Phoenix Islands Protected Area
2012 Preliminary Expedition Report

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Executive Summary

The fifth multi-disciplinary scientific research expedition to the Phoenix Islands Protected Area (PIPA) took place in June 2012 (June 6-20). This was a multi-institutional collaboration between the Government of Kiribati (GoK), Woods Hole Oceanographic Institution (WHOI), New England Aquarium (NEAq), and Red Sea Research Center (RSRC) at KAUST. Some logistical and technical support was received from Conservation International (CI), and additional scientific collaborators from Scripps Institution of Oceanography and Penn State University (PSU) were onboard. The purpose of this expedition was two-fold: first, to continue long-term monitoring efforts that, for the past decade, have contributed towards achieving the management needs of PIPA. The remaining focus was on several new research objectives that were stated goals of the 10-year PIPA research vision. These projects centered around the themes of determining connectivity of organisms within and between islands, and assessing current and historical reef resistance, resilience, and recovery to high thermal events. Details of expedition objectives, sample collections, loggers and tag deployments, and other scientific goals are found within this report.

Results from the 2009 expedition showed a rapid recovery of coral cover, with a 50% recovery of the cover lost at 15m depth, and an overall increase in cover of 26% since the 2002/2003 bleaching (Stone et al. 2009). Fish abundance and biomass was high and dominated by large predatory species (Stone et al. 2009). On this expedition, coral recovery may have been stalled or slowed in some areas due to a high thermal event recorded in 2010 by our in situ temperature loggers as well as by SST data (ARGO and TAO). Though no one was onsite in 2010 to observe the probable bleaching event, such an event may be deduced from the reported bleaching of the U.S. Phoenix Islands (Vargas-Angel et al. 2010). Verification of a bleaching event may be possible with the analysis of over 1000 photos of benthic habitat, and analysis of the coral cores collected on this expedition. One notable observation on this expedition was the seeming resurgence of shark populations following the no-take implementation in 2008, including small juveniles (especially at Kanton). Following the 2002/2003 bleaching event, *Acropora* table corals also appear to be rapidly recolonizing the Kanton lagoon; a major improvement from previous reports in 2009. On this trip, a large number of temperature loggers were deployed throughout the five atolls visited, which should result in a better understanding of the temperature variation throughout PIPA.

For many of the projects on this expedition, results will be forthcoming over the next 2-3 years. Tags placed on mantas will remain for 9 months before the data is transmitted by satellite and thus available for analysis. Tissues from fish and coral cores will require significant time and effort to process the samples at the WHOI, KAUST, and PSU laboratories. Monitoring data analysis, as well as intensive image analysis of both photoquadrat and photomosaics, will require substantial effort from both NEAq and Scripps. All findings, publications, and discoveries will be relayed to the Kiribati government when available, so that the information can be used for improved understanding and management of PIPA.
Introduction and Acknowledgments

This is a preliminary report on the fifth scientific expedition to the Phoenix Islands, Republic of Kiribati. The Kiribati Phoenix Islands are a remote string of eight islands and two shallow submerged reefs in the Central Pacific, just five degrees south of the equator. The Phoenix Islands Protected Area was formally gazetted in 2006, and extended in 2008 to become the largest Marine Protected Area (MPA) in the world, with a surface area of 408,250 km$^2$. The Phoenix Islands Protected Area (PIPA) is the first MPA in the region to include large areas of deep-water and includes 14 seamounts. In 2010 the Phoenix Islands was declared as a World Heritage Area. PIPA is considered of crucial scientific importance for calibrating the effects of isolated fishing events, monitoring the process of sea level change and evaluating the effects of climate change. The near pristine conditions of the reefs as they were discovered in 2000 serve as a benchmark for understanding and potentially restoring other degraded hard coral ecosystems.

Foremost, we thank the government of the Republic of Kiribati for the permission to conduct this research. The research agenda was developed by David Obura, Randi Rotjan, Simon Thorrold, Anne Cohen, Michael Berumen, Stuart Sandin and Iliana Baums, and contributes to the 10-year PIPA research vision. We are grateful for the assistance of Craig Andreiko and Mosese Tuivuna for assisting with the photomosaics in the field, and Rob Barrel and the staff of the Nai’a for providing logistical support. We also thank Heather Tausig, Regen Jamieson and Randi Rotjan for the hard work that went into planning and executing this expedition and Jeff Ives and Emily Bauernfeind (NEAq) for communicating our work through various social media. As of July, 2012, blog posts from this expedition exceeded 16,000 page views. This expedition was funded through the generous support of The Thomas W. Haas Foundation, The Woods Hole Oceanographic Institution Ocean Life Initiative, The New England Aquarium, Craig Andreiko, and the Prince Albert of Monaco II Foundation.

Expedition Details

For this trip, the expedition team chartered the Nai’a, based out of Fiji. The Nai’a is 120 feet long, by 30 feet in beam, by 11 feet draft; 240 tons. She is a Dutch-built motor sailor, built in Amsterdam in 1979 and re-built by Rob Barrel in Fiji in 1992. The expedition team of 16 people spent 13.5 days on-site from June 6-20, completing over 40 SCUBA dives. Five islands were visited in 2012 in the following order: Kanton (4.5 days), Enderbury (3 days), Rawaki (1 day), Orona (1.5 days) and Nikumaroro (3.5 days), with transit time between. Transit time to and from Phoenix Islands Protected Area (PIPA) was approximately 3 days each way. The expedition followed strictly the Kiribati Biosecurity protocols to prevent the introduction of foreign organisms to PIPA.

