NOAA OCEAN AND GREAT LAKES ACIDIFICATION

RESEARCH PLAN HIGHLIGHTS

NOAA Ocean Acidification Steering Committee

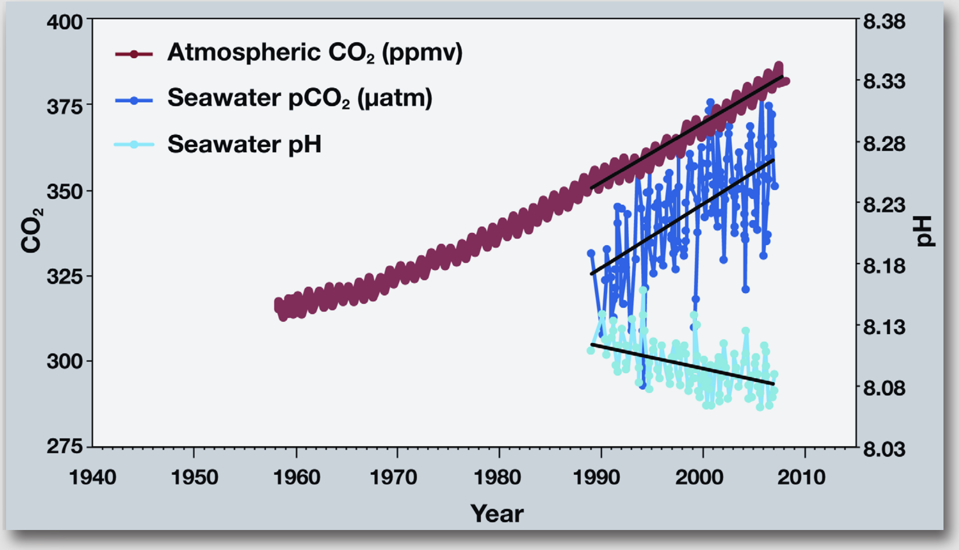
NOAA'S ROLE IN OCEAN ACIDIFICATION MONITORING AND RESEARCH

The National Oceanic and Atmospheric Administration (NOAA) has the operational responsibility to protect and preserve ocean, coastal, and Great Lakes resources and to provide critical and accurate weather, climate, and ecosystem forecasts that support national safety and commerce. The Federal Ocean Acidification Research and Monitoring (FOARAM) Act of 2009 mandates that NOAA have an active monitoring and research program to determine potential impacts of decreased ocean pH and carbonate saturation states.

Freshly harvested oysters from Yaquina Bay, Oregon (Photo credit: NOAA)

Front cover: Octocorallia: Alcyonacea, the "mushroom coral" has stinging cells or nematocysts within its tentacles that are used to capture minute prey. (Photo credit: NOAA/OER)

OCEAN ACIDIFICATION is the ongoing decrease in the pH of the Earth's ocean, caused by its uptake of carbon dioxide from the atmosphere. pH is a measure of ocean acidity. In addition to other impacts of global climate change, ocean acidification poses potentially serious threats to the health of the world's ocean and its ecosystems. We need ocean ecosystems for the oxygen we breathe, the seafood we eat, the beaches we enjoy, and many other services they provide. Today, more than a billion people worldwide rely on food from the ocean as their primary source of protein. Many jobs and economies in the U.S. and around the world depend on the fish and shellfish in our ocean.



This graph shows the correlation between rising levels of carbon dioxide (CO_2) in the atmosphere shown in violet, with rising CO_2 levels in the ocean, shown in bright blue. As more CO_2 accumulates in the ocean, the pH of the ocean decreases, shown in pale aqua. (Modified after R.A. Feely, Bulletin of the American Meteorological Society, July 2008)

Scientists are rapidly expanding what we know about ocean acidification, but the science of ocean acidification is still in its infancy. Sustained efforts to monitor ocean acidification worldwide are only beginning, and the impacts of ocean acidification at local and regional levels are not well understood. With the pace of ocean acidification accelerating, scientists, resource managers, and policymakers recognize the urgent need to strengthen the science as a basis for sound decision making and action.

