NOAA Pacific Islands Fisheries Science Center (PIFSC)
Ocean Acidification Research Implementation Plan for FY11

1. Introduction

1.1. Geographic Domain and Ecosystems

The Pacific Islands Region (PIR) encompasses the largest geographical management area within NOAA with a total area of responsibility of more than 1.5 million square nautical miles. This is roughly equal to the size of all of the remaining U.S. Exclusive Economic Zones (EEZ) waters combined. These areas; which span from Hawaii in the east, to Guam and the Northern Mariana Islands (NMI) in the west, to American Samoa in the south, are separated by many 1000s of kilometers of vast international waters.

Coral reefs provide substantial ecological goods and services, and economic and cultural vitality to island communities across the PIR through fisheries, tourism, building materials, coastal protection, and biogeochemical research for pharmaceuticals (*Hoegh-Guldberg* 2007). Reefs of the Main Hawaiian Islands (MHI) have an estimated net value of nearly $10 billion with an average annual benefit of $385 million, with the largest contribution from recreation and tourism (*Cesar* 2000, 2008). According to even the most optimistic climate models, a critical atmospheric CO_2 threshold of 480 - 500ppm will be surpassed within the next 80 years, at which point coral reef communities will likely undergo significant ecological phase shifts with calcification of reef-building corals and crustose coralline algae unable to keep pace with bioerosion processes (*Hoegh-Guldberg* 2007). As this occurs, many of the ecological, economic, and cultural values provided by coral reefs to the local communities of the Pacific Islands could be devastatingly impacted.

2. Recent PIFSC Ocean Acidification Research

As part of NOAA's interdisciplinary Pacific Reef Assessment and Monitoring Program (Pacific RAMP), led by the Pacific Islands Fisheries Science Center Coral Reef Ecosystem Division (CRED), efforts to establish baselines and monitor changes in both carbonate chemistry and the associated ecological impacts of ocean acidification were initiated in 2005 and evolved slowly up until FY10 when efforts were significantly upscaled through the completion of the Pacific Islands Region Ocean Acidification Research Plan and the NMFS Ocean Acidification Research Program was initiated. The PIFCS has implemented a comprehensive ecosystem-wide approach to carbonate chemistry and biological response monitoring to ocean acidification.