This is the fifth multi-disciplinary expedition to the Phoenix Islands and was a multi-institutional collaboration between the government of Kiribati, Woods Hole Oceanographic Institution, the New England Aquarium, and the Red Sea Research Center - KAUST. Some logistical and technical support was received from Conservation International, and additional scientific collaborators from Scripps Institution of Oceanography and Penn State University were
onboard. The purpose of this expedition was two-fold: first, to continue long-term monitoring efforts that, for the past decade, have contributed towards achieving the management needs of PIPA. The remaining focus was on several new research objectives that were stated goals of the 10-year PIPA research vision. This report is organized around them as follows:

1. **Monitoring objective:** assessment of coral reef habitats and fish species to contribute to the long-term monitoring of the PIPA and the 2014 State of the PIPA report. Specifically monitoring was done to assess:
   a. Benthic habitats
   b. Coral community structure
   c. Coral recruitment
   d. Corallivory
   e. Fish abundance and biomass
   f. *In situ* sea surface temperature readings

2. **Connectivity objective:** To determine how far animals move within and among PIPA islands and Pacific archipelagos to develop a greater understanding of connectivity. Specifically research was conducted on:
   a. Tracking movement of reef-associated ocean megafauna (manta rays) using FASTLOC GPS pop-up satellite archival transmitting tags.
   b. Tissue collection for subsequent stable isotope and microsatellite DNA analysis of reef fishes, corals, invertebrates and macroalgae at all reefs visited.
   c. Ocean currents and sea surface temperatures in the Phoenix Islands.
   d. Coral genotypic diversity

3. **Resistance and Reef Recovery objective:** PIPA is a natural laboratory for climate science. The absence of local human impacts enables research on the natural factors influencing resistance and reef recovery. On the 2012 expedition, the resistance and response of corals to thermal stress was studied by examining their stress ecophysiology as recorded in their skeletons. This includes:
   a. Collection of water samples for carbonate chemistry analysis in lagoons at Kanton and Nikumaroro, and the reefs adjacent to open water on all islands.
   b. Collection of long 4-inch diameter cores from large *Porites* corals, which will provide records of coral growth and sea surface temperature over the last several centuries.
   c. Collection of short cores from a number of *Porites* corals to measure extension rates over the last 10-20 years and provide estimates of community calcification rates. This will yield insights into past bleaching events and recovery dynamics.

4. **Medical objective:** Because of PIPA’s remote location, safety is always of the utmost importance. The Nai’a is an extremely safe dive platform, and supervises transport to/from dive sites and in-water safety. Dr. Craig Cook (MD) will be onboard; he has been on previous PIPA expeditions and is a well-seasoned expedition physician. The expedition also a rented hyperbaric chamber onboard, and all participants were extremely experienced divers. All
divers had essential safety gear (safety sausages, EPIRBS, Nautilus LifeLine GPS units) appropriate for each dive. In addition, NITROX was used to reduce fatigue.

5. **Media objective**: To enable high quality documentation for both scientific and public relations purposes, a professional photographer was on board. Keith Ellenbogen often works with both NEAq and CI, and was a great asset to the trip. His photos can be used for PIPA-related needs, as well as for the NEAq blog and post-expedition exhibits. Blogs were posted live from the expedition and will remain archived at: pipa.neaq.org. In June and July 2012 alone, there were 20,931 page views, and a total of 86,648 page views for the blog overall. These blogs have served as an online reference and archive of NEAq PIPA expeditions, and have been used as sources by others (including the Boston Globe, and Education Week), describing these trips, for example in 2009, as “a modern day voyage of the Beagle”.

1. **Monitoring objectives**

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**Introduction**

The Phoenix Islands long term monitoring program for coral reefs has been conducted in 2000, 2002, 2005 and 2009. The main goal of this expedition was to collect reef health and resilience data to contribute to this long term monitoring dataset for the Phoenix Islands, to understand changes in coral and fish communities over time. Most significantly, this is the third sample point after mass bleaching and mortality of corals in 2002/2003, that was likely the most severe temperature anomaly for coral reefs in recorded history (Obura and Mangubhai, 2011). Coral mortality between 2002 and 2005 was estimated at 60% on average, though varied between 40-80% on an island-wide scale, and from 20-100% on a site-specific scale (Obura and Mangubhai, 2011).

During the 2012 PIPA expedition we conducted repeated quantitative assessments, including photoquadrats, to assess percent live coral cover, coral size class information, coral recruitment
and fish density and biomass. Coral size class, recruitment and fish data provide insight into the recovery dynamics of corals and fish, and the overall resilience of reef communities to disturbances like bleaching events. In addition, we installed permanent stakes and undertook benthic photo mosaics to monitor fine scale community recruitment and mortality dynamics. The Phoenix Islands provides the unique opportunity to study how healthy coral reefs recovery from bleaching events in the absence of other anthropogenic threats (such as overfishing, pollution and sedimentation) that stress reefs in other parts of the world.

In addition, we collected small tissue samples of the massive coral *Porites* to examine genotypic diversity in the Phoenix Islands. Preliminary analyses suggest that there is high clonal diversity of *P. lobata* at Enderbury (N=24, 100% unique). High genotypic diversity within a dominant foundation species such as corals might therefore confer resistance or resilience on the coral reef community level similar to species diversity (Booth and Grime 2003; Reusch et al. 2005).

**Methods**
The methods we used are adapted from the IUCN Resilience Assessment protocol (Obura and Grimsditch 2009). Six data datasets were collected:

1. Benthic cover (transect based and permanent benthic mosaics)
2. Coral genus size class distributions
3. Coral recruitment
4. Corallivory
5. Fish density and biomass
6. Sea surface temperatures

**Benthic Cover**
Benthic photos were taken on all of the islands visited at 10-12m at both permanent monitoring and rapid assessment sites established in 2000 and 2002. Digital still photographs of the reef substrate were taken from a height of approximately 0.6-0.75 meters above the substrate using natural light and setting the white balance at the survey depth to enhance reds and help distinguish classes such as coralline algae. Photographs were taken haphazardly over the study site, following the line of the coral size class belt transects. 40-45 images were collected per site, from which images for analysis will be randomly selected. Photographs are downloaded onto a computer, and will be analyzed for benthic composition using Coral Point Count (CPCe; Kohler and Gill 2006) or software by PhotoGrid, Inc.

