Bridging Science and Management in the Pacific Remote Islands Marine National Monument

Authors
Shannon Boyle, Vanessa De Anda, Kara Koenig,
Erin O'Reilly, and Monique Schafer

Photo: Palmyra Atoll, National Geographic

Faculty Advisor
Dr. Mark Buntaine

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Authors
Shannon Boyle
Vanessa De Anda
Kara Koenig
Erin O'Reilly
Monique Schafer

Faculty Advisor
Dr. Mark Buntaine

Client
Coral Reef Ecosystem Program & Pacific Islands Regional Office at
National Oceanic and Atmospheric Administration

PhD Advisor
Owen Liu

External Advisors
Darcy Bradley

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As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

Shannon Boyle	Erin O'Reilly

Vanessa De Anda	Monique Schafer

Kara Koenig

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

Dr. Mark Buntaine

Date

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LIST OF ABBREVIATIONS

CAU	Calcification Accretion Unit
CCA	Crustose Coralline Algae
COTS	Crown-of-Thorns Starfish
CRED	Coral Reef Ecosystem Division
CREP	Coral Reef Ecosystem Program
DHW	Degree Heating Weeks
ENSO	El Niño Southern Oscillation
EUC	Equatorial Undercurrent
GBR	Great Barrier Reef
MHI	Main Hawaiian Islands
MMP	Monument Management Plan
MNM	Marine National Monument
MPA	Marine Protected Area
MRCV	Multiple Response Categorical Variables (R Package)
NEC	North Equatorial Current
NECC	North Equatorial Countercurrent
NOAA	National Ocean and Atmospheric Administration
NWHI	Northwestern Hawaiian Islands
PARC	Palmyra Atoll Research Consortium
PIFSC	Pacific Islands Fisheries Science Center
PIRO	Pacific Islands Regional Office
PMNM	Papahānaumokuākea Marine National Monument
PRIMNM	Pacific Remote Islands Marine National Monument
RAMP	Reef Assessment and Monitoring Program
REA	Rapid Ecological Assessment
SPC	Stationary Point Count
SST	Sea Surface Temperature
StRS	Stratified Random Survey Design
TDS	Towed-diver Survey
U.S.	United States of America
UCSB	University of California, Santa Barbara
USFWS	United States Fish and Wildlife Service

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ABSTRACT

The importance of coral reefs is almost unparalleled to any other ecosystem; reefs host high levels of biodiversity, and provide ecosystem services to millions of people worldwide. Thus, the conservation of coral reefs is critical for the future of our world. The Pacific Remote Islands Marine National Monument (PRIMNM), consists of seven islands and atolls in the central Pacific Ocean. The islands span an estimated 20 degrees of latitude and span across gradients of environmental and oceanographic conditions. They are mostly uninhabited and relatively free from the direct impacts of human presence. Therefore, the PRIMNM can help provide an insight into how different coral reef ecosystems are changing as a result of climate change. In order to do this, the general trends in ecological health and threats from changing climate and seasonal variability must first be understood by not only scientists, but also those responsible for managing natural resources. The general public, an often unrecognized stakeholder in large scale federal marine national monuments, must also understand the importance of the monuments and their role in protecting these special places to ensure the persistence of these efforts. The objectives of this project were twofold and involved synthesizing and analyzing the vast biological and oceanographic data to 1) to effectively communicate PRIMNM coral reef ecosystem health across spatial and temporal scales to resource managers; we also distributed a broad public engagement survey to 2) help educate the public on the threat climate change poses to ocean health and increase public awareness of, and support for marine conservation efforts. We found that in general, the PRIMNM exhibited healthy biological conditions (measured through analysis of benthic and fish communities), but are still subjected to the threats of climate change. Our survey found that while many people believed that climate change was a threat to coral reef ecosystems, they were unaware of the efforts in place by the federal government to conserve coral reefs. We thus decided that it was necessary to create communication materials, targeted at a broad audience to help the public understand their role, as effective communication of marine ecosystem health is essential for the continued support for the PRIMNM and other critical marine habitats around the world.

EXECUTIVE SUMMARY

INTRODUCTION

Coral reefs are vitally important ecosystems, both ecologically and economically. Despite covering only 0.1-0.5% of the world's oceans, the biodiversity present on coral reefs is greater than in any other marine ecosystem. In addition to the immense biodiversity present on coral reefs, populations across the globe heavily depend on the ecosystem services these reefs provide. Today, these ecosystems are faced with a suite of local and global threats, locally through direct human impact (*e.g. overfishing and land based pollution*), and globally through indirect human impact (*e.g. climate change*); these impacts are causing significant declines in coral reefs worldwide.

The Pacific Remote Islands Marine National Monument (PRIMNM), one of the Marine National Monuments (MNM) co-managed by the National Oceanic and Atmospheric Administration (NOAA) and U.S. Fish and Wildlife Service (USFWS), provides one of the last remaining opportunities to assess how coral reefs function in the absence of major direct human impacts. The seven islands protected under this Monument—Baker, Howland, Jarvis, Johnston, Kingman, Palmyra, and Wake—are relatively uninhabited and support unique networks of communities unlike many other reef systems in the world. Although the islands of the PRIMNM are not subject to direct human pressures, the marine communities found within the PRIMNM face threats from ocean warming and acidification. Since these threats are expected to increase in the future, it is important to monitor how climatic and seasonal variability impacts these ecosystems in the absence of direct anthropogenic impacts, to help determine what can be done to mitigate these threats.

NOAA's Coral Reef Ecosystem Monitoring Program (CREP) conducts comprehensive ecosystem monitoring surveys across the Pacific, including the PRIMNM. These monitoring surveys provide data used to answer critical questions on resource status, long-term trends, impacts at various spatial scales, biological and community ecology, and efficacy of various management actions. Observations can then be applied by NOAA's Pacific Islands Regional Office (PIRO) to address specific management needs through the implementation of monument management plans and outreach strategies. The PRIMNM Management Plan has yet to be developed, so specific management objectives are not clearly defined for this Monument. To better protect and preserve marine ecosystems, such as those in the PRIMNM, it is essential for agencies to foster effective communication between scientists, managers, and the public.

The study described here is an effort to bridge two gaps identified between 1) NOAA scientists and managers, and 2) NOAA and the public. These gaps currently hinder effective management of, and support for the PRIMNM. Through this study, we examine how to cogently communicate and frame monitoring data, and analyze pre-existing public perceptions of large-

scale marine protected areas (MPAs) and threats facing our oceans, in order to determine how we most effectively bridge these gaps.

OBJECTIVES

To address the gap identified between NOAA scientists and managers, we sought to effectively communicate PRIMNM coral reef ecosystem health across spatial and temporal scales to resources managers.

To address the gap identified between NOAA and the public, we aimed to educate the public on the threat climate change poses to ocean health and increase public awareness of and support for marine conservation efforts.

METHODS

To fulfill our first objective, we first synthesized a wide range of data across biological, physical, and physical scales in the PRIMNM, using various methods to ensure we were communicating information representative of the PRIMNM ecosystem. We then created a multi-metric condition index that integrates multiple coral reef metrics encompassing both the biological community and oceanographic and climatological indicators at the islands within the PRIMNM. This index offers a succinct representation of ecosystem health. After data synthesis and index creation, we compiled this information to complete the first single coalesced coral reef ecosystems overview booklet for the PRIMNM, which will then be used by resource managers to develop the PRIMNM Management Plan. To effectively communicate our findings within this booklet, we structured the booklet to compare patterns and trends found across the PRIMNM to other regions in the Pacific, within the PRIMNM, and concluded with island highlights which accented unique findings, quantitative and/or qualitative, for each island within the Monument.

To fulfill our second objective, we first developed a 15-question survey to gauge public perceptions of large-scale marine protected areas, ocean health, and threats facing our oceans. This survey was then distributed online. Once our response quota was met, we analyzed the survey data to determine key survey results, which were used to identify awareness gaps. Five communication materials were then created to specifically target these awareness gaps.

OVERALL FINDINGS

From our data synthesis, we found that coral reefs of the PRIMNM are relatively healthy compared to other islands across the Pacific. Although relatively free from direct human pressures, the most significant threat facing the PRIMNM is climate change, which is shown through the multi-metric condition index and three of the island highlights discussed in the overview booklet.

From our survey, we discovered that the American public is largely unaware of Marine National Monuments in the Pacific, and more specifically the PRIMNM. Additionally, many members of the public believe climate change poses little to no threat to coral reefs or are unsure if it poses a threat at all. The majority of the public view aesthetics as the most important ocean benefit.

CONCLUSION AND RECOMMENDATIONS

Our findings from this study revealed that climate change poses a threat to the PRIMNM, and that the American public is largely unaware of their role as a stakeholder in federal marine conservation in the Pacific. To effectively manage large-scale marine protected areas such as the PRIMNM in the face of confounding local and global threats to coral reefs, it is essential for agencies to foster effective communication between scientists, managers, and the public. To do this for the PRIMNM, scientists and managers need to communicate more efficiently, so that monitoring conducted within this Monument better fulfills the needs of management. Additionally, NOAA should implement a more robust and widespread communication and outreach strategy for the PRIMNM and the other MNMs, using the communication materials we developed that were targeted to not only address awareness gaps, but to also to appeal to the public's interest through aesthetically pleasing imagery of the PRIMNM's immensely diverse coral reef ecosystems. In conclusion, effective communication of marine ecosystem health is essential for the continued support for the PRIMNM and other critical marine habitats around the world.

BACKGROUND

IMPORTANCE OF CORAL REEFS

Coral reefs are among the most ecologically and economically valuable ecosystems on earth (Moberg and Folke, 1999; Veron et al., 2009). Despite covering only 0.1-0.5% of the world's oceans, the biodiversity present on coral reefs is greater than in any other marine ecosystem (Connell, 1978; Reaka-Kudla et. al., 1996). Of the 33 phyla present on Earth, 32 phyla can be found on coral reefs, and 15 of the 32 are found exclusively in coral reef ecosystems (Bryant et al., 1998). These ecosystems represent essential spawning, nursery, and feeding grounds for over 25% of Earth's total marine biodiversity (Bryant et al., 1998). In addition to the immense biodiversity, over one billion people rely on coastal resources to survive, and half of those rely entirely on coral reefs (Frieler et al., 2013). These ecosystems provide economic and environmental services such as seafood, shoreline protection, and contributions to local economies through tourism and recreation industries (National Ocean Service, 2008). Despite their global importance, many coral reefs are in various stages of decline due to detrimental human impacts and ineffective management (Bellwood et al., 2004; Hoegh-Guldberg et al., 2007).

Coral reef ecosystems exist along the entire spectrum of human presence with many reefs located adjacent to exploited highly polluted, and overpopulated coastlines. It is rare to observe a reef ecosystem free from the pervasive influence of humans (Friedlander and DeMartini, 2002). Understanding the dynamics of these ecosystems and how they function in the absence of human presence provides fundamental insight into conservation and restoration needs globally (Sandin et al., 2008). Such a benchmark of ecosystem health prior to anthropogenic influence is necessary to set appropriate and effective management objectives (Bradley et al., 2017).

THE PACIFIC REMOTE ISLANDS

The Pacific Remote Islands Marine National Monument (PRIMNM) provides one of the last remaining opportunities to assess how a coral reef functions in the absence of major direct anthropogenic impacts. The coral reef communities at the islands of the PRIMNM are regularly studied as they represent a benchmark of these communities in the absence of human presence. For example, the Line Islands, including Palmyra Atoll and Kingman Reef, have often been comparatively studied to isolate the effects of direct and indirect anthropogenic impacts (Sandin et al., 2008; Stevenson et al., 2006). Results of studies along anthropogenic impact gradients emphasize the importance and of the remote islands of the PRIMNM, as well as the other Marine National Monuments (MNM) as ecological reference points (Williams et al., 2010; Friedlander and DeMartini, 2002).

First designated in 2009 by President George W. Bush to "protect and preserve the diversity and abundance of ocean life in the waters surrounding the islands", the PRIMNM consists of seven islands and atolls spread across the central Pacific Ocean. The islands protected under the

monument belong to three different island chains: the Line Islands (Palmyra Atoll, Kingman Reef, Johnston Island), the Phoenix Islands (Baker and Howland Islands), and the Marshall Islands (Wake Atoll). When the Monument was expanded by President Barack Obama in 2014, it represented the largest marine protected area (MPA) in the world. Today, the PRIMNM encompasses an area six times its original size, approximately three times the size of California (~370,000 nautical miles).

Relative to other Pacific islands, the islands of the PRIMNM are mostly uninhabited. Today, Wake Atoll maintains a small population of less than 100 military personnel, Palmyra hosts the Palmyra Research Consortium (PARC) with a rotating population of approximately 4-20 researchers and technicians, and finally, Johnston hosts about 4-5 US Fish and Wildlife personnel working on invasive ant eradication seasonally. Because of the lack of extreme human influence, most islands have remained mostly undisturbed and continue to maintain some of the healthiest coral reef ecosystems in the world (Friedlander and DeMartini, 2002; Sandin et al., 2008).

Unlike many other large-scale MPAs, the PRIMNM surrounds seven somewhat disconnected islands and atolls, thus it is not a contiguous area as is the case for other Pacific Marine National Monuments (MNM). The southernmost Baker, Howland, and Jarvis Islands straddle the equator. These three islands are particularly productive as they are strongly influenced by the Equatorial Undercurrent (EUC) which brings cool, nutrient-rich waters to the surface on the western side of the islands. In contrast, the North Equatorial Current (NEC), a nutrient-poor, well-mixed current surrounds the waters of Wake and Johnston Atolls southwest of Hawai'i. Located at latitudes between the two gradients, Kingman Reef and Palmyra Atoll receive waters from both the NEC and the North Equatorial Countercurrent (NECC). The islands of the PRIMNM span an immense geographical area and are thus, subject to vastly different oceanographic and ecological regimes.

While the islands are located within different biogeographical regions of the Pacific, each island supports a unique network of communities. The PRIMNM is home to a wide range of intrinsic species that have been depleted in many other coral reef ecosystems. Wake Atoll is home to one of the largest spawning aggregations of bumphead parrotfish (*Bolbometopon muricatum*) (Munoz et al., 2014), and Kingman Reef hosts some of the highest densities of giant clams (*Tridacna maxima* and *Tridacna squamosa*) found anywhere in the world. Deep sea corals; five different sea turtle species; pearl oysters; coconut crabs; grouper; manta rays; and some of the highest abundance and diversity of reef and oceanic sharks in the world all grace the waters of these islands (US Fish and Wildlife Service, n.d.).

THREATS TO THE PRIMNM

The islands of the PRIMNM are relatively free from direct, destructive human pressures, such as overfishing and land-based pollution. Despite the persistence of islands like the PRIMNM, and other uninhabited islands such as the Northwestern Hawai'ian Islands, Palau and a few other places, today over half of the world's coral reefs are in various stages of decline (Bellwood et al., 2004; Hoegh-Guldberg et al., 2007). In a recent comprehensive report on the status of coral

reefs, it was estimated that over 19% of the world's original coral reefs have been lost and another 35% are at some risk of being lost in the next few decades (Wilkinson, 2008).

Although the islands of the PRIMNM are not subject to direct human pressures relative to highly populated Pacific islands, the diverse, abundant marine communities found at the PRIMNM remain threatened by the ubiquitous and widespread threat of ocean warming and acidification. Anthropogenic climate change has resulted in increased average sea surface temperature (SST) in recent decades (Collins et al., 2010). Higher ocean temperatures lead to the breakdown of coral-algal symbiosis, the mutualistic relationship responsible for the vitality of coral reefs (Knowlton, 2001; Knowlton and Jackson, 2008). As SST increases, corals and their associated photosynthetic symbionts experience thermal stress. When the resulting stress surpasses a tolerance threshold, the symbionts are expelled from the corals resulting in coral bleaching (Buddemeier et al., 2008; Coles and Brown, 2003; Diaz-Pulido et al., 2012; West and Salm, 2003; Wilkinson, 2008). These phenomena can lead to coral mortality exceeding 90%. For example, during the extreme El Niño event in 1998, the associated increase in SST resulted in 16% of the world's corals to perish (Bryant et al., 1998). As SST continues to rise, extreme mass mortality events are likely to become a more commonplace over the next twenty years (Hoegh-Guldberg et al., 2007; Pandolfi et al., 2011).

In addition to thermal stress, corals worldwide face the additional threat of ocean acidification, a result of increased atmospheric carbon dioxide. As the pH of the ocean decreases, growth rates of calcifying organisms including corals, crustose coralline algae (CCA), mollusks, and crustaceans decrease as the concentration of essential carbonate ions needed for skeletal growth is reduced (Cohen and Holcomb, 2009; Doney et al., 2009; Hoegh-Guldberg et al., 2007). Reduced growth rates of reef building species contribute to substantial degradation of reef structure as rates of bioerosion increase. These processes reduce the capacity of reefs to maintain the fundamental integrity of their three dimensional structure and can have widespread impacts on the entire ecosystem (Hoegh-Guldberg et al., 2007; Reyes-Nivia et al., 2013; Wisshak et al., 2012). Furthermore, when taxa are consistently exposed to elevated sea surface temperatures reefs exhibit enhanced sensitivity to ocean acidification (Kroeker et al., 2013).

Due to the widespread impacts of ocean warming and acidification, understanding the immensity of these acute stressors is a priority for future research (Kleypas and Langdon, 2006). Moreover, studying the effect of global change in the absence of human pressures will allow for the further understanding of the synergistic effects between local impacts and global change. Additionally, such studies can shed light on the processes necessary for recovery of degraded reefs (Knowlton and Jackson, 2008). These threats are expected to increase into the future, it is therefore important to monitor how climatic and seasonal variability impacts these ecosystems in the absence of direct confounding impacts, to help determine what can be done to mitigate these threats.

CORAL REEF MONITORING

With growing concern of coral reef decline, international coral conservation initiatives and monitoring networks began to develop worldwide in the early 1980s. In 1998 President Bill

Clinton made coral reef conservation a priority of the United States (Brainard et al., 2012). In response to the mandates and policies developed in the United States, the Coral Reef Ecosystem Division (CRED), now Coral Reef Ecosystem Program (CREP), of the NOAA Pacific Islands Fisheries Science Center (PIFSC) was formed in 2001.

NOAA's Coral Reef Ecosystem Program (CREP), our client, attempts to bridge the gap between science and management by implementing a systematic, long-term environmental and ecological monitoring program with the goal to provide pertinent scientific information to resource managers. In fact, CREP's mission statement is "to provide high-quality scientific information about the status and trends of coral reef ecosystems of the central and western Pacific (see map) to the resource managers, policymakers, and the public at domestic and international scales" (NOAA PIFSC, n.d.).

CREP heads the Pacific Reef Assessment and Monitoring Program (Pacific RAMP), a research program with standardized methods for coral reef monitoring. CREP conducts comprehensive ecosystem monitoring surveys at approximately 50 islands, atolls, and shallow banks in the Pacific, including the PRIMNM. Monitoring surveys are completed using NOAA research vessels capable of supporting research teams of 20-22 scientists for voyages lasting 2-3 months (Brainard et al., 2012). These monitoring surveys provide data used to answer critical questions on resource status, long-term trends, impacts at various spatial scales, biological and community ecology, and efficacy of various management actions (Hill and Wilkinson, 2004). In addition, the standardized methods used by CREP allow for Pacific-wide comparisons of present and future reef conditions.

Effective coral reef management requires a fundamental understanding of the spatial patterns and temporal trends of marine resources and how they are expected to change in the future. A recurring issue with management of these ecosystems is the lack of long-term data on their status and function. Coral reef ecosystem monitoring programs, such as those conducted by NOAA, aim to fill this gap to provide the knowledge necessary to inform management decisions.

CORAL REEF MANAGEMENT & PUBLIC ENGAGEMENT

Management programs and policies that promote conservation are essential for the preservation of marine ecosystems. Although there are many different management schemes available to manage and protect natural resources, marine protected areas (MPAs) are scheme most commonly used for the protection of marine resources. MPAs have been a successful tool for improving habitat, increasing biodiversity, and rebuilding fish stocks (Edgar et al., 2007). While usually thought of as a fisheries management tool used to mitigate the negative impacts of overfishing, if managed correctly, MPAs also benefit entire coral reef ecosystems. MPAs indirectly benefit corals by preserving biodiversity and ecosystem function; this can increase reef resilience to natural disturbances such as coral bleaching, coral diseases, and crown-of-thorns seastar outbreaks (Knowlton and Jackson, 2008; Mellin, et al., 2016). As oceans are faced with increasing local and global threats, it is important for MPA resource managers to preserve coral reef ecosystem biodiversity and health to improve reef resilience in the face of climate change.

U.S. Marine National Monuments (MNM), designated by Presidential Proclamation, are an example of a well-established MPA. The MNMs protect areas of outstanding scientific, cultural, conservation and aesthetic value, and provide for the long-term persistence of these natural and cultural legacies (NOAA Pacific Islands Regional Office, n.d.-a). There are four designated MNM across the Pacific Ocean: the Marianas Trench MNM, Pacific Remote Islands MNM, Papahānaumokuākea MNM and Rose Atoll MNM. These Monuments are all cooperatively managed by the Secretary of Commerce (NOAA) and the Secretary of the Interior (U.S. Fish & Wildlife), along with other federal, regional, and state agencies for each specific Monument.

Under NOAA's existing authorities and the Antiquities Act, NOAA's MNM Program collaborates with these partners, along with other stakeholders, to conserve and protect the marine resources in these marine protected areas (NOAA Pacific Islands Regional Office, n.d. - a). The MNM Program also coordinates the development of management plans within the MNMs in the Pacific Islands Region. The mission of the MNM Program is "to understand and protect the unique natural and cultural resources within the MNMs through the advancement of scientific research, exploration, and public education" (NOAA Pacific Islands Regional Office, n.d. -b). This mission is achieved through the following goals:

1. Collaboratively develop and adaptively manage governance structures for the Marine National Monuments.
2. Develop a program for scientific exploration and research.
3. Increase stakeholder awareness, engagement, and support for the Marine National Monuments.

By designating these areas of the Pacific Ocean as MNMs, the United States helps to ensure that these marine environments receive the highest level of environmental recognition and conservation (NOAA Pacific Islands Regional Office, n.d. -b).

The unparalleled biodiversity and unimpacted conditions found at the PRIMNM prompted its Monument designation. Today, the Monument is cooperatively managed by three agencies: the Pacific Islands Regional Office (NOAA), the U.S. Fish and Wildlife Service (USFWS), and the Department of Defense (in the case of Wake Atoll, which maintains a small military presence) (USFWS, NWRS, & NOAA, 2011). Currently, NOAA and the USFWS are working to develop the PRIMNM Management Plan which will 1) integrate management and conservation of marine and terrestrial ecosystems, and 2) address local and global threats to the ecosystems located within the Monument (USFWS, NWRS, & NOAA, 2011). Although management objectives are not yet finalized for the PRIMNM, other MNMs across the Pacific have established management plans, such as Papahānaumokuākea Marine National Monument (PMNM). Within PMNM's Management Plan, there are 22 action plans, organized under six priority management needs (NOAA, USFWS, & State of Hawai'i DLNR, 2008). These needs include: understanding and interpreting the Northwestern Hawai'ian Islands, conserving wildlife and habitats, reducing threats to monument resources, managing human uses, coordinating conservation and management activities, and achieving effective monument operations. The action plans describe specific strategies and associated activities to address these management

needs (NOAA, USFWS, & State of Hawai'i DLNR, 2008). Similarly for the PRIMNM, once management objectives are clearly defined, action plans will be designed to meet identified management needs for the Monument.

In addition to managing marine resources, it is essential to have effective communication strategies that engage stakeholders and increase awareness about MNMs. Conservation plans to protect marine environments from threats such as climate change, overfishing, and pollution are more likely to succeed if they have broad public approval. Public support is ultimately generated by educating citizens on current environmental issues and informing them about the benefits of policies. Failure to communicate the benefits of regulations is one of the greatest shortcomings of nongovernmental and governmental agencies, as it hinders public support. MPA regulations, particularly in populated areas, will likely fail if the management plans do not include education and outreach components that aim to increase awareness on marine threats and conservation efforts (Agardy et al., 2011). Awareness leads to societal behavior changes that decrease pressures on marine ecosystems and create support for sustainable management decisions (Jefferson et al., 2015). Thus, NOAA's Pacific Islands Regional Office (PIRO) seeks to educate the general population about the regional office's mission by providing educational and outreach opportunities that increase support for their conservation management programs (NOAA Pacific Islands Regional Office, n.d.-a; NOAA National Marine Fisheries Service, n.d.).

The overall objective of PIRO's outreach and education program is to seek and create opportunities to inform and educate the public of the regional office's mission and its impact on the economy and environment in the Pacific. PIRO aims to achieve this objective by creating a range of materials to support proactive and strategic communications (e.g., fact sheets, posters, brochures, FAQs, web stories), participating in public and school presentations, developing web resources for teacher and students, and networking with various partners and stakeholders. With these various outreach strategies, PIRO hopes to "raise the awareness of the general public to gain support for the MNM Program and grow stewards of the environment." (NOAA Pacific Islands Regional Office, n.d. -c). Through effective management and communication, PIRO can better preserve the PRIMNM's marine ecosystems and provide for the continued protection of these valuable resources.

PROJECT SIGNIFICANCE

Our group identified two gaps critical for effective management of the MNMs. Despite the commitment to providing science to pertinent audiences including resource managers, policymakers, and the public, such information had yet to be reported in a meaningful way. As a result of this disconnect, resource managers at NOAA had not established management objectives for the PRIMNM and the public is disengaged from their role as a stakeholder.

To further CREP's mission, our project aims to effectively communicate the trends of ecosystem health at the PRIMNM across various spatial scales to resource managers. In so doing, we equip NOAA managers with the capacity to outline management objectives, develop action plans, and implement ecosystem-based management at each of the PRIMNM islands.

Lastly, a largely overlooked stakeholder of federally protected, large-scale marine reserves is the American public. Both CREP and PIRO are driven by a mission to increase awareness of the public, foster support for the MNM Program, and promote environmental stewardship. However, their current strategies have failed to reach a broad audience of the American public or understand pre-existing conditions to develop targeted communications strategies. Thus, our group empirically determined the beliefs and awareness of the public. We therefore determined pre-existing perceptions to identify specific awareness gaps that we then targeted with specific communication materials. We also identified the ways in which people value and connect with the ocean and the issues affecting it, this allows us to effectively engage the public (Jefferson et al., 2015). If produced materials successfully resonate with the public, perhaps the results of this project and future work can begin to introduce societal behavior changes that benefit ocean health.

The PRIMNM offers a unique opportunity to study intact ecosystems, design scientifically informed management actions, and also engage the public in marine conservation. The lessons learned through this project specific to the PRIMNM are widely applicable to all marine protected areas regardless of proximity to inhabited coastlines. Understanding ecosystem dynamics in the absence of human presence will illuminate the synergistic effects of local impacts and global change thereby improving management of degraded reefs. Furthermore, targeting the aspects of the ocean that resonate deeply with the public through strategic engagement efforts will facilitate marine conservation.

PROJECT OBJECTIVES

1. Effectively communicate PRIMNM coral reef ecosystem health across spatial and temporal scales to resource managers.
2. Educate the public on the threat climate change poses to ocean health and increase public awareness of and support for marine conservation efforts.

CHAPTER 1

CORAL REEF ECOSYSTEMS OF THE PACIFIC REMOTE ISLANDS MARINE NATIONAL MONUMENT OVERVIEW REPORT

INTRODUCTION

Through the collection of a wide variety of data on bi-annual and tri-annual NOAA Pacific RAMP cruises, NOAA collects data on multiple scales of biological, chemical and physical indicators of ecosystem health. The data collected allows for synthesis of trends for these indicators over time. Example indicators of ecosystem health include carbonate accretion, coral cover, fish biomass, and microbialization. NOAA has conducted cruises throughout the PRIMNM since 2000. As mentioned herein, we used this data to complete the first single coalesced overview booklet that summarizes our data synthesis, with the ultimate goal of determining overall coral reef ecosystem health and communicating the results effectively.

Note: This chapter is an addendum to the Coral Reef Ecosystems of the Pacific Remote Islands Overview Report (Appendix A), a primary deliverable for this project. For explanation and significance of chosen methods, please refer to Appendix A.

METHODOLOGY

To synthesize the data that were collected across biological, chemical, and physical scales, various methods were applied to each dataset to remove biases and adjust for noise in the data to ensure we were communicating information representative of the PRIMNM ecosystem. This section details the methods used for oceanographic, benthic community, and fish community data collection, analysis, and synthesis. It is important for these methods to be clearly understood and well documented so that scientists, managers, and members of the public can replicate the methodology for other regions if they chose to do so.

OCEANOGRAPHY

Coral reef ecosystems are influenced by a diverse suite of oceanographic and climatological factors, including but not limited to temperature, wind, waves, currents, nutrients, carbonate chemistry, light, and productivity. Satellite-derived and in-situ oceanographic data were collected and analyzed to assess the variability of each of these factors across the Pacific. Satellite observations provide broad spatial coverage and a historical context of surface processes, whereas in-situ observations provide subsurface measurements of the physical and chemical conditions directly influencing coral reef communities. See Appendix A, *Coral Reef Ecosystems of the Pacific Remote Islands Marine National Monument: a 2000-2016 Overview*, for in-situ oceanographic

data collection methods and for further description of the following oceanographic parameters and their roles in influencing biological communities.

SATELLITE DATA

To determine long-term spatial patterns in sea surface temperature and chlorophyll-*a* across the Pacific basin, satellite data for chlorophyll-*a* concentration and sea surface temperature (SST) were obtained from ERDDAP, a data server that allows scientific datasets to be downloaded as subsets and in common file formats. Chlorophyll-*a* concentration data is from National Aeronautics and Space Administration's *Aqua MODIS* (ERDDAP, 2016), and these data were subset to span across the Pacific (20°S–32°N, 140°E–150°W) from 2003 to 2016. SST data is from NOAA's *POES AVHRR* (ERDDAP, 2016). These data were subset to span across the Pacific (25°S–35°N, 135°E–145°W) from 2003 to 2016. The long-term averages for chlorophyll-*a* concentration and SST were calculated by taking the averages of the values for every subsetted longitude-latitude data point over the 13-year time span for each respective dataset. The averages for each data point were interpolated in ArcGIS using inverse distance weighting for both SST and chlorophyll-*a* (See Appendix A, Figures 8-9).

CARBONATE CHEMISTRY

To compare carbonate chemistry parameters within and across our Pacific regions of interest, mean aragonite saturation state and mean carbonate accretion rate values were synthesized.

Mean aragonite saturation states per island were calculated by taking the averages of benthic aragonite saturation state values from 2013-2015 for each island. The aragonite saturation state values used to calculate means were pre-calculated by CREP. These values were pre-calculated from dissolved inorganic carbon and total alkalinity values measured from in situ water sampling close to the substrate. Lagoonal sites were removed from the analysis because CREP scientists determined that aragonite saturation state values are much higher in reef lagoons than the values in near offshore waters. Therefore, in order to accurately compare aragonite saturation states across islands and regions throughout the Pacific, lagoonal sites were removed so that island means were not skewed by high lagoonal values.

Mean carbonate accretion rates per island were calculated by taking the averages of carbonate accretion rates from 2012-2015 for each island. The carbonate accretion rate values used to calculate means were measured by CREP through Calcification Accretion Units (CAUs). CAUs are described in the Methods section of the PRIMNM Overview Booklet (See Appendix A, Figure 10).

DEGREE HEATING WEEKS & SEA SURFACE TEMPERATURE

To identify periods of extremely high sea surface temperatures and potential thermal stress across the PRIMNM, Degree Heating Weeks (DHW) and SST data were processed from NOAA Coral Reef Watch's 50 km Virtual Stations (NOAA Coral Reef Watch, 2011). The data

spans from 11/28/2000 to 10/13/2016. No additional analysis was done for the DHW data; the data were plotted for each island and faceted by island grouping (Northernmost Islands: Johnston Atoll and Wake Atoll, Central Transition Islands: Kingman Reef and Palmyra Atoll, Equatorial Islands: Baker Island, Howland Island, and Jarvis Island). Baker and Howland were grouped together into one data output by NOAA Coral Reef Watch because they share extremely similar oceanographic conditions. To display the SST data, a time-series graph was created for Howland and Baker (grouped together), and individually for Jarvis to highlight and compare how long the SST surpassed the coral bleaching threshold (1°C above the maximum monthly mean) during the El Niño seasons. The coral bleaching threshold was calculated by taking the averages of the monthly data to obtain twelve monthly SST means, and then taking the highest of those twelve monthly mean SST values and adding 1°C to that value. The coral bleaching threshold is calculated in this manner because ambient water temperatures as little as 1 to 2°C above a coral's tolerance level, indicated by summer monthly mean temperatures, can cause coral bleaching (Berkelmans and Willis, 1999; Reaser et al., 2000) (See Appendix A, Figures 24-26).

BENTHIC COMMUNITY

The benthic composition, measured as percent cover, was determined using data from rapid ecological assessment (REA) methods. While towed-diver surveys (TDS) also measure benthic parameters such as benthic cover, TDS are designed to cover a larger sample area and are used as a broader measurement. Towed-diver estimates frequently overestimate benthic cover and community composition, while REA survey design provides a more detailed and accurate estimate of benthic community and composition. Additionally, TDS do not decipher between turf and macroalgal functional groups; therefore, the REA line-point intercept method was determined to the most practical measurement for percent cover. For an overview of NOAA's survey methodology, see Appendix A pp. 15. In 2014, REA methods were changed from permanent REA sites, to stratified random sampling (StRS) design. StRS design allows for random sampling of various habitat strata to obtain differences in functional categories across strata, for this survey method sampling effort is allocated based on strata area. Both REA survey designs used the line-point intercept method to determine percent cover for each functional group, generic richness, as well as bleaching and disease occurrence. Mean cover, richness, bleaching and disease occurrence were all weighted by strata area. To make the permanent site data and StRS data more comparable, data were filtered for forereef and mid-depth habitat strata only, with the exception of the generic richness component, in which all depths and all strata were used. This was done for consistency as forereef and mid-depth habitat strata were the surveyed with the most consistency through time, despite survey methods changes. Thus, subsetting for only this habitat reduced the variability in the data inherent with changing survey methods through time.

BENTHIC PERCENT COVER

As mentioned above, benthic cover estimates were calculated using REA data. For StRS data weighted means per stratum area were calculated to determine coral, macroalgae, crustose

coralline algae, and turf algae cover. Strata estimates for forereef mid-depth strata were then used for analysis. For the permanent site data, estimates were standard means subsetted for forereef mid-depth habitat strata only.

GENERIC RICHNESS

Generic richness was calculated as the total number of genera present in the order *Scleractinia*. The generic richness values were weighted; the mean weighted generic richness was computed per habitat stratum weighted by stratum area for each island based on the most recent 2014–2015 StRS REA surveys. The generic richness component included all strata in case other strata contained unique genera not found in the forereef at mid-depths.

BLEACHING AND DISEASE OCCURRENCE

Occurrence was calculated as the number of colonies exhibiting signs of bleaching (irrespective of severity or extent) or exhibiting disease divided by the total number of colonies for adult hard scleractinian corals. However, due to the change in survey design (permanent site to StRS) the mean prevalence was calculated as follows: for permanent REA sites occurrence was calculated as the sum of all infected colonies divided by the sum of the total colonies for each island. For StRS surveys (2014-2015), the occurrence is the mean occurrence by island calculated for each StRS sampling site. Estimates are shown in Appendix A, Figure 20.

MACROINVERTEBRATE DENSITIES

In order to understand where both crown-of-thorns (COTS) and giant clams were present in the highest abundances on each island, densities from TDS were mapped for each survey year using ArcGIS. COTS densities below outbreak levels (1500 COTS 100 m^{-2}) were not shown in the plot, so outbreak level densities were apparent. The COTS remained in bubble plot format, as each year outbreak occurred in different areas around the reef and each year mean densities changed significantly. For giant clams, the density through time and space did not change significantly. Therefore, giant clam densities were interpolated using the inverse distance weighted tool in ArcGIS.

FISH COMMUNITY

The Pacific RAMP surveys the fish community using two methods: stationary point counts (SPC) and towed-diver surveys (TDS). SPC surveys are performed according to a stratified random survey design (StRS) at each island and have been employed at the MNM islands since 2009 (see Appendix A for explanation of NOAA's survey methods). The site specific, small scale of the SPC surveys do not capture larger, roaming fishes and often overestimate the biomass of roving species such as sharks and jacks. Thus, the estimate for large piscivore biomass is not included in total fish biomass but instead estimated from TDS.

Large, often predatory coral reef fish can be difficult to survey using site-specific surveys due to behaviors that reduce the probability of an encounter (Richards et al., 2011). These fishes are often relatively rare and can be highly migratory or have comparatively large home ranges. As a result, certain groups of large coral reef fishes are sampled using TDS rather than stratified random SPC surveys. Encounter rates and statistical power have both been shown to increase when using TDS to survey large fishes as this method allows for more complete and representative coverage of large areas (Richards et al., 2011). TDS of large coral reef fishes provide managers and scientists with improved estimates of key spatial and temporal metrics of the fish community necessary for effective management of these populations (Richards et al., 2011).

TOTAL FISH BIOMASS

The physical structure of coral reefs significantly influences the distribution and abundance of coral reef organisms including reef fishes (Komyakova et al., 2013). Most reef fishes have specific habitat requirements or preferences based on the trophic level, feeding behavior or other life history traits. As a result, the reef fish community can vary widely across coral reef microhabitats. Large roving predatory fishes dominated deeper forereef habitats at Kingman Reef relative to backreef and lagoon habitats, for example (Friedlander et al., 2010). Such variability in habitat structure across a reef can introduce significant biases when comparing reef fish communities to confound information on the true community. Therefore, the fish biomass data were synthesized in a way that reduces the biases associated with these interhabitat differences that may not be indicative of the de facto fish community. Specifically, only the SPC data from mid-depth, forereef habitats were used.

In addition, as mentioned above, certain species' life histories can result in an over- or under-representation of these species and the associated community. For example, extremely rare, or, when encountered, schooling species such as manta rays (*Manta birostris*), are systematically overestimated using conventional survey methods. Similarly, other schooling fishes such as mackerel scad (*Decapterus macarellus*) are infrequently seen in extremely large, fast-moving schools around islands near deep water (Froese and Pauly, 2016). When schools, such as these are sighted by SPC surveyors, the biomass estimates confound biomass estimates of the fish community because the probability of sighting these species is so low. In other words, fast-moving, schooling, rare encounters represent a large amount of noise in the data and do not offer a true representation of the fish communities found at these islands. To account for the effect of these species, certain species were filtered from the dataset that represented rare sightings or introduced significant noise. In addition to non-fish species such as sea turtles and marine mammals, six fish species were removed from biomass estimates: *Decapterus macarellus* (Family: Carangidae), *Encrasicholina purpurea* (Family: Engraulidae), *Manta birostris* (Family: Myliobatidae), *Spratelloides delicatulus* (Family: Clupeidae), *Selar crumenophthalmus* (Family: Carangidae), and *Kuhlia sandvicensis* (Family: Kuhlidae). Biomass of these six species is overestimated in SPC surveys and rather than improving the estimates of the fish community these species introduce a large amount of noise in the data that does not indicate the natural state of the community.

