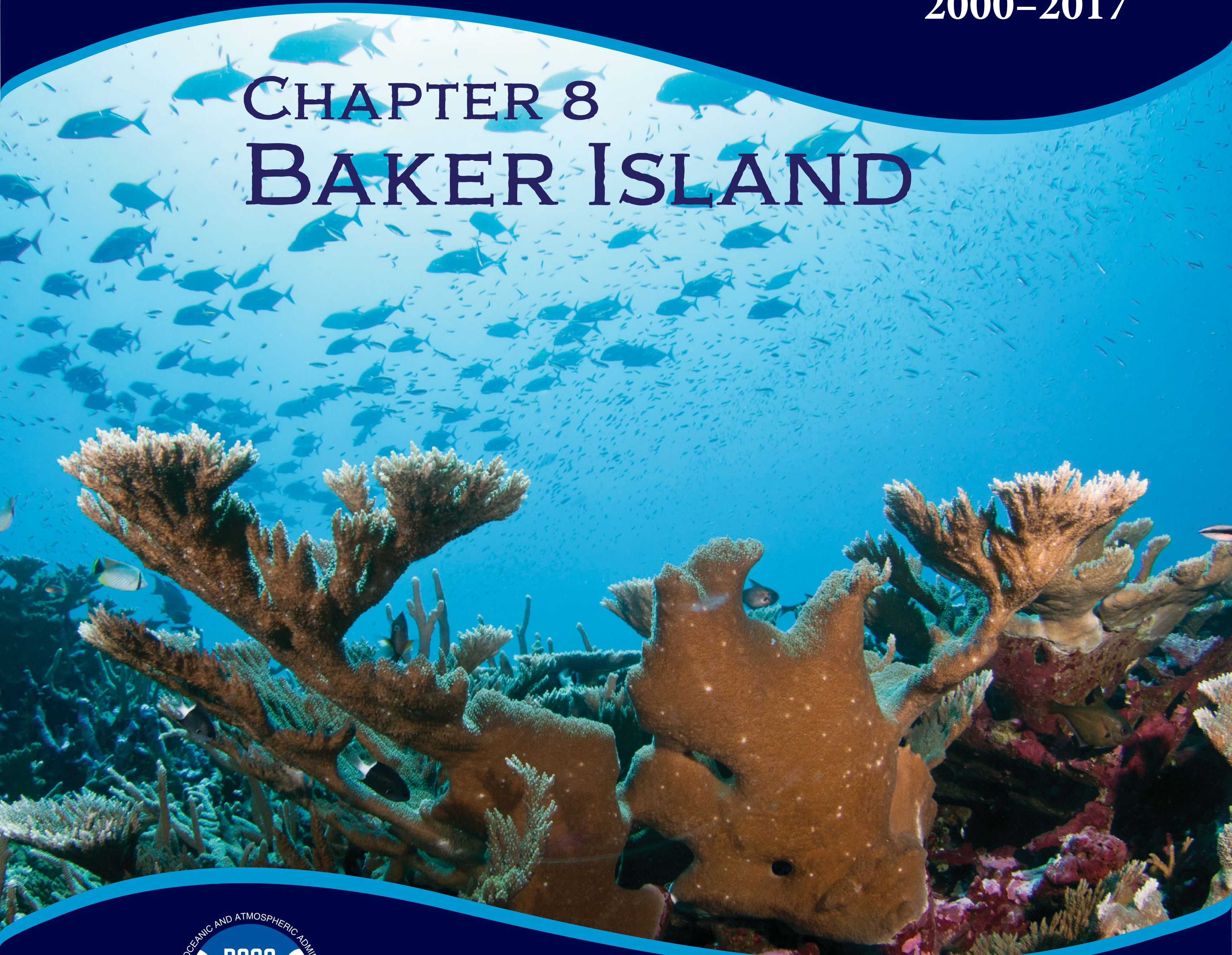
Coral Reef Ecosystem Monitoring Report For The Pacific Remote Islands Marine National Monument

2000–2017

Chapter 8 Baker Island



Ecosystem Sciences Division

Pacific Islands Fisheries Science Center

Coral Reef Ecosystem Monitoring Report for the Pacific Remote Islands Marine National Monument 2000–2017

Chapter 8: Baker Island

Authors

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Citations

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Front Cover: *Acropora* and *Caranx lugubris* at Baker Island. Photo: Jeff Milisen, NOAA Fisheries.

Back Cover: *Acropora* and several anthias at Baker Island. Photo: Jeff Milisen, NOAA Fisheries.

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Executive Summary

The work presented within the *Coral Reef Ecosystem Monitoring Report for the Pacific Remote Islands Marine National Monument 2000–2017* is a direct result of nearly 20 years of research in the U.S. Pacific Remote Islands Marine National Monument (PRIMNM) conducted over hundreds of field days aboard National Oceanic and Atmospheric Administration (NOAA) ships by dozens of contributors from NOAA, University of Hawaii–Joint Institute for Marine and Atmospheric Research, and partner scientists. For their efforts, we are eternally grateful and appreciative of their work.

Here, we examine seven islands and atolls within the PRIMNM, using a variety of methods across multiple disciplines in order to gauge how these unique ecosystems have fared through time. In brief, this report describes and highlights the spatial patterns and temporal trends of marine ecosystems associated with Johnston Atoll, Howland Island, Baker Island, Jarvis Island, Palmyra Atoll, Kingman Atoll, and Wake Atoll, along with cross-comparative assessments among the islands, reefs, and atolls of the PRIMNM and other island areas of the U.S. Pacific Islands region in "Chapter 9: Pacific Remote Islands Marine National Monument in the Pacific-wide Context."

Each island, reef, and atoll chapter, along with the Pacific-wide chapter, is constructed as follows: Introduction, Benthic Characterization, Ocean and Climate Variability, Coral Reef Benthic Communities, Cryptofauna Biodiversity (in the Pacific-wide chapter only), Microbiota, Reef Fishes, Marine Debris, and Ecosystem Integration.

Key Findings

- Given the wide geographic extent and large variance in oceanographic conditions experienced across the PRIMNM, it is more informative to consider the PRIMNM as three groupings: the northernmost oligotrophic islands of Johnston and Wake Atolls, the central transition islands of Kingman Reef and Palmyra Atoll, and the equatorial upwelling islands of Howland, Baker, and Jarvis Islands.
- Due to the combined effects of equatorial and locally-intense topographic upwelling of the eastward-flowing subsurface Equatorial Undercurrent, Jarvis Island, and to a lesser extent Howland and Baker Islands, are subject to noticeably cooler mean sea surface temperatures (SSTs) than their nearest neighbors (Palmyra Atoll and Kingman Reef). The upwelling routinely experienced by these islands further results in the highest chlorophyll *a* (chl-*a*) concentrations and associated biological productivity measured across the PRIMNM. In contrast, the lower chl-*a* concentrations observed at Wake and Johnston Atolls are similar to concentrations within the Mariana Archipelago and American Samoa, which are located in the oligotrophic gyres of the North Pacific and South Pacific.
- Higher aragonite saturation values correspond to the greater availability of carbonate ions, and thus favor the growth of corals, crustose coralline algae, and other marine calcifiers. The PRIMNM's northernmost oligotrophic islands (Johnston and Wake Atolls) retained two of the lowest average carbonate accretion rates in the U.S. Pacific Islands, indicating low reef growth over time.

- Jarvis Island experienced a massive decline in coral cover in response to acute thermal stress associated with the 2015–2016 El Niño warming event; Jarvis has shown no substantial recovery in coral cover since. Coral cover at Baker Island and Kingman Reef also declined from 2015 to 2018, reflecting a 13% decline over 3 years at both islands.
- Calcifiers comprised approximately half of the benthic communities at Howland Island, Kingman Reef, and Baker Island. Despite Jarvis's catastrophic decline in coral cover in 2016, the recent proportion of calcifiers at Jarvis Island remains high, likely due to a marked increase in cover of crustose coralline algae (CCA) observed in 2018.
- Across the PRIMNM, the crown-of-thorns sea star (*Acanthaster planci*, COTS) was consistently observed only at Kingman Reef and Johnston Atoll, though densities at these islands fluctuated across survey years. Localized outbreaks that were synchronized in timing across central Pacific reefs appeared to be genetically independent, rather than spread via the planktonic larvae released from a primary outbreak source.
- Mean reef fish biomass varied by a factor of >15 among all U.S. Pacific islands surveyed. The equatorial upwelling and central transition islands of the PRIMNM were among the islands that retained the highest biomass, especially of piscivores and planktivores, although Wake Atoll was an exception to this trend.
- The PRIMNM has also been notable for supporting larger abundances of species listed by the Endangered Species Act (ESA), including the greatest densities of the green sea turtle (*Chelonia mydas*) observed in the U.S. Pacific.

Scientists are increasingly recognizing the magnitude of ongoing and projected effects from global warming and ocean acidification on coral reef ecosystems. As such, this report provides an essential scientific foundation for informed decision making for the long-term conservation and management of the coral reef ecosystems within the PRIMNM. By summarizing trends in ecosystem response across space and time, this report is the first step towards assessing ecosystem resilience and identifying potential underlying drivers that impede or promote such resilience. Understanding these trends can inform the prioritization among candidate areas for management, as well as among the various types of policies and management actions themselves. In conclusion, the individual island, reef, atoll and Pacific-wide comparison chapters give resource managers and policymakers an unprecedented scale of spatial status and temporal trends to examine each ecosystem throughout the PRIMNM, with the hope of protecting and conserving these unique resources for generations to come.

Acknowledgements

We would like to give credit to all National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center (PIFSC) and Research Corporation of the University of Hawaii/Joint Institute for Marine and Atmospheric Research (JIMAR) scientists and staff, and the numerous partners who provided support to the Pacific Reef Assessment and Monitoring Program (Pacific RAMP) during 2000–2017, and contributed to the development of this report. We extend a special thanks to the officers and crews from the NOAA Ships *Townsend Cromwell*, *Oscar Elton Sette*, and *Hi'ialakai* who provided field support for the Pacific RAMP surveys. We further express our sincere appreciation to PIFSC, JIMAR, the NOAA Coral Reef Conservation Program (CRCP), and Pacific Islands Regional Office (PIRO) for funding and providing collaborative resources throughout these efforts.

We specifically acknowledge Malia Chow as PIRO branch chief for the Essential Fish Habitat-Pacific Marine National Monuments, along with PIRO's Heidi Hirsh and Richard Hall for their collaboration, reviews, and inputs throughout this report's genesis, along with their participation in associated workshops. We would like to recognize the United States Fish and Wildlife Service Pacific Islands Refuges and Monuments Office for their partnership throughout Pacific RAMP history and their participation in the workshops associated with the report. In addition, we appreciate their reviews and those of PIRO interns, Jesi Bautista and Savannah Smith of Kupu Hawaii, who collectively provided valuable inputs toward the "History and Human Influences" sections for each island, reef, and atoll chapter. We further extend our thanks to the United States Air Force, 611th CES/CEIE, Joint Base Pearl Harbor, Hawaii for their collaborative efforts at Wake Atoll and inputs toward the report and at workshops.

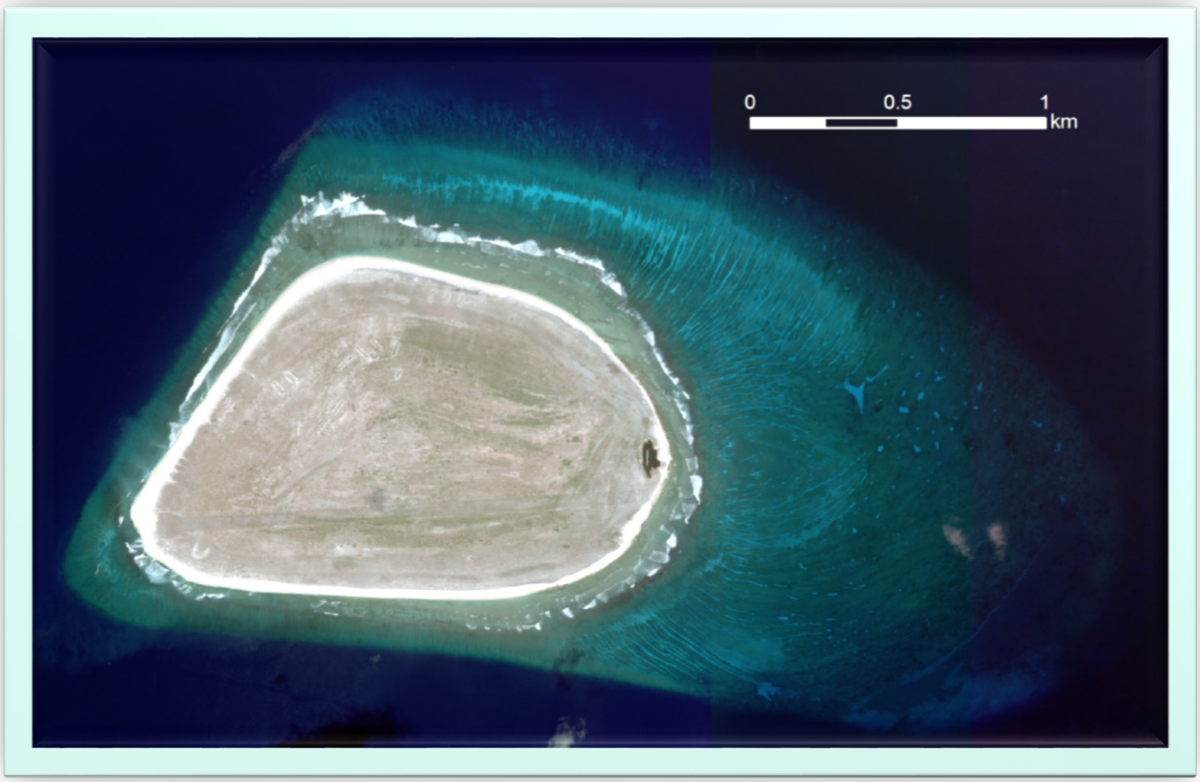
We would like to recognize PIFSC Editorial Services, in particular, Jill Coyle, Katie Davis, and Hoku Johnson for their inputs throughout the editorial process, Donald Kobayashi, PIFSC, for his extensive time and insights in conducting chapter technical reviews, and PIFSC Director Michael Seki and PIFSC ESD Director Frank Parrish for their support and reviews. In addition, we wish to express our gratitude to the CRCP Coral Reef Information System and JIMAR data managers for their efforts to manage and make Pacific RAMP data publicly accessible and compliant with the Public Access to Research Results requirements.

Lastly, we are appreciative of Tom Hourigan and Dale Brown of NOAA Fisheries, two of the earliest visionaries in the establishment of the first Pacific long-term, integrated ecosystem-based monitoring program.

PIFSC has been fortunate to work with many partners who contributed to Pacific RAMP and associated efforts, and while this list is by no means comprehensive, we sincerely thank each and every one of you. Your contributions helped make this report possible, and as a result, we have collectively provided valuable inputs to the management and conservation of the coral reef ecosystems of the Pacific Remote Islands Marine National Monument.

Coral Reef Ecosystem Monitoring Report for the Pacific Remote Islands Marine National Monument 2000–2017

Chapter 8: Baker Island



Satellite image of Baker Island, December 4, 2016.
Photo: © DigitalGlobe Inc. All rights reserved.

8.1 Introduction

Report Overview

The *Coral Reef Ecosystem Monitoring Report for the Pacific Remote Islands Marine National Monument 2000–2017* provides an overview of key spatial patterns and temporal trends of the environmental and oceanographic conditions, biological resources, and composition of coral reef ecosystems across the seven islands, atolls, and reefs of the Pacific Remote Islands Marine National Monument (PRIMNM). The data compiled for this report are from Pacific Reef Assessment and Monitoring Program (Pacific RAMP) research surveys conducted over the period from 2000 through 2017, by the National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center (PIFSC) Ecosystem Sciences Division (ESD) and external collaborating scientists.

This report represents one of many installments of ESD's ongoing efforts to bring resource managers and interested stakeholders the best available, ecosystem-based data to help them make informed decisions about the sustainable use and conservation of the resources they manage, in this case, coral reef ecosystem in the PRIMNM. The information herein serves three main purposes:

- Provide snapshots of the status and condition of coral reef resources around each of the islands, atolls, and reefs in the PRIMNM over the course of the survey periods.
- Provide a foundation of knowledge regarding ecosystem conditions in the PRIMNM for ongoing monitoring of temporal changes to the ecosystem.
- Serve as a resource for stakeholders and resource managers for understanding marine areas of interest and formulating evolving management questions about how to best manage and conserve marine resources in the face of climate and ocean changes.

The report consists of nine chapters. In addition, attached to "Chapter 9: Pacific Remote Islands Marine National Monument in the Pacific-wide Context" are Appendix A, "Total Generic Richness of Hard Corals in the PRIMNM," and Appendix B, "Reef Fish Encounter Frequency in the PRIMNM." For more background information on the report as a whole, operational background, Pacific RAMP methods, and Public Access to Research Results, refer to "Chapter 1: Overview."

