



PHOENIX ISLANDS PROTECTED AREA

Phoenix Islands Protected Area Climate Change Vulnerability Assessment and Management

Contributing Authors:

David Obura, Simon Donner, Sheila Walsh, Sangeeta Mangubhai, and Randi Rotjan



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1. Executive Summary

Kiribati is an atoll and ocean nation of some 100,000 people straddling the equator and the dateline, in the Central Pacific Ocean. Its land area is some 811 km² spread across 3.6 million km² of ocean. With human populations growing and testing the limits of island resources, climate change is now becoming the most pressing threat to the nation. With three primary concerns: (1) eventual relocation from the islands as a result of sea level rise that will make them uninhabitable; (2) decreasing availability of freshwater and ability to grow food crops, due to changing rainfall patterns, drought and salinization of groundwater; and (3) changes in the marine environment, such as migration of fish stocks and bleaching of coral reefs, on which they have depended for centuries for protein and coastal protection. With both pressures from overpopulation and climate change, identifying the causes of synergistic problems can be impossible. Nevertheless some islands in Kiribati have no human populations, and one entire group, the Phoenix Islands, is essentially uninhabited. It thus forms a natural reference site for comparison with populated and overpopulated islands. Further, when the Phoenix Islands was designated by the government it was the largest Marine Protected Area (MPAs) in the world, covering 408,250km², some 11.3% of Kiribati' total Exclusive Economic Zone (EEZ), and comprising 8 islands, 2 submerged reefs, some 14 seamounts, open ocean and abyssal seafloor to 5000m deep. It remains the largest and the largest and deepest UNESCO World Heritage Site on earth. As of Jan 1, 2015, the Phoenix Islands Protected Area was closed to commercial fishing.

The Phoenix Islands Protected Area (PIPA) Management Plan 2010-2014 specifies action for PIPA with respect to climate change under Strategic Action Plan (SAP) 2.7. It calls for three key targets: a) best practice measures for climate change adaptation in tropical marine protected areas will be investigated and implemented, b) a PIPA Climate Change Research Programme be designed and c) PIPA be promoted as a globally important sentinel site or "climate change research laboratory" to understand the impacts of climate change on tropical marine and island atoll systems in the virtual absence of other anthropogenic factors. The PIPA Management Plan is currently being reviewed and the next version drafted, and this scoping study addresses these three targets by:

- outlining the climate context of PIPA;
- identifying its key vulnerabilities and strengths;
- outlining PIPA's relevance to broader (geographic and human) climate change issues in Kiribati, and globally; and
- identifying opportunities for action
- and identifying principal risks.

Key results from this assessment are as follows, and are bolded in the report:

- *The El Niño / Southern Oscillation drives substantial year-to-year variability in Sea Surface Temperatures and rainfall that have significant implications for PIPA's shallow and deep water ecosystems and the I-Kiribati residents of Kanton Atoll.*
- *The mean air temperature for the PIPA region is project to increase by 1.6°C above 1980-1999 levels by the 2050s and 2.6°C above 1980-1999 levels by the 2090s under business-as-usual scenario.*
- *Rainfall is also expected to increase in the PIPA region, however there is less agreement between models due to disagreement about future El Niño dynamics.*

- *Ocean warming due to climate change is expected to lead to frequent heat stress on PIPA's coral reefs, with the probability of Bleaching Alerts in a given year rising to 70% by mid-century.*
- *While PIPA's coral reefs are unlikely to erode (or dissolve) like some high latitude reefs, changes in ocean pH would have some impact and potential long-term degradation of the reef framework.*
- *The Phoenix Islands could experience up to a metre or more of sea-level rise this century, with regular high tides commonly exceeding current "king tide" levels and causing inundation of land and freshwater lenses with seawater.*
- *The time to full recovery of coral cover may be estimated therefore at 12-15 years for general recovery, with a time scale of 6-8 years for the sites with fastest recovery.*

It should be noted that this is a living document, meant to be updated as the years progress. As such, please note the current date of this document: now updated January 18, 2016. The most updated version can be found on the Phoenix Islands Protected Area website: <http://phoenixislands.org/>

2. Introduction

Kiribati is an atoll and ocean nation of some 100,000 people straddling the equator and the dateline, in the Central Pacific Ocean. Its land area is some 811 km² spread across 3.6 million km² of ocean. With centuries of tradition living on remote tropical islands, the people of Kiribati have a keen sense of their relation to the environment. With human populations growing and testing the limits of island resources, climate change is now becoming the most pressing threat to the nation, clearly recognized by President Anote Tong in his frequent references at the United Nations and at intergovernmental fora. Given its low-lying islands and location in the Pacific, Kiribati is particularly vulnerable to periodic storm surges and droughts, particularly during La Niña years¹. By 2050, Kiribati could face economic damages from climate change of US\$ 8-16 million a year, equivalent to 17-34% of its 1998 GDP¹.

The people of Kiribati eloquently express their concerns about their vulnerability to climate change in videos (Rising Waters, Kiribati: A climate change reality) that capture the principal threats they face²:

- eventual relocation from the islands as a result of sea level rise that will make them uninhabitable;
- decreasing availability of freshwater and ability to grow food crops, due to changing rainfall patterns, drought and salinization of groundwater;
- changes in the marine environment, such as migration of fish stocks and bleaching of coral reefs, on which they have depended for centuries for protein and coastal protection.

With both pressures from overpopulation and climate change, identifying the causes of synergistic problems can be impossible. Nevertheless some islands in Kiribati have no human populations, and one entire group, the Phoenix Islands, is essentially uninhabited. It thus forms a natural reference site for comparison with populated and overpopulated islands in the region. Further, when the Phoenix Islands was designated by the government it was the largest Marine Protected Area (MPAs) in the world, covering 408,250km², some 11.3% of Kiribati' total Exclusive Economic Zone (EEZ), and comprising 8 islands, 2 submerged reefs, some 14 seamounts, open ocean and abyssal seafloor to 5000m deep. It remains the largest and the largest and deepest UNESCO World Heritage Site on earth. As of Jan 1, 2015, the Phoenix Islands Protected Area was closed to commercial fishing.

Climate change poses the most substantial threat to this vast protected area, recently gazetted and offered by the Kiribati people as a gift to the world. Yet, the threat of climate change to this vast ocean wilderness area under explicit management by a national authority provides an exceptional opportunity to examine the influences of global change without local, anthropogenic influence. This natural laboratory is significant at two levels:

- For Kiribati, to understand how degradation of ecosystem goods and services on populated islands undermines the resilience both of natural systems (the islands and marine systems) and society to climate change threats (freshwater, salinization, fishing, agriculture, public health, etc.)

¹ Ramsay et al. 2008; Thompson et al., 2008

² <https://www.youtube.com/watch?v=cTMkhh0TiCk>; <https://www.youtube.com/watch?v=HTLOulRStKc>

- For the world, as one of the few reference sites with significance globally for the issues listed above, as well as to larger scale climate issues such as ocean acidification, circulation patterns and the ENSO cycles that originate in this part of the Pacific.

3. Objectives of the Study

The Phoenix Islands Protected Area (PIPA) Management Plan 2010-2014 specifies action for PIPA with respect to climate change under Strategic Action Plan (SAP) 2.7. It calls for three key targets: a) best practice measures for climate change adaptation in tropical marine protected areas will be investigated and implemented, b) a PIPA Climate Change Research Programme be designed and c) PIPA be promoted as a globally important sentinel site or “climate change research laboratory” to understand the impacts of climate change on tropical marine and island atoll systems in the virtual absence of other anthropogenic factors. This scoping study addresses these three targets by:

- outlining the climate context of PIPA;
- identifying its key vulnerabilities and strengths;
- outlining PIPA’s relevance to broader (geographic and human) climate change issues in Kiribati, and globally; and
- identifying opportunities for action and principal risks.

4. Vulnerability Assessment:

4.1. PIPA – status and management

The Phoenix Islands Protected Area (PIPA) was declared in 2006, and legally established in 2008. In 2008, 3.1% of the MPA was no-take (12,714 km²), which was expanded in 2015 to 99.4% (405,755 km²) no-take. The remaining ~0.6% will remain a restricted use zone around Kanton Island to accommodate subsistence fishing for a small caretaker population (Fig. 1). The PIPA Management Committee and Director have been operational since 2007, formulating and guiding the building of capacity for managing the protected area, and focused on the Management Plan. PIPA was successfully nominated as a World Heritage Site in 2010. Financing for management operations are underway through grants raised through the PIPA Conservation Trust, the Government of Kiribati, and PIPA partners New England Aquarium (NEAq) and Conservation International (CI).

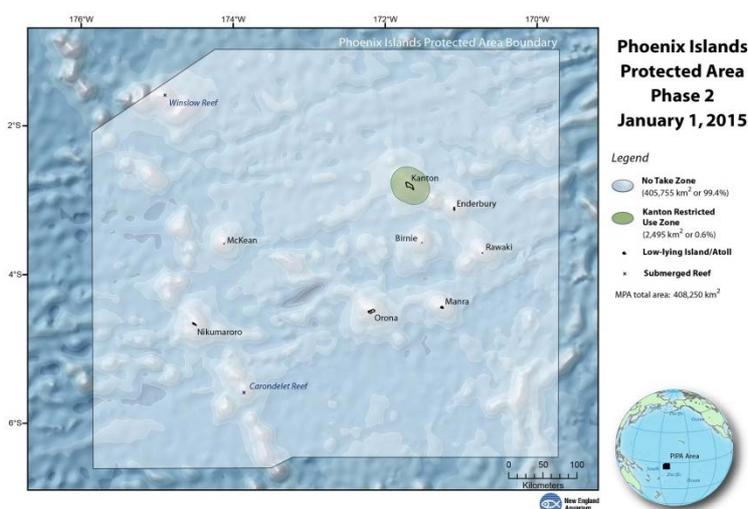


Fig. 1. PIPA map showing Phase 2 zonation, effective Jan 1 2015.