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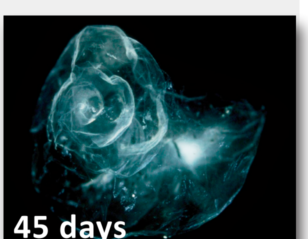
*The **overarching goal** of the **NOAA Ocean and Great Lakes Acidification Research Plan** is to predict how ecosystems will respond to acidification and to provide information that resource managers can use to address acidification issues. This document is a synopsis of the NOAA Ocean and Great Lakes Acidification Research Plan.*

THE CASE FOR OCEAN ACIDIFICATION MONITORING AND RESEARCH

Since the beginning of the Industrial Revolution in the mid-18th century, atmospheric levels of carbon dioxide, or CO_2, rose from 280 to 390 parts per million. About 50 percent of the increase occurred over the last 30 years. Nearly one-third of the CO_2 released into the atmosphere every year is absorbed by the ocean. This means that as atmospheric CO_2 levels go up, CO_2 levels in the ocean also increase. This increase translates to a shift in the chemical balance in ocean water, lowering the pH of the ocean and reducing the availability of carbonate ions. This effect, known as ocean acidification, has implications for the ocean and, ultimately, what we depend on from it.

Ocean acidification is expected to impact ocean species to varying degrees. A more acidic environment has a dramatic effect on some calcifying species, or species that build calcium carbonate shells, such as oysters. The panel of photographs on the left shows what happens to a pteropod, a shelled free-swimming marine snail, when it is exposed to ocean water adjusted to sea water chemistry projected for the year 2100. Its shell dissolves after approximately 45 days in this environment. This is one of several direct effects of ocean acidification described on the opposite page.

*The **pteropod**, or "**sea butterfly**", is a tiny sea creature about the size of a small pea. Pteropods are a major food source for many species of fish. The photos below show what happens to a pteropod's shell when placed in sea water with pH and carbonate levels projected for the year 2100. The shell slowly dissolves after 45 days. (Photo credit: R. Hopcroft, University of Alaska Fairbanks)*



From the 18th century until today, ocean pH decreased by 0.1 pH units. By the year 2100, scientists project that ocean pH will drop an additional 0.1-0.3 units from the current pH of 8.1- up to a 150% increase in acidity relative to the beginning of the industrial era. A pH unit is a measure of acidity ranging from 0-14. The lower the value, the more acidic the measurement. Becoming more acidic is a relative shift in pH to a lower value. Even this seemingly small change in pH toward increased acidity is significant to a living organism.

Photo credit: Used with permission, National Geographic Images

When shelled organisms are at risk, the entire food web also is at risk. For example, pteropods are an important food source for salmon. According to some research reports, a 10 percent drop in pteropod production could result in a 20 percent drop in the mature body weight of pink salmon.

Other species that may be affected by ocean acidification include oysters, clams, sea urchins, shallow water and deep-sea corals, the calcium carbonate-shelled organisms known as formanifera, and some fish species. Organisms potentially vulnerable to ocean acidification will be studied under the NOAA research program.

Chinook salmon (Photo credit: NOAA)

Selected Legislative Drivers

- Federal Ocean Acidification Research and Monitoring Act (FOARAM)
- Magnuson-Stevens Fisheries Conservation Act
- Coastal Zone Management Act
- Coastal Monitoring Act
- Marine Mammal Protection Act
- National Marine Sanctuaries Act
- Endangered Species Act
- Coral Reef Conservation Act
- Clean Water Act
- Harmful Algal Bloom and Hypoxia Research and Control Act

POTENTIAL DIRECT EFFECTS OF OCEAN ACIDIFICATION

Reduced calcification rate of shell-forming animals – The reduced saturation state affects the ability to produce a calcium carbonate shell. This, in turn, could lead to dissolution of existing calcium carbonate structures.

Altered reproduction and survival at lower pH – Organisms generally require energy to maintain appropriate intracellular pH balance. Altering the external pH of seawater can overwhelm pH control mechanisms, affecting reproduction or survival.

Reduced olfaction in fish – Increased CO_2 in seawater can affect the ability of fish to detect critical olfactory, or sensory, cues.

Increased photosynthesis – Because CO_2 is required for photosynthesis, some photosynthetic organisms, especially those without effective carbon concentrating mechanisms, may have increased photosynthetic rates with increased CO_2.