**Benthic Photo Mosaics**
60m² permanent quadrats were staked on the reef using threaded stainless steel rod, at 10-12m depth. Two digital Nikon SLR’s D7000, housed in a tandem frame were used to photograph the substrate within the plot from a height of approximately 1.5-2.0m above the reef. Each Nikon is set at a different zoom, one at 18mm and one at 55mm. The photographs are calibrated using two mounted lasers on the camera housings, at a set distance apart. The photographs have approximately 90% overlap, and the photographs will be assembled into a mosaic using an algorithm (Gleason et al., University of Miami).
Coral size class distributions
A 25 x 1 m belt transect was used for measuring the number of corals >10cm within fixed size classes. Following a preliminary assessment, all coral genera were selected to cover a range of resistance to bleaching from low to high. Size class data was collected at 10-12m in 2009 and again in 2012. The number of colonies in the targeted genera (>10 cm) were counted under the following size classes: 11–20, 21–40, 41–80, 81–160, 161–320 and >320cm. Only those colonies with their centers within the belt transect were counted. A 0.5m stick was used to help guide estimation of transect width and the quadrats, and marked to distinguish size classes at 10, 20, 40 and 80 cm. All hard coral genera were recorded.

Recruitment
Coral recruits, defined as those colonies <10cm in maximum diameter, were surveyed in 18 x 1 m² square quadrats randomly placed at permanent monitoring sites where time permitted. All recruits were identified to genus and sizes were recorded in the following size classes: 0–2.5, 3–5, 6–10cm. Corals that appeared to be fragmented adults were not recorded. Recruit surveys were conducted at 10-12m. Recruitment surveys were conducted on Kanton, Enderbury, Orona and Nikumaroro islands.

Corallivory
Corallivory rates were indirectly determined in *Porites* coral by counting grazing scars on massive colonies located within a 25 x 1m transect using methods described by Rotjan and Lewis (2006), and used on the previous expedition (Stone et al. 2009). For each grazed *Porites*, the number of bites was counted and a photograph with scale bar was taken to estimate maximum colony length and width and estimate bite sizes by measuring the length and width of 3 typical bites per colony. These measurements can be used in calculation of grazing incidence (number of colonies grazed) and grazing intensity (coral tissue area removed) (Rotjan 2007). The number of surface-visible macroborers (e.g. serpulids, vermetids, and others) were counted on grazed and intact tissue for each colony as in Rotjan and Lewis (2005), and genetic
samples (as described earlier) were taken from each colony to detect differences in corallivory pressure on sister/cryptic species within the *Porites* genus.

**Fish density and biomass**

Surveys were conducted by a single diver. Sites were chosen based on previous surveys and overlapped with benthic photoquadrat, size class and recruitment data collected during the expedition. Species selected for surveys were based on data collected in 2009 (Stone et al. 2009). At each site the diver counted fish numbers and sizes (binned by 5-cm total length, TL) in three 25m length transects. Transects were surveyed along depth contours (between 10–11m). Large-bodied fishes (>20cm TL) were counted within an 8m wide strip, surveyed on the first pass of the transect. The swim out was completed in 3-5 minutes, and each transect took approximately 10-15 minutes to complete. Small-bodied, more site-attached fish (< 20cm in TL) were counted during the second pass of the transect. Each site thus covered 300 m² area of reef.

**Sea surface temperature loggers**

Hobo Onset Pro V (U-22) sea surface temperature (SST) loggers installed in 2009 throughout the Phoenix Islands. Of the 13 loggers installed in 2009, 4 were retrieved, downloaded and replaced again *in situ*, and 9 loggers could not be found and were likely lost during storm damage or covered by new coral growth. Additional loggers were installed by two other research teams providing a wider coverage of sites (see sections 2 and 3).

**Sites**

Reef health data were collected at 26 sites on five of eight atolls in the Phoenix Islands – Kanton, Enderbury, Rawaki, Orona, Nikumaroro. Of these, 18 were leeward sites, 7 were windward and 1 was a lagoon site. Repeat dives were down at permanent monitoring sites to enable multiple datasets to be collected. Priority was given to sites surveyed both before and after the 2002/2003 coral bleaching event.

**Preliminary Results**

Sample photo quadrat. Photos of the benthos were taken at each site for later area measurements of various benthic categories (left). Photo by: S. Mangubhai. Collecting reef resilience data (right). Photo by: Keith Ellenbogen.
Condition of coral reefs
Recovery continues to be low on leeward sites that are influenced by lagoonal waters, especially on Kanton and Nikumaroro. The influence is maximum closest the mouth and decreases as you move further away. The reef immediately north of the Kanton channel (Weird Eddy) has recovered well due to high fragmentation of branching *Hydnophora* and there is relatively good recruitment at this site. However, reefs south of the Kanton channel and north of the mouth of Nikumaroro lagoon showed almost no recovery, and were dominated by herbivorous fish but devoid of live adult corals (<1%) or coral recruits. The windward site Mystery Wreck on Enderbury was also devoid of coral but had high populations of herbivorous fish. All sites where coral recovery was almost zero had in the past, or still had, a shipwreck present. It is likely that the shipwrecks, which cause iron enrichment in otherwise iron-poor oceanic waters, may be causing low coral health and inhibiting recovery. These findings are consistent with findings in other regions (Kelly et al. 2011).

Similarly to the findings of the 2009 expedition (Stone et al. 2009), windward reefs showed remarkable recovery, particularly at sites where there is good available substrate for coral recruits to settle and without extensive rubble fields. These sites were dominated by *Favias* (especially *F. stelligera*), *Montipora*, *Porites* and in some places *Echinopora* and branching *Hydnophora*. Much of this recovery is at 10-20m. Although data were not collected, our observations suggest that the shallow reef areas (5-10m) which recorded high mortality during the 2002/2003 coral bleaching event are making slow recovery. Previously these shallow areas were dominated by faster growing *Acropora* and *Pocillopora*, as well as *Millepora* species, which are now absent or in very low abundance generally throughout the Phoenix Islands. The percent cover of different benthic categories (e.g. coral, algae, hard substrate, rubble, etc.) at different sites will be calculated once benthic photoquadrats are processed, and will provide a more quantitative picture of coral recovery in the Phoenix Islands.

Recruitment
A total of 19 genera were recorded in recruitment surveys in the Phoenix Islands, the most common of which were *Pavona* and *Montipora*. Recruit density averaged 4.4 recruits/m² (SD=4.4 recruits/m²). The highest recruitment was recorded at Weird Eddy and the lowest at the leeward sites north of the mouth of the Nikumaroro lagoon and Algae Corner which were dominated by fine red filamentous algae. For the three largest atolls the highest number of recruits were in the 3-5cm size class, and the lowest number of recruits was recorded in the 0-2.5cm size class. There did not appear to be any significant difference in recruitment densities between leeward versus windward reefs.