Chapter Overview

Baker Island is a low-lying, uninhabited coral-reef platform that sits atop an ancient submarine volcano from the Cretaceous Period (~120–75 million years ago) located just north of the equator in the central equatorial Pacific Ocean at 0°11′N, 176°28′W. It is part of the larger Phoenix Islands group that also includes Howland Island (U.S.) and several Republic of Kiribati islands and atolls. The land area of Baker covers is a mere 2.1 km^2 (0.81 mi^2), with a peak elevation of 8 m (26 ft) above sea level and a depressed central area, but no lagoon. This small coral island has 4.8 km (3 mi) of coastline surrounded by a narrow fringing reef. The only remnants of previous human activity consist of an abandoned settlement and aircraft runway, a crumbling cemetery, and a former navigational day beacon.

This chapter provides a compilation of information to assist managers in making informed decisions relating to Baker Island and its coral reef ecosystems. "Benthic Characterization" sets the stage, followed by summarized data and trends for "Ocean and Climate Variability," "Coral Reef Benthic Communities," "Microbiota," "Reef Fishes," and "Marine Debris." Information from these sections is then tied together in the "Ecosystem Integration" section to provide a better understanding of the interactions and relationships among ecosystem components at Baker Island.

To facilitate discussions about the spatial patterns of ecological and oceanographic observations that appear throughout this chapter, five geographic regions, hereafter referred to as georegions, were defined for Baker Island (Figure 1). Most map-based figures throughout this chapter use the basemap template as shown in Figure 1, which includes georegions, land features, and the 30 m and 100 m depth contours (isobaths).

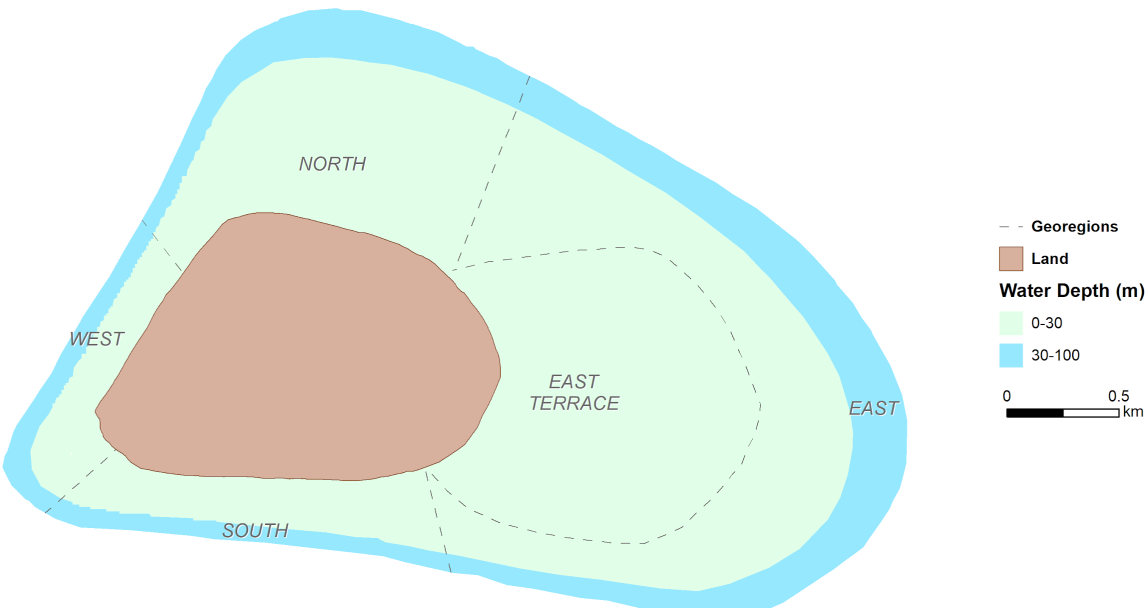


Figure 1. The five geographic regions, or georegions, for Baker Island: North, South, East, West, and East Terrace.

History and Human Influences

Baker Island was first discovered in 1818 by Captain Elisha Folger of the Nantucket whaling ship *Equator*. Several other whaling ships recorded sighting the island. The island is named after the American captain, Michael Baker, aboard the whaler *Gideon Howland,* who visited the island in 1834, and claimed possession of it in 1839. In 1855, his rights were passed to Alfred G. Benson and other trustees of the American Guano Company. The U.S. took possession of Baker Island in 1857, claiming it under the Guano Islands Act of 1856. The island's guano deposits were heavily mined by the American Guano Company from 1859 to 1878. During this period, many mining ships, such as the *Shaftsbury* and *Robin Hood*, ran aground and wrecked at Baker.

In 1885, the island was leased to the British firm John T. Arundel and Company, which made the island its headquarters for guano mining operations in the Pacific from 1886 to 1891. The United

Kingdom then considered Baker Island to be a British territory, although never formally annexed. The U.S. sought to reclaim Baker at the beginning of the 1920s. In 1935, the U.S. launched the American Equatorial Islands Colonization Project, Hui Panalaʻau, placing Hawaiian students from Kamehameha School for Boys and Army furloughed personnel at Baker, Howland, and Jarvis Islands to record weather, maintain daily logs, record fish caught and birds observed, collect samples, and cultivate plants. This was followed in 1936 by Executive Order 7368 proclaiming Baker under the jurisdiction of the United States (House of Representatives - Natural Resources 2016).

The flora and fauna of Baker Island were first described by a scientific party from the Bishop Museum of Honolulu on an expedition aboard the U.S.S. *Whippoorwill* in 1924, which conducted biological and ornithological surveys of Kingman Reef, Palmyra Atoll, and Christmas, Howland, Baker, and Jarvis Islands.

In 1935, colonists from the American Equatorial Islands Colonization Project arrived on Baker to establish a permanent U.S. presence in the Central Pacific. It began with a rotating group of four male students and alumni from the Kamehameha School in Honolulu as part of the Hui Panalaʻau project under President Franklin Roosevelt's effort to colonize the Pacific islands. The recruits had signed on as part of a scientific expedition and expected to spend their three-month assignment collecting botanical and biological samples. A settlement was formed and named Meyerton after Captain H.A. Meyer of the U.S. Army, who helped establish the camp in 1935. The colonists were evacuated in 1942 after Japanese naval and air attacks (Zisk 2002).

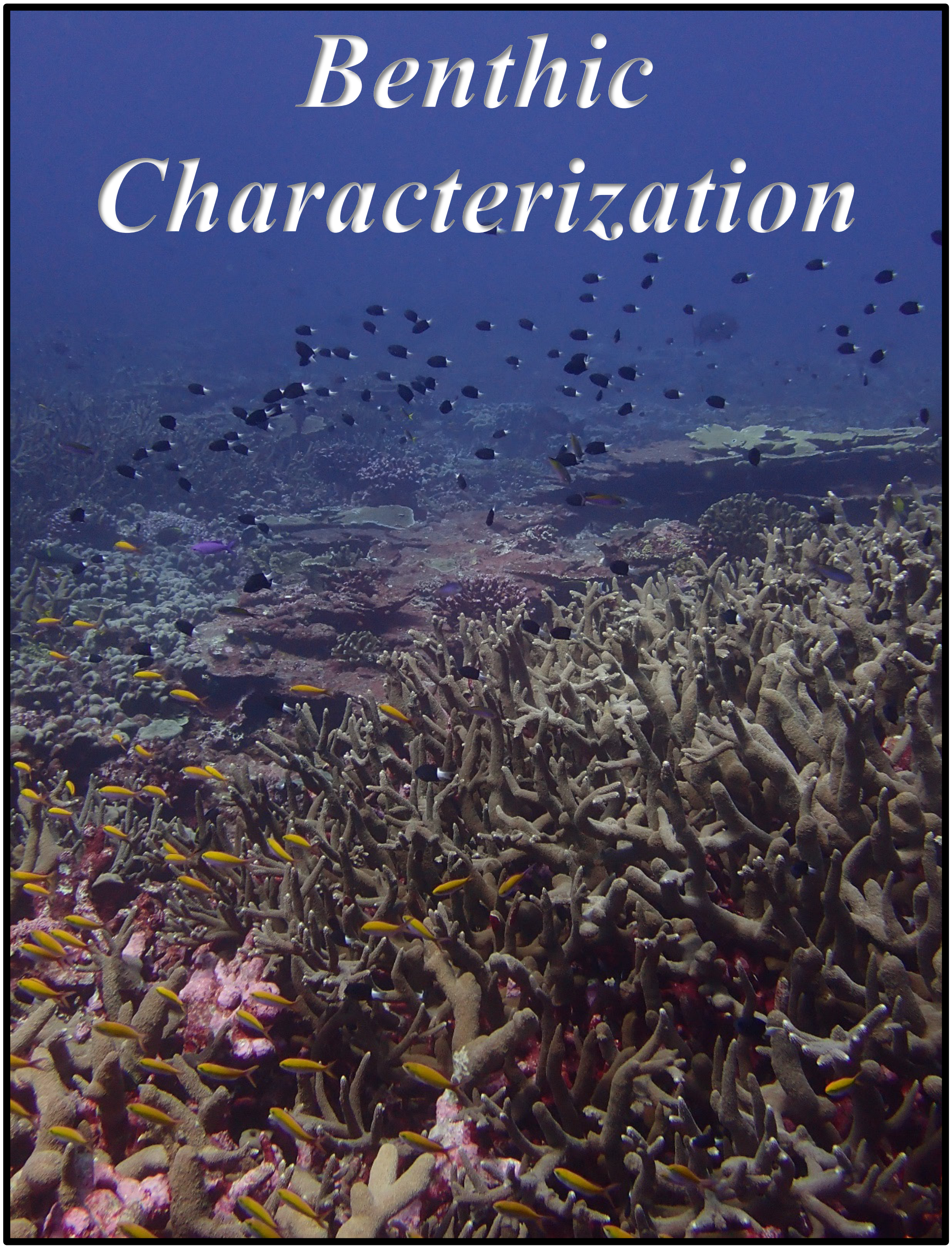
The U.S. military then occupied Baker Island from 1943 to 1944, establishing an airfield and runway. Debris from several crashed airplanes and large equipment from this period remain scattered around the island today. Excavations containing the remnants of metal fuel and water drums are scattered about the north edge of the island. The Navy also reported the loss of 11 landing craft in the surf during World War II (Pacific Remote Islands National Wildlife Refuge Complex 2007).

In 1974, Baker Island National Wildlife Refuge was established and included the land, waters, as well as submerged and emergent lands, from the mean low tide water lines out to 3 nm. In 2009, President George W. Bush established the PRIMNM to protect and preserve the marine environment from 0 to 50 nm around Baker, Howland, and Jarvis Islands, Wake, Johnston, and Palmyra Atolls, and Kingman Reef, for the proper care and management of the historic and scientific objects therein (Federal Register 2009). As part of the PRIMNM designation, the Refuge boundaries were extended to include the waters and submerged lands from 0–3 nm to 12 nm. The monument waters and submerged and emergent lands from 0 to 50 nm are cooperatively managed by the U.S. Fish and Wildlife Service and NOAA.

Geology and Environmental Influences

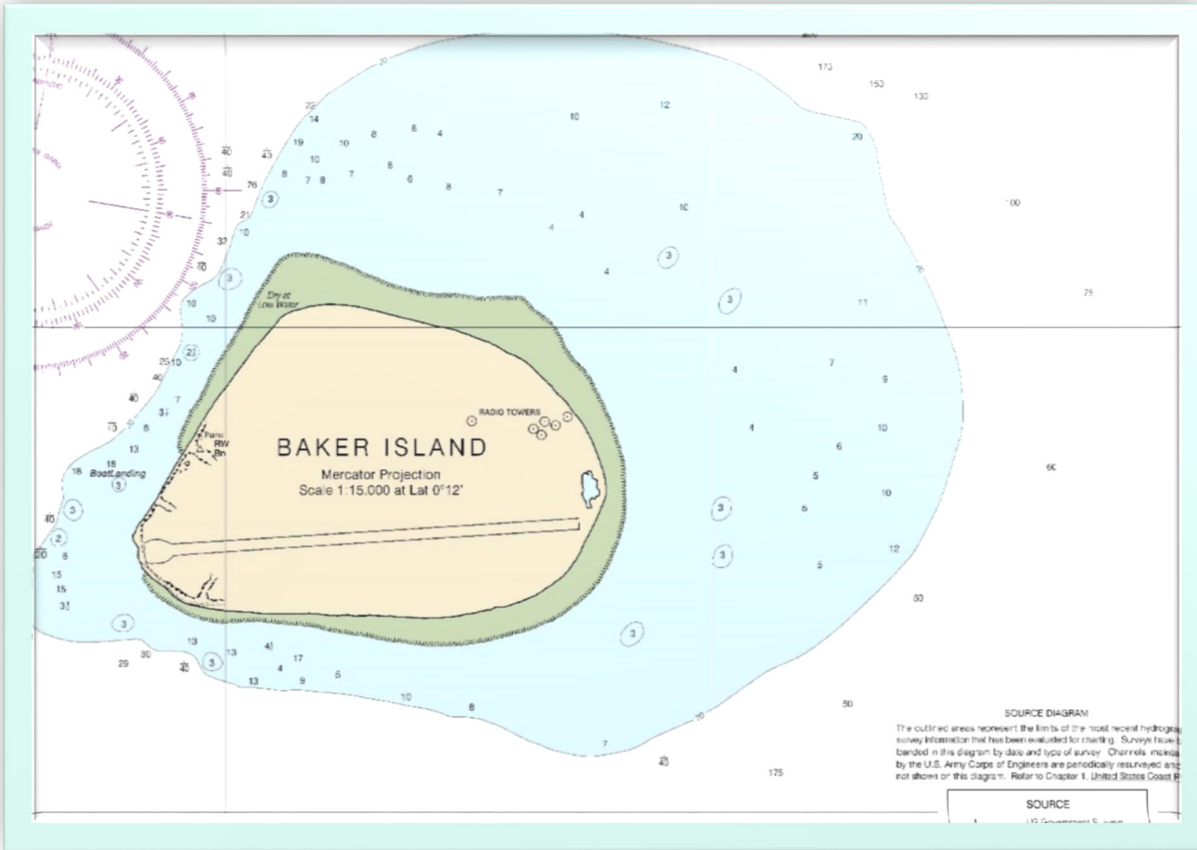
Located along the equator, the climate at Baker Island is characterized as arid (i.e., little rainfall) and sunny, with temperatures moderated by consistent easterly trade winds and relatively cool upwelled surrounding waters. There are no natural freshwater resources on Baker, and scattered grasses, vines, and low-growing Pisonia trees and shrubs are the only vegetation. Baker provides nesting, roosting, and foraging habitats for both seabirds and shorebirds. The waters surrounding

Baker are nutrient-rich due to wind-driven equatorial upwelling and topographic upwelling of the eastward-flowing Equatorial Undercurrents (EUCs) that interact with the western submerged flank of the island, pushing cool, nutrient-rich waters up into the sunlit zone, thereby increasing marine productivity and benefiting many species of marine life (White 2011).



A typical reefscape of Baker Island's eastern terrace.
Photo: Ariel Halperin, NOAA Fisheries.

8.2 Benthic Characterization



NOAA Nautical Chart of Baker Island.
Source: [NOAA, 5th Ed., Sep. 2006.](#)

In this section, the benthic habitats of Baker Island are characterized for the depth range from 0 to 1,000 m, using integrated and synthesized data from numerous sources.

Survey Effort

NOAA has been collecting benthic habitat mapping data for the nearshore areas around Baker Island since 2006, using a variety of methods as described in the "Benthic Characterization Methods" section of "Chapter 1: Overview." These methods include multibeam bathymetric and backscatter surveys, single-beam surveys for depth validation, and towed-camera surveys for habitat validation.

Multibeam Surveys

Mapping surveys were conducted around Baker Island using multibeam sonar systems during the 2006 Pacific RAMP research cruise aboard the NOAA Ship *Hi'ialakai* (Simrad EM 300 and EM

3002D) and R/V *AHI* (Reson 8101-ER). Bathymetric and backscatter data were collected for depths between approximately 8 and 4,500 m and used to derive mapping products covering a total of approximately 256 km^2. Approximately 2.6 km^2 between 0 and ~20 m depths remained unmapped because the shallower areas around the island were inaccessible to survey with vessel-mounted multibeam systems.

Two of the resulting gridded bathymetric products are a 5 m high-resolution grid of the reefs, banks, shelf, and slope habitats to allow for the identification of fine-scale features to a depth of 300 m, and a coarser 40 m mid-resolution grid that includes the full extent of the multibeam bathymetric data collected (Figure 2). The data and supporting documentation are available on the Baker Bathymetry page of the Pacific Islands Benthic Habitat Mapping Center (PIBHMC) website.

