7 Reduce Impacts of Climate Change

Introduction

The 2007 Intergovernmental Panel on Climate Change assessment reports that global temperature has increased substantially over the last 100 years, due in large part to the burning of fossil fuels. Increases in ocean temperatures as a consequence of rising atmospheric carbon dioxide (CO_2) levels threaten coral reef ecosystems through increased frequency and severity of mass coral bleaching and disease events, sea level rise, and possibly storm activity. In addition, increasing atmospheric CO_2 is likely to reduce calcification rates in reef-building organisms by altering the chemistry of seawater. Reduction in calcification rates directly affects the growth of individual corals and the reef's ability to maintain itself against erosional forces, potentially compounding the "drowning" of reefs caused by sea level rise.

Given that controlling climate change is beyond the purview of coral reef managers, effective management of coral ecosystems in light of climate change requires a better understanding of ecosystem resilience. Reef resilience has been defined by the United Nations Environment Programme as "the return of a coral reef ecosystem to a state in which living, reef-building corals play a prominent functional role, after this role has been disrupted by a stress or perturbation." One management strategy is to mitigate stress and damage caused by local stressors to improve reef condition, thus reducing the ecosystem's vulnerability to regional or global bleaching events. After-the-fact management actions to reduce local stressors also may facilitate recovery after a bleaching event.[1]

CRCP addresses the need to reduce the impacts of climate change by supporting activities that improve our understanding of the impacts of climate change, increase public awareness regarding those impacts, and promote the development of management strategies. CRCP efforts funded under this category broadly support the NOAA goal to sustain healthy and productive coastal and marine ecosystems that benefit society. Climate projects support the CRCP program goal of enhancing resilience of coral reef ecosystems.

The types of activities supported by the CRCP under this category include both internal NOAA projects conducted through the Coral Reef Ecosystem Integrated Observing System (CREIOS) and external grant projects funded through the CRCP Grants Program. Activities include long-term climatic data gathering, mass coral bleaching monitoring and response, research targeting both ocean acidification and the bleaching of corals and other reef invertebrates, and the

[1] The introductory text is excerpted, with slight modifications, from the NOAA Coral Reef Ecosystem Research Plan (2007).

development of outreach and education products. CRCP has funded and implemented projects in two areas of concern:

- Coral Bleaching and Resilience to Climate Change
- Ocean Acidification

Between 2002 and 2006, the CRCP provided $0.4 million (M) to directly support 11 projects in this category, and accounted for less than 1% of the overall CRCP funding and overall number of projects (Exhibit III-7-1). Indirect funding of climate issues through CREIOS funding is difficult to estimate; CREIOS funding between 2002 and 2006 was $42.2M total, including $22.9M for monitoring efforts which address long-term climatic data records, thermal stress observations, ocean acidification research, and paleoclimatic analyses. For more information on CREIOS, please refer to Tab III, Chapter 1.

Exhibit III-7-1
Investment in Reduce Impacts of Climate Change, 2002-2006

Spend Plan Category	Number of Projects	% Category Projects	% Total Projects	Funding	% Category Projects	% Total Projects
Reduce Impacts of Climate Change	**11**	**0.8**	**0.8**	**$398,096**	**0.3**	**0.3**
Reduce Impacts of Climate Change	11	100.0	0.8	$398,096	100	0.3

The distribution of funds and effort by tool for this category is shown in Exhibits III-7-2a and -2b. The majority of climate funding is spent on research tools (43%).