Management actions that have occurred to date in PIPA include the following:

- research and monitoring focused on coral reefs, bird populations and invasive species, but with preliminary data collected on other natural assets of the protected area, including

deep reef slopes, deep water and oceanic invertebrates, marine megafauna and island vegetation;

- invasive alien species eradications (rabbits, rats, cats, mice) on three islands with additional islands planned for the near future;
- consultations on Kanton with existing government staff and the resident community on the management of Kanton Atoll, including a draft zoning of the island and adjacent waters;
- consultations on enforcement with partner countries, including New Zealand, the US and Australia;
- improved legislation and regulations concerning fisheries observers, management, and enforcement;
- outreach programs implemented in Tarawa and more broader nationally (e.g. radio) to raise awareness, support and pride in PIPA; and
- establishment of a PIPA office and a PIPA Trust office in Tarawa
- apprehension for maritime offenses in other parts of Kiribati, demonstrating competence to do the same for PIPA;
- establishment of the PIPA Trust Fund
- a Signed Conservation Contract between the Government of Kiribati and the PIPA Trust
- implementation of satellite surveillance technology and geofencing to enforce fishing regulations and no-take status
- installation of MPA signs on 7 of the 8 Phoenix Islands informing any potential visitors of MPA status and rules

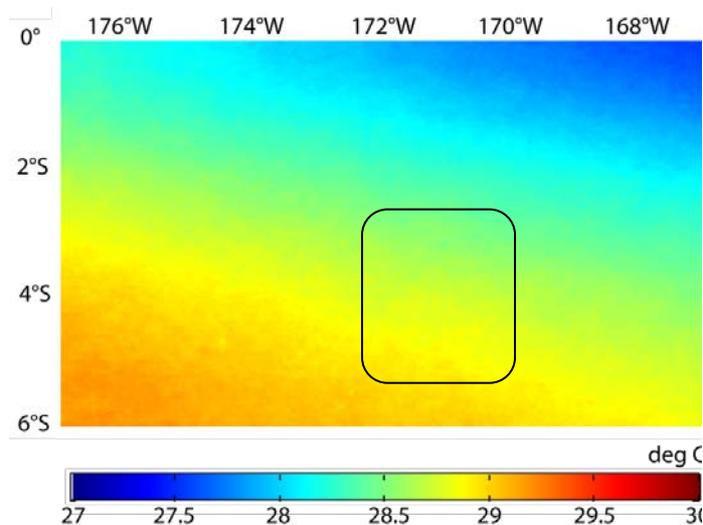


Figure 2. Average annual sea surface temperature (SST) across the central Pacific region, calculated from 4 km x 4 km NOAA AVHRR satellite SST data for 1985-2007. The box insert indicates the position of the Phoenix Islands Protected Area.

4.2. Past climate and ocean variability

The Phoenix Islands, like the Gilbert Islands and the Line Islands, have a unique tropical climate that is heavily influenced by the El Niño / Southern Oscillation. The Phoenix Islands are one of the few tropical island chains that experience greater year-to-year variability in temperature and rainfall than seasonal variability in temperature and rainfall. Understanding the causes of the year-to-year, and decade-to-decade, variability in the climate of the Phoenix Islands is crucial to understanding the range of conditions the ecosystems in PIPA have experienced in the past and may experience in the future. A summary of the climate of PIPA is provided below, with more detailed information provided in Appendix 1.

4.2.1. *Climate overview*

The Phoenix Islands lie to the east of the West Pacific Warm Pool, where open ocean temperatures are consistently higher than 28°C, but to the west of the colder eastern equatorial waters. The dominant easterly trade winds drive strong upwelling of cooler waters in the eastern equatorial Pacific and a weak westward flowing surface current, known as the South Equatorial Current (~0.3 m/s), through the Phoenix Islands. This westward current creates an east-west gradient in sea surface temperatures (SSTs) and an increase in the thickness, or depth, of the well-mixed surface layer of the ocean. This gradient can be seen in a map of average annual SSTs (average for 1985-2007) for the region of the Phoenix Islands (Fig. 2). Temperatures increase from the eastern equatorial corner of PIPA towards the west and away from the equator. The surface mixed layer is also typically deep in the Phoenix Islands in contrast to the eastern Pacific.

Air temperatures across the Phoenix Islands are warm and very stable year-round. Meteorological data has been collected on Kanton since 1937, though there are gaps in the data record that extend for multiple months or years in some cases. During the period of uninterrupted data recording from 1984 to 2008, the mean daily maximum air temperature was between 31.5°C and 32.5°C for every month of the year. There is even less variation in the mean daily minimum temperature, with a low of 25.0°C in February and a high of 25.4°C in May.

The Phoenix Islands are considerably drier than many other equatorial locations, including the westerly Gilbert Island chain. The westward movement of air and water along the equator, coupled with the warmer western equatorial Pacific waters, lead to greater convection and more rainfall in the western Pacific than in the Phoenix Islands. Rainfall is highest in the Phoenix Islands during the Southern Hemisphere autumn (April through June), when the trade winds and South Equatorial Current (SEC) weakens and reverses. The Kanton meteorological data show that rainfall is highest during April, May and June. A second smaller seasonal peak in rainfall and SSTs occurs in Southern Hemisphere summer (December and January).

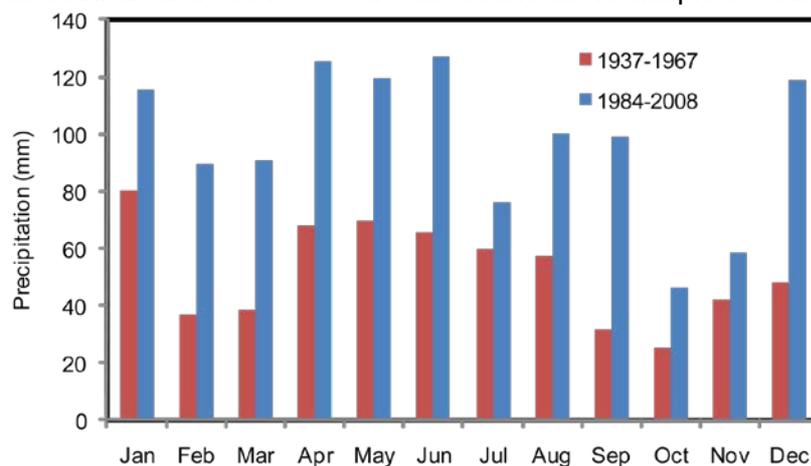


Figure 3. Average monthly precipitation (rainfall) in mm at Kanton for the periods 1937-1967 and 1984-2008 from the Kiribati Meteorological Service.

The two wet seasons can be seen in the averages for the two multi-decade periods of uninterrupted rainfall data collection (1937-1967; 1984-2008) in Kanton (Fig. 3) and in the seasonal SSTs in much of the region (Fig. 4). Rainfall was significantly lower in Kanton during the early period of data collection from the 1930s through the 1960s. The data should be

viewed with some caution, as the record is discontinuous and there may have been recording issues. However, the general conclusion that the earlier period was drier agrees with historical accounts and the limited rainfall data collected during the inhabitation of Nikumaroro (1951–1963), Orona (1953–1963) and Manra (1948–1961). This is described further below.

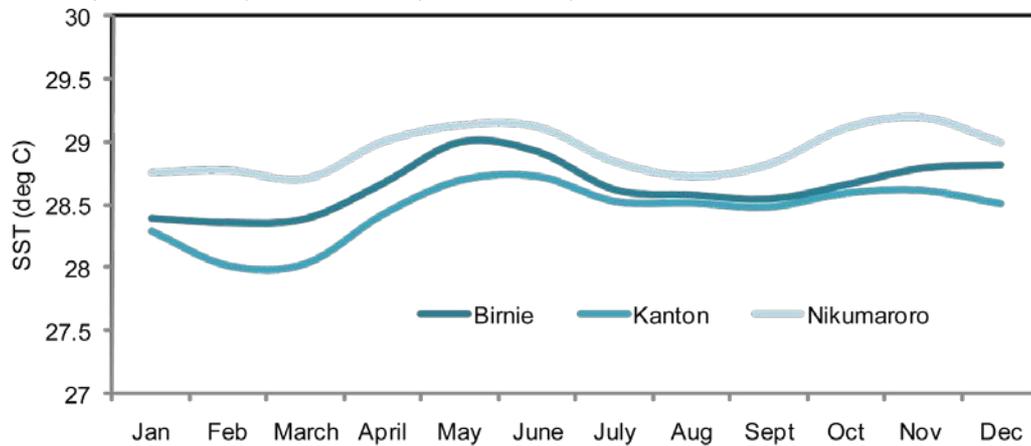


Figure 4. Average monthly sea surface temperature (SSTs) for the grid cell nearest to Birnie, Kanton and Nikumaroro from 4 km x 4 km NOAA AVHRR satellite SST data for 1985-2007.

4.2.2. *Climate variability and El Niño*

The El Niño / Southern Oscillation drives substantial year-to-year variability in SSTs and rainfall that have significant implications for PIPA's shallow and deep water ecosystems and the I-Kiribati residents of Kanton Atoll. This section explains the phenomena, the influence on the climate of the Phoenix Islands, and the implications for PIPA.