The large fish biomass towed-diver survey data did not require manipulation.

CONCLUSION

Please refer to Appendix A for results and conclusions.

CHAPTER 2

CORAL REEF MULTI-METRIC CONDITION INDEX

INTRODUCTION

Despite NOAA's long term monitoring efforts, there are currently few products that can quickly and clearly convey the overall status of coral reef ecosystems to non-scientific audiences. Managers would benefit from a concise synthesis of the current status and health of the PRIMNM as well as the key threats this ecosystem faces. In order to facilitate management actions within the monument, we present a multi-metric condition index that integrates multiple coral reef metrics encompassing both the biological community and oceanographic and climatological indicators at these islands. This index offers a succinct representation of ecosystem health. Therefore, the metrics can be used to measure changes in reef condition through time, determine the efficacy of management actions in the future, and help compare differences in reef condition across the Pacific. This index is the first iteration of a Coral Reef Ecosystem Report Card for the PRIMNM. Using comparable methods, similar Report Cards will be produced for every Pacific archipelago managed by NOAA.

The objective of this project component is to develop a multi-metric condition index that integrates the status of the fish and benthic communities and the risks to the ecosystem due to climate change. This index will effectively communicate the current health of the PRIMNM ecosystem, providing managers with a baseline measurement to evaluate changes through time and the efficacy of management strategies in the future.

METHODOLOGY

CLIMATE

The oceanography and climate component of the index includes three metrics: temperature stress, ocean acidification and reef material growth. Degree heating weeks (DHW) were used as a proxy for temperature stress to indicate the duration and severity of heat stress. Since corals can bleach due to a 1-2°C exceedance of the bleaching threshold, the temperature stress metric serves to understand the threat of warm sea surface temperatures and their effect on the coral community.

The ocean acidification and reef material growth metrics are both based on the carbonate chemistry of the reef system. Corals ability to calcify depends on the chemical conditions of their seawater environment. Ocean acidification was measured with aragonite saturation state, which determines if the environment is more or less conducive to calcification. In other words, when seawater has a higher aragonite saturation state, conditions are more favorable for calcification

for reef building corals. Reef material growth was measured through calcification accretion units. Net carbonate accretion rates provide an indicator of the reef's overall growth. A net-accreting reef is growing or maintaining its three-dimensional structure, whereas a reef experiencing net removal of calcium carbonate is in the process of flattening. Therefore, ocean acidification and reef material growth determine if a reef will persist through time.

DEGREE HEATING WEEKS

Degree heating weeks (DHW) are a measure of temperature severity and duration, and are calculated as 1°C above the highest summertime mean sea surface temperature. DHWs were used as a proxy for temperature stress. Temperature stress data were collected from NOAA's Coral Reef Watch satellite data, which spans from 2001-2016. The methodology was developed by the Coral Reef Watch program, which uses DHW history to score how frequent and severe the thermal anomalies have been. The scoring thresholds developed stem from their standard bleaching alert threshold levels (0-4, 4-8, 8+), where significant coral bleaching usually occurs when DHW values reach 4°C-weeks, and widespread bleaching is likely and significant mortality can be expected when values reach when reach 8°C-weeks.

The last 16 years of DHW data were obtained and converted to annual maxima. First, the frequency of severe DHW events during the past 4 years was determined. Then, due to the nature of extreme heat stress events, the last 16 years of data was examined to see if there were any extreme events that may have lingering effects. These maxima were tallied and scored based on the frequencies in Table 2.1. The final grade assigned is associated with the most extreme DHW event over the last 16 years. Since temperature stress is detrimental to the ecosystem and can cause coral bleaching, as the number of degree heating weeks increase, condition scores decrease.

Table 2.1. Scoring methodology for Degree Heating Week (DHW) events as an indicator for thermal stress present at each location. DHW stress is reported as a frequency of occurrence over a 4-year reporting period.

Event Frequency per 4 Year Reporting Period

Condition	0<DHW<4	4≤DHW<8	8≤DHW<12	12≤DHW<16	16≤DHW<20	20≤DHW
Superb	0					
Excellent	2	0				
Good	4	1	0			
Fair		2	0.5	0		
Poor		4	1	0.5	0	0
Very Poor			2	1	0.5	0.25

ARAGONITE SATURATION STATE

The ocean acidification metric is based on aragonite saturation mean measurements from surveys conducted between 2010 and 2015. Threshold methods were developed by Thomas Oliver and Derek Manzello. In order to determine the thresholds, pCO_2 was used to model past and future conditions. Since aragonite saturation state is the key variable for determining ocean acidification, these threshold levels were converted to aragonite saturation state. The superb condition was set at pre-industrial pCO_2 levels and the very poor condition was set at two times this preindustrial level. The very poor condition was set at this level because coral reefs may start dissolving when atmospheric carbon dioxide doubles (Silverman et al., 2009), and the associated aragonite saturation state ($\Omega arag = 3$) is a commonly known carbonate tipping point for reef growth. Additionally, most preindustrial reefs had an aragonite saturation state greater than 3.3, which also coincides with the last remaining reef in the Galapagos, and is therefore representative of a poor condition (Hoegh-Guldberg, et al., 2007).

The scoring thresholds were based on an even split between the upper and lower scores at 70 μatm increments. The resulting thresholds can be seen in Table 2.2. Based on these intervals, two linear regression equations were determined to analyze aragonite saturation state. For aragonite saturation states greater than 3.63, the equation $y = 30.8x - 41.5$ was used. For values less than 3.63, the equation $y = 200x - 600$ was used. The aragonite saturation state values from 2010 – 2015 were then entered into these equations to determine a final score. Since higher aragonite saturation states are more conducive to coral calcification, condition scores increase with the increase in aragonite saturation state.

Table 2.2. Scoring of Aragonite Saturation State and Reef Material Growth.

Condition	Final Score	Aragonite Saturation State	Reef Material Growth
Superb	100	4.6	0.22616 - infinity
Excellent	90	4.28	0.10991 - 0.22616
Good	80	3.95	0.05342 - 0.10991
Fair	70	3.63	0.02596 - 0.05342
Poor	60	3.3	0.01262 - 0.02596
Very Poor	0	3	0 - 0.01262

NET CARBONATE ACCRETION RATE

The reef material growth metric is based on mean carbonate accretion rate measurements from surveys conducted between 2012 and 2015. A set of thresholds was derived by Tom Oliver based on a Pacific-wide distribution. Since there was no baseline for carbonate accretion rate, a Pacific-wide distribution of carbonate accretion values was log-transformed to make it an approximately normal distribution. Then, even quantiles were set at 0, 20, 40, 60, 80, and 100 that correspond with very poor to superb conditions. The resulting thresholds are included in Table 2.2. The logistic equation corresponding with the distribution was $y = 12.753 * \ln(x) + 117.55$. Carbonate accretion rates were then plugged into this equation to determine the final score. Since higher carbonate accretion rates are associated with reef building, higher reef material growth resulted in higher condition scores.

CLIMATE CONDITION INDEX

Each island's individual scores for temperature stress, ocean acidification, and reef material growth were averaged to find the overall climate condition index for each island.

BENTHIC COMMUNITIES

For the benthic component, scoring was based on benthic cover and coral population data. Benthic cover included estimates of coral cover, crustose coralline algae (CCA) cover, and macroalgal cover; coral populations indicators included estimates of adult and juvenile colony densities, partial mortality, and generic richness.

To score benthic cover, Pacific-wide percent cover data for coral, CCA, and macroalgal cover was divided into 20% quantiles to determine threshold reference points, reference points are listed in Table 2.3. The weighted mean for each island and each functional group obtained from REA StRS data, was then scored accordingly. A final benthic cover score was calculated for each island as a composite score of the three major components. CCA is a major reef builder for stony corals, and therefore high CCA cover was an indicator for a healthy reef. Excessive macroalgae in a system is often an indicator for decreased piscivore biomass, and systems with extensive macroalgae cover may exhibit future phase shifts from hard coral dominated systems to algae dominated systems. Therefore, as coral and crustose coralline algae cover increases scores also increase; as macroalgae percent cover increases, scores decrease. The scoring thresholds or reference points generated for benthic composition match thresholds published in other scorecards throughout the Pacific (Kaufman et al., 2011). The scoring thresholds, while arbitrary, were determined by looking at ranges and distributions of health indicator values across the Pacific, and incorporating expert opinion to ensure that the range values were justifiable.

Table 2.3. Reference points and corresponding scores for each indicator. For generic richness, juvenile and adult densities, and partial mortality scores were standardized based on maximum values. Maximum values were determined Pacific-wide for richness and partial mortality, and region-wide for adult and juvenile densities.

Final Score	Coral Cover (%)	CCA Cover (%)	Macroalgal Cover (%)	Generic Richness Standardized Score	Juvenile and Adult Density Standardized Score	Partial Mortality Standardized Score
Excellent: 90-100	≥ 40	≥ 20	≤ 5	> 80 – 100	> 60 – 100	0 – 20
Good: 80-90	40 – < 30	20 – < 10	5 – < 10	> 60 – 80	> 40 – 60	> 20 – 40
Fair: 70-80	30 – < 20	10 – < 5	10 – < 20	> 40 – 60	> 20 – 40	> 40 – 60
Poor: 60-70	20 – < 10	5 – < 2	20 – <30	> 15 – 40	> 10 – 20	> 60 – 80
Very Poor: 0-60	< 10	< 2	30 – < 40	0 – 15	0 – 10	> 80 – 100

GENERIC RICHNESS

For generic richness, adult and juvenile coral colony densities, and partial mortality, there is limited data available for scoring benchmarks. Therefore, observed maximums were used to standardize the scoring. To score generic richness, the total count of unique hard coral genera present at each of the islands was weighted. The weighted generic richness is the average generic richness for each sampling site, which accounts for differences in the total reef area. Weighted richness values were compared across the Pacific, and the maximum value of 30 genera was used to standardize the scoring. Standardized scores were placed into 20% bins and scored accordingly (Table 2.10). Because more diverse systems tend to be resilient to changing conditions and biodiversity can be used as an indicator for overall health, as richness increased, scores increase.

ADULT AND JUVENILE CORAL COLONY DENSITIES

To score adult and juvenile density estimates, genera and species were selected for each island based on their abundance, importance, and consistent identification across the islands. The species and genera selected are shown in Table 2.4. As colony size increased, scores increased. Observed maximums for each selected genera and species across islands were used to standardize scores for each taxon. Standardized scores were then assigned into bins, based on 20% quantiles, which were truncated at a low range as a conservative approach, accounting for habitat specific differences in density for adults and juveniles (Table 2.3). Scores were then calculated for each island. The use of the selected taxon provides information about existing coral populations that are naturally present at each island to help account for differences in ecological gradients. Additionally, the coral population component incorporates a mechanism to determine how coral populations are changing over time, by incorporating juvenile coral densities. Juvenile densities help to provide information about the potential outlook for coral populations.

Table 2.4: Selected genera and species by island. Selected based on adult and juvenile coral colony abundance and relative importance and contribution to reef building.

Genera Selected by Island						
Baker	**Howland**	**Kingman**	**Palmyra**	**Jarvis**	**Johnston**	**Wake**
Acropora sp.	*Acropora sp.*	*Acropora sp.*	*Acropora sp.*	*Acropora sp.*	*Acropora sp.*	*Acanthastrea sp.*
Favia sp.	*Psammocora sp.*	*Favia sp.*	*Favia sp.*	*Fungia sp.*	*Montipora sp.*	*Astreopora sp.*
Fungia sp.	*Porites sp.*	*Favites sp.*	*Favites sp.*	*Leptoseris sp.*	*Pavona sp.*	*Cyphastrea sp.*
Leptastrea sp.	*Pocillopora sp.*	*Fungia sp.*	*Fungia sp.*	*Montipora sp.*	*Pocillopora sp.*	*Favia sp.*
Leptoseris sp.	*Pavona sp.*	*Leptastrea sp.*	*Hydnophora sp.*	*Pavona sp.*	*Porites sp.*	*Goniastrea sp.*
Montipora sp.	*Montipora sp.*	*Montastraea sp.*	*Montastraea sp.*	*Pocillopora sp.*	*Psammocora sp.*	*Montastraea sp.*
Pavona sp.	*Leptoseris sp.*	*Montipora sp.*	*Montipora sp.*	*Porites sp.*		*Montipora sp.*
Pocillopora sp.	*Leptastrea sp.*	*Pavona sp.*	*Pavona sp.*	*Psammocora sp.*		*Pavona sp.*
Porites sp.	*Fungia sp.*	*Pocillopora sp.*	*Pocillopora sp.*			*Pocillopora sp.*
Psammocora sp.	*Favia sp.*	*Porites sp.*	*Porites sp.*			*Porites sp.*
		Turbinaria sp.	*Turbinaria sp.*			*Acropora sp.*

Species Selected by Island						
Baker	**Howland**	**Kingman**	**Palmyra**	**Jarvis**	**Johnston**	**Wake**
Pavona chiriquiensis	*Pavona varians*	*Favia stelligera*	*Favia stelligera*	*Leptoseris incrustans*	*Pocillopora damicornis*	*Favia matthaii*
Psammocora haimeana	*Montipora caliculata*	*Montastraea curta*	*Montastraea curta*	*Pavona duerdeni*	*Pavona duerdeni*	*Goniastrea edwardsi*
Leptoseris incrustans	*Pavona duerdeni*	*Pavona duerdeni*	*Pavona duerdeni*	*Pavona varians*	*Pavona maldivensis*	*Montastraea curta*
Pavona varians	*Favia stelligera*	*Pavona varians*	*Pavona varians*		*Psammocora stellata*	*Platygyra daedalea*
Favia matthaii	*Psammocora haimeana*	*Turbinaria reniformis*	*Turbinaria reniformis*			*Pavona varians*

PARTIAL MORTALITY

The adult coral partial mortality indicator was calculated as mean 'old dead' percent of selected genera and species. Old dead mortality is defined as the non-living portion of a colony where coralline structures are either gone or covered over by organisms that are not easily removed. Partial mortality scoring used the same selection of genera and species as the adult and juvenile density coral population estimates (Table 2.3). As partial mortality increased, the score decreased. Ranges in mortality were evaluated across the Pacific to determine a maximum threshold. A maximum of 30% mortality was used to standardize the scores, and standardized scores were based placed in 20% quantile bins and assigned scores accordingly (Table 2.3). This is a conservative approach, but can help to indicate significant shifts in partial mortality through time.

FISH COMMUNITIES

The fish community component of the index was composed of three metrics: instantaneous fish biomass, mean size of key families, and a predator score including average shark abundance and piscivore biomass. The amount of fish present at a reef is measured from instantaneous fish biomass. The predator score indicates the state of piscivores and other predators on a reef. Finally, mean size is a measure of whether the fishes present at a reef are of reproductive size. Extreme human impact alters the community by selectively removing large fish and predators; this ultimately reduces diversity, mean size and, alters community structure (Friedlander and DeMartini, 2002). These metrics highlight the differences between urbanized, heavily fished areas and uninhabited, unfished or lightly fished areas such as the PRIMNM and other remote islands in the Pacific.

INSTANTANEOUS FISH BIOMASS

Estimated fish biomass per unit area (grams per meter squared) collected from SPC surveys at each Pacific island was used to score the Instantaneous Fish Biomass component of the reef fish community index. SPC surveys were conducted between 2010 and 2015 and the mean of fish biomass was calculated for each island as the primary response variable.

Individual island scores were determined using modeled island-level mean fish biomass in the absence of human presence obtained from Williams et al. (2015). Using a suite of anthropogenic and oceanographic indicators including local and distant human population per reef area, wave energy, SST, chlorophyll-*a*, hard coral cover, and mean substrate this study used generalized additive models to predict total reef fish biomass in the absence of people. Williams et al. (2015) found that predicted total reef fish biomass was highest at Kingman Reef and Palmyra with many of the other PRIMNM islands also exhibiting the highest modeled biomass. This study offered a unique opportunity to determine how present day reef fish populations compared to otherwise "unimpacted" states (Williams et al. 2015).

The first metric of the fish community index was calculated using these data on present day, mean fish biomass and predicted mean fish biomass. First, for every Pacific island, the proportion of present biomass relative to modeled biomass was calculated. Based on the proportions of inhabited islands, arbitrary scores were assigned to the highest and lowest proportions found at these islands. For example, Oahu in the Main Hawai'ian Island Archipelago was found to have the lowest proportion of biomass relative to the modeled estimates. The proportion at Oahu, 0.24 (i.e., reef fish biomass at Oahu is 24.6% of the modeled fish biomass estimates determined from Williams et al., 2015) was used to assign the lowest possible score for all islands in the Pacific, a "failing," "very poor" score, or a 50% grade. From the failing score at Oahu, scoring was then assigned based to assign a passing grade to the inhabited island with the highest score and a "fair" grade to a proportion of 0.33. The inhabited island with the highest proportion, Swains in American Samoa with a proportion of 0.77, was assigned a "good" score. These designations allowed us to determine scoring equations based on a regression for the lower and higher scoring islands (Table 2.5). The scoring equations were

arbitrarily determined with the intention of having the less populated islands receiving a "fair" or "good" score.

Table 2.5. Scoring equations for instantaneous fish biomass at all US Pacific islands for the reef condition index.

Range of Proportional Instantaneous Fish Biomass	Scoring Equation
> 0.90	y = 100
0.33 - 0.90	y = 55.7 + (Proportion * 42.8)
< 0.33	y = (Proportion * 210)

Ultimately, if an island had a proportion of modeled biomass of 0.8, the associated score was "good" or a grade of 90%. Anything higher than 0.9 was given a score of "excellent" or a 100% grade, anything between 0.33 and 0.77 (not inclusive) received a score of "fair" and a grade between 70% and 80% (not inclusive). A "poor" score (between 60% and 70%, not inclusive) was assigned to proportions between 0.33 and the lowest proportion, 0.24.

This method ensures that each island is being compared only to conditions present at each individual island. Williams et al., (2015) modeled fish biomass by accounting for confounding effects of oceanographic characteristics. The modeled estimates and thus the resulting condition scores reflect the status of the fish community without biogeographical or oceanographic biases.

PREDATOR AVERAGE

The predator average component of the reef fish index was composed of two individual metrics: shark abundance and piscivore biomass. Scoring for piscivore biomass was done in the same way as instantaneous fish biomass, the first metric included in the fish index that was described in the previous section. The scoring equations were similarly determined from a range of relative piscivore biomass found at inhabited islands in the Pacific. The equations were arbitrarily determined to ensure the lowest scores "failed" and the best inhabited islands received a "fair" or "good" score (Table 2.6). This scoring method results in most all-remote islands received an "excellent" score (i.e., 100%).

Table 2.6. Scoring equations for piscivore biomass at all US Pacific islands for the predator average index and ultimately the reef fish condition index.

Range of Proportional Piscivore Biomass	Scoring Equation
> 0.90	y = 100
0.10 - 0.90	y = 60 + ((Proportion - 10) * 0.50)
< 0.10	y = 60 * (Proportion/10)

The second metric included in the predator average index was shark abundance. Shark abundance was scored similarly to both instantaneous fish biomass and piscivore biomass; however, the modeled baseline of shark abundance was obtained from a different study. Nadon et al., (2012) modeled shark abundance, measured as sightings from towed-diver surveys between 2010 and 2015, in the absence of human presence, these island-level estimates of shark density offered a reconstructed baseline of biomass and abundance of key groups which incorporated natural pressures and drivers, as well as anthropogenic forcing that contribute to differences in the fish community across the Pacific (Nadon et al., 2012). With the data on modeled "pristine" (i.e., in the absence of human presence or influence) shark abundance, this metric was scored in the same way as both piscivore and instantaneous fish biomass. The scoring equations are found in Table 2.7.

Table 2.7. Scoring equations for shark abundance at all US Pacific islands for the predator average index and ultimately the reef fish condition index.

Range of Proportional Shark Abundance	Scoring Equation
> 0.60	y = 100
0.10 - 0.60	y = 60 + ((Proportion - 10) * 0.80)
0.02 - 0.10	y = 50 * ((Proportion - 2) * 1.25)
< 0.02	y = 50 * (Proportion/2)

Finally, the predator average score was determined by averaging the scores for the two predator metrics, piscivore biomass and shark abundance, at each island. This resulted in a specific predator average score for each island.

Mean size of key fish families was included as a proxy for sustainability of the fish community. In other inhabited island regions, this metric includes mean size of recreational and commercial targets. Due to the absence of fishing in this monument, we used key families that were present at all islands and represent important ecological functions (Heenan and Williams, 2013). The families included were Acanthuridae, Serranidae, Scaridae, Lethrinidae, and Lutjanidae. Fishes of these families represent important ecological roles on coral reefs. These fishes were present at all island with one exception, at Johnston Atoll Serranids have never been sighted.

First, to account for differences in fish community because of biogeographical and large-scale oceanographic gradients, we first had to determine meaningful regions to group the Pacific islands. Varying environmental conditions such as nutrient availability and temperature significantly influence the naturally occurring community at each island. In particular, highly productive waters of the equatorial upwelling islands tend to have higher biomass of sharks, other piscivores, and planktivores (Williams et al., 2015). Grouping islands by bioregion allowed for standardized comparison across islands that are not confounded by natural variation in oceanographic characteristics.

The islands in the Pacific were divided into three unique bioregions: tropical Western Pacific (Mariana Archipelago and Wake Atoll), central Polynesia (American Samoa, Palmyra Atoll, Baker and Howland Islands, and Kingman Reef), and Hawai'i (Main and NW archipelagos). Once the biogeographic regions were determined, the island-level, mean size of each family was standardized within each region and subsequently scored. This method ensured that the range of scores (i.e., excellent, good, fair, poor, and very poor) were specific to each region and accounted for the effect of large-scale oceanographic differences.

To score this metric, for all the islands within each of the three regions, the mean and standard deviation was calculated for each fish family. Second, the standard Z-score was calculated based the equation:

$$Z = (X - \mu) / \sigma$$

where X is the island-level mean size of each family, μ is the region-level mean of each family, and σ is the standard deviation. After the Z-scores for each island and family were calculated, the Z-scores were averaged across all families for each island. This resulted in an island-level Z-score that accounts for broad biogeographical differences in the mean size of five key fish families. Then, the mean Z-scores across all 40 islands included were ranked from highest (largest positive deviation from the region specific mean) to lowest (largest negative deviation from the region specific mean). Finally, the final score was similarly arbitrarily determined. If the mean Z-score was greater than 1, the island received a score of 100% (i.e., "excellent"). Conversely, a Z-score of -1 was assigned a 60% (i.e., "poor") score. The linear relationship between the lowest (-1) and highest (1) Z-scores was then calculated to determine the scoring equation. This linear equation:

$$y = 0.2x + 0.8$$

was subsequently used to score the other islands.

REEF FISH CONDITION INDEX

To find the overall score for each island for the fish component, scores for each metric were averaged overall.

RESULTS

CLIMATE CONDITION SCORE

Overall, the Pacific Remote Islands did not score highly for the oceanography and climate metrics with mostly fair to very poor conditions (Table 2.8). Overall, the temperature stress metric resulted in the lowest conditions because of the extended period of anomalously warm water temperatures associated with the 2015-2016 El Niño and global coral bleaching event. Due to their equatorial location, Baker, Howland, and Jarvis experienced the brunt of the extreme warm waters during the past El Niño, and therefore all received very poor health conditions for temperature stress. Johnston, Kingman, and Palmyra received poor conditions and Wake received a good condition for the temperature stress metric.

The ocean acidification conditions were also relatively low because they were based on a comparison with pre-industrial levels that were more optimal for growth of coral reefs, and are therefore relatively low at most or all coral reef locations in the PRIMNM. Baker and Howland received a fair condition; Johnston, Kingman, Palmyra, and Wake received a poor condition; and Jarvis received a very poor condition for ocean acidification.

Except for Wake and Johnston, all other islands are in good condition based on the reef material growth metric (Table 2.8), but this higher score was pulled down by the temperature stress and aragonite saturation state metrics for the final combined climate metric. The final, combined Climate Condition Index results are as follows: Baker (fair), Howland (fair), Jarvis (poor), Johnston (poor), Kingman (fair), Palmyra (fair), and Wake (fair).

Table 2.8. Average scores for oceanography and climate at all islands. Scores were calculated from average scores of temperature stress, aragonite saturation and reef material growth.

Island	Temperature Stress Condition	Aragonite Saturation State Score	Aragonite Saturation State Grade	Reef Material Growth Score	Reef Material Growth Grade	Final Combined Grade
Baker	Very Poor	70.4	Fair	84.2	Good	**Fair**
Howland	Very Poor	71.1	Fair	82.5	Good	**Fair**
Jarvis	Very Poor	56.5	Very Poor	83.8	Good	**Poor**
Johnston	Poor	64.1	Poor	68.0	Poor	**Poor**
Kingman	Poor	64.7	Poor	85.1	Good	**Fair**
Palmyra	Poor	64.5	Poor	84.1	Good	**Fair**
Wake	Good	67.7	Poor	65.7	Poor	**Fair**

BENTHIC COMMUNITIES SCORE

Scores for benthic composition (percent cover) were good to fair for all islands, with numeric scores ranging from 71 to 83. Kingman Reef exhibited the highest score in terms of benthic cover, as it had the highest mean CCA and coral cover, with the lowest mean macroalgal cover. Final scores for benthic cover are shown in Table 2.9.

Table 2.9. Average benthic composition score for each island calculated as an average of the island-level scores for each individual benthic metric.

Island	Coral Score	CCA Score	Macroalgae Score	Final Scaled Score: Percent Cover	Condition Score
Baker	79	94	74	83	**Good**
Howland	73	97	75	82	**Good**
Jarvis	68	96	65	76	**Fair**
Johnston	43	83	87	71	**Fair**
Kingman	83	81	84	83	**Good**
Palmyra	79	89	77	82	**Good**
Wake	86	79	74	80	**Good**

The maximum weighted generic richness scores across islands in the Pacific was estimated to be about 30 genera per island; therefore, to standardize scores, mean weighted richness at each island was divided by the 30, and multiplied by 100. All islands with the exception of Johnston ended up in the good to fair range (Table 2.10).

Table 2.10. Score of benthic metric, weighted generic richness at each island. Standardized scores based on maximum richness of 30 genera.

Island	Standardized Scores	Scaled Score	Condition Score
Baker	48	74	Fair
Howland	52	76	Fair
Jarvis	40	70	Fair
Johnston	19	61.6	Poor
Kingman	76	88	Good
Palmyra	79	89	Good
Wake	53	76.5	Fair

Adult coral colony densities were substantially higher than juvenile colony densities. Kingman and Palmyra exhibited coral colony density in the "excellent" range, while Jarvis and Johnston exhibited lower coral colony densities in the "fair" range. For juvenile densities, Kingman and Wake showed the highest coral colony densities resulting in an "excellent" scores. Johnston exhibited "good" values for coral colony densities, while the other islands scored in the "fair" range (Table 2.11).

Table 2.11. Standardized scores for adult and juvenile coral densities.

Island	Adult Density Standardized Score	Scaled Score	Juvenile Density Standardized Score	Scaled Score
Baker	38	79	38	79
Howland	45	82.5	30	75
Jarvis	35	77.5	23	71.5
Johnston	59	89.5	51	85.5
Kingman	73	93.25	63	90.75
Palmyra	64	91	37	78.5
Wake	64	91	67	91.75

All islands in the PRIMNM exhibited low mortality, resulting in "good" conditions (Table 2.12). Kingman Reef exhibited the lowest partial mortality, resulting in the highest score. Palmyra, Howland, and Jarvis had the high partial mortality scores resulting in slightly lower scores in the "good" range. When compared to the rest of the Pacific, islands within the PRIMNM scored high for partial mortality. In comparison, many of the Main Hawai'ian Islands exhibit partial mortality that result in "poor" and "very poor" rankings.

Table 2.12. Partial mortality scores at each island.

Island	Standardized Score	Scaled Score	Condition Score
Baker	27.8	86	Good
Howland	35.2	82.5	Good
Jarvis	34.6	82.5	Good
Johnston	25.5	87	Good
Kingman	21.7	89	Good
Palmyra	34.5	82.5	Good
Wake	29.3	85.5	Good

When the scores were averaged for each of the benthic index components, and each weighted equally, all of the islands resulted in "good" scores with the exception of Jarvis and Johnston, which scored in the "fair" range, as shown in Table 2.13.

Table 2.13. Final combined scores for benthic condition.

Island	Numeric Score	Condition Score
Baker	80	Good
Howland	80	Good
Jarvis	76	Fair
Johnston	79	Fair
Kingman	89	Good
Palmyra	85	Good
Wake	85	Good

FISH COMMUNITIES SCORE

All islands in the PRIMNM received above acceptable scores for instantaneous fish biomass (Table 2.14). All islands except for Wake and Baker received an "excellent" score while Wake and Baker only received a "good" score for instantaneous fish biomass. Whereas the majority of islands received an "excellent" score for mean size, Baker and Howland received a "good" score while Johnston received a "fair" score. Finally, all PRIMNM islands received either an "excellent" or a "good" score for the predator component. Generally, piscivore biomass was lower at the islands but all islands had relatively high shark abundance, which adjusted the predator average score (Table 2.14).

Table 2.14. Scores for each individual metric included in the average fish composition score by island.

Island	Inst. Reef Fish Biomass	Mean Size	Predator Component 1: Piscivore Biomass	Predator Component 2: Shark Abundance	Predator Average
Baker	81	80	79	100	90
Howland	100	89	78	100	89
Jarvis	100	100	100	100	100
Johnston	100	78	88	85	87
Kingman	100	95	100	100	100
Palmyra	100	92	100	100	100
Wake	83	99	79	100	90

Overall, the fish metrics at all seven islands scored very high with all but two islands receiving an "excellent" score (Table 2.15). Baker and Johnston received a good grade with scores between 80% and 90%. The lower average score at Baker was driven primarily by lower mean size, piscivore biomass and instantaneous reef fish biomass. Johnston, on the other hand, had lower scores in mean size and shark abundance.

Table 2.15. Average scores for fish community composition at all islands. Scores were calculated from average scores of instantaneous reef fish biomass, mean size of key families, and a predator average including piscivore biomass and shark abundance.

Island	Final Numeric Score	Condition Score
Baker	83.7	Good
Howland	92.8	Excellent
Jarvis	100.0	Excellent
Johnston	88.1	Good
Kingman	98.3	Excellent
Palmyra	97.2	Excellent
Wake	90.7	Excellent

The benthic and fish components of the index offer a snapshot of the state of these resources and the health of the biological community. The oceanography and climate portion of the index instead offers a conceptualized indication of the climate change associated risks present at each of these islands. Overall, the final combined scores indicate that the majority of our islands are in good condition, with the exception of Baker and Johnston, which are in fair condition (Table 2.16).

Table 2.16. Final scores for the PRIMNM. Includes scores for all components (fish, benthic, and climate) each weighted equally.

Island	Final Numeric Score	Final Condition Score (All Components)
Baker	78	Fair
Howland	81	Good
Jarvis	80	Good
Johnston	78	Fair
Kingman	86	Good
Palmyra	84	Good
Wake	83	Good

CONCLUSION

A coral reef condition index provides a way to integrate multiple types of information in a manner that is easily interpreted. The index offers a clear tool for managers to understand the state of the resources they are tasked with managing. Furthermore, the index provides a snapshot of resources and allows future statuses to be compared to this "baseline condition" to determine efficacy of potential management actions.

The primary sources of uncertainty are resultant from threshold setting and baseline determinations for each metric. For example, the fish metrics are scored using reconstructed, modeled baselines of fish biomass and shark abundance in the absence of human presence. The benthic scores, generally base the scores off the distribution of variables across either the entire Pacific, or when necessary base the scores on the ranges observed within the PRIMNM, as was done for coral populations.

Additionally, due to the changes in survey methods, different sampling years were used for each of the metrics. While benthic surveys indicate that there have been few observed changes in the

benthic conditions from 2001-2015, methods have changed in monitoring; therefore, the benthic component of the index only used the most recent years of data. The fish component, on the other hand, uses data from 2010-2015. This brings about a large discrepancy between each component. To calculate scores for condition indices in the future, we recommended that future surveys maintain standardardized methods, and if methods do change calibration years should occur to allow for better comparison between methods and years.

CHAPTER 3

PUBLIC PERCEPTIONS OF REMOTE CORAL REEF ECOSYSTEMS AND LARGE-SCALE MARINE MANAGEMENT

INTRODUCTION

Substantial benefits can be derived from distributing scientific information and engaging community members in conservation efforts. Awareness leads to societal behavior changes that decrease pressure on marine ecosystems, creates support for sustainable management decisions, and increases conservation programs such as MPA designations (Jefferson et al., 2015). Creating strategic communication and outreach education materials that engender support for MPAs requires identifying the general public's existing knowledge, attitudes, and perceptions of large scale MPAs and threats facing our oceans. Because the general public is heterogeneous and citizens have different levels of expertise, it is important to look at how perceptions and attitudes differ amongst various demographics, such as age, gender, and relative proximity to the coast. This sets a knowledge baseline, provides a direction for communication, and highlights target audiences. More importantly, this guides effective engagement strategies and communication materials that will resonate with the target audiences (Jefferson et al., 2015). Research can also identify commonalities between coastal users and be used to bridge the gap between various stakeholders who challenge conservation efforts (Voyer et al., 2015).

Multiple studies have already gathered information on public opinion and knowledge of coral reef ecosystems and marine environments. For example, a study conducted by NOAA's Pacific Islands Fisheries Science Center surveyed residents who used Hawai'ian resources on their knowledge and attitudes toward coral reefs in two priority sites. The study sought to identify resident's perceptions of coral reef health, watershed resources, threats to those resources, and potential management strategies (NOAA PIFSC, 2016). Another example is the study conducted by the Australian Government Great Barrier Reef Marine Park Authority, which measured community awareness and attitudes towards the Great Barrier Reef (GBR) in 2007. The goal was to promote understanding of the GBR and issues affecting its health and management. Findings showed that 17 to 29 year olds were significantly less likely to be aware of the existence of the GBR Marine Park, but were significantly more likely to support the delegation of non-fishing areas. Furthermore, visitors were more likely to list water pollution, pest species, agriculture, and commercial fishing as main threats to the GBR than non-visitors (Young and Temperton, 2008). Similarly, the New Zealand Department of Conservation distributed a survey to research the level of public awareness, support, and involvement in marine issues. The findings were also used to inform policy development, education and outreach programs, resource allocation, and monitoring in the region (Arnold, 2004). Though numerous studies have identified the general population's knowledge and perceptions of marine issues, these studies have focused on populated regions with significant anthropogenic impacts. The PRIMNM differs from these

previous study regions because it is remote and relatively uninhabited; therefore, it is necessary to perform a new survey that solely focuses on the PRIMNM and on the general population's knowledge of federally managed MPAs across the Pacific Ocean.

Empirical evidence shows that is it essential to bridge the gap between public and expert understanding of marine issues to generate support for conservation efforts. Effective communication materials for selected target audiences will help advance science, conservation programs, and policies that protect marine life. More importantly, this study will help in the development of communication materials that will further advance PIRO's mission in the PRIMNM.

The objectives of this project component are two-fold: 1) determine knowledge, attitudes, and perceptions of the general public towards MPAs, ocean ecosystem threats, and marine conservation efforts and, 2) create communication materials targeted at previously identified awareness gaps.

METHODOLOGY

SURVEY DESIGN

Our 15-question survey was modeled after two previous surveys that uncovered the general public's knowledge, attitudes, and perceptions of marine ecosystems and conservation efforts. The first survey measured community attitudes and awareness toward the GBR and the other survey identified public attitudes towards marine issues in New Zealand (Young and Temperton, 2008; Arnold, 2004). Our survey differed in that questions were geared specifically to our study region in the Pacific Ocean. Our survey, titled *Understanding and Awareness of Large-Scale Federal Marine Conservation Efforts in the Pacific Ocean* (Appendix B), was composed of five distinct sections that allowed us to determine:

1. Relationship with the Ocean (Appendix B, Questions 2-4)
2. Marine Protected Areas (Appendix B, Questions 5-8).
3. Threats to Coral Reefs (Appendix B, Questions 9-10).
4. Ocean Footprint (Appendix B, Questions 11-12).
5. Media Preference (Appendix B, Question 13).

The survey was reviewed by UCSB's Office of Research Human Subjects Committee and deemed exempt (Survey ID 9-17-0017).

SURVEY DISTRIBUTION

The survey was distributed online because this channel has proven to be the fastest, most efficient method for survey distribution. Not only do online surveys minimize time and cost of survey distribution, they also have the potential to access unique populations that would be difficult to reach through other mediums (Wright, 2005). Our survey was distributed through

SurveyMonkey, a reputable online survey software with a membership base that consists of more than 30 million people (SurveyMonkey, 2017). SurveyMonkey was chosen because the software balances panelist populations with gender and age quotas that mimic census data. This ensures that respondents are diverse and representative of the target population. No additional quotas or restrictions were applied to this survey.

To take a survey, a volunteer must first complete a profile and provide basic demographic information, including age, gender, and income. Then they must click "Take a survey" on their dashboard. SurveyMonkey will automatically send volunteers a survey based on the survey's preset quotas and specifications. A survey is deemed complete when the respondent has answered all required questions and submitted the survey at the end (SurveyMonkey, 2017). For our survey, participants were required to answer every single question to move forward. The subject population of this study is any individual 18 years or older who lives in any territory or region in the United States. Participants must be a SurveyMonkey member and have a complete profile that discloses their age, gender, and region for balancing results. Respondents may be of any gender, income, or found in any location within the U.S.

DISTRIBUTION LIMITATIONS

There are several limitations associated with online survey distribution. First, the data collected is only representative of the online community. Sampling from a specific organization can also lead to self-selection biases where only certain individuals complete the survey. This hinders the ability to generalize the findings (Wright, 2005). These biases can be further propagated by SurveyMonkey's systematic design. The SurveyMonkey Contribute program automatically makes a $0.50 donation to the respondent's charity of choice listed on their profile for every survey they complete (SurveyMonkey, 2016). This may bias our findings because our sample size may overestimate individuals who have a tendency to support charitable causes, including marine conservation efforts. SurveyMonkey also gives the volunteer a chance to win a sweepstake price for every completed survey (SurveyMonkey, 2016). This may influence our results because it can encourage respondents to haphazardly click through surveys as quickly as possible to participate in more sweepstake games and increase their chances of winning.

SURVEY DATA ANALYSIS

Descriptive statistics were performed to understand the general response distribution. A chi-square goodness-of-fit was performed on questions where respondents were required to select a single answer. This test determined if significant differences existed between various demographics and responses. Chi-squared post-hoc tests were performed to determine which specific variables were statistically different. Survey questions for which respondents could select multiple responses were analyzed with a test analogous to Pearson's chi-square test for independence provided by the Multiple Response Categorical Variables (MRCV) package in R. This method accounts for the within-subject dependence among responses (Koziol and Bilder, 2014).