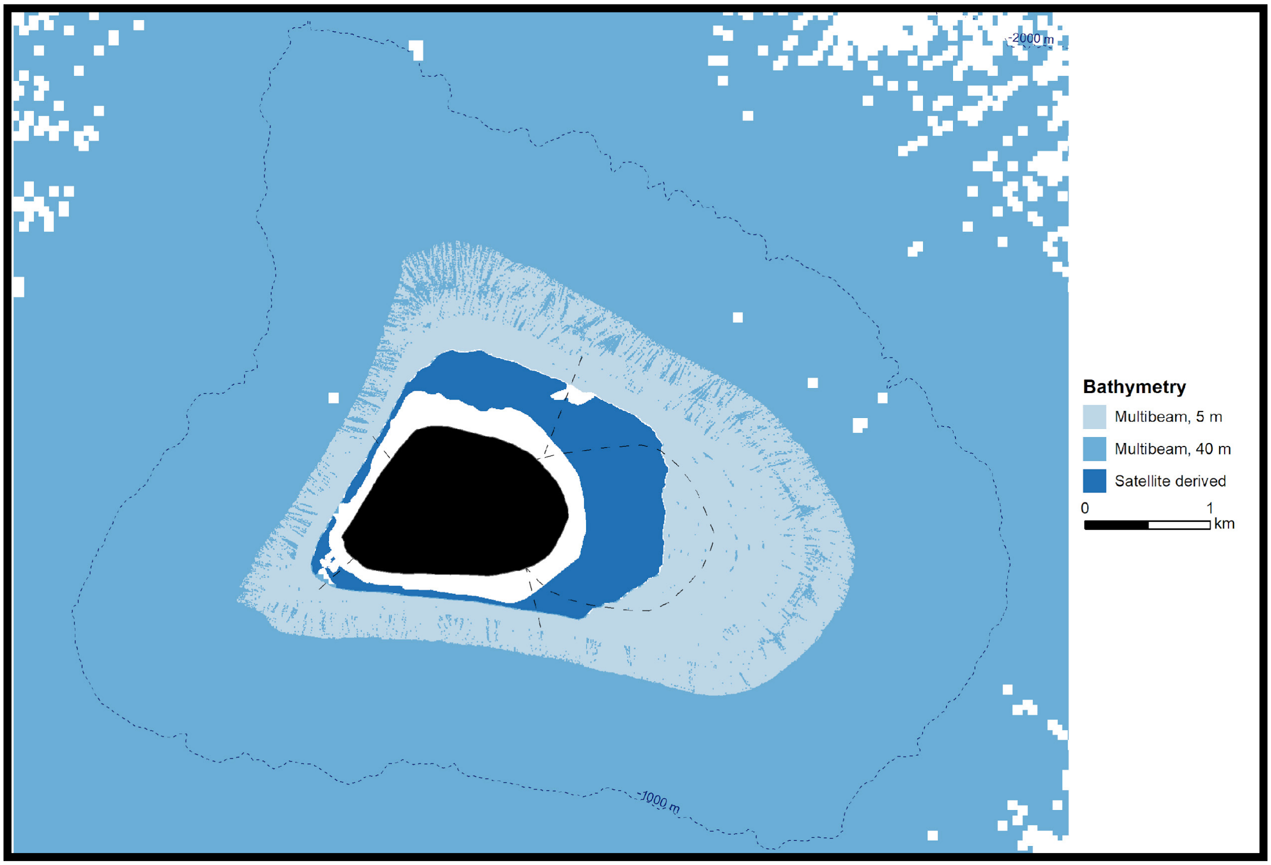


Figure 2. Bathymetric coverage map for Baker Island showing extent of high- (5 m) and mid-resolution (40 m) gridded multibeam data acquired by Ecosystem Sciences Division (ESD) in 2006 (lighter blues), and estimated bathymetry derived by ESD from satellite imagery (dark blue). The dotted dark blue line represents the 1,000 m depth contour. Gaps in bathymetric coverage are shown in white and land features in black. Satellite-derived bathymetry is discussed later in this section.

The backscatter data from the shallower surveys conducted from the R/V *AHI* were gridded at 1 m resolution, while the data from the deeper surveys conducted from the *Hi'ialakai* were gridded at 5 m resolution. Acoustic backscatter intensities reveal characteristics of the seabed around Baker Island that can be related to topography and slope. While these data are useful for geomorphology and habitat interpretation, both the shallow and deeper backscatter data have severe quality issues, including high noise levels and patchiness in the coverage. The data and supporting documentation are available on the Baker Backscatter page of the PIBHMC website.

Single-beam Surveys

Single-beam sonar data were acquired around Baker Island from depths between approximately 0 and 266 m in 2012, between approximately 2 and 350 m in 2015, and between approximately 4 and 1,160 m in 2017 (Figure 3). As ocean conditions varied each year and new survey equipment was introduced in 2017, the errors associated with the three years of data also varied. Soundings error for depths between 0 and 60 m was found to be greater in 2012 and 2015 (1.45 and 1.27 m, respectively) compared with 2017 (0.57 m). In 2017, soundings collected while transiting at higher speeds in deeper waters (>60 m) were unreliable; therefore, the data collected in 2017 were filtered to exclude depths deeper than 60 m in Figure 3.

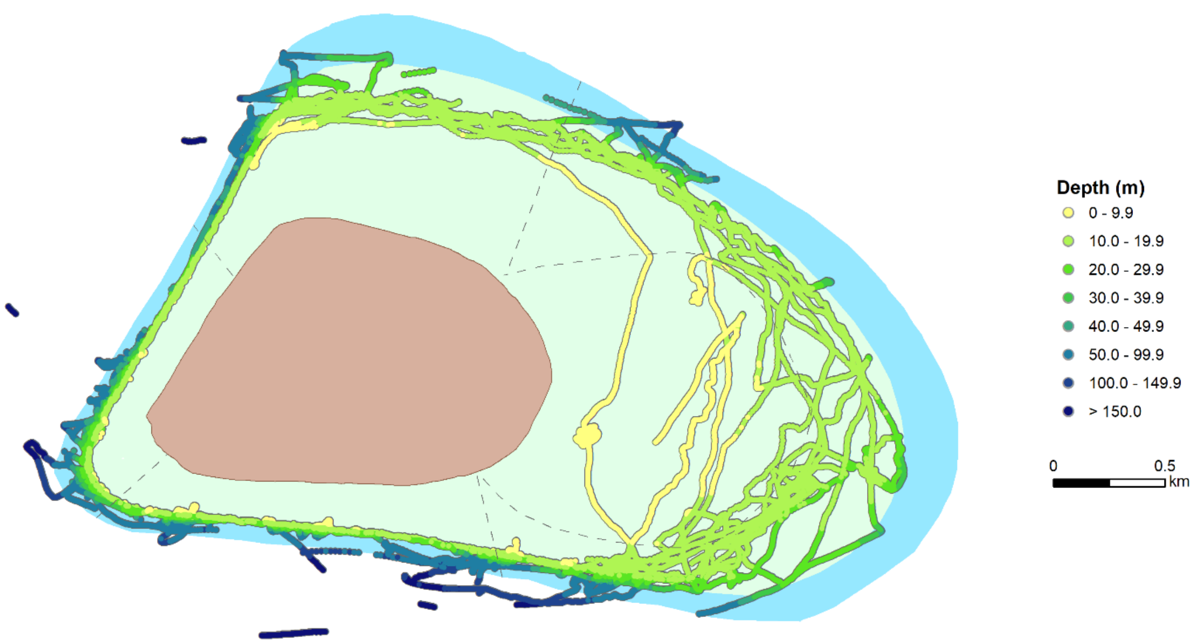


Figure 3. Depth validation data for Baker Island collected by Ecosystem Sciences Division in 2012, 2015, and 2017. Soundings >60 m have been excluded from the 2017 surveys due to data quality concerns.

Towed-camera Surveys

Habitat validation data in the form of underwater video and still photographs were acquired in the North and East georegions of Baker Island from depths between 15 m and approximately 250 m by ESD in 2002 and 2004, using the Towed Optical Assessment Device (TOAD). A subset of the TOAD images collected were classified into substrate types (e.g., sand, rubble, boulder), biological cover type (e.g., coral, macroalgae, coralline algae), and coral growth morphology (e.g., branching, columnar, encrusting) to produce a map of percent cover for observed scleractinian coral at the image collection point. The data and supporting documentation are available on the Baker Optical Validation page of the PIBHMC website.

Habitat Characterization

Satellite-derived Bathymetry

ESD derived estimated depths between approximately 2 and 18 m from WorldView-2 satellite imagery acquired in 2012 to fill gaps in the nearshore shallow-water bathymetric coverage around Baker Island. Depths from towed-diver surveys (TDS) conducted during the period 2001–2010 were used to develop the model for and to validate the satellite-derived depths, resulting in 68% average agreement between the overlapping towed-diver and estimated depths (see the "Coral Reef Benthic Communities" section for more information about TDS). The data and supporting documentation are available on the Baker Bathymetry page of the PIBHMC website. Though these estimated depths provide useful information for areas with little or no bathymetric measurements, the poor depth accuracy limits the use of these data. See Figure 3 for the extent of satellite-derived depths generated by ESD that partially filled the bathymetric coverage gap around Baker.

Integrated Bathymetry

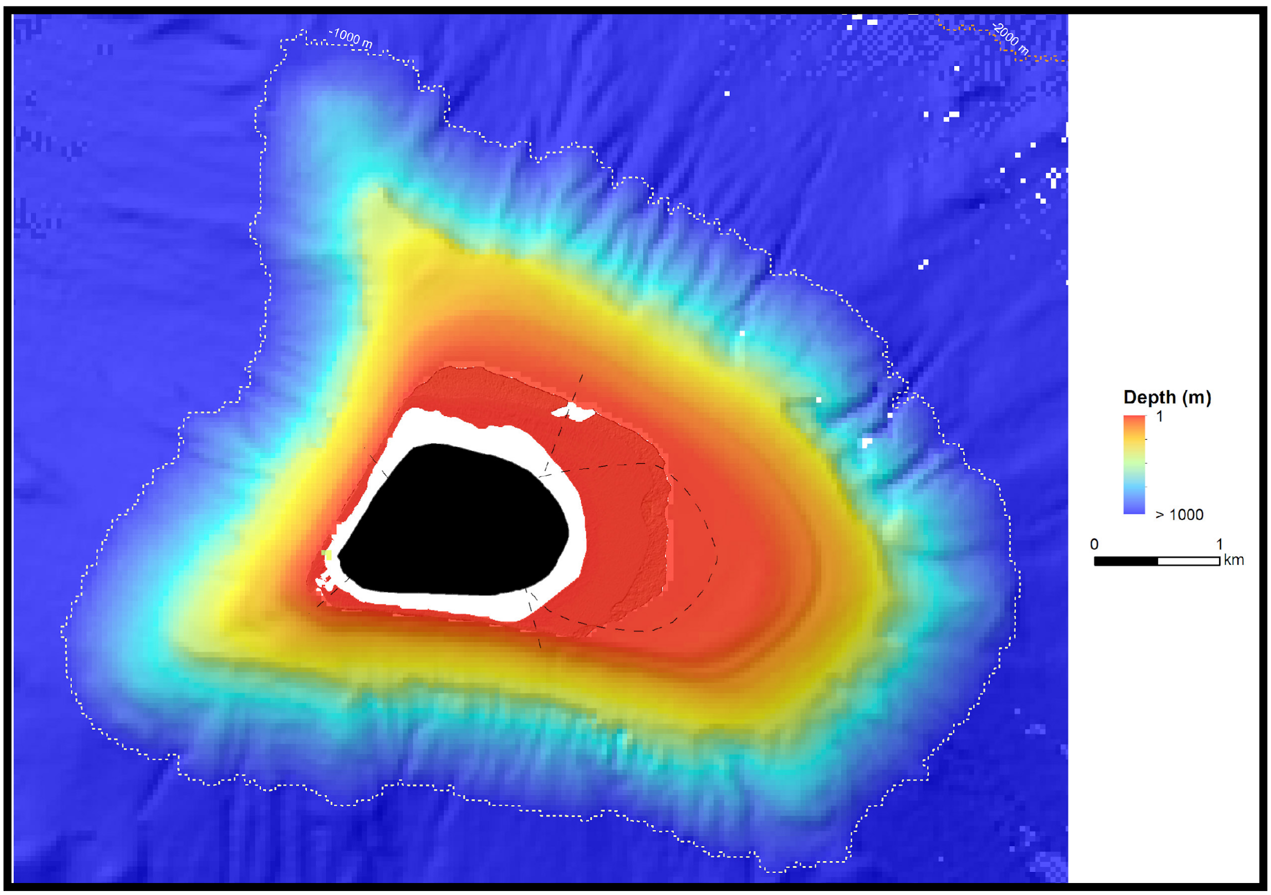


Figure 4. Integrated bathymetric map focusing on depths from 0 m to ~1,000 m for Baker Island, with gaps in bathymetric coverage shown in white and land features in black. The dotted lines represent the 1,000 m depth contours.

ESD's multibeam bathymetry and satellite-derived depths were combined to produce an integrated bathymetric map for Baker Island (Figure 4).

The bathymetry around Baker Island is characterized by a fringing reef around most of the island, shallow terraces, steep forereef slopes in the South and West georegions, and highly complex, shallow banks approximately 0.5–1.5 km wide in the East Terrace and North georegions (Maragos et al. 2008).

Bathymetric Derivatives

Several geomorphological layers derived from ESD's multibeam bathymetric grids were developed for Baker Island, including slope (i.e., the rate of change in elevation between a location and its surroundings, usually expressed in degrees), rugosity (a measure of the roughness or complexity of the seafloor surface), and bathymetric position index (BPI) zones and structures (i.e., a measure of where a location with a defined elevation is relative to the overall landscape, classified into broad scale and fine scale features, respectively). Each of these layers is available as high- (5 m) and mid-resolution (20 m) gridded products on the Baker Seafloor Characterization page of the PIBHMC website. The mid-resolution slope and BPI zones maps are presented here.

Slope

Nearshore 20 m resolution gridded slope values around Baker Island reflect steep drop-offs in the South and West georegions in the form of nearshore walls in the shallower depths (Figure 5). Terraces and plateaus are evident in various depths and indicate possible previous sea level stands. The East and North georegions show shallow forereef terraces with the northern terrace system continuing along the rift zone into deeper depths. Steep drop-offs as well as mass-volume shifting and deposit features can be observed beyond the 1,000 m isobath around the entire island (Maragos et al. 2008).

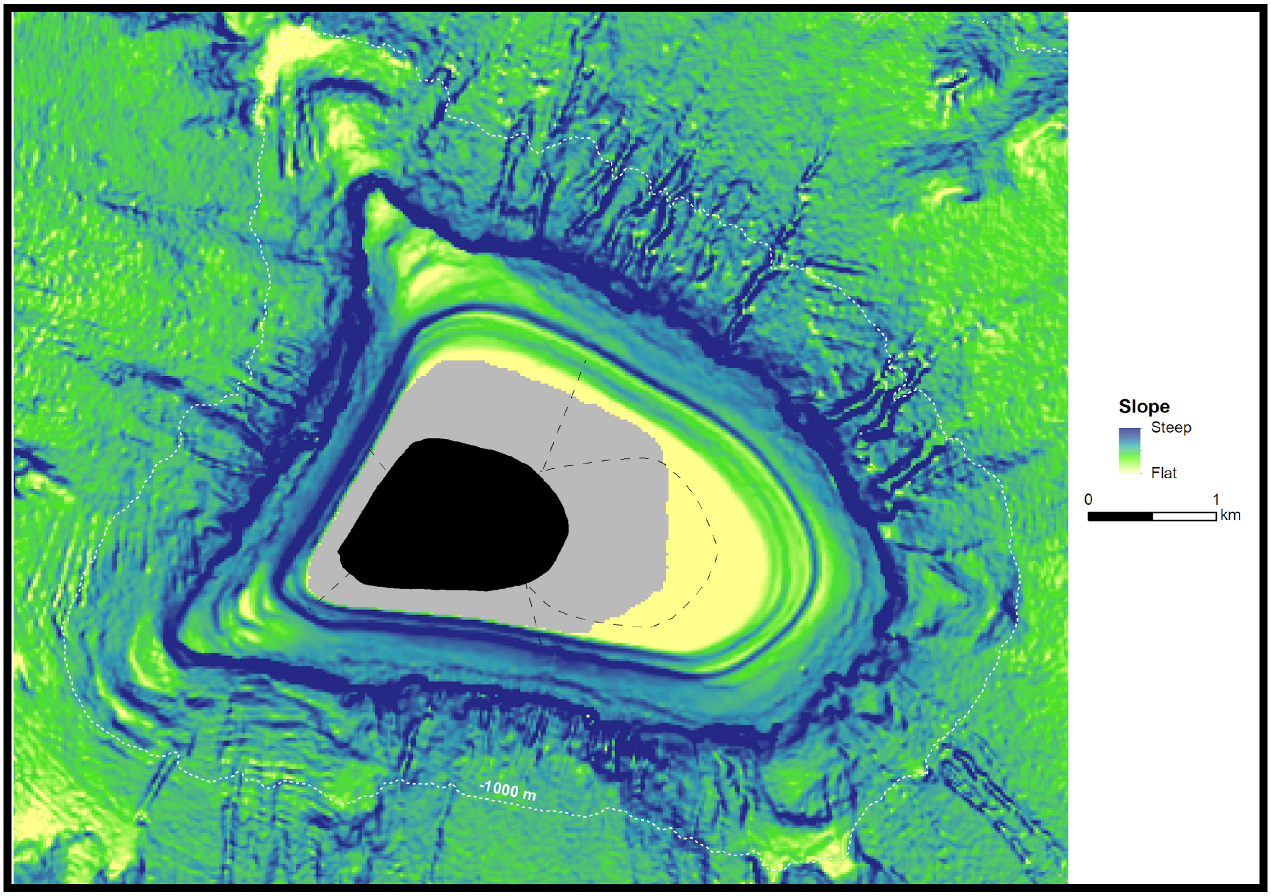


Figure 5. Slope map for Baker Island with data gaps shown in grey and land features in black. The dotted white lines represent 1,000 m interval depth contours.