El Niño events typically bring unusually warm water temperature and high rainfall to the Phoenix Islands, typically beginning in July or August and ending the following March or April. The La Niña or cold phase events bring cooler water temperatures and drought conditions over the same period. Figure 5 shows the September to November SST anomaly (departure from the 1985-1994 average) for the PIPA region for a La Niña event (1989) and two different El Niño events (1997, 2002). Subsequent El Niño events occurred in 2010³ and 2015-16⁴. Because of strong relationships between El Niño events

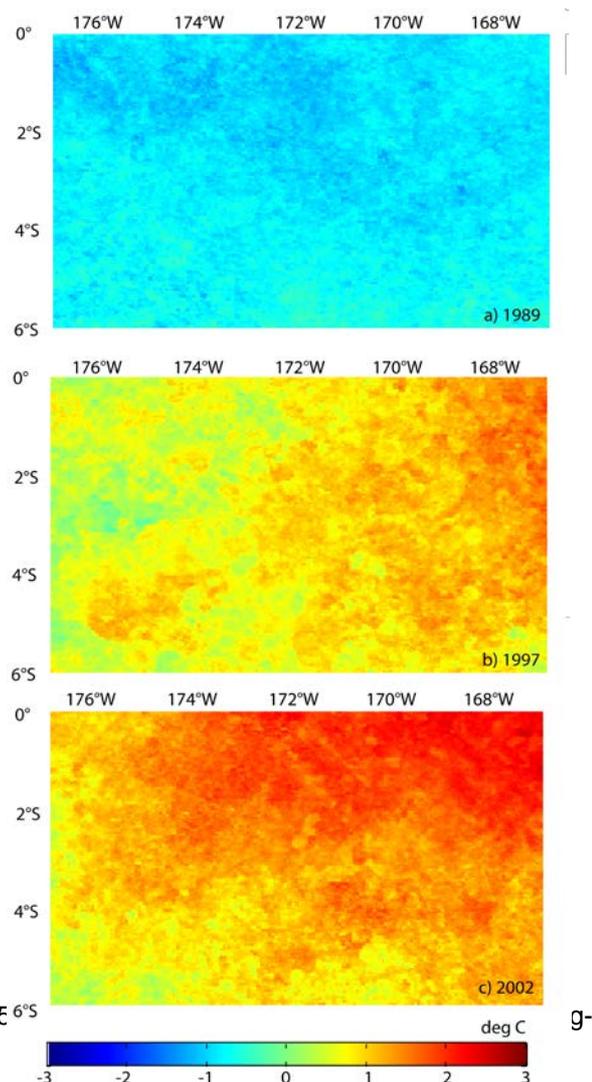


Figure 5. Mean September–November sea surface temperature (SST) in 1989, 1997 and 2002 calculated from 4 km x 4 km NOAA AVHRR satellite SST data.

³ Vargas-Angel et al. 2011

⁴<http://www.noaanews.noaa.gov/stories2015/100815655event.html>

and weather patterns, the Kiribati Meteorological Service can monitor the development of El Niño and La Niña events and predict the likely rainfall and SSTs patterns in the Phoenix Islands. To that end, they release monthly reports “the Kiribati Climate Outlook” showing the weather and climate data and predictions for all three Kiribati archipelagos.

El Niño events are not all created equal. Researchers are now reporting the existence of ‘central Pacific’ and ‘eastern Pacific’ El Niño events, with distinct evolutions and characteristics⁵. The 1997/98 event depicted in Figure 5 is an example of a traditional “Eastern Pacific” event. During these strong events, the Pacific-wide slowing and reversal of the trade winds leads to high SSTs and wet conditions across the eastern equatorial Pacific. The 2002/3 event depicted in Figure 5 is an example of a “central Pacific” events or El Niño Modoki. During these events, the trade wind shift does not extend across the entire equatorial Pacific, and the high SSTs and wet conditions are concentrated in the central Pacific, including the Phoenix Islands⁶. The frequency of the different El Niño events and of La Niña events is known to vary from decade to decade along with the general background conditions of the Pacific Ocean. For example, the frequency of central Pacific El Niño events and of La Niña events has been higher over the past fifteen years, with four central Pacific events and five La Niña events but no eastern Pacific events since 1997/98 according to one assessment⁷.

The recent central Pacific El Niño events led to periods of abnormally high SSTs which create heat stress on the PIPA coral reefs and may cause coral bleaching, as observed in 2002-03⁸, 2010⁹, and 2015¹⁰. The heat stress can be estimated by the Degree Heating Months (in °C-month), which is a summation of temperatures in excess of the usual maximum for the year commonly used to predict the likelihood of coral bleaching (Fig. 6). Historical data provided by NOAA Coral Reef Watch averaged over the PIPA region shows that the Degree Heating Months exceeded the “Bleaching Alert Level II” threshold of 2°C-month, during the 1986-7, 1990-1994, 1997-98 and 2002-3, and 2006-7 El Niño events. The highest value for the region to date is 5.5°C-month was in December 2002, which occurred during the peak of the 2002-2003 central Pacific El Niño event. This specific event resulted in mass coral bleaching in the region¹¹. More recent data (not included in Fig. 6) indicates the heat stress also reached

What is El Nino?

During El Niño events (also known as ENSO events), weakening or reversal of the easterly trade winds and the equatorial current brings unusually high SSTs and rainfall to the central and eastern equatorial Pacific. From a global climate perspective, El Niño events have been interpreted as a means by which the climate system discharges heat from the tropical Pacific. The discharge of heat is thought to lead the equatorial Pacific to move from the warm El Niño phase into the cool “La Niña” phase, in which SSTs are anomalously cool in the central and eastern equatorial Pacific. El Nino event timing is irregular.

⁵ Larkin and Harrison 2005; Trenberth and Smith 2006; Ashok et al. 2007; Kao and Yu 2009; Kug et al. 2009

⁶ Kao and Yu 2009; Ashok et al. 2007

⁷ Banholzer and Donner, 2014

⁸ Obura and Mangubhai 2011, Mangubhai et al 2014

⁹ Vargas-Angel et al. 2011

¹⁰ Mangubhai and Rotjan 2015

¹¹ Ailing et al. 2007; Obura and Mangubhai 2011

the Alert Level II during the subsequent 2009/10 central Pacific El Niño event and the ongoing 2015/16 El Niño event. The subsequent 2009/10 central Pacific event is known to have caused mass coral bleaching in the U.S. outlying islands neighboring the Phoenix Islands¹², as well as the Gilbert Islands. It should be noted, however, that past studies have suggested that this standard method of estimating heat stress on coral reefs may not be ideally suited to areas like PIPA that experience high year-to-year variability in SSTs¹³.

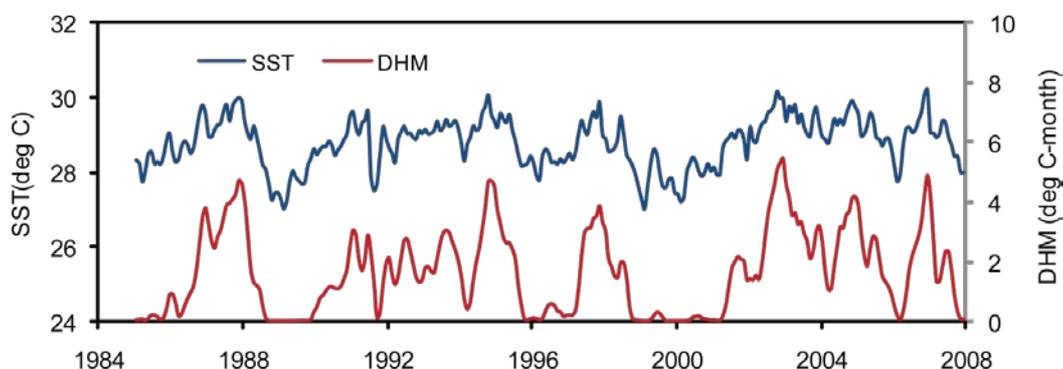


Figure 6. Monthly sea surface temperature (SST) and degree heating month (DHM) from NOAA AVHRR satellite data 4 km x 4 km 1985-2007 data. The DHM is the rolling three-month accumulation of SSTs above the average of the maximum monthly temperatures over the 1985-2000 period.

Rainfall in the Phoenix Islands is also directly affected by the El Niño / Southern Oscillation, with lower rainfall and drought typically occurring during La Niña conditions and higher rainfall occurring during both types of El Niño conditions. The average annual rainfall of 1089 mm at Kanton in the 1984-2008 period was almost twice (95%) the average value of 559 mm for the 1937–1967 period, largely because of a greater El Niño frequency in the latter period (Fig. 3). From 1984 to 2008, there were five years with rainfall greater than 2000 mm (1987, 1992, 1997, 1998, 2002) all of which coincided with the onset or decay of an El Niño event. Drought analysis conducted for the Kiribati Adaptation Project also found higher rainfall frequency in the earlier period¹⁴.

4.2.3. *Climate change projections*

The projected impacts of global climate change on the Phoenix Islands can be estimated from the output of general circulation models of the atmosphere and oceans that take into consideration possible future greenhouse gas concentrations in the atmosphere. There are two important sources of uncertainty in these projections. The first is that the projected greenhouse gas concentrations depend upon assumptions about the future energy use, economic growth and population growth, as well as the ability of the oceans and terrestrial ecosystems to absorb a fraction of greenhouse gas emissions (particularly carbon dioxide). The second area of uncertainty is the ability of the climate models to simulate the climate of the particular region. Only a few of the climate models used in the IPCC Assessments have demonstrated the capacity to realistically simulate the frequency of El Niño and La Niña events. The projections for this PIPA vulnerability assessment are derived from the climate models GFDL CM2.0 and GFDL CM2.1, which are among the most effective models at describing central Pacific and eastern Pacific El Niño events and have been used in past coral reef and fisheries

¹² Vargas-Angel et al., 2011

¹³ Donner, 2011; Obura and Mangubhai 2011

¹⁴ Thompson et al. 2008

assessments¹⁵. The output reported for the “business as usual” scenario, where carbon dioxide (CO₂) concentrations are predicted to reach more than twice present levels by the end of the century. It is supplemented with results from other studies where appropriate.

4.2.3.1. Air temperature and rainfall

The mean air temperature for the PIPA region is projected to increase by 1.6°C above 1980-1999 levels by the 2050s and 2.6°C above 1980-1999 levels by the 2090s under business-as-usual scenario. This rate of warming agrees with that reported in the study of future drought probabilities originally computed for the Kiribati Adaptation Project¹⁶. For example, Thompson et al. (2008) found that mean air temperature will increase 0.6°C and 1.2°C by the 2050s and the 2090s, respectively, in the lower emitting scenario, and by 1.5°C and 2.6°C in the 2050s and the 2090s respectively, in the business-as-usual scenario.