Exhibit III-7-2a
Reduce Impacts of Climate Change
Investments by Tool

Tool	2002		2003		2004		2005		2006		TOTALS 2002-2006			
	Number of Projects	Funding	Number of Projects	Funding	Number of Projects	Funding	Number of Projects	Funding	Number of Projects	Funding	Number of Projects	% of Total Subcategory Projects	Funding	% of Total Subcategory Funding
Ecosystem Research	0	$0	0	$0	3	$49,010	3	$46,787	1	$77,299	**7**	**64**	**$173,096**	**43**
Socioeconomic Research	0	$0	0	$0	0	$0	1	$15,000	0	$0	**1**	**9.1**	**$15,000**	**4**
Mapping and Monitoring	0	$0	0	$0	0	$0	0	$0	1	$50,000	**1**	**9**	**$50,000**	**13**
Outreach	1	$55,000	0	$0	0	$0	0	$0	0	$0	**1**	**9.1**	**$55,000**	**14**
Management: Direct Implementation	0	$0	0	$0	0	$0	0	$0	0	$0	**0**	**0**	**$0**	**0**
Management: Training/Technical Assistance	0	$0	0	$0	1	$105,000	0	$0	0	$0	**1**	**9.1**	**$105,000**	**26**
None or N/A	0	$0	0	$0	0	$0	0	$0	0	$0	**0**	**0**	**$0**	**0**
TOTALS	**1**	**$55,000**	**0**	**$0**	**4**	**$154,010**	**4**	**$61,787**	**2**	**$127,299**	**11**	**100**	**$398,096**	**100**

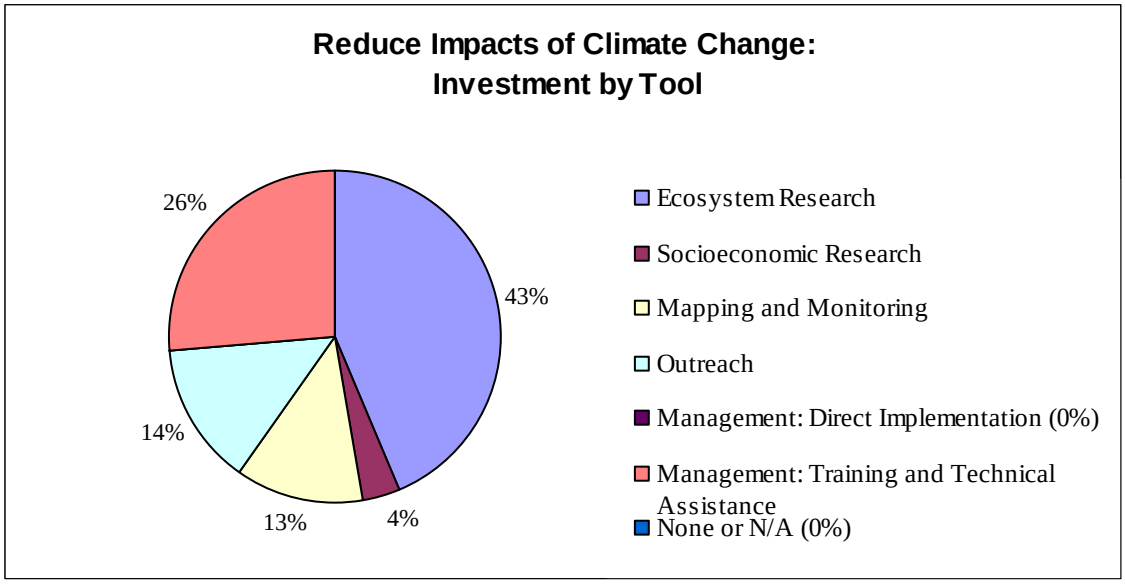

Exhibit III-7-2b. Distribution of Investments by Tool, 2002-2006

The distribution of funds and effort by region for this category is shown in Exhibits III-7-3a and 3b. Most of the funding is split between the Atlantic/Caribbean (47%) and all regions (43%).

