IMPLEMENTATION OF THE STRATEGIC PLAN FOR FEDERAL RESEARCH AND MONITORING OF OCEAN ACIDIFICATION

PRODUCT OF THE

National Science and Technology Council
Subcommittee on Ocean Science and Technology

December 2016

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About the Interagency Working Group on Ocean Acidification

Interagency Working Group on Ocean Acidification advises and assists the SOST 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 (P.L. 111-11, Subtitle D).

About this Document

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Introduction

The National Science and Technology Council (NSTC) released the *Strategic Plan for Federal Research and Monitoring of Ocean Acidification* (Strategic Research Plan) in 2014 as part of the Federal government's fulfillment of the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act, P.L. 111-11, Subtitle D). The Strategic Research Plan, which was prepared by the Interagency Working Group on Ocean Acidification (IWG-OA) under the NSTC Subcommittee on Ocean Science and Technology, outlines what research and information dissemination efforts the Federal government should undertake to guide its response to ocean acidification (OA). Federal agency members of the IWG-OA work to align agency activities with the research activities outlined in the Strategic Research Plan and achieve complementarity among agencies, with the aim of meeting all of the goals of the Strategic Research Plan. To aid this process, the IWG-OA developed this informal Implementation Plan for the Strategic Research Plan.

This document has three primary objectives: 1) identify the needs and activities described in the Strategic Research Plan that are currently being addressed by Federal agencies; 2) coordinate future Federal activities that are guided by and align with the goals of the Strategic Research Plan; and 3) communicate Federal actions on ocean acidification to the public. Implementation of the Strategic Research Plan will be an ongoing, long-term, iterative process to ensure that Federal ocean acidification activities address goals outlined in the Strategic Research Plan. In this ongoing work, the IWG-OA will be vigilant about identifying parts of the Strategic Research Plan not currently being addressed and, when gaps exist, Federal agency members of the IWG-OA will work to address the needs that fulfill their mission.

Federal agencies will use the Strategic Research Plan as a guide for future Federal investment addressing ocean acidification, but agencies are not limited by the goals outlined in the Strategic Research Plan. For example, the FOARAM Act calls for Federal agencies to develop adaptation and mitigation strategies for ocean acidification. Specific research activities addressing this topic, however, are not captured by the goals of the Strategic Research Plan. Similarly, while the need for analyses to assess vulnerability to various scenarios of ocean acidification is emphasized in the Strategic Research Plan, the goals of the Strategic Research Plan do not capture this activity well. The IWG-OA expects that agencies will engage on these lines of work, and the group will capture those activities in its reporting, as required.

This Implementation Plan represents a summary of current, planned, and prioritized Federal activities. In general, each agency should focus on mission-related goals, which results in complementarity among agencies. Particular focus will be on activities in the Strategic Research Plan that are currently not being addressed by the agencies, or will not be addressed in the near future. One challenge with ensuring future coverage of the Strategic Research Plan goals is that the agencies that fund ocean acidification work through peer-reviewed, competitive processes are often unable to dictate the exact goals that this future work will address because projects are awarded by merit, not topic.

Questions often arise regarding what level of effort on a certain goal is sufficient and when work on a goal will be complete. Given that ocean acidification is a recently recognized phenomenon, research on the process of acidification, how it will influence ecological and human communities, and how human communities could successfully adapt to these changes is in its infancy. Thus, it is premature to determine how much work and investment is sufficient on a given topic. The IWG-OA will not set quantitative, numerical metrics for each goal for the foreseeable future. Instead, both expenditures and implementation reporting can be used to track the relative amount of Federal activity on each theme in the Strategic Research Plan (see Figures 1 and 2 and the Appendix). This reporting is also a requirement

in the FOARAM Act. It is expected that the IWG-OA will revise the Strategic Research Plan every five years. Accordingly, the Implementation Plan will be revised as necessary. The IWG-OA will also work over the long term to identify future metrics to measure and track success.

Coordination of Federal Activities for Meeting Strategic Research Plan Priorities

The IWG-OA has no authority to control individual agency priorities or agendas on ocean acidification. The IWG-OA tracks Federal progress on the goals outlined in the Strategic Research Plan and helps focus Federal activities on ocean acidification in a way that a single agency could not due to agency-specific mission, authorities, and mandates. Biennial reports from each IWG-OA member agency will provide an update on the progress made in addressing the goals of the Strategic Research Plan during the previous 2 years and communicate near-term plans (see the 2014 tracking document in the Appendix). In addition and as required by the FOARAM Act, the IWG-OA will complete a biennial narrative summary of Federal ocean acidification activities that will be submitted to Congress and made publically accessible. The reports for fiscal years (FY) 2009–2013 are currently available on the IWG-OA website.

The IWG-OA has regular meetings to share information on activities related to the seven thematic areas of the Strategic Research Plan:

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

At these meetings, the IWG-OA records activities related to the Strategic Research Plan themes, explores opportunities for collaboration on activities related to the themes, identifies ways to address gaps between Federal activities and the goals outlined in the Strategic Research Plan, and discusses potential ways to prioritize efforts to fill these gaps. In addition, the IWG-OA works to increase awareness of agency activities on ocean acidification and how agencies can work together. For example, in FY 2014, the IWG-ocean acidification participated in a formal review of the FY 2015–2017 work plans submitted to the National Oceanic and Atmospheric Administration (NOAA) Ocean Acidification Program by NOAA laboratories and science centers to assess their alignment with the Strategic Research Plan. Other activities to increase coordination and awareness may include developing joint requests-for-proposals on ocean acidification research; fostering interaction between the IWG-OA and the NSTC Interagency Working Group on Aquaculture (IWG-A)[1]; and collaborating and coordinating on monitoring activities, fleet operations, and online portals for ocean acidification-related data.

[1] The IWG-A formerly the Joint Subcommittee on Aquaculture, is a long-standing Federal interagency coordinating group under the NSTC. As a mandate from the National Aquaculture Act of 1980, the IWG-A coordinates Federal activities as it relates to aquaculture in the United States.

Establishing the National Ocean Acidification Program and Program Office

The Strategic Research Plan calls for establishment of a National Ocean Acidification Program and associated Program Office to coordinate ocean acidification activities among interested Federal and non-Federal stakeholders nationwide. This Program would advise the IWG-OA on Federal implementation of the Strategic Research Plan and galvanize the stakeholder community to support and complement Federal ocean acidification activities. The effort would complement the work of Federal agencies in fulfilling their missions. NOAA's Ocean Acidification Program and the IWG-OA provide some coordination and stakeholder engagement. NOAA's work, however, is primarily directed toward specific NOAA-priority activities. Conversations on the feasibility and interest in establishing a national program and a dedicated Program Office are ongoing.

National Ocean Acidification Information Exchange

The Government Accountability Office report on Federal efforts to address ocean acidification highlighted, among other items, that the Federal government had not yet established an ocean acidification "information exchange" as called for in the FOARAM Act. The legislation mandates that an ocean acidification information exchange be established to provide a coordination function for all entities involved in ocean acidification research, response, and information dissemination (Federal, tribal, and state agencies, industry, nongovernmental organizations, foundations, international coordination bodies, etc.). It could be a component of the National Ocean Acidification Program Office described above. Conversations on establishing an information exchange are ongoing.

Funding Availability

Future Federal funding levels for ocean acidification-related activities are unknown at this time, presenting a challenge for establishing an agency-specific, long-term plan for implementation of the IWG-OA Strategic Research Plan. Within this uncertainty, however, agencies can outline an expected plan of action and commit to some specific activities under level-funding scenarios as described in the agency chapters outlined below.

Overview of Alignment of Federal Agency Activities with the Strategic Research Plan

Federal agencies are actively working on each of the seven thematic areas outlined in the Federal Strategic Research Plan. At present, Themes 1 (Research to understand responses to ocean acidification) and 2 (Monitoring of ocean chemistry and biological impacts) have the highest level of engagement by Federal agencies. Of the 97 actions discussed in the Strategic Research Plan (see Appendix), 6 remain unaddressed. Most of the unaddressed actions are related to data integration and management.

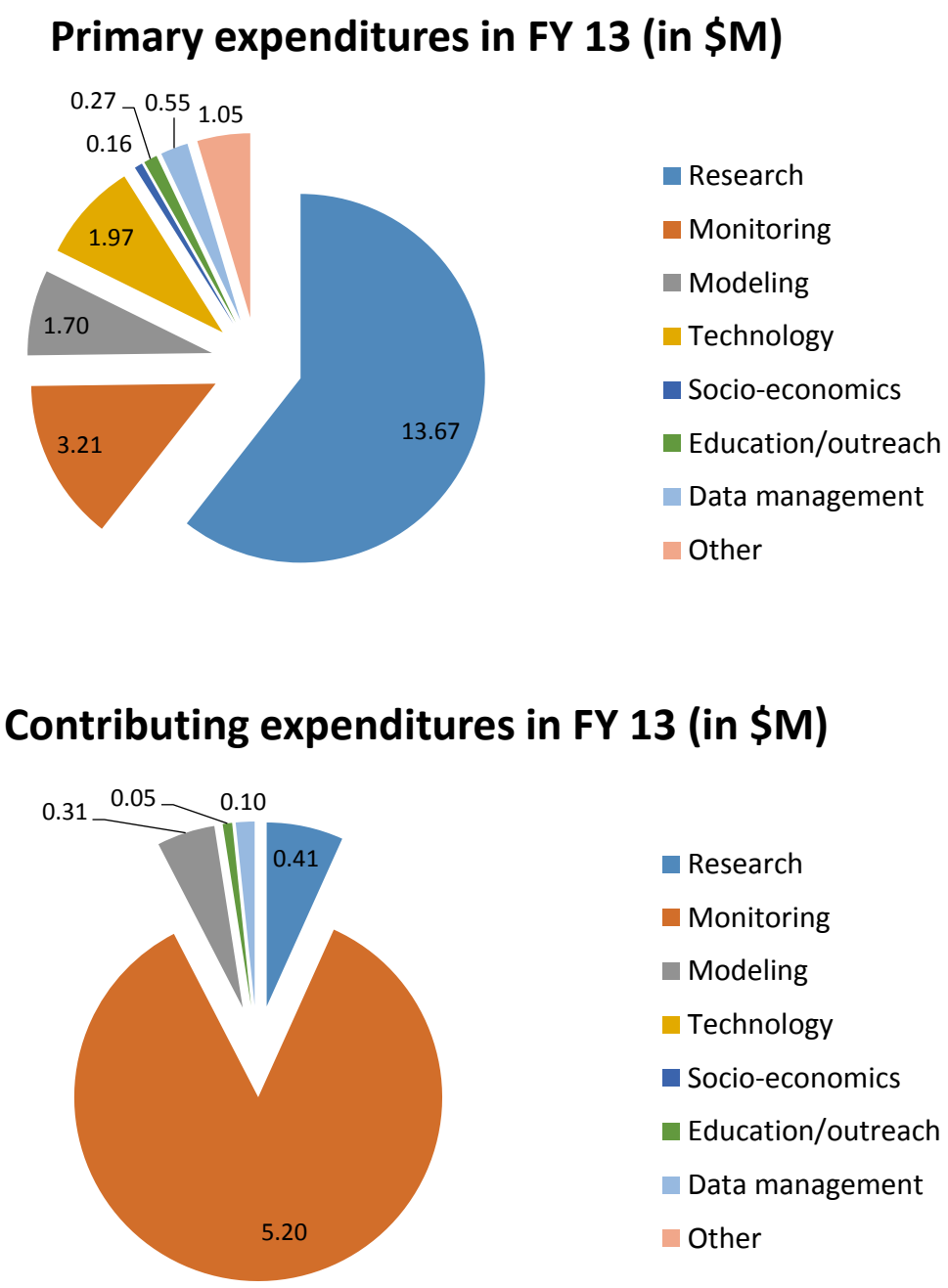

Figure 1. Federal expenditures on ocean acidification in FY 2013 categorized by thematic areas in the Strategic Research Plan for Federal Research and Monitoring of Ocean Acidification. Activities and expenditures on specific themes are classified as having either a primary focus on ocean acidification or being contributing activities. Contributing activities are those designed for other purposes but clearly provide information useful for understanding ocean acidification. Values are given in millions of dollars.

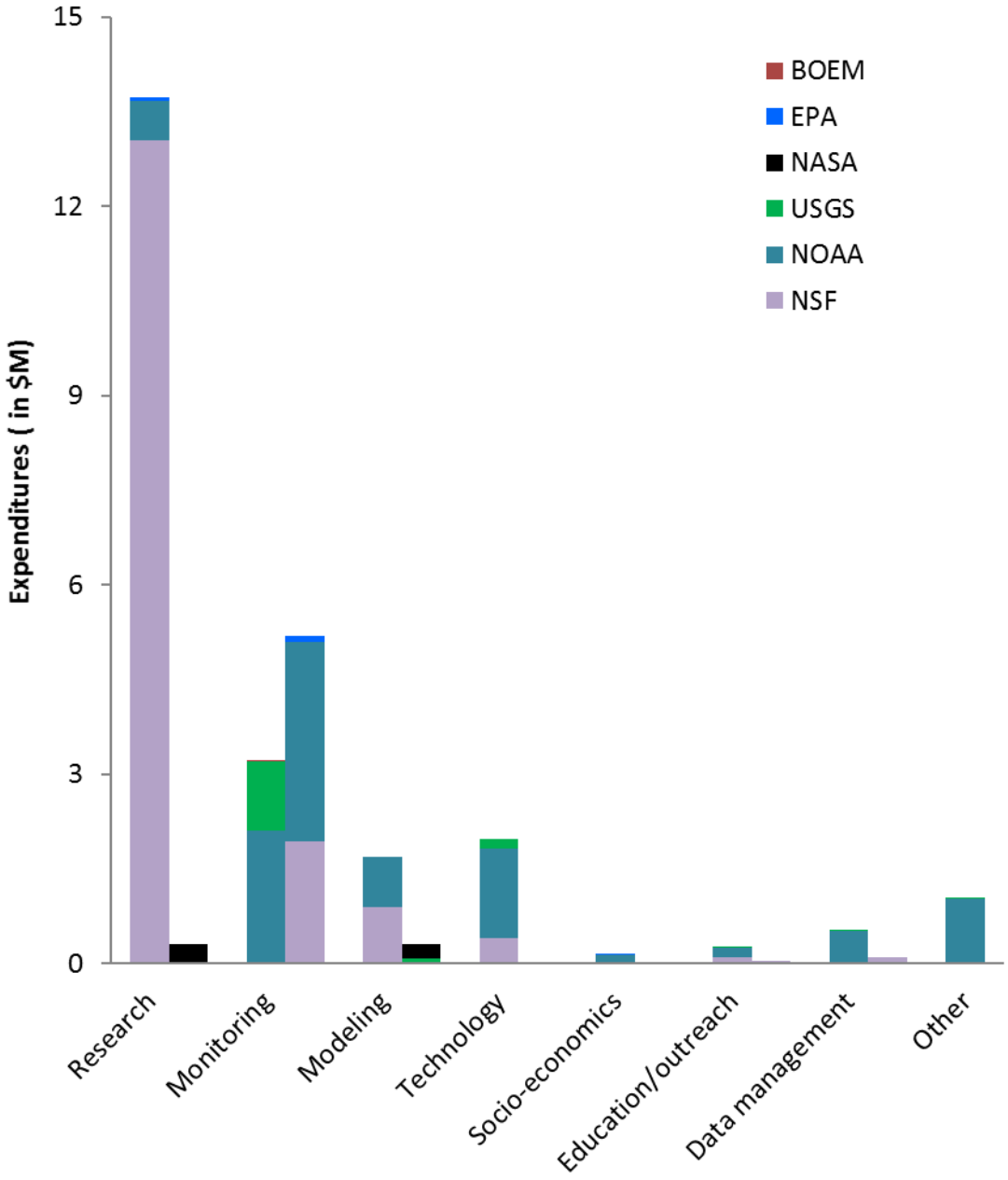

Figure 2. Federal expenditures on ocean acidification in FY 2013 for each IWG-OA agency categorized by thematic areas in the Strategic Research Plan for Federal Research and Monitoring of Ocean Acidification. The left bar for each theme represents expenditures for primary activities, and the right bar represents expenditures on contributing activities.