Rugosity

A 20 m resolution gridded rugosity map (not shown) is available for Baker Island. Rugosity, along with a range of other bathymetric derivatives, was tested in the analysis conducted to derive seafloor substrates (discussed later in this section); however, it was highly spatially correlated with slope and therefore did not provide unique information to inform the substrate predictions.

Bathymetric Position Index (BPI)

The 20 m resolution gridded BPI zones map for Baker Island shows the seafloor landscape around the island was predominantly comprised of broad crests (red areas) and steep slopes (blue areas) in the shallower depth ranges (Figure 6). An extensive flat is located in the East Terrace georegion, and the data suggest the edges of the flat have partially eroded, leaving steep slopes and partial crests behind. The northwest rift zone is apparent from the crest features outside the North georegion beyond the nearshore depths. Numerous topographic depressions are located around the island at the flanks of the steep slopes.

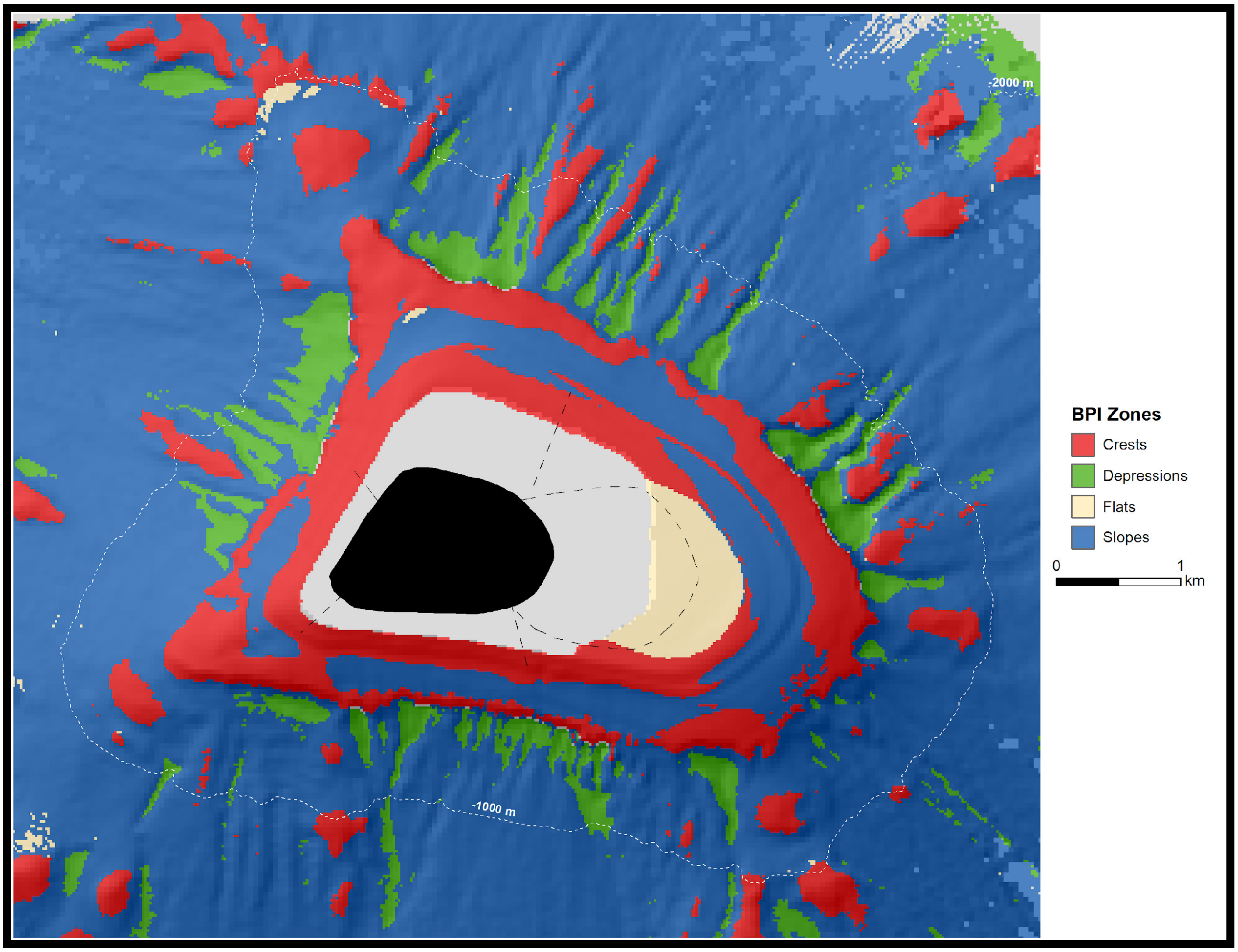


Figure 6. Map of bathymetric position index (BPI) zones for Baker Island, with data gaps shown in grey and land features in black. The dotted white lines represent 1,000 m interval depth contours.

The 20 m resolution gridded BPI structures map for Baker Island (not shown) shows the finer-scale details of each major BPI zone.

Seafloor Substrate

ESD generated predicted seafloor substrates (i.e., hard or soft bottom) for Baker Island in 2018 (Figure 7). The source data used to produce the substrate map for Baker for water depths to 1,000 m include multibeam bathymetric and backscatter data from the 2006 *Hiʻialakai* surveys and satellite imagery acquired in 2012 (WorldView-2) and in 2016 (WorldView-3). The data and supporting documentation are available on the Baker Seafloor Characterization page of the PIBHMC website.

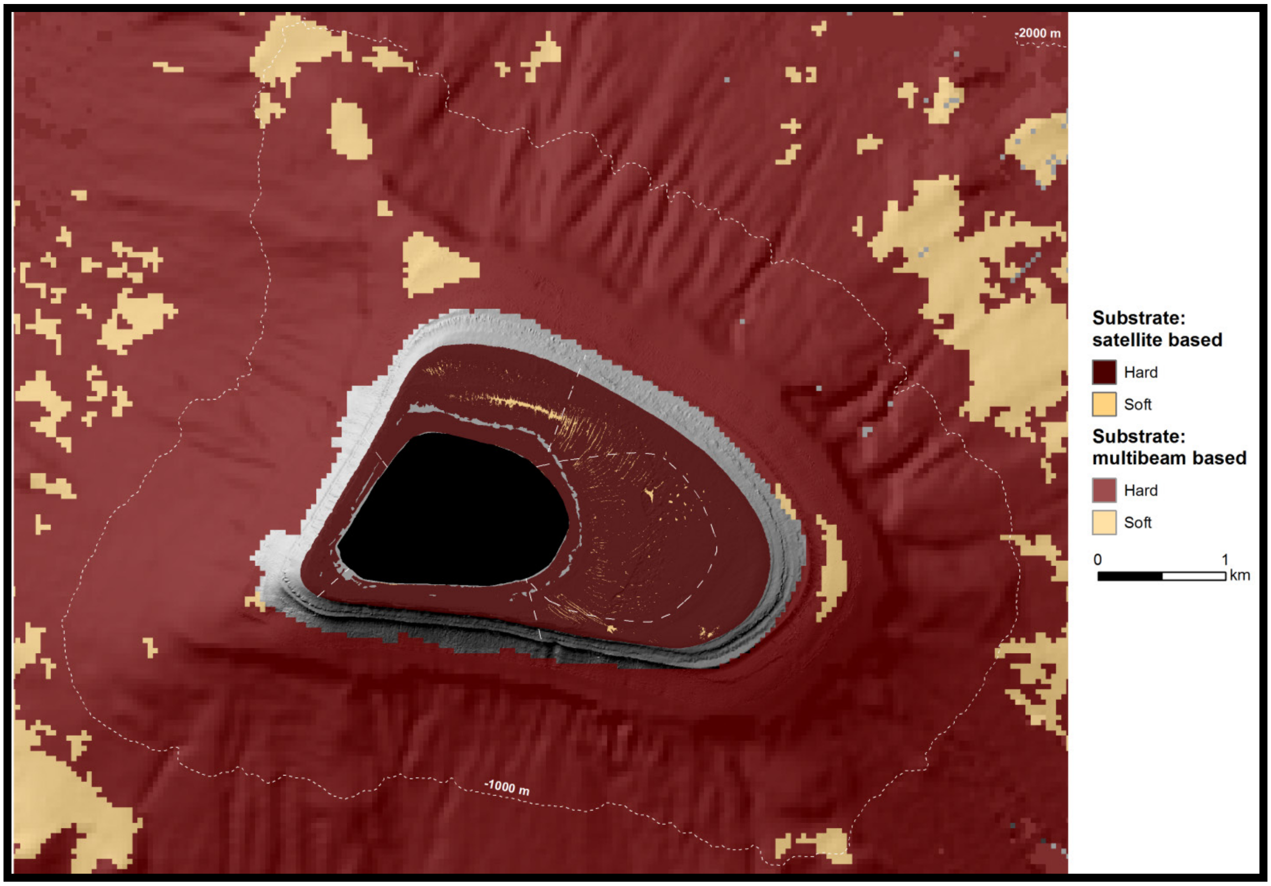


Figure 7. Seafloor substrate map of Baker Island showing hard- and soft-bottom habitats. Depths from ~0 to 30 m were derived from WorldView satellite imagery and depths >30 m were based on gridded multibeam bathymetric and backscatter data (40 m and 5 m resolution, respectively). The dotted white lines represent 1,000 m interval depth contours. Gaps in substrate coverage are shown in grey and land features in black.

Analyses indicate that due to the poor quality of backscatter data at Baker Island, the bathymetric data more significantly influenced the substrate predictions. The seafloor surrounding Baker to 1,000 m depths is predominantly hard substrate with relatively small patches of soft-bottom habitat. In shallower depths to approximately 30 m, spur and groove habitats are apparent in the North, East, and East Terrace georegions from the alternating pattern of hard and soft features as shown in Figure 8, which compares the predicted substrate map (left) with a satellite image (right) for an area of the forereef terrace in the North and East georegions.

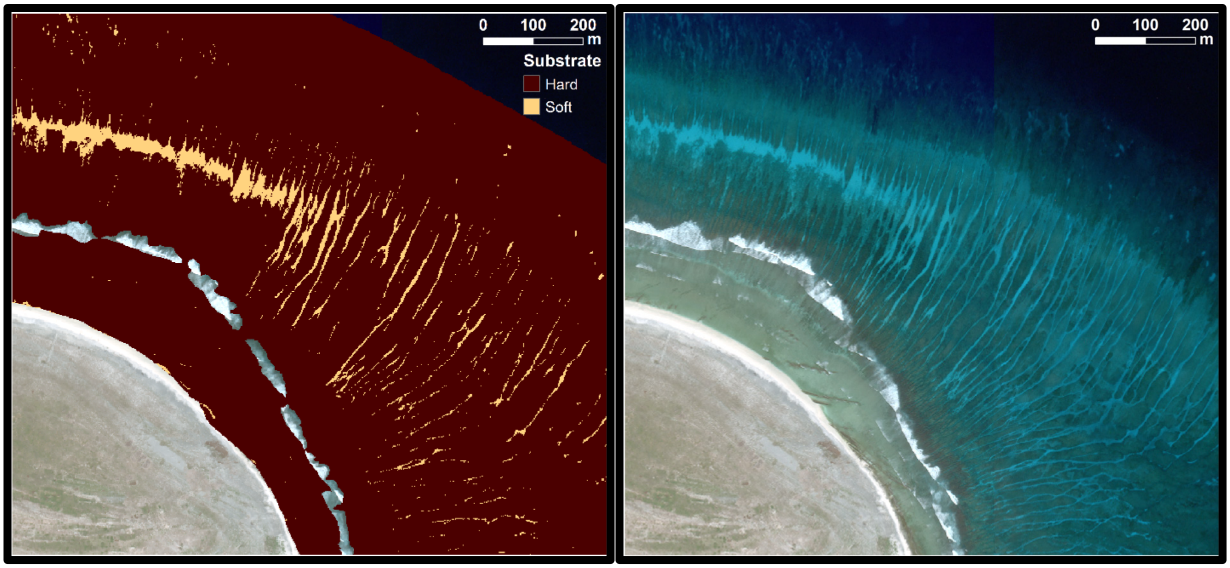


Figure 8. Satellite-derived substrate predictions (left) compared with a satellite image of the same area (right), demonstrating how the predicted substrates accurately delineate features, such as spur and groove habitat, on the seafloor at Baker Island.

Maps to Inform the Coral Reef Fish and Benthic Monitoring Survey Design

Many biological communities are structured by depth and habitat (i.e., reef zone), often due to differences in associated environmental parameters, such as light, temperature, salinity, and wave energy. The current Pacific RAMP stratified-random survey design restricts monitoring surveys to hard-bottom habitats in the 0 to 30 m depth range, stratified by both depth and reef zone.

Depth Strata

The integrated bathymetry shown in Figure 4 was used to classify depth bins (Figure 9) from 0 to 1,000 m for Baker Island. For the Pacific RAMP surveys, depth strata have been defined as shallow (>0–6 m), mid (>6–18 m), and deep (>18–30 m). Estimated seafloor areas for each of the depth strata are included in Table 1.

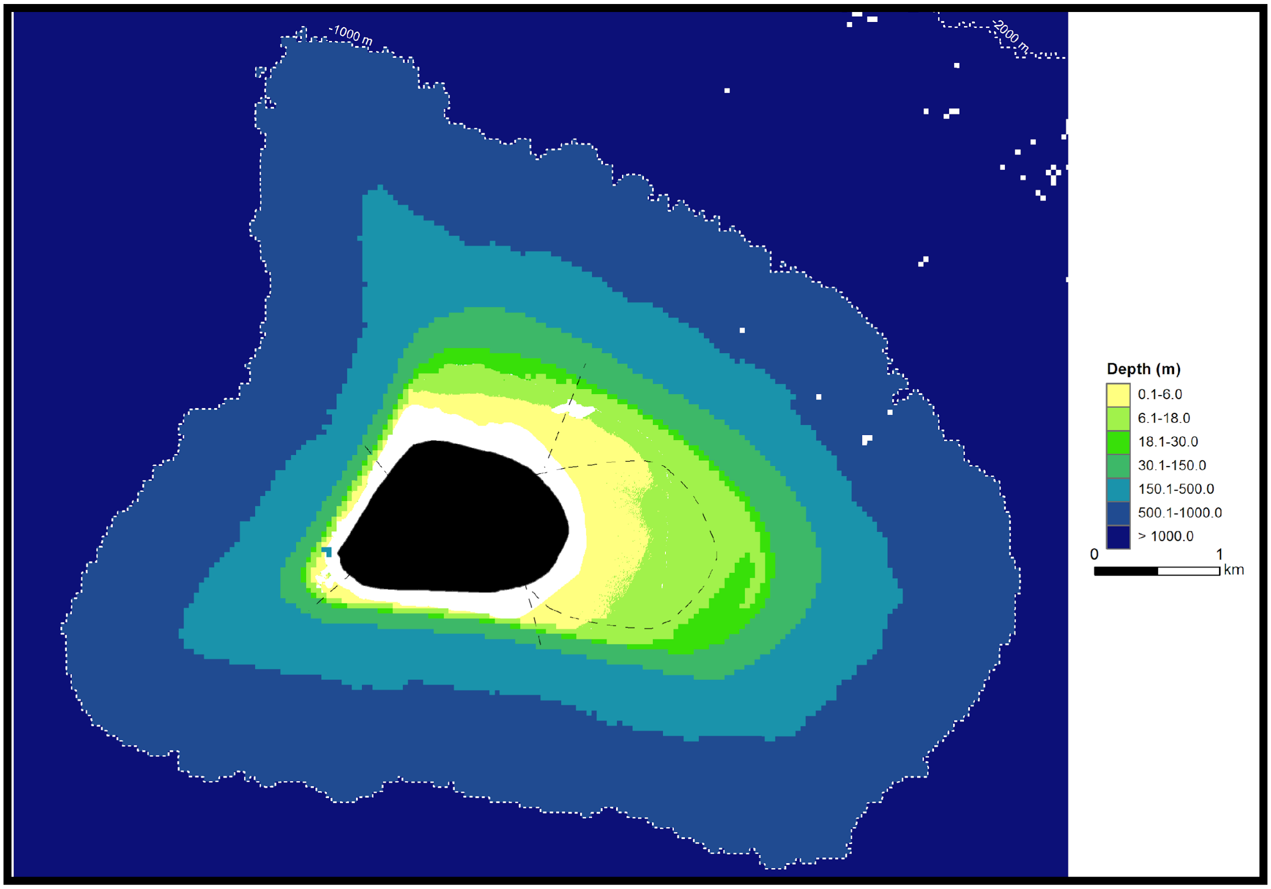


Figure 9. Depth strata map for Baker Island from 0 to 1,000 m, with gaps in bathymetric coverage shown in white and land features in black. The dotted white lines represent 1,000 m interval depth contours.