Despite the large amount of available rock substrate following the mass mortality in 2002/2003, resilience surveys confirm low levels of recruitment in the Phoenix Islands. Given the paucity now of fast growing and reproducing corals such as *Acropora* and *Pocillopora* species, it is likely that recovery through new recruits will continue to be slow. The main recovery continues to be the regrowth of coral fragments, especially *Montipora* and *Hydnophora* species.
Coral Size Classes

Coral reef communities in Phoenix Islands. Photos by: Keith Ellenbogen

Twenty-seven coral genera were recorded in size class belt transects. Montipora was the dominant and most widespread genus, followed by Favia, Pavona, Porites, Echinopora and Pocillopora recording >600 colonies. Enderbury and many of the windward reefs showed extensive Montipora plates covering the slopes. Pocillopora appears to have increased in abundance, compared to 2009 surveys. 74% of corals recorded abundances of <200 colonies. Many of the larger Favia colonies, especially those belonging to F. stelligera showed partial mortality, likely from the 2002/2003 coral bleaching. Genera not recorded in the 2012 size class surveys were Coscinaraea, Plerogyra, Turbinaria, Sandalolitha, Stylophora, Tubastrea, Podabacia, though it is noted that the first three genera listed were observed at sites, just not within transects. Coral communities were dominated by corals in the 11-20cm in 2012, which differed from 2009, when 21-40cm size class dominated. This may be an indicator that though recruitment rates are relatively low (above), there is successful regrowth into the smaller adult size classes and over time this may lead to increases in larger adult colonies.

The highest densities of corals were recorded at Crash Landing (Kanton) Aerials (Orona) and Dolphin Ledge (Orona), with the lowest recorded at wreck sites and Algae Corner at Orona. Rawaki generally had lower densities of corals in belt transects, likely reflecting the size of the atoll and its higher exposure to ocean conditions.

Corallivory
A total of 8 transects were conducted at 7 sites on 5 islands in Phoenix Islands. Two transects were completed at windward sites and 6 were leeward. Overall incidence of corallivory on massive Porites was high. About 76% (n=94) had greater than 3 pairs of spot biting scars or one large excavating scar. Both freshly made and recovering scars were counted.
Fish Density and Biomass

Schools of snappers (left) and surgeonfish at Orona Atoll. Photos by: Keith Ellenbogen.

Large schools of planktivores, abundant large-bodied fish, and high predator biomass characterized the fish assemblages in the Phoenix Island Protected Area (PIPA). Across five islands and 25 sites, the average fish density was 4.1 (# of fish*m⁻²), and the average fish biomass was 220.9 (g*m⁻²). This is comparable to previous surveys of the Phoenix Islands in 2009 (5.5, 259.6, respectively). The primary driver of abundance was small-bodied planktivores. Fish densities varied among islands, however, the pattern of abundance is consistent with previous fish surveys in PIPA (2009). Nikumaroro had the lowest overall abundance of fishes and the highest abundance of herbivores. The high abundance and biomass of herbivores may be correlated with lower coral cover and increased presence of algae at Nikumaroro.

Total biomass is comparable across sites. Rawaki had the lowest overall biomass and lowest top predator biomass. Among islands the patterns of biomass may be attributed to top predators (groupers, snapper, sharks) and herbivores. All sharks surveyed were relatively small-bodied (<150 cm), and there is evidence to suggest that this is due to recent shark finning operations. Previous surveys in 2009 found a striking increase in the biomass of top predators (sharks) in Enderbury. The change in top predator biomass from 2009 to 2012 could be due to site selection during surveys (not all sites were re-surveyed in 2012), or it could be evidence of another fishing event.

Reef fish assemblages in PIPA continue to be diverse, healthy examples of remote island systems with small anthropogenic influence. Abundance and biomass of fishes hold patterns consistent with previous years. Despite multiple coral bleaching events recorded in recent history, PIPA persists as an excellent example of a resilient coral reef system. Local conservation and management efforts continue to sustain fish assemblages that provide valuable insights into historical baseline states.

Sea surface temperatures
SSTs were rising when loggers were installed in September 2009 and peaked and remained above 30°C for 3 months from November 2009-January 2010 (Fig. 1.11). This peak was not observed in 2011 or 2012 suggesting that this was an anomalous high temperature event, over
a 6-month period in Kanton and Orona, and possibly the wider Phoenix Islands. SST patterns were similar at all depths, though temperatures were slightly higher in the shallows (5m), as expected. The SST patterns recorded in situ by loggers are consistent with the broader NOAA SST data (Fig. 1.12).

This peak is analogous to that which happened in 2002-3, that caused massive coral mortality (Obura and Mangubhai 2011). Until the benthic quadrats are analyzed however, it is not possible to say whether high SSTs in 2009/2010 caused any bleaching and mortality in the Phoenix Islands.

Figure 1.11: Sea surface temperatures at Kanton (top) and Orona (bottom). Red indicates temperatures at 5m, green at 12m and blue at 27m.
Figure 1.1. Shows the sea surface temperature patterns and anomalies in the Phoenix Islands between 1980-2012 (top) and over the last 12 years (2000-2012). Data source: NOAA ERSST (Version 3B).

2. Connectivity objective

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**Movement Ecology of _Manta birostris_**

_Manta birostris in Phoenix Islands. Pop-up satellite archival tags. Photographs by: Mark Priest_

**Introduction**

In 2006, _Manta birostris_ was listed as a Near Threatened species by the IUCN (Dulvy et al. 2008). The giant manta is believed to occupy tropical and subtropical waters worldwide, however very little research has been conducted to understand population connectivity and movement patterns. Movement and migration behavior of individuals can reveal key ecological characteristics and population dynamics of a species. This is especially interesting in a location as remote as the Phoenix Islands where population connectivity may be sparse and any individual movement outside of the Phoenix Islands chain must be substantial. As the world’s largest MPA it is critical to understand how large, pelagic species that occur within PIPA move within and beyond its borders.
Pop-up satellite archival tags (PSAT) have been used successfully on many species worldwide including whale, white, and basking sharks, manta rays, and devil rays (Jorgenson et al. 2009, Skomal et al. 2009, S. Thorrold unpubl.). The information gathered will elucidate horizontal movements in addition to vertical and horizontal habitat utilization, diving behavior, and temperature and depth preferences of these fish. This data can improve our understanding of what factors influence manta ray behavior and thus improve conservation and management strategies for this species. A well-studied manta ray population can also help inform basic population, growth, and maturity metrics that are currently poorly understood for this species.