Only complete surveys were considered for this analysis. SurveyMonkey guaranteed a representative sample by using census demographics for age and gender as a quota for complete responses. Regional distribution also closely resembled census demographics (Figures 3.1). Income distribution, however, was overrepresented in this survey. 8% of the U.S. population reported an annual income of more than $100,000, though 24% of survey respondents fell above this income level (Figures 3.1c). An overrepresentation of affluent respondents may bias the results as these individuals may have higher education levels and access to information. Nonetheless, we disregarded income as parameter and assumed that our results were representative of the United States population in terms of age, gender, and region. Assuming this sample is representative of the U.S. population accounts for attrition and thus eliminating incomplete surveys will not affect the results. Furthermore, because gender and income will not influence the subsequent communication strategy and materials, these demographics were not analyzed.

It is important to correct for biases and to account for respondents who carelessly selected answers in order to prevent Type II errors in hypothesis testing. To correct the effect of careless responding, some survey answers were designed to contain "dummy variables," which were incorrect or false answers. The average number of responses for each dummy answer was subtracted from the real answers, and the dummy variables were eliminated from the analysis. In many cases this resulted in a negative number of respondents if the average of the number of "dummy" respondents was higher than the number of respondents selecting real options. In these cases, the negative number of respondents was corrected to zero.

SURVEY OUTCOME

We received 763 complete responses of the attempted 828. The 65 abandoned respondents equal an attrition rate of 18%, which SurveyMonkey deemed a normal rate of abandonment. The median time to complete the survey was 3 minutes and 44 seconds and ranged from a few seconds to over 30 minutes in some cases. While a larger sample size would reduce the margin of error, the error of our study was within an acceptable margin to make the conclusions we are interested in. The SurveyMonkey demographic distribution (Figure 3.1a-d) closely resembles U.S. Census data (U.S. Census Bureau, 2016) (Figure 3.2a-d).

A

Age

B

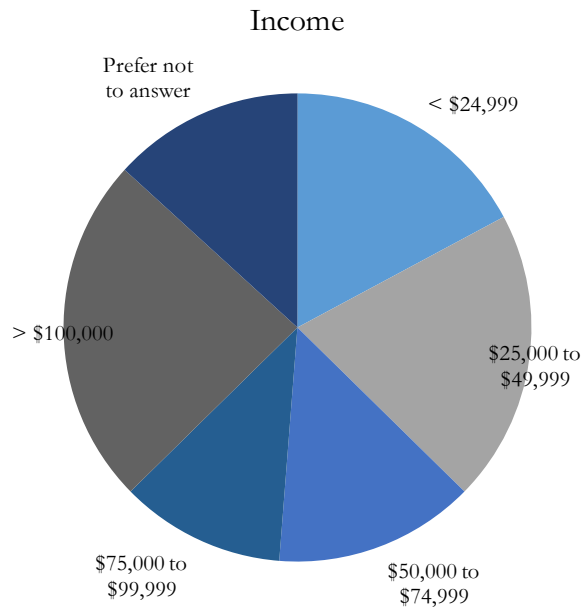### Gender

C

Income

D
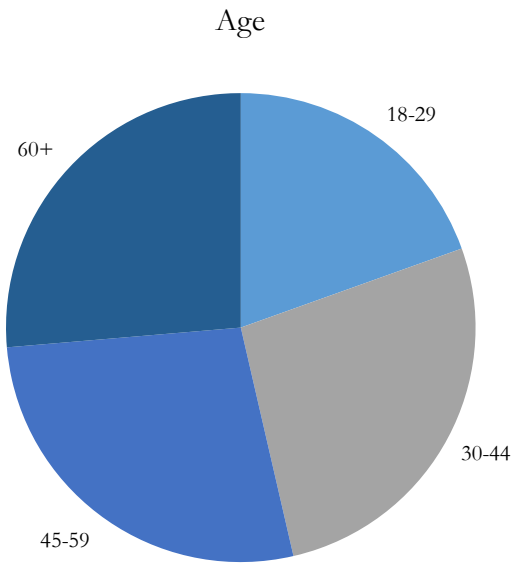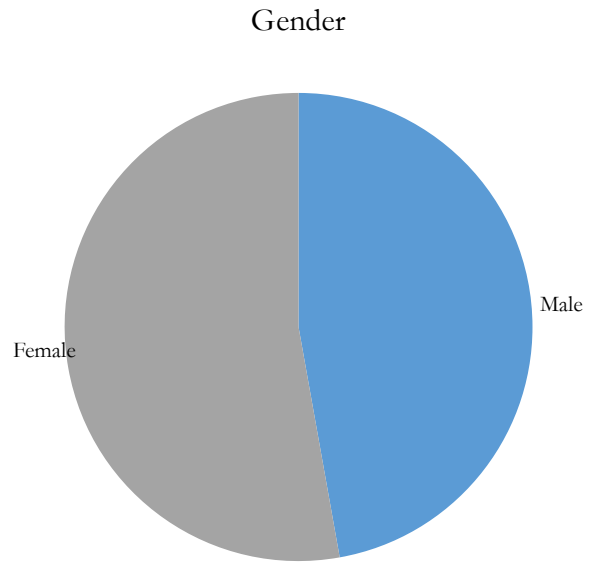
Region
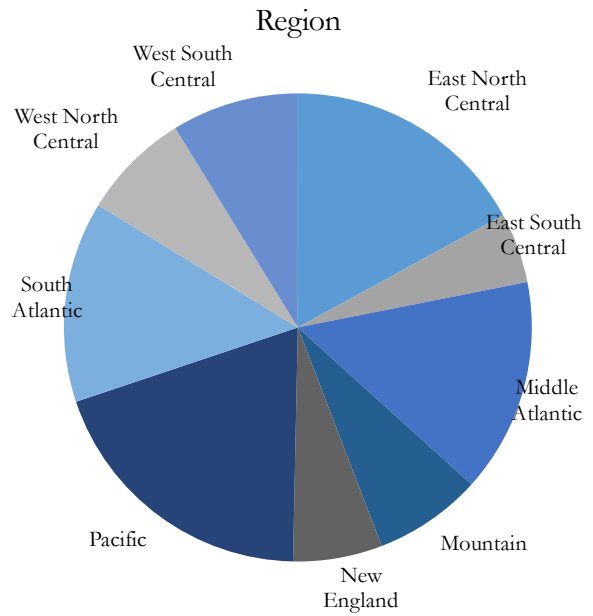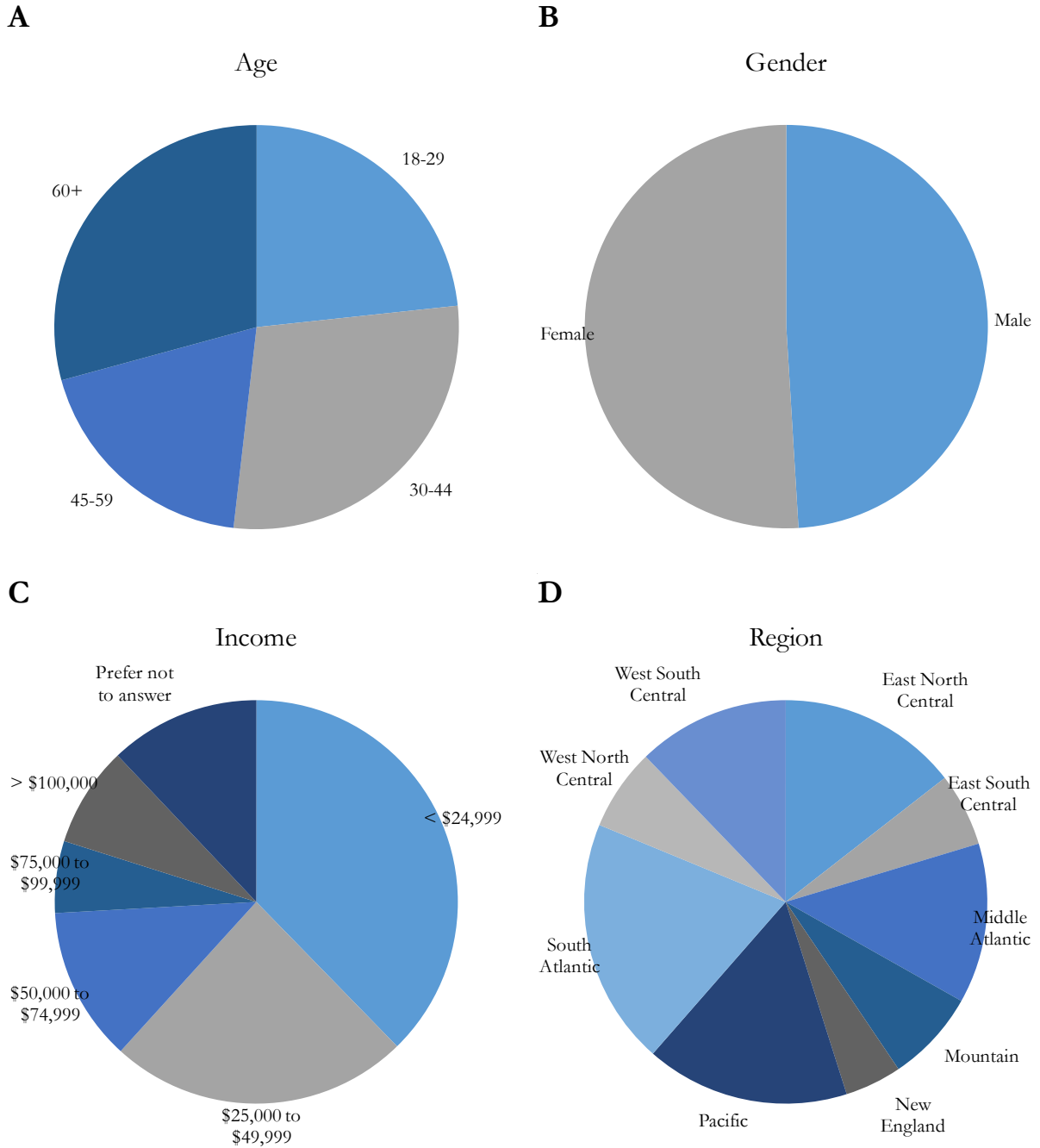

Figure 3.1 (a-d). SurveyMonkey respondent demographic breakdown of 763 respondents for: a) age, b) gender, c) income, and d) region.

A

Age

B

Gender

C

Income

D

Region

Figure 3.2 (a-d). United States population demographic breakdown for: a) age, b) gender, c) income, and d) region (U.S. Census Bureau, 2016).

RELATIONSHIP WITH THE OCEAN

WHAT OCEAN BENEFITS, IF ANY, DO YOU THINK ARE MOST IMPORTANT?

Panelists were allowed to select up to two ocean benefits they deemed to be the most important. The top three ocean benefits selected by all respondents were; aesthetic value (57%), recreation (46%), and food (41%). Livelihood, cultural, and no ocean benefits were all selected by less than 20% of all respondents (Figure 3.3). MRCV's test that is analogous to Pearson's chi-square test for association with a Bonferroni adjustment was performed to determine whether there were significant differences between selected ocean benefits and respondent demographics. Region did not significantly influence the respondents' responses. However, there was a significant association between age and the selected benefits ($p < 0.05$). Specifically, there was a significant association between 18-29 year olds and cultural value ($p < 0.01$). Younger respondents were more likely to select cultural value than any other age group.
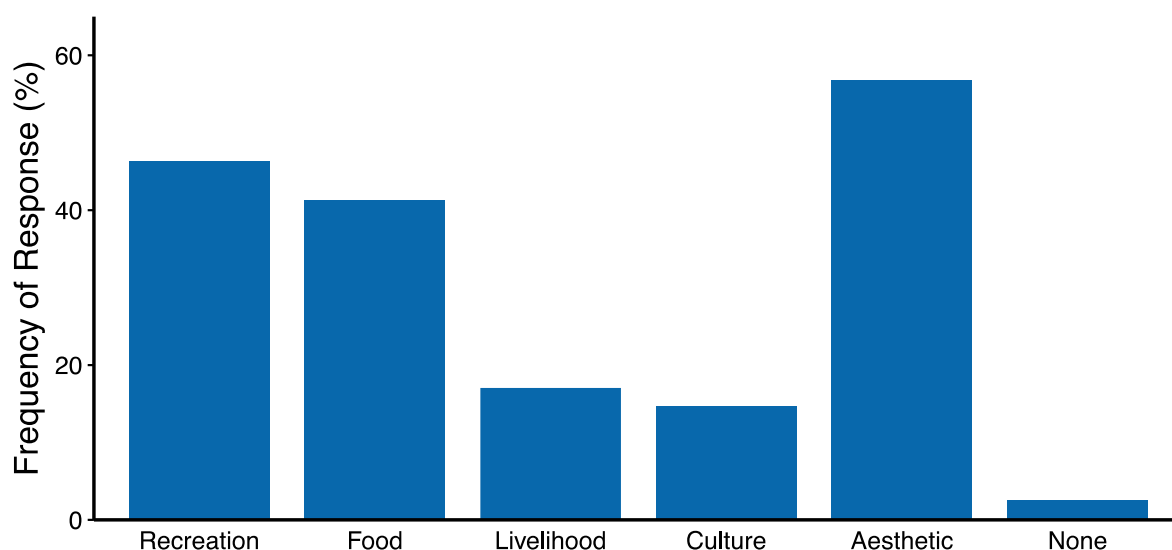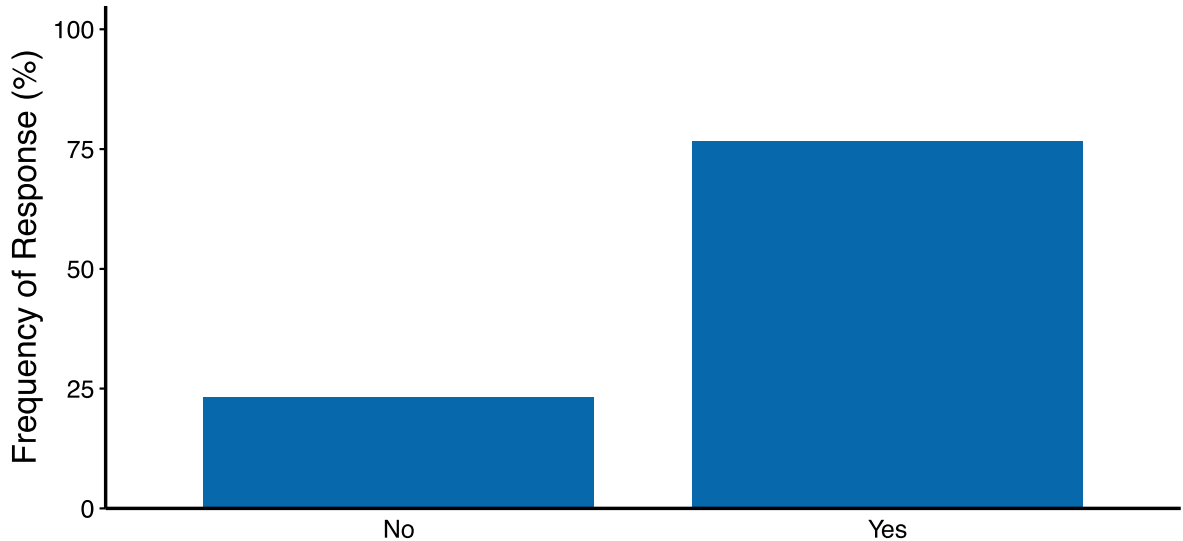

**Figure 3.3.** Distribution of perceived benefits obtained from the ocean (n = 763).

HAVE YOU HEARD OF A MARINE PROTECTED AREA?

Panelists were asked whether they had previously heard of an MPA. Overall, 23% of the respondents selected that they had not heard of an MPA (Figure 3.4).

Figure 3.4. Distribution of respondents who had heard of a Marine Protected Area (n = 763).

A chi-square goodness-of-fit was performed to determine whether there were significant differences in proportions of respondents who had heard of an MPA. There was no significant regional difference in responses. However, there was a significant difference between age and MPA familiarity ($X2 = 16.1$, df = 3, p-value < 0.001). A chi-square post hoc test determined significant differences between 18-29 and 60+ year olds (p < 0.001) and significant differences between 18-29 and 45-59 (p < 0.05). Young respondents were much less likely to have heard of an MPA, whereas 60+ year olds were much more likely to have heard of one. Only 65% of 18-29 year olds selected yes compared to 83% of 60+ year olds who reported yes (Figure 3.5).
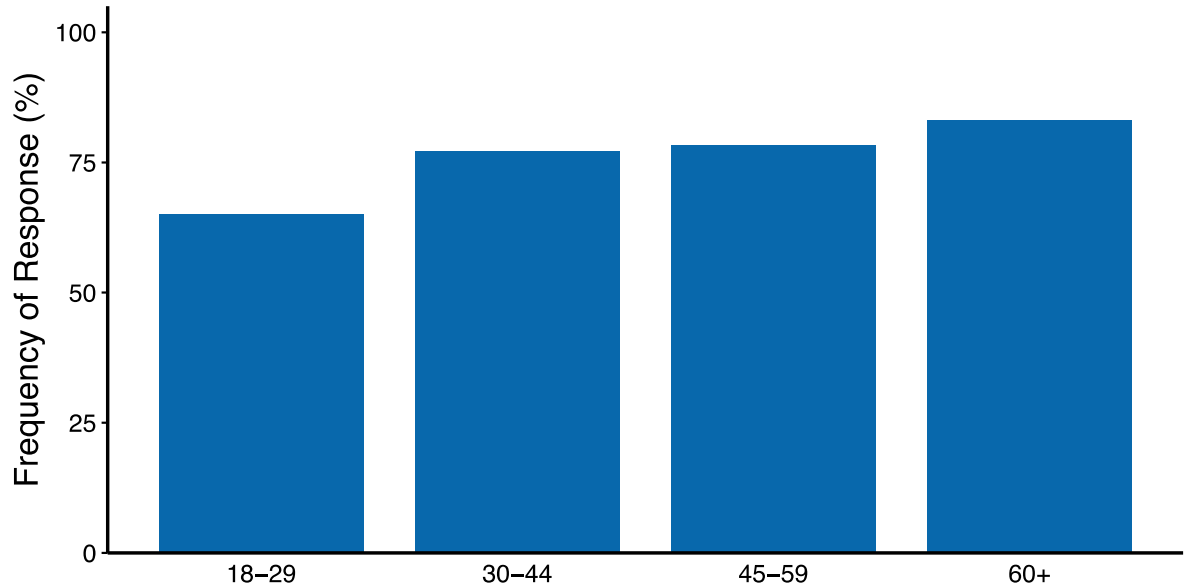
Figure 3.5. Distribution of respondents who had heard of a Marine Protected Area by age groups (n = 763).

HAVE YOU HEARD OF THESE FOLLOWING MARINE NATIONAL MONUMENTS LOCATED IN THE PACIFIC OCEAN?

Respondents were presented with a list of Marine National Monuments (MNM) located in the Pacific Ocean and were asked to select all of the monuments they recognized. These MNM included Papahānaumokuākea, Marianas Trench, PRIMNM, and Rose Atoll, as well as two fake monuments – Moorea and Coral Triangle. The analysis for this question was performed before adjusting for the dummy variables to identify the general public's unadjusted recognition of Marine National Monuments. MRCV's test that is analogous to Pearson's chi-square test for association determined that there are no significant associations between MNM recognition and respondent demographics for age and region. The results were then adjusted for biases by averaging and subtracting the fake variables from all correct responses to demonstrate the knowledge respondents have on MNM recognition. Adjusted results determined that 61% of all respondents have never heard of any of the listed MNM, regardless of age and region, and only 6% of respondents had heard of the PRIMNM (Figure 3.6).
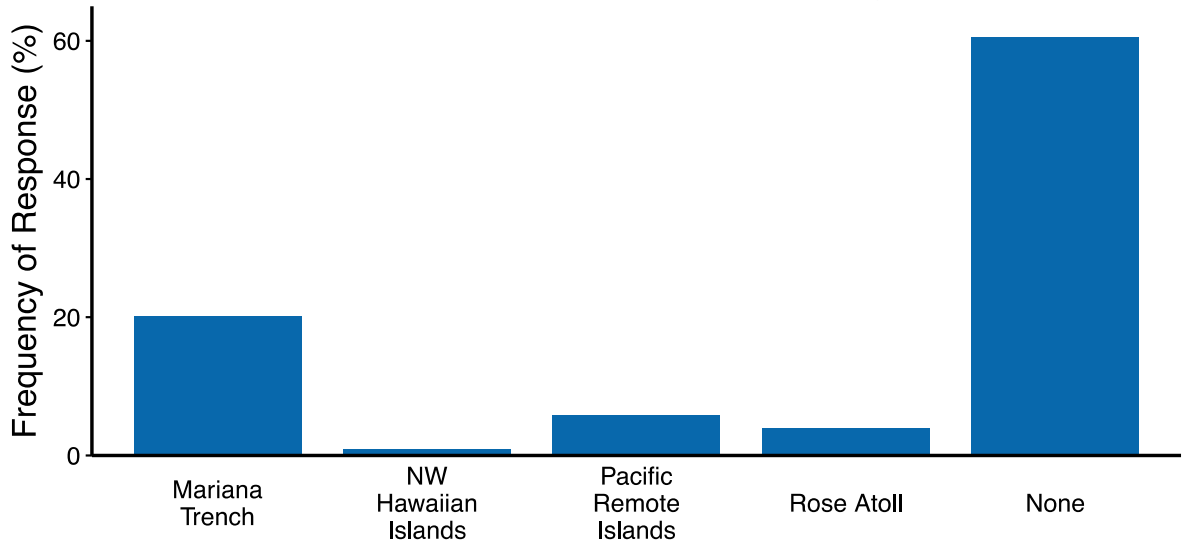
Figure 3.6. Distribution Marine National Monuments in the Pacific Ocean that respondents have heard of. Results were adjusted to account for incorrect answers (n = 713).

WHICH ACTIONS OR POLICIES WOULD YOU SUPPORT TO PROTECT CORAL REEF ECOSYSTEMS?

Panelists were asked to select the top three actions or policies they would support to protect coral reef ecosystems. Actions and policies such as developing MPAs, regulating coastal pollution, and supporting both research and education were chosen more frequently and selected by over 40% of respondents. Regulating fishing did not differ significantly from expected. "Encourage tourism," "Restrict all access," and "Protecting coral reefs is not a priority for me" were chosen by less than 20% of respondents and were significantly less likely to be chosen (Figure 3.7). MRCV's test analogous to Pearson's chi-square test for association was performed to determine if there was an association between respondent demographics and the policies or actions they support. However, neither region nor age were found to significantly influence respondent's selection of actions or policies to protect coral reef ecosystems.
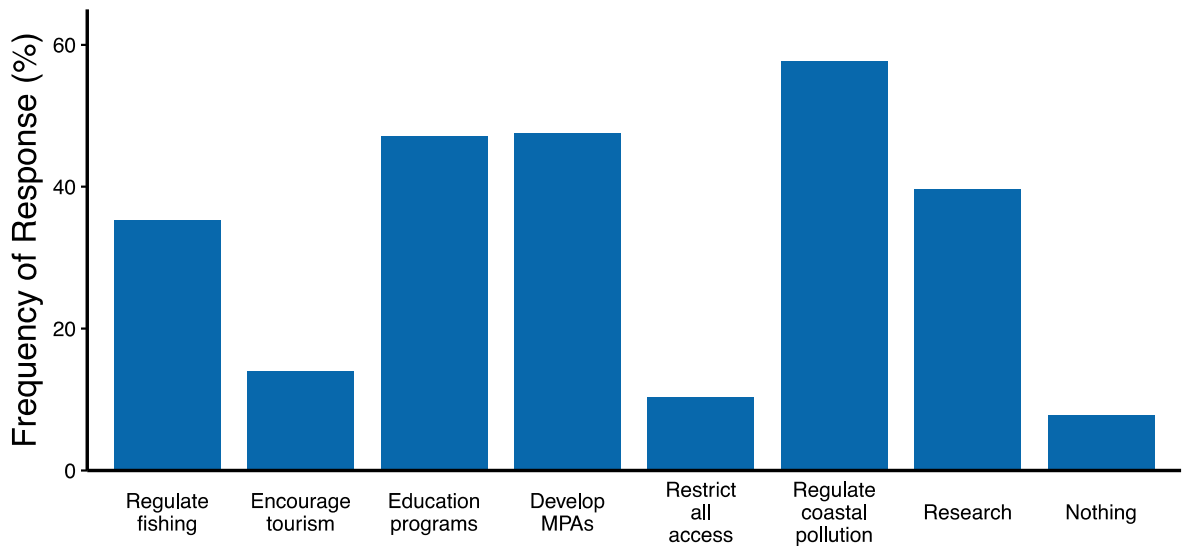
Figure 3.7. Distribution of actions and policies respondents would be more likely to support to protect coral reef ecosystems (n = 763).

WHICH OF THE FOLLOWING DO YOU CONSIDER TO BE BENEFITS OFFERED BY MARINE PROTECTED AREAS?

Respondents selected the top two ocean benefits they value most. "Protects habitat" and "Increases biodiversity" were selected more frequently than all the other answers. "Reduces marine debris" and "Prevents sea surface temperatures from increasing" were two false answers provided to gage the respondents' misconceptions of MPAs. 26% and 51% of respondents selected these two incorrect answers, respectively. The analysis for this question was performed before adjusting for these dummy variables to identify the respondents' beliefs of MPAs. MRCV's test comparable to Pearson's chi-square test for association determined that there was a significant association between 60+ year-old respondents and selecting "Prevents sea surface temperatures from increasing" as a benefit provided by MPAs. This age group was less likely to believe that sea surface temperature increases can be prevented by MPAs. There was no significant association between respondent region and MPA benefits. The results were then corrected using the incorrect answers to identify the respondents' knowledge of MPAs. Four of the seven answers were reduced to zero after correcting for these variables, leaving "Protects habitat" and "Increases biodiversity" with a selection rate of 72% and 27%, respectively (Figure 3.8).
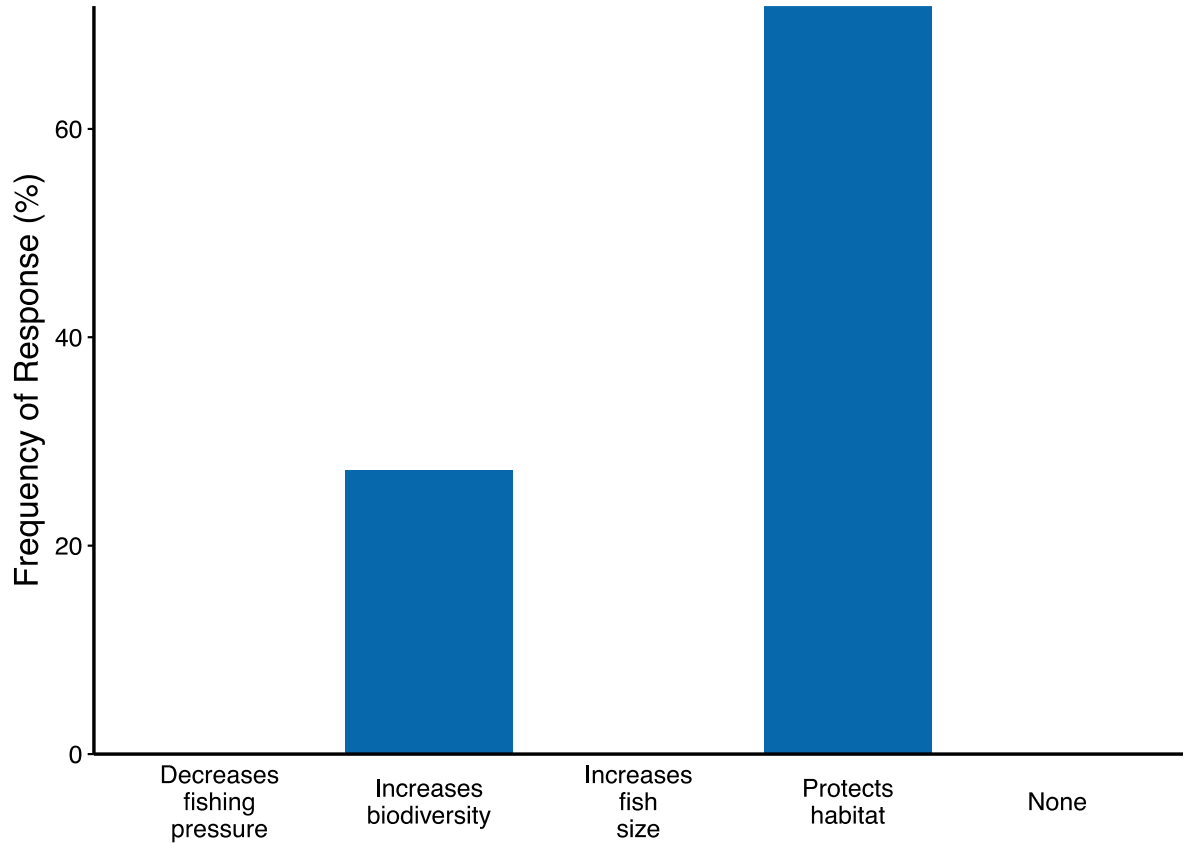
Figure 3.8. Distribution of perceived benefits provided by MPAs. Results were adjusted to account for incorrect answers (n = 471.5).

IN YOUR OPINION, THE HEALTH OF CORAL REEFS IN THE PACIFIC IS:

In order to understand the general public's knowledge of coral reef health in the Pacific Ocean, respondents were asked to rank the health of coral reefs. Of 763 respondents, 3% believe coral reef health in the Pacific Ocean is excellent, 11% believe that it the general health is good, 32% believe it is fair, and 22% believe it is poor. 31% of the respondents do not know the health of coral reefs (Figure 3.9). A chi-square test determined that there were no significant differences in responses and panel demographics.
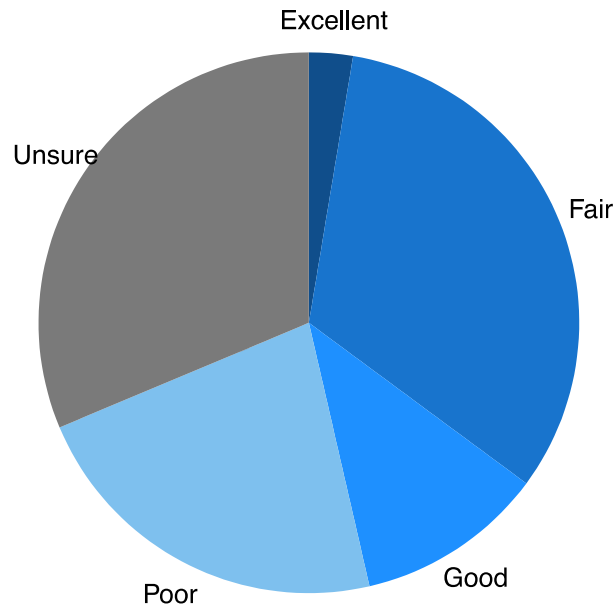
Figure 3.9. Distribution of perceived coral reef health in the Pacific Ocean (n = 763).

TO WHAT EXTENT DO YOU FEEL CLIMATE CHANGE POSES A THREAT TO CORAL REEFS?

Respondents were asked to select to what extent climate change threatens coral reefs since this is one of the most pressing threats at the PRIMNM. Of all individuals surveyed, 40% believed that climate change posed an extreme threat to coral reefs and 18% believed that it was a very large threat. 26% of respondents did not believe or were unsure if climate change posed a threat to coral reefs (Figure 3.10). A chi-squared goodness of fit determined that there were no associations between age and the extent to which respondents believe that climate change threatens reefs. Nonetheless, 83% of 18 – 29-year-old respondents believed that climate change is at least a moderate threat, with only 1% of respondents in the age group responding that it is not at all a threat. In contrast, the other age groups exhibited more variability in their responses. On average, more individuals in the older age groups believed that climate change is not at all a threat to coral reefs. A chi-squared test determined that there is a significant association between region and responses (X^2 = 57.3, df = 40, p < 0.05). Pacific and Middle Atlantic respondents were more likely to believe that climate change poses a very large or extreme threat to reefs, whereas West South Central respondents were less like to believe that. West South Central respondents were also more likely to believe that climate change poses a moderate threat, whereas Mountain respondents were less likely to believe that.
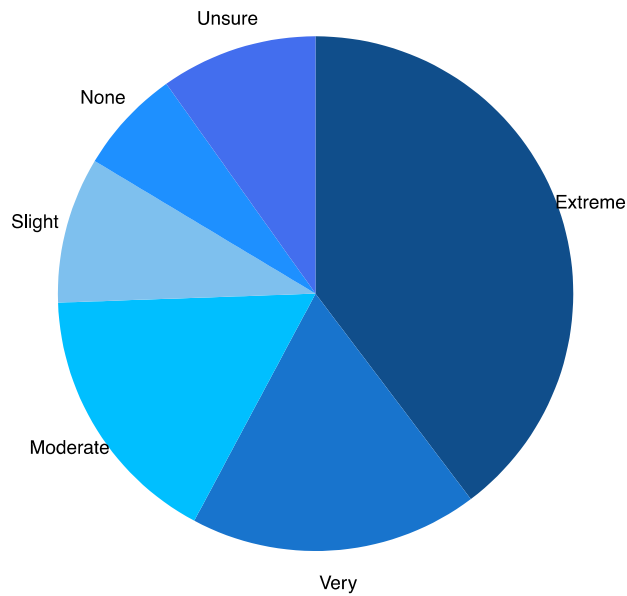
Figure 3.10. Distribution of the perceived threat that climate change poses to coral reefs (n = 763).

TO WHAT EXTENT DO YOU FEEL OVERFISHING POSES A THREAT TO CORAL REEFS?

Panelists were asked to what extent does overfishing pose a threat to coral reefs. Overall, 79% of respondents selected that overfishing was at least a moderate threat, with 33% responding that it is an extreme threat. Only 14% of respondents did not believe or were unsure that overfishing posed a threat to coral reefs (Figure 3.11). A chi-squared goodness of fit determined that there were no significant associations between either region or age and the extent to which overfishing is believed to pose a threat to reefs.
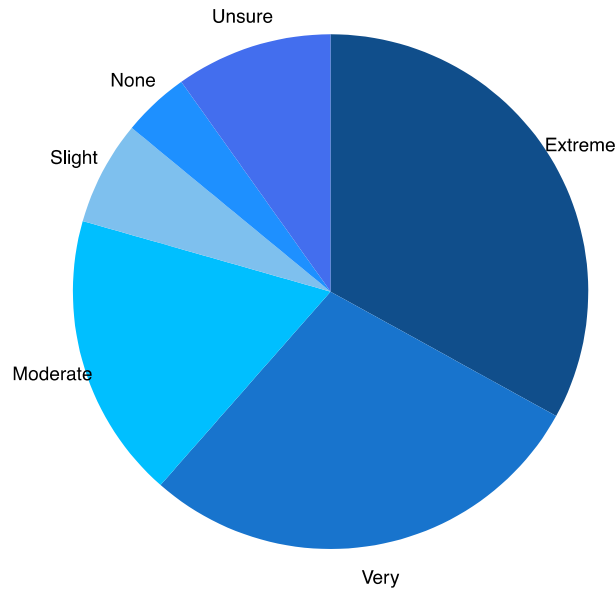
Figure 3.11. Distribution of the perceived threat that overfishing poses to coral reefs (n = 763).

TO WHAT EXTENT DO YOU FEEL MARINE DEBRIS POSE A THREAT TO CORAL REEFS?

Respondents were asked to what extent does marine debris pose a threat to coral reefs. An overwhelming number of individuals felt that marine debris posed a threat to coral reefs. 86% of respondents felt that it was at least a moderate threat to coral reefs, with a total of 46% of respondents indicating that they felt is an extreme threat. Only 2% of respondents felt that it was no threat at all and 9% of respondents were unsure (Figure 3.12). A chi-squared goodness of fit was performed to determine if there is an association between demographics and extent to which marine debris is believed to pose a threat to reefs. The test showed that there are no significant associations these demographics and marine debris perceptions.
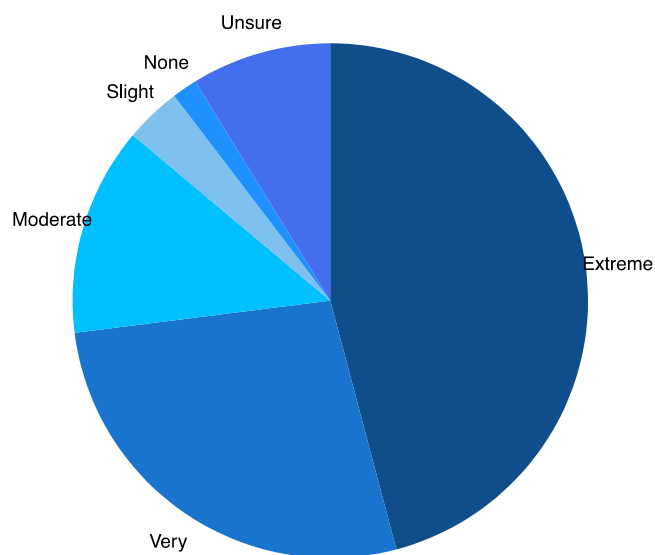
Figure 3.12. Distribution of the perceived threat that marine debris poses to coral reefs (n = 763).

OCEAN FOOTPRINT

HOW MUCH IMPACT DO YOU THINK YOU PERSONALLY HAVE ON THE OCEAN?

Respondents were asked to determine their perceived ocean footprint. 34% of respondents believed they had a high or moderate impact on coral reefs, whereas 59% of respondents believed that they had very little to no impact on reef ecosystems (Figure 3.13). A chi-squared test determined that the region in which respondents live did not affect how people responded to this question. Surprisingly, people who live in coastal regions were not more likely to indicate that they have a higher impact on the ocean. A chi-squared test determined that there is a significant association between age and the impact people perceive to have on the ocean ($X^2 = 39.4$, df = 12, p-value < 0.001). 18 – 29-year-olds were much more likely to believe they have a high impact on the ocean and less likely to believe that they do not have an impact on oceans. 30-44 year olds were more likely to believe they have a moderate impact on the ocean, and 45-59 year olds were less likely to respond that they have moderate impact and much more likely to believe that they have very little impact on the ocean. 60+ year old respondents, were much less likely to believe that they have a high impact on the ocean.
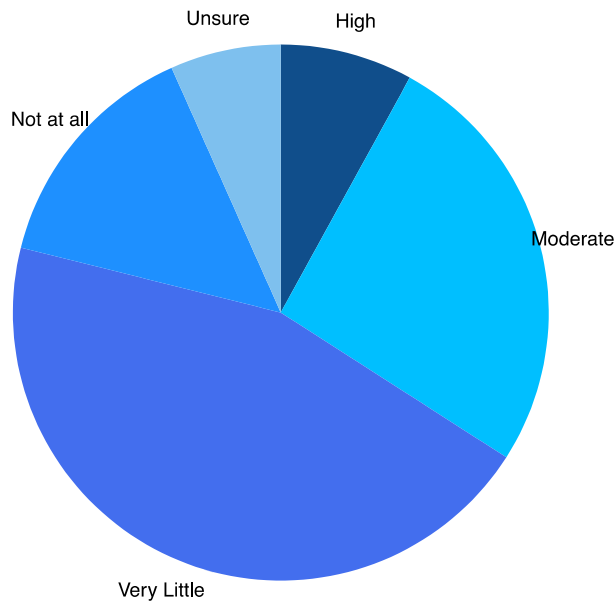
Figure 3.13. Distribution of the perceived impact respondents have on the ocean (n = 763).