The actual mapped seafloor area for the two shallowest depth strata differs from the estimated seafloor area (Table 1). At Baker Island, 76% of the seafloor between 0 and 18 m depths was mapped, leaving an approximately 0.9 km^2 gap. The map of the seafloor from 18 to 1,000 m depths was spatially complete.

Table 1. Land and seafloor area by depth strata from 0 to 1,000 m depths for Baker Island. Seafloor area statistics include actual mapped area (km^2) and estimated seafloor area (km^2) based on the integrated bathymetric map for Baker. Land area is 1.6 km^2.

Depth (m)	Estimated Seafloor (km^2)	Mapped Seafloor (km^2)
>0–6	2.0	1.2
>6–18	1.8	1.7
>18–30	0.6	0.6
Subtotal: >0–30	**4.4**	**3.5**
>30–150	2.1	2.1
>150–500	6.6	6.6
>500–1000	16.1	16.1
Total: >0–1000	**29.3**	**28.3**

Reef Zones

To support the stratified-random design for Pacific RAMP monitoring surveys, reef zones have been delineated for Baker Island, including forereef, reef crest/reef flat, and land (Figure 10). Satellite imagery was primarily used to manually digitize the zones. Reef crest/reef flat areas include the shoreline out to and including breaking waves; however, the date of the satellite image may influence the accurate delineation of the reef crest (i.e., due to seasonal changes in wave action).

Only forereef habitats have been surveyed around the island, because these habitats most commonly occur in coral reef areas. Therefore, results from surveys at Baker can be compared with results from surveys across all coral reefs of the U.S. Pacific Islands. Moreover, hazards from emergent reef in the shallow reef crest/reef flat areas precluded surveys in these habitats at Baker.

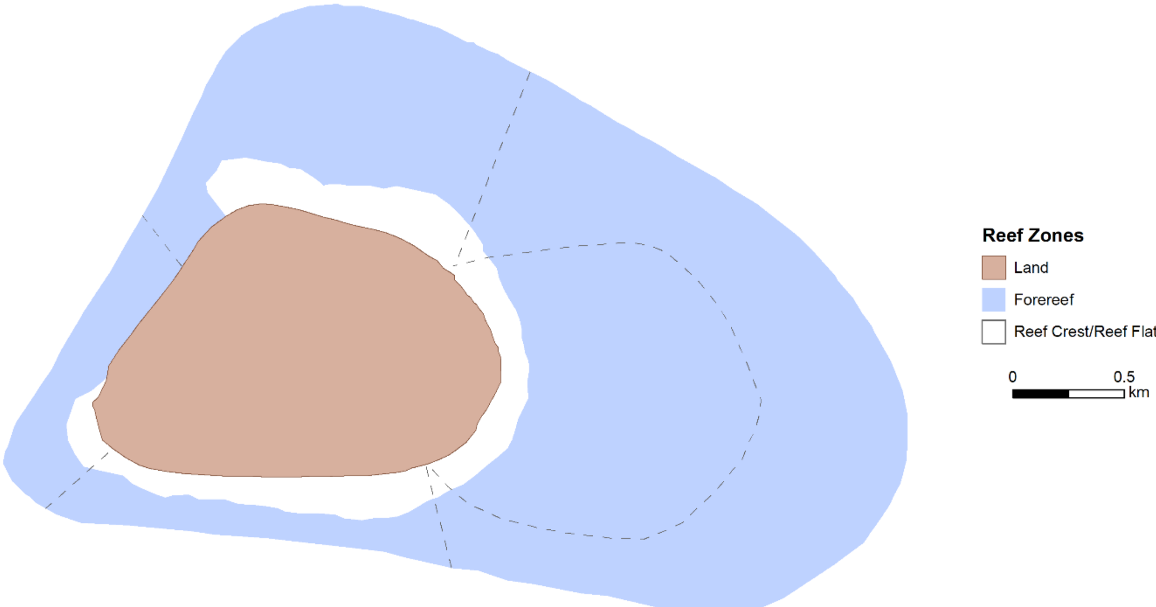


Figure 10. Reef zones for Baker Island.

Substrate

Only hard-bottom substrates were targeted for stratified-random reef fish and benthic monitoring surveys of Pacific RAMP. However, at the time the survey strata were established for Baker Island, no substrate information existed. As previously discussed, predicted seafloor substrates have since been developed for Baker and will be incorporated into the survey strata in advance of the Pacific RAMP surveys at Baker scheduled for 2021. In general, the majority of the nearshore seafloor area around the island is hard bottom with patches of soft-bottom substrates in the spur-and-groove habitat areas (Figure 7).

Survey Strata

To date, the survey strata used for the stratified-random fish and benthic surveys were based on depth only (Figure 9). A cursory assessment of the new substrate and reef zone data together with the depth strata indicate approximately 3.5 km^2 of surveyable seafloor is available within forereef, hard-bottom habitats in the 0 m to 30 m depth range at Baker Island.

Field operations at Baker Island.
Photo: Andrew Gray, NOAA Fisheries

Ocean and Climate Variability

8.3 Ocean and Climate Variability

Ocean and Climate Change team installing a water-sampling package at Baker Island.
Photo: NOAA Fisheries

Survey Effort and Site Information

Located just north of the equator in the central Pacific, Baker Island sits directly in the path of both the westward-flowing South Equatorial Current (SEC) at the surface and the opposing eastward-flowing subsurface EUC. Both wind-driven equatorial upwelling and topographic upwelling that occur as the EUC encounters the steep western slope of the island bring cool, low-pH, and nutrient-rich waters to the surface, where photosynthesis drives unusually high biological productivity that bathes the coral reef ecosystems surrounding Baker. The strength of the EUC and trade winds that drive the intensity of topographic and equatorial upwelling at Baker vary with the interannual variability in the El Niño Southern Oscillation (ENSO). During La Niña years, strong trade winds increase equatorial upwelling and a strong EUC drives intense localized upwelling on the island's west side, resulting in both anomalously cool temperatures and high productivity. During El Niño events, a weaker EUC and weaker trade winds decrease upwelling, which results in warmer temperatures and reduced productivity.

ENSO-driven fluctuations in nearshore ocean conditions affect the health and function of the coral reef ecosystems surrounding Baker Island. These environmental oscillations are affected and exacerbated by global climate change, as concentrations of carbon dioxide in the atmosphere alter the temperature and chemistry influencing coral reef habitats. Episodic periods of anomalously warm seawater temperatures, largely during El Niño events, have led to increases in the frequency and intensity of coral bleaching in the past few decades. In addition, the dissolution of carbon dioxide in ocean surface waters sets off a chain of chemical reactions in seawater that decrease pH and make it more difficult for corals and calcifying reef organisms to grow. Understanding the recent shifts in ocean conditions and the sensitivity of coral reef ecosystems to these changes is crucial for projecting their survival under 21st century climate change.

Since 2000, Pacific RAMP efforts have monitored the oceanographic environments of coral reef ecosystems in the PRIMNM. Data were collected on key parameters using: (1) a diverse suite of moored instruments, (2) nearshore conductivity, temperature, and depth (CTD) vertical profiles of water column structure, (3) discrete water samples to assess dissolved nutrients, chlorophyll-*a* (chl-*a*), and carbonate chemistry, and (4) estimates of calcium carbonate accretion, coral growth, and skeletal density to examine the balance between production and removal of calcium carbonate on the reef (Figure 11, Figure 12, Figure 13, Figure 14, Figure 15). A summary of the environmental survey efforts around Baker Island from 2000 to 2017 is shown in Table 2. Refer to "Chapter 1: Overview" for oceanographic instrumentation specifics and water sample collection methodologies.

Field data collections were coupled with satellite remote sensing data sets and model products to provide the large-scale climate and oceanographic context for our in situ observations. Those used specifically include the Oceanic Niño Index (ONI, the standard index of ENSO activity), sea surface temperature (SST) anomalies from the Optimum Interpolation SST data set, the Degree Heating Week (DHW) index from Coral Reef Watch, chl-*a* (a proxy for primary productivity) anomalies from the Sea-Viewing Wide Field-of-View Sensor and Moderate Resolution Imaging Spectroradiometer Aqua, and global WaveWatch III model output to explore multi-decadal variability in ocean conditions.

Table 2. Summary of the ocean and climate survey efforts at Baker Island by year from 2000 through 2017. The following instrument types were deployed: sea surface temperature (SST) buoy, subsurface temperature recorder (STR), ecological acoustic recorder (EAR), SoundTrap acoustic recorder, ocean data platform (ODP), calcification accretion unit (CAU), and autonomous reef monitoring structures (ARMS). Conductivity-temperature-depth (CTD) casts, shallow (near reef) and deep (offshore), have corresponding discrete water samples, shallow (near reef) and deep (offshore). Coral cores of *Porites* spp. were collected using a hydraulic drill. Numbers indicate the quantity of instruments deployed (D) and retrieved (R) as D/R, water samples, CTD casts, and coral cores per year.

	Instruments							CTD Casts		Water Samples		Coral Cores
Year	**SST**	**STR**	**EAR**	**SoundTrap**	**ODP**	**CAU**	**ARMS**	**Shallow**	**Deep**	**Shallow**	**Deep**	***Porites* spp.**
2000	–	–	–	–	–	–	–	21	–	–	–	–
2001	–	–	–	–	–	–	–	17	–	–	–	–
2002	–	–	–	–	1/-	–	–	24	–	–	–	–
2004	–	4/-	–	–	1/1	–	–	35	–	–	–	–
2006	1/-	4/4	–	–	1/1	–	–	26	8	20	40	–
2008	–	4/4	–	–	1/1	–	6/-	5	6	4	30	1
2010	–	5/4	–	–	-/1	20/-	6/6	13	8	8	40	–
2012	–	9/5	–	–	–	25/19	-/6	5	8	10	40	–
2015	–	7/7	–	–	–	20/10	–	10	–	10	–	–
2017	–	1/1	1/-	1/-	–	–	–	4	–	7	–	–
Total	**1/-**	**34/25**	**1/-**	**1/-**	**4/4**	**65/29**	**12**	**160**	**30**	**59**	**150**	**1**

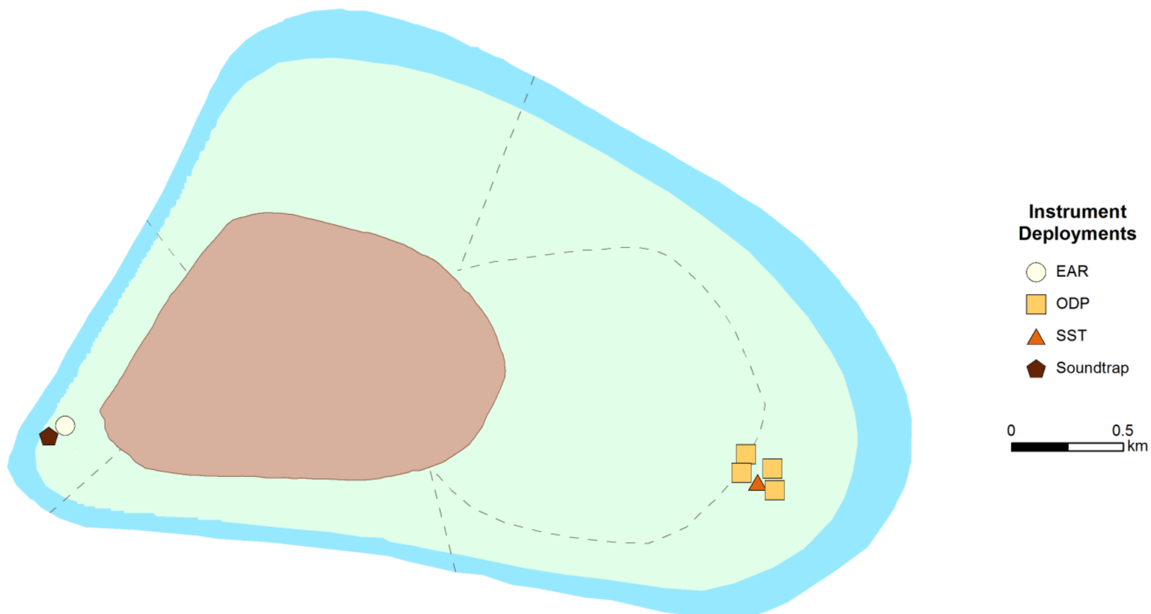


Figure 11. Deployment locations of an ecological acoustic recorder (EAR), ocean data platforms (ODP), sea surface temperature (SST) buoy, and a SoundTrap acoustic recorder at Baker Island. Instrument deployments at the same location over multiple years have been plotted adjacent to one another and organized around their shared location on the map.

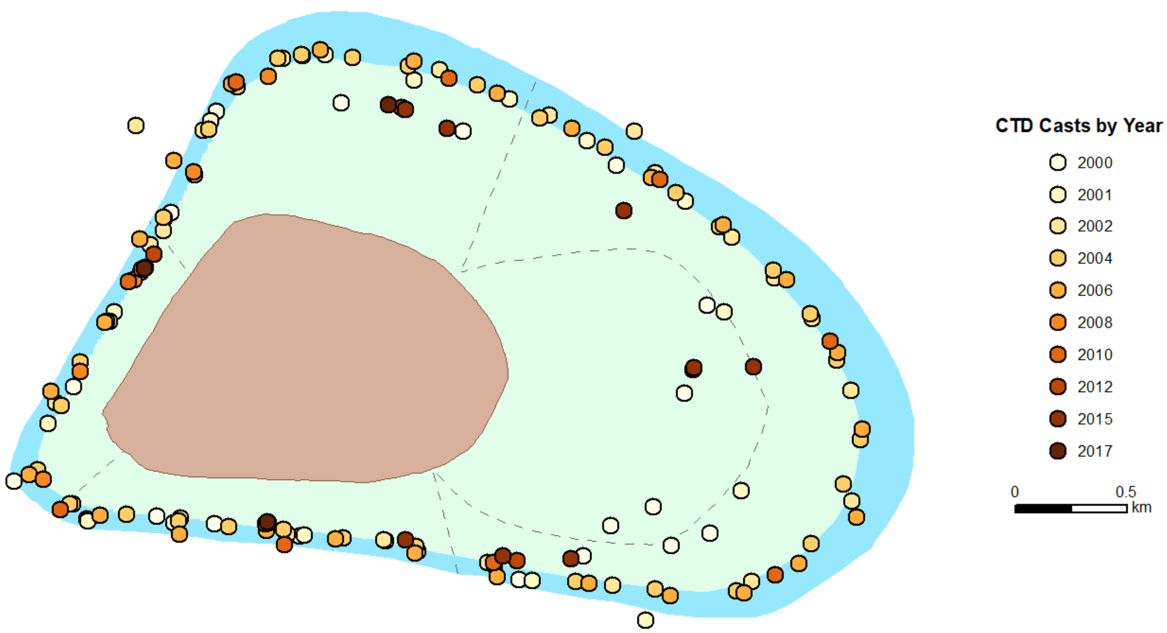


Figure 12. Locations of nearshore conductivity-temperature-depth (CTD) hydrocasts (measuring water column salinity and temperature) from the ocean surface to depths of ~30 m around Baker Island per survey year.

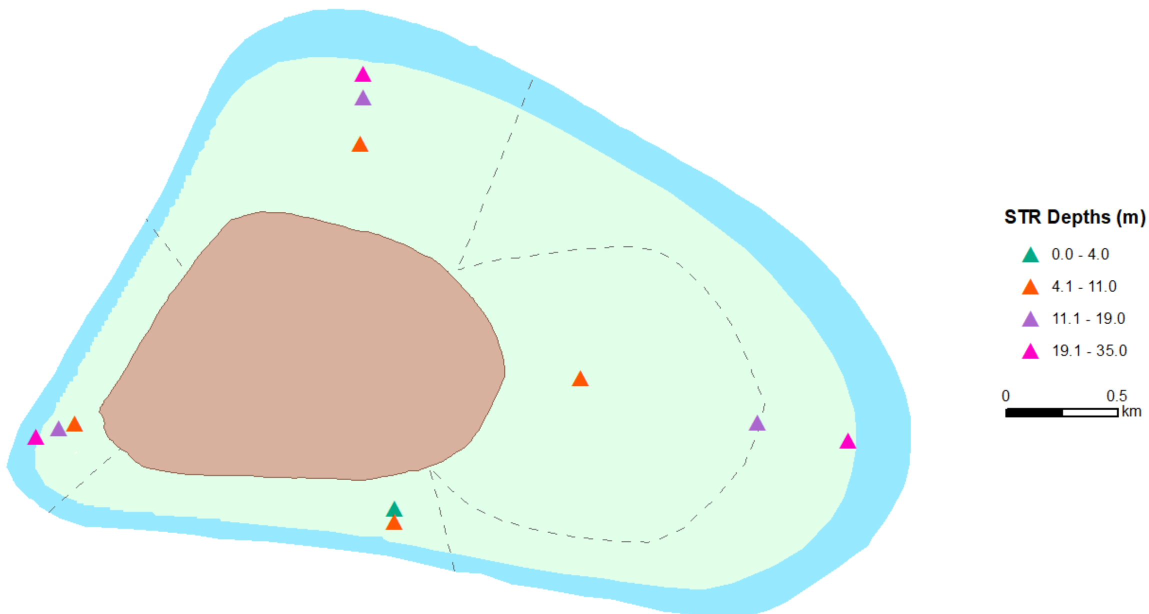


Figure 13. Locations of subsurface temperature recorders (STRs), deployed on the reef substrate in depths ranging from 1 to 35 m around Baker Island. Multiple STRs may have been collected at the same location over multiple years; however, they are represented by a single marker on the map.