Hypercapnia – Increased CO_2 in internal fluids, especially in highly energetic species like squid, can affect mobility, survival or reproduction. The ability of organisms to decrease CO_2 concentrations in internal fluids by transferring CO_2 across membranes to seawater is reduced when seawater CO_2 concentrations are high.

Acoustic disruption from reduced sound absorption – Changes in ocean pH will alter the acoustic properties of the ocean, increasing transmission of low frequency sounds, which may affect species relying on acoustic information.

Changes in speciation of some metals, nutrients, or toxic compounds – Acidification will alter speciation (ionic form) of various metals, nutrients, or toxins in a way that may affect species reproduction and survival.

STRATEGIC SCIENCE-BASED GUIDANCE

A set of core hypotheses are intended to provide strategic science-based guidance to the NOAA research community and to help integrate the broad range of proposed activities toward a common purpose. These hypotheses focus on characterizing biogeochemical changes across a range of environments, evaluating responses of key aquatic organisms and ecosystems, and illuminating the range of vulnerabilities, all of which inform adaptive management strategies.

Hypotheses

- Rates and magnitudes of ocean acidification will vary.
- Ocean acidification will change ecosystem structure, function, and biodiversity.
- Species-specific vulnerabilities will differ at regional and local scales.

Themes

1. **Monitor**

   Develop the monitoring capacity to quantify and track ocean acidification and its impacts in open-ocean, coastal, and Great Lakes systems

2. **Assess**

   Assess the response of organisms to ocean and lake acidification

3. **Forecast**

   Forecast biogeochemical and ecological responses to acidification

4. **Manage**

   Develop management strategies for responding and adapting to consequences of ocean acidification

5. **Synthesize**

   Provide a synthesis of ocean and Great Lakes acidification data and information

6. **Engage**

   Provide an engagement strategy for education and public outreach

The themes outlined above are designed to achieve specific outcomes, while addressing the three hypotheses. New methodologies and approaches will be integrated as they become available. A coordinated, multidisciplinary program of field observations, laboratory studies, and modeling is critical to achieving a successful research strategy for ocean acidification. Such a program will improve our ability to predict present and project future responses of marine and Great Lakes biota, ecosystem processes, and biogeochemistry to acidification.

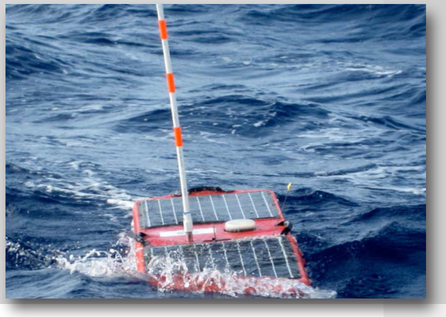
Repeat hydrographic surveys and time series measurements largely drive our current understanding of long-term changes in the ocean's carbon system. Despite the central importance of these measurements, coordinated observing networks in U.S. coastal and estuarine waters do not exist. Consequently, these environments are grossly under-sampled. Enhancing and expanding the global moored time series network with new carbon and pH sensors will greatly improve that understanding.

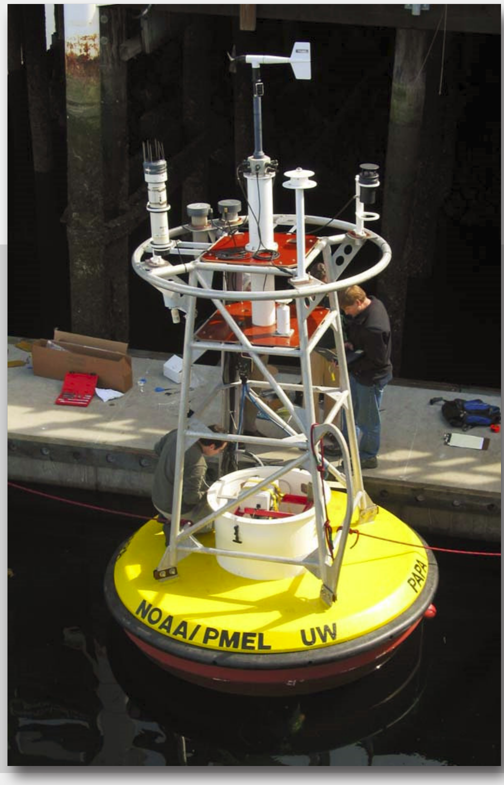
Temporal and spatial trends will be monitored through ship-based and moored observations of key physical, chemical, and biological parameters. Building on existing coastal, coral reef, and estuarine networks made up of shipboard and remote autonomous systems is a cost-efficient approach for establishing a U.S. coastal and estuarine network. NOAA is well poised to enhance many of its capabilities within NOAA that can be used to establish an ocean and Great Lakes acidification ecosystem monitoring network to characterize the carbon chemistry of these environments.