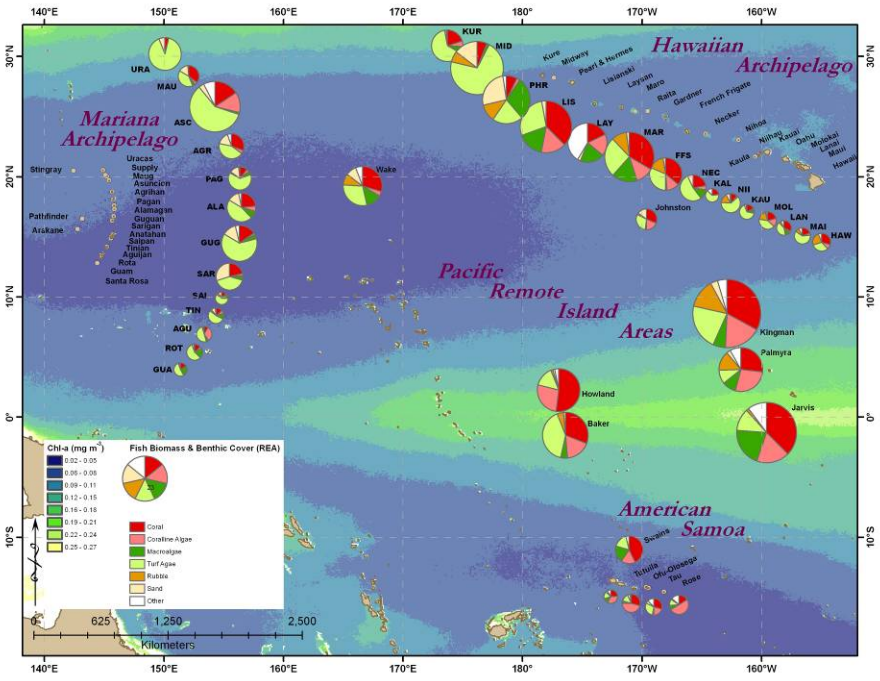

Figure 1. Breadth and scope of Pacific RAMP across the Pacific Islands region. Size of pie charts represent total reef fish biomass for 40 islands and atolls from rapid ecological assessment (REA) surveys. Composition of pie charts represents benthic composition from towed-diver benthic surveys. Pie charts are plotted over mean chlorophyll a concentrations from SeaWiFS ocean color. (*Brainard et al.*, 2010)

2.1. Carbonate Chemistry

The carbonate chemistry monitoring led by PIFSC, in collaboration with NOAA's Pacific Marine Environmental Laboratory (PMEL), Coral Reef Watch, and Atlantic Oceanographic and Meteorological Laboratory (AOML) has focused on determining spatial patterns and temporal variability across gradients of biogeography, oceanographic/environmental conditions, and habitat types (pelagic, forereef, backreef, lagoon, etc) throughout the PIR. From 2008 to 2011, monitoring of carbonate chemistry has focused primarily on simpler unpopulated low islands and atolls, mostly within PMNM, the Pacific Remote Islands Marine National Monument (MNM), the Mariana Trench MNM, and Rose Atoll MNM, which do not have these confounding issues. The PIFSC has leveraged funds from the Coral Reef Conservation Program to fund much of the carbonate chemistry aspect of PIFSC Ocean Acidification research, with NMFS funding focused on the monitoring of the biological and ecological responses to changing carbonate chemistry. However, without the carbonate chemistry aspect, the approach would be greatly limited in scope.

2.2. Biological Monitoring

In the PIR, PIFSC has initiated efforts to assess and monitor the broad-scale, long-term ecological impacts of ocean acidification on coral reef ecosystems, which include the nesting and breeding habitats for endangered monk seals and threatened sea turtles. Biennial Pacific Reef Assessment and Monitoring Program (Pacific RAMP) surveys include quantitative spatial and temporal monitoring of composition, abundance, distribution, size, and condition of non-cryptic

biota, and key oceanographic parameters influencing ecosystem health, such as temperature, salinity, wave energy, nutrients, chlorophyll *a*, and turbidity.

In 2010 PIFSC initiated a large number of ocean acidification projects to constrain and better understand the biological response to ocean acidification. These included coral coring, calcification plate installation, computer modeling, and investigations into invertebrate diversity using Autonomous Reef Monitoring Structures (ARMS). Coral cores from 18 separate *Porites spp* were collected from the Line Islands and shipped to WHOI for analysis with CT-Scan technology, a novel technique for imaging corals. Preliminary results show that *Porites spp.* growth rates for Jarvis Island are ~16mm/yr and at Palmyra are ~14mm/yr, both higher than the Indo-Pacific average of ~10mm/year. Additionally, Jarvis Island calcification rates are equivalent to Great Barrier Reef *Porites spp.*, at ~1.2 g/cm^2/yr. Palmyra *Porites spp.* have higher calcification rates of ~1.6 g/cm^2/yr. A total of 517 Calcification Acidification Units (CAUs) were installed in forereef communities throughout the Pacific to assess spatial patterns and monitor long-term trends in carbonate accretion. The first CAU plates, deployed in 2010, will be recovered in FY12. A number of modeling techniques were used to quantitatively examine rates of coral cover change due climate change and ocean acidification (*Hoeke et al 2010*). This PIFSC-CRED paper, written in collaboration with Hawai'i Institue of Marine Biology (HIMB) was utilized by the Biological Review Team tasked with developing the Status Review Report assessing the status of and estimating the risk of extinction to 82 candidate coral species petitioned for listing under the U.S. Endangered Species Act.