Ocean Acidification Activities by Federal Department/Agency

Most of the Federal agencies represented on the IWG-OA contributed information for this Implementation Plan describing their efforts on ocean acidification, including current and planned work, and outlining ideas to increase ocean acidification work within their and other agencies. While some agencies used a common format to organize this information, others determined that an alternative format would best allow them to reflect their agency's activities. Agencies whose work on ocean acidification is limited did not submit information.

Bureau of Ocean Energy Management

Broad Overview of and Rationale for Ocean Acidification Work

The Bureau of Ocean Energy Management (BOEM) in the Department of the Interior is responsible for managing the use of oil, gas, renewable, and marine mineral resources along the outer continental shelf of the United States. BOEM is contributing to the knowledge of ocean acidification through research activities taking place along the West Coast and in Alaska and the Gulf of Mexico. BOEM's Environmental Studies Program develops, conducts and oversees world-class scientific research specifically to inform policy decisions regarding development of outer continental shelf energy and mineral resources. This research includes the topic of ocean acidification as it applies to BOEM's jurisdictional purview. In particular, an increased understanding of ocean acidification-induced biogeochemical changes informs BOEM's cumulative impacts analysis as part of National Environmental Policy Act, which considers environmental impacts from energy development in addition to other potential stressors, such as climate change. Further information is needed to assist BOEM in predicting and detecting the effects of offshore energy activities by describing baseline environmental conditions and if and how they are shifting. BOEM is working to address these information needs and will also use information collected by other entities, including Federal agencies.

On-going Projects Related to Ocean Acidification

In 2008, the BOEM Alaska Region partnered with the University of Alaska and NOAA on a study to examine the biogeochemical characteristics of Arctic seas off the coast of Alaska in light of climate change and ocean acidification. The field and laboratory components of this study have been completed. The Final Report is available here.

The Pacific Regional Intertidal Sampling and Monitoring (PRISM) team is a group of BOEM biologists within the BOEM Pacific Region that has conducted monitoring since 1991. The PRISM team, on behalf of BOEM, is partnering with the Channel Islands National Park and the University of California, Santa Barbara to maintain an ocean monitoring station (ocean pH, temperature, and salinity) within the park boundaries. In initial stages of this ocean acidification monitoring, BOEM funds contributed in FY 2012 helped with testing water samples and general quality assurance work and in FY 2013 purchased a pH sensor that was deployed in the summer of 2014. This monitoring at Channel Islands National Park is done in partnership with a broader network of agencies and university groups to track ocean acidification on the Pacific coast.

Near-future Activities Related to Ocean Acidification (Planned within the Next 2 Years)

In the Gulf of Mexico, BOEM is leading an effort in partnership with Shell Exploration and Production Company, NOAA, and Texas A&M University to establish an ocean acidification coral monitoring site, including an instrumented mooring and a sample validation program. This study will assess variability in carbonate chemistry at the Flower Garden Banks National Marine Sanctuary and will eventually help understand the implications of regional ocean acidification-related changes. The study was awarded in FY 2014, with Texas A&M University acting as Principal Investigator. The sub-surface and surface ocean

acidification moorings are currently being built and are scheduled to be deployed at Flower Garden Banks in 2016.

In the Beaufort Sea, the *Marine Arctic Ecosystem Study Ecosystem Dynamics and Monitoring of the Beaufort Sea, An integrated-science approach* study began in FY 2014, and is continuing for an undetermined period of time, with funding currently proposed through FY 2018. This study is designed to examine, in part, the complex interplay of ocean currents, downward radiation, suspended matter, nutrients, carbon, and sea ice coverage. This interplay requires more research because it is poorly understood at the spatial and temporal scales needed to understand marine ecosystem functioning in the Beaufort Sea.

Far-future Activities Related to Ocean Acidification (Planned within the Next 3-5 Years)

The BOEM Pacific Regional Office has proposed a study called *Predicting and Detecting the Effects of Climate Change and Ocean Acidification Using Long-term Ecological Data* to use Department of the Interior long-term monitoring programs to predict how global climate change and ocean acidification will alter rocky reef ecosystems in southern California and to detect effects already underway. Funding for this study has yet to be allotted.

Gaps in Agency Portfolio of Activities Related to Ocean Acidification, Compared to Priorities Outlined in the Strategic Research Plan

The potential to sequester carbon below the seabed on the outer continental shelf with engineering technology exists, and its regulation falls under Federal jurisdiction. If carbon sequestration on the outer continental shelf proceeds, it is likely an activity 7-10 years out. Prior to it being a realistic possibility, however, BOEM research may need to develop an improved understanding of potential impacts from sub-seabed carbon sequestration on ocean acidification.

BOEM is conducting research to develop best management practices for CO_2 sub-seabed sequestration on the outer continental shelf. This study was initiated in 2010 with the University of Texas at Austin, Bureau of Economic Geology, and completed in late 2015. A worldwide literature and data survey conducted as part of this study will aid in the development of best management practices that will address all aspects of sub-seabed geologic CO_2 transport and sequestration projects. The literature references have been collected into a database that will be made publically available with the best management practices upon project completion.

Untapped Opportunities Inside of Agency for Projects Related to Ocean Acidification

BOEM funds much ocean monitoring, and the potential exists to leverage these investments by adding measurements related to ocean acidification. For example, BOEM could consider including the analysis of parameters used to measure/evaluate ocean acidification (seawater pH, partial pressure of carbon dioxide (pCO_2), dissolved inorganic carbon, and total alkalinity) as an addition to any studies that include field work or that could easily accommodate this extra collection/analysis. BOEM could also consider the addition of instrumentation to planned meteorological buoys or platforms within offshore lease areas and to the collection of water samples pertinent to pCO_2 or ocean buffering capacity (e.g., dissolved inorganic carbon, dissolved organic carbon, colored dissolved organic matter, absorption/attenuation) during routine servicing of buoys or platforms.

Ideas for How Agency Could Work with Other Federal Agencies on Activities Related to Ocean Acidification

BOEM is open to discussion for improved data sharing and standardized methodology for collections related to ocean acidification.

Areas Where Agency Mission is Being Inhibited by Knowledge Gaps that Fall out of Agency's Purview

BOEM environmental analyses would benefit from an improved understanding of climate change and ocean acidification for identification of cumulative impacts and potential mitigation and minimization measures for BOEM jurisdictional actions.

Environmental Protection Agency

Broad Overview of and Rationale for Ocean Acidification Work

The Environmental Protection Agency's (EPA) mission is to protect human health and the environment, which includes identifying impacts on the Nation's coastal waters due to ocean acidification. EPA authorities under the Clean Air Act and the Clean Water Act can play an important role in addressing ocean acidification. EPA's activities under the Clean Air Act to mitigate greenhouse gases have implications for ocean acidification because atmospheric concentrations of CO_2 from anthropogenic sources are considered to be the primary driver of acidification in the open ocean and in the waters that ocean circulation brings to coastal environments. EPA and state programs under the Clean Water Act come into play in two ways: 1) acidification may affect the ability of coastal waters to support states' applicable water quality standards; and 2) these programs help states identify and address land-based sources of pollution (e.g., nutrients) that are considered by the scientific community to be an important driver of coastal acidification.

EPA has recently developed a nationally-oriented ocean and coastal acidification program that includes applied research on ecological responses to acidification, efforts to enhance monitoring in coastal waters, and modeling to assess local drivers and forecast environmental and socioeconomic consequences of acidification. EPA's Office of Research and Development (ORD) provides scientific support on ocean and coastal acidification to the agency's air and water programs and regions. Prior to FY 2016, ORD ocean acidification research was primarily incidental, capitalizing on sampling opportunities that were driven by other programmatic priorities. Beginning in FY 2016, ORD is conducting targeted research on the causes and responses to acidification and hypoxia in the coastal environment, with a strong emphasis on the role of nutrients. This includes field experiments and sampling activities, laboratory investigations of the response of aquatic life to acidification in EPA's marine laboratories, and water quality modeling studies that include carbonate chemistry.

On-going Projects Related to Ocean Acidification

EPA ORD is investigating the effects of nutrient enrichment on carbonate chemistry in coastal areas of the United States Northeast, Northwest, and Gulf coasts. ORD was a participant in studies of coastal acidification in the northern Gulf of Mexico; Narragansett Bay (Rhode Island), Long Island Sound (New York), and Puget Sound (Washington), some of which are continuing. In 2014, ORD began pairing seawater carbon chemistry measurements with ongoing nutrient and isotope transects in Narragansett Bay, spatially intensive nutrient sampling in Delaware Bay, and coastal shelf nutrient transects in the mid-Atlantic Bight, helping to fill a gap that lies inshore of most Federal observing programs. In 2016, ORD initiated field studies in Tillamook Estuary (Oregon) to quantify the local drivers influencing carbonate chemistry, utilizing *in situ* carbonate chemistry measurements and stable isotope sampling. These efforts, combined with other earlier and planned studies, are supporting EPA's effort to incorporate carbonate chemistry into ecosystem and water quality models.

In close alignment with these field and modeling studies, the effects of coastally-relevant changes in carbonate chemistry and hypoxia on corals, crustaceans, and other aquatic life are the subject of ongoing and new experiments in EPA's seawater laboratories in Florida, Oregon, and Rhode Island. This

includes evaluation of laboratory studies as predictors of ecological effects of acidification on shellfish populations in the field (in collaboration with NOAA-funded investigators at the State University of New York – Stony Brook). ORD is extending and continuing this work through shellfish field experiments and sampling of carbonate chemistry in Narragansett Bay. In collaboration with the University of Rhode Island, ORD conducts experiments examining the effects of acidification on whole estuarine phytoplankton communities. Experiments examining the combined effects of low oxygen and low pH on aquatic life are also getting underway at ORD's laboratory in Florida.

EPA's Office of Water (OW) and National Center for Environmental Economics are collaborating on the development of models for valuing marine ecosystem services and assessing economic impacts from ocean acidification. Initial efforts will focus on impacts in northwestern and northeastern coastal waters of the United States.

EPA's Region 10 (Pacific Northwest) and OW are collaborating with the Washington State Department of Ecology to develop water quality models for the Salish Sea (Washington and British Columbia, Canada). The models will provide estimates of the effect of watershed and airshed pollution on acidification (e.g., pH and aragonite saturation) throughout the marine waters of the Salish Sea.

EPA's OW and Region 1 (New England) are collaborating with the Casco Bay Estuary Partnership (Maine) to monitor pH and pCO_2 in estuarine waters. This work is being coupled with ongoing studies of nutrient concentrations to better understand how nutrients can exacerbate ocean acidification. Additionally, OW is supporting the development of a stakeholder engagement strategy by the Northeast Coastal Acidification Network.

The National Coastal Condition Assessment, one of the EPA's National Aquatic Resource Surveys, is a statistical survey of a core suite of coastal water quality parameters conducted once every 5 years. EPA is developing standard operating procedures for collecting ocean acidification-related parameters as an add-on indicator for upcoming surveys in 2020.

Beginning in 2015, EPA's ORD and Region 10's Regional Applied Research Effort program paired seawater carbon chemistry measurements with spatially intensive nutrient and isotope sampling in the Snohomish River Delta (Washington) to quantify the role of anthropogenic nutrient inputs on acidification in the nearshore environment.

EPA is increasing capacity to monitor for coastal acidification by providing five National Estuary Programs (Casco Bay (Maine), Santa Monica Bay (California), Coastal Bend Bays and Estuaries (Texas), Long Island Sound Study (Connecticut/New York), and Barnegat Bay (New Jersey)) with funding for the procurement of instrumentation for high-frequency and high-precision measurement of pH and dissolved CO_2.

EPA continues to engage with scientist and stakeholder networks to develop improvements in monitoring of coastal acidification. This includes partnerships in the Northeast Coastal Acidification Network, the Southeast Ocean and Coastal Acidification Network, and more locally organized networks, such as the Oregon Acidification Monitoring Network, that have spawned from workshops and educational meetings.

Near-future Activities Related to Ocean Acidification (Planned within the next 2 Years)

Beginning in 2016, ORD initiated research on nutrient enhanced coastal acidification and hypoxia with a focus on identifying local sources that may be contributing to coastal acidification in estuaries and impacts on estuarine organisms. As part of this broad effort, new experiments and field and modeling studies are planned. These include the addition of new sites to ORD's field studies of coastal acidification and the addition of carbonate chemistry, including effects of benthic processes on pH and

alkalinity, to existing ecosystem and water quality models. Modeling efforts will be supported by experiments beginning in 2016, including additional studies of biological responses to altered carbonate chemistry, as well as laboratory mesocosm and phytoplankton incubation studies in which the response of carbonate chemistry to nutrient enrichment will be evaluated. Laboratory research will also identify sensitive coastal species and establish adverse effects thresholds for acidification and hypoxia. Planned synthesis and modeling activities related to coastal eutrophication continue to provide opportunities to assess the potential for near-term mitigation of acidification through nutrient abatement programs, but formal incorporation into either non-regulatory or regulatory programs is uncertain at this time.

Far-future Activities Related to Ocean Acidification (Planned within the Next 3-5 Years)

Research planning on the far-future time horizon at EPA is underway. Activities specifically related to ocean and coastal acidification will be identified at a later time.

Gaps in Portfolio of Activities Related to Ocean Acidification, Compared to Priorities Outlined in the Strategic Research Plan

Federal research activities related to acidification in the coastal environment are limited. It remains unclear whether these efforts will address the information gaps relevant to EPA protection and restoration activities. In general, these gaps exist because coverage by each agency is not well-delineated in terms of either spatial or taxonomic domain.

National Aeronautics and Space Administration

Broad Overview of and Rationale for Ocean Acidification Work

The National Aeronautics and Space Administration (NASA) responds to the FOARAM through its role as vice-chair of the IWG-OA and by funding research that contributes to increased understanding of ocean acidification. NASA has supported targeted, approximately annual research opportunities to facilitate ocean acidification research since 2007, details of which are included in the IWG-OA's biennial reports to Congress. Funded research utilizes NASA's satellite remote sensing observations, as well as in situ observations and models, to support the FOARAM Act's objectives and NASA's mission. NASA's ocean acidification research may also facilitate operational and management responsibilities of other agencies included in the FOARAM Act, such as the requirement to develop adaptation strategies to conserve aquatic ecosystems vulnerable to the effects of ocean acidification.