Rainfall is also expected to increase in the PIPA region, however there is less agreement between models due to disagreement about future El Niño dynamics. The higher temperatures and the changing El Niño dynamics cause significant increase in rainfall in most model simulations used in the 2007 and 2013 IPCC Assessments. The average increase in rainfall by the 2090s across all the 2007 IPCC models is 0.4 mm/day or 146 mm/year in the Phoenix Islands region. For example, at Kanton, a day of rainfall that occurs once every fifty years at Kanton today could occur closer to once in 20 years by the end of the century¹⁷. This expected rainfall increase is driven by more frequent El Niño events, leading to more and more intense wet years. However, due to disagreement in model projections of El Niño dynamics, the projected change in rainfall in the central equatorial Pacific, including PIPA, was not considered statistically significant in the more recent 2013 IPCC assessment.

4.2.3.2. Sea surface temperatures (SSTs) and thermal stress

Ocean warming due to climate change is expected to lead to frequent heat stress on PIPA’s coral reefs, with the probability of Bleaching Alerts in a given year rising to 70% by mid-century. The increase in SSTs in the model simulations tracks with the increase in surface air temperatures. The likelihood of bleaching-level heat stress for PIPA is estimated from the “business-as-usual” scenario, using a thermal stress threshold defined by the historical temperature variability in the region developed in Donner (2009) specifically for high variability regions like PIPA. The mean DHM reaches 3.1°C-month by the 2030s, 5.2°C-month by the 2050s, and 8.8 °C-month by the 2090s. The probability of reaching Bleaching Alert Level II in a given year increases to 45% of the time in the 2030s, 70% of the time in the 2050s, and 100% of the time by the end of the century. If acclimation or adaptation by corals and their symbionts to rising temperatures increased the threshold beyond which thermal stress accumulates by 1.5°C, the probability of Bleaching Alert Level II in a given year would still be 30%, 55% and 90% in the 2030s, 2050s and 2090s respectively.

¹⁵ Donner 2009; Cheung et al. 2009

¹⁶ Ramsay et al. 2008; Thompson et al, 2008

¹⁷ Thompson et al. 2008

4.2.3.3. Ocean pH and coral calcification

The mean pH and aragonite saturation state for the PIPA region were obtained from a modelling study by the Carnegie Institution at Stanford University¹⁸. The mean pH of the region was 8.16 and $\Omega_{\text{aragonite}}$ was 4.21 in pre-industrial times, and decreased to a pH of 8.05 and $\Omega_{\text{aragonite}}$ of 3.62 by the year 2000. Hoegh-Guldberg et al. (2007) report that net reef growth will approach zero if the aragonite saturation passes below 3.3 as the rate of calcification will lower to the rate of erosion. This means coral reefs will no longer be able to grow. Above that level, coral reefs are expected to erode down and hard corals (with calcium carbonate skeletons) which currently dominate our reef ecosystems are expected to become less common. The model results show that if atmospheric CO₂ concentration reaches 450 ppm, expected to occur by the 2030s under business-as-usual scenario, the $\Omega_{\text{aragonite}}$ will decrease to 3.31 in the PIPA region. If atmospheric CO₂ concentration reaches 550 ppm, expected to occur by the 2030s under business-as-usual scenario, the $\Omega_{\text{aragonite}}$ will decrease to 2.99 in the PIPA region. Therefore, under business-as-usual, net reef growth could reach zero between the 2030s and the 2050s.

If CO₂ levels continue to rise in the latter half of the century, reef growth globally will become increasingly negative. At atmospheric CO₂ levels of 750 ppm, expected in slightly more than a century under business-as-usual scenario, the aragonite saturation state would reach 2.54¹⁹. **While PIPA's coral reefs are unlikely to erode (or dissolve) like some high latitude reefs, changes in ocean pH would have some impact and potential long-term degradation of the reef framework²⁰.**

4.2.3.4. Sea level rise

The Phoenix Islands could experience up to a metre or more of sea-level rise this century, with regular high tides commonly exceeding current "king tide" levels and causing inundation of land and freshwater lenses with seawater. The sea-level has been rising and will continue to rise in the Phoenix Islands over the past century due to ocean warming and land ice melt. However, the rate of rise varies from decade-to-decade due to variability in the trade winds, ocean temperatures and South Equatorial Current associated

What is Ocean Acidification?

The increase in atmospheric CO₂ has direct impacts on marine chemistry and ecosystems. Atmospheric CO₂ dissolves in ocean water to form carbonic acid (H₂CO₃). The carbonic acid releases hydrogen ions (H⁺) to form bicarbonate (HCO₃⁻) and carbonate (CO₃²⁻). Additional CO₂ dissolution brought about by the rise in atmospheric CO₂ concentrations increases the release of H⁺ thus decreases the seawater pH (pH is an inverse log of H⁺ concentrations). The excess H⁺ reacts with carbonate to form bicarbonate, which reduces the ability of organisms like corals to secrete calcium carbonate (CaCO₃) and build reefs. The ability of reefs to calcify can be measured by the aragonite saturation state ($\Omega_{\text{aragonite}}$), which refers to the particular form of calcium carbonate formed by tropical corals.

¹⁸ Caldiera and Cao (2008)

¹⁹ Cao and Caldeira, 2008

²⁰ Hoegh-Gulberg et al. 2007

with the El Niño / Southern Oscillation. Sea-level rise rose faster at Kanton since 1950 (2.1 mm/year, to 2009) than the global rate of rise (1.8 mm/yr)²¹. However, that pattern reversed in the past twenty years, due to stronger trade winds associated with the more frequent La Niña events and lack of eastern Pacific El Niño events²². While there are no specific sea-level predictions for the Phoenix Islands, the 2013 IPCC Assessment projected that, under a “business as usual” future scenario, sea-level was “likely” to rise globally by 52 to 98 cm by 2100 and that the year-to-year variability in sea-level in the central equatorial Pacific would increase by 2-4 cm²³. This projected increase in both mean sea-level and sea-level variability implies a substantial increase in the frequency of coastal inundation; an analysis conducted for the KAP with older IPCC model data, concluded that average high tides would exceed current astronomical or “king” tide levels by the end of the century.²⁴

²¹ Becker et al. 2012

²² Becker et al. 2012

²³ Church et al. 2013

²⁵ Maragos et al. 2007

4.3. Climate sensitive systems and species

This section focuses on the potential impact of climate change on the principal ecosystems and species in the Phoenix Islands, identified in the management plan.

4.3.1. Pelagic ecosystems and tuna

Deep and shallow open water systems contain the largest volume of habitable space in PIPA, including the photic zone and deep abyssal waters. Two major currents pass through the PIPA region, the Equatorial Undercurrent (EUC) and South Equatorial Current (SEC), with significant structure with depth, and seasonal variations in strength, latitude and depth²⁵. The EUC is cold and nutrient rich²⁶ flowing eastward below the surface and averaging 100-150 m deep in the region of the Phoenix Islands. It has a wide range of velocities about 1.0 ms^{-1} ²⁷. The SEC is above the EUC, on the surface, and is generally weaker ($\sim 0.3 \text{ ms}^{-1}$) and warmer²⁸.

Climate change impacts on pelagic systems may be caused by: (i) temperature (in the upper levels), (ii) acidification (at all levels), and (iii) shifts in currents that change the locations of large bodies of water and the fronts between current systems. Temperature and ocean acidification impacts to species will be physiological, potentially changing recruitment, growth, reproduction and survival patterns. Species assemblages may shift as different water masses move in and out of the PIPA boundaries. An example of this has already been demonstrated – during ENSO events the SEC weakens and the western equatorial Pacific warm water pool shifts to the east. Entire pelagic systems shift with the water mass, which has been documented for skipjack tuna – under these conditions the stocks also shift to the east, into the Phoenix Islands region²⁹, followed by fishing effort. Such changes in the location of pelagic fish stocks of economic significance will likely increase with climate change as the dynamics of SST heating intensify. The implications for biodiversity and management of PIPA may be impacted.

²⁵ Maragos et al. 2007

²⁶ Chavez et al. 1999

²⁷ Yu and McPhaden 1999

²⁸ Yu and McPhaden 1999; Keenlyside and Kleeman 2002

²⁹ Lehodey et al. 1997

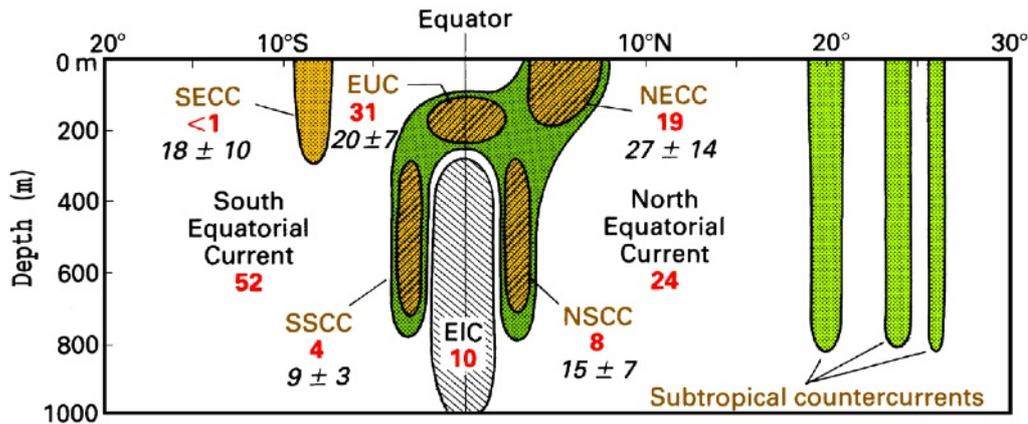


Figure 14: Sketch of the equatorial current system in the central Pacific Ocean (170°W). Shown in the figure in crosshatch are the subsurface Equatorial Intermediate Current (EIC) and the North and South Subsurface Countercurrents (NSCC and SECC). Eastward flow is colored green or brown to better distinguish the individual currents, and Westward flow is white. The black numbers represent transports in Sverdrups (155°W) and bold red numbers are based on observation (modified from Tomczak and Godfrey 2003).

Figure 7. Current structures at 170°W, from Maragos et al 2007 (fig. 14, including its caption). PIPA is located at 2-4°S.