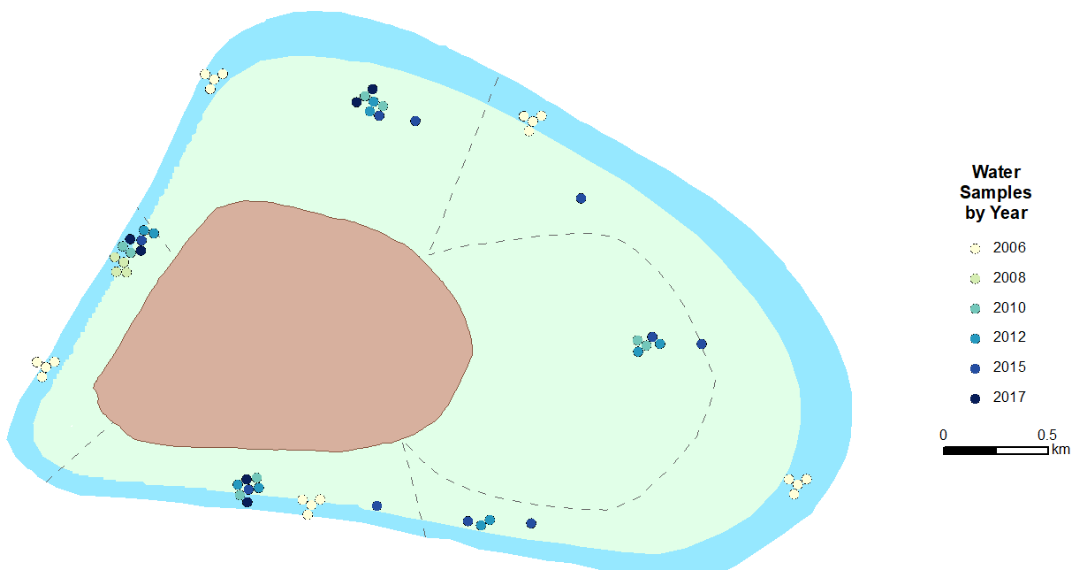


Figure 14. Locations of discrete seawater sample collections from 1 to 35 m depths around Baker Island. Samples evaluated for various analytes: dissolved inorganic carbon, total alkalinity, chlorophyll *a*, and dissolved inorganic nutrients. Water samples collected at the same location over multiple years have been plotted adjacent to one another and organized around their shared location on the map.

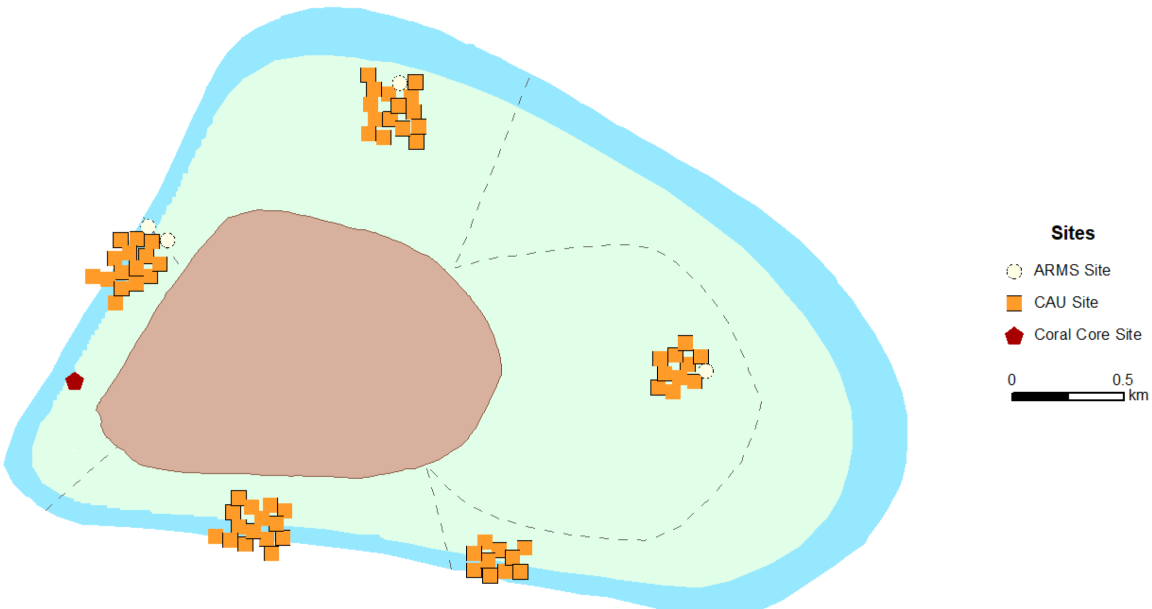


Figure 15. Locations of autonomous reef monitoring structures (ARMS, 3 per site) and calcification accretion units (CAU, 5 per site) deployed on the reef at ~15 m depths around Baker Island. One coral core of *Porites* spp. was collected opportunistically at ~9 m depth.

Oceanographic Observations

Oceanographic conditions around Baker Island show a strong relationship with ENSO variability. The ONI, SST anomalies, DHWs, and chl-a anomalies for the period 1981 to 2017, as available, are shown in Figure 16a. The ONI shows the variability and frequency of warm El Niño (positive ONI) and cool La Niña (negative ONI) periods (Figure 17a). While patterns in Baker SST largely tracked variability in ENSO, there were notable breaks from a strong correlation with the ONI. In particular, Baker experienced relatively small SST anomalies compared to the magnitude of the ONI during the extreme 1997–1998 and 2015–2016 El Niño events, while experiencing relatively large SST anomalies during the more moderate 2005–2006 and 2009–2010 El Niño events (Figure 16a, b).

The coral reefs surrounding Baker Island have experienced several prolonged episodes of ENSO-driven anomalously-warm temperatures over the past four decades, visualized as DHW in Figure 16c. DHWs estimate the amount of thermal stress that has accumulated in an area over a 12-week period by summing any temperature exceeding the maximum monthly mean by 1 °C. SST anomalies above this “bleaching threshold” can drive significant coral bleaching when sustained for several weeks to months, with moderate bleaching predicted when DHW >4 °C-weeks and severe bleaching expected when DHW >8 °C-weeks. The cumulative DHWs during this period related directly to strong warming observed in the ONI (Figure 16), with DHWs accumulated at Baker in response to El Niño events in 1987–1988, 1991–1992, 1994–1995, 2002–2003, 2006, 2009–2010, and 2015–2016. The most severe thermal stress events (DHWs exceeding 10 °C-weeks) to influence the coral reefs at Baker occurred during the 1994–1995, 2002–2003, 2006–2007, 2009–2010, and 2015–2016 El Niños.

An inverse relationship exists between ENSO-driven variability in SST and phytoplankton chl-a pigment concentration, where increased temperatures were associated with decreased concentrations of chl-*a* (Figure 16d, Figure 17b). During La Niña conditions, enhanced upwelling of anomalously cool, nutrient-rich deeper water drove high chl-a concentrations and associated primary productivity. During El Niño conditions, upwelling was suppressed causing decreased chl-a concentrations and associated productivity. Chl-*a* anomalies were negative during the severe 1997–1998, 2002–2003, 2006–2007, 2009–2010, and 2015–2016 El Niño events. Chl-*a* anomalies abruptly spiked during the transitions from El Niño to La Niña in 2006–2007 and 2009–2010. Because a strong La Niña did not follow the extreme 2015–2016 El Niño, a similar abrupt spike in chl-*a* or productivity was not observed that year.

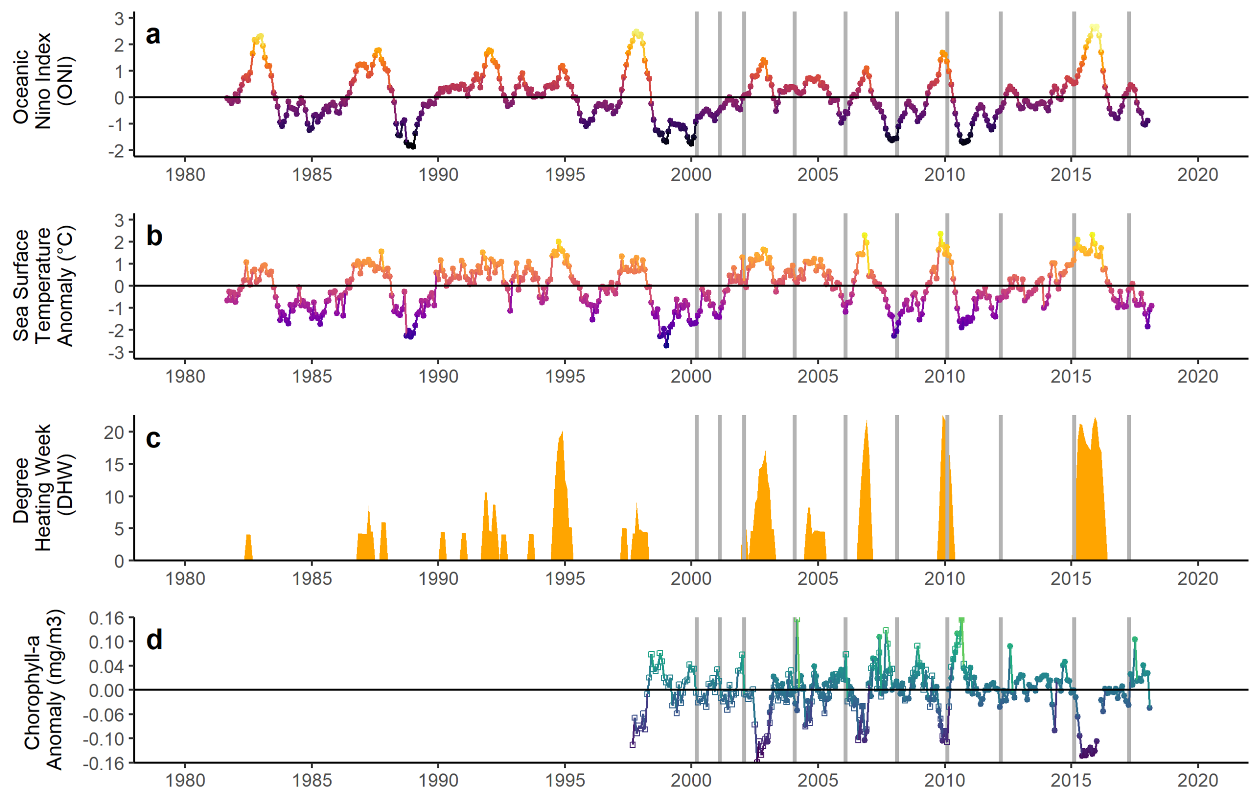


Figure 16. Time series of oceanographic conditions at Baker Island: (a) a 3-month rolling mean of Oceanic Niño Index (ONI) from September 1981 to April 2018 in the El Niño 3.4 region (5°N–5°S, 120°W–170°W), (b) SST anomalies from September 1981 to April 2018, (c) Cumulative Degree Heating Weeks (DHW) from 1985 to 2017, and (d) phytoplankton chlorophyll-*a* (chl-*a*) pigment concentrations from 1997 to 2017. Available data for ONI, SST, DHW, and chl-*a* were extracted for a box around Baker (0°05.7′N to 0°18.0′N and 176° 34.7′W to 176°21.9′W). Shading for SST and chl-*a* data indicates the magnitude of the anomaly. The grey vertical bars within each time series denote the timing of Pacific Reef Assessment and Monitoring Program survey missions to Baker.

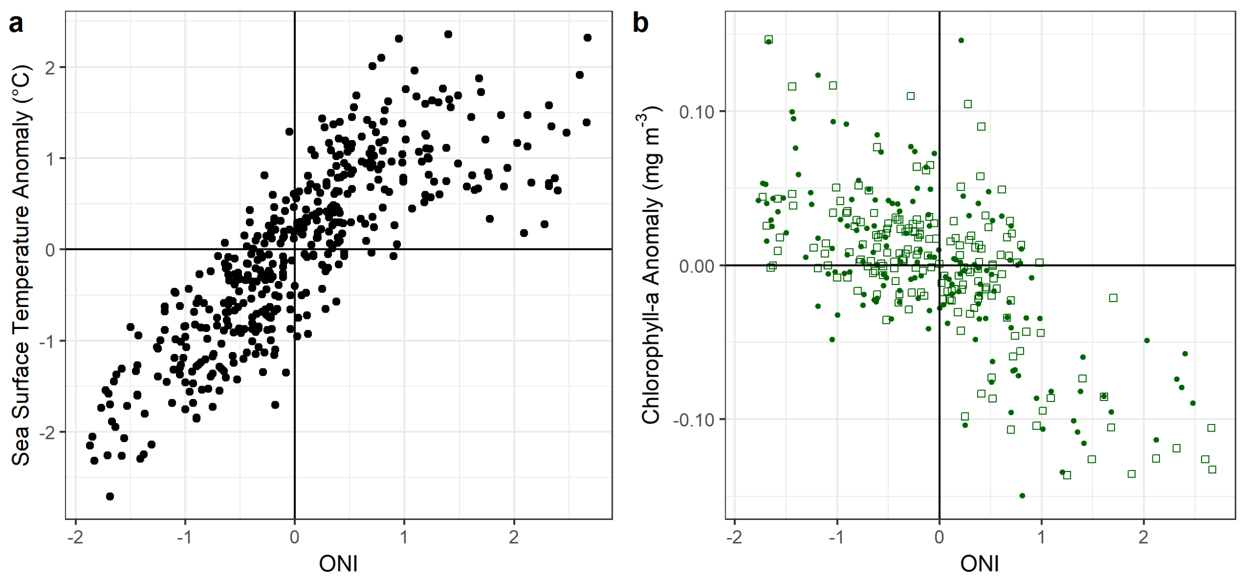
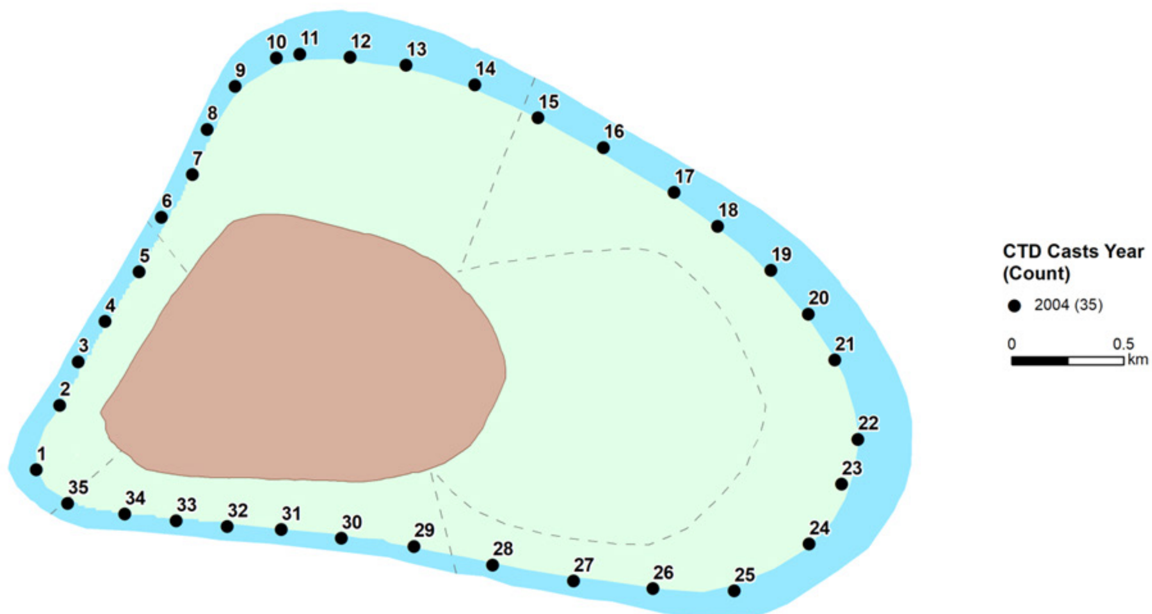


Figure 17. Relationship between monthly-averaged oceanographic conditions at Baker Island: (a) Oceanic Niño Index (ONI) vs. sea surface temperature (SST) anomaly, and (b) ONI vs. satellite-derived chlorophyll *a* (chl-*a*, Sea-Viewing Wide Field-of-View Sensor in boxes and Moderate Resolution Imaging Spectroradiometer in circles) anomaly data. Available data for ONI, SST anomaly, and chl-*a* were extracted for a box around Baker (0°05.7′N to 0°18.0′N and 176°34.7′W to 176°21.9′W).