To study the Earth as a whole system and understand how it is changing, NASA develops and supports a large number of Earth observing missions. These missions provide Earth science researchers with the necessary data to address key questions about global climate change. They provide global observations and data about the Earth, and are used to estimate properties of the Earth system. These data include information on the land, ocean, atmosphere, solid Earth, and cryosphere. While NASA's Earth observing satellite data may be used to understand and conduct research on – and perhaps even monitor – ocean acidification globally, it would be nearly impossible to delineate which NASA missions or data sets are used for studies to support research in ocean acidification. Continuity of key systematic and new satellite observations is critical for Earth science research and other agencies' management efforts on a local and global scale. NASA's data users in Earth sciences number in the hundreds of thousands internationally. NASA's direct contributions to ocean acidification research, however, are via the NASA-funded projects.

Specific examples of NASA-funded research include projects focused on a type of calcifying phytoplankton known as coccolithophores, as blooms of coccolithophores can be seen from space. As part of the Impacts of Climate on the Eco-Systems and Chemistry of the Arctic Pacific Environment (ICESCAPE) project field work (2009-2015), the research team working in the Beaufort and Chukchi Seas

explored the roles of these calcifiers in the ecosystem and whether these organisms are harbingers of a polar biogeochemical province in transition. The dataset collected by this project can help us understand how the biological pump, a component of ocean carbon cycling, and ocean albedo (i.e., reflectiveness to solar radiation) might change in the future under ocean acidification. It will also help discern long time-scale changes in Arctic Ocean calcifiers associated with climate change. Similar to the ICESCAPE program, NASA has funded studies on the Arctic Pacific shelves on the biogeochemical cycling of inorganic carbon and air-sea CO_2 fluxes, both of which are fundamental to understanding ocean acidification.

Ocean acidification research has also been funded by calls from NASA's Carbon Cycle Science program since approximately 2007. For example, a funded project is assessing the impact of ocean acidification on calcification in marine plankton using satellite analysis and Earth system modeling. Marine planktonic calcifiers, such as coccolithophores, foramanifera, and pteropods, are an important component of the ocean carbon system, and their role in ocean carbon cycling may be modified substantially by rising atmospheric CO_2 and climate change. The overall goal of this project is to better understand the magnitude of ocean acidification and climate change impacts on marine inorganic carbon dynamics, ocean carbon storage and atmospheric CO_2 levels over the next several decades to centuries.

The NASA annual research announcement entitled Research Opportunities in Space and Earth Sciences (ROSES) solicits basic and applied research in support of NASA's Science Mission Directorate. Within the annual ROSES omnibus solicitation from 2007 through 2012, there were approximately ten open opportunities (referred to as ROSES program elements) for institutions to propose to NASA research on ocean acidification. There were three ROSES program elements identified where peer-reviewed projects that proposed to undertake ocean acidification research were selected. For the approximately seven ROSES program elements where ocean acidification research was not supported, either the agency did not receive proposals in the topical area of ocean acidification, or the proposals the agency received in the topical area of ocean acidification were not highly peer-reviewed and therein were not recommended by the agency for support. For the ROSES program elements where proposals to conduct research in ocean acidification were selected and supported, the agency could have identified ocean acidification as a priority topic, or the proposing institutions could have identified ocean acidification as a priority topic in response to an open science competition.

NASA's Earth Science Research Program supports research activities that address the Earth system to characterize its properties on a broad range of spatial and temporal scales, understand the naturally occurring and human-induced processes that drive them, and improve capabilities for predicting Earth system's future evolution. The focus of the Earth Science Research Program is the use of spaceborne and aircraft measurements to provide information not available by other means, and data collected by it addresses ocean acidification. This program is end-to-end in its scope in that it develops observational techniques and the instrument technology needed to implement them; tests them in the laboratory and from an appropriate set of surface-, balloon-, aircraft-, and/or space-based platforms; uses the results to increase basic process knowledge; incorporates results into complex computational models that can be used to more fully characterize the present state and future evolution of the Earth system; and develops partnerships with other national and international organizations that can use the generated information in environmental forecasting and in policy, business, and management decisions.

Near-future Activities Related to Ocean Acidification (Planned within the Next 2 Years)

In FY 2014 and 2015, NASA solicited proposals for Carbon Cycle Science investigations jointly with the U.S. Departments of Agriculture and Energy and NOAA. Projects funded by NASA under this solicitation relevant to ocean acidification research will be conducted over the next three years. Some examples of

planned research include combining satellite, autonomous underwater vehicle, and ship-based measurements from the multi-decadal time series Gulf of Maine North Atlantic Time Series to model the carbon cycle in the Gulf of Maine. This project will continue the Gulf of Maine North Atlantic Time Series which is a 35-plus year, NASA-centric, field program that crosses the Gulf of Maine to collect bio-optical, hydrographical, biological, biogeochemical, and chemical (including carbon-relevant) data for use in satellite calibration/validation studies, as well as a long-term transect time series. It will also provide insight about the long-term carbon cycle changes in the Gulf of Maine and the major processes that affect the coastal ocean, including from climate-driven changes such as increased precipitation and temperature. The longer duration time series supported by this project will better resolve climatological phenomena spanning time scales of days to decades and a coupled physical/ecosystem model that can be used test hypotheses relevant to each part of the Gulf of Maine carbon cycle and the impacts of climate change.

NASA is currently funding a modeling project focused on the variability of acidification in coastal waters. This project seeks to improve understanding of processes controlling carbonate system variability in coastal areas, and to demonstrate that ocean color satellite data are poised to play an integral role in this field of research. It will provide estimates of processes affecting acidification including physical residence times, mixing, dispersion, and net local terms associated with community productivity.

NASA is also funding carbon synthesis activities, including air-sea CO_2 flux and carbon budget synthesis and modeling in the entire Gulf of Mexico. Uncertainties in coastal carbon fluxes are such that the net uptake of carbon in the coastal margins remains a poorly constrained term in global budgets. The State of the Carbon Cycle Report (Takahashi et al., 2009) indicated that the Gulf of Mexico was the single largest area that was unknown with respect to the direction of CO_2 flux (i.e., sink or source) in the entire US coastal margin. As a result, this team will undertake a data synthesis and modeling plan with goal of characterizing the carbon budget and carbon fluxes in this region.

Far-future Activities Related to Ocean Acidification (Planned within the Next 3-5 Years)

Each year, NASA develops and releases the ROSES omnibus solicitation anew. NASA revises the ROSES content, including Agency and program research priorities, as per the Agency mission in conjunction with the domestic and international research communities' and programmatic priorities. NASA seeks to build on the latest cutting edge research and state-of-the art findings in Earth Science with opportunities in the annual ROSES omnibus solicitation. NASA accepts proposals in a very wide range of topics, and will continue to work with the research community and agency partners to prioritize research topics and opportunities for collaboration.

National Institute of Standards and Technology

While the National Institute of Standards and Technology (NIST) does not have a large program specifically focused on ocean acidification, NIST provides a number of measurement and calibration capabilities that support the efforts of other agencies (e.g., NASA, NOAA) and the broader research community to monitor ocean changes, including acidification. For example, NIST provides a number of advanced satellite calibration standards, including color standards and sensor calibrations to support the Marine Optical Buoy program. Additionally, NIST, through the Hollings Marine Laboratory in Charleston, South Carolina, runs the Marine Environmental Specimen Bank, which cryogenically banks well-documented environmental specimens collected as part of other agency marine research and monitoring programs. In 2010, NIST expanded this effort through the establishment of the NIST U.S. Pacific Islands Program to help address environmental and ecological questions that are unique to the region. This program includes collaboration with NOAA; other Federal, state, local, and regional agencies; private organization; universities; and research institutes to establish a biorepository in the

region and to advance measurement capabilities for environmental health research. A major element of this effort relevant to ocean acidification is a new coral reef banking program known as the Archive of Coral Ecosystem Specimens. The new coral reef banking program will create a formal repository of calcium carbonate skeletons and tissues from corals and other reef taxa to serve as a resource for long-term monitoring and research. Localized stressors, such as impaired water quality, and global climate stressors, such as thermal stress and ocean acidification, impact elemental/isotopic signatures and biomarkers in carbonate skeletons and tissues that will be measured and archived to record past, present, and future environmental conditions and the associated organismal responses.

National Oceanic and Atmospheric Administration

Broad Overview of and Rationale for Ocean Acidification Work

Understanding ocean acidification and developing reliable projections for how ocean acidification will affect living marine resources drives NOAA's work on ocean acidification. NOAA's activities on these topics are necessary for sustainably managing living marine resources in a changing world, enabling local communities to better understand, prepare for, and adapt to changes, and informing national and international carbon assessments and mitigation discussions. NOAA's Ocean Acidification Program (OAP) was established under Section 12406 of the FOARAM Act to oversee and coordinate ocean acidification research, monitoring, and other activities consistent with the Strategic Research Plan. As part of its responsibilities, the OAP incorporates a competitive, merit-based process for awarding grants on ocean acidification research. To date, the OAP has provided grants for research projects that explore the effects of ocean acidification on ecosystems and human socioeconomics.

On-going Projects Related to Ocean Acidification

The NOAA Ocean Acidification Program supports activities across NOAA and in close partnership with academic institutions. The NOAA OAP Director also chairs the IWG-OA. Current ocean acidification activities funded through NOAA's OAP office require considerable leverage from the participating NOAA labs and science centers. The OAP's trans-disciplinary portfolio of research and monitoring includes: the establishment and maintenance of a long-term ocean acidification monitoring network; experimental species response studies; biogeochemical, ecological, and socioeconomic modeling, including projections of ocean acidification and its impacts; and fostering the development of adaptation strategies for impacted stakeholders. The ocean acidification monitoring network is currently comprised of regional geochemical/ecological surveys, fixed time-series stations, and autonomous underway observations. To date, these research and monitoring efforts have been primarily focused on documenting the complex dynamics of carbonate chemistry within the United States coastal margins and coral reef ecosystems but also include a limited number of international long-term, open-ocean sites. Experimental studies supported by the OAP investigate how species' survival, growth, and physiology are impacted by ocean acidification, and explore how coastal and marine species may respond to ocean acidification. NOAA researchers use data from these studies to improve understanding of how aquaculture, wild fisheries, and food webs may change in response to ocean acidification. NOAA's National Centers for Environmental Information serves as the data management focal point for the diverse range of data sets generated by the OAP through its newly developed Ocean Acidification Data Stewardship project.

Near-future Activities Related to Ocean Acidification (Planned within the Next 2 Years)

NOAA near-future ocean acidification activities are categorized as those that could occur under OAP funding at the current level and new activities that could occur under higher funding levels. At higher funding levels, NOAA will improve understanding of progression of ocean acidification in coastal and

marine environments and the impacts of ocean acidification on marine resources and will develop tools and adaptive strategies for resource managers, affected industries, and stakeholders.

Existing Activities that will Continue under the Current Funding Level

Research to understand the implications of ocean acidification – NOAA supports five experimental facilities to study the response of species to ocean acidification (Highlands, New Jersey; Kodiak, Alaska; Mukilteo and Manchester, Washington; Newport, Oregon). Research at these facilities targets a range of shellfish, finfish, zooplankton, and phytoplankton species, all of which are economically or ecologically important. NOAA also engages in vulnerability analyses of select regions to ocean acidification and supports meta-analysis work that builds understanding of patterns in species-response to ocean acidification.

Monitoring of ocean chemistry and biological effects – 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. NOAA monitors the status and trends of United States coral reef ecosystems, assessing parameters related to both carbonate chemistry and ecology at one site in the Pacific Ocean basin and two in the Atlantic Ocean basin. NOAA has also added carbon chemistry measurements to time series measurements of zooplankton in both the north Pacific and the north Atlantic Oceans.

Modeling to predict changes in the ocean carbon cycle and response of marine ecosystems and organisms – NOAA supports a number of regional modeling exercises on ocean carbon chemistry in the Greater Caribbean region and the California Current. NOAA also models how ocean acidification may affect coastal and marine ecosystems and living marine resources in the north Pacific and north Atlantic Oceans and compares the potential impacts of ocean acidification to the potential impacts of climate change and human uses of the marine environment. Ongoing research in NOAA uses advanced global earth system models to explore the global and regional historical and projected future expression of ocean acidification, incorporating emerging scientific understanding of the mechanisms, impacts, and feedbacks of ocean acidification in ocean biogeochemistry and marine ecosystems. Quantifying past and future ocean carbon uptake associated with ocean acidification is an important part of NOAA's efforts to understand and project future climate, information that informs overall environmental stewardship.

Technology development and quality assurance – NOAA's ocean acidification-related technology activities focus on the development of observing gliders and a dissolved inorganic carbon sensor and on methods for determining variation in the progression of ocean acidification and ecosystem response in coral reefs. NOAA is also investing in development of easy-to-use, low-cost, shore-based monitoring systems that are being tested in partnership with the oyster industry on the United States West and East Coasts and Alaska as systems useful for allowing industry to adapt to ocean acidification. Additionally, NOAA focuses on development of laboratory systems to study species response to ocean acidification and alternatives for optimizing carbon chemistry measurements in these systems.

Assessment of socioeconomic impacts and adaptive strategies to conserve marine organisms and marine ecosystems – NOAA's ocean acidification-related socio-economic work focuses on the impacts of ocean acidification on fisheries and fishery-based economies. These projects use food web or population models (sometimes linked to economic models) to explore the potential changes in abundance, productivity, and distribution of living marine resources; alternatives for managing living marine

resources under acidified conditions; and potential impacts of ocean acidification on human socio-economic systems.

Education, outreach, and engagement strategy on ocean acidification – NOAA released an Ocean Acidification Education Implementation Plan in September 2014. To fulfill goal 1 of the Plan, NOAA is conducting a national needs assessment of ocean acidification education and communication providers to determine effective messages and resources, and identify challenges, lessons learned, gaps, and needs. NOAA National Marine Sanctuaries and Ocean Acidification Program also co-host a national webinar series called Sharing Ocean Acidification Resources for Communicators and Educators, which provides tools to formal and informal educators and stakeholders across the country to promote a more integrated and effective ocean acidification education community. NOAA works with a number of experiential learning facilities, such as the Seattle Aquarium in Washington and the Exploratorium in California, to educate the public about ocean acidification and its impacts, and has hosted workshops to facilitate these educational efforts. NOAA staff participates in efforts of local, state, tribal, 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). NOAA is heavily involved in emerging regional ocean acidification collaboratives or networks such as the California Current Acidification Network, Northeast Coastal Acidification Network, and Southeast Ocean and Coastal Acidification Network. NOAA develops a variety of educational and outreach resources, including outreach kits with lesson plans and websites with summaries and explanations of ocean acidification, ocean acidification-related science efforts, and potential impacts on living marine resources internationally, nationally, and regionally. NOAA also trains many undergraduate students in ocean acidification research methodologies through the NOAA Hollings Scholar Program and other internship programs.