WHICH ACTIONS DO YOU TAKE AT HOME FOR ENVIRONMENTAL REASONS?

Respondents were asked to select the top three sustainable actions they take at home. This question revealed that respondents do take actions at home for environmental reasons. The most popular actions that people take at home include using reusable bags and recycling. Many respondents indicated that they also take care in properly disposing of harmful chemicals (Figure 3.14). A test analogous to Pearson's chi-square test for association with a Bonferroni adjustment provided by MRCV package found a significant association between age demographics and activities performed at home (p < 0.0001). 18 – 29-year-olds were less likely to properly dispose of chemicals (p < 0.001) whereas 60+ year olds were more likely to dispose of chemicals (p < 0.001). 18-29 year olds were more likely to use alternative modes of transportation (p < 0.05) and less likely to take no action (p < 0.01). 11% of 18 – 29-year-old respondents indicating that they do not take personal action, or they were more willing to admit that they do not take actions at home for environmental reasons. There were no significant associations between respondent demographics and sustainable actions taken at home.
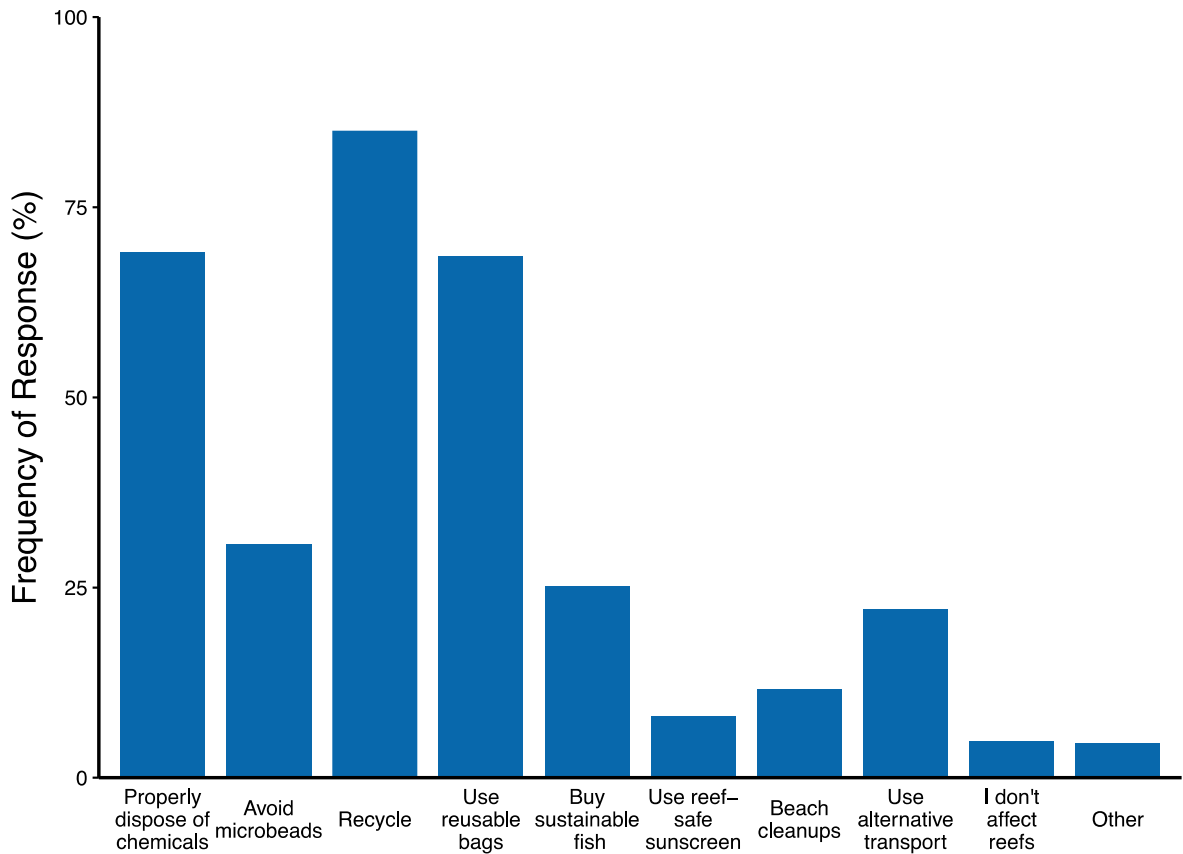
Figure 3.14. Distribution of sustainable actions respondents take at home for environmental reasons (n = 763).

MEDIA PREFERENCE

MARINE CONSERVATION INFORMATION IS OFTEN PUBLISHED IN VARIOUS WAYS. GIVEN THE FOLLOWING OPTIONS, WHICH WOULD YOU BE MOST RESPONSIVE TO?

In order to gauge media preference for dissemination of marine conservation information, survey respondents were asked to choose which communication medium they would be most responsive to, if any. Overall, respondents preferred video (26%), followed by written (22%), photos (22%), interactive map (14%), other (2%). The remaining 14% of respondents would not seek out media about marine conservation. A chi-squared test found no significant association between media preference and region. However, a chi-squared test determined that there is a significant association between age and media preference (X^2 = 43.8, df = 15, p-value < 0.0001). 18 – 29-year-olds were much more likely to prefer videos and significantly less likely to seek out written materials. In contrast, 60+ year olds were less likely to seek videos and much more likely to prefer written materials to learn about marine conservation. 30-44 year olds were more likely to select "other." When comparing within specific age groups, 18 – 29-year-olds and 45 – 59-year-olds both preferred videos (32% and 30% respectively), 30 – 44-year-olds preferred photos

(25%), and a written informational piece was favored by the 60+ year-old age bracket (34%). These results will be important to incorporate when determining specific mediums for communication materials (Figure 3.15).
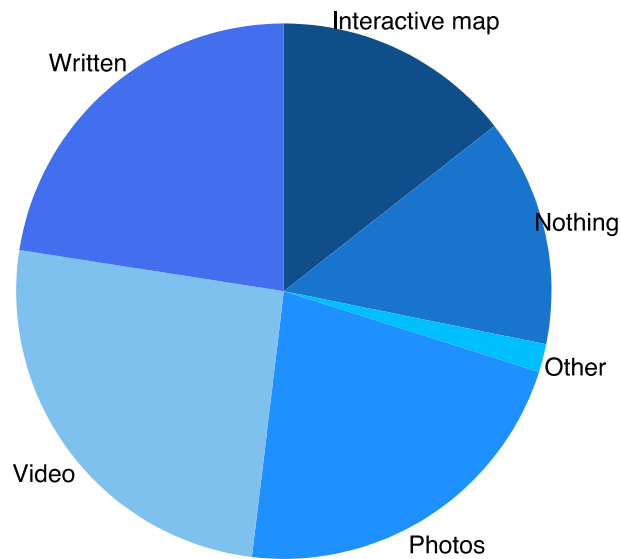
Figure 3.15. Distribution of media type preferred by respondents to receive marine conservation information (n = 763).

COMMUNICATION MATERIALS

The results of the survey helped determine the public's baseline understanding of marine protected areas, threats our ocean faces, and overall ocean health. Communication materials were created to target the awareness gaps identified through our survey analysis. We strive to educate the public on Marine National Monuments, benefits of marine protected areas, and the impact of human activities on ocean health through these communication materials. When combining the media preference along with key survey results, the goals and targets for each communication material were devised and the following communication materials were developed.

COMMUNICATION DELIVERABLE 1:
VIDEO OF GENERAL INTRODUCTION TO THE PRIMNM

Title: The Pacific Remote Islands Marine National Monument

Goal: To generate awareness of the existence of the PRIMNM and the uniqueness of its intact ecosystem

The first communication material we created focuses specifically on the PRIMNM. This piece targets the following awareness gap identified in the survey: only 6% of respondents have heard of the PRIMNM. Additionally, 57% of respondents selected aesthetics as the most important ocean benefit, and most respondents preferred a video to learn more about marine conservation. These elements were combined to produce a video that appeals to aesthetic values and introduces people to the PRIMNM.

The deliverable highlights why this Monument is so unique, accenting the biodiversity of the reefs through video footage of megafauna, fish, and benthic communities filmed within the PRIMNM, as well as wide reef film shots emphasizing how intact these coral reefs are. Since respondents will never be able to physically visit the PRIMNM, it is imperative for this communication material to drive home the uniqueness and importance of this remote area in the Pacific.

COMMUNICATION DELIVERABLE 2:
STORYMAP OF MARINE NATIONAL MONUMENTS IN THE PACIFIC OCEAN

Title: Exploring U.S. Pacific Marine National Monuments

Goal: To increase awareness of Marine National Monuments located in the Pacific Ocean

The second communication material focuses more broadly on all U.S. Marine National Monuments (MNM) in the Pacific Ocean, which include the Marianas Trench MNM, Pacific Remote Islands MNM, Papahānaumokuākea MNM, and Rose Atoll MNM. This piece targets the following awareness gap identified in the survey: 61% of respondents have never heard of a MNM. This was a unique survey finding given the fact that 76% of respondents have heard of a marine protected area. Since Marine National Monuments are a type of marine protected area, there is an obvious disconnect in the public's awareness of the connection between the two.

This deliverable is in the form of a StoryMap, which provides an interactive way to explore these Monuments. The StoryMap highlights various characteristics of each MNM, which include:

- Designation year and Executive Order number
- Location and boundaries
- Facts highlighting the uniqueness of each Monument

- Photos of coral reef ecosystems within each Monument

Through the creation of this material, we hope to better inform the public of the existence of Marine National Monuments across the Pacific.

COMMUNICATION DELIVERABLE 3:
WRITTEN PIECE ADDRESSING HUMAN IMPACTS ON OCEANS

Title: From Home to Habitat: What We Can Do at Home to Protect Coral Reefs

Goal: To provide the link between common household activities and how they affect the ocean

The third communication material focuses on linking local household activities to broader ocean threats. This piece targets the following awareness gaps: 59% of respondents believe they have very little (45%) to no (14%) personal impact on the ocean, and the impact respondents believe they have on the ocean decreases with age (24% of 18-29 year olds, 15% of 30-44 year olds, 13% of 45-59 year olds, and 9% of 60+ year olds believe they have moderate to high impact). Additionally, when looking at media preference for marine conservation information, respondents 60 years of age or older prefer a written piece (34% written, 19% video, 18% photos). These elements were combined to create a written communication piece that addresses the impact people can have on the ocean, as well as tips to decrease human impact by making simple changes to common household activities.

This written deliverable is in infographic format that is available for print or online viewing. The poster highlights how people impact the ocean through everyday activity and provides recommended tips for how individuals can lessen their ocean impact. Through our survey, many respondents mentioned that they already recycle, properly dispose of chemicals, and use reusable bags as ways of protecting the environment. While still including these activities on our infographic, we primarily focus on other changes they can make to protect the ocean that are not as well known.

COMMUNICATION MATERIAL 4:
VIDEO OF THREATS TO CORAL REEFS

Title: Reefs in Peril: A Changing Climate for Coral Reefs

Goal: To increase awareness of threats to coral reefs, with an emphasis on the global threat of climate change

The fourth communication material focuses on threats most detrimental to coral reefs, emphasizing climate change's global threat to our oceans. Respondents identified that marine debris, climate change, and overfishing pose an extreme threat to coral reefs on a gradient of not at all to extremely (46%, 40%, 33% respectively). Although this number is relatively high, 25%

of respondents believe climate change poses little (9.2%) to no (6.6%) threat to coral reefs, or are unsure (9.7%) if climate change is a threat.

This deliverable is in the form of a video that makes the threats to our oceans more visible. Some threats, such as climate change, remain a relatively invisible threat on the reef, as it is difficult to physically visualize rising sea temperatures or decreasing pH levels in the ocean. This video will help make these invisible threats visible by first explaining why they are threats to the ocean, and follow with examples of how these threats have affected coral reef ecosystems. Footage will include bleached corals and algal dominated reefs, marine organisms entangled in marine debris, historic and recent photos of fish size, and detrimental fishing practices. The piece will end with a glimmer of hope and show how the PRIMNM can be resilient to these threats.

COMMUNICATION MATERIAL 5:
STORYMAP OF MPA BENEFITS AND SUCCESS STORIES

Title: Marine Protected Area Success Stories

Goal: To educate the public on the benefits of MPAs

The fifth communication material focuses on the benefits of MPAs to ocean ecosystems. Benefits of MPAs include;

- Maintaining biodiversity
- Protecting critical habitats from destructive human activities and allowing them to recover
- Increasing fish size by allowing them to reproduce, spawn and grow in the absence of fishing pressure
- Providing a spillover effect, or an increase in fish catch, in surrounding waters
- Building resilience to protect against local and global threats, such as climate change (World Wildlife Fund, 2017)

When respondents were asked what they consider to be benefits offered by MPAs, the top two answers selected were increases biodiversity and protects habitat. Increases fish size was selected the least out of all benefit options, but this is often viewed as one of the major benefits of MPAs. From these responses, it is indicative that benefits of MPAs are not fully understood. Along with addressing the specific benefits of MPAs, the StoryMap features MPA success stories from across the globe which include:

- *Cabo Pulmo National Park* in Baja California
- *Apo Island Marine Reserve* in the Philippines
- *Portofino Marine Park* in Italy
- *Dry Tortugas Ecological Reserve* in the United States
- *Hol Chan Marine Reserve* in Belize

- *Andavadoaka Marine Protected Area* in Madagascar

By sharing these success stories we hope to emphasize how effective and essential marine protected areas can be worldwide, and why now, more than ever, it is important to protect vital ocean ecosystems.

To view these communication deliverables, please visit the Media page of our project website.

NEXT STEPS

PRE- AND POST-TESTING FOR COMMUNICATION MATERIAL EFFICACY

Once communication materials have been developed, a major question remains: are these materials effective in achieving the goals of each communication deliverable? One valuable way to test the effectiveness of our deliverables is by pre- and post-testing. A pre- and post-test allows for the measurement of knowledge before and after a learning session albeit a lecture, communication material, or a demonstration. For our project, we would design a series of pre-test questions tailored to each communication piece, show respondents the specific communication piece we wanted to test, and then ask the same questions in the post-test to determine if the respondents gained any awareness or understanding from that same piece. From the results of this, we would be able to determine which deliverables, if any, are effective in communicating their goals. Unfortunately, due to the time constraint and budget of our project, the completion of this product is not achievable at this time.

CONCLUSION

Our survey has revealed that the American public is largely unaware of their role as a stakeholder in federal marine conservation in the Pacific. While most people will not have the opportunity to go to these places, they arguably play an important role in their future protection. It is important to not only connect the people to the place, but also help the general public understand that their cumulative actions at home can help protect coral reef ecosystems such as those found in the PRIMNM. While survey takers were relatively unaware of the role that MPAs and Marine National Monuments play in ocean conservation, they were generally aware of the threats facing the ocean (e.g. overfishing, climate change, and marine debris).

From the awareness gaps identified through our survey, we sought to create effective, clear, and informative communication materials for public use. Our materials aim to increase public awareness of marine protected areas, the benefits they provide, the threats coral reefs are facing, and what people can do at home to help; this is important for garnering stakeholder support for marine conservation efforts. By advancing public education and support for marine conservation, we hope to bridge the gap between the public, managers, and scientific communities.

PROJECT CONCLUSIONS

RECOMMENDATIONS

While talking with the resource managers at PIRO, we found that the scientific monitoring that takes place on PRAMP cruises did not always fulfill the needs of management. For example, managers often asked questions about the presence of marine debris, endangered species, and invasive species; however, these were parameters that were not necessarily monitored for on cruises. We therefore recommend a realignment of future monitoring so that the goals of both science and management are met. Monitoring on these islands should not only encompass the broad ecological characteristics (which monitoring currently includes), but also potential threats than can more easily be managed for, such as invasive species, endangered species, and marine debris. As an additional recommendation, we suggest that survey methods remain unchanged (or calibration years are present to determine the difference in monitoring methods), as analyzing trends through time was difficult due to the various changes in survey methods.

CONCLUSION

REVIEW OF PROJECT

Our project was driven by NOAA's mission to provide high-quality scientific information about the status and trends of coral reef ecosystems of the Pacific to the resource managers, policymakers, and public. Evidence shows that agencies must foster effective communication between all stakeholders in order to successfully manage large-scale marine protected areas such as the PRIMNM. However, this project identified significant communication deficiencies between scientists, managers, and the public. To ensure the continued success of the PRIMNM, our work sought to bridge the prevailing gap between CREP scientists and PIRO managers as well as between NOAA and general public

The first gap we identified was between NOAA scientists and managers. While long-term datasets exist for the PRIMNM, they have yet to be synthesized in an easily understood manner for the management team. In order to bridge this gap, we created the first ever ecosystem health overview report for the PRIMNM. To achieve this, a synthesis of sixteen years of ecological and climatological monitoring data was performed to identify long term trends of ecosystem health and status within the PRIMNM. Key findings include:

- PRIMNM ecosystem is largely intact and relatively healthy due to their remote location and relative absence of human presence
- Average coral cover is highest in the PRIMNM compared to all other NOAA monitored regions in the Pacific
- Average fish biomass at the PRIMNM is approximately three times higher than populated regions NOAA monitors within the Pacific

- Benthic and fish communities are in good to excellent condition, but climate conditions are in poor to fair condition based on the multi-metric Reef Condition Index
- Climate change and recurring high temperature stress events such as ENSO are the most significant threats the islands face

These ecosystem health findings are included in the PRIMNM overview booklet, which will serve as the foundation for the creation of the Monument Management Plan.

The second gap we identified exists between NOAA and the general public. Overall, there is a lack of a strategic communication materials that generate awareness and support for Marine National Monuments such as the PRIMNM. To fill this gap and identify awareness gaps, the *Understanding and Awareness of Large-Scale Federal Marine Conservation Efforts in the Pacific Ocean* survey was distributed across the United States. Key findings include:

- American public is largely unaware of Marine National Monuments in the Pacific, especially the PRIMNM
- Public is largely uninformed of the benefits that MPAs provide
- Large portion of public does not know the health status of coral reefs in the Pacific
- Majority of the population believes they have little to no impact on ocean health
- Aesthetic value is the most important ocean benefit, followed by recreation and food
- Large portion of the public do not believe or are unsure of the extent that climate change poses a threat to coral reefs

These survey results were used to inform strategic communication methods that consists of five outreach materials that each target a different awareness gap.

With the development of communication and outreach materials, we have initiated better communication that bridges the gap between scientists, managers, and the general public. Our overview booklet will help managers develop a monument management plan, and the five outreach materials will increase awareness of the PRIMNM, the threats it faces, and what we can do at home to lessen our impact. Through our project, it has become clear that effective communication of marine ecosystem health to all stakeholders is essential for the continued support for the PRIMNM and other critical marine habitats around the world.

RELEVANCE BEYOND THE PRIMNM

All the methods and tactics used in this project to communicate the health of the PRIMNM are transferable to other marine protected areas around the world. Effective communication of information between all stakeholders is indispensable for establishing successful conservation and management programs. Easily disseminated scientific data is imperative for the management of marine protected areas, and using this data to inform outreach materials that relay the importance of these ecosystems to the general public will garner support for marine conservation efforts. Now more than ever, marine ecosystems need our help,

and effective communication can be used to support these large-scale marine conservation efforts worldwide.

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APPENDIX A: OVERVIEW REPORT

CORAL REEF ECOSYSTEMS

of the Pacific Remote Islands Marine National Monument:
a 2000-2016 Overview

DRAFT

Front cover: Giant clams at Kingman Reef, Photo: NOAA Fisheries.

Back cover: Grey reef sharks (Carcharhinus amblyrhynchos) and barracudas at Jarvis Island, Photo: NOAA Fisheries/James Morioka.

TABLE OF CONTENTS

This booklet provides an overview of key findings about spatial patterns and temporal trends of the coral reef ecosystems observed during NOAA's Pacific Reef Assessment and Monitoring Program (Pacific RAMP) research surveys conducted in the U.S. Pacific Remote Islands Marine National Monument from 2000 to 2016 by the Coral Reef Ecosystem Program (CREP) of the NOAA Pacific Islands Fisheries Science Center (PIFSC) with financial support from NOAA's Coral Reef Conservation Program. All data sets used in this booklet are documented at NOAA InPort Metadata catalog at https://inport.nmfs.noaa.gov/inport/hierarchy/select/36446 and will soon be archived at the NOAA National Centers for Environmental Information (NCEI). For more in-depth information, consult the scientific papers referenced throughout this booklet.

HISTORY OF CORAL REEF ECOSYSTEM MONITORING BY CREP

National coral reef conservation efforts in the United States were advanced in 1998, with the issuance of Executive Order #13089 by President Clinton to "preserve and protect the biodiversity, health, heritage, and social and economic value of U.S. coral reef ecosystems and the marine environment." This executive order established the U.S. Coral Reef Task Force (USCRTF) and emphasized the need to undertake a comprehensive approach to research, map, and monitor all U.S. coral reef ecosystems. In 2000, the USCRTF developed the National Action Plan to Conserve Coral Reefs (USCRTF 2000), and the Coral Reef Conservation Act of 2000 laid out a national framework to address the degradation of U.S. coral reef ecosystems and other coral reef conservation issues (16 U.S. Code §6401[2000]). The Coral Reef Conservation Act also led to the creation of the national Coral Reef Conservation Program under the direction of the Secretary of Commerce. This legislation requires NOAA to conduct scientific research, mitigation, and outreach activities that directly contribute to the conservation of coral reef ecosystems. In response to mandates and with the support of NOAA's Coral Reef Conservation Program, the NOAA Pacific Islands Fisheries Science Center initiated the Pacific Reef Assessment and Monitoring Program (Pacific RAMP) in early 2000, and established the Coral Reef Ecosystem Program (CREP) in 2001. In 2002, NOAA, in cooperation with the USCRTF, released A National Coral Reef Action Strategy to address and reduce threats to coral reefs worldwide.

A primary mission of CREP is to provide high-quality, scientific information about the status and trends of coral reef ecosystems of the U.S. and U.S.-affiliated Pacific Islands to the public, resource managers, policymakers, and scientists to support ecosystem-based management and conservation of coral reefs on local, regional, national, and international levels.

Opposite page: Threadfin-butterflyfish (Chaetodon-auriga) at Kingman Reef, Photo: NOAA Fisheries/Kevin Lino.
Left: Red pencil urchins among the corals at Kingman Reef, Photo: NOAA Fisheries.

To fulfill this mission, CREP conducts a comprehensive suite of interdisciplinary monitoring and research activities, including habitat mapping, oceanographic and climate studies, and long-term monitoring of multiple components of coral reef ecosystems in the U.S. Pacific islands (Fig. 1). CREP has conducted biennial Pacific RAMP surveys from 2000 to 2012, and triennial surveys from 2012–2016, in each of the U.S. Pacific and U.S. affiliated management jurisdictions. Using consistent survey methodologies across over 40 Pacific island, atoll, and shallow-bank ecosystems enables comparative analyses across diverse gradients of biogeography, environmental conditions, and human uses. Accurate and up-to-date characterizations of coral reef ecosystems are necessary to inform ecosystem-based management and evaluate the effectiveness of management actions for sustainable use and long-term conservation. Pacific RAMP survey results are also used to improve our understanding of ecosystem processes and the cause-and-effect mechanisms that influence the status and resilience of coral reefs.

The initial exploratory surveys of the Pacific RAMP in 2000–2003 provided the first-ever baseline characterizations of the biodiversity, abundance, and distributions of coral reef habitats and associated resources across the U.S. Pacific Islands region. Those early surveys and the inherent logistical and budgetary constraints posed by the vast and remote U.S. Pacific Islands region have shaped many aspects of the long-term Pacific RAMP. By collecting biennial and triennial reef ecosystem 'snapshot' surveys during ship-based research expeditions, the Pacific RAMP was designed to observe the status and detect long-term changes in reef ecosystem conditions over periods of many years to several decades. They provide an improved understanding of island- and region-scale conditions that serve as background context to support more frequent and finer-scale local monitoring in populated island communities and jurisdictions designed to evaluate effectiveness of local management actions.
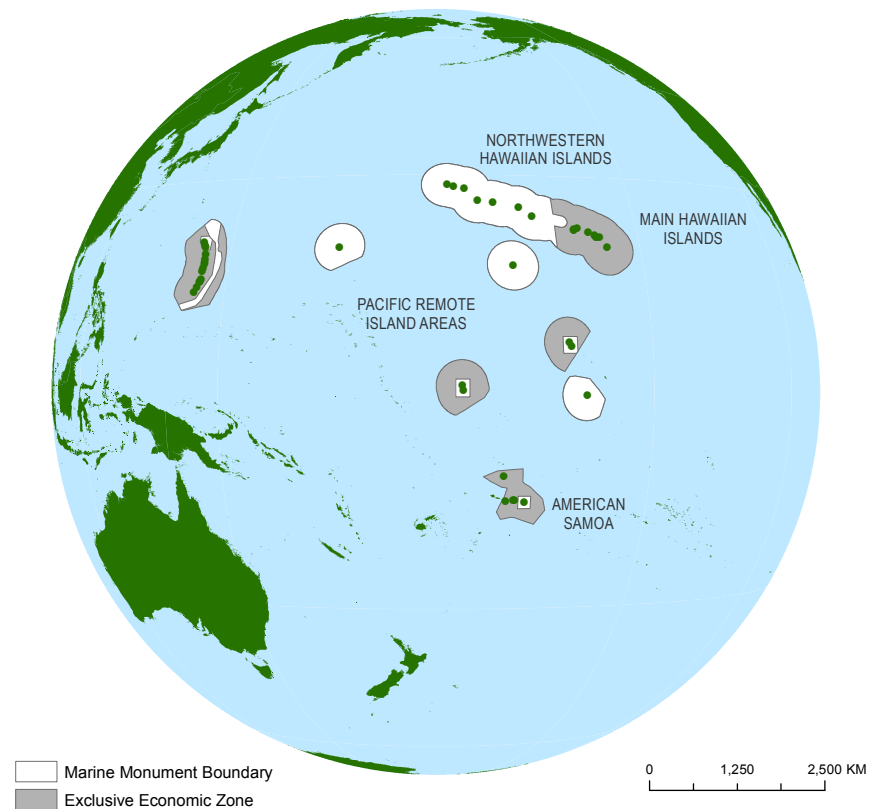
Figure 1. CREP monitors the status and trends of coral reef ecosystems of ~40 islands, atolls, and shallow banks spanning the waters of American Samoa, the Hawaiian Archipelago, the Mariana Archipelago, and the Pacific Remote Island Areas. Gray areas represent the U.S. Exclusive Economic Zones and the white areas represent the four large Marine National Monuments in the Pacific including the Pacific Remote Islands Marine National Monument, Papahānaumokuākea Marine National Monument, Marianas Trench Marine National Monument, and Rose Atoll Marine National Monument.

Over the past few decades, there has been a steadily increasing shift toward ecosystem-based management (EBM) in the United States and globally. EBM requires efforts to monitor holistic ecosystem indicators, which include information on the status and trends of species, habitats, and environmental conditions in the biophysical and human systems. The goal of these ecosystem-based monitoring programs is to balance ecological scales with management scales so that monitoring meets the needs of management decision making processes. In 2010, NOAA's Coral Reef Conservation Program unified NOAA's monitoring efforts by establishing the National Coral Reef Monitoring Program (NCRMP) which collects data across biological, climatic, and socio-economic domains. For the U.S. Pacific Islands, NCRMP augmented the ongoing Pacific RAMP surveys with long-term socio-economic surveys aimed at better establishing linkages between the ecological status of coral reefs and the human uses and benefits of coral reef ecosystems. Over the past 16 years, NOAA's Pacific RAMP and NCRMP have been able to continually adapt to evolving management needs and changing political environments without detracting from the overarching goal of long-term coral reef ecosystem status and trends monitoring (Heenan et al., 2016).

As is typical for any long-term monitoring effort, CREP survey protocols have been refined over time to match the priority information needs for management given the resources available for monitoring. For example, ecological survey methods were refined to reduce observer variability and expand the suite of monitored indicators to assess impacts of ocean acidification. To date, CREP has conducted 38 Pacific RAMP survey cruises, including nine to the Pacific Remote Islands Marine National Monument. Information on individual cruises can be found in the cruise reports for these expeditions at www.pifsc.noaa.gov/library/cruise.php. An extensive monitoring report compiling the results of the past Pacific RAMP cruises (2000–2015) is currently in production and will be published in 2018.

THE PACIFIC REMOTE ISLANDS
MARINE NATIONAL MONUMENT

The U.S. Pacific Remote Islands encompass seven islands and atolls scattered across the Central Pacific, spanning natural gradients in oceanographic conditions. The islands and reefs can be divided into three groups based on ecological characteristics: (1) the equatorial upwelling islands, Baker, Howland, and Jarvis Islands; (2) the central transition islands, Kingman Reef and Palmyra Atoll; and (3) the northernmost oligotrophic islands, Wake and Johnston Atolls (Fig. 2). The equatorial islands are especially productive as they benefit from the combined effects of regional equatorial upwelling and localized topographic upwelling of the subsurface Equatorial Undercurrent that collectively bring cool, nutrient-rich waters to the sunlit surface where photosynthesis thrives. In contrast, the northernmost islands are situated in the nutrient-poor waters of the central gyre characterized by low biological productivity. The central transition islands, located at the northern edge of the enhanced productivity region, experience a moderate level of biological productivity (Miller et al., 2008).

To protect and preserve the diversity and abundance of ocean life in these waters, all seven islands and atolls were established as the Pacific Remote Islands Marine National Monument (PRIMNM) by Presidential Proclamation #8336 in January 2009. To further care for and manage historic and scientific objects, such as the pelagic ecosystem, deep sea corals, and seamounts, the Monument protection was expanded around Jarvis, Johnston, and Wake Islands by Presidential Proclamation #9173 in 2014. The Monument area is approximately 370,000 square nautical miles (1,269,065 square kilometers [km^2]).
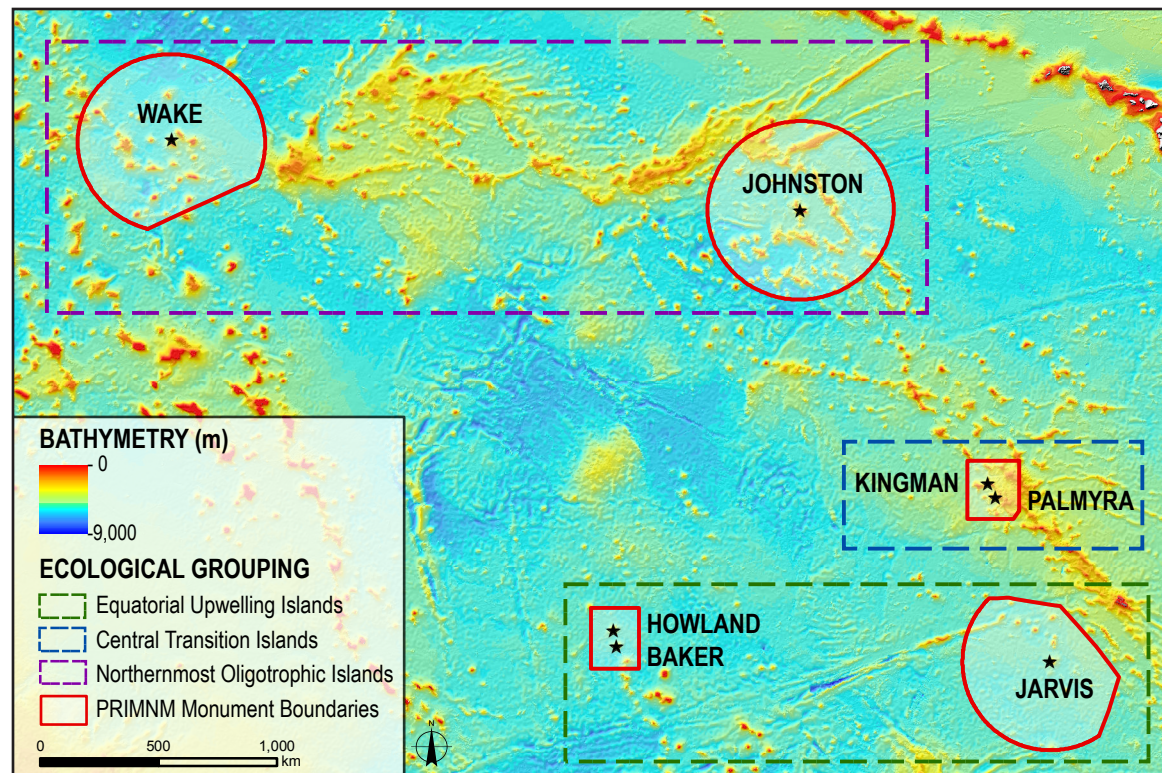
Opposite page: Grey reef sharks (Carcharhinus amblyrhynchos) and schools of anthias at Jarvis Island, Photo: NOAA Fisheries/Kelvin Gorospe,

Figure 2. Pacific Remote Islands Marine National Monument boundaries and bathymetry (Becker 2009, Smith and Sandwell 1997) © 2008 The Regents of the University of California.

ISLAND	BAKER	HOWLAND	JARVIS	KINGMAN	PALMYRA	JOHNSTON	WAKE
Relative Shape and Size 30 m Contour							
Land Area (km²)	2	2	4	0	2	3	7
Seafloor Area 0-30 m (km²)	4	3	4	48	53	194	19
Reef Area 0-30 m (km²)	4	2	4	37	42	94	13
Seafloor Area 30-150 m (km²)	2	2	3	37	9	49	3
Monument Area (km²)	51,658		315,085	53,503		442,447	407,785
Population	0	0	0	0	4-20	4-5	94
Age (Million Yrs)	~124	~125	~111	~112	~112	~171	>160
Ecological Grouping	Equatorial Upwelling Island	Equatorial Upwelling Island	Equatorial Upwelling Island	Central Transition Island	Central Transition Island	Northernmost Oligotrophic Island	Northernmost Oligotrophic Island
Island Chain	Phoenix Islands	Phoenix Islands	Line Islands	Line Islands	Line Islands	Line Islands	Marshall Islands

Table 1. Summary table of island characteristics across the PRIMNM. Blue area represents the 30 m depth contour around the islands. Colors indicate land area. All areas calculated using geographic information systems techniques. Monument areas were calculated by NOAA's Pacific Island Regional Office. Population estimates were collected from both the Federal Fish and Wildlife Services and Wikipedia. The ages of Baker, Howland, Jarvis, Kingman, and Palmyra were obtained from the Seamount Biogeosciences Network (https://earthref. org/SC/#top). Age of Johnston was determined through Fish and Wildlife Service documentation (http://www.fws.gov/refuge/Johnston_Atoll/about.html), and the age of Wake was obtained from the Pacific Islands Benthic Habitat Mapping Center (http://www.soest.hawaii.edu/pibhmc/pibhmc_pria.htm).

Each of the Pacific Remote Islands is also unique in terms of size. Wake is the largest of the Pacific Remote Islands with a land area of approximately 7 km^2. The rest of the Pacific Remote Islands have land areas less than 5 km^2. While these islands are small in size, reef areas range from approximately 2 km^2 surrounding Howland to 94 km^2 surrounding Johnston (Table 1). With the exception of Johnston, Palmyra and Wake, which have small mission-focused human presence, the Pacific Remote Islands are currently uninhabited (Fig. 3). However, the Pacific Remote Islands have a rich human history that dates back to Polynesian voyages through these waters. In the mid-1800s, some of the islands experienced active whaling and guano mining. Other islands played active roles during WWII and the Cold War. Currently on Wake Atoll, there is a U.S. Air Force installation with a resident military population of ~94; on Palmyra Atoll there is a contingent population of ~ 30 researchers working seasonally with U.S. Fish and Wildlife Service and The Nature Conservancy through the Palmyra Atoll Research Consortium; and on Johnston Atoll there is a small team of volunteers working with the U.S. Fish and Wildlife Service to eradicate invasive ants.

Due to their remoteness and relative absence of significant human impacts, the PRIMNM is home to some of the least impacted coral reef ecosystems in the world. However, despite their remote location, relatively intact condition, and on-going conservation management efforts, the coral reefs remain vulnerable to global changes in climate. Studies in the PRIMNM present a unique opportunity to understand ecological responses to climate change and ocean acidification in the absence of direct confounding anthropogenic impacts, such as overfishing and land-based pollution, which are common in most other coral reefs around the world (Friedlander et al., 2010).