4.3.2. Coral reefs

Corals and their symbiotic algae ('zooxanthellae of the genus *Symbiodinium*') are particularly vulnerable to increased SSTs and to acidification of seawater. Rising temperatures and acidification strongly undermine their ability to function together and trap sunlight that provides the resources to grow skeletons and build reef systems. In 2002-2003 the Phoenix Islands suffered the most intense sea temperature 'hotspot' yet recorded, which resulted in massive mortality, averaging 60% across the island group and increasing to near 100% in the most sensitive habitats³⁰. Repeat visits in 2005, 2009 and 2012 by the New England Aquarium and Conservation International researchers³¹, found that the intactness of the reef systems was enabling rapid recovery (Fig. 8). Specifically, they found:

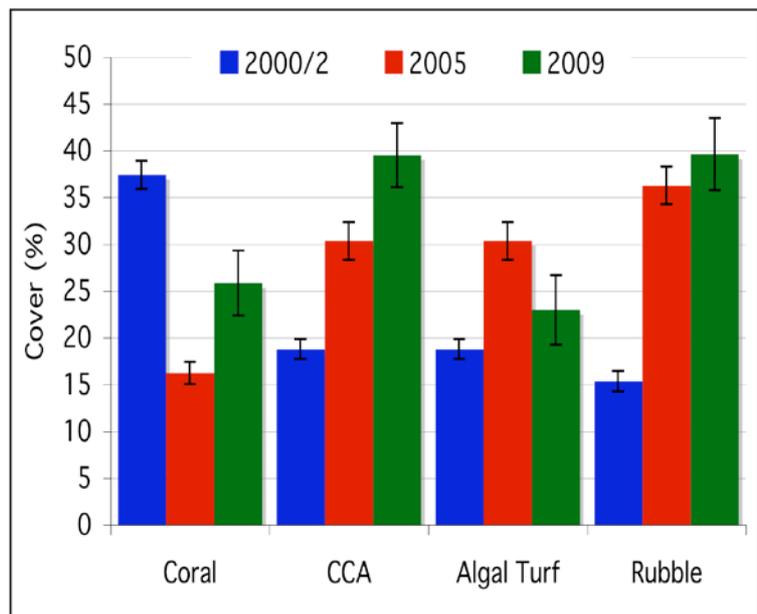


Figure 8. Benthic recovery of coral, crustose coralline algae (CCA), algal turf and rubble in the Phoenix Islands from 2000 to 2009.

- the initial increase in turf algae in 2005 had been reversed by 2009, most likely due to heavy grazing pressure from healthy fish herbivore populations;

³⁰ Alling et al. 2006, Obura and Mangubhai 2011

³¹ Rotjan et al. 2009; Mangubhai 2012

- b) crustose coralline algae (CCA) increased from 2002-2005 and 2005-2009 reflecting the availability of new space, and grazing pressure from herbivores promoting coralline algae over more disruptive macroalgae or turf algae;
- c) very rapid recovery of coral cover from 2005-2009, regaining 50% of the cover lost from 2002-2005, with continued recovery in 2012 and 2015 on sites without shipwrecks. At the best sites, coral cover was back to levels before bleaching occurred, with re-growth from mainly pre-existing corals that were abundant on reefs such as: *Montipora aequituberculata* (a fast growing plating coral with high levels of breakage and re-growth of fragments), and *Favia stelligera* (a columnar submassive coral who's tissue breaks into many fragments which regrew back rapidly post-bleaching). At these sites the full diversity corals documented before the bleaching was not yet re-established, nor the full size class range. In some sites, such as the Kanton lagoon, recovery of corals in 2015 resembled the original communities noted in 2000 and 2002.
- d) at intermediate sites of coral recovery, high levels of rubble were still present, though almost 100% covered by coralline algae – the rubble retards re-growth of coral recruits, but will eventually be cemented into the reef or transported off by wave energy;
- e) recruitment of new corals was good in 2009, 2012, and 2015 though not high, and this may reflect the isolation of the islands and low reproductive success due to low densities of adult corals following the bleaching, and their reliance on self-seeding (i.e. larvae from PIPA as opposed to outside of PIPA) for recruitment. Recovery appears to be predominantly from regrowth of colonies that suffered partial mortality, but survived.

The discrete nature of the islands and isolation from one another, and lack of compounding human threats enabled researchers to identify the factors that contributed to the slow recovery of some of the sites. For example:

- a) lagoon and leeward reef waters were heated more than windward waters, and lagoon waters contain more nutrients and sediment load than open reef waters. On the islands with lagoons (Kanton, Orona, Nikumaroro), a clear effect of the lagoon waters was visible in that recovery of corals was slow, algal turf levels were higher and fish herbivore populations were higher. Algal turf and microbial growth are fertilized more by high nutrient/silt content in the water than corals are, and all these factors together have negative impacts on coral regrowth and on colonization of the substrate by coral larvae.
- b) shipwrecks of various ages are present in PIPA, with known intact ones going back to the 1930s and Second World War, and older ones evident from chains, anchors and isolated ship parts. Iron enrichment in these low-nutrient open ocean waters appears to result in poisoning of corals and most other reef invertebrates, and promoting a black algal turf community³², and at lower levels promoting a dark pink-purple coralline algae³³. Clearest evidence of iron-related reef impacts are at Nikumaroro (Norwich City shipwreck), Kanton (President Taylor shipwreck) and Orona (Algae Corner site). At the last site, the coral community was lacking even before the bleaching event, which was originally misinterpreted as being due to eutrophication³⁴. The most recent shipwreck, of a freighter on the windward side of McKean in 2001 showed a small area of impact at 5 m in the shallows, but the high wave energy and strong currents appear to limit the impact of this wreck from iron enrichment.

³² Barott et al 2013; Kelly et al. 2012; Schroeder et al. 2008; Work et al 2008

³³ Rotjan and Obura 2009, Mangubhai et al. 2012

³⁴ Obura et al. 2003

- c) each of the islands shows some distinct effects of isolation (e.g. recovery of corals at Rawaki was dominated by *Porites* spp., while at Enderbury it was by *Montipora* and *Favia* spp.). The clearest evidence of isolation was on McKean, which had slow recovery post-bleaching in 2002 due to apparently low/no adult surviving stock with which to re-populate reefs. In 2000 (pre-bleaching), McKean had a poor leeward coral community likely as a result of guano enrichment, but a coral community on the windward side similar to other islands. In 2009 the windward side showed evidence of similar levels of bleaching mortality as on other islands, but no recovery by newly recruited corals. For this small most-remote island, there was apparently little surviving stock of corals successfully reproducing and providing recruits, and insufficient connectivity with the other islands to compensate for the lack of a resident population of adults.

These negative factors on reef recovery are particularly useful as indicators of local human impacts in other reef systems in Kiribati and globally. For example, in the Northern Line Islands group, the lagoon effect is magnified by anthropogenic additions of nutrients to reef waters, particularly to existing lagoons, magnifying their influence on adjacent reef systems, and shown by the gradient in reef health from unpopulated to populated islands, and from low to high lagoon influence³⁵. Both the iron and lagoon effects are indicators of chemical pollution of different types, indicating potential effects of chemical pollutants on the health of individual organisms and general trophic and reef dynamics. The importance of connectivity for recovery is shown by the lack of recruitment to islands with the smallest coral population before bleaching, and the importance, where possible, in other systems of maintaining healthy reef communities within distance limits for reseeding.

Overall therefore, the Phoenix Islands coral reefs are showing a clear ability to recover faster than is reported from more impacted systems, with 50% recovery of coral cover at 6 years after a massive mortality following bleaching. **The time to full recovery of coral cover may be estimated therefore at 12-15 years for general recovery, with a time scale of 6-8 years for the sites with fastest recovery.** Recovery of the full complement of coral species and colony size classes takes longer, but at 8-15 years we can expect the benthic community to have regained its prior function. However, these optimistic recovery trajectories may be disrupted if there are more frequent thermal stresses as temperatures rise further (see section 2.4.4.2). Further, increasing acidification will increasingly also undermine coral health. Even without local threats, the ability of corals and reefs to resist these two threats is under serious doubt.

Other components of the reef biota are also susceptible to climate threats. Microbial and algal populations may thrive under warmer conditions, particularly under conditions where corals are under stress. Other invertebrates are also susceptible to higher temperatures, particularly symbiotic invertebrates such as giant clams. Trophic webs may be altered by changing temperatures and acidification, as primary producers shift in abundance and biomass as a result of changing conditions.

4.3.3. Other climate sensitive features in PIPA

The remote and small nature of the islands and shallow marine systems of PIPA make them all susceptible to dramatic changes and environmental shifts, such as are occurring from climate

³⁵ Sandin et al. 2008

change. Thus further studies and assessments of these other sensitive systems need to be undertaken to fully account for the climate sensitivity of PIPA. Some brief introduction to these is presented here.

Deep sea, seamounts – The deep sea comprises the largest area cover of any habitat in PIPA (approx. 70%), but is also the least known. Sensitivity of deep communities to acidification is not very well known. Fourteen seamounts rise to within 500-1500 m of the surface, and emerging evidence shows that these isolated systems will be highly vulnerable to climate changes, including potentially acidification and changes in current patterns at depth.

Marine turtles - Green turtles are abundant in the Phoenix Islands, with large numbers of nests observed on the beaches, particularly on Enderbury. Sea turtles are highly sensitive to nest temperatures, as increasing temperature alters the sex ratio in favour of males.

Marine mammals - Marine mammals are not known to be highly sensitive to temperature changes in the tropics, but may be vulnerable as a result of changing trophic dynamics, and shifting water masses will affect planktonic and fish populations that they depend on.

Islands and shorelines – erosion of the carbonate framework of the islands will be accelerated by multiple climate change factors, including sea level rise, changes in storm patterns, changes in groundwater, and acidification.

Groundwater and freshwater dynamics – sea level rise results in salt water intrusion to freshwater aquifers, and low-lying carbonate islands are particularly vulnerable to this. Given also that the Phoenix Islands are in a relatively dry zone in the Central Pacific, there will be less freshwater recharge to counter-balance saltwater intrusion. Only the largest of the islands have a freshwater lens sufficient to support tree vegetation.