Exhibit III-7-3a
Reduce Impacts of Climate Change
Investments by Region

Region	2002		2003		2004		2005		2006		TOTALS 2002-2006			
	Number of Projects	Funding	Number of Projects	Funding	Number of Projects	Funding	Number of Projects	Funding	Number of Projects	Funding	Number of Projects	% of Total Subcategory Projects	Funding	% of Total Subcategory Funding
Atlantic/Caribbean	0	$0	0	$0	1	$15,410	2	$44,887	2	$127,299	**5**	**45.5**	**$187,596**	**47.1**
Pacific	0	$0	0	$0	2	$33,600	1	$6,900	0	$0	**3**	**27.3**	**$40,500**	**10.2**
FAS(International)	0	$0	0	$0	0	$0	0	$0	0	$0	**0**	**0.0**	**$0**	**0**
International	0	$0	0	$0	0	$0	0	$0	0	$0	**0**	**0**	**$0**	**0**
All Regions	1	$55,000	0	$0	1	$105,000	1	$10,000	0	$0	**3**	**27.3**	**$170,000**	**42.7**
TOTALS	**1**	**$55,000**	**0**	**$0**	**4**	**$154,010**	**4**	**$61,787**	**2**	**$127,299**	**11**	**100**	**$398,096**	**100**

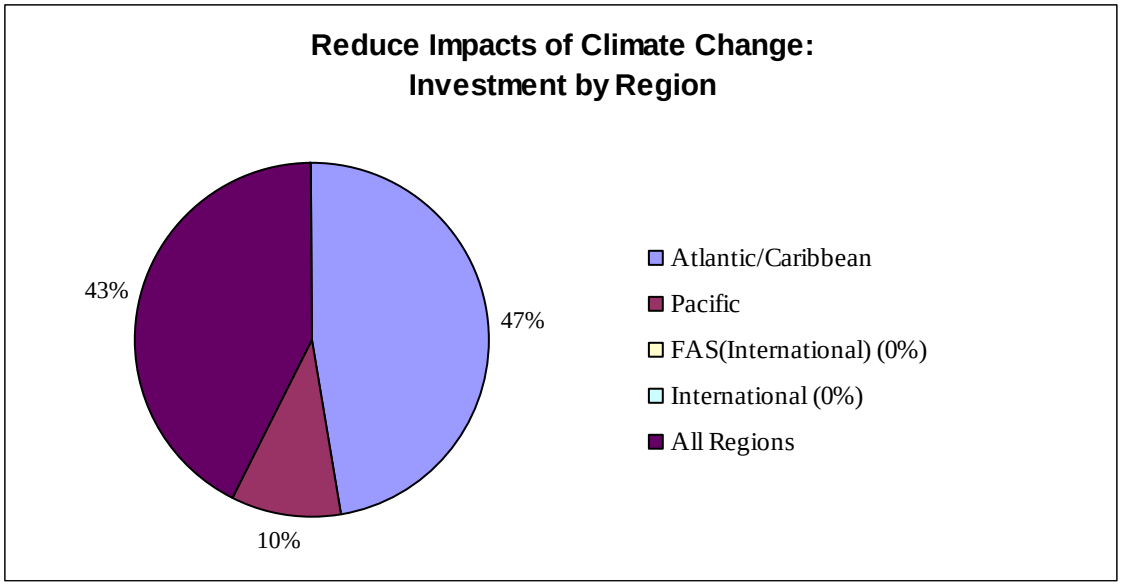

Exhibit III-7-3b. Distribution of Investments by Region, 2002-2006

Focus Area: Coral Bleaching and Resilience to Climate Change

The coral bleaching and resilience effort includes projects and activities that address climate change vulnerability, local management strategies for building resilience to climate change, socioeconomic modeling, bleaching physiology, and outreach efforts. The projects funded under this category are often supported, complemented, and enhanced by other CRCP projects, particularly those covered in Tab III, Chapter 1: Assess and Characterize U.S. Coral Reefs (CREIOS).