Methods
We deployed 9 PSATs with Fast-Loc GPS technology (model MK10-F; Wildlife Computers, Redmond, WA, USA) on *Manta birostris* within PIPA using a sling spear while snorkeling. Tags were secured in the dorsal musculature near the tail with a steel, T-bar style spear tip and stainless steel wire with chafe protection tubing. The tags were programmed to record GPS locations (when the individual visits the surface), depth, temperature, and light levels (for supplementary geolocation). Collected data will be archived until the tag tether is severed (after a pre-set deployment duration set for 2013), and the tag begins transmitting data to Argos satellites.

Results
Seven mantas were tagged near the lagoon mouth at Kanton. The remaining two tags were deployed at Orona. No mantas were observed at any other location.

Foodweb dynamics and carbon pathways

Introduction
Coral reefs are considered to be one of the most productive and biologically diverse ecosystems on Earth. Tropical coral reefs contain nearly one third of the world’s marine fish species and produce upwards of 10% of the fish consumed by humans, despite covering less than 0.5% of the ocean floor. One of the more important, and somewhat paradoxical, questions in coral reef ecology is: How are coral reefs so productive and diverse in such oligotrophic conditions? One hypothesis suggests that intense grazing of phytoplankton from the surrounding water column is the major carbon source on coral reefs. An alternative hypothesis links high productivity on coral reefs to efficient recycling mechanisms of reef derived carbon, such as symbioses and microbi ally-reworked detrital pathways. Teasing apart the relative contributions of these two important carbon source pathways is crucial for developing mechanistic models of carbon flow and food web dynamics on coral reefs. The need for this research is becoming increasingly urgent with the decline in function and resilience of coral reef ecosystems on a global scale associated with habitat destruction, unsustainable exploitation, and climate change.

The Phoenix Islands present a rather unique opportunity to examine how food web dynamics and carbon pathways operate in remote, relatively pristine reef systems. The trophic structure of the Phoenix Islands is quite distinct from reefs in other parts of the world, due to the high
biomass of upper trophic level consumers. As such, the Phoenix Islands provide a unique and rather remarkable opportunity to see how coral reefs used to function before the over exploitation of most of the top predators on reefs systems worldwide. One of our goals on this expedition was quantify carbon flow pathways and trophic dynamics on coral reefs in the Phoenix Islands. These data will provide empirical support to model energy transport in reef systems and predict changes to ecosystem structure and function in light of climate change and anthropogenic disturbance. Such efforts are critical to design effective management strategies to promote coral reef fisheries conservation and sustainable harvest.

Methods
We collected samples from a variety of coral reef fishes that span a wide range of feeding guilds. In total we visited five different Islands: Kanton, Enderbury, Rawaki, Orona, and Nikumaroro. At each Island we targeted ten individuals from seven different species of coral reef fishes: Bicolor chromis (*Chromis margaritifer*), Golden gregory (*Stegastes aureus*), Arc-eye hawkfish (*Paracirrhites arcatus*), Chevroned butterflyfish (*Chaetodon trifascialis*), Bullethead parrotfish (*Chlorurus sordidus*), Bluespotted bristletooth (*Ctenochaetus marginatus*), and Twospot snapper (*Lutjanus bohar*). In Islands where few *C. trifascialis* were found, a similar obligate corallivore, the Ornate butterflyfish (*C. ornatissimus*) was collected. Similarly, at Islands where few *C. sordidus* were found, a similar herbivore, the Tricolor parrotfish *Scarus tricolor*, was collected. All fish were collected by spear and held on ice until processing aboard the Nai’a.

For each of the fish, we measured fork length and height to examine length and growth relationships. We also collected fin clips, otoliths, and muscle samples. The fin clips were taken from the caudal fin and stored in 95% ethanol. These samples will be taken to King Abdullah University of Science and Technology (KAUST) for genetic analyses to see how populations of fish within and among reef systems are related. Otoliths were stored dry and will be taken to Woods Hole Oceanographic Institution (WHOI). One otolith will cross sectioned and aged to examine life history dynamics. The other otolith will be used for microchemistry (stable isotopes and trace element analyses) to examine movement and trophic dynamics.

Finally, we collected white muscle tissue each fish. Muscle samples were frozen and then lyophilized (freeze-dried) prior to transport to WHOI for stable isotope analyses. Muscle stable isotope values will be used to examine carbon flow pathways and trophic dynamics of fish. In addition, we collected 5 replicate samples from four different base of the food web end members: coral, algae, phytoplankton, and detritus. We used zooplankton as a proxy for phytoplankton, and sea cucumbers as a proxy for detritus. Samples of two coral species, *Acropora* spp. and *Pocillopora* spp., were air picked to isolate live tissue. Coral samples represent a consortium of coral tissue, mucus and associated microbial communities. We collected macroalgae, primarily *Halimeda* and filamentous rhodophytes, from the reef flat by hand.

Zooplankton were collected by a 1 m diameter, 333 μm mesh net towed in open water adjacent to the reef for 5 minutes at a depth of approximately 3 m. Two species of sea cucumber were collected by hand. The lollyfish sea cucumber, *Holothuria atra*, was collected from shallow
sandy lagoons and the whitespotted sea cucumber, *Actinopyga varians*, was collected from the reef crest. All base of the food web samples were freeze dried and lyophilized, prior to transport to WHOI for stable isotope analysis. By comparing the isotope values of the fish to the base of the food web end members, we will examine carbon flow pathways from primary producers to top predators.