MONITOR
ASSESS
FORECAST

MANAGE
SYNTHESIZE
ENGAGE

New technology and enabling activities still need to be developed or adapted to improve monitoring efforts, including new biogeochemical sensors for carbon species, gliders, genomic tags, and a center of expertise for carbon measurements.



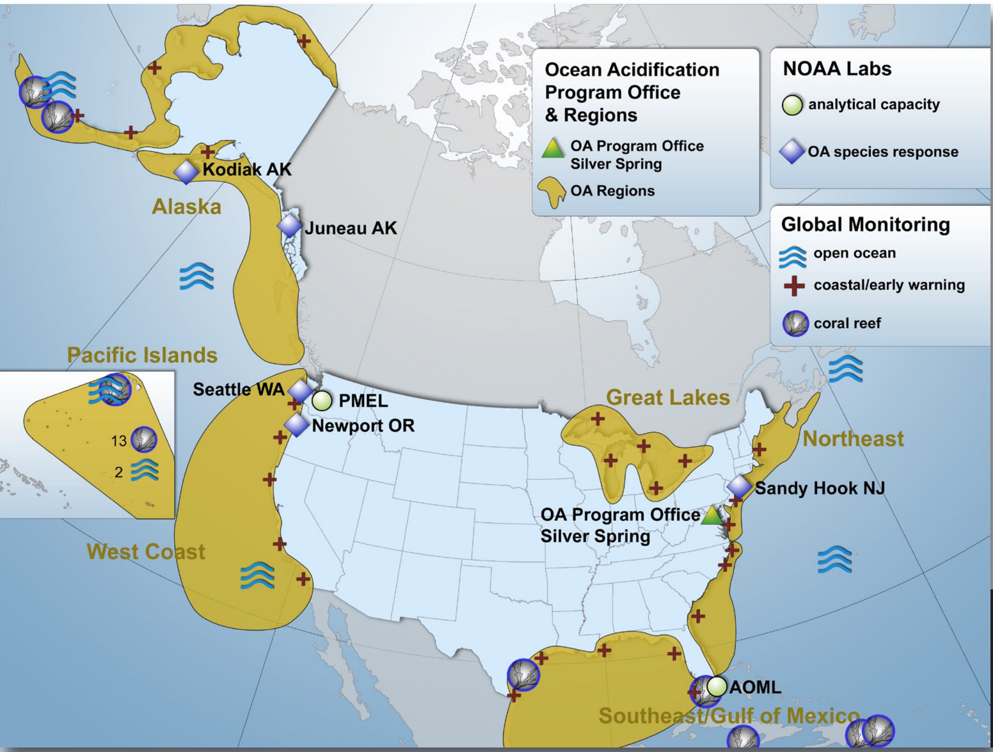


Similar monitoring platforms will be used to study ecosystem responses. Critical changes in community metabolic processes must be assessed to determine the ultimate "carbon thresholds" for ecosystem responses. Laboratory experiments, mesocosm, and field studies will be carried out to describe physiological responses to acidified waters. Species likely to respond include those vulnerable to direct effects and those vulnerable via indirect effects, such as trophic cascades.

Modeling studies of large-scale changes in water chemistry will help us understand and predict ecosystem responses. Models will be used to inform development of adaptation strategies to ocean and lake acidification. New modeling approaches also will be explored.