TIMELINE

BAKER

1830-1870 Active whaling

1866-1872 Peak guano mining

1935-1942 Hui Panala'au occupation: students from Kamehameha Schools sent to establish U.S. territories

1943-1946 U.S. military present—more than 15,000 men built and maintained airstrip

1965 Operation Magic Sword: biological carrier experiment

1974 Named U.S. National Wildlife Refuge

2001-present Coral Reef Ecosystems Fishery Management Plan: designated no-take Marine Protected Area (MPA)

2009 PRIMNM established

HOWLAND

1830-1870 Active whaling

1859-1871 Peak guano mining

1935-1942 Hui Panala'au occupation: students from Kamehameha Schools sent to establish U.S. territories

1943-1946 U.S. military present

1950's Visited by whalers who harvested marine life for ship supplies

1962 Reef bombed by U.S. Atomic Energy Commission to use land as nuclear site

1974 Named U.S. National Wildlife Refuge

2001-present Coral Reef Ecosystems Fishery Management Plan: designated no-take MPA

2009 PRIMNM established

JARVIS

1830-1870 Active whaling

1858-1879 Guano mining

1935-1942 Hui Panala'au occupation: students from Kamehameha Schools sent to establish U.S. territories

1950's Visited by whalers who harvested marine life for ship supplies

1974 Named U.S. National Wildlife Refuge

2001-present Coral Reef Ecosystems Fishery Management Plan: designated no-take MPA

2009 PRIMNM established

2014 PRIMNM expanded

KINGMAN

1830-1870 Active whaling

1934 Franklin D. Roosevelt placed Kingman under naval administration

1935 U.S. Bureau of Air Commerce stationed supply ship in the lagoon as a seaplane base

1938 Seaplane base abandoned

1941 Franklin D. Roosevelt declared Kingman a naval defense sea area

2001 Named U.S. National Wildlife Refuge

2001-present Coral Reef Ecosystems Fishery Management Plan: designated no-take MPA

2007 Fishing vessel grounded on reef

2009 PRIMNM established

2014 Fishing vessel removed

1850

1900

1950

2000

10

PALMYRA

1830-1870 Active whaling

1922 Expansion of existing coconut plantation

1941-1945 U.S. military present; Palmyra housed ~6,000 men, dredged channel, built causeways to connect islets, stripped vegetation for runway

1991 Fishing vessel grounded on reef

2000 Purchased by The Nature Conservancy; established Palmyra Atoll Research Consortium

2001 Named U.S. National Wildlife Refuge
2001-present Coral Reef Ecosystems Fishery Management Plan: designated low-use MPA

2009 PRIMNM established
2011 Rat eradication begins
2013 Declared "rat free" by U.S. Fish & Wildlife Service
2014 Longline fishing vessel and barge removed

JOHNSTON

1858-1910 Guano mining

1926 Named U.S.National Wildlife Refuge

1934 Franklin D. Roosevelt placed Johnston under naval administration
1939-1942 Construction for U.S. military operations— enlarged island, built islet, dredged coral
1958 Radioactive material weapon testing began
1962 Spilled americium and plutonium over atoll—raked sand into "Mount Pluto" pile
1963-1964 Dredged coral to enlarge island, built runway, built two islands
1965 Operation Magic Sword: biological carrier experiment
1971 U.S. transferred chemical munitions from Japan to Johnston for demilitarization
1985 Construction of Johnston Atoll Chemical Agent Disposal System (JACADS) facility
1990 JACADS began destruction of 6% of nation's original stockpile of chemical agents on Johnston
2001 JACADS ends stockpile elimination; over 4 million lbs. of nerve and mustard agents destroyed without releasing into the environment
2001-present Coral Reef Ecosystems Fishery Management Plan: designated low-use MPA

2009 PRIMNM established
2010 Yellow crazy ants detected; eradication and monitoring ongoing
2014 PRIMNM expanded

WAKE

1934 Franklin D. Roosevelt placed Wake under naval administration
1935 Pan American Airways constructed "PAAville" village, made major alterations for airport

1941-1945 Japanese took control; Wake occupied by ~4,000 Japanese soldiers while U.S. bombed atoll
1945-present Japanese surrendered and Wake placed under jurisdiction of U.S. Navy; used as missile launch test site

1975 Vietnamese refugee camp for more than 8,000 refugees

1985 Designated U.S. National Historic Landmark

2001-present Coral Reef Ecosystems Fishery Management Plan: designated low-use MPA

2009 PRIMNM established
2009 Named U.S. National Wildlife Refuge

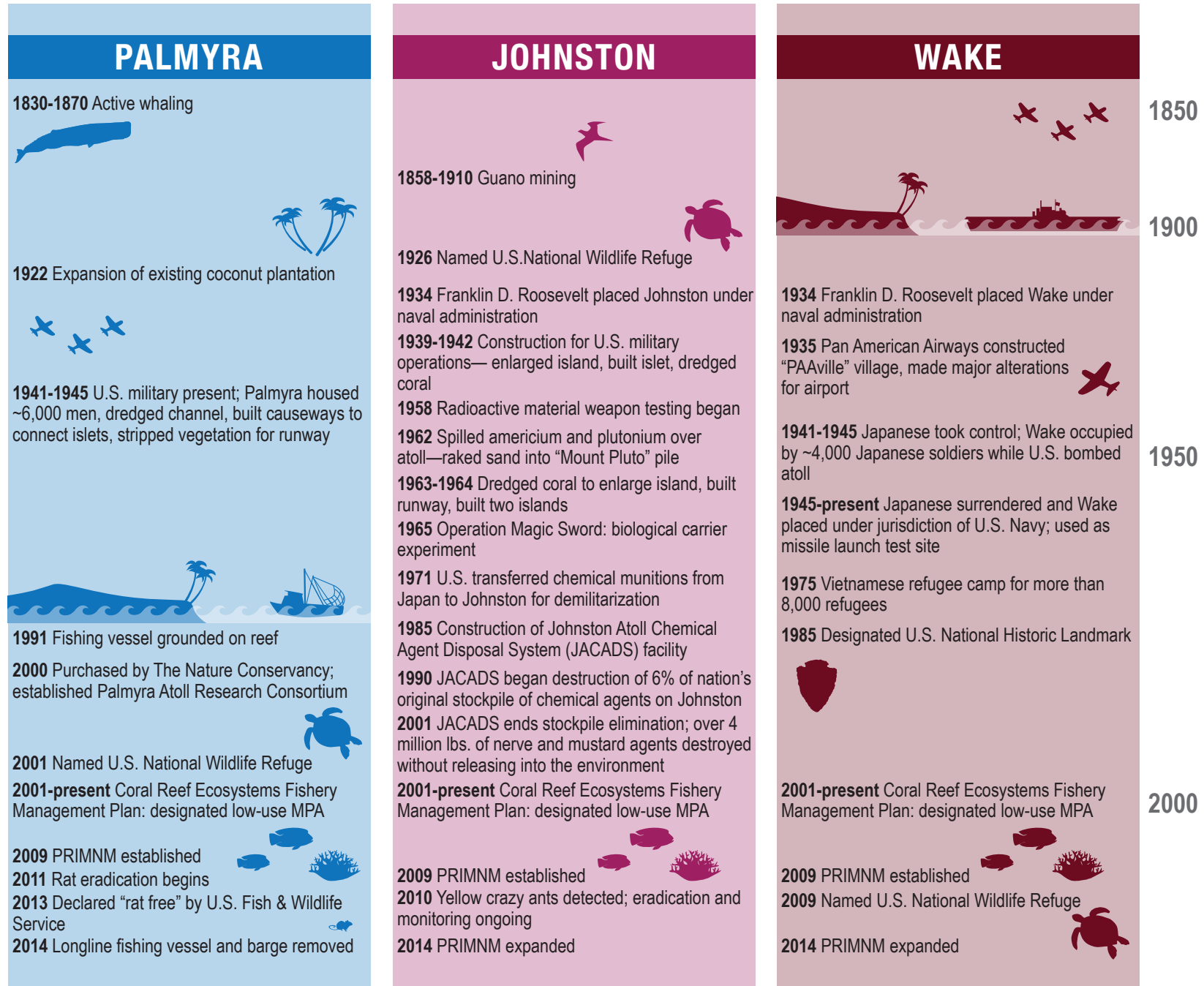**2014** PRIMNM expanded

TIMELINE

1850
1900
1950
2000

Figure 3. Timeline of historical events for each island of the Pacific Remote Islands Marine National Monument (PRIMNM).

METHODS OVERVIEW

METHODS

Interdisciplinary biological, physical, and chemical surveys were conducted to document the status and trends of the conditions of, and processes influencing, the coral reef ecosystems around each of the Pacific Remote Islands. From 2000–2016, CREP conducted ten Pacific RAMP cruises to Jarvis; nine cruises to Baker, Howland, Kingman, and Palmyra; six cruises to Johnston; and five cruises to Wake (Fig. 4).

CREP scientists have collected spatial and temporal observations of key oceanographic parameters to document time-varying oceanographic conditions that influence ecological processes and ecosystem health (Hoeke et al., 2009). The dominant physical drivers influencing coral reefs are temperature, salinity, ocean currents, and waves that are measured using both moored instruments for time series observations and profiling instruments that provide information about conditions at different depths. The dominant chemical parameters influencing coral reefs are carbonate chemistry, dissolved oxygen, and nutrients that are measured with recording instruments and water samples.

BIOLOGICAL
- **ARMS** - autonomous reef monitoring structure
- **BMU**- bioerosion monitoring unit
- **CAUs** - calcification accretion unit
- **Rapid Ecological Assessment (REA)** - detailed species-level surveys of benthic and fish community structure
- **TOWED DIVER** - broad surveys of benthic cover, macroinvertebrates, and large fish
- **TOAD** - optical validation and habitat characterization

PHYSICAL/ CHEMICAL
- **MOORED INSTRUMENTS** - collection of continuous oceanographic data
- **CTD CASTS -** measurements of conductivity, temperature and depth
- **WATER SAMPLES -** nutrients, Chl-a, carbonate chemistry (DIC, TA)

MAPPING
- **MULTIBEAM SONAR** - generates bathymetry, habitat characterization
- **SATELLITE IMAGERY** - estimates bathymetry

PACIFIC RAMP TIMELINE

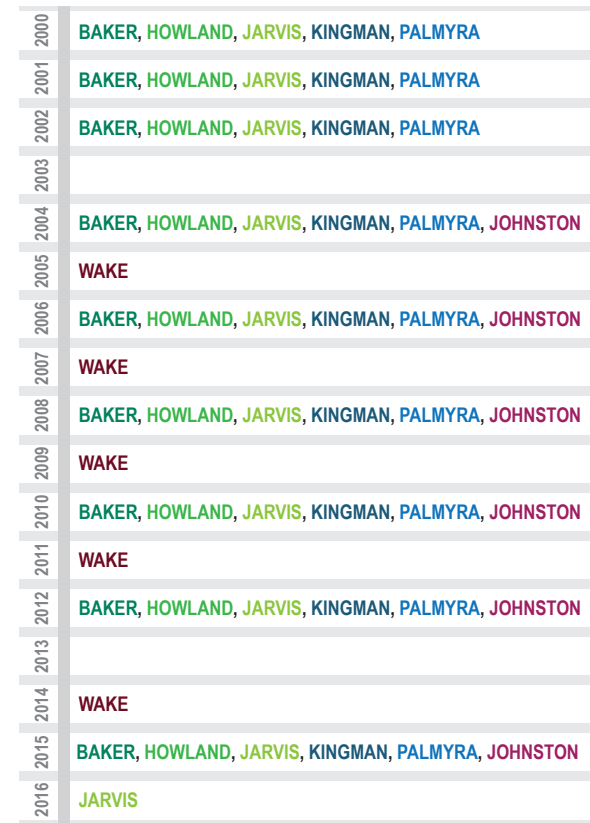| Year	Locations
2000	BAKER, HOWLAND, JARVIS, KINGMAN, PALMYRA
2001	BAKER, HOWLAND, JARVIS, KINGMAN, PALMYRA
2002	BAKER, HOWLAND, JARVIS, KINGMAN, PALMYRA
2003	
2004	BAKER, HOWLAND, JARVIS, KINGMAN, PALMYRA, JOHNSTON
2005	WAKE
2006	BAKER, HOWLAND, JARVIS, KINGMAN, PALMYRA, JOHNSTON
2007	WAKE
2008	BAKER, HOWLAND, JARVIS, KINGMAN, PALMYRA, JOHNSTON
2009	WAKE
2010	BAKER, HOWLAND, JARVIS, KINGMAN, PALMYRA, JOHNSTON
2011	WAKE
2012	BAKER, HOWLAND, JARVIS, KINGMAN, PALMYRA, JOHNSTON
2013	
2014	WAKE
2015	BAKER, HOWLAND, JARVIS, KINGMAN, PALMYRA, JOHNSTON
2016	JARVIS

Figure 4. Timeline of Pacific RAMP research cruises to the PRIMNM since 2000.

Opposite page: Diver takes photoquads above the reef at Baker Island, Photo: NOAA Fisheries/Kelvin Gorospe.
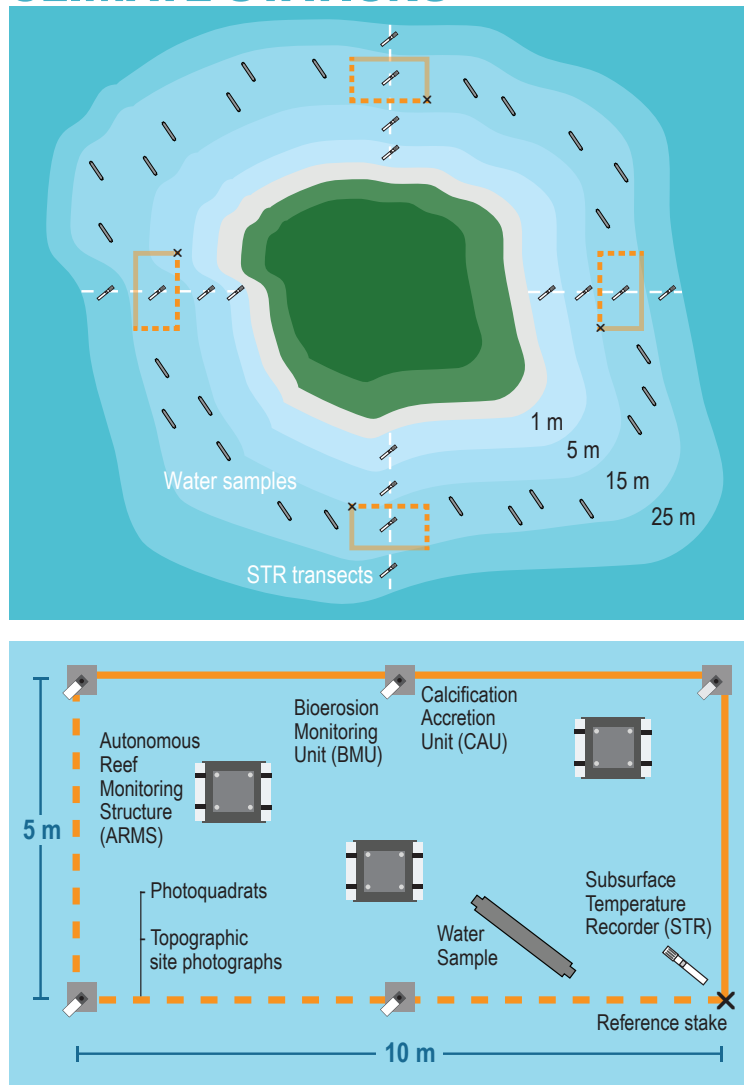
CLIMATE STATIONS

Figure 5. Climate station installation at a sample island location showing depths and instrumentation; additional monitoring efforts include coral cores and reef area photomosaics.

Several methods are deployed by the ocean and climate change team to measure the balance between the production and removal of calcium carbonate, a major reef building material, within the reef ecosystem. If bioerosion, or the removal of calcium carbonate substrate, is excessive, then coral destruction will exceed coral growth, which can lead to a flattening of the reef. Calcification accretion units (CAUs), coral cores, and carbonate chemistry are used to compute net ecosystem calcification and production. Coral cores, bioerosion monitoring units (BMUs), and carbonate chemistry are used to estimate net removal of calcium carbonate through bioerosion and chemical dissolution (Fig. 5). Collectively, these methods are used to determine the balance of calcium carbonate in the system, and indicate whether the reef will be able to persist over time.

In addition to oceanographic characteristics, information on the condition, abundance, diversity, and distribution of biological communities around these islands is collected using towed-diver surveys (Fig. 6), towed optical assessment device (TOAD) surveys, and rapid ecological assessments (REA) (Fig. 6). Towed-diver surveys encompass various habitats along a ~ 15 m depth contour and provide a broad overview of benthic cover, key macroinvertebrate presence, and abundance and size of large fish (> 50 cm). During each towed-diver survey, underwater video footage and still photographs of the benthos are collected (Kenyon et al. 2006). The TOAD surveys are used for benthic habitat characterization in depths greater than 30 m. REA surveys were adopted beginning in 2001, to gain more detailed site-specific information on the benthic community structure and associated fish assemblages.

REA METHODS

AREA & UNITS: LONG-TERM REA SITES

- Depths of 0-30 m
- Surveys along two transects of 10 m^2
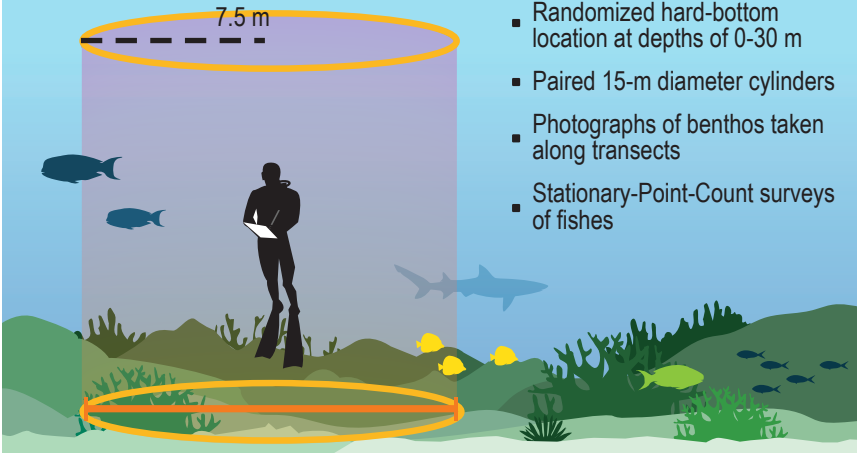- Quadrat and belt surveys along transects

TRANSECT

Figure 6. Schematic diagrams of Rapid Ecological Assessment (REA) method and towed-diver method. REA method shows 1. one of two divers conducting a belt-transect survey along a 25-m transect line (left) and 2. one of two divers conducting a Stationary-Point-Count (SPC) survey at a random REA site (below left). Towed-diver method shows one of two divers conducting a towed-diver survey (below).

AREA & UNITS: RANDOM REA SITES

7.5 m

- Randomized hard-bottom location at depths of 0-30 m
- Paired 15-m diameter cylinders
- Photographs of benthos taken along transects
- Stationary-Point-Count surveys of fishes

TOWED-DIVER METHOD

AREA & UNITS
- Depths of 0-30 m
- Surveys of 1.5-2.5 km
- Quadrat and belt surveys along transects

5 m

60 m to boat

1 m

mounted camera

5 m
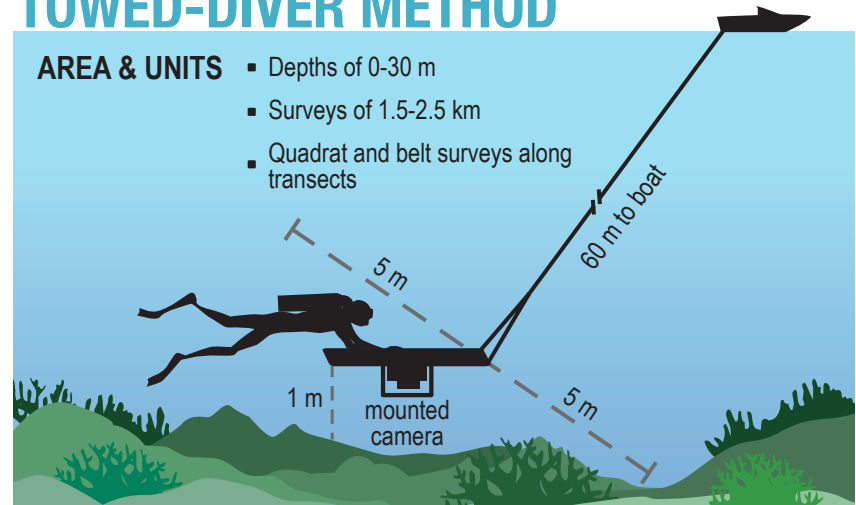
Originally, REA surveys were conducted along belt transects at semi-fixed and haphazardly selected sites. In 2008, the sampling design and method for the REA fish surveys were changed to a depth-stratified random approach (with shallow (0–6 m), mid (>6–18 m), and deep (>18–30 m) depth strata) using a stationary-point-count (SPC) method to obtain more representative estimates of abundance, size, and diversity of reef fishes on shallow (< 30 m) reefs at island or atoll scales (Ayotte et al. 2015). In SPC surveys, some larger fish, such as sharks and jacks, are sometimes attracted to divers resulting in overestimation of abundance. The biomass of these groups is instead reported more accurately using the towed-diver survey methodology. The REA benthic surveys were changed from semi-fixed and haphazardly selected sites in mid-depths (6–18 m) to a depth-stratified random sampling (StRS) design covering the same depth strata as the REA fish surveys. The survey methods employed by CREP in the Pacific Remote Islands during the period of 2000–2016, are described in greater detail in the Coral Reef Ecosystem Monitoring Report for the Pacific Remote Islands 2000–2016 (in prep).

JARVIS

SURVEY SITES
- Fish REA survey sites
- Benthic REA survey sites
- Climate stations
- Towed-diver tracks
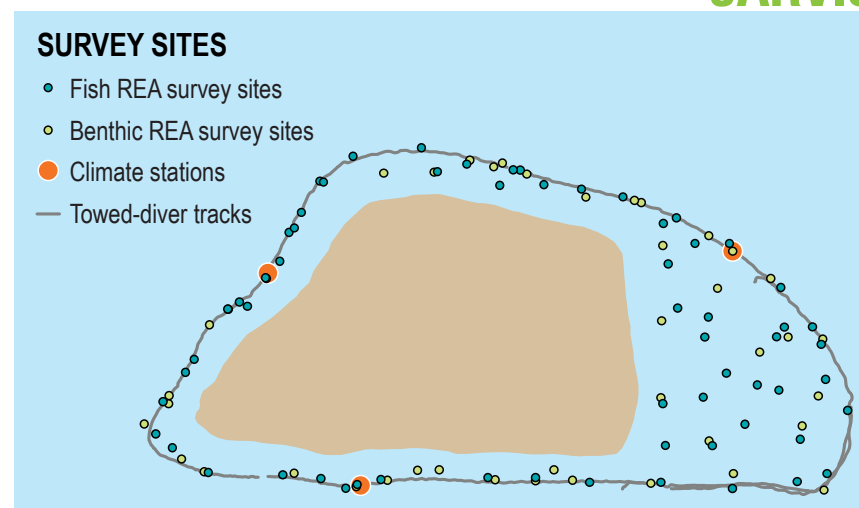
Figure 7. Jarvis Island as an example of survey efforts and site locations.

Since 2009, microbial community data have been collected during all Pacific RAMP cruises in collaboration with San Diego State University to examine relationships between the metabolic energy requirements of microbes and those of reef fishes. For the Pacific Remote Islands, our colleagues collected and filtered large volumes of seawater adjacent to the coral reefs at a subset of our monitoring sites to determine the abundance and diversity of microbes present. Using standard equations (McDole et al. 2012), we converted the abundances of microbes and reef fishes in a 10 m^3 volume of reef water to their metabolic energy requirements, or how much energy fishes and microbes use to live. With these two values, we calculate the microbialization score as the microbial metabolic energy needs of a coral reef divided by the total metabolic energy needs of fish and microbes (McDole et al. 2012). This work has shown that in more human-impacted ecosystems, microbes dominate the food web, or specifically, the metabolic energy that moves between reef organisms as they eat each other.

PACIFIC REMOTE ISLANDS
IN A PACIFIC-WIDE CONTEXT

The CREP uses standardized survey methods across all of the U.S. Pacific Islands to enable direct comparison of reef ecosystem metrics across broad biogeographic, geologic, oceanographic, and human-impact gradients. To better understand the status of coral reefs in the PRIMNM on a broader scale, a Pacific-wide comparison was performed for oceanographic conditions, benthic community, fish community and the microbial community.

OCEANOGRAPHY

Coral reef ecosystems are influenced by a diverse suite of oceanographic and meteorological factors, including but not limited to temperature, wind, waves, currents, nutrients, carbonate chemistry, light, and productivity. These factors all vary on daily, seasonal, interannual, and longer time scales. A combination of satellite-derived and in-situ information collected during Pacific RAMP surveys was analyzed to assess the variability of each of these factors across the U.S. Pacific Islands. Satellite observations provide broad spatial coverage and a historical context of surface processes, whereas in-situ observations provide subsurface measurements of the physical and chemical conditions directly influencing coral reef communities. Synthesis and integration of these data sets increases our understanding of the ecological processes that influence the status and trends in the condition of coral reefs in the PRIMNM and how the reefs of the PRIMNM compare to other coral reef ecosystems across the Pacific.

Opposite page: Two-spot red snapper (Lutjanus bohar) at Palmyra Atoll, Photo: NOAA Fisheries/Andrew E. Gray.

Long-term averages of satellite-derived sea-surface temperature (SST) highlight some of the differences observed in oceanic conditions. Due to the PRIMNM's expansive geographic range, the average SST varies considerably across the monument. Jarvis Island exhibits a noticeably cooler SST than its closest neighbors, Palmyra and Kingman, due to equatorial upwelling and locally intense topographic upwelling of the strong eastward flowing subsurface Equatorial Undercurrent (Gove et al., 2006). The northernmost Pacific island chains, the Main Hawaiian Islands and Northwestern Hawaiian Islands, have lower sea surface temperatures (23–27°C) compared to the other Pacific regions, whereas islands of the Mariana Archipelago and American Samoa show higher than Pacific-wide average sea surface temperatures, upwards of 28–29°C (Fig. 8).

Similar to SST, satellite-derived long-term averages of chlorophyll-a concentrations (Chl-a; a proxy for primary productivity) show significant variability across the Pacific, exhibiting highest concentrations in the equatorial region, particularly at Jarvis (0.22 mg·m^{-3}), Howland, and Baker Islands due to wind-driven equatorial upwelling. The lower chlorophyll concentrations seen at Wake and Johnston are similar to concentrations within the Mariana Archipelago and American Samoa (Fig. 9), which are all located in oligotrophic gyres.
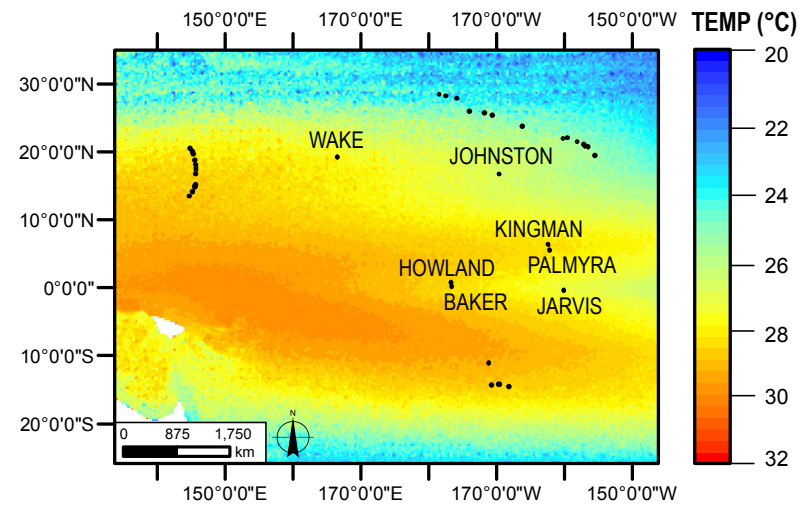
Figure 8. Long-term average sea surface temperature across the Pacific Ocean for 2003–2016, from satellite-derived data (NOAA POES AVHRR) for the geographic area 25°S–35°N, 135°E–145°W. White space indicates areas with no data. Black areas are island midpoints (http://gis.ncdc.noaa.gov/all-records/catalog/search/resource/details.page?id=gov.noaa.ncdc:C00284).
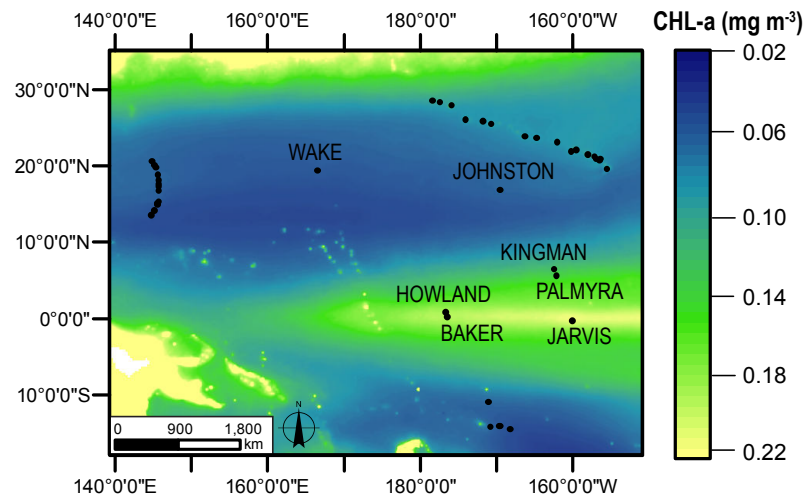
Figure 9. Long term average Chlorophyll-a concentrations across the Pacific for 2003–2016, from satellite-derived data (National Aeronautics and Space Administration Aqua MODIS). White space indicates areas with no data. Black areas are island midpoints (https://oceandata.sci.gsfc.nasa.gov/MODIS-Aqua/L3SMI).

19

Coral reefs rely on the ability of reef-building corals and crustose coralline algae to build, or calcify, and maintain the calcium carbonate structures that provide the three-dimensional habitat for the entire reef ecosystem. Corals precipitate mineral carbonate out of seawater and incorporate it into their skeletons. Their ability to calcify depends on the chemical conditions of their seawater environment. A common metric used to describe whether the environment is more or less conducive to calcification is the saturation state relative to the mineral aragonite (Ω_{arag}). When seawater has a higher Ω_{arag}, conditions are more favorable for calcification of reef building corals and crustose coralline algae and vice versa.

During the last few decades, Ω_{arag} and pH have been declining and are expected to continue to decline as the oceans absorb increasing levels of human-induced CO_2, in a process often referred to as ocean acidification. Using multiple methods, CREP scientists are actively monitoring both the changes in carbonate chemistry on coral reefs as well as rates of calcification, accretion, and bioerosion to assess the ability of coral reefs to persist. Across the Pacific Basin there are strong natural Ω_{arag} gradients (Young et al., in prep). Baseline observations of Ω_{arag} ranged from 3.07 at Lisianski Island in the Northwestern Hawaiian Islands to 3.93 at Swains Island in American Samoa (Fig 8). American Samoa and the Mariana Archipelago exhibited the highest regional mean aragonite saturation states of 3.85 and 3.7, respectively. The Pacific Remote Islands, Northwestern Hawaiian Islands, and Main Hawaiian Islands all possess average aragonite saturation states within the 3.2 to 3.6 range.

In the pre-industrial era, similar cross-Pacific gradients in aragonite saturation state were present, but Ω_{arag} levels were likely about 0.5–1 unit higher (~3.5–4.5; Ricke et al 2013). Reduction of a full unit of saturation state can reduce coral calcification by around 15–20% (Chan and Connolly 2013) and reduce net accretion of crustose coralline algae by as much as 70–86% (Kuffner et al 2008, Jokiel et al 2008, Johnson et al. 2014). Reef ecosystems exposed to Ω_{arag} consistently below 3.0 generally have little or no carbonate reef structure (Manzello et al, 2008).

In relation to aragonite saturation state, carbonate accretion rates were highly variable across the Pacific regions (Fig. 10), ranging from 0.015 g $CaCO_3$ cm^{-2}yr^{-1} at Kure Atoll in the Northwestern Hawaiian Islands to 0.133 g $CaCO_3$ cm^{-2}yr^{-1} at Rose Atoll in American Samoa. American Samoa and the Pacific Remote Islands exhibited the highest carbonate accretion rates of the U.S. Pacific Islands with regional averages of 0.089 g $CaCO_3$ cm^{-2}yr^{-1} and 0.062 g $CaCO_3$ cm^{-2}yr^{-1}, respectively. The PRIMNM's northernmost oligotrophic islands, Johnston and Wake, had two of the lowest average carbonate accretion rates, with values of 0.020 g $CaCO_3$ cm^{-2}yr^{-1} and 0.017 g $CaCO_3$ cm^{-2}yr^{-1}, respectively. Regional averages for the Mariana Archipelago and the Northwestern Hawaiian Islands were 0.039 g $CaCO_3$ cm^{-2}yr^{-1} and 0.021 g $CaCO_3$ cm^{-2}yr^{-1}, respectively. Much of the habitat provided by coral reefs comes from the structural complexity of their calcium carbonate foundations. Net carbonate accretion rates provide an indicator of the reef's growth overall; hence, the low rates observed, especially around the Northwestern Hawaiian Islands, could be cause for concern.
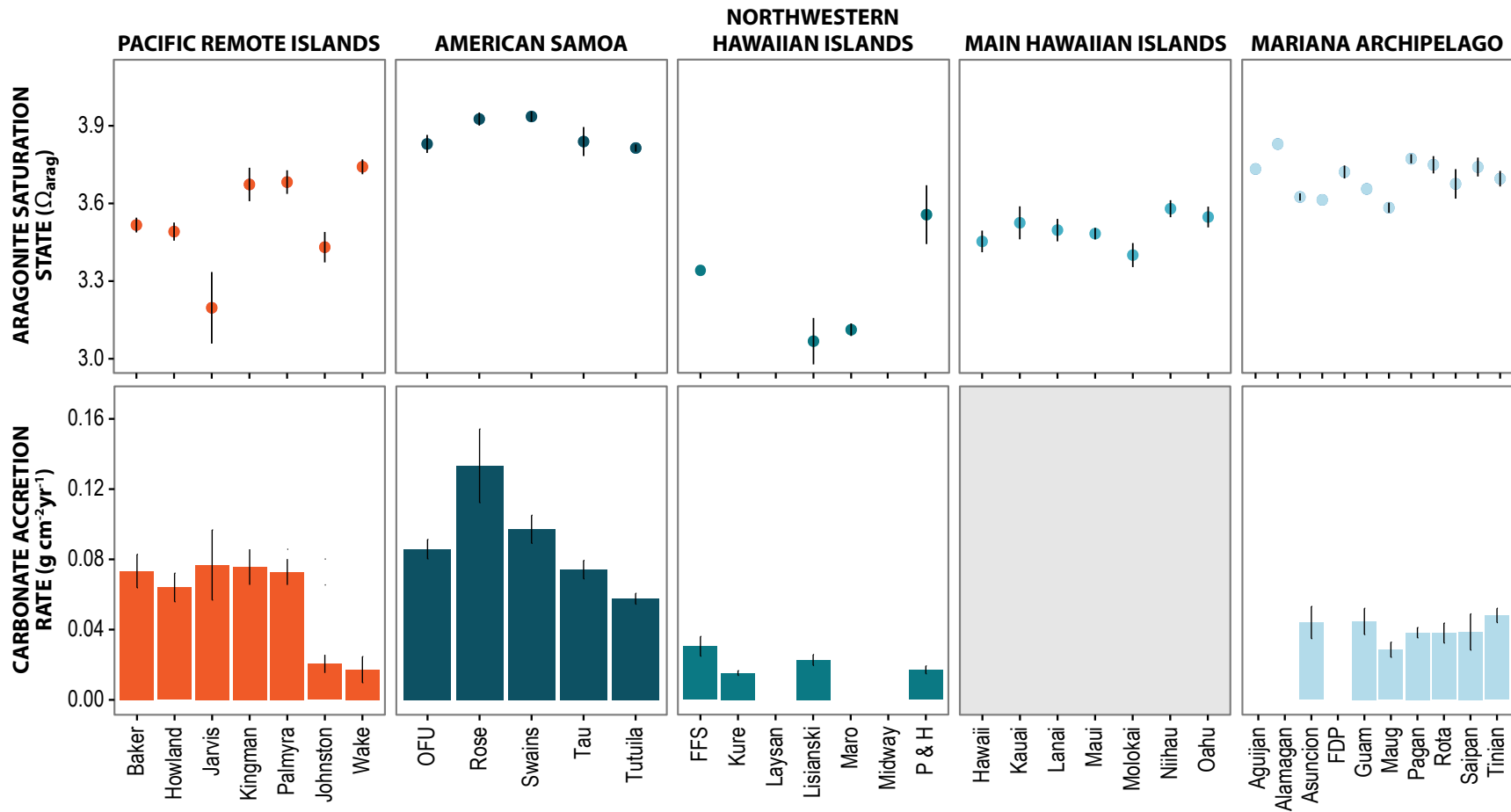
Figure 10. Most recent mean aragonite saturation state per island from 2013–2015 (Main Hawaiian Islands 2013, Mariana Archipelago and Wake Atoll 2014, American Samoa, Northwestern Hawaiian Islands, and Pacific Remote Islands 2015) (top). Aragonite saturation state values were calculated from dissolved inorganic carbon and total alkalinity values measured from in situ water sampling close to the substrate. Lagoonal sites were removed from the analysis. Error bars indicate standard error (± 1 SE) of the mean. Islands with no error bars only had one water sample. Mean carbonate accretion rate per island from 2012–2015. Carbonate accretion rates were measured via CAUs (bottom). Error bars indicate standard error (± 1 SE) of the mean. No CAU samples were recovered from the Main Hawaiian Islands until late 2016 and those samples are still being processed and analyzed.

The distinctions seen in patterns of aragonite saturation state and CAU accretion rate (Fig. 10) highlight the importance of tracking both environmental exposures to the seawater carbonate chemistry and ecological responses to that chemistry. For example, you can see that while the equatorial islands are exposed to low aragonite saturation states, largely due to their upwelling environment, they still manage high rates of net accretion (Fig. 11). Conversely, coral reefs at Wake and Johnston show similar in-situ aragonite saturation states, but low rates of accretion. There is strong forcing of net accretion on CAUs by aragonite saturation state (e.g. in American Samoa both aragonite saturation and accretion rates are high), but this distinction is likely modified by the relative high and low productivity of the equatorial islands and northern oligotrophic islands, respectively.
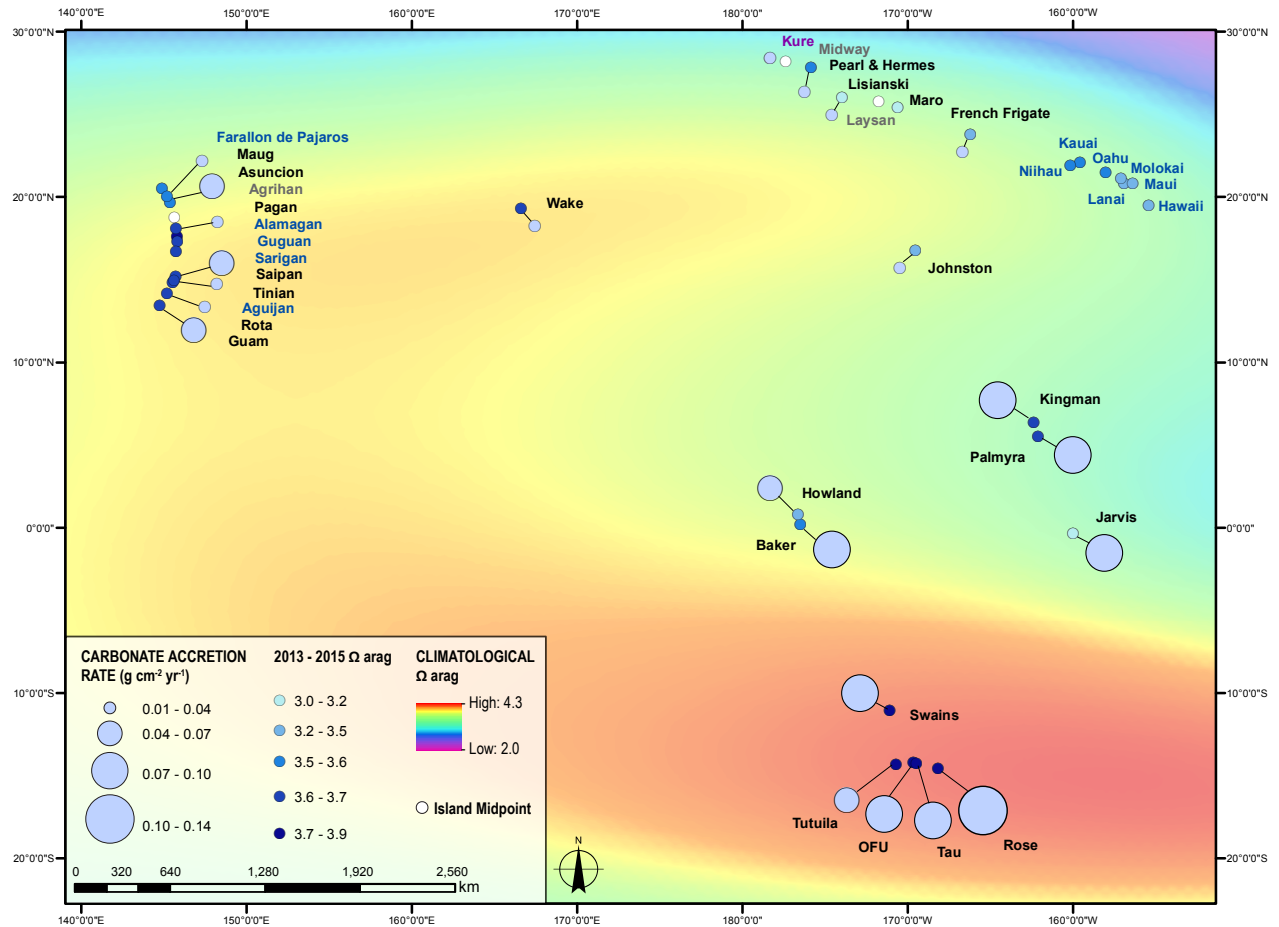
Figure 11. Pacific-wide open ocean climatological distributions of aragonite saturation state (Ω_{arag}) in surface waters (from GLODAP v2), benthic in-situ aragonite saturation state (within island circles), and mean carbonate accretion rate per island from 2012–2015. Size of bubble indicates island-level carbonate accretion rate measured via CAUs. Climatological aragonite saturation state source: Jiang et al. 2015; colors show gridded values based on interpolation through Data Interpolating Variational Analysis (DIVA) Software.