**Coral Population Genetics**

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*Principal Investigator: Iliana Baums (PSU)*

**Introduction**

Corals disperse and exchange genes primarily via planktonic larvae. Local retention of larvae leads to inbreeding and population subdivision. Where habitat is discontinuous, such as the Phoenix Islands, planktonic larval dispersal among islands might counteract local recruitment. However large geographic distances such as among islands in the central Pacific, might limit larval exchange among populations leading to regional isolation. The recent protection of marine habitat within PIPA is a great benefit to coral reef conservation in the region; but, without knowledge of dispersal breakpoints, which disrupt gene flow and result in isolated breeding groups, important sources of genetic diversity may be ignored. Connectivity among marine populations therefore remains crucial to marine conservation and reserve design (Bohonak 1999; Sale et al. 2005; Hedgecock et al. 2007). Larval retention mechanisms and cryptic barriers can prevent larvae from dispersing. Larvae therefore recruit locally despite the potential to travel vast distances (Swearer et al. 1999; Ayre and Hughes 2000; Almany et al. 2007). This leads to population structure in species with high dispersal potential (Taylor and Hellberg 2003). However, the absence of biophysical barriers and high dispersal ability can lead to genetic connectivity across large geographical ranges (Klanten et al. 2007).

During this expedition we sampled *Porites lobata* from the Phoenix Islands to determine if this species showed high levels of ongoing gene flow or limited gene flow across open ocean channels. This question will be examined within PIPA and between PIPA and other Pacific islands where *P. lobata* samples have previously been collected and analyzed, including the Marshall Islands, American Samoa, the Northern Line Islands, Fiji, Johnston Atoll, Hawaii, Moorea, and the Marquesas.

Collecting *Porites* tissue to survey for genotypic diversity. Photos by: Keith Ellenbogen.
Methods
Tissue samples (~1cm x 1cm) of ~30 Porites lobata colonies were obtained from each island. The sampling design follows Baums et al. (2006). 15m radius circular plots were randomly sampled for massive Porites at two sites dominated by Porites. An underwater photograph was taken of each colony sampled for future reference and to determine colony size (Table 2.4). No colony was sampled twice and the sampling of a particular plot ceased after 15 colonies were collected. All colonies (sampled and not sampled) within each 15m radius circle were counted so that density and sampling effort could be calculated. Fragments were placed in individual zip-lock bags underwater (with the identifying number) and then transferred to vials containing 95% ethanol on the surface. A GPS reading, depth and general description of each dive site was recorded.

Samples were preserved in 95% non-denatured until DNA extraction. Genomic DNA from coral tissue will be extracted for each sample following the manufacturer instructions in the DNeasy 96 Blood and Tissue Kit (Qiagen). Four multiplex and one singleplex 10μl polymerase chain reactions (PCR) will be performed for each P. lobata sample using fourteen primers fluorescently labeled with NED, VIC, PET, or 6FAM (Applied Biosystems) (see Polato et al. 2010 for full reaction concentrations). Fragments will be analyzed using an ABI 3730 with internal size standard (Genescan LiZ-500, Applied Biosystems). Allele size calls will be made by visualization of electrophoregrams in GENEMAPPER 4.0. Genotyping errors will be detected with GENCLONE 2.0. Population level genetic structure will be analyzed using standard methods implemented in the programs Alrequin (AMOVA) and STRUCTURE (Bayesian clustering).

Ocean currents and temperatures

Ben Hodges (WHOI)
Principal Investigators: Simon Thorrold and Anne Cohen (WHOI)

A diver secures a temperature logger (left). Photo by: Camrin Braun. A surface drifter just prior to deployment. Photo by: Keith Ellenbogen

Exchange of nutrients and biota between the coral reef environment and the open ocean is a key process in sustaining the ecosystem. Physical interactions between the reef waters and the
surrounding oligotrophic sea drive this exchange, and they occur on a wide range of timescales. At the short end of the spectrum, internal waves with frequencies of just minutes can deliver boluses of slope water up into the shallow reef environment; patterns of ocean currents vary over much longer periods. Resolving all these timescales, from minutes to years, presents an observational challenge. Our approach during the expedition involves two types of instruments: temperature loggers and surface drifters.

Temperature loggers

Temperature, unlike many other water properties, can easily be measured accurately and economically. Water temperature has a direct impact on coral and other reef organisms, but it is also a fluid tracer which, when measured in multiple locations, can reveal flow patterns.

During the 2012 PIPA expedition we deployed 25 high-accuracy rapid-response temperature loggers. Made by Sea-Bird Electronics, the SBE56 temperature logger records water temperature every 30 seconds, and can record data up to 3 years. The loggers were fixed to anchors with flags and deployed in groups of four at 5, 15, 25 and 40m. This sampling strategy is designed to capture long-term trends and inter-island relationships as well as internal wave action at each transect site. Temperature measurements are accurate to within 0.002°C, and the temperature-compensated on-board clock drifts by less than a second per year, ensuring that internal wave propagation will be represented correctly in the resulting array of temperature data.

Surface drifters

Near-surface currents in the ocean transport nutrients, plankton, and other water properties, and drive reef fish larval dispersal. Knowledge of the ocean currents surrounding the Phoenix Islands is a key component of understanding the connectivity of the islands’ ecosystems. Drifters are designed to accurately measure surface currents by mimicking the motion of a single parcel of seawater. A drifter is composed of two parts: a surface float containing a transmitter, and a drogue, hanging below, which is a hollow tube of canvas 60cm in diameter and a few meters long. The transmitter regularly relays the GPS position of the drifter to a ground station via the Argos satellite network, and the drogue ensures that the drifter accurately follows a water parcel, resisting the motion that would otherwise be induced by wind. A drifter can continuously report positions for approximately 2 years.
Figure 2.1. Map of drifter deployment locations. Stations are labeled with arrival dates. 20 drifters were deployed during the cruise, 14 individually, and the remaining 6 in pairs. Arrows depict mean June currents derived from satellite measurements.
Twenty drifters were deployed during the expedition. Eleven were distributed within the rim of the Phoenix Islands archipelago, with the remaining nine spaced out along the transect to Samoa (Fig. 2.1). The prevailing westward current will likely carry the Phoenix Islands drifters near downstream islands, providing multiple realizations of the paths taken by water (and everything suspended in it) as it flows from island to island. Six of these drifters were deployed in three pairs, beginning their voyage only meters apart. Though pairing drifters tends to decrease spatial coverage, it provides an indication of the rate of separation of initially colocated particles; a sampling plan incorporating drifter pairs can provide an estimate for the size of the area over which larva are dispersed, rather than simply the expected distance and direction.