Data management and synthesis – NOAA provides dedicated, long-term, archival online data discovery and access for a diverse range of OA data from multi-disciplinary field observations, laboratory experiments, and modeling exercises for both NOAA and interagency OA data partners. NOAA developed a metadata content standard that is capable of accommodating OA data from moorings, research cruises, models, and laboratory or mesocosm studies on species' response to OA. With the metadata template, NOAA has established metadata display formats that can best serve information about OA data sets to data users. An OA data search portal was launched in 2015 to allow users to discover and access OA data sets with ease. NOAA is also investing in development of an online OA data submission interface that will make it easier for users to submit OA data. NOAA supports OA data management through the development of global synthesis products. Over the last year, NOAA authors published their first synthesis effort on the global distribution of aragonite saturation state. A similar effort on the global pH distribution is under development.

New Activities under Higher Funding Levels

Enhanced U.S. coastal ocean acidification observing system – Improved understanding of coastal ocean acidification processes requires strategic coordination of observing infrastructure and chemical, physical, and ecological process monitoring. Development of regional observing networks (e.g., Puget Sound, Gulf of Maine, select Pacific islands, Chesapeake Bay, United States Southeast Coast including Caribbean coral reefs, and Gulf of Mexico including the Flower Garden Banks) would be informed through competitive projects designed to optimize observing assets with respect to improved skill and cost efficiency. These studies would guide the development of an integrated enterprise of multi-platform observing and coupled ecological-process monitoring necessary to track carbon cycle dynamics and associated ecosystem response.

National Coral Reef Monitoring Program – The NOAA Coral Reef Conservation Program has initiated implementation of the National Coral Reef Monitoring Program (NCRMP), which will provide a consistent flow of information about the status and trends of: environmental conditions at United States coral reefs, living coral reef resources, and the people and processes that interact with coral reef ecosystems. The NCRMP coordinates a NOAA-wide, long-term approach to monitor coral reef ecosystems, including a partnership with NOAA's OAP to support carbonate chemistry measurements in coral reef areas. Monitoring of the ecological responses of coral reef ecosystems to ocean acidification (e.g., changes to coral reef carbonate budgets, coral growth rates, bioerosion, and framework integrity) are made possible through OAP funding of targeted benthic community characterization, fine-scale rugosity assessments (e.g., how wrinkled structures are), indices of biodiversity (including that of cryptic species), coral coring, and crustose coralline algae recruitment and accretion rate monitoring. The NCRMP calls for establishing 6 sentinel sites across the United States coral reef ecosystems in the Atlantic and Pacific Oceans. Three such sites have been established (Puerto Rico, Florida, and Hawaii), and in coming years, at least two additional sites would be established, including the Flower Garden Banks National Marine Sanctuary.

Understanding species and ecosystem response to ocean acidification – To address information gaps on the impact of ocean acidification on species of high economic vulnerability, the OAP would direct funding through regional requests for proposals, likely through regional Sea Grant programs. New funding would be directed towards enhancing the NOAA experimental systems used to study species response to ocean acidification with new control and chemistry monitoring technologies. The OAP would also consider expanding the types of species response metrics that can be measured during experiments (e.g., genomics, neurophysiology).

Far-future Activities Related to Ocean Acidification (Planned within the Next 3-5 Years)

NOAA far-future ocean acidification activities are categorized as those that could occur under OAP funding at the current level and new activities that could occur under higher funding levels.

Existing Activities that will Continue under the Current Funding Level

Assure continuity of core existing and sustained ocean acidification activities – The OAP's leveraging of other NOAA funds to support its sustained activities leaves the OAP dependent on the funding for and strategic direction of the participating NOAA labs and science centers. Because the OAP aims to establish long-term time-series related to ocean acidification, the OAP will work closely with participating NOAA labs and science centers to maintain leverage support, which includes dedicated personnel to carry-out ocean acidification-related projects.

Enhance existing ocean acidification observational and experimental technologies – The OAP will adopt new but demonstrated observing technologies to improve the quality of ocean acidification data collected and reduce costs.

Foster integration of biological studies and geochemical monitoring – The OAP supports a diverse portfolio of ocean acidification activities ranging from direct geochemical observations at sea to manipulative controlled experiments in the laboratory. The OAP will foster the integration of these interdisciplinary efforts to improve understanding of the progression and consequences of ocean acidification. Through NCRMP monitoring and development of the Global Ocean Acidification Observing Network strategy, the OAP already is working to tightly link geochemical observations with ecological response monitoring. Increasingly, the OAP will work to define gaps in ocean acidification observing requirements defined by ocean acidification species response studies and conversely assure that geochemical data inform ocean acidification biological response studies.

Ocean acidification capacity building – The OAP will strengthen efforts to foster international, national, tribal, regional, state, and local engagement on ocean acidification, such as the California Current Acidification Network, Northeast Coast Acidification Network, Global Ocean Acidification Observing Network, and Ocean Acidification International Coordination Center. A key part of strengthening engagement efforts is funding capacity-building projects (e.g., workshops, journal special issues, and website development).

New Activities under Higher Funding Levels

Regional coastal ocean acidification models – NOAA would advance the development of coastal ocean acidification models that are regionally optimized for characterizing carbonate chemistry dynamics. To do so, OAP would develop competitive Federal funding opportunities to upgrade existing models of carbon chemistry. These models would provide information relevant to coastal management, such as nutrient or local atmospheric inputs into coastal systems and how these inputs affect local acidification at a range of spatial and temporal scales. The models would rely heavily on data collected by the enhanced coastal observing system (described above) for validation.

Regional ocean acidification synthesis products for outreach – Data products developed for specific user types (e.g., resource managers and shellfish hatchery operators) would integrate ocean acidification data to clearly communicate how ocean acidification is affecting coastal resources, ecosystems, and human communities. Products would include: 1) near real-time maps of ocean chemistry for regions identified as high priority for living marine resources and communities dependent on these resources; 2) short- and long-term forecasts of ocean chemistry (e.g., early warnings for shellfish growers); and 3) visualizations pertinent to the coastal resources (e.g., fisheries, protected habitats, and coral reefs) potentially threatened by ocean acidification. These products will be developed in close coordination with regional stakeholders and will be informed by the OAP's outreach and engagement strategies (described above).

Gaps in Portfolio of Activities Related to Ocean Acidification, Compared to Priorities Outlined in the Strategic Research Plan

Free ocean CO_2 experiments and field mesocosm facilities – Free ocean CO_2 experiments or field mesocosm facilities could be developed and used as part of OAP's competitive funding opportunities, as long as the projects making use of them demonstrate National Environmental Policy Act compliance and the proposed research offers valuable and necessary insights that support NOAA's mission and promotes the research goals outlined within the Strategic Research Plan.

Carbonate dissolution and bioerosion – Bioerosion rates are likely to change under ocean acidification due to changes in seawater chemistry and biological communities. Currently, NOAA monitors bioerosion rates in coral reefs, though it would be appropriate to monitor bioerosion in other ecosystems where bioerosion is an important contributor to the carbonate mass balance of the system, such as oyster reefs. While NOAA would be eager to adopt monitoring techniques on carbonate dissolution and bioerosion as part of its portfolio, the methods for doing so remain crude and poorly developed.

Observations in non-US, ocean-acidification hot spots – NOAA currently has limited resources to invest on monitoring outside of United States territorial or coastal waters. The open ocean is largely unmonitored for ocean acidification, including some global 'hot spots', such as the Arctic, Southern, and Indian Oceans. Limited ocean observations of these areas are provided through NOAA Climate Program Office investments and the efforts of other nations.

Biogeochemical proxies – Extending contemporary time-series obtained through NOAA observing efforts back through time by means of reliable proxies is a fruitful avenue of research. While NOAA's National Climate Data Center currently archives a number of paleoclimatology datasets, including coral cores and an extensive calcium carbonate housing data from 295 marine sediment cores, these datasets have not been widely applied to ocean acidification. Furthermore, the sustained ocean acidification monitoring time-series provide a valuable opportunity for researchers to develop calibration and validation studies of paleo-ecological and geochemical proxy techniques.

Untapped Opportunities Inside of Agency for Projects Related to Ocean Acidification

The NOAA OAP actively seeks out and promotes partnerships across the agency to both leverage resources and solicit diverse input to prioritization exercises on ocean acidification research. This intra-agency outreach allows the OAP to better meet NOAA's mission and align NOAA ocean acidification activities with FOARAM Act requirements. Through NOAA's internal Ocean Acidification Working Group, the OAP receives regular updates from across the NOAA organization on on-going and planned efforts relevant to ocean acidification. The OAP jointly funds a number of ocean acidification-related projects with other NOAA programs, including the Climate Program Office, NOAA Integrated Ocean Observing System, Coral Reef Conservation Program, National Centers for Coastal Ocean Science, and NOAA Cooperative Institutes. Additionally, all resources directed to fund ocean acidification activities inside of NOAA are significantly leveraged by NOAA laboratories and science centers. In future years, the OAP will consider approaches to significantly bolster these existing partnerships within the agency, especially with the National Marine Fisheries Service, and expand the portfolio of ocean acidification-related partnerships to include the National Sea Grant College Program and the Office of Ocean Exploration and Research. The OAP will also seek out coordination of ocean acidification monitoring efforts to include the merging of *in situ* observations with existing satellite observations (e.g., sea surface salinity, sea surface temperature, ocean color).

Ideas for How Agency Could Work with other Federal Agencies on Activities Related to Ocean Acidification

Optimization of existing/planned fleet schedules – While NOAA works internally to coordinate and leverage fleet activities and capitalize on existing sustained fleet survey efforts, coordinating some of NOAA's fleet activities with those outside of NOAA could better serve the ocean acidification-related needs of multiple agencies. For example, NOAA is working to establish coastal ocean acidification surveys along all United States coastal and coral reef systems that occur in each region every three years. The current suite of geochemical observations could be extended to include ocean color or non-carbonate chemical measures if partnering agencies were able to contribute to the science cost of these missions. Conversely, with proper coordination, NOAA could piggy-back on other agencies' platforms to carry out or supplement NOAA survey requirements relevant to ocean acidification.

Coordinate monitoring efforts – One of NOAA's strengths is its ability to conduct sustained monitoring of ocean conditions and living marine resources. NOAA has established a sustained network for monitoring the progression and extent of ocean acidification and is starting to monitor for the impacts of ocean acidification on some species in certain locations (e.g., pteropods along United States West Coast). NOAA's monitoring network, however, is limited in its spatial and temporal scope and capacity for ecological monitoring beyond coral reefs. NOAA welcomes coordination with other Federal agencies on the development of a monitoring system for ocean acidification. Such coordination could leverage the ocean acidification monitoring activities of all agencies and aid in the development of a comprehensive and efficient monitoring network for ocean acidification and its impacts.

Joint funding calls – One important way that Federal agencies can work together on ocean acidification is joint funding calls. Joint funding calls permit two or more agencies to design requests for proposals that address the needs of all agencies involved, and provide a mechanism to leverage Federal funding. The National Oceanographic Partnership Program provides a valuable mechanism through which the IWG-OA can foster coordinated Federal funding opportunities targeting mutually agreed upon areas of ocean acidification research.

Areas Where Agency Mission is Being Inhibited by Knowledge Gaps that Fall out of Agency's Purview

These areas are primarily addressed in the below sections. Of special note, however, may be refining the delineation between various agencies roles and responsibility specific to coastal acidification.

Response of non-calcifying species to ocean acidification – NOAA is advancing and will continue to advance research to quantify the physiological, developmental, and genetic responses of non-calcifying species to ocean acidification. Most of this research currently focuses on early life stages of finfish. While some research has been conducted at the NOAA Northeast Fisheries Science Center on phytoplankton and the Northwest Fisheries Science Center on squid, no research is planned for examining the response of bacteria, fungi, macroalgae, seagrasses, tunicates, or jellies to ocean acidification. Research projects to examine the response of these organisms could be solicited and supported through a competitive proposal and review process, and potentially including a focus on commercially and culturally important species.

Marine calcifying processes – While NOAA is actively engaged in quantifying changes in physiological, developmental, and genetic processes governing marine calcification, a fully mechanistic understanding of biocalcification largely remains the research purview of NSF. As such, NOAA would strongly encourage NSF to remain supportive of high-quality research proposals which advance understanding of this topic.

Non-carbonate geochemical cycles – While many of NOAA's ocean observing assets currently deployed and envisioned in future years could provide valuable platforms for advancing understanding of the impacts of ocean acidification to the broader geochemical cycle, NOAA does not have explicit plans to develop its ocean observing capacities much beyond carbonate chemistry. NOAA would welcome interagency partnerships to leverage ocean observing systems with capabilities to examine how ocean acidification may alter the nitrogen, iron, phosphorous, silicate, oxygen, and sulfur cycles, particularly in cases where changes in the cycles could impact marine resources.

Closing uncertainties related to the carbon chemistry system and biomineral thermodynamics/kinetics – Foundational work necessary for calculating ocean carbon chemistry parameters and understanding the kinetics of calcium carbonate produced by marine organisms remains undone. For example, the equations used to characterize the carbon chemistry of low salinity waters with high biological activity need to be improved for us to properly study and understand acidification in coastal regions. This fundamental science largely falls outside of the purview of NOAA's mission, and it is critical that other agencies better suited towards addressing these critical gaps pick up the charge.

National Park Service

Broad Overview of and Rationale for Ocean Acidification Work

The National Park Service (NPS) in the Department of the Interior manages all United States national parks, many national monuments, and other conservation and historical properties. The National Park Service Organic Act of 1916 provides the NPS with a clear mission statement: "To conserve the scenery and the natural and historic objects and wild life therein to provide for the enjoyment of the same in a

manner and by such means as will leave them unimpaired for the enjoyment of future generations." The NPS is entrusted with conserving 79 ocean parks, including over 10,000 shoreline miles and over 2 million water acres, including many tidally influenced estuaries. Marine parks are distributed around the United States from tropical to polar environments, including Alaska, the Pacific coast, the South Pacific islands, the Gulf of Mexico, the Atlantic coast, and the Caribbean. These parks house a wide variety of marine life and span a diverse array of habitats including coral reefs, kelp forests, seagrass beds, rocky and sandy shorelines, and glaciated fjords. Ocean acidification will likely influence all United States marine parks. Understanding the effects of ocean acidification is necessary to inform actions to conserve natural resources within these parks. Maintaining resilient marine ecosystems through restoration and species protection are positive actions the NPS can take to combat the effects of ocean acidification. The NPS represents a unique spatial network of marine habitats and natural resources that are ideal for ocean acidification research, monitoring, and public outreach. Such activities are central to the mission of the National Park Service to conserve these special areas.

On-going Projects Related to Ocean Acidification

The NPS is contributing to knowledge of ocean acidification through research, monitoring, and outreach activities:

In Olympic National Park in Washington, continuously operating, multi-parameter sensors and periodic, discrete seawater samples have been used since 2010 to continuously monitor seawater carbonate chemistry parameters and other associated physical and chemical parameters. The park is currently upgrading its continuous pH monitoring equipment, and is expanding its water chemistry monitoring into the Salish Sea at San Juan National Historical Park. This monitoring program is being conducted in collaboration with the Washington State Ocean Acidification Center at the University of Washington and the University of California, Santa Barbara.