Coral bleaching, caused by an interaction between increasing ocean temperatures and light exposure, is now considered a major threat to coral reef ecosystems. Climate predictions call for even greater frequency and severity of mass bleaching events over the next 50 years. NOAA is conducting long-term monitoring and research to understand the underlying causes of coral bleaching, to clarify initial and long-term impacts of coral bleaching events, and to identify factors affecting resistance and resilience to coral bleaching. Monitoring of key physical and chemical data at coral reef sites allows us to relate environmental changes with observed responses, such as coral bleaching, algal blooms, and disease.

NOAA also supports physiological studies through its grants program to study temperature tolerances of coral-algal symbioses and other reef invertebrates. Great strides have been made to understand the physiological mechanisms linking climate change to bleaching, but variability in bleaching responses are just beginning to be understood. For example, much more information is needed to understand how ultraviolet and photosynthetically active radiation (PAR) interact with temperature to induce coral bleaching.

a. Activities

CREIOS provides long-term monitoring that enables coral reef managers to detect and act on significant natural or anthropogenic changes to these ecosystems. Integration of the long-term spatial and temporal data from surface and subsurface moorings, *in situ* human observations, and satellite remote sensing provides researchers and resource managers with an improved understanding of the influences of global climate change on coral reef ecosystems. (For more detailed information on CREIOS, please see Tab 3, Chapter 1.)

CREIOS monitors conditions that can cause mass coral bleaching by tracking sea surface temperatures and providing local managers and scientists with the information they need to make informed decisions. Coral bleaching alerts allow managers and scientists to deploy monitoring efforts and take actions to reduce local stressors that further threaten bleached corals, frequently in advance of the bleaching.

NOAA conducts a wide variety of research-to-operations activities using *in situ* and satellite data, including analyses of historical satellite data, coral geochemistry and skeletal growth analyses to develop paleoclimatic data records, and domestic and international training workshops on satellite tools and reef resilience. In addition, NOAA is supporting work to predict socioeconomic effects that may arise from predicted levels of climate change and coral bleaching for the Florida Keys. This effort is based on similar work on communities dependent on Australia's Great Barrier Reef.

The CRCP Grants Program has funded external partners to:

- Assess the vulnerability of American Samoa's reefs to climate change, including identifying temperature tolerant coral areas.
- Develop an outreach and education campaign on coral reefs and climate change, and implement a reef resilience program in Florida.
- Support targeted research on bleaching physiology.
- Improve the understanding of the impacts of bleaching on barrel sponge mortality, recruitment, growth, and demography on Florida reefs.
- Develop a predictive model for coral bleaching that takes into account the physiology and diversity of zooxanthellae.

b. Funding Recipients and Partners

To carry out the projects dealing with coral bleaching and resilience to climate change, the CRCP partnered with the NOAA offices and external partners listed in Exhibit III-7-4.

Exhibit III-7-4
Coral Bleaching and Resilience to Climate Change
Funding Recipients and Partners

NOAA Offices	Other Federal Agencies	States and Territories	Academic Institutions	Non-Governmental Organizations
• NESDIS - Center for Satellite Applications and Research	• Great Barrier Reef Marine Park Authority (Australia)	• American Samoa	• University of Delaware	• National Wildlife Federation
• NMFS - Pacific Islands Fisheries Science Center	• Australian Institute of Marine Science	• Palau	• University of North Carolina at Wilmington	• The Nature Conservancy
• NOS - Office of Response and Restoration			• University of Queensland (Australia)	• The World Bank and the Global Environment Facility
• NOS - Office of National Marine Sanctuaries				
• NMFS - Southeast Regional Office				
• OAR - Atlantic Oceanographic and Meteorological Laboratory				

c. Outputs

CRCP provides a suite of operational satellite-based and experimental *in situ* coral bleaching monitoring products. When data show that conditions are conducive to bleaching, we provide watches, warnings, and alerts via e-mail to users around the globe. CRCP, in partnership with the World Bank and the Global Environment Facility, has conducted a series of Coral Bleaching Satellite Tools Workshops to train international and domestic managers and scientists on satellite monitoring products for coral bleaching.