Water Column Observations

The physical properties and stratification of the water column surrounding Baker Island varied both temporally with phases of ENSO and spatially around the exposed forereef. Figure 18 shows the location of shallow-water CTD casts conducted in the nearshore waters around Baker in 2004 (35 casts) and 2006 (26 casts). Cast data document measurable differences in temperature, salinity, and density profiles between neutral ENSO conditions in 2004 and moderate La Niña conditions in 2006. Temperatures were about 3 °C cooler and densities were about 0.5 kg m^{-3} higher in 2006, indicative of increased equatorial upwelling and topographic upwelling of the EUC that is typical during La Niña years.

Nearshore waters around Baker Island were vertically well-mixed across depths in 2004 and slightly stratified in 2006 when a shallow lens of relatively fresh, e.g., low salinity, water was observed in the upper few meters (Figure 19). These vertical profiles show stronger upwelling activity on the western side of the island in 2006 (hydrocasts #1–5, 21–25), where lower temperatures, higher salinities, and associated higher seawater densities were observed relative to the rest of the reef (Figure 19).



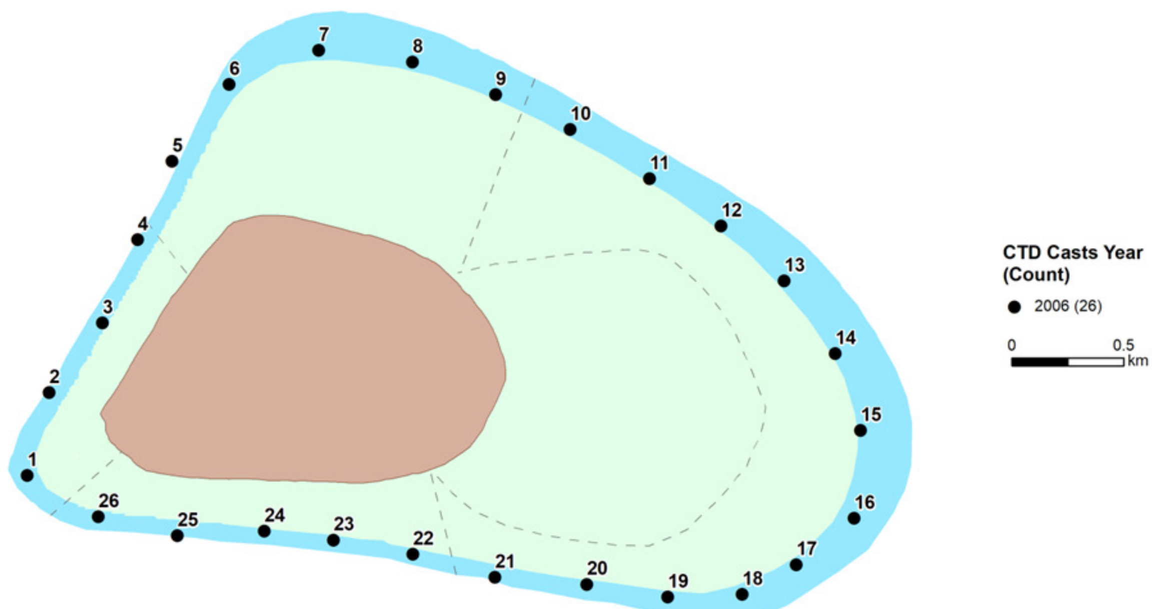


Figure 18. Shallow-water conductivity-temperature-depth (CTD) sampling locations around Baker Island. CTDs were conducted during January of 2004 (35 casts), and January of 2006 (26 casts). The casts are numbered sequentially in a clockwise direction around the island from left to right.

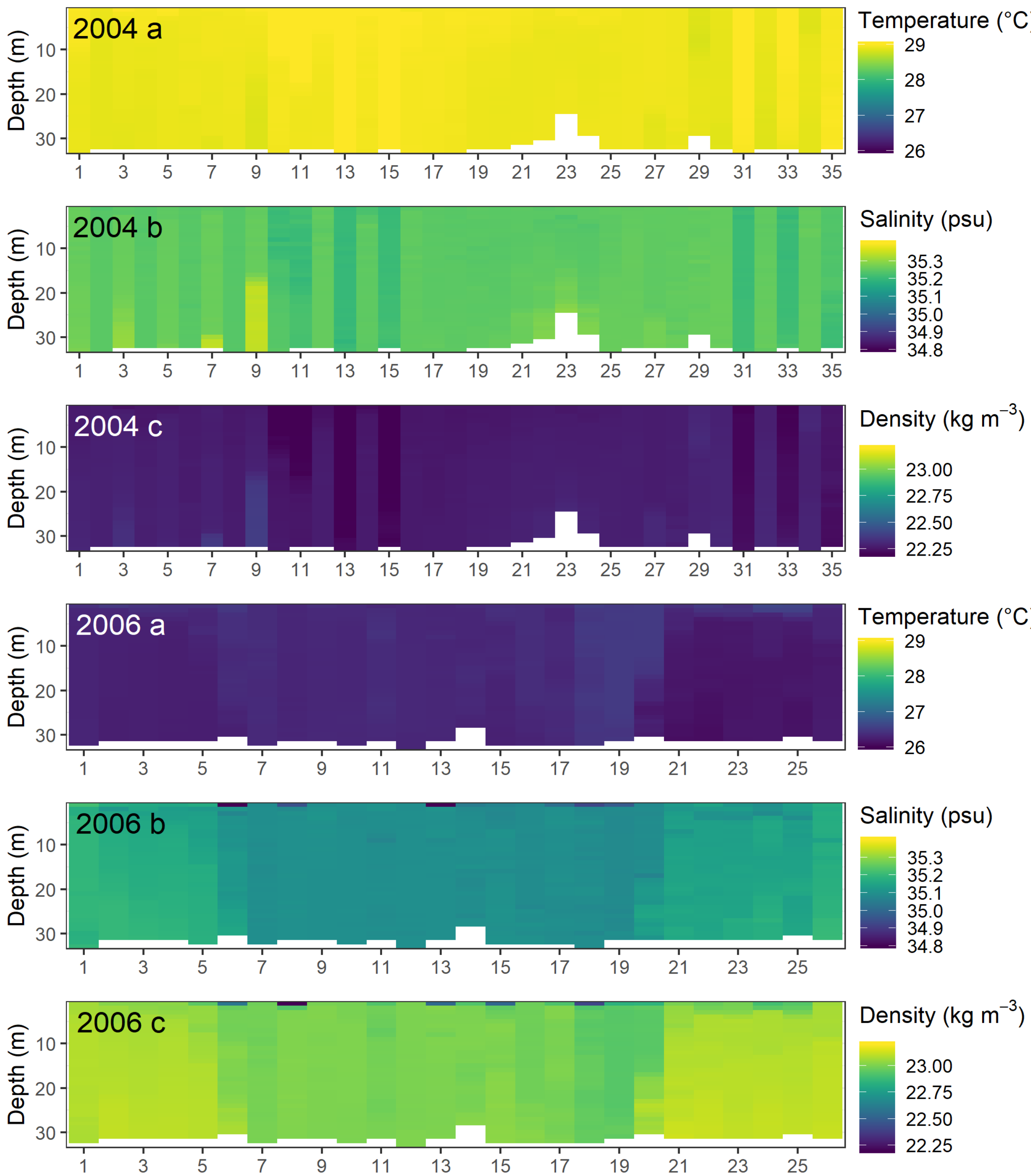


Figure 19. Profiles from shallow-water conductivity-temperature-depth casts around Baker Island in January 2004 (top three panels) and January 2006 (bottom three panels) for (a) temperature (°C), (b) salinity (psu), and (c) sigma-t density (density of seawater at atmospheric pressure in kg m^{-3}-1,000), from the surface to depths of ~35 m. The casts are numbered sequentially in a clockwise direction around the island. The top three panels show 2001 profiles 1–30, while the bottom three panels show 2006 profiles 1–72.

Between 2002 and 2017, a total of 25 moored subsurface temperature recorders (STRs) collected time series of temperature at depths between 1 and 31 m (Figure 13). This suite of STRs provided in situ vertical thermal structure observations to characterize the temperature regimes experienced by the coral reefs surrounding Baker Island at smaller spatial scales, reef depths, and at finer temporal resolution (5–15 minutes) than is possible using satellite SST data. Interannual temperature variability was large; temperatures ranged from above 30 °C during El Niño years (2006, 2010, 2016) to as low as 25 °C during La Niña years (2008, late 2010; Figure 20). All four sides of the island generally showed similarly homogeneous thermal conditions, both geographically and with depth, indicating a fairly well-mixed system.

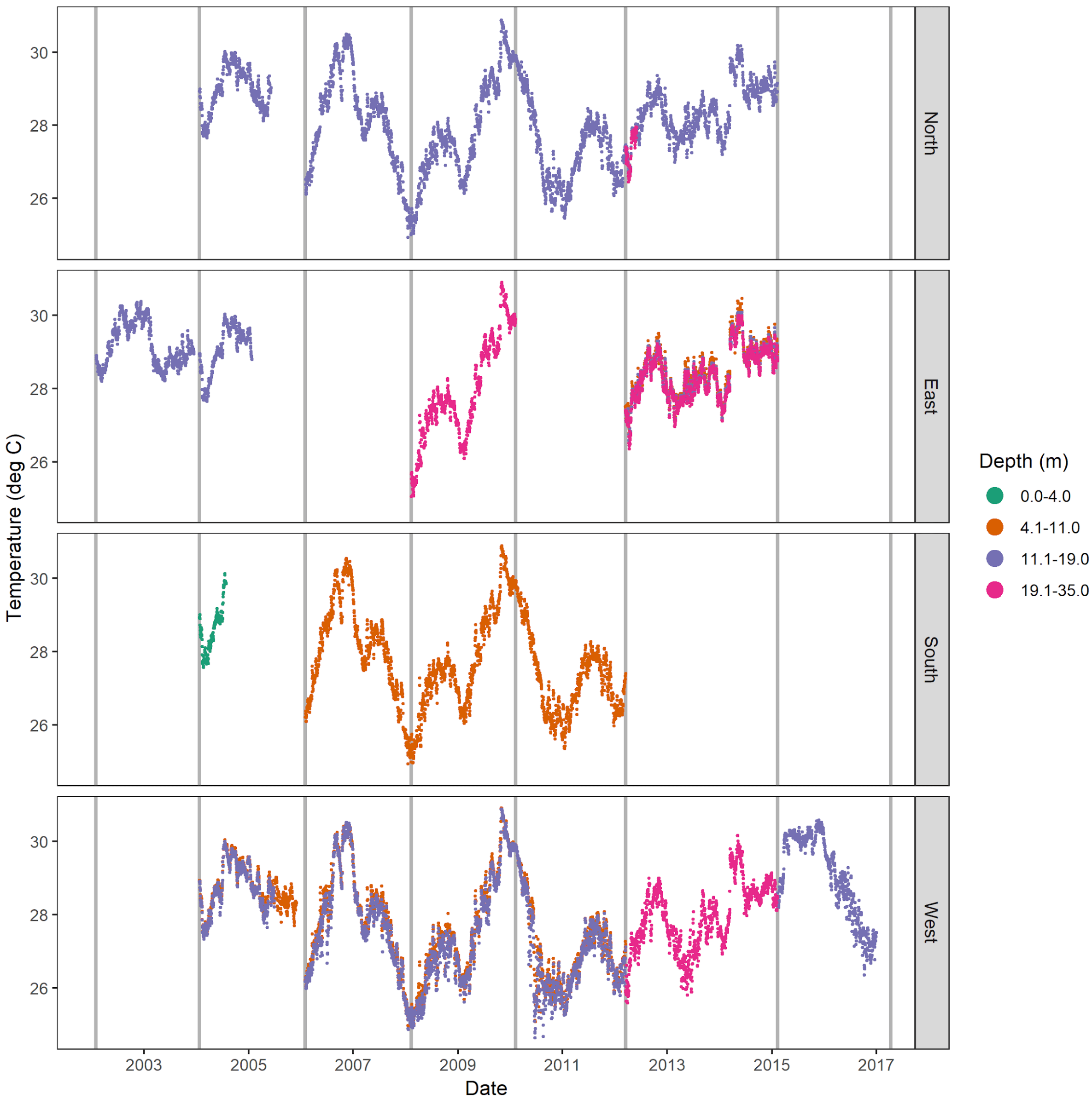


Figure 20. Daily subsurface temperature recorder time-series observations between 2002 and 2017, collected around Baker Island (North, East, South and West). Four different depth ranges were defined at each of these locations: green (0–4.0 m), red (4.1–11.0 m), blue (11.1–19.0 m), and magenta (19.1–35.0 m). The vertical grey bars denote the survey missions to Baker.

Wave Energy

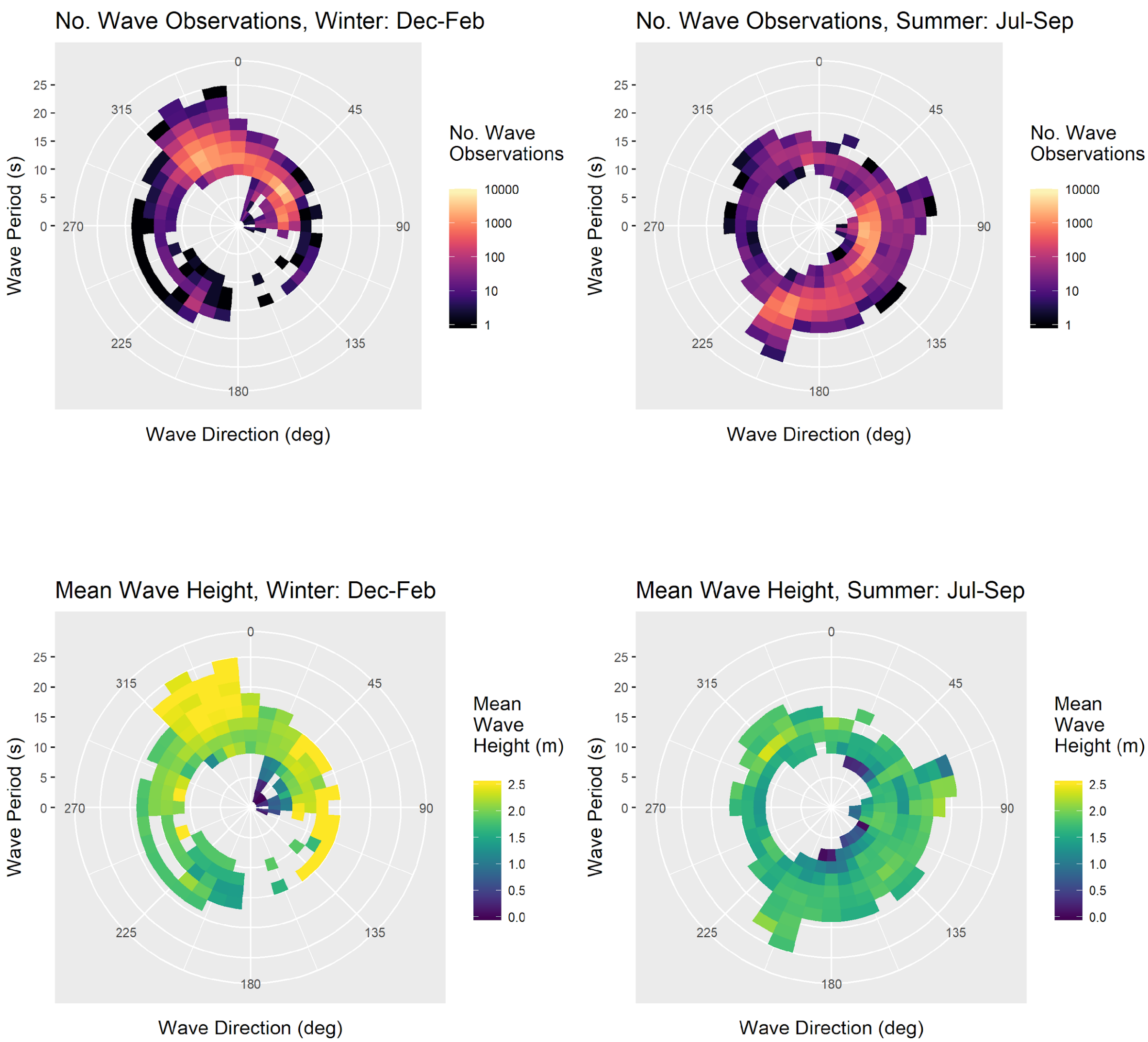


Figure 21. WaveWatch III model outputs over the period 2010–2016. Top panels: Polar plot of the percent of wave observations coming from different directions between December–February (left), and between July–September (right). Bottom panels: Polar plot of derived mean wave height between December–February (left), and between July–September (right). The position of wave data around the 360° circle (in 10° bins) displays the direction from which the waves hitting Baker Island travel, with 0° indicating wave arrival from due north and 180° from due south. The height of each directional bin from the center shows the wave period (greater distances from center represent longer wave periods), and the shading shows the number of hourly observations (top) and mean wave height (bottom) for each direction and period.

Ocean wave dynamics strongly influence the environmental conditions of nearshore coastal and island habitats. The energy generated by ocean waves varies on seasonal and interannual time scales, and spatial differences in the direction, magnitude, and frequency of waves around an island or atoll can have significant impacts on the sub-island distribution of coral reef communities. Hourly wave model outputs for 2010–2016 are shown in Figure 21. The northwest side of Baker Island experienced more waves with longer periods (the length of time between crests) and greater heights (vertical distance from trough to crest) over the winter period from December through February (Figure 21, left panels). The south and east sides were exposed to more waves with both higher periods and heights from July through September (Figure 21, right panels). The mean annual integrated wave power shows that the North, East, and South georegions of Baker were most impacted by wave patterns while the West georegion was relatively sheltered (Figure 22).