National Parks near the Gulf of Maine (Acadia National Park, Saint Croix Island International Historic Site, Roosevelt Campobello International Park) are experiencing changes in environmental conditions, and park managers are concerned that ocean acidification along with ocean temperature change will create severe shifts in the ecosystems conserved within park boundaries. In Acadia National Park, the National Park Service, Schoodic Institute, Cedar Crest College, and Earthwatch Institute are working together on projects investigating the impacts of ocean acidification on biodiversity, invertebrate shell strength, and intertidal predator-prey interactions. The projects use a "citizen science" approach to meet the park's science needs and to improve participants' science literacy and understanding of the challenges posed by ocean acidification. High school students and other volunteers come to the park's Research Learning Center for a week or more to collect data in the intertidal zone and perform lab experiments investigating snail-crab interactions in tanks with different pH conditions. Dr. John Cigliano, a professor at Cedar Crest College, is directing these projects and analyzing the data. The NPS anticipate that this partnership will continue as a long-term study into the impacts of ocean acidification on the Acadia National Park intertidal ecosystem.

At Gateway National Recreation Area, researchers are investigating acidification, hypoxia, and algal blooms as barriers to current and future ecosystem restoration and climate change resilience in Jamaica Bay, New York. The goal of this study is to quantify the temporal and spatial dynamics of hypoxia, acidification, calcium carbonate saturation state, and bivalve growth in Jamaica Bay. The study will examine the vulnerabilities of the bivalves that may be targeted for restoration in Jamaica Bay to various environmental conditions and will link the existing conditions to dominant primary producers and nutrient loading in the system. The findings will provide information to refine and improve future ecosystem restoration efforts. This project will further identify the regions of Jamaica Bay likely to be most and least resilient to future climate-change-intensified hypoxia, acidification, and warming.

Near-future Activities Related to Ocean Acidification (Planned within the next 2 Years)

Currently, the NPS does not have a service-wide ocean acidification monitoring network in place. Within the next two years, the NPS Natural Resource Stewardship and Science Directorate will collaborate with other Federal partners to increase research and monitoring in the national parks, national monuments, and other conservation and historical properties parks managed by NPS and will conduct outreach on ocean acidification to NPS staff and visitors. The NPS will also work to develop ocean acidification monitoring protocols for parks, and supplement data collection by the NPS Inventory and Monitoring Program.

In Alaska, which is home to a number of National Parks, a regional conceptual model will be developed to inform NPS managers of the potential impacts of ocean acidification on the state's many marine park resources. This model will identify linkages between the physical, chemical, and biological components of Alaska's marine National Parks and how ocean acidification affects or is affected by these component systems. In addition, the NPS has funded a project at Glacier Bay National Park that will lay the foundation for tying ocean acidification to biological impacts in Alaska's National Parks. Understanding how ocean acidification impacts the base of the food web in Alaska's coastal marine systems increases understanding of how ocean acidification is already affecting and will affect parks' ecosystems and resources. This knowledge is essential to park management in developing a strategic approach to addressing and communicating the potential implications of ocean acidification.

In the Pacific Northwest, continuous ocean acidification monitoring will be enhanced on the outer Pacific coast (Olympic National Park) and in the Salish Sea (San Juan Island National Historical Park). This enhanced monitoring will include continuous pH (using new SeaFET technology), salinity, temperature, and dissolved oxygen, along with periodic sampling of nutrients, total alkalinity, and dissolved inorganic carbon. This monitoring is being incorporated into the North Coast and Cascades Network of the NPS Inventory and Monitoring Program. Additionally, this work will be part of the PhD dissertation work for Jonathan Jones, an NPS George Melendez Wright Young Leader in Climate Change Fellow at the University of California Santa Barbara. A component of this work will include examining potential changes in intertidal rocky organism community structure as a result of ocean acidification.

Far-future Activities Related to Ocean Acidification (Planned within the Next 3-5 Years)

In the next 3 to 5 years, the NPS will promote the development of conceptual models of ocean acidification effects on a regional/local scale to help identify and prioritize future ocean acidification work, including research and monitoring. With adequate resources, the NPS will investigate the potential effects of ocean acidification on food webs and terrestrial resources that are dependent on marine resources (e.g., bears and wolves that feed on fish). This research will illustrate the cascading effects of changes in the marine ecosystem on the terrestrial food web.

With adequate resources, the NPS will create a 4-year term position in the Ocean and Coastal Branch of the Water Resources Division that will be dedicated to education and research for ocean acidification. During this time-frame the NPS will also work towards developing a national ocean acidification monitoring program, active resource management training, and public outreach and education.

Ideas for How Agency Could Work with Other Federal Agencies on Activities Related to Ocean Acidification

National Parks contain prime examples of natural resources and processes, including significant genetic resources, that have value for long-term observational studies or as control areas for research taking place outside the parks. National Parks often cooperate with other Federal agencies in identifying park sites for planning, research, and educational activities related to ocean acidification and climate change.

The NPS willingly cooperates with many Federal agencies that are collecting data related to ocean acidification, including the United States Geological Survey (USGS) and NOAA. The NPS continues to support the current and future activities related to ocean acidification that result from partnerships and collaborations with other Federal, tribal, state, and academic institutions. The NPS is willing to improve data sharing and standardized methodology for collecting data relevant to ocean acidification monitoring.

Areas Where Agency Mission is Being Inhibited by Knowledge Gaps that Fall out of Agency's Purview

The NPS would benefit from an improved understanding of climate change and ocean acidification for the identification of impacts on natural and cultural resources within National Parks. In particular, the nature of ocean circulation patterns, changes in freshwater inputs, and nutrient enrichment of marine waters near National Parks are often key information gaps. This knowledge would be useful for formulating possible mitigation and minimization measures for the NPS to implement service wide.

National Science Foundation

Agency Mission

The National Science Foundation (NSF) is an independent Federal agency responsible for advancing science, engineering, and science and engineering education in the United States. The agency is the funding source for approximately 24 percent of all federally supported fundamental research conducted by United States colleges and universities. Through a competitive, transparent, and in-depth merit review process, NSF seeks and supports the best ideas, tools, facilities, and people to expand the frontiers of knowledge.

NSF Ocean Acidification Project Support

NSF supports basic research concerning the nature, extent, and impact of ocean acidification on oceanic environments in the past, present, and future. NSF is committed to research that seeks to understand: 1) the chemistry and physical chemistry of ocean acidification; 2) how ocean acidification interacts with processes at the organismal level; and 3) how the Earth system history informs understanding of the effects of ocean acidification on the ocean now and in the future.

Beginning in FY 2010, NSF initiated targeted solicitations for ocean acidification research as part of the NSF-wide Climate Research Investments and Science, Engineering and Education for Sustainability activities. During the five years these targeted solicitations were active, NSF invested over $50M in support of basic research on ocean acidification. No other targeted ocean acidification solicitations are expected under these NSF-wide activities.

In FY 2016 and beyond, NSF may support ocean acidification research through programs that managed and participated in the Climate Research Investments and Science, Engineering and Education for Sustainability activities (Making Waves June 2014, "Whither Ocean Acidification"). Programs that participated in the NSF-wide ocean acidification solicitations include:

- Directorate for Geosciences;
    - Division of Ocean Sciences;
        - Biological Oceanography Program;
        - Marine Geology & Geophysics Program;
        - Chemical Oceanography Program;
    - Division of Polar Programs;
        - Antarctic Organisms and Ecosystems;

        - Arctic Natural Sciences;
- Directorate for Biological Sciences;
    - Division of Environmental Biology – Evolutionary Ecology Program;
    - Division of Integrative Organismal Systems – Integrated Ecological Physiology Program; and
    - Division of Cellular Biosciences – Cellular Dynamics and Function Cluster.

It is important that researchers interested in submitting an ocean acidification-related proposal to NSF contact the most relevant program(s) prior to preparing the proposal to determine whether the subject matter is appropriate for submission to that particular program.

NSF Support for Community Building Activities

NSF and NASA provide support for the Ocean Carbon and Biogeochemistry Program Office, which includes an Ocean Acidification Subcommittee to promote, plan, and coordinate collaborative, multidisciplinary research opportunities related to ocean acidification. This subcommittee has organized and staged national ocean acidification principal investigator workshops in 2011, 2013, and 2015, and held an Ocean Acidification Short Course in 2009 at the Woods Hole Oceanographic Institution.

NSF Activities that Contribute to Understanding Ocean Acidification

NSF supports a number of activities that while not directly focused on ocean acidification contribute significantly to understanding ocean acidification and other climate-related changes in the marine environment. Many of these activities are ongoing efforts that are evaluated on a regular basis but are expected to receive support for an extended period. Ongoing efforts include work at ocean time series stations and Long-Term Ecological Research (LTER) sites. NSF created the LTER Network in 1980 to conduct research on ecological issues that can last decades and span extensive geographical areas. The following ocean time series stations and coastal LTER sites conduct or have conducted ocean acidification-related research:

- Hawaii Ocean Time-Series;
- Bermuda Atlantic Time-Series;
- Santa Barbara Coastal LTER;
- Georgia Coastal Ecosystems LTER;
- California Current Ecosystem LTER;
- Plum Island Ecosystems LTER;
- Palmer Antarctic LTER; and
- Moorea Coral Reef LTER.

Components of the NSF Ocean Observatories Initiative are operational and are producing environmental data to support research efforts, as well as providing ocean data to a wide range of users.

The NSF-supported Biological and Chemical Oceanography Data Management Office works with researchers to provide data online from projects funded by the NSF Biological and Chemical Oceanography Programs in the Division of Ocean Sciences, and the Antarctic Organisms and Ecosystems Program in the Division of Polar Programs. The Biological and Chemical Oceanography Data Management Office has managed the data sharing and archiving for all projects funded by targeted ocean acidification programs at NSF.

NSF Support for Technology, Infrastructure, Equipment, and Research Platforms

The following NSF programs provide funding to researchers to support technology, infrastructure, equipment, and research platforms that may be relevant to ocean acidification research:

- The Oceanographic Technology and Interdisciplinary Coordination Program in the Division of Ocean Sciences supports a broad range of research and technology development activities;
- Facilities development and improvement at marine laboratories may be supported by Improvements in Facilities, Communications, and Equipment at Biological Field Stations and Marine Laboratories, an NSF crosscutting activity led by the Division of Biological Infrastructure and the Division of Ocean Sciences;
- The Major Research Instrumentation Program serves to increase access to shared scientific and engineering instruments for research and research training in United States institutions of higher education and not-for-profit museums, science centers, and scientific and engineering research organizations; and
- Oceanographic facilities and equipment are supported by the Integrative Programs Section of the Division of Ocean Sciences Division.

United States Department of Agriculture

Broad Overview of and Rationale for Ocean Acidification Work

Although the United States Department of Agriculture (USDA) has few programs or projects that directly address ocean acidification, USDA, in its partnerships with other Federal agencies as a member of the National Ocean Council, supports continuing efforts that address recommendations made by the National Policy for the Stewardship of the Ocean, Our Coasts, and the Great Lakes Task Force. By promoting and implementing sustainable agricultural programs and practices on land and sustainable aquaculture practices in freshwater and saltwater environments, USDA programs will improve the health of the ocean, coasts, and Great Lakes as well as provide jobs important in the revitalization of our rural and coastal communities.

Water connects farms across the United States to coastal communities and the ocean. USDA conducts and funds research, technology transfer, and extension education programs that address issues related to climate change, nutrient runoff, carbon sequestration, marine and freshwater aquaculture, and atmospheric deposition of nitrogen and sulfur compounds. These programs directly or indirectly address ocean acidification and improve resilience to ocean acidification by helping to invigorate coastal economies, strengthen national food security, and improve the health of the atmosphere, water resources, and ocean.

USDA's research, technology transfer, extension, outreach, and education programs aimed at the food production industry address issues related to ocean acidification, climate change, water quality, and agriculture and aquaculture production methods. USDA has several programs aimed at the reduction of nutrients going into United States waterways and the atmosphere and eventually ending up in the ocean. Nutrient runoff provides essential nutrients effecting primary productivity in estuarine, ocean, and Great Lakes ecosystems. Excess nutrients produce zones in the ocean that are both hypoxic and acidified, such as those seen in the Gulf of Mexico. USDA also has programs that focus on reducing emissions of greenhouse gasses by the production of agriculture-based biofuels from woody biomass and algae. These programs reduce reliance upon fossil fuels that would otherwise increase atmospheric CO_2 and other indirect effects on ocean acidification. USDA will continue its involvement in strategic partnerships with a variety of stakeholders that will address and support programs for reducing nutrient and sediment loads, the adoption of conservation efforts on public and private lands, and monitoring programs that will determine and evaluate the efficacy of these programs to reduce nutrients loads in United States waterways and greenhouse gases in the atmosphere.

On-going Projects Related to Ocean Acidification

Many agencies within USDA fund programs and conduct projects that do not directly target ocean acidification, but help reduce its primary causes. These programs and projects are implemented primarily by farmers in the United States and include air and water quality programs and other soil- and water-conservation efforts.

USDA has major programs related to emissions of the atmospheric gases that cause to ocean acidification (carbon dioxide, nitrous oxides, sulfur oxides). The USDA's National Institute of Food and Agriculture's Air Quality Program focuses on the reduction of greenhouse gas emissions. The Water Program is aimed at the reduction of nutrients going into the Nation's waterways. Other farm-management programs can increase carbon sequestration in agricultural and forest production systems and aid in the preparation of United States agriculture and forests to adapt to variable climates. The USDA Agricultural Research Service has an in-house soil and air research program that works to develop tools and improved management in order to increase soil conservation and reduce runoff and leaching. Effort through this program reduces impact on ground and surface waters and helps reduce atmospheric and land-based deposition of CO_2 and nitrous oxides into the oceans. Efforts such as the Long Term Agroecosystem Research project of the USDA Agricultural Research Service are seeking to develop new approaches to agricultural production that minimize impacts in the region and downstream.

USDA also funds and implements aquaculture-related research, education for students and practitioners, and technology transfer programs. Within these programs, USDA has funded projects on the effects of reduced pH on sea urchin larvae and adults and the development of emerging genomics tools (custom microarrays and quantitative polymerase chain reaction) to assess whether sea urchins can tolerate and thrive under the environmental conditions expected with climate change and ocean acidification. USDA has also funded research on the effects of climate change and ocean acidification on diseases impacting the oyster aquaculture industry. This research includes studies of the diseases caused by the parasite *Haplosporidium nelsoni* on the East coast of the United States and the bacterium *Vibrio tubiashii* on the West coast of the United States. USDA also conducts genetics and genomics research on commercially important shellfish species and develops improved commercial lines of oysters that are resistant to changing environmental conditions, such as reduced pH resulting from ocean acidification, and diseases.

USDA is involved in strategic interagency partnerships for monitoring, modeling, and assessment of water quality in priority watersheds such as the Mississippi River Basin Healthy Watersheds Initiative, the Great Lakes Restoration Initiative, and the Chesapeake Bay Watershed Initiative. The purpose of these partnerships is to better evaluate the efficacy of land treatment practices for nutrient and sediment reduction.

Near-future Activities Related to Ocean Acidification (Planned within the Next 2 Years)

USDA will continue to direct research, education, and extension funding and programs that address ocean acidification in the broader context. Addressing carbon dioxide emissions is included in the USDA climate change portfolio, and the many programs focused on this topical area will continue. USDA programs aimed at reducing nutrient runoff into United States waterways will also continue.