BENTHIC COMMUNITY

Percent cover of different benthic substrates is one of the most widely used metrics of reef condition. Live coral cover is the end product of a series of biological and environmental processes; significant changes in percent cover through time are indicative of disturbances. While the balance between algal communities and hard coral can be altered by coral mortality events, the ability of reef ecosystems to return to their natural balance after a disturbance, often termed resilience, is crucial for recovery and survival of coral reefs. This highlights the importance of long-term monitoring for management and conservation of coral reef ecosystems. In general, coral reefs of the PRIMNM have relatively high percent live coral cover and relatively low algal cover compared to the other U.S. Pacific regions. However, natural variability in coral cover occurs across the Pacific as a result of varying oceanic conditions and substrate. For example, the remote reefs of the Northwestern Hawaiian Islands have oceanographic conditions that naturally support predominantly algal-dominated reef communities (Vroom and Braun, 2010).

Across the U.S. Pacific Islands, results from REA surveys conducted from 2013–2015, showed island-wide mean estimates of live coral cover to range between 2% at Midway Atoll and 36% at Wake Atoll (Fig. 12). The coral reefs of the PRIMNM exhibited relatively higher mean island-wide live coral cover with all of the islands, except Johnston (11.4%), having mean coral cover greater than 26%.
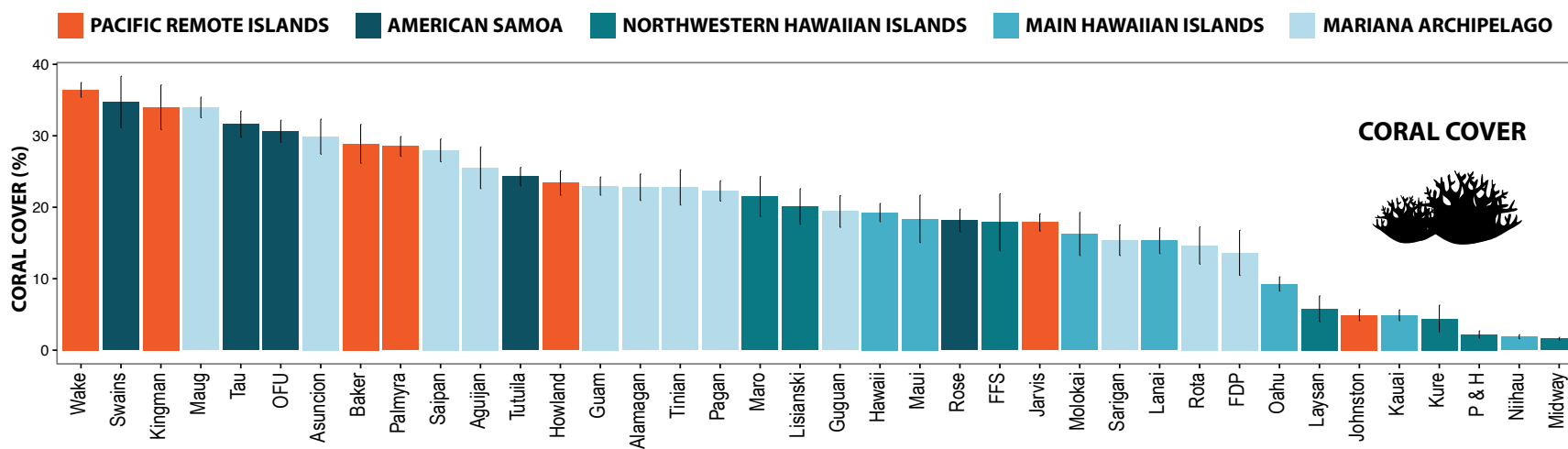

Figure 12. Mean coral cover (%) on forereef habitats from REA StRS surveys and for the Northwestern Hawaiian Islands from benthic visual estimates at SPC fish sites, conducted during the most recent survey years (2013–2015). OFU includes Ofu and Olosega Islands; P & H: Pearl and Hermes Atoll; FFS: French Frigate Shoals; FDP: Farallon de Pajaros. Error bars indicate standard error (± 1SE) of the mean.

FISH COMMUNITY

Gradients of oceanic productivity as well as other factors, such as sea surface temperature (SST), contribute to large natural variability in fish biomass, particularly for sharks, other piscivores, and planktivores (Nadon et al. 2012, Williams et al. 2015). As such, the highly productive waters of the equatorial upwelling islands tended to have high biomass of large-bodied fishes (sharks and other piscivores), which contributed to high total fish biomass. In addition to natural variability, there are clear negative relationships between human population density and large-fish biomass (Williams et al. 2011, Williams et al. 2015) (Fig.13).

Figure 13. Pacific-wide long-term climatological mean of chlorophyll-a (mg·m⁻³) from 2003 to 2016, and total reef fish biomass (g·m⁻²), not including sharks and jacks, from stratified random SPC surveys (depths of 0–30 m, n > 25 per island) conducted during the most recent survey years (2009–2015). Size distribution is shown by pie-chart slices: biomass of small-bodied (0–20 cm in total length; light orange), mid-sized (20–50 cm in total length; medium orange), and large-bodied (≥ 50 cm in total length; dark orange) fishes. Size of pie-chart shows mean total reef fish biomass.
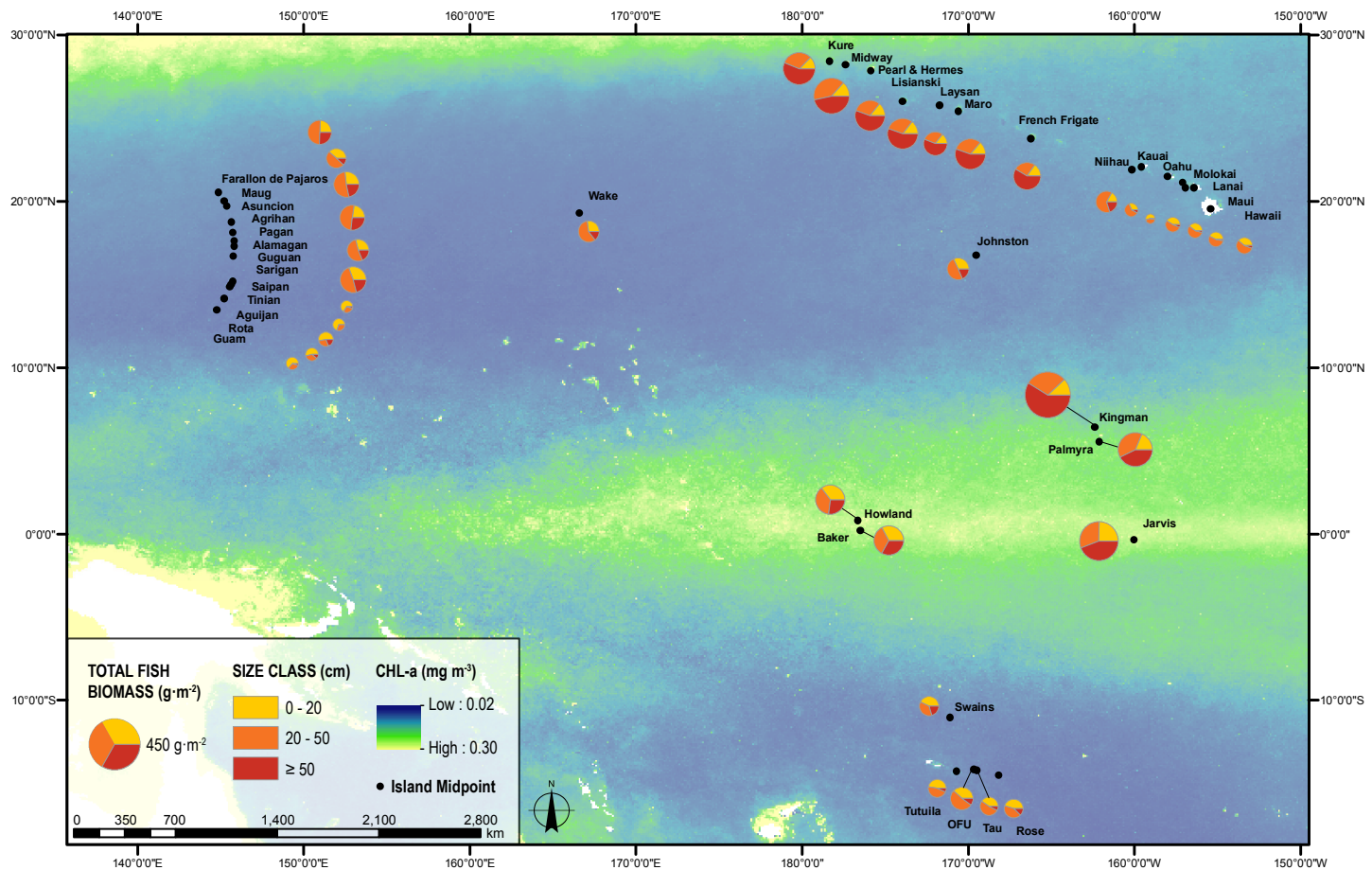
Total reef fish biomass varied from 11.1 g·m^{-2} at Oahu to 246.8 g·m^{-2} at Kingman Reef (Fig. 14)[1]. In general, total fish biomass was lower at inhabited, heavily impacted islands, such as the Main Hawaiian Islands and the southern Mariana Islands, and higher at remote, uninhabited islands. The PRIMNM and the Northwestern Hawaiian Islands exhibited the highest total reef fish biomass in the U.S. Pacific regions with mean total fish biomass of 125.0 g·m^{-2} and 120.9 g·m^{-2}, respectively. By contrast, average reef fish biomass was 45.6 g·m^{-2} in the Marianas, 45.0 g·m^{-2} in American Samoa, and 28.2 g·m^{-2} in the Main Hawaiian Islands.
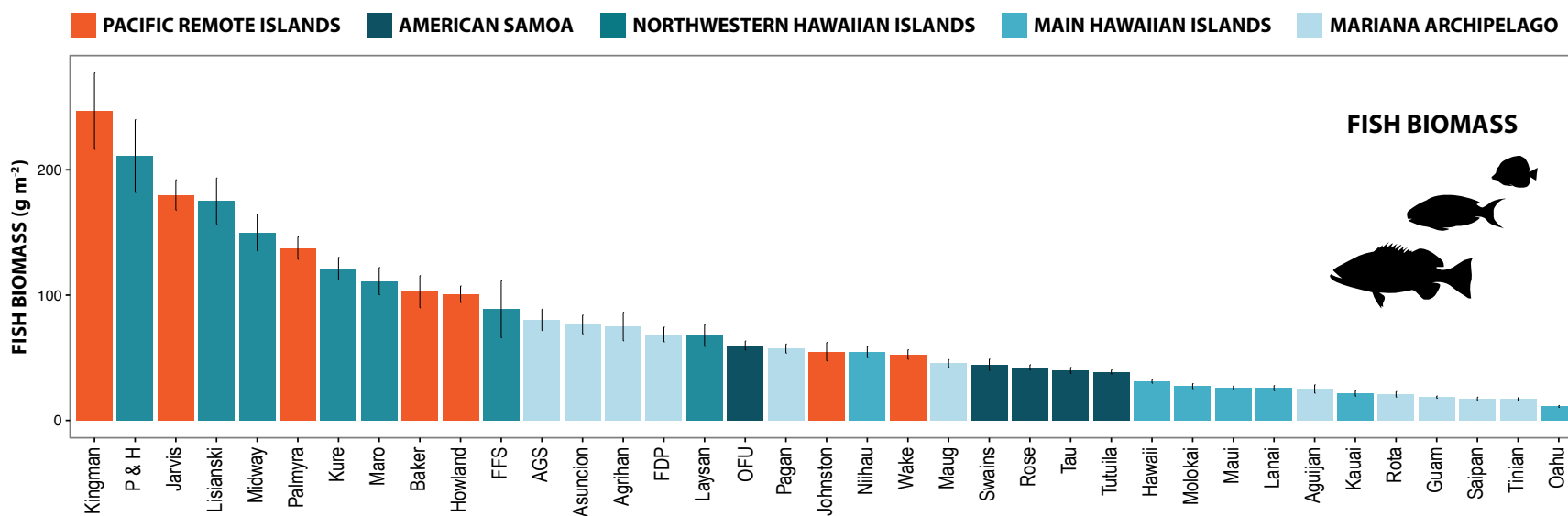
Figure 14. Pacific-wide comparisons of total reef-fish biomass (g·m^{-2}) from stratified random SPC surveys (depths of 0–30 m) conducted during the most recent survey years (2009–2015). P & H is Pearl and Hermes Atoll; FDP is Farallon de Pajaros; FFS is French Frigate Shoals; and OFU includes Ofu and Olosega Islands; AGS is Agrihan, Guguan, and Sarigan. Error bars indicate standard error (± 1 SE) of the mean.

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[1] Estimates of reef fish biomass from SPC surveys always exclude sharks and jacks.

These differences in total fish biomass can be largely attributed to the substantial differences in the fish size distribution among islands (Fig. 15). The distribution of small-bodied fishes (0–20 cm in length) was relatively uniform across U.S. Pacific regions, with the exception of the equatorial upwelling islands within the PRIMNM, where biomass of small-bodied fishes was very high due to enhanced productivity. Biomass of mid-sized fishes (20–50 cm in total length) differed across the regions and was substantially lower in the highly populated regions of the MHI and the southern Mariana Islands compared to less populated areas across the Pacific. The greatest differences of reef fish biomass across the regions can be attributed to the relative lack of large-bodied fishes (≥ 50 cm in total length) at inhabited islands.
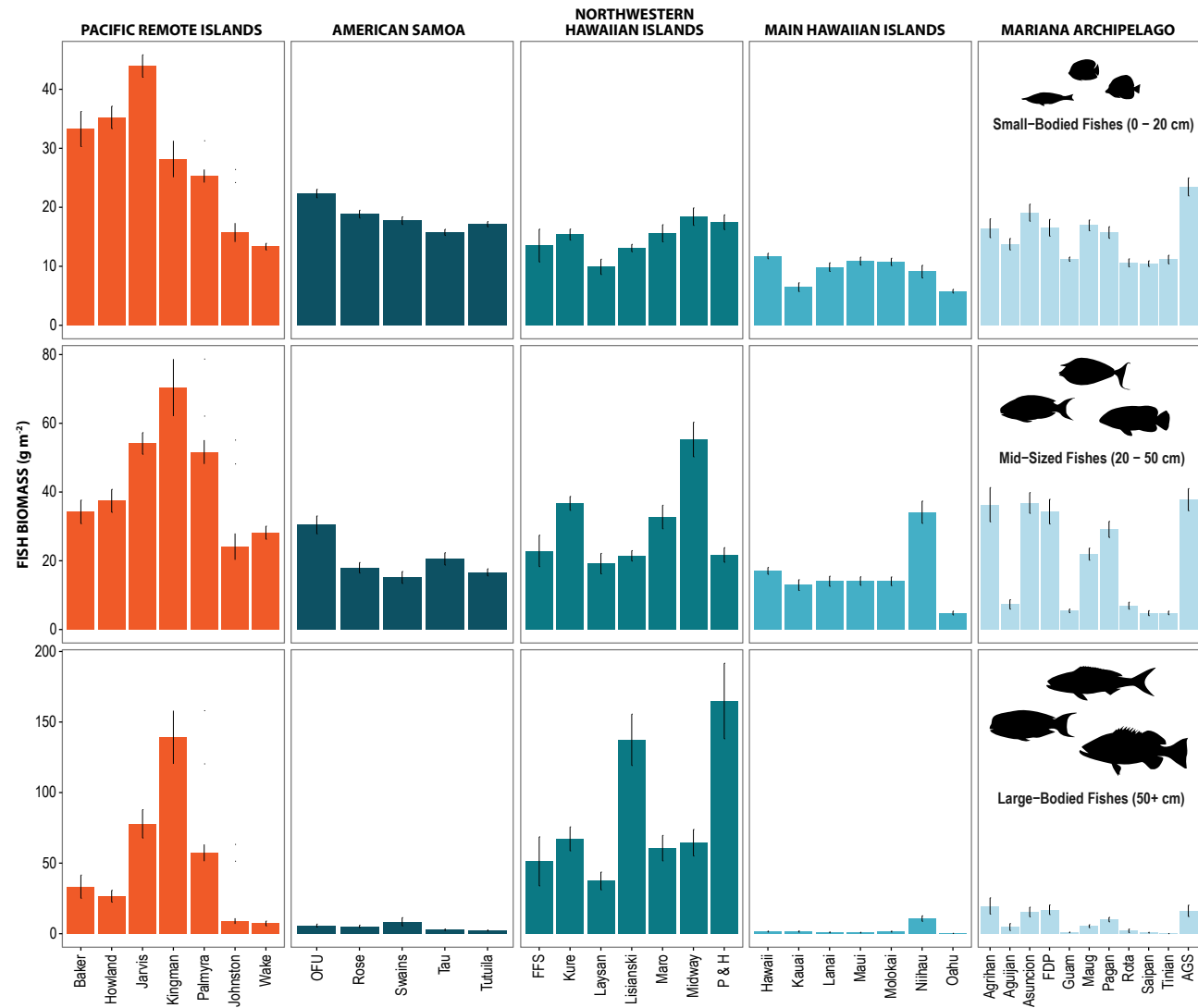
Figure 15. Pacific-wide comparisons of reef-fish biomass (g·m⁻²) per size class from stratified random SPC surveys (depths of 0–30 m; n > 25 per island) conducted during the most recent survey years (2009–2015). Note the differences in scale on the y-axes. Biomass of small-bodied (0–20 cm in total length; top row), mid-sized (20–50 cm in total length; middle row), and large-bodied (≥ 50 cm in total length; bottom row) fishes. P & H is Pearl and Hermes Atoll; FDP is Farallon de Pajaros; FFS is French Frigate Shoals; and OFU includes Ofu and Olosega Islands. Error bars indicate standard error (± 1 SE) of the mean.

MICROBIAL COMMUNITY

Nutrient-rich organic material released by corals constitutes an important foundation for the marine trophic food web and the associated biodiversity of coral reef ecosystems. In any coral reef, this organic material forms the base of a microbial and 'macrobial' food web of higher consumers. When a reef ecosystem shifts from being dominated by corals to being dominated by macroalgae, the microbial community and recycling mechanisms are disrupted. For example, the organic material released by these non-calcifying organisms (fleshy macroalgae and turf algae) is taken up by fast growing, opportunistic microbial communities; and, hence, shift these energetic materials away from supporting higher consumers, like fish. This phenomenon is referred to as microbialization (McDole et al. 2012).

One way to look at larger patterns of microbialization is to compare metabolic rates between microbes and fish. Given the mass of an organism, regardless of whether a fish or a bacterium, we can calculate how much energy it needs to survive, i.e. the metabolic needs of that organism. By counting and noting the sizes of fish and microbes, we can calculate the total metabolic needs of each group at a particular reef. We have a strong argument that microbialization is occurring when the microbes' metabolic needs constitute an increasing proportion of the total metabolic needs of the reef ecosystem (i.e. both fish and microbes; Fig. 17).
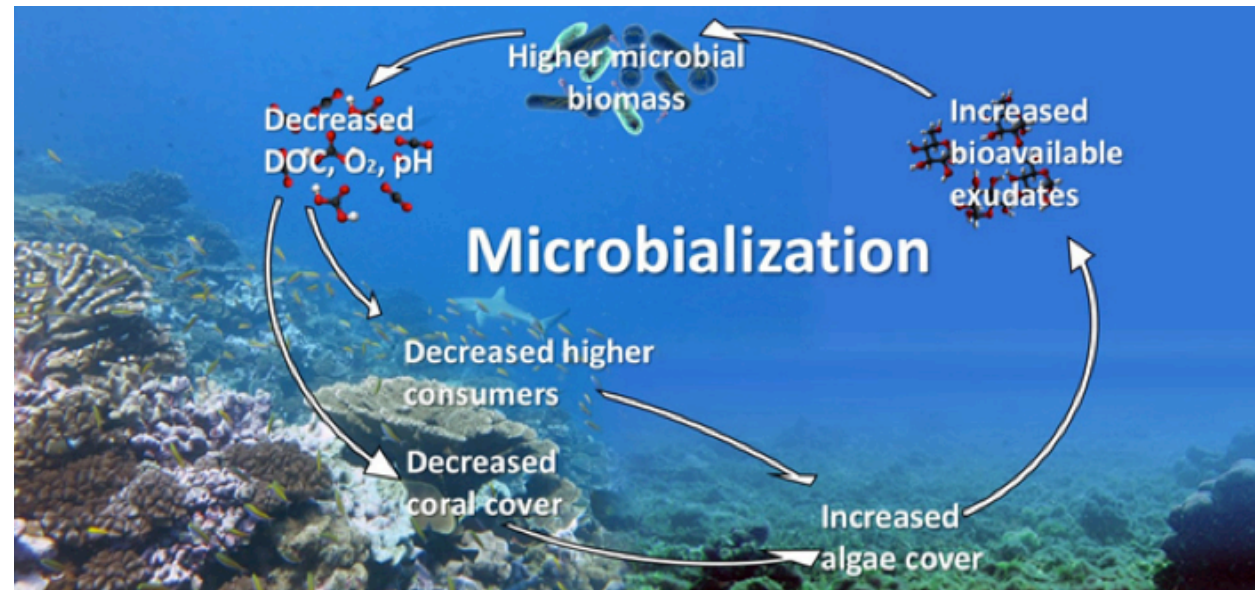

Figure 16. Conceptual depiction of microbialization positive feedback loop. Initially higher release of organic materials sustains higher microbial metabolism. The increased microbial metabolism depletes resources at the expense of higher trophic levels, giving algae a competitive advantage and creating a self-perpetuating feedback.
Credit:

When we look at those patterns, we see that as human impacts on reef ecosystems increases, so does the share of a reef's energy needs going through microbes. In low impacted reef areas, microbial energy needs are about 20% of the total energy used on a reef (e.g. Baker, Jarvis, Palmyra, Kingman), and this increases to about 90% of total energy in highly impacted reefs (Maui, Kauai, Oahu; Fig. 17). A strong significant positive correlation between the microbial share of reef metabolism (i.e., microbialization) and the cumulative human impact scores on reefs from National Center of Ecological Analysis and Synthesis (NCEAS) can be seen on islands from the four archipelagic regions of Pacific RAMP as a result of reef degradation and lower fish biomass (McDole et al., 2012).

The shift towards increased microbial biomass and metabolism at the potential expense of higher trophic levels might create a sustained positive feedback loop (Fig. 16). Consequently, once a regime shift to an algal-dominated state has occurred, the process of microbialization has the potential to make returning to a coral dominated state more difficult.
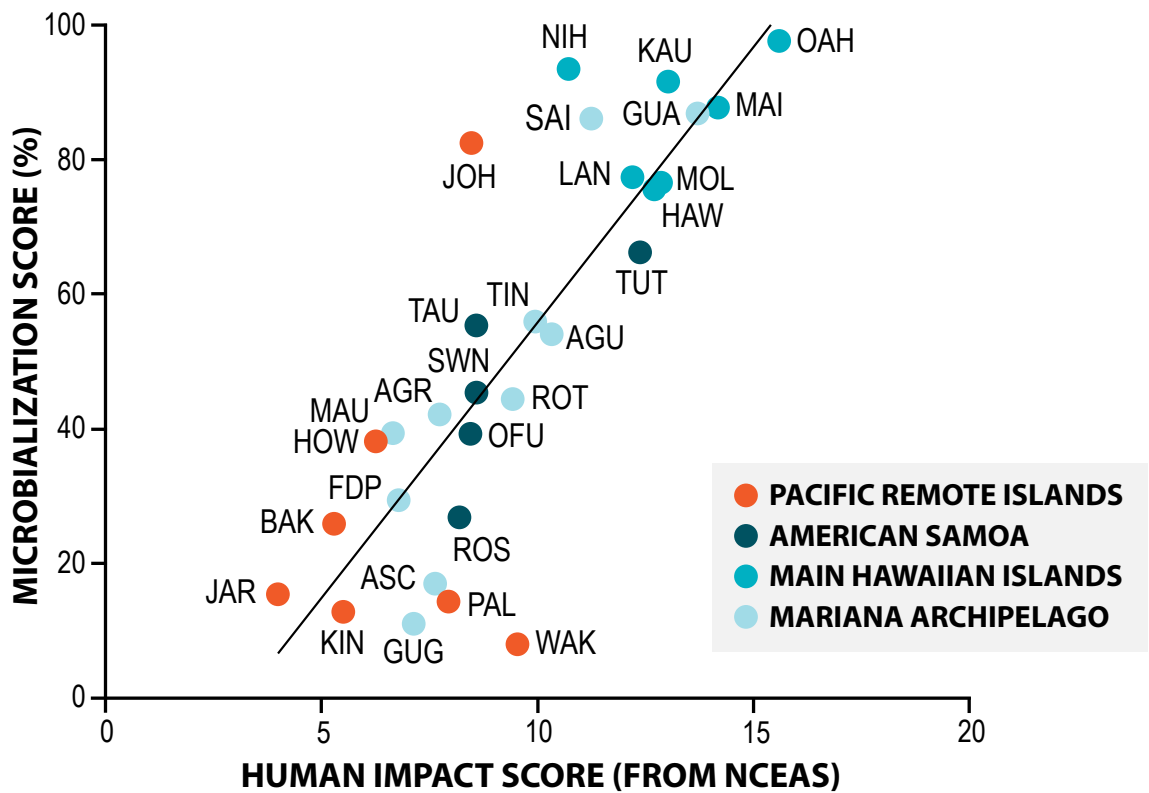
Figure 17. Proportion of Total Reef Metabolic Rate composed of Microbial Metabolic Rate (i.e. "Microbialization Score") against the cumulative human impact scores (NCEAS) on U.S. Pacific coral reefs. Black line is the linear regression line showing the positive relationship between cumulative human impact score and the microbialization score (y = 8.19x-26.1, R2 = 0.68, 95% CI = 5.994 to 10.39). Regions are indicated by color and islands are indicated by the first three letters of their name. Higher microbialization scores may indicate a vulnerability of that ecosystem to phase shifts between coral and macroalgal dominated states.

**PACIFIC REMOTE ISLANDS
IN A MONUMENT CONTEXT**

BENTHIC COMMUNITY

Spatial Comparisons of Benthic Cover

Percent cover of benthic functional groups, including coral, crustose coralline algae (CCA), macroalgae, and turf algae, is a widely utilized indicator of coral reef condition. CREP uses both towed-diver and REA surveys to measure percent cover; however, these methods sometimes produce different results, which should be acknowledged when evaluating percent cover estimates. Visual estimates during broad-scale towed-diver surveys sometimes overestimate coral and CCA cover in a given segment (~2,000 m^2). Additionally, the towed-diver surveys do not differentiate between macroalgal cover and turf algal cover. Because turf and macroalgae have different ecological roles in the coral reef ecosystem, REA surveys should be used when evaluating these two functional groups. Generally, high live coral cover and high CCA cover, as commonly observed for reefs in the PRIMNM, are indicative of healthy coral reefs. Based on percent cover observed throughout the U.S. Pacific, reefs exhibiting coral cover above 20% are considered to be in fair condition, reefs exhibiting coral cover above 30% are considered very good, and reefs exceeding 40% coral cover are considered excellent. For CCA cover, reefs exceeding 10% cover are considered to be in good condition and reefs exceeding 20% cover are considered excellent. These reference points were used to score the islands in the reef condition index summarized later in the document.

From 2014–2015 REA surveys, live coral cover in the PRIMNM ranged from 4.9% at Johnston Island to 36.4% at Wake Atoll, both in the northernmost oligotrophic island group. The central transition islands exhibited live coral cover at 34.0% and 28.5% at Kingman and Palmyra, respectively. The equatorial islands exhibited live coral cover at 28.9%, 23.4%, and 17.8 % at Baker, Howland, and Jarvis respectively. No obvious trends between islands groups were observed.

For CCA cover, estimates in the northernmost islands of the PRIMNM were 9.5% at Wake and 13.82% at Johnston. The central transition islands exhibited CCA cover at 9.8% and 18.9% for Kingman and Palmyra, respectively. CCA cover at the equatorial islands was highest at Howland with CCA cover estimated at 26.9%. CCA cover was an estimated 25.6% at Jarvis and 24.2% at Baker.

Opposite page: Bumphead parrotfish (Bolbometopon muricatum) at Wake Atoll,
Photo: NOAA Fisheries/Kevin Lino.

Generally, reefs with lower percent macroalgal cover are considered healthier. Throughout the U.S. Pacific, reefs exhibiting macroalgal cover less than 10% are considered to be in good health, reefs exhibiting macroalgae cover between 10% and 20% are considered to be in fair health. Johnston exhibited the lowest macroalgal cover at 6.4%, while Wake exhibited macroalgal cover at 16.5%. The central transition islands exhibited macroalgal cover at 7.2% and 12.8% for Kingman and Palmyra, respectively. For all the PRIMNM, Jarvis exhibited the highest macroalgal cover with estimates at 25.4%, likely a result of the high productivity. The other equatorial islands, Howland and Baker, exhibited macroalgal cover at 14.9% and 15.6%, respectively.

Turf algal cover at the PRIMNM was highest at Johnston, which exhibited exceptionally high turf algal cover of 64.0%. With the exception of Johnston, turf algal cover for all of the PRIMNM remained below 29%. Wake exhibited turf algal percent cover at 28.6%. Kingman and Palmyra exhibited turf algal cover at 29.0% and 24.3%, respectively. Turf algal cover at Jarvis, Howland, and Baker was 25.5%, 24.8%, and 22.3%, respectively. Turf algal cover was not included in the reef condition index.

Temporal Comparisons of Benthic Cover

Though there were changes in benthic cover over time, some significant, there were no obvious steadily increasing or decreasing trends from 2006-2015 at any of the Pacific Remote Islands. Percent cover has remained relatively stable for all of the functional groups at each of the islands, with the exception of Johnston. Beginning in 2010, there was a significant increase in turf algae and corresponding decrease in CCA cover at Johnston (Fig. 18). In 2010, percent cover of turf algae at Johnston was only 12.5% in 2010, but increased to 64.0% by 2015. Conversely, percent cover of CCA at Johnston was estimated at 57.7% in 2010, but decreased to 13.8% in 2015. The most significant temporal change observed in the PRIMNM occurred during the 2015-2016 El Niño warming event and will be discussed in the island highlights section on Jarvis Island.
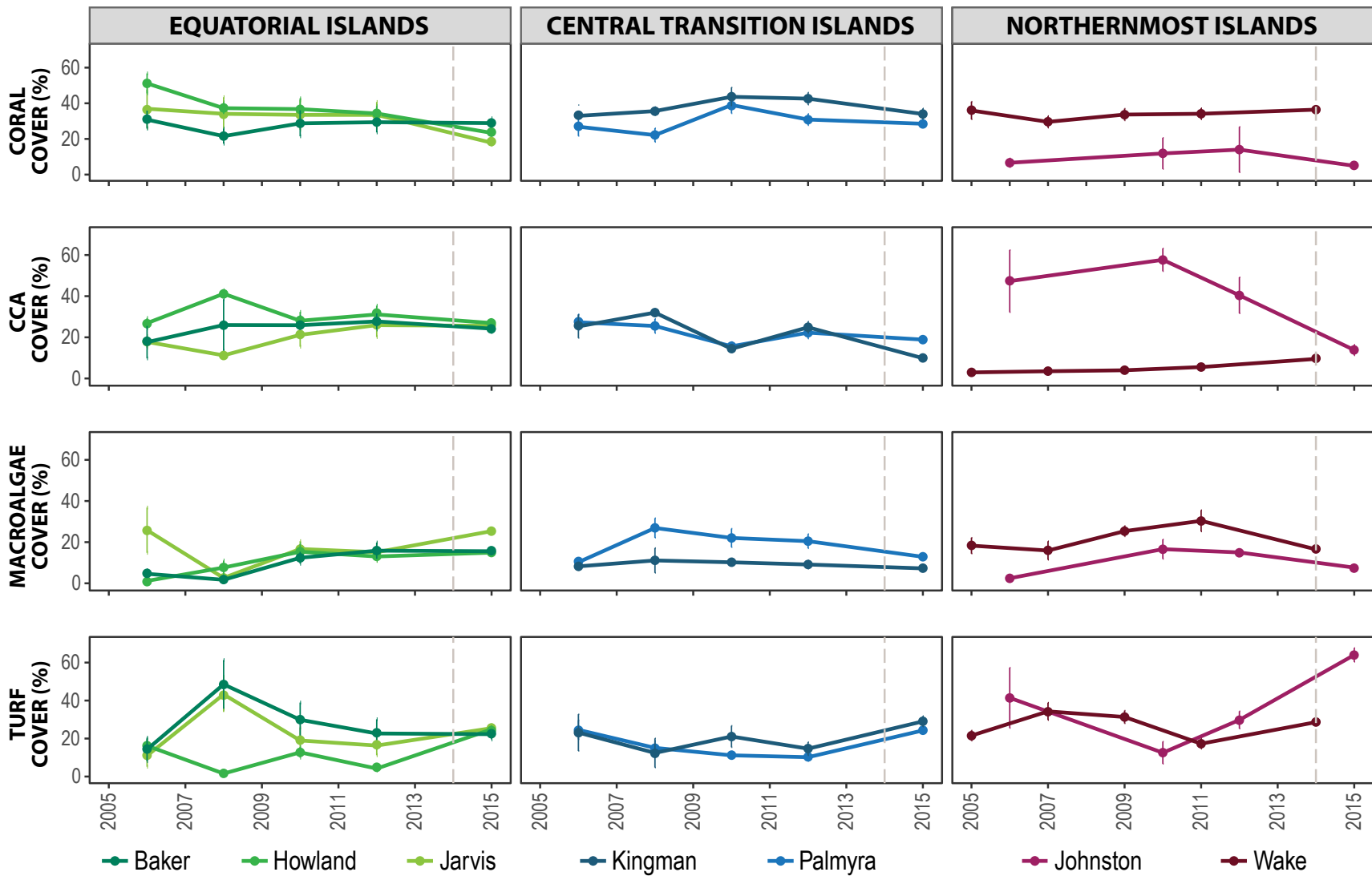
Figure 18. Temporal trends in percent cover for four primary benthic functional groups, including coral, CCA, macroalgae, and turf algae in the forereef habitats from REA surveys conducted in 2005–2015, shown by island group. In 2014, survey design changed from REA sites to stratified random sampling design (StRS), survey design change indicated by dashed vertical line. Error bars indicate standard error (± 1 SE) of the mean.

Coral Diversity

Coral reefs represent the most biologically diverse marine ecosystems in the world, and numerous studies have shown that diverse systems are more resilient to disturbances through time (Folke et al., 2004; Hughes et al., 2005; Worm et al., 2006). Generic richness is the total number of unique genera recorded around each island and, among other measures, is often used as an indicator of coral diversity. Since larger reef ecosystems often support a wider range of habitat types, oceanographic conditions, and taxa, we computed an average generic richness per habitat stratum weighted by stratum area for each island based on our 2014–2015 StRS REA surveys. Kingman and Palmyra had the highest weighted coral generic richness values with mean values of 22.7 and 23.7 species, respectively. Johnston had the lowest generic coral richness with 5.8 species (Fig. 19).
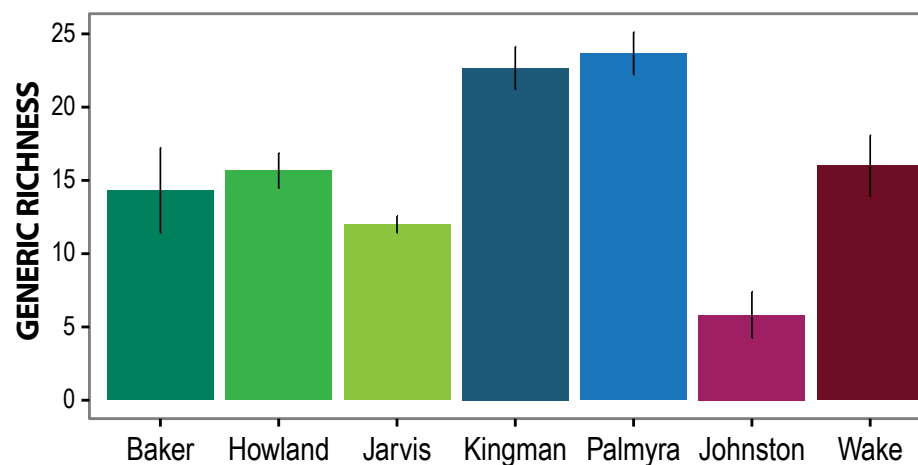

Figure 19. Mean generic richness of adult hard corals for each island estimated from 2014–2015 REA StRS surveys. Generic richness is the total count of unique genera in a sampling area. Error bars indicate standard error (± 1 SE) of the mean.