Left to right: Left, Research cruises will continue to be essential to ocean acidification monitoring and research. Shown is NOAA Ship Ronald H. Brown, *a state-of-the-art oceanographic and atmospheric platform. Autonomous underwater vehicle (AUV) in foreground. (Photo credit: NOAA); Center: The Wave Glider, a solar-powered AUV, is being tested for use with a variety of sensors to detect ocean acidifcation. (Photo credit: With permission from Liquid Robotics, Inc.); Right, First ocean acidification mooring deployed in Gulf of Alaska at Papa Station, 2007 (Photo credit: NOAA).*

REGIONAL APPROACH



6 regions

Alaska Region
West Coast Region
Pacific Islands Region
Northeast Region
Great Lakes Region
Southeast Atlantic
and Gulf of Mexico Region

Regions for ocean and lake acidification monitoring and research are shown in the tan shaded areas.

All six themes of the research plan will be executed at the regional level with strong national coordination. The Implementation Timeline can be viewed on page 10 of this document.

MONITOR

- Ocean acidification
- (OA) moorings
- Coral reef monitoring sites
- OA sensors on NOAA research vessels and Voluntary Observing Ships (VOS)

MANAGE

- Socioeconomic models and decision support tools
- Test mitigation approaches in lab

ASSESS

- Single species experiments
- Multi-species mesocosm experiments

SYNTHESIZE

- Data management coordination, synthesis, integrated synthesis activities

FORECAST

- Test/evaluate existing global and regional models
- Develop high resolution physical-biogeochemical-ecosystem models
- Coastal early warning system

ENGAGE

- Education and outreach planning
- Curricula and product development

ALASKA

The Alaska region produces nearly 50 percent of all U.S. seafood. Climate change, most notably sea ice loss and ocean warming, already affects habitats in this sensitive region. Combined effects of ocean acidification and climate change on food webs and, ultimately, seafood production are not known. Existing food web models for the region will be used to predict changes in productivity upon incorporating ocean acidification data and climate change scenarios. At present, the region is sparsely monitored. The first dedicated ocean acidification buoy to be implemented is sited in the Gulf of Alaska. Monitoring will be implemented in Katchemak Bay, Bering Sea, Arctic Ocean, Gulf of Alaska and southeast Alaska.

King crab
Euphausiids
Deep-sea corals • Walleye pollock

WEST COAST

Commercial fisheries in the West coast region generated $504 million in ex-vessel revenue from finfish and shellfish in 2008. Deep, nutrient-rich waters brought to the surface by the coastal upwelling process is a life support system for the region's fisheries. However, coastal upwelling also brings some of the oldest and most corrosive upwelled waters to the surface. Ocean acidification has been implicated in the near-total failure of the $100 million a year oyster industry over the past four out of five years. To provide a basis for an "early warning system" for ocean acidification and to follow its long-term patterns, the California Current System from Canada to Mexico will be monitored. Impacts on key species and downstream effects on overall carbon cycling and rates of ocean acidification will be examined.

Bivalves (geoduck, oysters) • Zooplankton
Deep-sea coral • Sea urchins
Dungeness crab • Pacific sardines • Rockfish

PACIFIC ISLANDS

Home to a large percentage of the Nation's most biologically diverse coral reef systems, the coral reefs of the Main Hawai'ian Islands are valued at nearly $10 billion (in 2002 dollars) with an annual benefit of $385 million. The region also provides habitats for many endangered marine mammals. With few pressures from pollution, fishing, tourism, recreation, and coastal development in remote areas of the Hawai'ian Archipelago, the region will focus on coral reef monitoring and understanding and assessing the effects of ocean acidification on reef growth and biodiversity. Because of their naturally rich CO_2 environments, shallow hydrothermal vents will serve as models for fine-scale changes in ocean chemistry. The largest international effort in the program, a Coral Reef Ocean Acidification Monitoring Network , is this region's highest priority.

Reef–building, crustose coralline algae
Coral reef diversity • Hawaiian monk seal • Hawksbill and green sea turtle • Protected cetaceans

ORGANISMS OF NEAR-TERM FOCUS

Organisms of near-term focus are species important to the region's ecosystems and economy. These species could be directly affected by acidification or through disturbance of species that they depend on for food.