From 2008 to present, as part of both Pacific RAMP and the Census of Marine Life's Census of Coral Reef Ecosystems (CReefs) project, PIFSC and multi-institutional partners have initiated a global assessment of cryptic biodiversity associated with coral reefs, often calcifying invertebrates and algae, to serve as an essential baseline to measure changes in benthic community structure in response to ocean acidification. In FY10, 161 Autonomous Reef Monitoring Structures (ARMS) were successfully recovered and processed during Pacific RAMP cruises (34 in the NWHI, 28 in the MHI, 33 in American Samoa, and 45 in the Pacific Remote Island Areas). Additionally, 144 ARMS units were redeployed during RAMP efforts to commence a time series in order to monitoring changes in the diversity of cryptic communities. ARMS deployments continue at many more select islands/atolls across the Pacific Island Region, Coral Triangle, Indian Ocean, and Caribbean Sea (Fig 2, *Brainard et al., 2009, Brainard et al., 2010*). These efforts will also be used to examine the role of biodiversity in sustaining ecosystem goods and services and enhancing ecosystem resilience.

Figure 2. Map showing the current and nearterm deployment locations of Autonomous Reef Monitoring Structures (ARMS) for establishing global baselines of cryptic coral reef biodiversity (*Brainard et al.*, 2010).

3. Proposed PIFSC Ocean Acidification Research in FY11

This proposal primarily aims to secure funding to continue the NMFS-funded efforts initiated in FY10, to continue implementing the highest priority components of the NOAA Pacific Islands region ocean acidification research plan (*Brainard et al. 2010*). Now that this important long-term comprehensive plan has been put into action, continuation of the Pacific RAMP cruises is vital for the continuation of these time series, the collection of installed instruments, and the sampling of corals and water chemistry throughout the PIR.

The long-term comprehensive plan includes three primary related components that are currently being implemented: 1) assessing and monitoring the ecological impacts of ocean acidification; 2) characterizing and monitoring carbonate chemistry; and 3) modeling and predicting biogeochemical and ecosystem responses to climate change and ocean acidification. While the numerous elements of these primary components are included in the *NOAA Ocean and Great Lakes Acidification Research Plan*, the portions of this plan that PIFSC will execute in FY11 with approved NMFS Ocean Acidification funding are outlined below. In FY11, the PIFSC proposes to continue on-going ocean acidification research through the deployment/recovery of CAUs and ARMS and collection of coral cores.

Additionally, outside funding has been secured to continue carbonate chemistry water sampling, surface pCO2 measurements, and the diurnal-frequency Remote Access Sampler collection. Through these multidisciplinary and multi-agency projects, a full ecosystem monitoring approach to changes in ocean chemistry, and effects of ocean acidification can be investigated.

Specifically, in FY11 the PIFSC will perform an investigation at the Maug caldera in the CNMI, where a naturally-occurring highly acidic oceanic environment occurs due to shallow-water subsurface volcanic activity. This enormously important region is one of few places on Earth where highly acidic water occurs naturally in shallow water coral reef systems.

3.1. Ecosystem Impacts of Ocean Acidification

All of the ocean acidification funding requested by PIFSC for FY11 will be directed toward research under the theme Ecosystem Impacts of Ocean Acidification. These efforts will expand upon on-going exploratory efforts to assess and monitor the impacts of ocean acidification on coral reef ecosystems. With these funds, PIFSC will conduct 3 key projects (Table 1) to assess

and/or initiate monitoring of the ecological impacts of ocean acidification on coral reef ecosystems across the PIR, with continued efforts focusing on examining reef-building calcifying organisms and broad biodiversity indicators. Of the reef-building calcifiers, particular emphasis in FY11 will be directed toward improving our understanding of the likely impacts of ocean acidification on the 75 Indo-Pacific coral species petitioned for listing under the U.S. Endangered Species Act. Specifically, the ocean acidification funding will support projects to assess the distribution, status, recruitment, calcification rates, critical habitats, and potential risk of extinction due to ocean acidification of the 75 Indo-Pacific coral species.