Terrestrial habitats - The Phoenix Islands are in a dry belt, though with a gradient from the northern islands to the southern islands, getting wetter. Periodic droughts result in reduced freshwater availability, poorer vegetation cover and implications for dependent species such as seabirds and insects. Past human settlements have failed as a result of climate variability, and climate change may exacerbate conditions.

Seabirds and other terrestrial species - The seabird populations of PIPA are among its most significant values. They differentiate by island depending on vegetation type, thus any changes in vegetation due to increased periods of drought and decreased availability of fresh water may have significant impacts on their nesting ability. Further, changes in ocean currents and pelagic systems may result in trophic changes that may de-synchronize food accessibility and nesting seasons, causing disturbances to seabird populations. Further all terrestrial species will be affected not only through their direct vulnerability to changing climate, but to the loss of island area over time.

4.4. Socio-economic resilience in Kiribati

The vast, and relatively abundant, marine resources of the 3.6 million km² exclusive economic zone are the cornerstone of Kiribati wealth. However, the Kiribati economy is constrained by isolation, limited land resources, frequent droughts, geographic fragmentation and a shortage of skilled workers. In addition, population growth, increasing consumerism, and the real and imminent threats from climate change are putting increasing pressure on Kiribati's most important natural capital assets. Kiribati has a history of prudent fiscal management, as exemplified by its management of the Revenue Equalization Reserve Fund (RERF), a fund established by the British administration in 1956 with royalties from the mining of phosphate in Banabaⁱ. Similar management of the PIPA Trust Fund and PIPA resources could play an important and strategic role in sustaining the Kiribati economy and enhancing climate adaptation efforts. PIPA is both a direct and indirect source of revenue and ecosystem services and can provide a reference for services derived locally on populated islands. Here we will describe the relationship between the Kiribati economy and marine ecosystem services, evaluate the current adaptive capacity of some representative islands, and identify potential value PIPA can add to the Kiribati economy and its adaptive capacity.

4.4.1. Dependence of Kiribati economy on marine ecosystem goods and services

The marine ecosystem is the foundation of the Kiribati economy not only because it is a key source of food and income, but coral reefs built the atoll structures of the Kiribati Islands and protect them from high tides and storms. Marine resources are far more abundant than land resources with an ocean area 4,500 times greater than the total land area and an average reef area eight times greater than the average atoll (Millennium Coral Reef Mapping Project). In addition, poor soils and limited ground water make the land relatively unproductive. Consequently, marine resources are the primary sources of wealth for the government and individual households.

The primary livelihoods in Kiribati are fishing, copra harvesting (a coconut cash crop for export only), government jobs, or small businesses. Kiribati has one of the highest rates of per capita fish consumption in the world, estimated at 72-207 kg/person/year^{ii,iii}. The overwhelming majority of this fish comes from local resources. Imported foods are expensive and unreliable and only a minority of people are cash employed (~25% overall, ~15% on outer islands)^{iv}. Almost all (97%) households engage in fishing to feed their families^v. On outer islands, households typically split their time between fishing for food (30%) and cutting copra (34%) to earn cash to pay for basic needs, such as rice and cooking oil and school or church fees^{vi}. However, these activities do not regularly occur in the Phoenix Islands, since there are no permanent inhabitants. The one currently inhabited atoll, Kanton, has a non-permanent population of approximately 40 government employees and their families. Nonetheless, fishing revenues generated from the Phoenix archipelago's EEZ contribute to the overall population of Kiribati via taxes, fees, and fishing licenses as while significant PIPA comprises just 54.9% of the EEZ surrounding the Phoenix Islands.

Fishing licenses are the largest single source of revenue for the central government (41% in 2008) (Fig. 9)^{vii}. Fishing licenses are primarily sold to tuna purse seine vessels from distant water fishing nations (DWFN), such as Japan, Taiwan, Korea, the United States, and Spain for fishing in the Kiribati EEZ^{viii}. During El Niño years, the warm water pool is displaced eastward into Kiribati waters (see section 2.4.2). The skipjack follow the warm water pool, making

Kiribati fishing licenses more desirable during El Niño years. As such, fishing license revenues may fluctuate with climate (Fig. 10).

The PIPA Conservation Trust has multiple activities, including provision of financial support for the management of PIPA and paying any fee that might be required to compensate the government for demonstrated declines in national fishing revenues as a result of the PIPA closures. These activities are managed and accomplished through the mechanism of a conservation contract, which was signed by the government of Kiribati and the PIPA Conservation Trust in 2014.

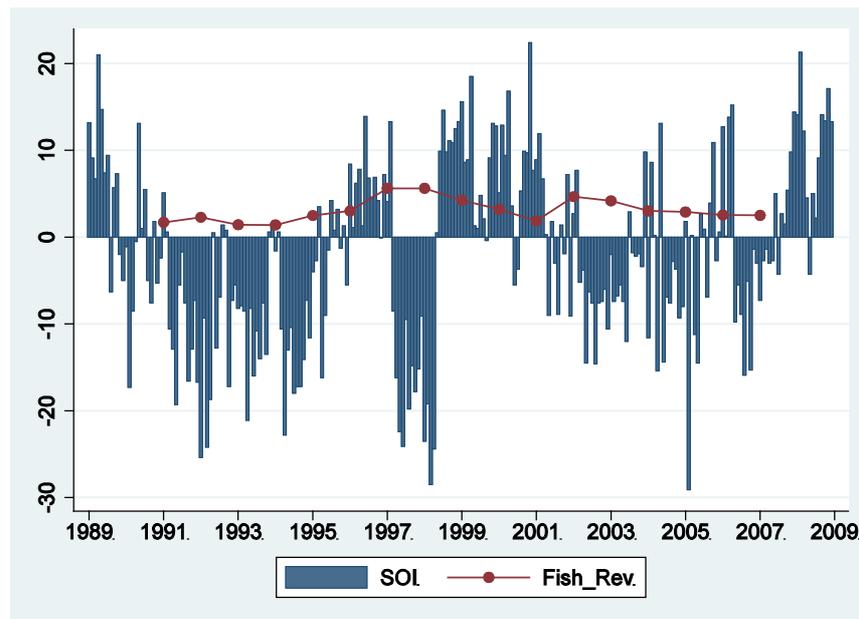


Figure 10. The Southern Oscillation Index and revenues from fishing licenses from 1989 to 2009, prior to the new implementation of the Vessel Day Scheme. Note that, pre-VDS, fishing revenues were also affected by exchange rates and international prices for tuna.

4.4.2. PIPA as a source of indirect use and non-use value from ecosystem services

Ecosystem services derived from PIPA can be separated into two broad categories, "use" and "non-use", based on their associated values (Fig. 11). As a protected area, PIPA does not provide direct use values, such as fish for food, but it does provide important in-direct use values. The populations of organisms in PIPA represent a genetic reservoir that may increase variation in populations³⁶, and hence, the probability that populations of organisms in populated islands in Kiribati or other countries have traits that are favorable in the face of climate change. The additional unfished oceanic, reef, and lagoon habitats of PIPA may enhance the productivity of nearby fisheries in Kiribati or Tuvalu. These intact ecosystems will also have important tourism and research potential for both local and international visitors. Transportation infrastructure built for tourism and research will link the three archipelagos of Kiribati that are currently only connected by boat or international flights, enhancing the flow of people and goods. Globally, the reefs and oceanic ecosystems of PIPA provide the services of carbon sequestration and oxygen generation.

³⁶ Polato et al. 2010; Baums et al. 2012

The non-use values of PIPA are the values that come from the ecosystem but do not involve any physical interaction. For instance, PIPA may have very high existence value arising from the benefits that people get from knowing that pristine marine ecosystems exist. The desire to protect this value may be motivated by the desire to share this knowledge or appreciation with friends or children or by sympathy for other living beings. PIPA also provides option value or the value of ensuring that some use value will be available in the future (however this depends on the duration or durability of the contract).

ES Values	Beneficiaries		
	Local	Regional	Global
Use Values			
<i>Direct</i>	NA		
<i>Indirect</i>			
Genetic Reservoir	[Bar spanning Local, Regional, and Global]		
Fisheries Habitat	[Bar spanning Local, Regional, and Global]		
Tourism	[Bar spanning Local, Regional, and Global]		
Research	[Bar spanning Local, Regional, and Global]		
Carbon Sequestration	[Bar spanning Local, Regional, and Global]		
Oxygen Generation	[Bar spanning Local, Regional, and Global]		
Transportation Hub	[Bar spanning Local, Regional, and Global]		
Non-use Values			
<i>Option value</i>	[Bar spanning Local, Regional, and Global]		
<i>Quasi-option value</i>	[Bar spanning Local, Regional, and Global]		
<i>Existence value</i>	[Bar spanning Local, Regional, and Global]		

Figure 11. Ecosystem services derived from PIPA and their beneficiaries.

4.4.3. Public awareness of climate change in Kiribati

The KAP supported studies of public awareness of climate change (e.g. Kaiteie and Hogan, 2008) providing useful findings that a) people are generally aware of the phenomenon climate change and generally fearful of its effects, particularly on future generations; b) that they do feel that almost anyone can undertake some level of adaptation action; and c) that radio, newspaper, DVDs, and workshops are the most useful avenues for outreach, education, and training. News of PIPA is now regularly broadcast on the government-owned all-Kiribati radio station, Kiribati Broadcasting and Publications Authority (AM 1440), and national pride is apparent. Signs celebrating PIPA are displayed in Kiribati International Airports on both Tarawa and Kiritimati Island, and songs, including “PIPA You Are My Gift To Humanity” have been written and are regularly sung to celebrate major PIPA milestones and events. Outreach initiatives also include messaging in schools that extend beyond PIPA issues alone, with a focus on encouraging a conservation mindset, building in-country capacity and expertise in areas relevant to ocean conservation and research, and promoting knowledge of all-of-Kiribati geography, since very few Kiribati citizens have ever been to the Phoenix Islands. The I-Kiribati also are invoking the local word ‘okai’ with regards to PIPA, which means a traditional storehouse where reserved foods and treasures are kept for future use – especially in times of prolonged droughts and bad times. Considering PIPA as an okai for potential food security as well as a bank of Central Pacific biodiversity has been an important part of the outreach

program to enable Kiribati residents to think about the multiple local and global benefits of ocean stewardship. With all of this education, outreach, and press coverage, coupled with social media, the domestic and international public are increasingly valuing PIPA's importance both as a national treasure and as an exploratory platform for climate change.