CRCP, in partnership with the Great Barrier Reef Marine Park Authority (GBRMPA) and many others, published *A Reef Manager's Guide to Coral Bleaching* (*Guide*) in 2006. This document answers the question: "What can local coral reef managers do to address coral bleaching events?" The *Guide* provides information on the causes and consequences of coral bleaching, and management strategies to help local and regional reef managers lessen the threat that bleaching poses to coral reef ecosystems. The document includes contributions from over 50 experts in coral bleaching and coral reef management from 30 organizations, and underwent extensive internal and external peer review.

CRCP also has supported paleoclimatic efforts to analyze coral geochemistry and skeletal growth records from the Florida Keys, Puerto Rico, and the USVI. These data extend the climate record into the past, beyond available *in situ* and satellite data records.

d. Performance Metrics

No specific performance metrics are tracked for this subcategory. Progress and performance are measured at the project level. Some climate-related CREIOS efforts may be tracked under the metric "Develop and make operational a comprehensive integrated coral reef ecosystem monitoring program."

e. Outcomes

The 2005 Caribbean bleaching event provided a good example of the outcomes of this work. While thermal stress around the world has increased over the last 20 years, thermal stress in the Caribbean in 2005 far exceeded previous levels, giving rise to the most intense mass coral bleaching event ever observed in the Caribbean. Many reefs, including those in the USVI, suffered bleaching of over 90 percent of their corals. NOAA's satellite and *in situ* monitoring were effective in alerting managers and scientists to this event as it developed. Subsequently, an interagency effort led by NOAA and the Department of Interior was convened under the USCRTF to engage many government and non-government partners from across the region to assess the impacts of this unprecedented event and make recommendations on how to prepare for and address future events. Detailed monitoring of reefs and investigations on the response of individual colonies should help elucidate why some corals survived while others perished.

In another example, CRCP, in partnership with the Australian Institute of Marine Science (AIMS) and The Nature Conservancy (TNC), developed a hydrodynamic model to predict the spatial distribution of heat stress on Palau's corals during a typical bleaching event. The model indicated regions that experienced less thermal variability and were generally protected from mild to moderate bleaching stress. Regions that typically undergo extremes of temperature variability were likely to have corals already adapted to thermal stress. The modeling effort was conducted in conjunction with efforts by the Palau Government to implement a Protected Areas Network (PAN) for Palau's coral reef ecosystem. The design of the PAN was undertaken following the unprecedented coral bleaching and mortality that occurred in Palau in 1998, in an attempt to build in resilience to mitigate against future climate change.

Projects funded through the CRCP grants program have improved the understanding of the basic biology and ecology of the Caribbean barrel sponge, *Xestospongia muta*. This sponge, much like coral reefs, provides critical complex habitat and has been observed to bleach. Results to date have documented the levels of bleaching to be greatest at deep sites, with as much as 71% of the deep-water sponge populations exhibiting some level of bleaching. Presently there is no evidence that the bleaching of these deeper populations results from elevated seawater temperatures.

Through the Coral Bleaching Satellite Tools Workshops, domestic and international reef managers are able to improve their understanding of how NOAA satellites can help them monitor for the conditions that cause coral bleaching. This knowledge helps trainees improve research and management of their coral resources in the face of future coral bleaching events and climate change. In addition, the success of these workshops has led to an expansion of the training program to include content from *A Reef Manager's Guide to Coral Bleaching*. These future workshops, in partnership with the GBRMPA, the World Bank/GEF Coral Reef Targeted Research Program, and TNC, will add a focus on concrete actions reef managers can take to protect their reefs from coral bleaching.