Coral Bleaching

REA StRS surveys measure bleaching and disease occurrence on hard scleractinian corals. Bleaching occurrence is presented as prevalence, calculated as the number of colonies exhibiting signs of bleaching (irrespective of severity or extent) divided by the total number of colonies for adult hard scleractinian corals. From 2009-2015, bleaching occurrence in the PRIMNM was generally low, below 5% at most islands. (Fig. 20). Spikes in bleaching occurrence occurred at Baker and Howland in 2010 due to the El Niño warm event with mean occurrence reaching 38.1% and 35.1%, respectively (Vargas-Angel et al., 2011). Noteworthy is the absence of these high bleaching occurrences in neighboring Jarvis Island. The coral bleaching events at Baker and Howland, as well as the massive 2015-2016 coral bleaching event at Jarvis, are evaluated further in the island highlights section.
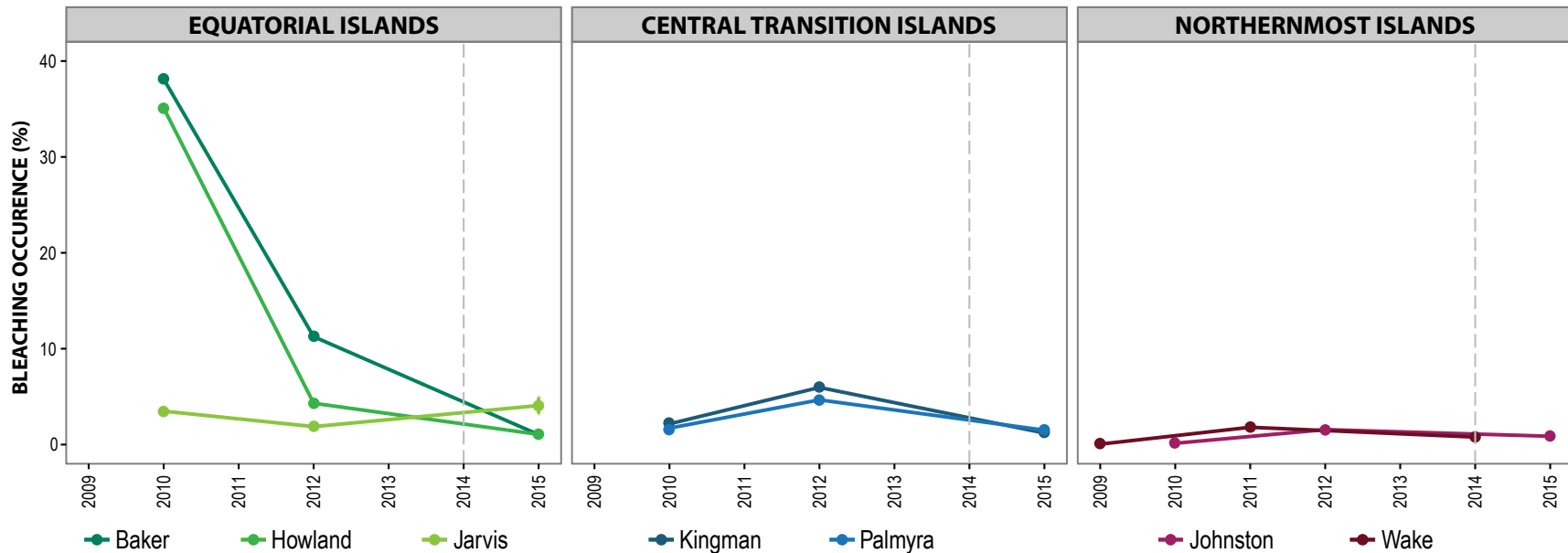
Figure 20. Mean bleaching occurrence - for adult hard corals at all depths and reef zones from 2014–2015, estimated from StRS method. The occurrence was calculated as the sum of all infected colonies divided by the total number of colonies. In the permanent site studies (2009-2013), occurrence is the sum of all infected colonies divided by the sum of the total colonies at each island. For StRS surveys (2014-2015), the occurrence is the mean occurrence by island calculated for each StRS sampling site.

Disease

Disease occurrence was calculated as the number of diseased colonies divided by the total number of colonies for adult hard scleractinian corals. Disease occurrence estimates are for all diseases except for lesions resulting from barnacle infestation and tubeworm infestation. Disease occurrence on hard corals across the PRIMNM during sampling years 2009–2015 ranged from 0.1% at Baker in 2010 to 3.3% on Palmyra in 2010. Diseases present included, among others: white syndrome, sub-acute tissue loss, skeletal growth anomalies, pigmentation responses, as well as fungal, algal, and cyanobacterial infections. In 2005 and 2006 surveys, Johnston exhibited significantly greater mean overall disease occurrence than other islands in the Pacific (Vargas-Angel, 2009). This trend is further evaluated in the island highlights section.

FISH COMMUNITY

Total Reef-Fish Biomass and Composition

Across the study period, the highest average total reef-fish biomass was observed at Jarvis Island (179.9 $g \cdot m^{-2}$) (Fig. 21) and Kingman Reef (246.8 $g \cdot m^{-2}$), both located in equatorial, nutrient-rich waters (Fig. 13). By contrast, in the northern oligotrophic waters, average fish biomass was lowest at Wake (52.6 $g \cdot m^{-2}$), followed by Johnston (54.9 $g \cdot m^{-2}$).

Reef fishes play an important role in the function of coral reef ecosystems through the transfer of energy from primary producers at the food web base to top predators and nutrient recycling in microbial and detrital food pathways. It can be usefulto consider fishes functionally, as defined by consumer groups, especially as some functional groups can promote ecosystem resilience. The four key functional groups are primary consumers, secondary consumers, planktivores, and piscivores. Primary consumers are fishes that eat algae and detritus (fine organic matters within algal turfs) and are believed to be important contributors to resilience of coral reef ecosystems (Green and Bellwood, 2009). Secondary consumers include omnivores, fishes that consume both algae and other organisms, and benthic invertivores, those that feed on benthic organisms such as crustaceans and other invertebrates. Planktivorous fishes consume both zooplankton and phytoplankton and are generally found feeding in the water column. Lastly, piscivores are fishes that consume other fish. Functional classification of pacific reef fishes is based largely on diet information taken from FishBase (Froese and Pauly, 2016).

Across the PRIMNM, like total reef-fish biomass, biomass of the four functional groups also varied considerably (Fig. 21). For example, biomass of primary consumers was markedly low at Kingman (19.7 $g \cdot m^{-2}$) relative to total biomass and accounted for less than 8% of total reef-fish biomass, on average, from 2010–2015. Estimates of total reef-fish biomass at Kingman were instead driven primarily by extremely high biomass of piscivorous (top predators) fishes (157.6 $g \cdot m^{-2}$), making up over 63% of total reef-fish biomass. By contrast, at Johnston and Wake, primary consumers accounted for a much higher proportion of the total fish community. Primary consumers made up 38% and 43% of total reef-fish biomass at Johnston and Wake, respectively, whereas piscivores were much less abundant at these islands.

Both mean piscivore biomass (8.8 $g \cdot m^{-2}$) and mean planktivore biomass (4.6 $g \cdot m^{-2}$) were lowest at Wake. Similarly, biomass of both piscivores (16.4 $g \cdot m^{-2}$) and planktivores (8.3 $g \cdot m^{-2}$) was also low at Johnston. At both islands, these two functional groups contributed least to overall fish biomass. Both planktivore and piscivore biomass were significantly higher at the equatorial upwelling islands (Kingman, Palmyra, Jarvis) due to the nutrient-rich water and high productivity. The nutrient-rich water promotes high biomass of large predatory fishes, as well as high

biomass of planktivores that feed on the abundant plankton surrounding the islands. The northern oligotrophic islands of Johnston and Wake are located in areas with naturally lower productivity and lower phytoplankton density compared to the other islands in the PRIMNM. Thus, due to the natural variability in oceanographic drivers, it is not unexpected for these islands to have lower biomass for these groups.
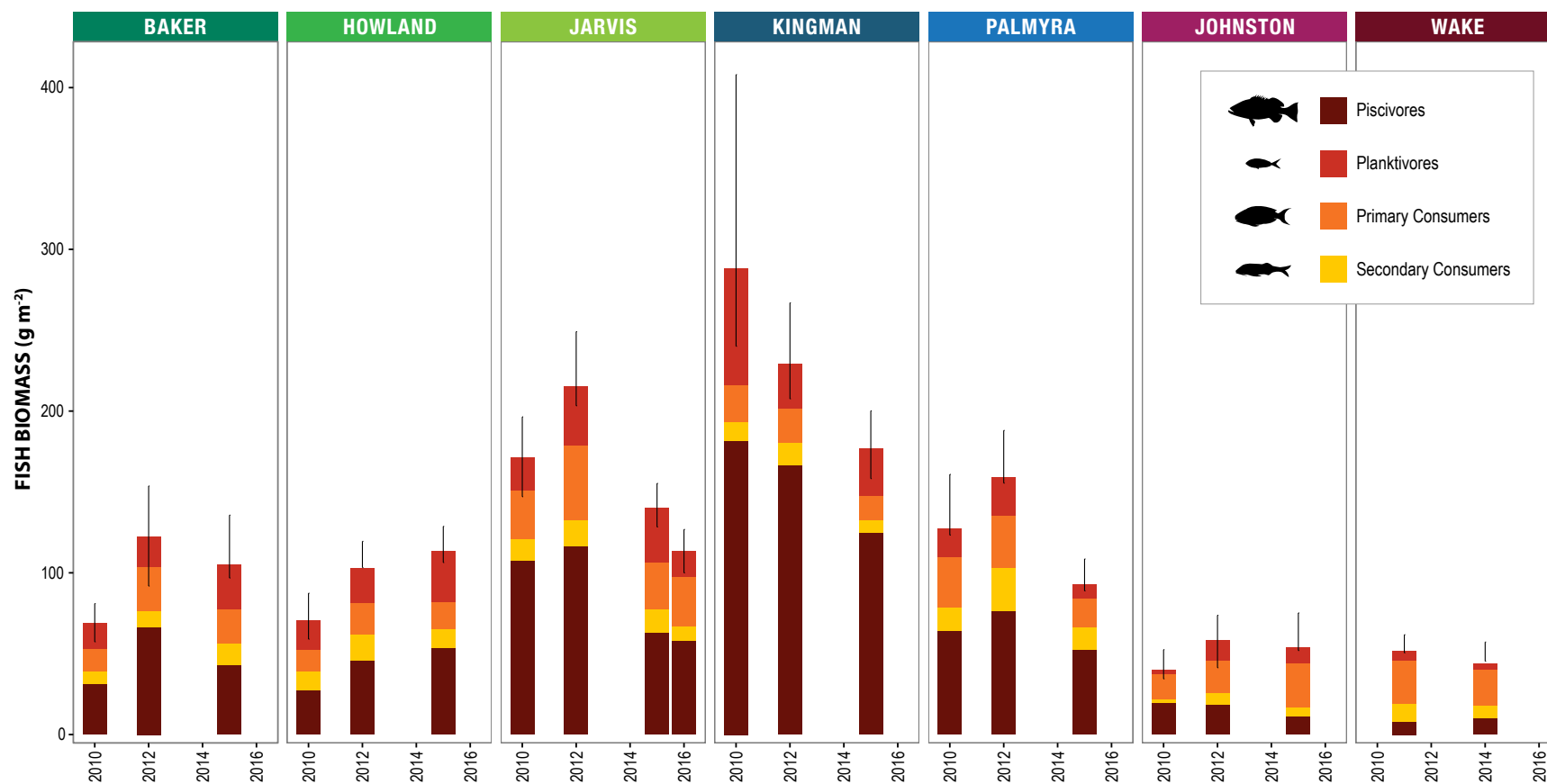

Figure 21. Trends in mean total reef-fish biomass (g·m⁻²) from mid-depth, forereef SPC surveys from 2010–2016, ordered by island, from left to right. Stacked bars show biomass per trophic group based on fish diet. Primary consumers include fishes that eat algae and detritus; secondary consumers include fishes with a wide variety in diet (omnivores) and fishes that eat invertebrates (following Williams et al. 2011). Error bars indicate standard error (± 1 SE) of the mean.
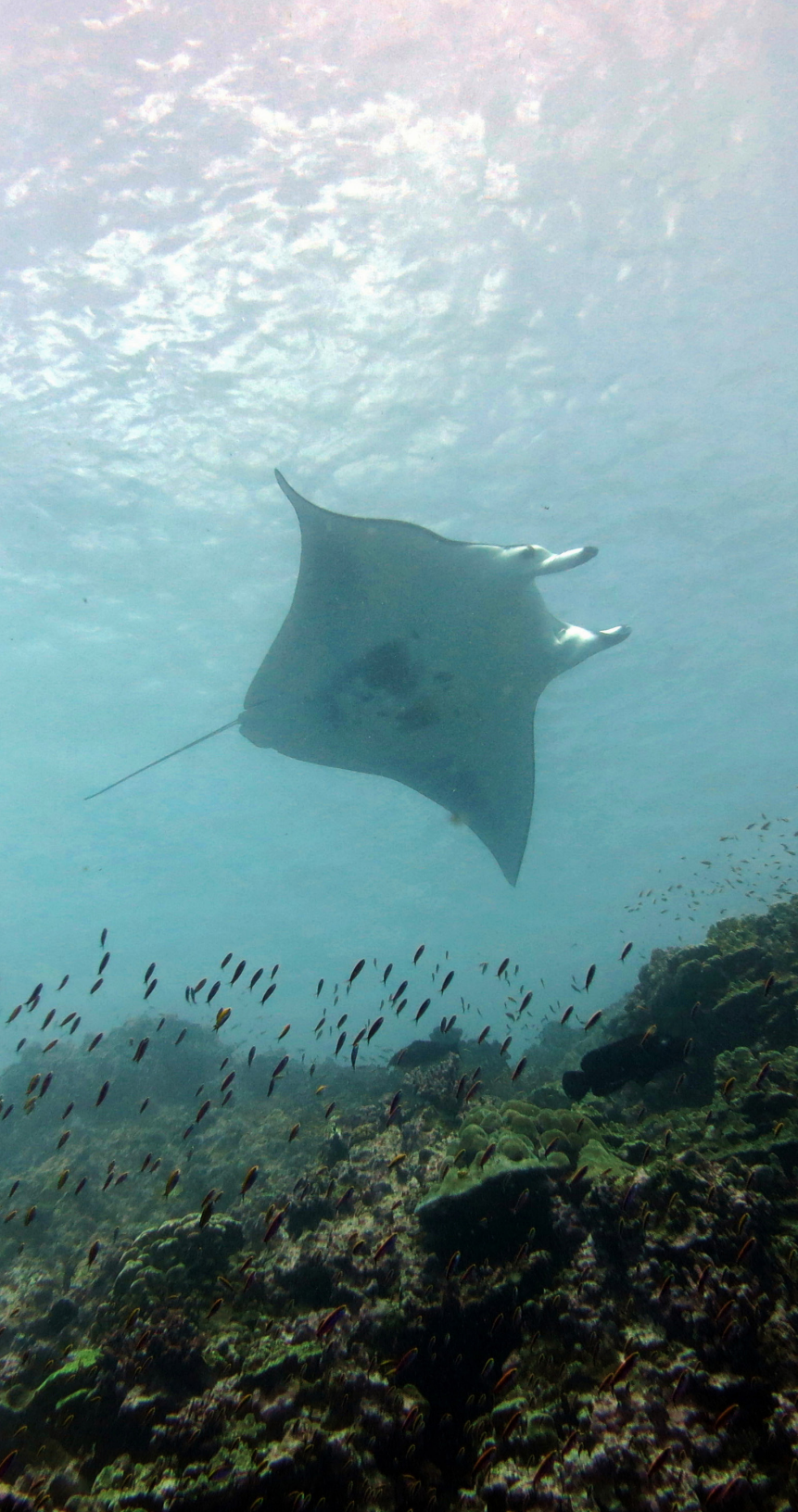
Large Fish Biomass

Compared to SPC surveys, towed-diver surveys provide better estimates of large-fish (≥ 50 cm in total length) biomass because the surveys allow divers to cover much larger areas during each survey (~22,000 m^2 per survey); thereby, increasing the frequency of encounters with large, rare fishes. Towed-diver surveys across the study period show that there were substantial differences in the biomass of large-bodied fishes across islands in the PRIMNM corresponding to the gradient in productivity (Fig. 22). Biomass of large fishes was highest at Jarvis, averaging 74.2 g · m^{-2} across the study period (2001–2015). At Johnston, large-fish biomass, was considerably lower, averaging 5.8 g·m^{-2} across the study period (2004–2015).

Likely, the primary reason for the stark differences in large fish biomass across the PRIMNM is the range of oceanic productivity, as mentioned herein. Jarvis is highly productive, and therefore supports a high abundance of both planktivores and piscivores as described above (Williams et al., 2015). For example, these conditions support high biomass of both sharks and rays. Similarly, Baker and Howland Islands also occur in productive waters, which is reflected in the high biomass of these same groups across the study period at these islands. By contrast, Johnston and Wake occur in the oligotrophic region of lowest oceanic productivity, unsurprisingly, they have substantially lower total large-fish biomass than the productive equatorial islands. Similar to Johnston, average large-fish biomass at Wake across the study period (2005–2014) was low, 19.5 g·m^{-2}, which was only 26% of the large-fish biomass observed at Jarvis. Notably, large-fish biomass appeared to decline at both Johnston and Wake over the study period.

Manta ray at Howland Island,
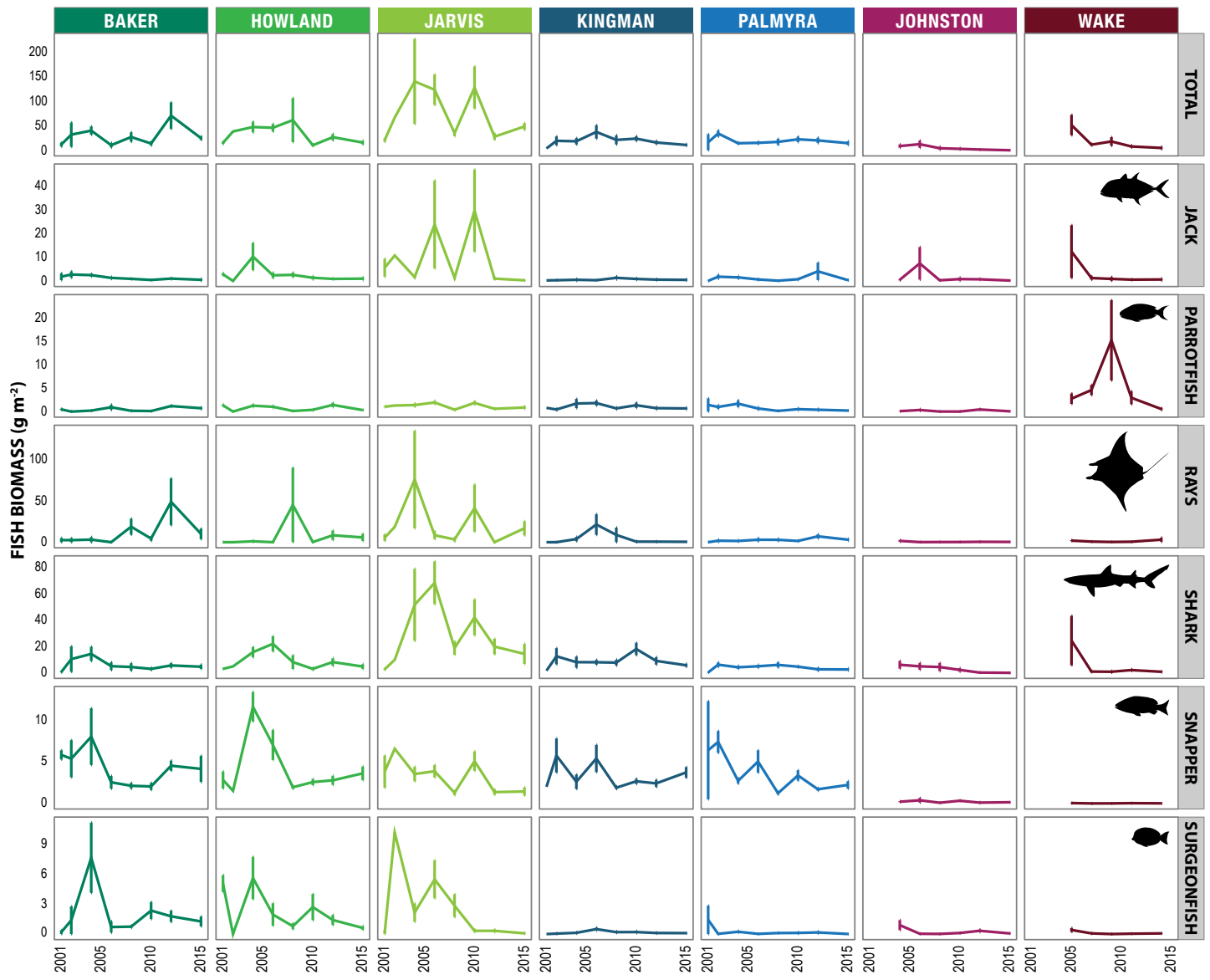*Photo: NOAA Fisheries/Paula Ayotte.*

Figure 22. Trends in mean biomass (g·m⁻²) of large-bodied fishes (≥ 50 cm total length) from towed-diver surveys across the study period 2001–2015 at Baker, Howland, Jarvis, Kingman, Palmyra, Johnston, and Wake. Total large fish biomass is shown for each island in top row. The following rows show biomass of key families: jacks (Carangidae), parrotfishes (Scaridae), rays (Myliobatidae), sharks (Carcharhinidae), snapper (Lutjanidae), and surgeonfishes (Acanthuridae). Sampling at all islands began in 2001, with the exception of Johnston and Wake, beginning in 2004 and 2005, respectively. Total large fish biomass is scaled to maximum large fish biomass found at each island with each subsequent family scale to maximum biomass found across the PRIMNM (note the differences in scale on the y-axes). Error bars indicate standard error (± 1 SE) of the mean.

INTEGRATING ECOSYSTEM COMPONENTS

With the transition toward ecosystem-based management, it is useful to develop indicators that integrate across ecosystem components to describe the overall condition or status of coral reefs. Following an approach developed for a suite of NCRMP Coral Reef Condition Report Cards, CREP has created a Benthic Condition Index, a Reef Fish Condition Index, and a Climate Condition Index that use various Pacific RAMP data sets collected in recent years. An overall Coral Reef Condition Index is composed of equally weighted Benthic Condition, Fish Condition, and Climate Condition Indices.

The components of the Benthic Condition Index are benthic cover, including coral, crustose coralline algae and macroalgae; generic richness; adult coral colony densities; juvenile coral colony densities; and partial mortality rates. Colony densities and partial mortality were based on selected coral genera that are ecologically important and abundant at each island. Scores increased with increasing values for all indicators other than macroalgae cover and partial mortality, for which scores decreased with increasing values. The components of the Reef Fish Condition Index are reef fish biomass, mean size of target families, and a combined predator index comprised of shark abundance and total piscivore biomass. The components of the Climate Condition Index are temperature stress, reef material growth, and ocean acidification. Scoring for the components was based on a variety of approaches, all with the goal of generating values on a 0–100 scale, where 90+ represents excellent conditions and less than 60 represents very poor conditions.

The Coral Reef Condition Index provides an interdisciplinary synthesis of the status of the coral reef ecosystems for each of the islands/atolls in the PRIMNM that is comparable with the other U.S. islands and atolls across the Pacific. The Coral Reef Condition Index values calculated for each island in the PRIMNM are displayed as excellent (dark green), good (light green), fair (yellow), poor (orange), or very poor (red) in Figure 23. The overall Coral Reef Condition Index is fair for Johnston (78) and Baker (78) and good for Jarvis (80), Howland (81), Wake (83), Palmyra (84), and Kingman (86). The Reef Fish Condition Index scores were typically the highest of the three indices. All islands scored between good and excellent. In common with other uninhabited (or very lightly populated in the case of Wake) locations, reef-fish communities at each of the PRIMNM islands are relatively intact, with scores ranging from 84 at Baker to 100 at Jarvis. The Benthic Condition Index for all islands in the PRIMNM were fair to good, with scores ranging from 76 at Jarvis to 89 at Kingman. The fair Benthic Condition Index values at Jarvis and Johnston were primarily due to benthic composition and generic richness components of the index. At Jarvis, the low coral cover score (68), the low macroalgae score (65), and the lower generic richness score (70) led to fair benthic condition scores (76). At Johnston, a low coral cover score (43) and low generic richness score (62) decreased Johnston's overall score (79). The Climate Condition Index scores were the lowest of the three indices, ranging from poor scores at Jarvis (65) and Johnston (66) to fair scores at Howland (70), Baker (70), Palmyra (71), Kingman (72), and Wake (73). The Climate Condition Index scores were
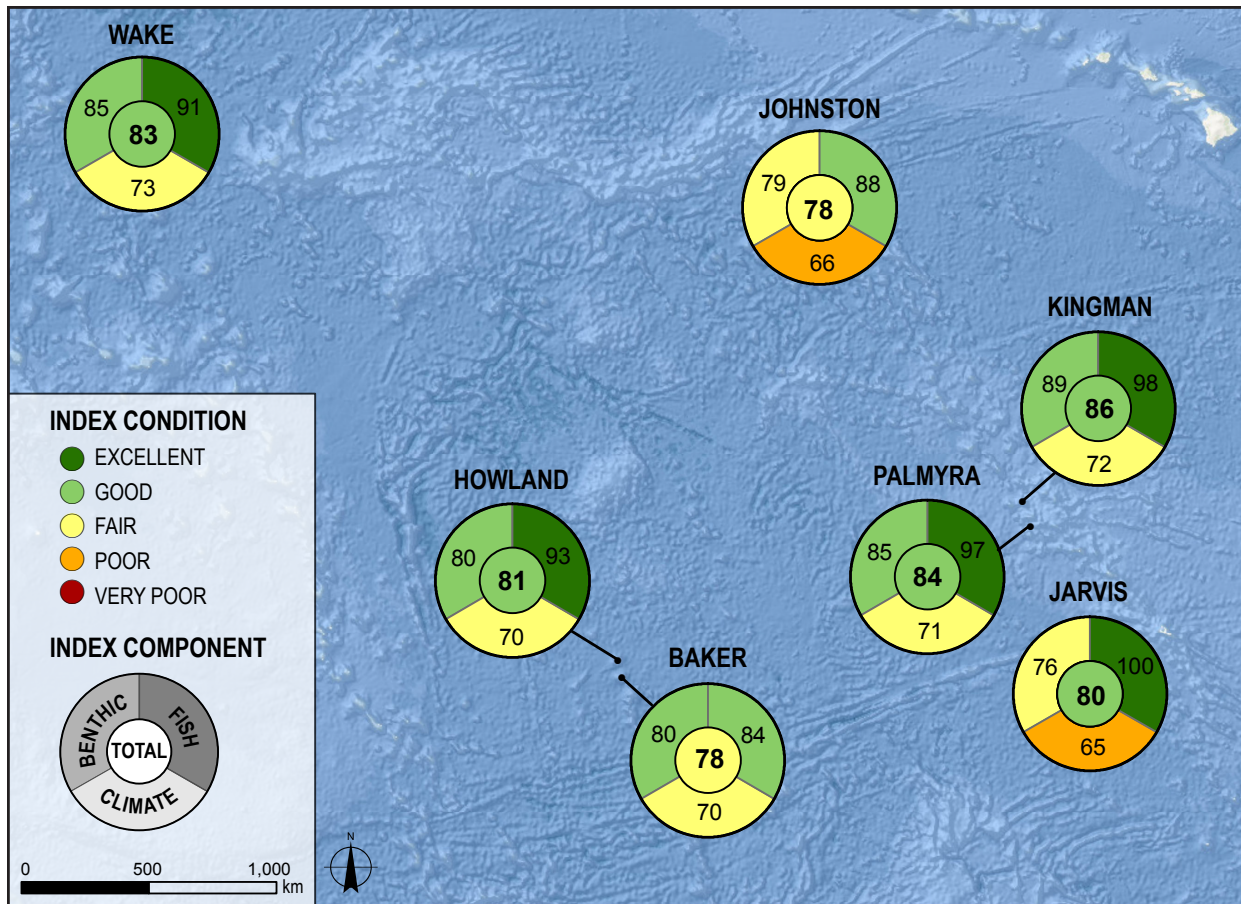
Figure 23. Coral Reef Condition Index across the PRIMNM. Reef Fish Condition, Climate Condition, and Benthic Condition Indices are represented within the pie chart components, with the circle in the middle representing the Coral Reef Condition Index (an equally weighted average of all 3 indices). Index condition ranges from excellent (dark green), good (light green), fair (yellow), poor (orange), to very poor (red).

relatively low due to the extended period of anomalously warm water temperatures associated with the 2014–2016 El Niño and global coral bleaching event. In addition, ocean acidification scores were based on comparison with pre-industrial levels that were more optimal for growth of coral reefs and are, therefore, relatively low at most or all coral reef locations in the PRIMNM. Despite these relatively low scores for the Climate Condition Index, the overall Coral Reef Condition Indices for all the islands remained fair to good through the end of 2015 (the last year of consistent data). Unfortunately, mass coral bleaching in 2015–2016 at the equatorial upwelling islands of Jarvis, Howland, and Baker, as discussed in the island highlights section, will likely decrease the Coral Reef Condition Index scores following the next round of Pacific RAMP surveys.

ISLAND HIGHLIGHTS

BAKER, HOWLAND, AND JARVIS: CORAL BLEACHING

Coral bleaching is characterized by the observed whitening of corals that results from the loss of their symbiotic algae, called zooxanthellae, whose pigments provide the colors normally associated with healthy corals. A variety of stressors can induce coral bleaching, including anomalously warm (or cold) water temperatures, increases in solar radiation, elevated water temperatures and solar radiation combined, reduced salinity, sedimentation and other land-based pollution, or bacteria and other infections (Brown, 1997). Bleaching events often coincide with El Niño episodes characterized by anomalously warm sea surface temperatures. Though bleaching does not mean the coral is dead, it can eventually lead to coral mortality, which can have devastating impacts on coral reef ecosystems. The mortality rate is often proportional to the intensity of the bleaching event (Hoegh-Guldberg, 1999), which can be measured via Degree Heating Weeks (DHW). DHWs show how much thermal stress has accumulated in an area within a given period by expressing the duration and magnitude by which temperatures have exceed a reference coral bleaching threshold, defined as 1°C above the highest summertime mean sea surface temperature (NOAA). Models have revealed that worldwide bleaching events are expected to increase rapidly in the future, though the Central Pacific will experience these events at the slowest rate (Hoegh-Guldberg, 1999). Bleaching-associated coral mortality rates are also expected to increase over the next couple of decades. Along with extreme events like ENSO, bleaching events will also be triggered by seasonal changes in water temperature in the future (Hoegh-Guldberg, 1999). Baker, Howland and Jarvis have all been impacted by these ocean warming events, causing disruption in the benthic community. Between 2009 and 2010, Baker and Howland experienced 20.65 DHW and Jarvis experienced 20.05 DHW. Between 2015 and 2016, Baker and Howland experienced 22.7 DHW and Jarvis experienced 35.8 DHW (Fig. 22). In comparison, the Central Transition Islands experienced approximately 9 DHW between 2009–2010 and 2015–2016, and the Northernmost Islands experienced 0 DHW between 2009 and 2010. During 2015–2016, the Northernmost Islands, Wake and Johnston, experienced 2 DHW and 9 DHW, respectively.
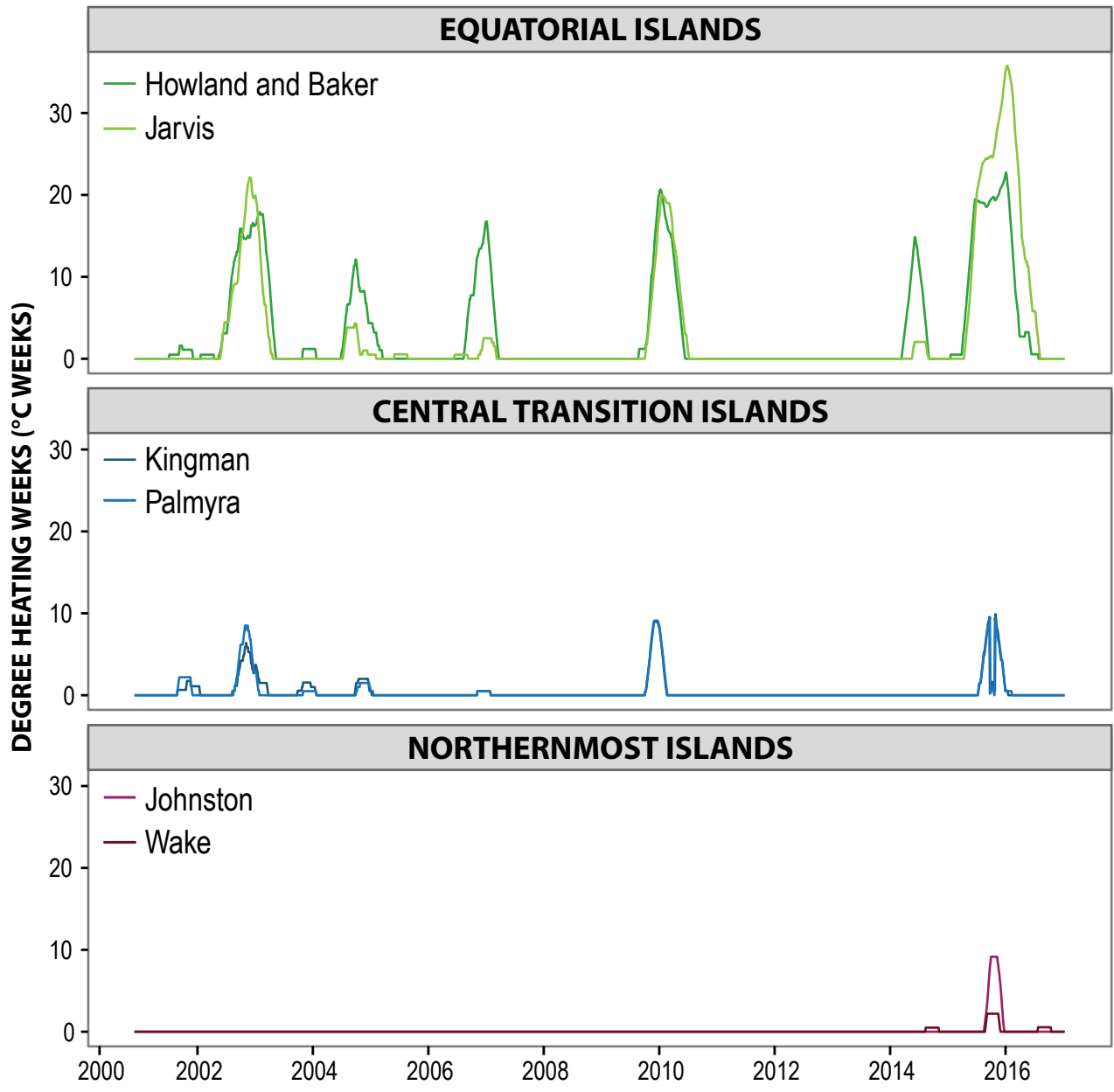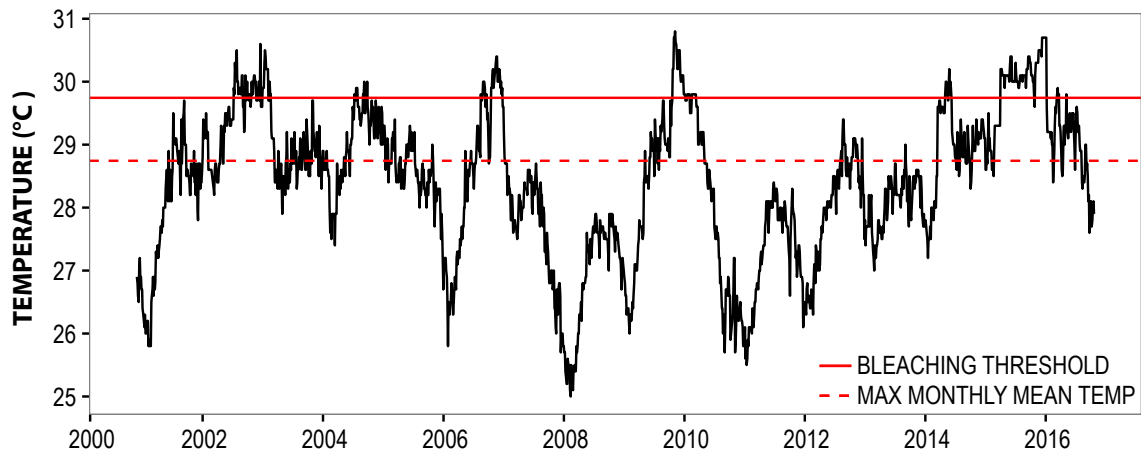
Figure 24. Degree Heating Weeks (DHW; °C weeks) across the PRIMNM from 2000–2016. Data Source: NOAA Coral Reef Watch 50-km Virtual Stations.

BAKER AND HOWLAND: 2010 BLEACHING EVENT

The equatorial islands, Baker and Howland, have high inter-annual variability in temperature, especially during El Niño years. During the 2009–2010 El Niño event, sea surface temperature exceeded the coral bleaching threshold of 29.7°C (1 degree C above the climatological maximum monthly mean; method source: Liu et al., 2006) continuously from October 22, 2009, to January 7, 2010 (Fig. 25). Sea surface temperature continued to fluctuate around the bleaching threshold from mid-January through mid-March, until the temperature progressively decreased after March 15, 2010.


Figure 25. Degree Heating Weeks (DHW; °C weeks) across the PRIMNM from 2000–2016. Data Source: NOAA Coral Reef Watch 50-km Virtual Stations.

A Pacific RAMP cruise surveyed reefs on Baker and Howland in February 2010, just after the El Niño event. The surveys indicated a spike in bleaching at those islands, with mean bleaching occurrence estimated at 38% for Baker and 35% for Howland. Despite similar degree heating week measurements in 2010, Jarvis did not exhibit the same spike in bleaching occurrence. By the following survey year, 2012, the bleaching occurrence had decreased to 11% and 4% for Baker and Howland, respectively (Fig. 20), indicating potential recovery since live coral cover did not decrease from 2009–2012. This is evident when comparing the long-term averages of coral cover from 2005–2015 (Fig. 18).

Reduction of local and global stressors is essential for sustaining benthic community health and promoting coral resilience after a bleaching (or other disturbance) event. Stressors can be reduced by decreasing land-based pollution and increasing connectivity and gene flow to bolster coral recovery from periodic bleaching events (Hughes et al., 2003, Hughes et al., 2010). Additionally, increasing grazer and detritivore biomass decreases macroalgal and turf algal cover and increases encrusting algae, including reef-building CCA. Furthermore, biomass of large parrotfish appears to be positively associated with increased live coral cover. The scraping and excavating of parrotfish open new sites on the reef that facilitate the settlement, survival, and growth of CCA and coral (Heenan and Williams, 2013). A healthy herbivorous fish community may have contributed to Baker and Howland's observed recovery from the 2010 bleaching event and prevented a possible phase shift to an algal-dominated reef (Fig. 18).