Untapped Opportunities Inside of Agency for Projects Related to Ocean Acidification

In the past, USDA has few funded projects that specifically address ocean acidification. Most of these projects were research on the effects of lowered pH on important commercial aquaculture species, including bivalve shellfish, echinoderms (sea urchins), larval marine finfish, and shrimp. The commercial

aquaculture industry is becoming increasingly concerned about changes in the habitat of these species, including changes in water chemistry brought about by ocean acidification, and the impacts of these changes on their industry. USDA could consider projects that benefit the commercial aquaculture industry by addressing these changes in habitat.

Ideas for How Agency Could Work with Other Federal Agencies on Activities Related to Ocean Acidification

USDA and the US aquaculture industry have a significant stake in the ocean acidification issue. The IWG-OA and the IWG-A will work together on issues of common concern relating to ocean acidification.

USDA-funded Cooperative Extension natural resource and aquaculture field agents work closely with Sea Grant Marine Advisory Service partners to provide science-based information on climate change and ocean acidification and their effects to the aquaculture industry and to coastal communities in the United States. Workshops have been conducted in Maine, Delaware, Louisiana, and other United States coastal and Great Lakes communities to educate residents about sea level rise, ocean acidification, and other effects of climate change on the ocean.

Through workshops, on-farm extension programs, and the eXtension initiative available on the Internet, USDA shares information on the results of research on new technologies that reduce greenhouse gas emissions and nutrient runoff and on programs to reduce atmospheric CO_2 and runoff of nutrients into United States waterways.

United States Department of State

Broad Overview of and Rationale for Ocean Acidification Work

The Department of State, through the Bureau of Oceans and International Environmental and Scientific Affairs (OES), engages with the world to build a healthier planet, a goal essential to the vitality and security of our Nation – and other nations – today and into the future. The Department of State, through OES, champions the role of science, technology, and innovation in foreign policy as an integral element of strengthening relationships, informing policy decisions, solving problems, and stimulating economic growth. OES issues, including ocean acidification and other climate-related impacts on the ocean, are part of the fabric of United States bilateral, regional, and multilateral relationships and typically represent positive aspects for engagement within the broad foundation that defines these relationships. Engaging on ocean acidification and other scientific issues provides the United States with opportunities to advance stability and economic growth globally.

On-going Projects Related to Ocean Acidification

Secretary of State John Kerry will host the third Our Ocean conference in Washington, D.C., September 15–16, 2016, focusing again on the key ocean issues of marine protected areas, sustainable fisheries, marine pollution, and climate-related impacts on the ocean, including ocean acidification. The Our Ocean conference, a Department of State initiative, has become an effective mechanism to identify commitments for significant and meaningful actions to protect the ocean and has complemented other international efforts addressing threats to the ocean. Participants at the past two conferences, held in Washington, D.C., in 2014 and in Valparaiso, Chile, in 2015, pledged almost $4 billion to conservation activities and committed to safeguard nearly 6 million square kilometers of ocean in marine protected areas. The 2016 conference again will focus on identifying commitments for action by participants and other stakeholders, as well as on following up on commitments made in previous years. Also, the Department of State, through voluntary contributions to the International Atomic Energy Agency's Peaceful Uses Initiative, continues to support the Ocean Acidification International Coordination Center located at the Environment Laboratories in Monaco.

Near-future Activities Related to Ocean Acidification (Planned within the Next 2 Years)

Ocean acidification is irreversibly impacting marine ecosystems, including important fisheries. Secretary of State John Kerry highlighted this issue during the 2014 Our Ocean Conference, committing to increase worldwide ocean acidification monitoring capacity by significantly increasing the number of trained monitors and managers by 2020. The OceAn pH Research Integration and Collaboration in Africa (ApHRICA) is a public-private partnership of government, civil society, and private stakeholders focusing on building capacity and closing data gaps for ocean acidification in Africa. This partnership is a recipient of Leveraging, Engaging, and Accelerating through Partnerships funding from the Secretary of State's Office of Global Partnerships. It will provide resources to build ocean acidification monitoring in the Indian Ocean, enhance capacity-building workshops, facilitate connections to global efforts, and explore business cases for new ocean acidification monitoring and countering technologies.

The United States has also elevated ocean acidification as a priority initiative during its chairmanship of the Arctic Council, and is seeking ways to enhance monitoring of ocean acidification throughout the entire Arctic Ocean. As part of the United States Arctic Council Chairmanship Priorities, the Department of State in conjunction with NOAA is planning a workshop intended to launch efforts to conduct a vulnerability assessment of the ocean acidification in the Arctic. It is hoped that the outcomes of this workshop and assessment will be included in the 2nd Arctic Ocean Acidification, Arctic Monitoring and Assessment Programme, slated for publication in 2017, near the conclusion of the United States Chairmanship of the Arctic Council.

United States Fish and Wildlife Service

Broad Overview of and Rationale for Ocean Acidification Work

The official mission of the United States Fish and Wildlife Service (FWS) within the Department of the Interior is to work with others to conserve, protect, and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people. The FWS is responsible for managing or co-managing 4 marine national monuments and 180 coastal wildlife refuges, including 118 designated marine protected areas. Ocean acidification will likely impact all of these monuments, refuges, and protected areas to some degree. It is important that the FWS understand the effects of ocean acidification on trust species (migratory birds, species listed under the Endangered Species Act, inter-jurisdiction fishes, marine mammals) as well as entire ecosystems.

On-going Projects Related to Ocean Acidification

A large portion of the FWS contribution to addressing ocean acidification consists of its management policies that contribute to locally healthy ecosystems. Healthy ecosystems are thought to be more resilient to ocean acidification. FWS management policies include setting aside coastal areas as wildlife refuges with restricted use policies in place; these policies protect ecosystems from stressors such as over fishing and harvesting, excessive recreational uses, and the effects of industrial activities. Preserving the ecological integrity of coastal and ocean ecosystems through restoration and management can increase the buffering capacity of seawater in these ecosystems, thus protecting them against the chemical changes that result in acidification.

Through Landscape Conservation Cooperatives, and in collaboration with many partners, including USGS and other Federal agencies, states, tribes, universities, nongovernmental organizations, and other public and private institutions, the FWS works to develop science-based conservation objectives and strategies, some of which address ocean acidification. For example, the Pacific Islands Climate Change Cooperative has funded two ocean acidification related projects. FWS is also engaging in global modeling to show

the relationship between projected coral bleaching and ocean acidification, information which should support economic and coastal planning and coral reef management.

The Wildlife & Sport Fish Restoration Program within FWS provides grant funding for long-term conservation of coastal wetland ecosystems by helping states and territories to protect, restore, and enhance coastal habitats. Projects funded include the acquisition of real property interest in coastal lands or waters and the restoration, enhancement, or management of coastal wetlands ecosystems, both of which contribute to ecosystem health and, thus, resilience to ocean acidification.

Partners for Fish and Wildlife and the Coastal Program are the FWS's voluntary, citizen- and community-based stewardship programs that work with private landowners, government agencies, tribes, and other conservation partners to support Federal, tribal, state, and local habitat conservation strategies and on-the-ground habitat restoration projects. These landscape-level collaborative efforts help mitigate the effects of climate change and ocean acidification. Over the past two years, Partners for Fish and Wildlife and the Coastal Program have restored nearly 130,000 wetland acres, over 540,000 upland acres, and over 1,100 stream miles. Restoration of these landscapes decreases the effects of climate change and ocean acidification by increasing ecosystem health.

Near-future Activities Related to Ocean Acidification (Planned within the Next 2 Years)

The FWS National Wildlife Refuge System Inventory and Monitoring Initiative, which assesses the status and trends of refuge lands, waters, plants, and wildlife and their responses to management actions, will continue to be developed. This initiative includes a suite of monitoring parameters throughout the National Wildlife Refuge System to assess impacts of ocean acidification on ocean species from reef building organisms to seabirds.

Gaps in Portfolio of Activities Related to Ocean Acidification, Compared to Priorities Outlined in the Strategic Research Plan

FWS currently collaborates with Federal agencies to monitor ocean carbon chemistry and conduct biological surveys within wildlife refuges. Although many current biological surveys are not conducted with a focus on ocean acidification, the data could be used to study how ocean acidification affects marine ecosystems.

FWS implementation of widespread monitoring of ocean carbon chemistry and the effects of changing ocean chemistry will likely be limited by the number of field personnel available for monitoring, or the cost and availability the equipment needed to monitor for ocean acidification.

Ideas for How Agency Could Work with other Federal Agencies on Activities Related to Ocean Acidification

Wildlife refuges can be ideal sampling locations due to restrictions on activities that may confound data collection in other areas. Marine protection strategies and techniques employed by refuges as well as biological and chemical measures can be evaluated through collaboration with other Federal agencies that are able to provide expertise and monitoring equipment. FWS personnel may be available at wildlife refuges to operate and maintain monitoring equipment provided by other agencies.

United States Geological Survey

Broad Overview of and Rationale for Ocean Acidification Work

The United States Geological Survey has no formal ocean acidification program or umbrella project designated solely as "ocean acidification," but it does have projects that address ocean acidification issues and are relevant to the USGS mission. These projects are threaded through multiple USGS programs, including Coastal and Marine Geology and Ecosystems Programs. Guidance for USGS ocean

acidification research is defined in two of the seven USGS mission area science strategies: Climate and Land Use Change and Ecosystems. One major goal under the Ecosystems mission area is to advance the understanding of how various anthropogenic and natural drivers influence ecosystem change. In that capacity, USGS work, in collaboration with other Federal government and academic efforts, focuses on investigating the magnitude of ocean acidification in various ecosystems and the ecosystem impacts of ocean acidification, including the degradation of marine systems and effects on of ocean acidification on carbonate producing organisms.

Four science projects with tasks that the USGS has implemented since 2009 to advance the Federal response to ocean acidification include: Florida Shelf Ecosystems Response to Climate Change, Arctic Ocean Acidification, Coral Reef Ecosystem Study, and Exploring the Links between Coral Reefs and Mangroves. These projects are discussed further below and on the USGS ocean acidification website. Two technical projects that have been implemented are CO2calc, a software program that facilitates the study of ocean acidification by making carbon chemistry calculations easier to do, and the development of a pH photometer (light-sensitive machinery) for use in a variety of aquatic environments.

On-going Projects Related to Ocean Acidification

West Florida Shelf and Estuaries Ecosystems Response to Climate Change

Temperate and subtropical ocean regions are home to a diverse range of environmental conditions, habitats, species, and fisheries. Scientists at the USGS are monitoring seawater chemistry associated with ocean acidification and benthic habitats on the Florida Shelf and its associated estuaries. Research under this project has four goals:

(1) Fill data gaps in the Gulf of Mexico for carbon flux (measured via pCO_2) and carbon system parameters, such as saturation state, so that resource managers can make informed natural resource management decisions related to ocean acidification. Global carbon chemistry models have generally neglected the Gulf of Mexico, a marginal but highly productive sea. Existing data on carbon system parameters do not sufficiently address the spatial and temporal variability in the carbon system in this temperate to sub-tropical sea. Working with Federal and academic partners, USGS has collected carbon chemistry data and is now undertaking a synthesis of these datasets as part of a NASA-funded project.

(2) Conduct laboratory experiments to investigate the effect of ocean acidification on the growth of marine calcifying organisms that produce calcium carbonate sediments in temperate, subtropical, and tropical marine ecosystems, and model calcium carbonate production rates under different CO_2 scenarios to predict the response of the organisms and sediment production over time. The process of calcium carbonate mineralization is essential in the formation of shells and other structures of many marine organisms such as shellfish, plankton, and algae. Laboratory research on the how ocean acidification may impact species suggests that the calcium carbonate mineralization processes is more expensive energetically under ocean acidification conditions. With increased ocean acidification, it is likely that many organisms that create calcium carbonate minerals to build their shells or other structures will be negatively affected. Calcium carbonate is also a major component in limestone and carbonate sands, resources that are critical to the resiliency of many of the beaches and coasts of the United States. Ocean acidification can cause a decrease in calcification and dissolution of carbonate sediments that may lead to erosion of underwater carbonate structures and increase the vulnerability of coastal communities to storms and seafloor habitat loss.

(3) Address data gaps in coastal waters of the West Florida Shelf related to ocean acidification, and increase understanding of how ocean acidification affects estuarine and shallow shelf marine waters. Shallow water cruises conducted by the USGS with Federal and state partners provide regional information on the saturation state and pCO_2 fluctuation at the seawater/air boundary using state-of-

the-art techniques. Data from the State of Florida shellfish harvest areas are being evaluated for changes in estuarine water chemistry over the last two and a half decades.

(4) Develop and maintain CO2calc, a software program that facilitates the study of ocean acidification by making carbon chemistry calculations easier to do, and initiate development of a new device for measuring pH. Advancement of pH measurements is fundamental to providing sufficient data on ocean carbon chemistry for understanding natural and anthropogenic variability and the signal of ocean acidification. USGS is working with academic partners to develop tools that are user friendly and inexpensive to facilitate wider access to data.

Arctic Ocean Acidification

With a fairly constant water temperature of 0°C, the Arctic Ocean has the ability to absorb carbon dioxide more readily than warmer waters. Ocean acidification may be occurring faster at the poles than other regions for several reasons:

- Cold water more readily absorbs CO_2, lowering the pH of the water;
- Added melt-water from glaciers and the ice cap and increased riverine input forces additional uptake of CO_2 in the Arctic Ocean;
- Reduced sea-ice coverage results in more seawater exposure to and uptake of atmospheric CO_2; and
- Expanded ocean-surface area may, in turn, alter the production and decomposition of organic carbon, a complex process that plays an important role in ocean chemistry.

Baseline data collected during cruises from 2010-2012 that USGS hosted or participated in provided over 30,000 records and more than doubled the existing data on the carbon chemistry of the Arctic Ocean. These baseline data define an area the size of Montana within the Canada Basin that is already undersaturated with respect to aragonite—a calcium carbonate mineral associated with organisms that are important to the food web – which suggests that carbon chemistry conditions may already influence species in the region. USGS continues to collect ocean acidification monitoring data from Arctic waters by participating in regional cruises operated by other Federal agencies.

Coral Reefs

Coral reefs are vital to the long-term viability of tropical coastal communities, providing economic, recreational, and aesthetic value upon which coastal communities thrive. Coral reefs provide nurseries and habitat for commercially important fish species, sand for beaches, and protection from storm waves. These coral reef services and resources depend on the ability of calcifying organisms to build the three-dimensional structure of the reef as they produce their calcium carbonate skeletons. Ocean acidification can cause a decrease in calcification and dissolution of carbonate sediments that may lead to erosion of reef structure. Researchers at the USGS are working with various Federal government and academic partners at a variety of locales around the globe to develop comprehensive records of modern and historical coral reef growth and calcification rates relative to changing seawater chemistry resulting from ocean acidification. These records will provide the foundation for predicting future impacts of ocean acidification and sea-level rise on coral reef growth through the following actions:

- Monitoring calcification and metabolism rates in living coral reef communities;
- Monitoring growth rates of individual coral species;
- Monitoring seawater chemistry associated with ocean acidification;
- Measuring historic coral growth rates from coral cores relative to historic changes in seawater pH; and

- Conducting field experiments to quantify the effect of predicted seawater pH and CO_2 levels on coral reef growth and accumulation rates.