Seagrass
Calcifying plankton • Oysters • Reef-building corals
White, brown, and pink shrimp

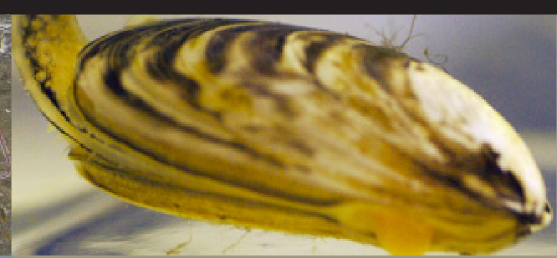
SOUTHEAST ATLANTIC AND GULF OF MEXICO

Already experiencing widespread eutrophication and associated oxygen depletion, commonly referred to as "dead zones," the entire $600 million commercial fishery in the Gulf and the entire $550 million commercial fishery along the Atlantic may be affected by ocean acidification. The Southeast Atlantic/Gulf of Mexico region's research and monitoring will focus on the interaction among these processes, as well as coral health, which has suffered significant declines over the past several decades. Sustained monitoring is coupled to focused hypothesis-guided studies and modeling. Impacts on seagrass and estuaries also will be studied, as will historical responses, where feasible.

Lobsters • Primary producers • Scallops • Clams
Mussels • Oysters • Deep-sea coral • Shortnose sturgeon • Flounder • Black sea bass • Right whale

NORTHEAST

Many of the 1,000 fish species in the Northeast region support a large fishing industry, which in 2006 produced fish and shellfish landings worth over $1.2 billion. The saturation state of surface waters off the coast of New England are expected to decline sooner than other areas of the Northeast, especially during the winter months. Hypoxia, a growing threat in the region's estuaries, may be adding CO_2 to Northeast waters. The combined effects of hypoxia and ocean acidification are poorly understood. In addition to response and modeling studies across the food web, a monitoring program will focus on the Northeast U.S. continental shelf ecosystem. Marine protected areas are potential sentinel sites for existing and new monitoring programs.