f. Challenges

While climate change is clearly recognized as a threat to coral reef ecosystems, and to the human communities that depend upon them, the CRCP directly allocates a small percentage of its budget to climate projects and bleaching physiology research. A great deal of effort is spent on programmatic planning and development of funding initiatives, and until a reasonable amount of resources are committed, many research and development activities will remain stalled and monitoring will not be started on many important climate relevant environmental parameters. NOAA needs to determine whether it will place a priority on climate change impacts on coral reef ecosystems and devote adequate funding to this effort.

g. Future Directions

Key actions the CRCP should take to achieve its climate goals include increased capacity and stability in staff; monitoring at multiple spatial and temporal scales to provide comparable data across regions and across the nation; expansion of parameters monitored using NOAA's existing fleet of satellites and *in situ* infrastructure; and expansion of existing monitoring programs for greater temporal and spatial resolution and to address questions on emerging issues (*e.g.*, climate change impacts and ocean acidification).

Currently NOAA has begun, or is considering, efforts to increase CRCP's climate funding through NOAA's budgetary planning process including:

- Improved satellite-based tools and integrated climate applications for coral reef managers.
- New coral bleaching forecast system that incorporates model-derived sea surface temperature forecasts to produce seasonal bleaching outlooks.
- Vulnerability assessments for U.S. coral reef ecosystems to understand predicted impacts and possible responses to climate change.
- Expanded workshops that will train managers and stakeholders on *A Reef Manager's Guide to Coral Bleaching.*

Given more funding for targeted research on coral reef resilience, CRCP would address new questions including:

- Do the addition of human impacts and the fragmentation of coral reef habitats (affecting gene flow) undermine coral reef resilience and make them more susceptible to coral bleaching?
- What is the relationship between the decline of coral ecosystems caused by bleaching and the condition of reef-dependent fisheries?
- Do increased thermal stress and bleaching frequency lead to increased incidence of coral diseases?
- What can be done at a local level to increase the chances of recovery after a bleaching event?
- What is the influence of changing carbon chemistry on corals and reefs and how does this interact with temperature?

Given more funding for targeted research on bleaching physiology, CRCP would address questions including:

- How much of the variability in bleaching observed within and among species (and within and among reefs) is explained by environmental patchiness (in temperature, light, water motion, chemistry), compared to phenotypic and genotypic variability in corals and their symbiotic algae?
- What is the relationship between coral bleaching and non-temperature related stressors such as light and pollutants?
- How could the answers to these questions contribute to our current products to improve predictions of bleaching, disease, and other stress-responses?

Focus Area: Ocean Acidification

The CRCP-funded ocean acidification efforts during 2002-2006 included some preliminary monitoring efforts and partial support of the interagency *Impacts of Ocean Acidification on Marine Calcifiers Workshop*. As ocean acidification has emerged as an issue, the CRCP has sought to develop a broad initiative across NOAA to support ocean acidification threat assessment, monitoring, and forecasting. The CRCP works closely with other parts of NOAA and Federal agency partners to advance this effort.

a. Activities

NOAA has been indirectly monitoring ocean acidification through cruises and hydrographic stations and has recently begun deployment of a limited number of autonomous sensors on buoys and fixed stations capable of measuring the relevant chemistry. CRCP has supported research activities seeking to couple *in situ* instruments, satellite data, and models to track changes in

ocean chemistry and monitor the responses of reef communities. Ocean acidification efforts include:

- Deployment of sensors to measure surface partial pressure of carbon dioxide (pCO_2).
- Satellite derived pCO_2 model development.
- Programmatic activities including presentations, workshops, NOAA-wide planning initiatives, and congressional briefings and hearings.

These monitoring and data integration efforts are considered to be part of CREIOS.

CRCP is a key component of a proposed NOAA-wide ocean acidification initiative. CRCP continues to support interagency strategic planning for ocean acidification research and monitoring.

b. Funding Recipients and Partners

To carry out the projects dealing with ocean acidification, the CRCP is seeking partnerships with the NOAA offices and external partners listed in Exhibit III-7-5.