4.5. Specific climate change sensitivities

Prioritizing climate change sensitivities is a complex undertaking, but the preceding suggestions suggest the following key vulnerabilities of PIPA:

- drought, sea level changes → impact on freshwater lens
- rising sea surface temperature → impacts on reefs
- changes in ocean circulation → fisheries, seabird populations
- acidification of seawater → impacts on reefs and marine organisms
- complex of changes related to circulation, temperature, and precipitation are all connected to ENSO fluctuations, resulting in changes in the dynamics of both central Pacific and eastern Pacific El Niños and intensified temperature increases.

These need to be reviewed and assessed in subsequent revisions of the PIPA Management Plan and/or this document.

5. PIPA linkages with adaptation programmes in Kiribati

Part of the purpose of this study is to identify clear-cut issues of climate adaptation and disaster risk reduction in Kiribati that relate to ecosystem services, resilience and natural resources for which the Phoenix Islands can serve as a reference point, and maximize the relevance of PIPA activities to national needs.

5.1. Kiribati Adaptation Programme

The Kiribati Adaptation Programme (KAP) for the Gilbert Island group was initiated in 2003. It was planned in three phases: Phase I from 2003-2005, in which national consultation and project preparation were undertaken; Phase II spanned 2006-2009 (extended to 2010) to implement pilot adaptation actions; and Phase III 2010-2015 to scale up pilot actions to the national level. The total Phase II programme budget was AU \$6.5M, from the World Bank (GEF), NZAID and AusAID, of which AU\$ 2.5M was slated for the following two pilot activities for the remainder of its term:

Improving protection of public assets – sea level rises, increased storm frequency and strength and eroding coastlines mean that inundation by the sea is a rising problem on Tarawa.

Supply and sustainability of freshwater – groundwater and freshwater resources are highly vulnerable in Kiribati not only from climate related threats (sea level rise, salinization of aquifers) but also from increased abstraction and pollution of water tables, driven by population growth. The project focuses on North Tarawa, Tabiteuea North and Abemama islands, with some activities on Temaiku, the principal freshwater aquifer for South Tarawa. Freshwater availability is identified as one of the most important factors that drives abandonment of atoll settlements, as evidence in the past by settlements in the Phoenix Islands which are in a dry belt, and from which all settlement schemes have retreated after some years.

The KAP programme has not explicitly addressed biodiversity as an asset at risk from climate change, nor as one valuable for adaptation. However a number of reports from KAP activities are relevant to activities that are complementary to PIPA's role as a reference site, including coral reef monitoring in the Gilbert Islands³⁷ and coastal monitoring networks³⁸.

5.2. National consultations and the Office of Te Beretitenti

Kiribati has adopted a Climate Change Adaptation Policy, Climate Change Adaptation Strategy in 2005 and also a National Adaptation Plan of Action (NAPA) in 2007 both under the UNFCCC and supported by UNDP. Through these processes complementarity between climate adaptation and Disaster Risk Reduction (DRR) initiatives became clear, in addition to the reality that these are cross-cutting issues shared among many sectors of government. Accordingly, the Office of the President (Office of Te Beretitenti) has taken on responsibility for coordination of these two sets of activities under the National Adaptation Steering Committee which includes representation from nine ministries. A Climate Change Study Team has been established with key technical officers from these ministries to provide expert advice to elected officials. In line with the two priority areas identified for KAP pilot projects, water resource management and coastal resilience, a new project titled "Increasing Resilience to Climate Variability and Hazards" was under development through discussions with the World Bank (GEF) and AusAid. The monthly Climate Outlook Updates also are released from the Office of Te Beretitenti. PIPA can serve as the reference for Gilbert planning, in concert with the Line Islands, for a "whole of Kiribati" approach that can help to isolate the impacts of climate change vs. more local anthropogenic impact.

5.3. The broader context

Additional climate adaptation initiatives, both within Kiribati and regionally, are likely to include aspects relevant to fisheries, the environment, the Sustainable Towns project (supported by New Zealand Aid), the Kiritimati freshwater resources (supported by AusAid) and many NGO-supported local initiatives. On a broader regional scale, the implications of de-population of the Gilbert Islands due to climate change and migration to other Pacific countries is important to note, as well as the potential legal implications of changing coastlines and EEZ boundaries with sea level rise. The Pacific Oceanscape and other regional platforms provide a relevant context for consideration of these broader aspects of climate change vulnerability of PIPA.

6. Climate change and management of PIPA

The impacts of climate change on PIPA are clearly expressed in the 2010- 2014 management plan in the following key sections:

1.1 Meteorology/1.5 Global Significance – notes that PIPA is located at the generation point of El Niño/La Niña cycles, and that this likely plays a strong role in the climatology of PIPA and may strongly influence how the flora and fauna may respond to climate change and variability.

2.2 Management Issues and challenges/SAP 2.2 PIPA Coral Reefs and Coastal Management – recent climate change impacts and a note on key vulnerabilities of PIPA are stated, particularly related to coral bleaching and island water tables. The vulnerability of ecosystems

³⁷ Donner 2007

³⁸ Biribo 2008

and the islands to climate change is noted. The text also notes that since PIPA is free from other human impacts, it can serve as a reference site for understanding and managing impacts at populated islands in Kiribati.

SAP 2.7 PIPA Climate Change - this section outlines the rationale for PIPA to develop adaptation actions to climate change during its first phase from 2010 to 2014. Three key actions are noted:

- completion of this Climate Change Scoping Study and incorporation of its recommendations and best practise into the Operational workplan for implementing the Management Plan, and the PIPA Business Plans.
- linkages made between PIPA and other climate change programmes in Kiribati, including the Kiribati National Adaptation Strategy, Kiribati Adaptation Programme (KAP) and the Climate Change Unit of the Environment and Conservation Division.
- development of plans to establish PIPA as a 'natural climate change research laboratory', including engagement with regional and international mechanisms to support this.

6.1. Adaptive management options

Developing options for managing Marine Protected Areas (MPAs) under the threat of climate change has been a strong focus of several groups since 2005. Regional organizations like the Secretariat for the Pacific Community (SPC) and Secretariat for the Regional Environment Programme provide technical support and much needed funding to Kiribati to help increase their adaptive capacity to climate change.

Some of the management actions relate to design and zonation of protected areas, i.e. are fixed in space and usually in time, so need to be incorporated into actual zoning maps of PIPA, especially at Kanton where there are plans to expand facilities and increase the number of people living and visiting the islands. Others relate to management actions and responses, and need to be incorporated into the activities of MPA staff. These are outlined in the following table.

Table 2. Management actions that may be taken to increase the resilience of PIPA to climate change.

Attribute	Relevance	Design/zonation	Management actions
Representation and replication - risk spreading	All systems should be represented in multiple locations, to minimize risk of losing all.	With all islands and marine areas under strict management regimes, all systems in PIPA are represented. Kanton needs to ensure subsistence fishing areas are sustainably managed to maintain the overall resilience of the ecosystem.	Clear guidelines on fishing gears and practices for the resident community on Kanton. Strict enforcement of existing regulations for PIPA, including the zoning plan for Kanton Atoll. Strict adherence and enforcement of biosecurity protocols. Development of new /

			appropriate actions in response to climate (e.g. bleaching event) or other threats (e.g. clandestine reef fishing).
Critical areas and refugia	Some sites have particular characteristics of resistance to climate threats and are key locations for conserving species and processes, and for recovery of less resistance locations.	Critical areas are fully protected and enforced	<p>Strict enforcement of existing regulations and biosecurity protocols.</p> <p>Development of new/appropriate actions in response to climate or other threats.</p>
Connectivity	Marine systems are connected by currents that disperse larvae, and island ecosystems are connected by air for birds and vegetation.	As oceanographic information is improved, changes to Kanton zoning system may be relevant for linking critical areas and other locations.	<p>Strict enforcement of existing regulations and biosecurity protocols.</p> <p>Development of new/appropriate actions in response to climate or other threats.</p>
Biodiversity and ecosystem integrity	Ecosystems with higher biodiversity and integrity, i.e. less impacted by other disturbances have greater resources for resisting or repairing damage from climate change.	<p>Zoning scheme that limits non-climate threats to certain areas and maintains the intactness of areas currently un-impacted.</p> <p>Limits of Acceptable Change should be set for Kanton Island, to maintain the quality of the area.</p>	Management actions, surveillance and enforcement that prevent non-climate threats from occurring and impacting on natural systems.

All of the items in the table require knowledge and understanding of the vulnerability of ecosystems and species to climate change. Monitoring and research programmes are necessary for this, but must be linked into the adaptive management regime in order to provide targeted recommendations for action. If necessary, revisions to the zoning scheme proposed for Kanton Island should be undertaken. The IUCN-CCCR (www.iucn.org/cccr) approach has been adapted to and applied in PIPA (in 2009 and 2012) for coral reef vulnerability to climate change, and similar initiatives should be undertaken for other ecosystems.

All development proposed for Kanton should proceed with extreme caution to minimise causing irreversible damage to the ecosystem. A Kanton Sustainable Resource Plan should be continually updated to address most up-to-date information and best practices for (i) current and future infrastructure plans for the island; (ii) the management of sea- and land-based tourism, and (iii) any plans for a research station. In 2014, the Phoenix Islands Scientific

Advisory Committee (SAC) was formed; this advising body can play a key role in evaluating plans for Kanton to minimize environmental impact and risk.

All zoning/MPA design aspects will need to be incorporated under review of section SAP 1.5 in the Management Plan. Adjustments to management actions may relate to a broader range of sections of the Management Plan, including nearly all of the Core Management sections (SAP 1.4 – 1.15) and the 'Issues to Results' sections SAP 2.1 – 2.6. The 'Issues to Results' section of the Management Plan SAP 2.7 is dedicated to climate change, and should include provision for annual review and updates of the Management Plan and Operational Workplans in accordance with the issues raised above.