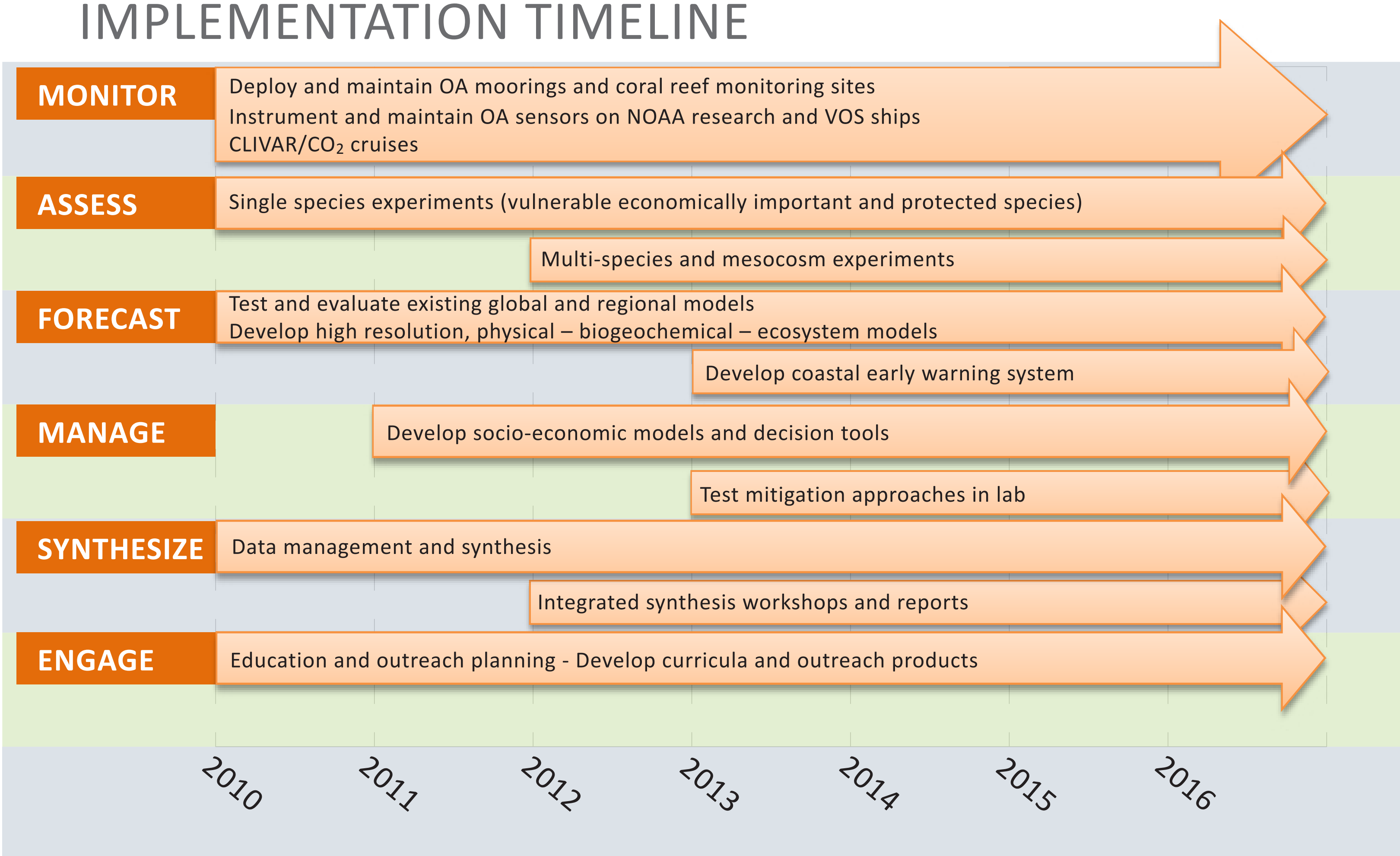


Invasive species: Zebra and quagga mussels
Native species: Unionid bivalves (42 species) and Amphipods

GREAT LAKES

Approximately 34 million people depend on the Great Lakes for drinking water. Its ecosystems currently face a number of grave environmental threats, including ecological impacts from roughly 185 non-native aquatic species, toxic and nutrient pollution, habitat destruction, animal and human disease outbreaks, and climate change. Patterns of lake acidification with respect to atmospheric CO_2 patterns and these stressors are not well understood. Because invasive zebra mussels have played an increasingly important role in the energy and nutrient cycles of the Great Lakes, impacts of elevated CO_2 on invasive and native bivalve populations will be investigated. A monitoring network will be implemented across all five lakes and all seasons.

IMPLEMENTATION TIMELINE



The Fiscal Year 2010 (FY10) enacted funding for ocean acidification activities in NOAA was $5.5M. In FY11, the President's Budget request is $11.6M for research on ocean acidification. NOAA requests an increase in FY11 to implement a NOAA Integrated Ocean Acidification (OA) Program. The OA Program will support research and long-term monitoring of ocean acidification for assessing climate change impacts on living marine resources. NOAA is actively working to implement the recently enacted Federal Ocean Acidification Research and Monitoring Act, which creates an Ocean Acidification Program within NOAA.

EXPECTED OUTCOMES

Themes

Monitor

Assess

Forecast

Manage

Synthesize

Engage

Expected Outcomes

Conservation of our marine ecosystems and sustenance of the services our oceans, coastal, and Great Lakes ecosystems in the face of climate change

Integrated assessments of ecological and societal impacts in each region

Early warning system for U.S. coastal waters and Great Lakes

Improved public understanding of ocean acidification and stewardship of the oceans and Great Lakes

INFRASTRUCTURE

As part of the Federal Ocean Acidification Research and Monitoring Act of 2009, the United States Joint Subcommittee on Ocean and Science Technology (JSOST) is designated as the subcommittee that coordinates federal activities on ocean acidification. Under this plan, JSOST established the Interagency Working Group on Ocean Acidification (IWGOA) to develop the strategic research and monitoring plan to guide federal research on ocean acidification. NOAA is the lead agency of the IWGOA.

PARTNERSHIPS

The development of a program to fulfill the NOAA Ocean and Great Lakes Acidification Research Plan benefits from a coordinated national research effort closely linked with other U.S. federal and state government, university, and private efforts.

Interagency Partners

National Science Foundation

National Aeronautics and Space Administration

Environmental Protection Agency

U.S. Fish and Wildlife Service

U.S. Geological Survey

Bureau of Ocean Energy Management, Regulation and Enforcement

Department of the Navy

Department of State

International cooperation

will be coordinated through the Surface Ocean–Lower Atmosphere Study (SOLAS) and Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) Working Group on Ocean Acidification. This international group has two main goals: (1) coordinate international research efforts in ocean acidification; and (2) undertake synthesis activities in ocean acidification at the international level.

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