Exhibit III-7-5
Ocean Acidification
Funding Recipients and Partners

NOAA Offices	Other Federal Agencies	Academic Institutions
• NESDIS - Center for Satellite Applications and Research	• DOI - U.S. Geological Survey	• University of Miami
• NOAA - Ecosystem Research Program	• National Science Foundation	• University of Puerto Rico
• NOAA - Ecosystem Observation Program		
• NOAA - Climate and Ecosystem Program		

c. Outputs

NOAA, in partnership with the National Science Foundation and the U.S. Geological Survey, recently released the interagency report *Impacts of Ocean Acidification on Coral Reefs and*

Other Marine Calcifiers: A Guide for Future Research, which documents the threats posed by ocean acidification and highlights actions that need to be taken.

Work has begun on developing concepts for a Coral Reef Metabolic Monitoring Network, which will characterize *in situ* carbonate chemistry near selected reefs in relation to offshore sea surface chemistry modeled from satellite remote sensing. This effort has three components:

- A new model based on satellite data to estimate surface pCO_2 and other carbon chemistry parameters for the Greater Caribbean Region.
- Deployment of oceanic sensors Caribbean reef sites to provide near-real-time pCO_2 data at Lee Stocking Island in the Bahamas, Molasses Reef in the Florida Keys, and La Parguera, Puerto Rico.
- A Caribbean pilot study of the new Reef Metabolic Index, which incorporates pCO_2 estimates from satellite data with *in situ* pCO_2 sensor data to monitor coral reef health in response to climate- and ocean acidification-related stress.

d. Performance Metrics

No specific performance metrics are tracked for this subcategory. Progress and performance are measured at the project level. Some climate-related CREIOS efforts may be tracked under the metric "Develop and make operational a comprehensive integrated coral reef ecosystem monitoring program."

e. Outcomes

Understanding how carbonate chemistry varies naturally on coral reefs provides a critical step in understanding the potential threat of continued ocean acidification. CRCP, together with the University of Miami, has led efforts to measure this variability at selected reefs and relate such changes to the larger regional context across the Greater Caribbean Region.

f. Challenges

While ocean acidification is clearly recognized as an emerging threat to coral reef ecosystems, limited funding is currently available in CRCP to address this issue. Great effort is spent on programmatic planning and development of funding initiatives, and until a reasonable amount of resources are committed, many research and development activities are stalled.

A critical challenge to the deployment of a carbon monitoring network is the need to develop advanced technologies for monitoring ocean acidification in coastal (reef) waters. This technological challenge falls beyond the purview of the CRCP, so continued collaborations with other NOAA programs, Federal agencies, and academia are necessary to meet this requirement.

One critical challenge for CREIOS is to plan, deploy, and integrate observing systems that will meet scientific requirements to answer key questions, while also providing long-term consistent data on key biological and physical parameters. Funding, infrastructure, and political considerations frequently hamper the integration of existing, but disparate, systems and the adaptation of observing systems to address new scientific questions (*e.g.,* ocean acidification). CREIOS needs the resources and focus to partner with other programs such as IGOS to take advantage of existing monitoring capabilities while expanding in a way that answers questions critical to understanding the impact of ocean acidification on coral reefs.

g. Future Directions

Currently NOAA has begun, or is considering, efforts to increase CRCP's ocean acidification funding through NOAA's budgetary planning process including:

- Autonomous moored systems designed to characterize *in situ* carbonate chemistry on and near coral reefs.
- Broad shore-based spatial surveys of carbonate chemistry and in-the-water calcification rates.

Given more funding for targeted research on ocean acidification, CRCP would address the new questions including:

- How will warming, sea level rise, changing circulation patterns, and increased dissolved carbon dioxide in the ocean affect the structure and function of coral reefs over the next 50 to 100 years?
- How have corals responded to climate and carbon dioxide variability in the past?
- What effect will decreased calcification and increased erosion have on ecosystem structure and function?
- How will increased acidification and rising temperatures interact?