The nine drifters deployed south of the Phoenix Islands are intended to complement the global array rather than to address PIPA-specific research objectives. Surface currents are part of a coupled ocean-atmosphere system, and their shifts are indicators of Earth’s evolving climate. Satellite measurements of ocean currents are less reliable in the equatorial band, and the residence time of drifters in the region is limited due to divergence of surface currents there. Our expedition took us across an area of the Pacific that is less well travelled than many other areas of the equatorial ocean, providing us an opportunity to help fill a perennial gap in the existing world-wide drifter array.

3. Resistance and Reef Recovery objective

*Pat Lohmann, Kathryn Rose, Jay Andrew, Hannah Barkley*

*Principal Investigator: Anne Cohen (WHOI)*

Pneumatic multi-coring of Porites corals (left). Hydraulic coring of Porites (right). Photos by: Craig Andreiko

**Introduction**

The range in marine habitats within the PIPA, from deep open-ocean to shallow restricted lagoons, offers a natural laboratory to examine the environmental factors that affect coral growth and chemistry. Our three primary objectives were to characterize the seawater carbonate chemistry and temperature at each study site, to drill and recover a statistically meaningful sample of the associated range in recent coral growth and, at selected sites, drill and recover long records of past changes in coral growth.
Methods

Seawater carbonate chemistry and temperature

*In situ* Niskin water samples were collected at 1m and 8m, then subsampled, and bottled for alkalinity and dissolved inorganic carbon (DIC), nutrients and salinity. The alkalinity and DIC samples were stabilized with MgCl immediately after collection. A total of 270 water samples (90 alkalinity/ DIC, 90 salinity and 90 nutrients) were collected from 21 sites across the 4 islands. A contemporaneous *in situ* measurement of seawater temperature was logged at each site. A mini-mooring with two 2-year duration temperature loggers, one at the seafloor and one about a meter above the seafloor, was installed at each of the 8 coring sites plus one additional site on the windward side of Enderbury (Table 3.3).

Pneumatic multi-coring

Pneumatic drills powered by SCUBA air were equipped with 5/8” diameter, 18” long core bits. For this project the target core length was 15cm, which for *Porites* should provide a record of coral growth for about the last 15 years, i.e., for the period from 1997 to the present, spanning the time and providing a record of the most recent bleaching events. Another objective was to relate coral growth to their environment, so we aimed to recover at least 6 cores per site to examine this relationship within a statistical context.

Hydraulic 4-inch diameter long coring

The relatively higher torque supplied by hydraulic power permits longer and larger diameter coring of coral colonies. The equipment required to drill and recover up to 4m of core (hydraulic and water pumps, 100-foot hoses, power head, down hole equipment) was easily accommodated in one of Nai’as 22ft RIBs.

Coral tissue for analysis of lipid and genetic composition

After core recovery and before sealing the corehole, chips of living coral were recovered and frozen for subsequent analysis of their lipid and genetic contents. The tissue samples from each coral were preserved using 3 different methods: frozen in seawater, frozen in RNA later and frozen 8% formalin.

Results

Seawater and coral samples were collected from four of eight atolls in the Phoenix Islands – Kanton, Enderbury, Rawaki, and Nikumaroro. 8 coring, 21 water sampling, and 9 temperature moorings stations were selected among the 4 islands.

Seawater carbonate chemistry and temperature

Samples for subsequent analysis of seawater carbonate chemistry were collected and *in situ* temperatures were measured from open ocean waters on both the leeward and windward sides of Kanton, Enderbury, Rawaki and Nikumaroro. Repeated transects were collected from the lagoon on Kanton. As most of the lagoon on Nikumaroro was inaccessible, only the main channel and mouth of the lagoon were sampled. There is no lagoon on either Enderbury or Rawaki. A total of 270 seawater samples were collected from 21 sites from the 4 islands.
Paired T-loggers were moored at 9 sites within the 4 islands to record long-term changes in seawater temperature.

**Pneumatic multi-coring for 15-year records of coral growth**
47 small diameter short cores were recovered from 8 sites within the 4 islands. When measurements of these cores are associated with the measurements of seawater chemistry, we can determine the relationship of coral growth to their environment.

**Hydraulic 4-inch diameter long coring for century-long records of growth**
7 large diameter long cores were recovered from 5 sites across the 4 islands. Analysis of these will provide long term records of regional differences in coral growth.

**Coral tissue for analysis of lipid and genetic composition**
A total of 153 samples were collected from 51 corals within the 4 islands.

**Discussion**
While it is too early, without laboratory analysis, to draw any conclusions, much of the data and samples collected during PIPA 2012 will likely provide (1) new information about the relationships between local environment and coral growth, (2) reconstructions of the events during and surrounding recent bleaching events, and (3) centuries-long records of environmentally-driven changes in coral growth in the Phoenix Islands. It is also likely that future visits will be required to confirm and test these results and explore any new ideas they suggest.

4. **Medical objectives**
   
   *Craig Cook*

![Figure 4.1 Recompression chamber (left) and EPIRB canister (right). Photos by: Craig Cook](image)

Conducting dive operations in remote locations requires special considerations and safety equipment to provide the lowest risk to those involved. Considerations included treatment of decompression illness and location and recovery of the lost diver in addition to the usual
medical issues inherent in a large remote expedition. The Phoenix Island Protective Area Expedition 2012 (PIPA 2012) implemented several unique protocols and dive plans.

**Decompression Illness**
While rare, any dive below two atmospheres absolute (ATA) carries a risk of decompression illness directly related to time and depth. During the course of the expedition over five-hundred hours of diving operations were conducted by the twelve member team without event. In the case of decompression illness, a portable recompression chamber was present onboard. The chamber was a Hyperlite monoplace capable of providing a US Navy Table 6 treatment table. The chamber insured that a diver could be treated within minutes of surfacing and symptom onset. Without an onboard chamber, medical evacuation would require air ambulance service with a possibility of delay up to 24 hours. The chamber was kept partially broken down in two large shipping crates due to space constraints and for protection. Oxygen and air cylinders with valves and umbilicals attached were kept on deck ready for deployment. The chamber was set up and broken down for operation checks twice during the expedition. Operation of the chamber was undertaken by the Diving Medical Officer on site.