Exploring the Links between Coral Reefs and Mangroves

Risk analyses indicate that more than 90 percent of the world's coral reefs will be threatened by climate change and local anthropogenic impacts by the year 2030 if no action is taken to curb carbon dioxide emissions. Increasing temperatures and solar radiation cause coral bleaching that has resulted in extensive coral mortality. Increasing CO_2 reduces seawater pH, slows coral growth, and may cause loss of coral reef structure. Management strategies to protect coral reefs in the face of ocean acidification include establishment of marine protected areas with environmental conditions that promote coral reef resiliency. Few coral reefs insensitive to the impacts of climate change and ocean acidification have been identified, however, and the factors that results in this resiliency are poorly defined. USGS researchers have characterized that mangroves can act as a refuge for corals from thermal stress and ocean acidification. In doing so, they have identified the first natural, non-reef refuge for corals from thermal stress and ocean acidification. This previously undocumented refuge for corals provides evidence for adaptation of coastal organisms and ecosystem transition due to recent climate change. Activities on this work include:

- Measurements of diurnal and seasonal variations in temperature, salinity, photosynthetically active radiation, and seawater chemistry (including dissolved oxygen and carbon system parameters);
- Characterization of substrate parameters including grain size and mineralogy;
- Examination of water circulation patterns in mangrove communities where scleractinian corals are growing attached to and under mangrove prop roots;
- Inventories of coral species and quantification of incidences of coral bleaching, mortality, and recovery for two major reef-building corals, *Colpophyllia natans* and *Diploria labyrinthiformis*, growing in mangrove shaded and exposed (unshaded) areas; and
- Identification and quantification of chemical, physical, and biological resiliency factors for mangrove-coral habitats.

Near-future Activities Related to Ocean Acidification (Planned within the Next 2 Years)

USGS will assess processes that are driving ocean acidification in the Gulf of Mexico and in the Florida Shelf and its associated estuaries. The Gulf of Mexico research will go hand-in-hand with NASA funded collaborative research on coastal carbon data synthesis using air-sea CO_2 flux data. Modeling of predicted changes in carbonate sediment production based on chemical and geological oceanographic data and biologic experiments will continue. Over the next two years, synthesis of Arctic Ocean carbon parameter data will continue, and new data will be acquired as funding permits. Through Landscape Conservation Cooperatives and in collaboration with Fish and Wildlife Service, USGS will address science-based conservation objectives and strategies related to ocean acidification.

In the Florida Shelf over the next two years, USGS will perform a transdisciplinary characterization of reef-scape scale processes affecting and affected by ocean acidification including: high resolution measurement of spatial and temporal variation of carbonate system and associated parameters at the seafloor and throughout the water column, sedimentologic and mineralogic characteristics, high resolution changes in seafloor elevation relative to sea level rise using Sediment Elevation Tables, coral transplant studies, microbial population dynamics, and paleoecological reconstruction. Measurement and monitoring of fine-scale elevation changes on the Florida Keys Reef Tract using Sediment Elevation Tables will quantify structural loss (or gain) of reef habitat accumulation relative to sea level rise.

Maintenance of the software carbon calculator CO2calc and development of the pH photometer will continue as funding permits.

Far-future Activities Related to Ocean Acidification (Planned within the Next 3-5 Years)

Far-future plans for USGS ocean acidification-related activities include continued support of current activities, and future activities that result from partnerships and collaborations with other Federal, tribal, state, academic, and private institutions and build on existing capabilities and leveraging of resources.

Gaps in Portfolio of Activities Related to Ocean Acidification, Compared to Priorities Outlined in the Strategic Research Plan

The Strategic Research Plan is an accurate representation of current and planned ocean acidification-related activities in the USGS.

Untapped Opportunities Inside of Agency for Projects Related to Ocean Acidification

It is projected that degradation of coral reef and other coastline habitats due to ocean acidification will result in the inability of coral reef growth to keep up with rising sea level. There are currently no monitoring programs for high-resolution changes in seafloor elevation. USGS is performing the first pilot study to use Sediment Elevation Table methods for fine scale measurement of loss or accretion of coastal habitats due to ecosystem transition relative to sea level rise and in context with the national coastline elevation database. These results will form the basis for development of a new monitoring program to complement habitat, seawater chemistry, oceanographic, and ecosystem process studies on the impacts of ocean acidification that could be implemented in the future.

USGS geologic expertise remains virtually untapped as it related to ocean acidification. For example, areas of knowledge related to ocean acidification include paleo-ecosystems, the processes of sedimentation and mineral formation, the composition of sediments, the geology of coastal ecosystems, and proxies for monitoring activities under projected environmental conditions.

Ideas for How Agency Could Work with Other Federal Agencies on Activities Related to Ocean Acidification

The USGS provides unique resources and expertise in geologic, oceanographic, and geochemical research and monitoring that complement other agencies' activities and can be used to facilitate and leverage future research activities.

Areas Where Agency Mission is Being Inhibited by Knowledge Gaps that Fall out of Agency's Purview

USGS would benefit from an improved numerical modeling of ocean acidification processes. USGS is collecting data that can be used to validate coastal ocean and ecosystem modeling activities, but resources limit production of models in house.

Appendix

One way that the IWG-OA tracks Federal progress on the goals outlined in the Strategic Research Plan is by biennial tracking of progress made on addressing the goals during the previous 2 years and communication of near-term plans. The most recent tracking was done in summer 2014, and it will be done again in summer 2016. The Smithsonian Institution and Department of Energy's Pacific Northwest National Laboratory were not members of the IWG-OA in summer 2014, so their work on ocean acidification is not reflected here. The U.S. Navy and Department of State chose to contribute to the tracking exercise, but did not contribute agency-specific text to this document because their work on ocean acidification is limited.

Instead of tracking progress on the goals of the Strategic Research Plan, the IWG-OA chose to develop objectives and actions based on the goals of each theme in the Strategic Research Plan and track progress on them. Doing so provides the specificity needed to track Federal activities well. The objective and actions presented below are not intended to replace the goals of the Strategic Research Plan.

Table 1. Agency activities, plans, and priorities as they relate to the Strategic Research Plan Theme 1: Research to Understand Responses to Ocean Acidification. YES = Agency is already addressing this action; PLAN = Agency plans to address this action; PRIORITY = Agency is not addressing this action, but it is a priority; NO = Agency is not addressing this action and it is not a priority.

Objective	Action	Agency										
		DOI/BOEM	EPA	FWS	NASA	NAVY	NOAA	NPS	NSF	STATE	USDA	USGS
Analyze the physiological response and adaptation potential of ecologically, economically and culturally important marine organisms to ocean acidification impacts	Evaluate changes in biological responses in marine calcifying organisms, including all relevant life history stages, caused by OA and its interaction with other stressors.	NO	YES	NO	NO	NO	YES	PLAN	YES	NO	YES	NO
	Evaluate changes in biological responses for a diversity of marine non-calcifying organisms, including all relevant life history	NO	PRIORITY	NO	NO	NO	YES	YES	YES	NO	YES	NO

	stages, caused by OA and its interaction with other stressors.											
	Build an understanding of why organisms respond differently to ocean acidification.	NO	NO	NO	YES	NO	YES	NO	YES	NO	NO	NO
	Conduct studies that take a "whole-organism" approach.	NO	NO		YES	NO	YES	NO	YES	NO	YES	YES
	Conduct research on species ability to evolve and adapt to ocean acidification.	NO	PRIORITY	NO	YES	NO	PRIORITY	NO	YES	NO	YES	NO
	Incorporate findings on individual species' responses into stock assessment and other fishery resource models.	NO	PLAN	PLAN	NO	NO	PLAN	NO	NO	NO	YES	NO
	Evaluate biogeochemical proxies of OA and organism response.	NO	PRIORITY	NO	YES	NO	NO	NO	YES	NO	NO	PLAN
Investigate how the effects of ocean acidification will propagate through food webs, altering community dynamics, and competitive interactions; along with how where this will happen	Use life history and population demography to scale up individual species response research findings to the population and ecosystem level.	NO	PRIORITY	PLAN	NO	NO	YES	YES	PLAN	NO	NO	NO
	Explore how rising ocean temperatures, elevated CO2, and decreased pH act	NO	PRIORITY	PLAN	YES	NO	YES	NO	YES	NO	NO	NO

	simultaneously on the marine food webs.											
	Develop a candidate list of organisms that can serve as marine ecosystem "sentinels" and develop standard operating procedures for their long-term monitoring.	NO	PRIORITY	PRIORITY	NO	NO	YES	PRIORITY	NO	NO	NO	NO
	Increase our understanding of impacts on more-vulnerable ecosystems, including those affected by multiple anthropogenic and environmental stressors.	NO	PLAN	PRIORITY	YES	NO	YES	PRIORITY	YES	NO	NO	YES
Identify key pathways and transformations of ocean carbon and nutrient cycles that will likely be affected by ocean acidification	Investigate key biogeochemical processes at the organism, community, and ecosystem scale.	YES	NO	NO	YES	NO	YES	NO	YES	NO	NO	YES
	Determine the controlling factors of calcium carbonate dissolution and breakdown.	YES	NO	NO	YES	NO	YES	NO	YES	NO	NO	YES
	Work closely with observing experts to characterize natural carbon chemistry of source waters so that experimental conditions represent realistic current and future conditions.	YES	PRIORITY	NO	YES	NO	YES	NO	YES	NO	NO	YES

	Investigate the effects of CO2- and pH-driven changes on the transfer of carbon from the ocean surface to its depths.	YES	PRIORITY	NO	YES	NO	YES	NO	YES	NO	NO	YES
	Investigate how OA may alter the geochemical cycles and their interactions with marine ecosystems.	YES	PRIORITY	NO	YES	NO	YES	NO	YES	NO	NO	YES
	Determine how OA will impact the solubility and dissolution rates for calcium carbonate.	YES	NO	NO	NO	NO	NO	NO	YES	NO	NO	YES
	Determine the timescale at which carbon is removed from the system by natural sequestration.	NO	PRIORITY	NO	YES	NO	YES	NO	YES	NO	NO	PRIORITY
Develop paleo proxy-based reconstructions of pH for the purpose of establishing a natural, unperturbed baseline in the modern and ancient oceans to inform ocean acidification modeling and predictions	Develop and refine proxies of ocean pH and carbonate saturation state.	NO	PRIORITY	NO	YES	NO	NO	NO	YES	NO	NO	PLAN
	Collect and evaluate historical records of organism and ecosystem response to changes in ocean chemistry.	NO	NO	NO	YES	NO	YES	PRIORITY	YES	NO	NO	PLAN
Identify shared-use ocean acidification facilities and coordinate field activities for	Create an inventory of existing and planned Federal and non-Federal OA facilities, including FOCE facilities	NO	NO	NO	NO	NO	PLAN	NO	NO	NO	NO	NO

conducting appropriately controlled, manipulative experiments on individual marine species and ecological communities	Identify geographic regions need of facilities and select a subset for targeted long-term ecosystem-level monitoring.	NO	NO	NO	NO	NO	YES	NO	YES	NO	NO	NO
Conduct periodic synthesis activities of observations and data analysis tools derived from ocean acidification monitoring, research and modeling to generate readily intelligible information products and capture the current state of understanding of ocean acidification	Conduct regular data synthesis to take stock of findings and set new priorities.	NO	NO	NO	YES	NO	PLAN	PRIORITY	YES	NO	NO	YES
	Identify weaknesses and gaps in the research.	NO	PRIORITY	NO	YES	NO	PLAN	NO	YES	NO	NO	YES

Table 2. Agency activities, plans, and priorities as they relate to the Strategic Research Plan Theme 2: Monitoring of Ocean Chemistry and Biological Impacts. YES = Agency is already addressing this action; PLAN = Agency plans to address this action; PRIORITY = Agency is not addressing this action, but it is a priority; NO = Agency is not addressing this action and it is not a priority.

Objective	**Action**	**Agency**										
		DOI/BOEM	**EPA**	**FWS**	**NASA**	**NAVY**	**NOAA**	**NPS**	**NSF**	**STATE**	**USDA/NIFA**	**USGS**
Determine the changes in seawater chemistry and	Improve adoption of standardized chemical, physical, and biological monitoring protocols.	NO	PRIORITY	PLAN	NO	NO	YES	YES	YES	NO	NO	YES

biology to understand the ecosystem changes that will ultimately control the size and composition of our fisheries and other biological resources.	Develop new technology that will allow for accurate in situ measurements of the carbon system and biological responses.	NO	NO	NO	YES	NO	YES	NO	YES	NO	NO	YES
	Synthesize observing data in an effort to describe and explain acidification status of U.S. waters, likely with a regional focus.	NO	PRIORITY	NO	YES	NO	YES	PLAN	YES	NO	NO	YES
	Foster closer connections between observing scientists and biologists in order to provide information about carbon chemistry of waters where species reside naturally.	NO	PRIORITY	PRIORITY	YES	NO	YES	NO	YES	NO	NO	PRIORITY
	Integrate models of biogeochemical processes with ecosystem forecasts.	NO	NO	PRIORITY	YES	NO	YES	NO	PLAN	NO	NO	YES
Coordinate an observational network for Ocean Acidification	Evaluate the geographical extent and capabilities of existing monitoring systems in regions and habitats where OA effects are most likely to be the greatest.	NO	PLAN	PLAN	NO	NO	YES	NO	NO	NO	NO	NO
	Expand existing coastal and ocean measurements by deploying new OA monitoring instrumentation.	YES	PLAN	PLAN	YES	NO	YES	YES	PLAN	NO	NO	YES
	Identify and deploy monitoring instrumentation in coastal and estuarine sites.	PLAN	PLAN	PLAN	YES	NO	YES	PLAN	YES	NO	NO	YES
	Work closely with regional and state entities to develop monitoring programs for OA in state/tribal waters.	NO	PRIORITY	NO	NO	NO	YES	NO	NO	NO	NO	PRIORITY
	Integrate observational data into regional and global models.	NO	PLAN	PLAN	YES	NO	YES	NO	PLAN	NO	NO	NO

Collect time-series measurements at fixed stations	Document trends in OA physical, chemical, and biological responses that can be used for real-time early warning systems and for verification of computer model outputs.	NO	NO	PLAN	YES	NO	YES	PRIORITY	YES	NO	NO	YES
	Compile and interpret existing coastal States' and Federal datasets on water quality.	NO	PRIORITY	PLAN	NO	NO	NO	NO	NO	NO	NO	YES
	Augment existing observing programs that collect time series measurements at fixed stations with OA measurements.	PLAN	NO	PLAN	NO	NO	YES	PRIORITY	YES	NO	NO	NO
	Develop new technologies to enhance chemical and biological sensors on floats and gliders.	NO	NO	NO	YES	NO	YES	NO	YES	NO	NO	NO
	Support satellite observations that inform modeling efforts.	NO	NO	NO	YES	NO	YES	NO	NO	NO	NO	NO

Table 3. Agency activities, plans, and priorities as they relate to the Strategic Research Plan Theme 3: Modeling to Predict Changes in the Ocean Carbon Cycle and Impacts on Marine Ecosystems and Organisms. YES = Agency is already addressing this action; PLAN = Agency plans to address this action; PRIORITY = Agency is not addressing this action, but it is a priority; NO = Agency is not addressing this action and it is not a priority.