The first of these projects will be used to continue the successful collaboration with A. Cohen at Woods Hole Oceanographic Institute (WHOI) to collect coral cores and specimens from locations in Guam, Wake Atoll and CNMI, to determine historical coral growth and accretion rates across key oceanographic (nutrient) gradients. Samples will be sent to WHOI for CAT-scan analyses of the three-dimensional growth structure of the corals (Fig. 3; *Cohen et al.* 2009). Developing historical records of calcification and growth rates will advance understanding of how accretion rates have changed since the industrial revolution and improve our ability to predict future changes in a high-CO_2 world. These funds will be granted to the UH Joint Institute for Marine and Atmospheric Research (JIMAR) to support scientific staff for data collection, laboratory experiments, data processing and analyses, and shipping of samples to WHOI.

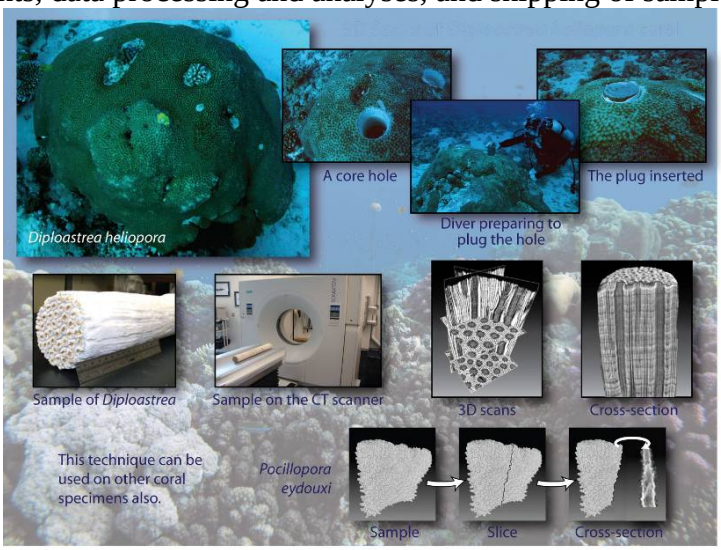

Figure 3. Diagram showing coring of *Diploastrea heliopora*, sample on the CT scanner, and 3D images. Bottom figures show same for *Pocillopora eydouxi*. Courtesy Anne Cohen, WHOI.

The 2nd project will continue the deployment of the Calcification Acidification Units (CAUs, Fig. 4a) across the Pacific in FY11, at Wake Atoll, Guam and the CNMI to complete the establishment of a baseline of calcification rates across the PIR and begin monitoring calcification rates of calcareous algae, predominantly crustose coralline algae, and sessile invertebrates. This project will be done in collaboration with J. Smith and N. Price at Scripps Institution of Oceanography (SIO).

a) b)

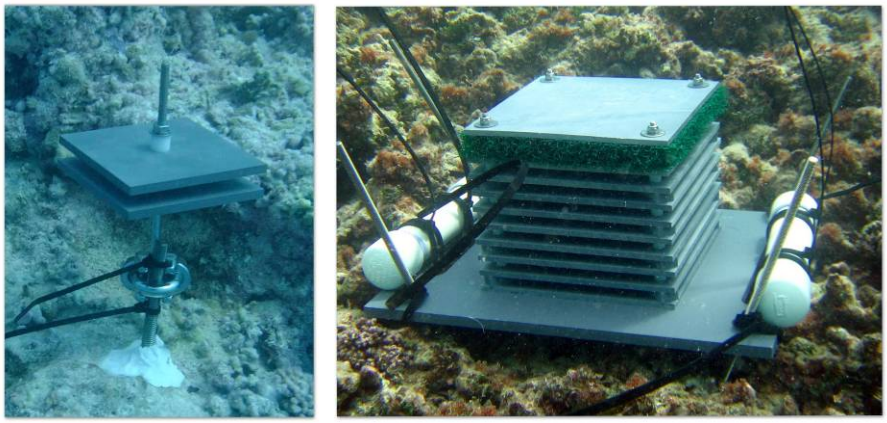

Figure 4. a) Calcification Acidification Unit (CAU) deployed in reef substrate to monitor calcification rates. b) Autonomous Reef Monitoring Structure (ARMS) deployed in reef substrate to assess and monitor cryptic biodiversity. Photos credit NOAA PIFSC CRED, D. Merritt.