**Diver Location Aides**
Diving operations were undertaken over a 25 dive sites and five islands under both windward and leeward conditions. The Phoenix Islands while under the Kiribatti administration have no search and rescue (SAR) capability in the event of a diver who becomes separated from the diving team. To maximize prompt diver recovery, each dive team member carried a surface location aide in the form of a safety sausage. In the rare circumstance that a diver would be out of visual range, each buddy pair carried either a VHF radio tuned to the ship monitoring frequency or a Personal Locator Beacon (PLB) in a pressure proof canister. Arrangements were made with the USCG Rescue Coordination Center Honolulu (RCC Honolulu) to provide the satellite latitude and longitude via SAT phone communication in the case of PLB activation. This would provide immediate positioning data to the ship without having to mobilize SAR rescue resources from the USCG. In addition a four element yagi direction finding antennae capable of homing to a 121.5 MHZ signal was available for PLB location. During the expedition, upon surfacing a considerable distance from the zodiacs, two members used their radios to call the bridge which directed the zodiacs to their location for a pickup. This setup considerably expedited their pickup.

A new handheld VHF radio (Nautilus Lifeline) was available to be carried by each expedition member. The unit had a number of advantages over past expedition VHF radios. The radio was more compact and was contained in its own built-in pressure proof case. It is MMSI compliant and able to send its own position and distress alerts. Upon testing it was found that the correct GPS position was readable on its display window but that position was not transmitted to the main monitoring radio on the bridge when the emergency distress button was pressed. Despite many attempts this issue was never solved, however, there were no events where the distress function was needed to be activated. The range was tested and found to be within one to two miles. This appears consistent with the lower output power (1.8 watts) compared with standard marine VHF handhelds of 4 to 6 watts. One unit flooded.
Medical Issues
The length and remoteness of the PIPA 2012 expedition placed an increased likelihood of a medical event becoming a possibility. Medical supplies were available as well as the presence of an onboard medical physician. There were 18 minor medical issues involving 12/16 or 75% of the expedition members at some point during the 17 day expedition. Three members of the crew required medical consultation and treatment. There was one major medical event involving a serious infection that potentially involved evacuation, however this was able to be successfully treated with antibiotics onboard with no evacuation necessary.

5. Media objective

Keith Ellenbogen (NEAq)

Professional Photographer Keith Ellenbogen (NEAq and bluereef.com) integrated a visual component to the onboard research and data collection on the marine environment. The goal was to photographically capture images to depict environmental issues and threats, and the conservation efforts within PIPA. His photographs on this assignment focused on the following areas:

A Human Element — As a means of expanding a project already developed with other coastal communities, i-Kiribati citizens approved the concept of using photography to create a personalized relationship between people and cultures. This project is a series of full-body portraits that aims at using photographic imagery to remove anonymity and connect people to places often separated by land and sea (Figure 5.1a). On Kanton Island, Keith worked directly with Tuake Teema, to ensure he photographed all of the people on the island as well as record all their names, ages, number of years of residence, job titles, and places of origin.

Figure 5.1 The faces of climate change. An i-Kiribati couple stationed as caretakers on Kanton
Island (L), and a Kanton student (Arieta Owen) thanks Emily Mead and NEAq for school supplies. Photos by Keith Ellenbogen

Seascapes and Marine life— Keith’s images and stories showcase the beauty and diversity of the marine habitat as well as environmental pressures that impact the Phoenix Islands and global marine conservation. Another focus of his work is to capture images that create emotional connections to the fish and animals. He also specializes in macro photography in which he brings to life the small coral polyps, intercut details, colors, patterns and textures. Many of these photos have been featured throughout this report.

Terrestrial / Aerial Photography — Additional emphasis was placed on photographing the landscapes and infrastructure on the Islands of Kanton and Orono in collaboration with Tuake Teema. Keith also experimented with kite photography and on this expedition collaborated with Randi Rotjan to prototype a GoPro camera that would showcase a bird’s eye view of flat islands. The first kite photographs captured in the Phoenix islands were on the Island of Nikumaroro.

Figure 5.2 Aerial photograph of Nikumaroro Lagoon. Photo by Keith Ellenbogen

Science in Action — As a means of communicating the complex scientific research occurring on this expedition, Keith photographed the scientists working in the field collecting data. On this expedition he highlighted images of coral coring, photo-megatron, collection of coral genetics, and the tagging mantas.

Media — Keith’s images are featured on the NEAq PIPA blog along with explanations and stories of the scientific process. This process was a collaborative effort in which stories were written and communicated by Sangeeta Mangubhai in the field, scientists on board and Randi Rotjan. For this expedition all the blogs were sent via Bgan Satellite from the Phoenix Islands around the world to Boston Massachusetts, USA where they were posted on the World Wide Web for all citizens.
Looking towards the future, it is the goal to use these images to create a comprehensive portrait and visual narrative of the Phoenix Islands that can communicate their wonderful story to an audience around the world. An additional emphasis will be to develop presentations, magazine articles as well as an art exhibition.


**Equipment** —The photographic equipment on this expedition includes: Canon 5D Mark II; a variety of lenses, Sea&Sea underwater housing, Sea&Sea YS-250 Strobes; Light & Motion video lights, studio umbrella’s and strobes.

6. **Other sampling objectives**

**Ocean Genome Legacy**

In accordance with the expedition permit and the drafted Material Receipt, Transfer, and Rights Agreement (MTA) between OGL, NEAq, and the Republic of Kiribati, a total of 185 genetic samples were collected from 9 fish species, 9 scleractinian species, and 1 holothurian for the Ocean Genome Legacy project. Five specimens were collected for each species. From each fish three tissue types were samples: fin, muscle, and gill. All samples were preserved in OGLfix in the provided tubes. As specified in the draft MTA, the samples will remain the property of the Government of Kiribati (GoK), OGL claims no rights to the materials or to any intellectual property derived therefrom, and the samples will not be distributed to third parties without the explicit written consent of the GoK given via a point of contact to be designated by GoK. Funding for the analysis of these samples has yet to be procured. Samples are currently being warehoused by the OGL in anticipation of future analysis.

**References and further reading:**