6.2. Specific adaptation opportunities

As further research is undertaken on other systems, specific recommendations for limiting climate impacts may be made, and the Management Plan should incorporate mechanisms for regular review of any new findings.

Specific recommendations for management include the following:

The tabular *Acropora* community of Kanton lagoon was the most vulnerable coral community to climate change based on the 2002/3, 2010 and bleaching events, and showed remarkable and unprecedented recovery in 2015. A recommendation based on this finding would be for the Kanton Sustainable Resource Plan (SAP 1.12) to designate this habitat as a strict protection zone with no fishing allowed, even for subsistence. This would remove perhaps 5 km² of lagoon area from fishing access, a reduction of only 10%. However, it is worth noting that this site is located close to the populated area of Kanton.

1. The leeward shores of Kanton and Nikumaroro, as they are affected by heated lagoon waters, have less ability for rapid recovery than reefs not exposed to lagoon waters. This is particularly important for Kanton, where development for increased access for management, tourism and research will occur under the Kanton Sustainable Resource Plan (SAP 1.12)
2. Shipwrecks release enough iron into surrounding waters that the recovery of corals from mass mortality is reduced. Two key actions may be considered:
 - a. Punitive fines to finance removal of any new shipwrecks should be developed, following practice from other coral reefs areas (Florida Keys, Egypt, Australia), and removal plans be designed to come into action when needed.
 - b. If possible, the large old shipwrecks and remnant iron be removed. This may only be important where the wrecks are submerged, and could potentially be dragged off the reef and released into deeper water. The sites most strongly affected include the western corner of Orona (no visible shipwreck at the surface), and the Norwich City on Nikumaroro. The President Taylor on Kanton has an impact on the entrance to the lagoon, but is likely too large to move.

6.3. Learning from climate change

Adaptive management is a framework of 'learning by doing'. The information-gathering and decision-making processes for developing management responses to climate change are not

only useful for PIPA management itself, but also in the broader context of understanding how climate impacts are manifesting in PIPA, and by comparison with other locations, how human impacts elsewhere interact with climate impacts. This is the essence of using PIPA as a Climate Change Research Laboratory, which is further detailed in section 5.

The different agency members of the PIPA Management Committee have comparable management and regulatory responsibilities in populated parts of Kiribati. Thus, adjustments to their contributions in PIPA can serve as a direct conduit to learning and adapting management to climate change in other parts of Kiribati. For example, monitoring of birds or invasive species by the Wildlife Conservation Unit (WCU) in the Phoenix Islands can help to improve management of the same species on Kiritimati island. Monitoring of reef fish populations in PIPA by the Fisheries Department can help inform management of the same species where they are exploited in the Gilbert and Line islands.

6.4. Climate change mitigation and PIPA

The role of PIPA in climate mitigation depends on whether ecosystems in PIPA emit or absorb carbon, or are neutral, and to their contribution relative to the rest of the world. Table 3 summarizes the issues for the principal ecosystems in PIPA. Overall, PIPA cannot be expected to be a major contributor to climate mitigation. The ecosystem with the largest area, the open ocean, absorbs CO₂, but this has a significant negative effect in the form of ocean acidification. The oligotrophic waters are not very productive, so geo-engineering solutions are likely to have low process rates, quite apart from them being contrary to the principles of PIPA. The terrestrial (vegetation) and shallow marine (lagoon) ecosystems that might be carbon absorbers are too small to have any significant contribution globally.

Table 3. Climate mitigation relevance of PIPA ecosystems

Ecosystem	Size	Interactions with atmospheric CO₂	Conclusion
Seafloor, seamounts	Very large (> 90% of PIPA area)	Minimal, as exchanges with the atmosphere are minimal.	No contribution
Pelagic ecosystems	Very large (> 90% of PIPA area)	Net absorption of CO ₂ , which results in acidification. Geo-engineering proposals (e.g. iron fertilization) likely not effective, and inconsistent with PIPA principles	Not feasible
Coral reefs	Very small, 34 km ²	Reef calcification is neutral with respect to CO ₂ absorption. Lagoons may have net CO ₂ deposition in sediments.	Area is too small to be of consequence globally
Island vegetation	Very small	Vegetation absorbs CO ₂ , which may get fixed as humus/peat in the soil of the islands. However low levels of woody vegetation.	Area is too small to be of consequence globally

7. PIPA as a Climate Change Research Laboratory

These sections are drawn from the PIPA 10-year Research Strategy (2010-2020), which was completed in October 2011. The PIPA Management Plan 2010-2014 expressly recognizes the contribution of research and monitoring to management and protection, and in relation to PIPA

as a climate change reference site due to the lack of other impacts within PIPA. The Management Plan identifies a commitment to build research into the PIPA Annual Operational Work Plan (SAP 1.15). The Management Plan expressly notes that PIPA is a microcosm not just of the other island groups in Kiribati, but of the planet, one of the few places where local human impacts have not accumulated. This is recognized in the preamble to the 2010-2014 management plan, on the relevance of PIPA under Kiribati's obligations to international conventions as a "Climate Change Research Laboratory", and is a foundation of PIPA's accession to the World Heritage list in 2010.

The Phoenix Islands are a remote archipelago in the Central Pacific that sits at the origin of an increasingly frequent ENSO (El Niño / Southern Oscillation) hotspot. At "ENSO Ground Zero", the Phoenix Islands recently suffered the most severe thermal stress event ever recorded (see prior sections). Remarkably, the reefs rapidly rebounded within a short (6 year) period, due in part to the lack of a local human population, thereby providing a natural laboratory to examine the science of resilience and recovery. Together, the three archipelagos within the Republic of Kiribati represent a unique, fully-factorial natural experiment with island replicates to examine climate, population, and all possible combinations thereof, on an unprecedented scale.

7.1. Climate change research

Climate change research in PIPA can capitalize on PIPA's attributes as being a large, remote, MPA that has limited other anthropogenic impacts. For example, building on the past work on coral reefs in PIPA, the 10-year strategy includes the following section:

Introduction to Resistance and Reef Recovery - The Phoenix Islands experienced the largest thermal stress event recorded on coral reefs, with limited interacting local anthropogenic stresses. Seven years later the reefs are demonstrating remarkable recovery but with variation among sites and islands that will help us understand what processes control reef resilience to and recovery from climate change. Our goal is to identify the important processes that facilitate recovery in a relatively undisturbed reef, and how these might be undermined by human threats in other parts of the world. Specifically, we aim to address the following questions: (a) What is the recovery capacity of a pristine reef system to climate change? and (b) Will the reefs recover before the next climate impact?

To answer these questions, we will use a mixed approach of observation plus experimentation to examine both patterns and processes (respectively) of reef recovery. This approach will be framed within three different scales – (i) a PIPA-wide whole-reef categorization of habitats, organisms, and processes, (ii) a detailed examination of holobiont eco-physiology, stress and dynamics, and (iii) a limited selection of transects and experiments to be performed on the scale of the Pacific Oceanscape, following the same methodology utilized throughout the Pacific, to enable comparisons of PIPA reef recovery with recovery happening elsewhere.

Similar research plans relevant to other sensitive elements of PIPA can be developed.

7.2. Research Partnerships

Successful research in such a remote location as PIPA requires significant resources, and often these are best achieved through partnerships. Thus, building partnerships with appropriate research and logistical partners will be essential to move forward. The models already achieved with respect to shallow marine surveys (New England Aquarium, Conservation International, Woods Hole Oceanographic Institute, Scripps Institute of

Oceanography) and terrestrial invasive species³⁹ provide a model for this, and more will be needed in other areas (see the Research Strategy for more details).

7.3. Contribution to national climate change policy and international conventions

As a climate change laboratory, information from PIPA can feed through into national policy in Kiribati and to international fora, particularly the UNFCCC, CBD and other environmental and development conventions.

8. Summary – key issues

A number of areas have not been covered in this preliminary scoping report that should be further developed. This report suggested the following as next steps:

- full scoping of the climate vulnerable species and habitats in PIPA;
- updated alignment between the key aspects of climate vulnerability in PIPA with adaptation initiatives and priorities in the Gilbert and Line islands;
- updated regional and international scoping of climate vulnerability and adaptation issues with respect to PIPA; and
- making the most of PIPA as a learning and education tool for the Gilbert and Line islands, both in terms of natural resource management, and for raising awareness among the public of their vulnerabilities, and how they may build their own resilience through ecosystem-based approaches demonstrated by the intact systems of PIPA. Video has been a profound outreach tool in Kiribati, and PIPA is a perfect setting for this given the visual appeal and identification that the public has with the island settings.

8.1. Monitoring and Research

A number of monitoring and research opportunities are highlighted below:

- Through PIPA's sister-site agreement with Papahānaumokuākea Marine National Monument (PMNM), establish a virtual bleaching station in the Kiribati Phoenix Islands, perhaps two at opposite ends of the temperature gradients, would provide a key data stream for PIPA monitoring and management;
- Through the partnership with the Pacific Remote Island Marine National Monument (PRIMNM), explore opportunities to collaborate on similar research interests, like migratory species and deepwater habitat.
- Coral reefs – continue long term monitoring for reef resilience (benthos, fish). Build links with GCRMN/KAP benthic monitoring initiatives for the Gilbert Islands – establish the monitoring stations outlined in Donner 2007 (p.8, 16-18), and conduct together with MFMRD fisheries resource surveys. Also, linkages with Lines and Kiritimati work, including Scripps collaborators should be pursued.
- Establish a full weather station for monitoring at Kanton
- Establish baselines/studies on coastal erosion.
- Establish sea level/groundwater /freshwater lens monitoring.

³⁹ Pearce 2013

- Establish vegetation and seabird monitoring with climate change objectives, through the ongoing invasive species work and linkages with similar monitoring on Kiritimati atoll. Restart WCU monitoring of islands and terrestrial resources as done in the past.
- Partner with climate change adaptation programmes in Gilberts/Lines to evaluate the efficacy of adaptation strategies – e.g. reefs/food security/coastal protection, etc.

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