The 3rd NMFS coordinated ocean acidification project is designed to augment and leverage efforts to establish baselines for assessing and monitoring shifts in biodiversity caused by ocean acidification using ARMS (Fig. 4b). Understanding the biodiversity impacts of ocean acidification is critical due to the role of biodiversity in providing ecosystem services and maintaining ecosystem resilience. This project leverages significantly on related projects that provide most of the funding for field survey and important ancillary data collection efforts (Pacific RAMP, CoML-CReefs, and Physical and Biological Monitoring Stations projects) led by PIFSC-CRED. The NMFS coordinated funding will be used to contract for ARMS materials and supplies and for JIMAR scientific staff support to build and deploy replacement ARMS, recover ~150 ARMS, and initiate taxonomic, photographic, and molecular analyses of ARMS samples. Organisms will be photographed and preserved in alcohol for mass parallel molecular sequencing by collaborators at Smithsonian Instit. (Drs. N. Knowlton, C. Meyer, L. Plaisance), Univ of Florida (Dr. G. Paulay), San Diego State University (Dr. F. Rohwer), and Moss Landing Marine Laboratory (Dr. J. Geller).

Significant amounts of funding for each of these Ocean Acidification research projects will be leveraged by existing related projects funded primarily by NOAA's Coral Reef Conservation Program (CRCP) and sea days provided aboard the NOAA ships *Hi'ialakai* for Pacific RAMP by OMAO and NMFS Science and Technology. Specifically, the CRCP will be funding efforts to initiate monitoring of the key carbonate chemistry parameters at all of the sites where CAUs and ARMS deployments and coral cores will be taken. Colleagues at WHOI and SIO have submitted companion proposals to NSF to cover their analysis costs. PIFSC also have a close collaborative relationship with colleagues at the Univ. of Hawaii's Hawaii Institute of Marine Biology (HIMB – P. Jokiel, *Jokiel et al.* 2008). These preliminary efforts will expand on-going HIMB controlled experimental mesososm studies of the organism responses to ocean acidification to include some of the key Pacific coral species in the Petition to list 82 corals under ESA.

Table 1. PIFSC NMFS-coordinated ocean acidification research projects for FY11
Theme: Ecosystem impacts of ocean acidification

Deliverable Product	Description	Budget Components
Carbonate chemistry near reefs	Developing understanding of carbonate chemistry changes through analysis of remote access samples for high-frequency variability, discrete water over various substrate types and surface pCO2 measurements via a flow-through ship-board system	funding leveraged through CRCP for carbonate chemistry work
Continue HIMB controlled mesocosm experiments.	Conduct experiments on the effect of CO_2 and temperature on corals and crustose coralline algae, increased focus of Petitioned species.	leveraged funds from partnership and collaboration with UH-HIMB (P. Jokiel).
Continue/expand study of calification rates of key reef-buidling coral taxa	Collect cores and specimens of key coral taxa to assess calcification/accretion rates. CAT-Scan image analysis at WHOI with leveraged funds.	funding requested
Initiate monitoring of calcification rates of crustose coraline algae and reef-building sessile invertebrates and algae	Deploy Calcification Acidification Units (CAUs) at Wake, Guam, and the CNMI to assess calcification rates of sessile invertebrates, particularly reef-building crustose coraline algae.	funding requested
Initiate monitoring of biodiversity and ecosystem function shifts caused by OA	Recover and initiate photographic, morphological, & molecular analyses of 150 ARMS from Wake, Guam, and CNMI. Collaboration w/ Smithsonian (Knowlton, Meyer), U.Florida (Paulay), AIMS (Caley), SDSU (Rohwer), and MLML (Geller).	funding requested

4. References

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