Objective	**Action**	**Agency**										
		DOI/BOEM	**EPA**	**FWS**	**NASA**	**NAVY**	**NOAA**	**NPS**	**NSF**	**STATE**	**USDA/NIFA**	**USGS**
Incorporate realistic biological parameters into global ocean models	Develop and improve models that can predict direct and indirect effects on culturally, economically, and ecologically important species and processes.	NO	YES	NO	NO	NO	YES	NO	NO	NO	NO	NO
	Strengthen ocean biology life history and trophic couplings in end-to-end models.	NO	PRIORITY	NO	YES	NO	YES	NO	YES	NO	NO	NO

	Develop models of impacts to exceptionally vulnerable species, communities, and geographic areas in order to inform prioritization of research.	NO	PRIORITY	NO	YES	NO	YES	PLAN	NO	NO	NO	NO
	Incorporate more detailed life history strategies of specific organisms at higher trophic levels.	NO	NO	NO	NO	NO	YES	NO	YES	NO	NO	NO
Develop regional and coastal models	Invest in and develop multi- and interdisciplinary models (coastal processes on both sides of the land-ocean boundary, as well as atmospheric processes).	NO	YES	NO	YES	NO	YES	NO	PLAN	NO	NO	NO
	Identify and track regional modeling efforts that include or could be expanded to include carbonate chemistry.	NO	YES	NO	NO	NO	YES	NO	NO	NO	NO	NO
	Continue progress on nesting downscaled regional models within global climate models.	NO	NO	NO	YES	NO	NO	NO	PLAN	NO	NO	NO
	Use high-resolution regional models to realistically represent coastal upwelling or coral reef hydrodynamics.	NO	NO	NO	YES	NO	YES	NO	PLAN	NO	NO	NO
	Develop models that will differentiate natural and anthropogenic CO2 sources.	NO	NO	NO	YES	NO	NO	NO	PLAN	NO	NO	NO
Ensure models can be used and interpreted by resource managers	Develop appropriate decision support tools, outreach, and training programs for regional and local resource managers.	NO	PRIORITY	PRIORITY	NO	NO	YES	YES	NO	NO	NO	NO
	Ensure adequate Federal capacity for archiving model code and results to support management and decision making.	NO	PRIORITY	NO	NO	NO	YES	NO	NO	NO	NO	PLAN

Table 4. Agency activities, plans, and priorities as they relate to the Strategic Research Plan Theme 4: Technology Development and Standardization of Measurement. YES = Agency is already addressing this action; PLAN = Agency plans to address this action; PRIORITY = Agency is not addressing this action, but it is a priority; NO = Agency is not addressing this action and it is not a priority.

Objective	Action	Agency										
		DOI/BOEM	EPA	FWS	NASA	NAVY	NOAA	NPS	NSF	STATE	USDA/NIFA	USGS
Develop standard methods for various relevant biological measurements	Establish validated SOPs for measurement of critical biological and geochemical parameters.	NO	PRIORITY	PLAN	YES	NO	PLAN	PLAN	YES	NO	NO	NO
	Produce Certified Reference Materials that outline procedures for measuring and analyzing organic and inorganic parameters.	NO	NO	PLAN	NO	NO	NO	NO	YES	NO	NO	NO
	Develop best practices for manipulative field experiments and for studies in natural CO2 venting sites and low pH regions.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	Develop a program to ensure that researchers are following consistent and appropriate analytical methods with documented QA/QC procedures.	NO	PRIORITY	PLAN	NO	NO	YES	NO	NO	NO	NO	NO
	Calibrate existing and develop new geochemical proxies to facilitate paleo-oceanographic studies of organismal and ecosystem response to OA.	NO	NO	PRIORITY	NO	NO	NO	NO	YES	NO	NO	PLAN
Develop additional monitoring technology to properly assess the full carbon system and quantify abundances of targeted organisms using unmanned platforms, including moorings, gliders, autonomous vehicles and floats.	Employ existing tools in new environments and modify as appropriate.	NO	NO	PLAN	YES	NO	YES	YES	YES	NO	NO	YES
	Calibrate existing OA-specific geochemical proxies and develop new multiple proxy techniques to complement growth and calcification measurements.	NO	PRIORITY	PLAN	NO	NO	NO	NO	YES	NO	NO	PLAN
	Enhance programs that foster development and deployment of new sensor technologies.	NO	NO	PLAN	YES	NO	YES	NO	YES	YES	NO	YES

Develop and commercialize instrumentation and techniques to improve capability to measure chemical (with special focus on DIC and TA) and biological variables over space and time, including affordable autonomous sensors, more accessible and affordable high-quality instrumentation, new remote sensing, and in situ technologies	Incorporate commercially available oxygen sensors to the nascent or existing international monitoring programs, such as the Argo Program.	NO	NO	NO	NO	NO	YES	NO	PLAN	NO	NO	NO
	Increase the number of sensors that take time-series measurements as well as other analytical devices on moored buoys in high productivity coastal and estuarine systems.	NO	PRIORITY	PRIORITY	YES	NO	YES	NO	YES	NO	NO	NO
	Develop programs that attract potential business partners and encourage commercialization of new instruments.	NO	NO	NO	YES	NO	YES	NO	NO	NO	NO	NO
	Develop novel platforms such as gliders, AUVs, drifters, and autonomous surface vehicles to accommodate sensors for OA research.	NO	NO	NO	YES	NO	YES	NO	PLAN	NO	NO	NO
	Facilitate the transition of newly developed technologies from research to commercial development.	NO	NO	NO	YES	NO	YES	NO	NO	NO	NO	NO

Table 5. Agency activities, plans, and priorities as they relate to the Strategic Research Plan Theme 5: Assessment of Socioeconomic Impacts and Development. YES = Agency is already addressing this action; PLAN = Agency plans to address this action; PRIORITY = Agency is not addressing this action, but it is a priority; NO = Agency is not addressing this action and it is not a priority.

Objective	**Action**	**Agency**										
		DOI/BOEM	**EPA**	**FWS**	**NASA**	**NAVY**	**NOAA**	**NPS**	**NSF**	**STATE**	**USDA/NIFA**	**USGS**
Assess cultural and economic impacts of	Focus research on the three key sector areas that are most likely to see cultural and economic effects from OA; 1) marine fisheries, 2) aquaculture, 3) tropical coral reef systems.	NO	YES	PLAN	YES	NO	YES	NO	YES	NO	NO	YES

ocean acidification	Identify stakeholder groups as a critical step in forming a research agenda.	NO	PRIORITY	PLAN	NO	NO	YES	NO	NO	NO	PLAN	PLAN
	Support inclusion of cultural and economic components in studies of the effects of ocean acidification.	NO	PRIORITY	PLAN	NO	NO	YES	PRIORITY	NO	NO	NO	NO
	Encourage marine policy programs to incorporate OA and its cultural and economic impacts into their curricula and areas of study	NO	NO	NO	NO	NO	PLAN	NO	NO	NO	NO	NO
	Foster communication and collaboration between natural and social scientists.	NO	PRIORITY	NO	YES	NO	PLAN	PLAN	Plan	NO	NO	NO
	Conduct non-market valuation studies to estimate damages from anticipated impacts of OA.	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	Develop integrated models that link physical, biological, and economic systems that estimate the economic and distributional impacts of OA.	NO	PRIORITY	NO	NO	NO	YES	NO	NO	NO	NO	NO
Identify adaptation and mitigation strategies	Encourage Federal agencies to include consideration of OA as part of their National Environmental Policy Act process.	NO		YES	NO	NO		PRIORITY	NO	NO	YES	NO
	Foster communication between researchers, stakeholders, and decision makers to develop efficient mitigation and adaptation strategies.	NO	PRIORITY	PLAN	NO	NO	YES	PRIORITY	NO	YES	NO	YES
	Develop metrics to test the efficacy of adaptation and mitigation strategies.	NO		PRIORITY	NO	NO	NO	PRIORITY	NO	NO	NO	NO
	Provide businesses and communities that will be adversely affected by OA with the information they need to develop adaptation action plans.	NO	PRIORITY	PRIORITY	NO	NO	YES	NO	NO	YES	NO	PLAN

Table 6. Agency activities, plans, and priorities as they relate to the Strategic Research Plan Theme 6: Education, Outreach, and Engagement Strategy on Ocean Acidification. YES = Agency is already addressing this action; PLAN = Agency plans to address this action; PRIORITY = Agency is not addressing this action, but it is a priority; NO = Agency is not addressing this action and it is not a priority.

Objective	Action	Agency

		DOI/BOEM	EPA	FWS	NASA	NAVY	NOAA	NPS	NSF	STATE	USDA/NIFA	USGS
Make information on ocean acidification accessible through electronic means, including information which would be useful to policymakers, researchers, and other stakeholders in mitigating or adapting to the impacts of ocean acidification	Launch a public web portal.	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	YES
	Facilitate an OA data and information exchange among stakeholders.	NO	PRIORITY	PRIORITY	YES	NO	PLAN	PLAN	YES	YES	PLAN	NO
	Make scientific assessments available to managers, policy makers, and the general public as useful education tools.	NO	PRIORITY	PRIORITY	NO	NO	PLAN	PRIORITY	NO	YES	PLAN	YES
Actively engage ocean acidification stakeholders in education and outreach activities	Coordinate efforts between NGOs, donors, government agencies, international entities, and other participants in education and outreach activities.	NO	NO	PRIORITY	NO	NO	YES	PRIORITY	NO	NO	PLAN	NO
	Engage current Cooperative Extension and National and state Sea Grant offices to develop and implement outreach programs focused on OA.	NO	NO	NO	NO	NO	PRIORITY	NO	NO	NO	PLAN	PLAN
Link to existing programs and organizations in an effort to leverage assets and	Solidify funding streams to foster development and maintenance of education, outreach, and engagement programs and activities.	NO		NO	YES	NO	PLAN	NO	YES	NO	PLAN	NO
	Establish a national mechanism that coordinates linkages between Federally supported OA researchers	NO		NO	NO	NO	YES	NO	NO	NO	PLAN	NO

expand these initiatives to address ocean acidification	and facilities and students, providing internships and fellowships.											
Forge new partnerships	Encourage and provide incentives for scientists doing OA research to actively engage the general public.	NO		NO	NO	NO	PRIORITY	NO	YES	NO	NO	NO
	Provide incentives to researchers and laboratories supported by Federal funds to engage in both formal and informal education efforts, and provide coordination of these efforts across the Federal government.	NO	PLAN	NO	NO	NO	PRIORITY	NO	YES	NO	NO	NO

Table 7. Agency activities, plans, and priorities as they relate to the Strategic Research Plan Theme 7: Data Management and Integration. YES = Agency is already addressing this action; PLAN = Agency plans to address this action; PRIORITY = Agency is not addressing this action, but it is a priority; NO = Agency is not addressing this action and it is not a priority.

Objective	**Action**	**Agency**										
		DOI/BOEM	**EPA**	**FWS**	**NASA**	**NAVY**	**NOAA**	**NPS**	**NSF**	**STATE**	**USDA/NIFA**	**USGS**
Establish an Ocean Acidification Data Management Program (or office) or a leadership project embedded within an existing Federally-supported data management	Develop appropriate data center(s), either new or from preexisting centers, for archiving OA data.	NO	PRIORITY	NO	YES	NO	YES	PLAN	YES	NO	NO	PRIORITY
	Establish collaborative relationships with data submitters and acquisition centers to ensure archival of the data, with sub-disciplines self-organizing around common procedures.	NO		NO	YES	NO	YES	NO	YES	NO	NO	NO
	Negotiate and implement system-specific approaches to interagency interoperability.	NO		NO	YES	NO	PRIORITY	NO	YES	NO	NO	NO
	Establish metadata requirements and data quality policies in partnership with the science community.	NO	PRIORITY	NO	YES	NO	YES	NO	YES	NO	NO	NO

activity, to oversee the many complex connections between institutions and data systems	Establish guidance on data and metadata accessibility.	NO	PRIORITY	NO	YES	NO	YES	NO	YES	NO	NO	NO
	Automate collection of metadata from “smart” sensors.	NO		NO	NO	NO	PRIORITY	NO	NO	NO	NO	NO
	Explore options for archival and data management procedures for non-traditional OA data sets, including socioeconomic data.	NO		NO	NO	NO	PRIORITY	NO	NO	NO	NO	NO
	Develop a catalog of relevant data and documentation.	NO		NO	YES	NO	YES	PRIORITY	NO	NO	NO	PRIORITY
	Establish tools and procedures to support community-wide data synthesis.	NO		NO	YES	NO	PRIORITY	NO	YES	NO	NO	NO
	Ensure there is a managed and shared data analysis environment to support community data synthesis and integration activities and a framework for model intercomparison.	NO	PRIORITY	NO	YES	NO	PRIORITY	NO	YES	NO	NO	PRIORITY
	Harmonize with the emerging IOOS and OOI framework.	NO	PRIORITY	NO	NO	NO	YES	NO	PLAN	NO	NO	NO
Develop and maintain dedicated online access for purposes of disseminating ocean acidification data and information across the spectrum of research, education, outreach and other applications	Determine the components of the OA data access framework.	NO	PRIORITY	NO	NO	NO	PLAN	NO	NO	NO	NO	NO
	Promote open and timely access to OA data and information from both Federal agencies and non-Federal partners, complying with Federal data policies.	NO	PRIORITY	NO	YES	NO	YES	NO	YES	NO	NO	YES
	Consult with user communities to determine the specific software tools that need to be supported.	NO	NO	NO	YES	NO	PRIORITY	NO	YES	NO	NO	YES
	Develop communications tools that convey the uncertainties associated with the data integration and application to assist management decisions.	NO	PRIORITY	NO	NO	NO	PRIORITY	NO	NO	NO	NO	NO
	Develop true system-of-systems integrated data and metadata exchange.	NO	NO	NO	NO	NO	PLAN	NO	YES	NO	NO	NO

Abbreviations

BOEM	Bureau of Ocean Energy Management
EPA	Environmental Protection Agency
FOARAM	Federal Ocean Acidification Research and Monitoring Act of 2009 (P.L. 111-11, Subtitle D)
FWS	United States Fish and Wildlife Service
FY	fiscal year
IWG-A	Interagency Working Group on Aquaculture
IWG-OA	Interagency Working Group on Ocean Acidification
LTER	Long-Term Ecological Research
NASA	National Aeronautics and Space Administration
NAVY	United States Navy
NCRMP	National Oceanic and Atmospheric Administration National Coral Reef Monitoring Program
NIFA	National Institute of Food and Agriculture
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSF	National Science Foundation
NSTC	National Science and Technology Council
OA	ocean acidification
OAP	National Oceanic and Atmospheric Administration Ocean Acidification Program
OES	Department of State Bureau of Oceans and International Environmental and Scientific Affairs
ORD	Environmental Protection Agency Office of Research and Development
OSTP	Office of Science and Technology Policy
OW	Environmental Protection Agency Office of Water
pCO_2	partial pressure of carbon dioxide
PRISM	Pacific Regional Intertidal Sampling and Monitoring
R&D	research and development
ROSES	National Aeronautics and Space Administration Research Opportunities in Space and Earth Sciences
STATE	United States Department of State

STEM	Science, Technology, Engineering, and Mathematics
USDA	United States Department of Agriculture
USGS	United States Geological Survey