agency Programs Involved in Ocean Acidification Research

Appendix II: Case Studies – Regional Approaches to Ocean Acidification Monitoring and Research