JARVIS: 2015-2016 BLEACHING EVENT

While Jarvis did not experience high levels of bleaching during the 2009–2010 El Niño as Baker and Howland did despite the same number of degree heating weeks (Fig. 24), Jarvis was severely impacted by the 2015–2016 El Niño, during which abnormally high sea surface temperatures continuously exceeded the coral bleaching threshold of 28.7 ºC from April 16, 2015, until February 29, 2016. SST continued to fluctuate around the bleaching threshold from early March through mid-May of 2016, until the temperature progressively returned to normal conditions after May 19, 2016 (Fig. 26). This amounted to Jarvis surpassing the coral bleaching threshold for 43 consecutive weeks, 3.7 times longer than that experienced by Baker and Howland in 2009–2010.
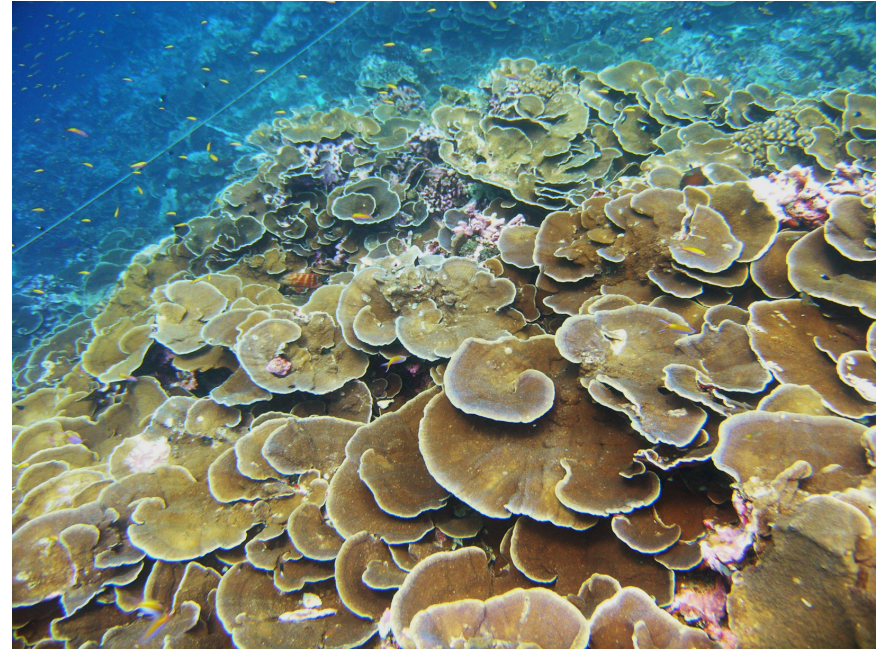
Forereef coral communities at Jarvis Island in 2006 before the bleaching event, Photo: NOAA Fisheries/Bernardo Vargas-Ángel.

Forereef coral communities at Jarvis Island during the 2015–2016 bleaching event, Photo: Woods Hole Oceographic Institution/Anne Cohen.

Based on REA StRS image analysis, the hard coral cover at Jarvis declined from 17.8% in 2015 (pre-bleaching event), to 0.31% in 2016 (post-bleaching event), representing a decrease of 98% (Fig. 27). The mass mortality of the coral community may have negative impacts elsewhere in the ecosystem. NOAA is currently studying not only how changes in coral cover are affecting the islands, but also how other biological aspects associated with the thermal stress have changed. A more comprehensive publication addressing these changes is forthcoming. Through the continuance of long-term monitoring, NOAA will quantify the impacts of the 2015-2016 El Niño on the coral reef ecosystem at Jarvis and track recovery. While NOAA did not visit Baker or Howland in 2016, it is likely that similar impacts occurred since ocean temperatures also exceeded the bleaching threshold (Fig. 25). As the frequency of these high temperature events is projected to increase in coming years, it is important to track how a coral reef ecosystem system with few human impacts, such as Jarvis, responds to climate events.
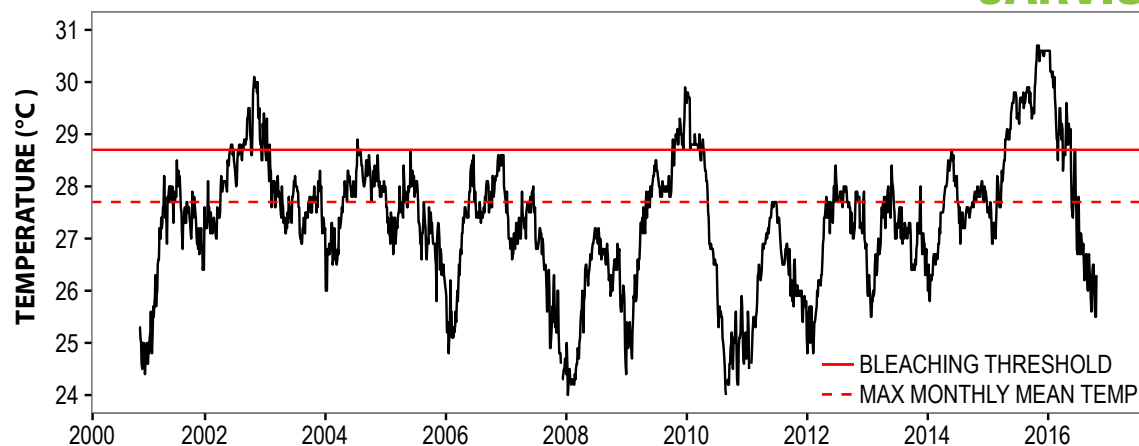
JARVIS

Figure 26. Sea Surface Temperature (SST) at Jarvis Island from 11/28/2000 to 10/13/2016. Data Source: NOAA Coral Reef Watch 50-km Virtual Stations.
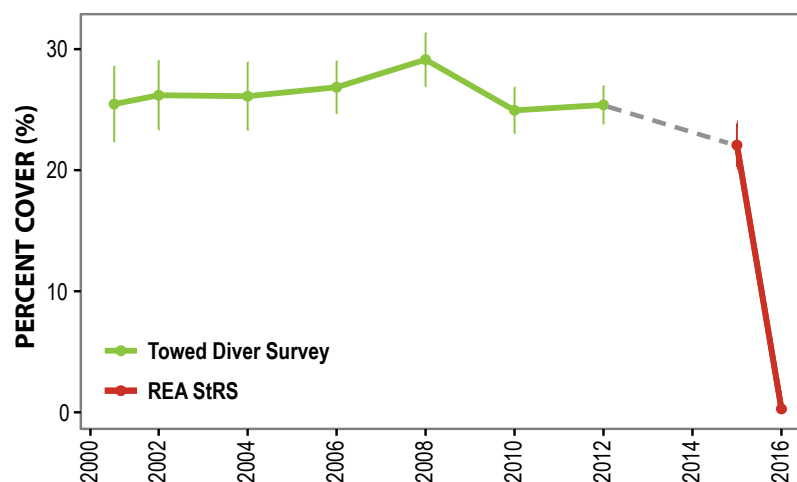

Figure 27. Percent coral cover for forereef strata at mid-depths at Jarvis from benthic towed-diver surveys from 2001–2012 (green) and from 2015–2016 REA StRS surveys (red). A severe drop in live coral cover from 2015 to 2016 is evident.
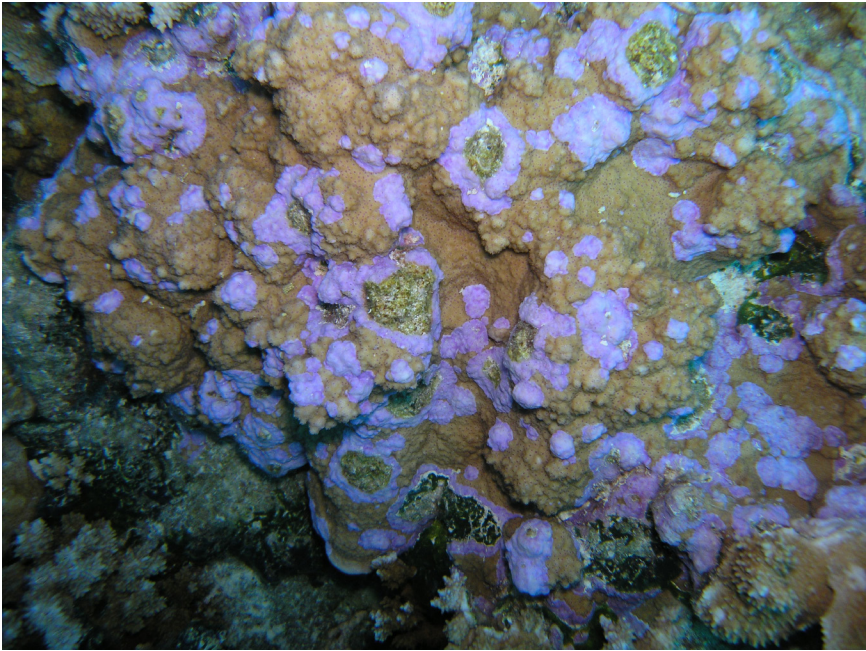
JOHNSTON

Johnston Atoll was impacted by human presence more than any other island within the PRIMNM. The navy dredged and filled the atoll to expand Johnston, making it an essential fueling depot for U.S. military aircrafts and submarines (Rauzo 2016; Coles et al. 2001). Johnston Atoll became one of the busiest terminals in the Pacific during WWII (Rauzo 2016; Magier et al. 2012). In 1958, President Kennedy initiated nuclear weapon testing at Johnston. In 1962, the Bluegill Triple Prime test failed and spilled americium and plutonium across the atoll. The contaminated sand was raked into a pile now referred to as "Mount Pluto." In 1969, the U.S. military removed its chemical weapon stockpile from Johnston after the accidental leakage of VX nerve gas injured 25 Japanese in Okinawa (Rauzo 2016). The Johnston Atoll Chemical Agent Disposal System (JACADS) was created in 1971, and incinerators and disassembly units were built on the downwind side of the island in 1985 (Rauzo, 2016; Magier et al. 2012; Coles et al. 2001). By 2000, JACADS had successfully destroyed 4 million pounds of toxic chemicals on Johnston, including 5,600 bombs, 13,300 land mines, 43,600 mortars, 72,300 rockets, and 277,800 projectiles. However, 30,000 gallons of herbicide Agent Orange were reported to have leaked into the soil (Rauzo 2016). The JACADS facility was dismantled after the mission was completed (Rauzo 2016; Magier et al. 2012). Johnston Atoll was decommissioned as a military base and most of the buildings were removed by 2004. Although there were multiple ecological disturbances experienced at Johnston Atoll, there is not enough baseline information to quantify the impacts of chemical contaminants on coral reef health (Johannes and Betzer, 1975). The sediments and fish in the northwest region of Johnston Island near the detonation areas and where the Agent Orange was stored exhibited the highest concentration of chemical pollutants. Contaminants in fish tissues were also higher at sites with polluted sediments (Lobel and Lobel, 2008). However, recent studies reveal that the remaining herbicide Agent Orange in the soil no longer poses significant ecological risks to the atoll (Lobel et al., 2012).

Leaking Agent Orange Barrels in storage at Johnston Atoll circa 1976, Photo: U.S. Government.


Johnston Atoll Chemical Agent Disposal System building, Photo: U.S. Army Chemical Materials Agency.

Skeletal growth anomalies on colony of Montipora at Johnston Atoll.
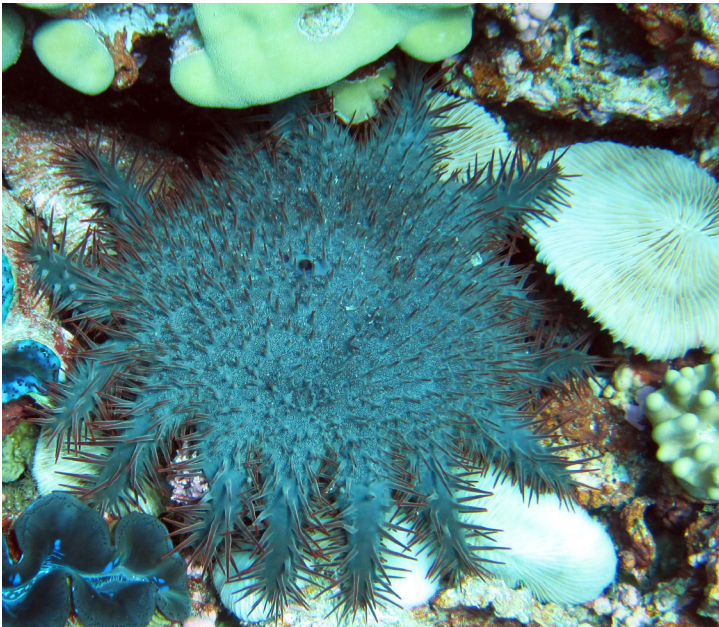*Photo: NOAA Fisheries/Bernardo Vargas-Ángel.*

Disease Occurrence

Surveys conducted in 2005-2006, revealed that the disease occurrence was significantly higher at Johnston than any other island in the PRIMNM (Vargas-Angel, 2009). While the anthropogenic disturbances at Johnston, described above, have not been directly linked to higher disease occurrence, the low occurrence of disease at other islands within the PRIMNM could suggest that the higher disease occurrence at Johnston may be associated with the past environmental disturbances. Notably, sites with closest proximity to environmental stressors (such as Agent Orange storage sites, explosive detonation areas, open burn pits) exhibited the highest levels of disease prevalence for all diseases at Johnston. Of the diseases present at Johnston, white-syndrome is particularly concerning, as it leads to rapid tissue loss. White-syndrome occurred primarily at Johnston Atoll with one case of white-syndrome at Wake (Vargas-Ángel, 2009).
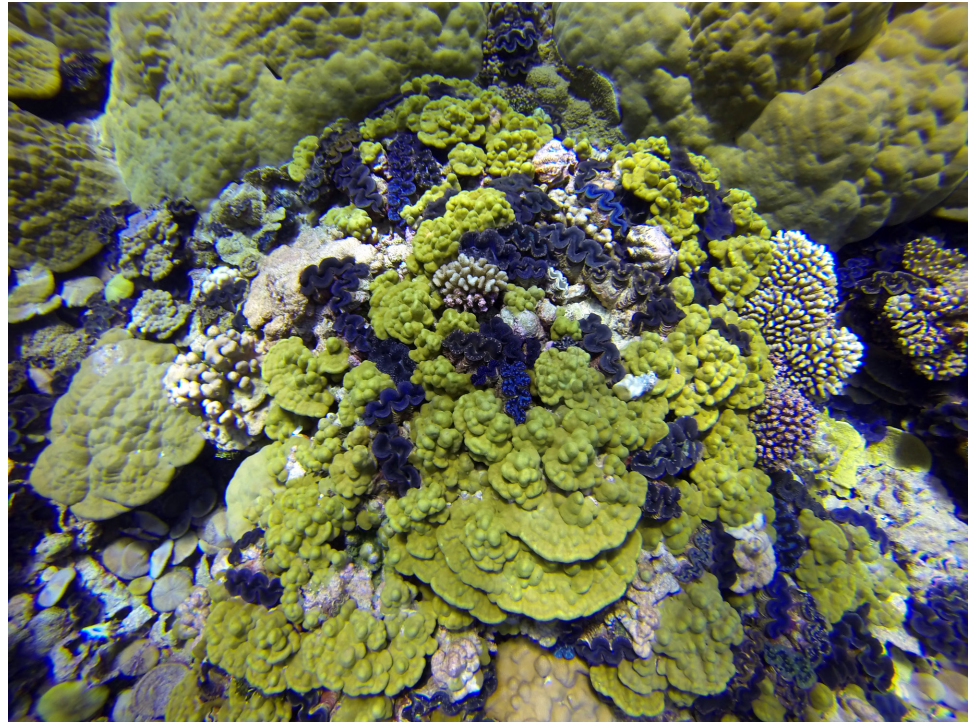
KINGMAN REEF

Kingman Reef is notable for its remarkably high fish biomass and high coral cover, but also for recurrent outbreak level populations of the corallivorous crown-of-thorns (*Acanthaster planci*) sea stars. Kingman Reef is also known for its large population of giant clams (*Tridacna maxima* and *Tridacna squamosa*).

Crown-of-thorns (Acanthaster planci) sea star close-up (left) and giant clams at Kingman Reef (above), Photos: NOAA Fisheries/James Morioka.

Crown-of-thorns at Kingman Reef, Photo: NOAA Fisheries/Paula Ayotte.

CROWN OF THORNS DENSITY

Year	Organisms per km⁻²
2001	1500 - 5000
2002	5000 - 10,000
2004	> 10,000
2006	
2008	Towed-diver tracks
2010	(2001-2015)
2012	
2015	

Figure 28. Crown-of-thorns (COTS) sea star outbreaks where densities exceeded 1500 organisms km⁻². Densities were calculated from towed-diver surveys at Kingman Reef conducted from 2001–2015. Colors represent different survey years. COTS at Kingman have historically demonstrated higher densities within the backreef reef zone.

Crown-of-Thorns Sea Stars

Crown-of-Thorns sea stars (COTS) are coral-eating invertebrates that can inflict devastating impacts to the ecological integrity of coral reefs. COTS outbreaks can alter coral community structure and functioning (Colgan 1987, Pratchett 2007), promote macroalgal growth (Moran 1986, Bradbury et al. 1985), and affect fish population dynamics (Williams 1986, Hart 1996). CREP implements towed-diver surveys to assess the status of COTS populations; densities greater than 1,500 organisms km⁻² are considered outbreak conditions (Moran, 1992). COTS populations at Kingman have consistently exhibited outbreak levels at multiple locations around the island since the inception of the surveys in 2002 (Fig. 28). The backreef region of Kingman Reef experienced the highest COTS densities with populations reaching more than 10,000 organisms km⁻². Although Kingman Reef is not a high island with terrestrial runoff, high nutrient loadings and specific climatic and ecological conditions are correlated with COTS outbreaks across the Indo-Pacific (Timmers, 2012). Despite persistent COTS outbreaks, Kingman has relatively high coral cover and relatively low macroalgal cover, per 2014–2015 REA and towed-diver surveys (Fig. 18).
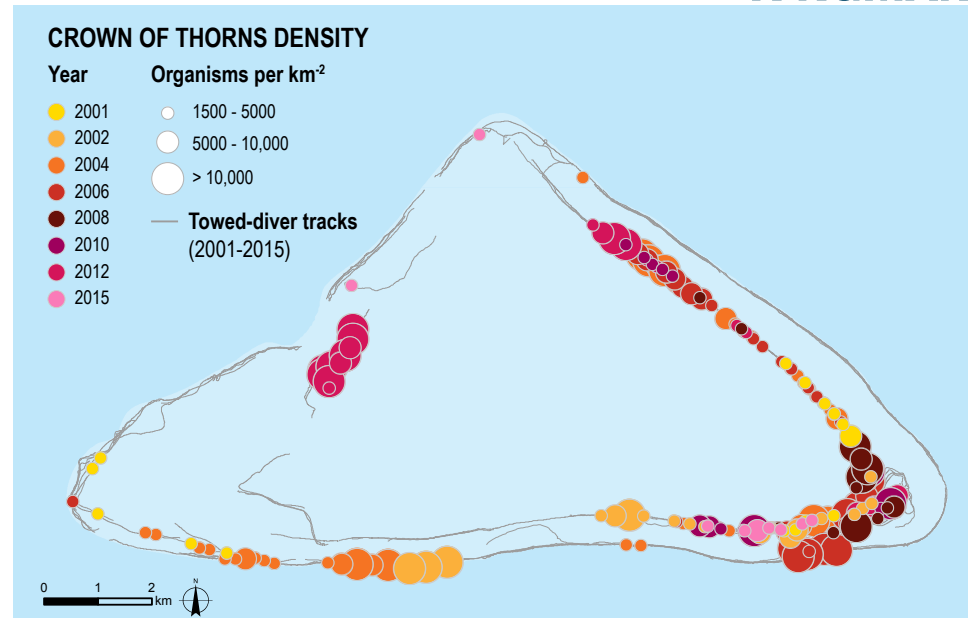
GIANT CLAMS DENSITY
Mean Interpolated Density
Giant Clams per 100 m^{-2}

- 0 - 1.00
- 1.01 - 2.00
- 2.01 - 5.00
- 5.01 - 15.00
- 15.01 - 25.00
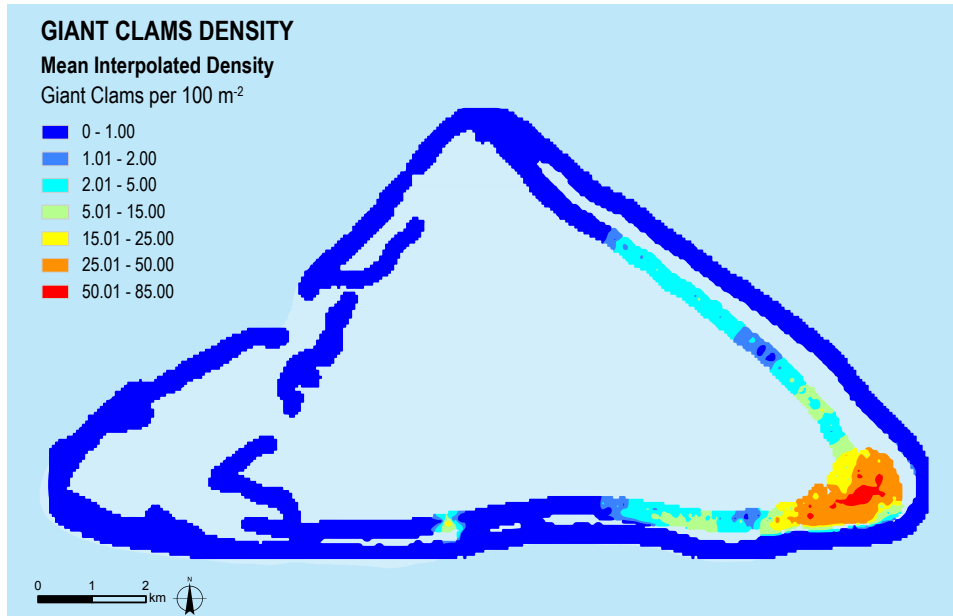- 25.01 - 50.00
- 50.01 - 85.00

Figure 29. Mean giant clam densities (organisms 100 m^{-2}) from towed-diver surveys at Kingman Reef. Towed-diver surveys indicate highest concentration of these clams in the southeastern clam garden.

Giant Clams

Giant clams are a valuable food source, and exports of clam meat coupled with shell harvesting are linked to their stock depletion. Habitat degradation and decreases in spawning success as giant clam abundances decline are also exacerbating population decreases (Teitelbaum and Friedman, 2008). *Tridacna maxima* and *T. squamosa*, both found at Kingman, are listed as species of "least concern" by the International Union for Conservation of Nature (IUCN) (Wells 1996). Their status, however, has not been evaluated by the IUCN since 1996. A petition was submitted to the Secretary of Commerce by the National Marine Fisheries Service to protect giant clams, including *T. maxima* and *T. squamosa* under the Endangered Species Act, and results are still pending (Meadows, 2016).

Extant species of giant clams are only found in the Indo-Pacific region (Newman and Gomez, 2000). These filter feeders form symbiotic relationships with photosynthetic algae, zooxanthellae that transfer carbon to host tissues (Klumpp et al., 1992). The zooxanthellae need sunlight to perform photosynthesis, thus giant clams are found in depths up to 20 meters and prefer clear, oceanic waters where light can penetrate to the bottom (Meadows, 2016). Their growth is limited by nitrogen in the environment, and addition of organic or inorganic nitrogen in the form of ammonium or nitrate can stimulate tissue growth (Hawkins and Klumpp, 1995).

Giant clams provide numerous ecological services to reefs. Predators, scavengers, and other feeders rely on their tissues, zooxanthellae discharges, and wastes for food. Their shells and mantle cavities allow for the colonization of epibionts, small organisms which live on the surface of their tissues. Furthermore, water filtering allows them to mitigate eutrophication. Giant clams also produce calcium carbonate shell material that is eventually incorporated into the reef framework (Neo et al., 2015). Towed-diver surveys revealed densities as high as 105 organisms 100 m^{-2} located within the southeastern clam garden; this is equivalent to about 1 clam for every square meter of reef habitat. Mean densities within this area for all survey years ranged from 50 to 85 clams 100 m^{-2}, or about 5–8 clams 10 m^{-2} (Fig. 29).

PALMYRA ATOLL

In 1991, the longline vessel, *F/V Hui Feng No. 1*, ran aground on the western terrace of Palmyra Atoll (USFWS, n.d.). The shipwreck led to leaching of iron, a limiting ocean nutrient, which fueled the proliferation of the invasive corallimorph *Rhodactis howesii* (Work et al., 2008; Kenyon, 2011). Multiple means of reproduction (sexual, budding, fragmentation, and fission) allow *Rhodactis* to quickly spread, smothering and killing the surrounding corals. At Palmyra, the spread of *Rhodactis* rapidly transformed the shipwreck reef area from a species-rich coral assemblage into a dense, monotypic stand of corallimorphs (Kenyon, 2011). Surveys indicated that in 2005–2006, the corallimorph outbreak extended 50–100 m from the ship and coral cover was estimated at 30% around the shipwreck (Work et al., 2008). By 2007, the corallimorph population had spread out to about 1100 m from the ship, and the surrounding coral cover surrounding had decreased to 1%. At the height of the invasion, prior to the shipwreck removal in 2013, the corallimorph invasion carpeted over 3 km^2 (741 acres) of reef once dominated by reef-building corals (Work et al., 2008).

Due to the devastation of the reef on this remote and relatively pristine atoll, the U.S. Fish and Wildlife Service removed the shipwreck as the first step in restoring the reef by cutting off the nutrient supply, a necessary resource for *Rhodactis*. The *Hui Feng No. 1* wreck site was declared clean and free of debris on December 31, 2013 (USFWS, n.d.). Along with the shipwreck removal, the U.S. Fish and Wildlife Service performed restoration efforts with the goal to remove 70% of the corallimorph by 2016 (Kenyon, 2011). Only partial removal occurred, and monitoring is ongoing to track the recovery process. Despite this invasion, island-wide mean coral cover and fish biomass were comparable to the other islands in the PRIMNM, and the Coral Reef Condition Index had a similar score (84) as neighboring Kingman Reef (86).
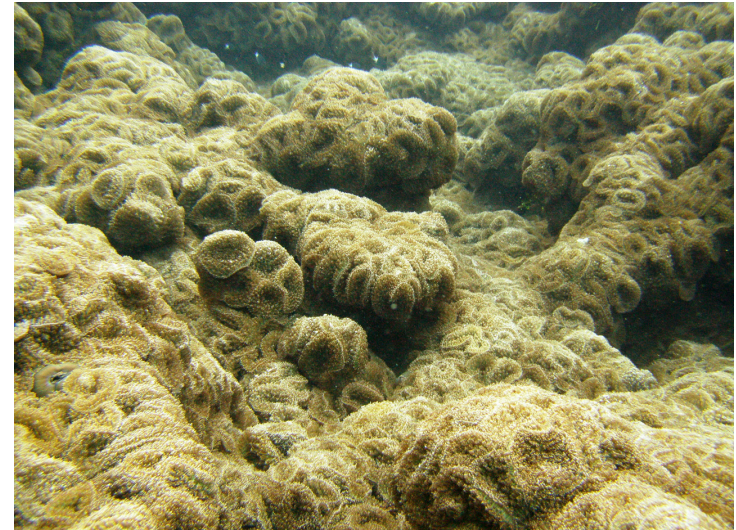
Monoculture of Rhodactis howesii at Palmyra Atoll in 2008, Photo: NOAA Fisheries.

Reef not affected by corallimorph infestation in Palmyra Atoll in 2015, Photo: NOAA Fisheries.

WAKE ATOLL

Two large fish species of interest in the Indo-Pacific are the humphead wrasse (*Cheilinus undulatus*) and bumphead parrotfish (*Bolbometopon muricatum*). The humphead wrasse is the largest member of the wrasse family and can reach a maximum size of 2 m and weight of 190 kg (Sadovy et al., 2003). The bumphead parrotfish is the largest herbivorous and corallivorous fish on coral reefs, and can reach 1.5 m in length and weigh over 75 kg (Muñoz et al., 2014). Populations of both of these ecologically important species have declined in parts of their range over the last several years (Kobayashi, et al., 2011; Sadovy et al., 2003). The bumphead parrotfish is a highly-prized fishery target and cultural resource, and the humphead wrasse is among the most prized in the live reef-fish trade and has considerable cultural value (Muñoz et al., 2014; Sadovy et al., 2003). Both fish species are particularly sensitive to fishing pressure, and due to their population decline, humphead wrasse and bumphead parrotfish are IUCN Red Listed as Endangered and Vulnerable, respectively. They are also species of concern for the National Marine Fisheries Service.

Bumphead parrotfish (Bolbometopon muricatum) and humphead wrasse (Cheilinus undulatus) at Wake Atoll, Photo: NOAA Fisheries/Kevin Lino.
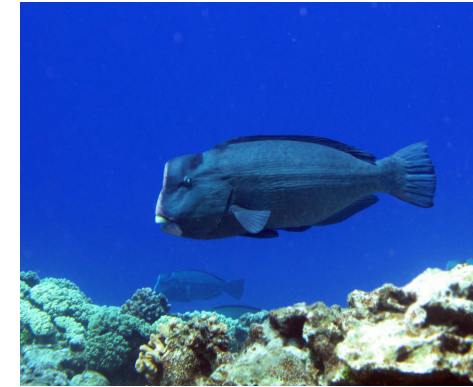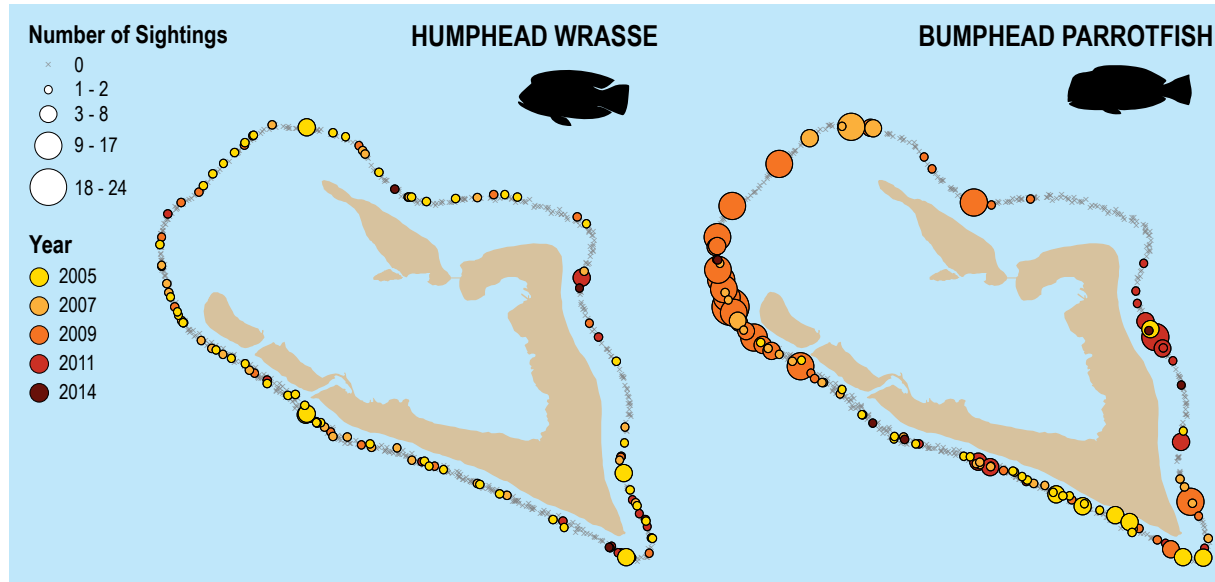
WAKE

Figure 30. Number of individuals seen per forereef towed-diver transect segment from 2005–2014. Bubble sizes represent the number of sightings and are colored by the representative year. Bumphead parrotfish at Wake Atoll, Photo: NOAA Fisheries/Kevin Lino.

Among the PRIMNM, Wake is notable for having a relatively low large fish biomass; however, the sightings of these two large species of concern are more common at Wake. The total number of sightings of humphead wrasse recorded on transect per year was 67 (2005), 34 (2007), 18 (2009), 24 (2011), and 3 (2014) (Fig. 30 left). The total number of sightings of bumphead parrotfish sighted on transect per year was 51 (2005), 62 (2007), 221 (2009), 40 (2011), and 5 (2014) (Fig. 30 right). Both humphead and bumphead abundance were lower in 2014 than in other years, but it is not clear whether those represent real population declines or are instead caused by some short-term phenomena at the time of the 2014 surveys. Any decline of bumpheads at Wake would be substantial, as Wake densities have been higher than at other U.S. Pacific Islands. Specifically, mean abundance of bumphead parrotfish at Wake over the five survey years was 2.8 individuals per hectare, whereas their abundance at the other 5 U.S. Pacific islands recorded by NRCMP surveys averaged less than 0.1 individuals per hectare over the same time period.

In addition to possible temporal trends, there are also spatial patterns in bumphead parrotfish abundance. Over several years of surveys, the CREP team has observed bumphead parrotfish sightings concentrated around the northwest corner of the island, which is thought to be the spawning aggregation area for this species (Muñoz et al., 2014). These spatial observations helped identify an area with high bumphead abundances, which allowed researchers to study mating and spawning aggregation behaviors and develop crucial baselines of population density, sex ratio composition, and productivity of a spawning aggregation in a place where bumphead are not exploited.

CONCLUSIONS

Standardized ecological and climatological monitoring surveys conducted by CREP are focused on long term trends of ecosystem health and status across the entire Pacific. Overall, the Pacific Remote Islands Marine National Monument fare well when compared to other islands in the U.S. Pacific, often having higher coral cover and fish biomass. The ecosystem is largely intact due to their remote location and relative absence of human presence. While these islands are not subjected to direct human pressures such as land-based sedimentation or fishing, they are significantly affected by climate change and recurring climate patterns such as ENSO. Climate change, especially rising ocean temperatures, remains a major threat to the Monument and may impact the health of the reef ecosystem. To track possible changes in the future, it is necessary for CREP to continue their Pacific-wide monitoring program. Additionally, marine debris and invasive species are a growing threat to these areas, despite their remote location. Thus, monitoring these risks may help to inform management in the future.

Slender Anthias (Luzonichthys whitleyi), Bartlett's Anthias (Pseudanthias bartlettorum), and Fusilier Damselfish (Lepidozygus tapeinosoma)at Jarvis Island, Photo: NOAA Fisheries/Kevin Lino.

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Heller's barracuda (Sphyraena helleri) at Jarvis Island,
Photo: NOAA Fisheries/Kevin Lino.

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APPENDIX B: SURVEY INSTRUMENT

Understanding and Awareness of Large-Scale Federal Marine Conservation Efforts in the Pacific Ocean

Purpose of Study

The purpose of this study is to identify the general public's knowledge, attitudes, and perceptions of large scale Marine Protected Areas (MPAs) and possible threats facing our oceans, with a primary focus on federally managed MPAs across the Pacific. This study is being conducted as part of our master's thesis project at the University of California, Santa Barbara. The study will add a valuable component to our project as it will help us identify potential knowledge gaps. We will use the survey responses to determine effective engagement strategies and materials to increase public awareness and understanding of marine conservation.

Background Information
1. In what state or U.S. Territory do you live?
   a. Dropdown or write in answer for all states

Relationship with the Ocean
2. About how frequently do you visit the ocean?
   a. Less than once a year
   b. Once a year
   c. Once every 6 months
   d. Once a month
   e. More than twice a month
   f. Once a week or more
3. If you visit the ocean, what activities are you most likely to participate in: (select all that apply)
   a. Sunbathing
   b. Surfing
   c. Swimming
   d. Fishing
   e. Snorkeling
   f. Scuba diving
   g. Non-motorized boating (kayaking, sailing, etc.)
   h. Motorized boating
   i. Walking the beach
   j. Other (write in option)
4. What ocean benefits, if any, do you think are most important? (select up to 2)
   a. Recreation
   b. Food
   c. Livelihood
   d. Cultural
   e. Aesthetic (beautiful appearance) value

       f. None

       g. Other

Marine Protected Areas

5. We know that people have different levels of familiarity with marine conservation issues. Have you heard of a marine protected area?
   a. Yes
   b. No
6. Have you heard of these following Marine National Monuments located in the Pacific Ocean? (select all that apply)
   a. Papahanaumokuakea Marine National Monument
   b. Marianas Trench Marine National Monument
   c. Moorea Marine National Monument
   d. Pacific Remote Islands Marine National Monument
   e. Rose Atoll Marine National Monument
   f. Coral Triangle Marine National Monument
   g. None
7. Which actions or policies would you support to protect coral reef ecosystems? (select up to 3?)
   a. Regulate fishing
   b. Encourage tourism
   c. Support education programs
   d. Development of marine protected areas (add definition?)
   e. Restrict all access
   f. Regulate coastal pollution
   g. Research
   h. Protecting coral reef ecosystems is not a priority for me
8. Which of the following do you consider to be benefits offered by marine protected areas? (select all that apply)
   a. Decreases fishing pressures
   b. Prevents sea surface temperatures from increasing
   c. Increases biodiversity
   d. Increases fish size
   e. Protects habitat
   f. Reduces marine debris
   g. None

Coral Reefs

9. In your opinion, the health of coral reefs in the Pacific is:
   a. Excellent
   b. Good
   c. Fair
   d. Poor
   e. Don't know
10. To what extent do you feel climate change poses a threat to coral reefs? (sliding bar)
    a. Not at all (0)
    b. Slightly (1)
    c. Moderately (2)
    d. Very (3)

e. Extremely (4)
f. Don't know (U)
11. To what extent do you feel overfishing poses a threat to coral reefs? (sliding bar)
   a. Not at all
   b. Slightly
   c. Moderately
   d. Very
   e. Extremely
   f. Don't know
12. To what extent do you feel marine debris poses a threat to coral reefs? (sliding bar)
   a. Not at all
   b. Slightly
   c. Moderately
   d. Very
   e. Extremely
   f. Don't know

Impacts on the Ocean
13. How much impact do you think you personally have on the ocean? (sliding bar)
   a. None at all
   b. Very Little
   c. Moderate
   d. High
   e. Don't know

14. Which actions do you take at home for environmental reasons? (select up to 3)
   a. Properly dispose of chemicals
   b. Don't use products with microbeads
   c. Recycle
   d. Use reusable bags
   e. Buy sustainably caught fish
   f. Use reef safe sunscreen
   g. Beach cleanup
   h. Use alternative transportation (bike, bus)
   i. I don't affect coral reefs
   j. Other

Media
15. Marine conservation information is often published in various ways. Given the following options, which would you be most responsive to? (select one)
   a. Video
   b. Interactive map
   c. Written (i.e. news article, blog)
   d. Photos
   e. Other (write in option)
   f. Would not seek out media about marine conservation