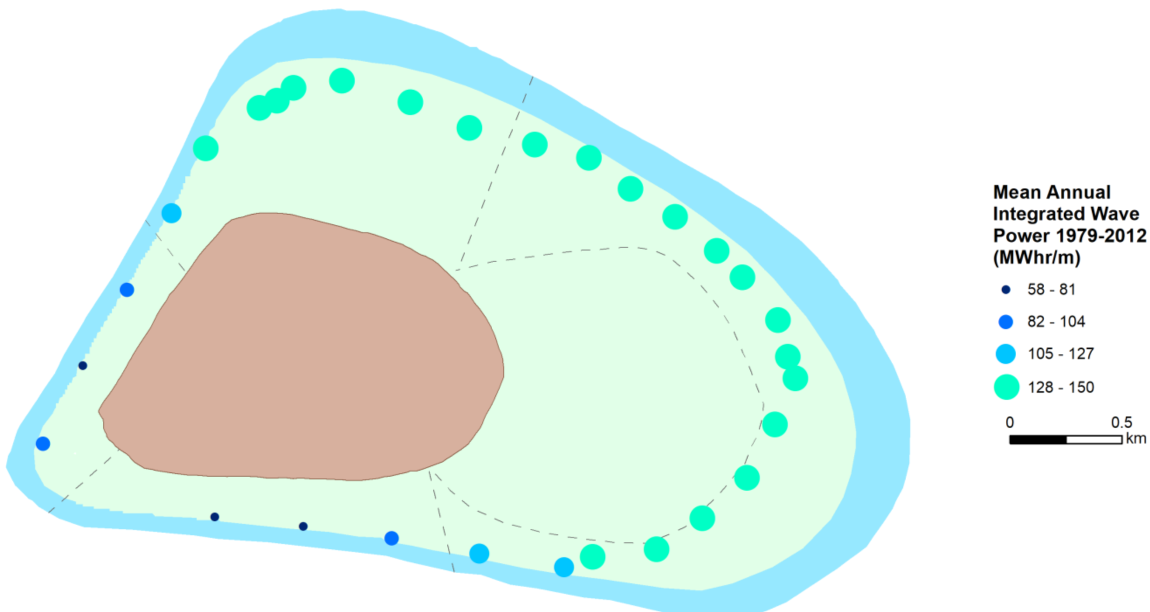


Figure 22. Mean annual integrated wave power (MWhr/m) at Baker Island. Data from 1979 to 2012 correspond to modified WaveWatch III by coastline shadowing using the incident wave swath method.

Carbonate Chemistry

Aragonite saturation state (Ω_A) measures the degree to which seawater is saturated with respect to the carbonate mineral aragonite, where Ω_A values above 1 indicate supersaturated conditions. Ω_A is often used as a more biologically-relevant alternative to pH because it reflects the availability of the carbonate ion (CO_3^{2-}) building blocks which calcifying organisms need in order to construct their calcium carbonate ($CaCO_3$) shells and skeletons. Greater values of Ω_A correspond to higher CO_3^{2-}concentrations and thus favor the growth of corals, crustose coralline algae (CCA), and other reef calcifiers. However, under the process of ocean acidification, with increased dissolution of carbon dioxide in seawater, the seawater pH, Ω_A, and concentrations of CO_3^{2-} all decrease. This makes it more difficult for corals and calcifying reef organisms to grow.

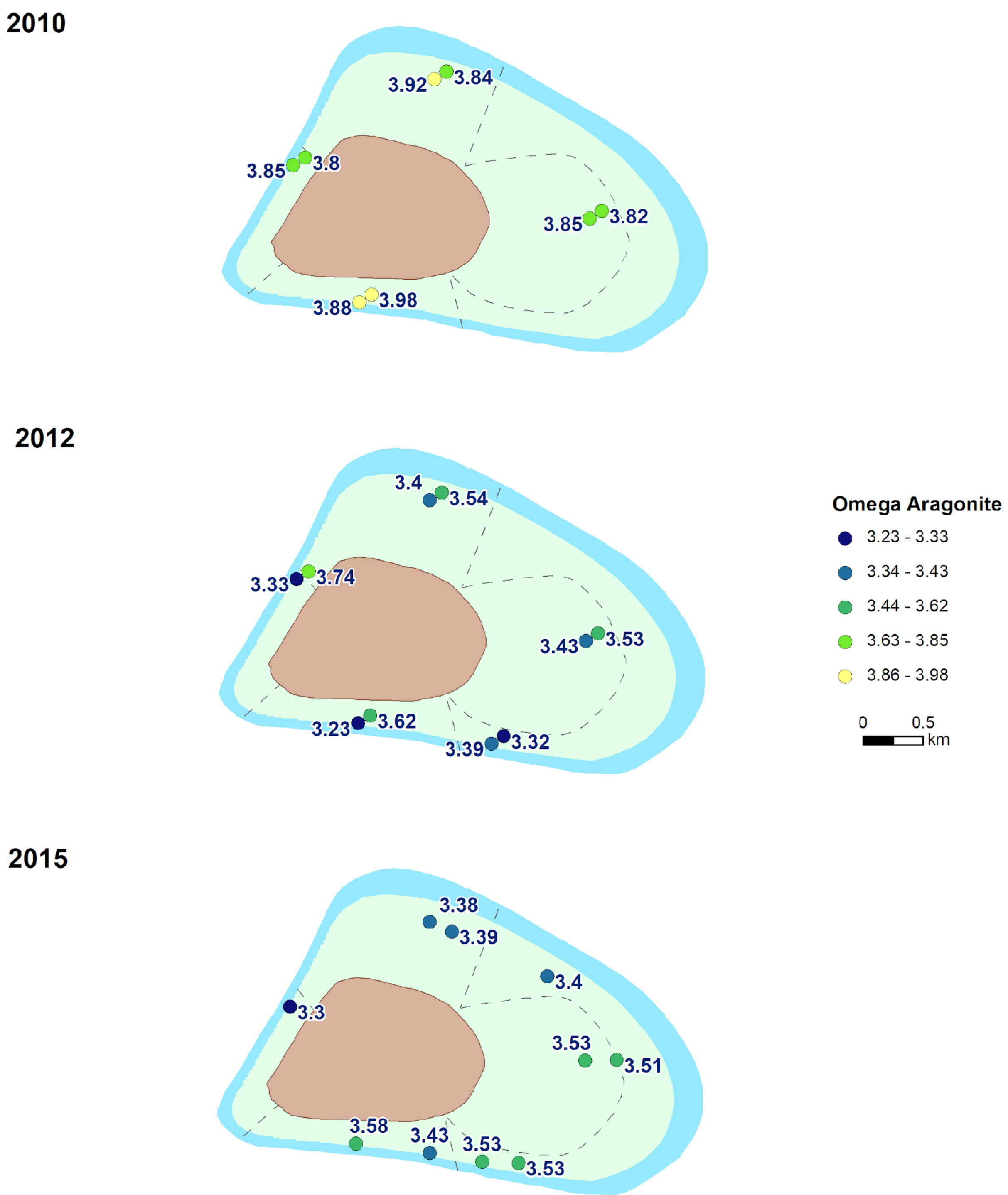


Figure 23. Spatial distribution of aragonite saturation state (Ω_A) observations during 2010, 2012, and 2015 around Baker Island.

There is strong interannual variability in Ω_A related to ENSO, with relatively low Ω_A during La Niña periods of increased upwelling, especially on the western side of the island, and relatively high Ω_A during El Niño conditions (Figure 23). The overall highest values in Ω_A were measured during moderately-strong El Niño conditions in 2010, likely driven by the cessation of upwelling that usually brings deep, lower-Ω_A water to the surface and by coral bleaching, which decreases the biological drawdown of Ω_A present on a healthy reef and thus causes Ω_A to rise. Conversely, Ω_A values during more ENSO-neutral periods in 2012 and 2015 were much lower than those measured in 2010 (2015 data were collected prior to the onset of warming shortly after the Pacific RAMP surveys). There were no clear and consistent sub-island scale spatial patterns of Ω_A for the reef waters around Baker Island, though we would anticipate lower values on the west side of the island during La Niña periods of strong, localized topographic upwelling. Compared with the island-wide median values of Ω_A and pH across the U.S. Pacific Islands region, values around Baker Island were substantially higher in 2010, and near or slightly below in 2012 and 2015 (Figure 24).

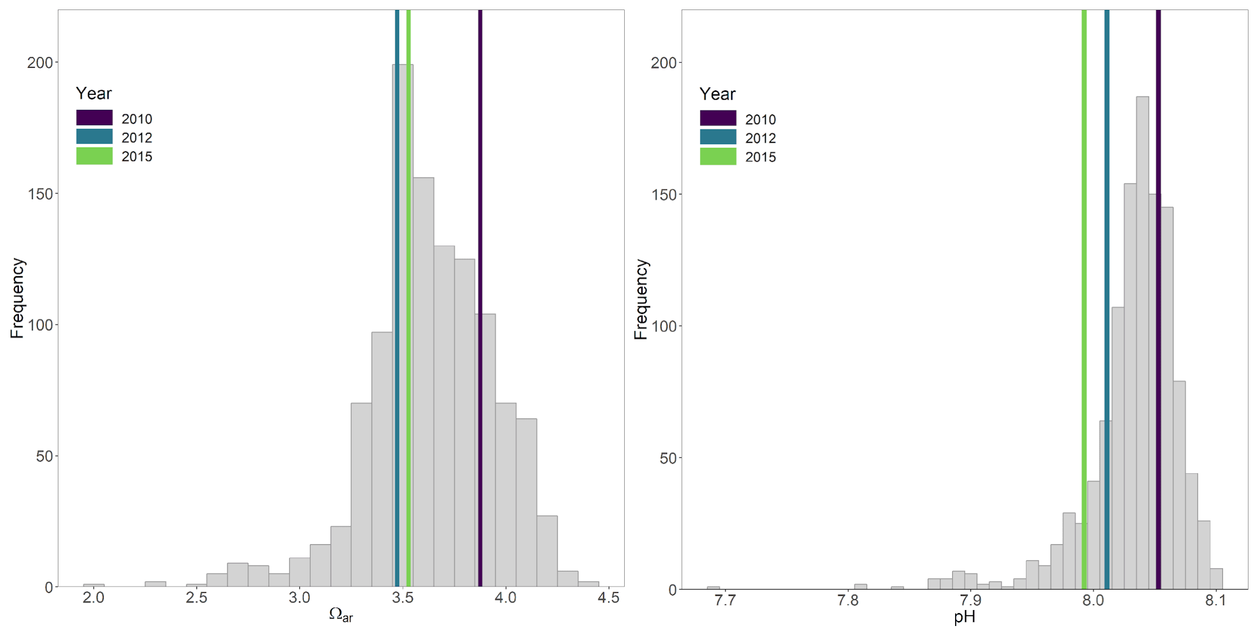


Figure 24. Histogram of all aragonite saturation state (Ω_A, left) and pH (right) values measured from discrete seawater samples across the U.S. Pacific Islands region from 2010–2017 (gray). Overlaid vertical bars show the medians of Baker Island data in 2010 (purple), 2012 (blue), and 2015 (green).

Net Carbonate Accretion

Calcification accretion units (CAUs) are simple, two-plate fouling structures that are deployed for 2–3 years and then analyzed for the total weight of $CaCO_3$ accreted by the calcareous organisms that recruit to the plates (largely, CCA and hard corals). CAUs provide an assessment of the net rate of $CaCO_3$ formation that results from the competing processes of carbonate precipitation by calcifying organisms and the removal of material by physical (e.g., strong waves) and/or biological (e.g., parrotfish, burrowing bivalves) erosion. $CaCO_3$ accretion is essential for reefs because it builds the structural framework for coral reef ecosystems and provides essential habitat for reef organisms. However, accretion rates are strongly influenced by nearshore environmental conditions. In particular, calcification rates of corals and CCA are sensitive to changes in carbonate chemistry and decline with decreasing pH and Ω_A (Pandolfi et al. 2011). Refer to “Chapter 1: Overview” for CAU-design specifics and deployment methodologies.

CAUs were deployed from 2010 to 2012 and from 2012 to 2015 around Baker Island to assess spatial and temporal variability in accretion. Carbonate accretion rates varied across deployment sites, although spatial patterns were consistent across years (Figure 25). The CAUs at the northern and eastern sites (BAK-14 and BAK-16, respectively) had higher accretion rates during both deployments (Figure 25). Overall, accretion rates were higher from 2012 to 2015 than from 2010 to 2012, which could be a result of more frequent El Niño conditions during the later period and less upwelling of cooler, lower pH, and lower Ω_A water (Figure 16). Compared to the rest of the Pacific, accretion rates at Baker were significantly greater than most surveyed sites (Figure 24). This may be due to the high nutrient concentrations driven by upwelling, which fuel productivity and can increase calcification rates of coral and CCA (Cohen and Holcomb 2009; Drenkard et al. 2013).

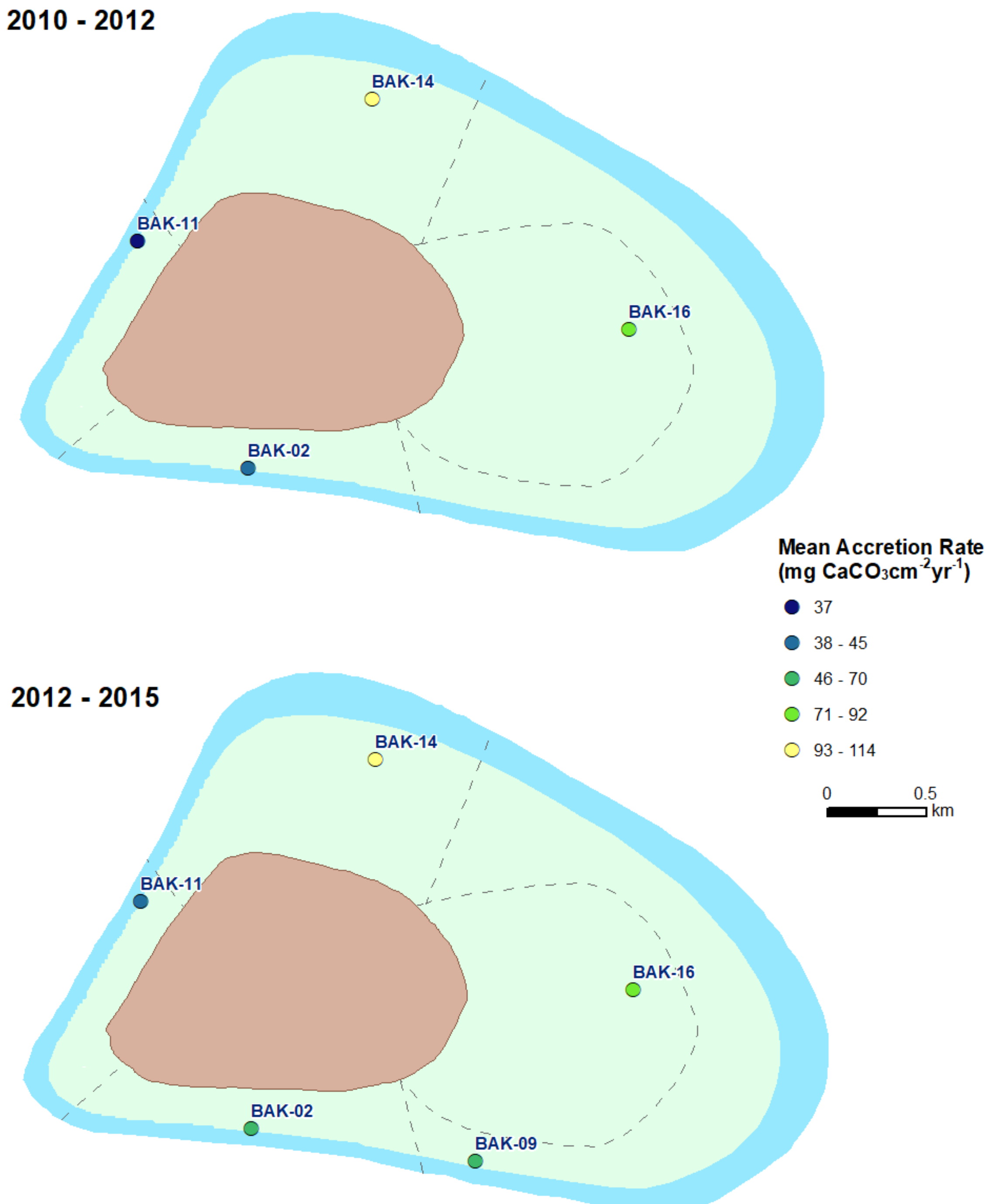


Figure 25. Spatial distribution of mean carbonate accretion rate (mg $CaCO_3$ cm^{-2} yr^{-1}) at Baker Island during 2010–2012 (top) and 2012–2015 (bottom). The calcification accretion units are labeled by location code.

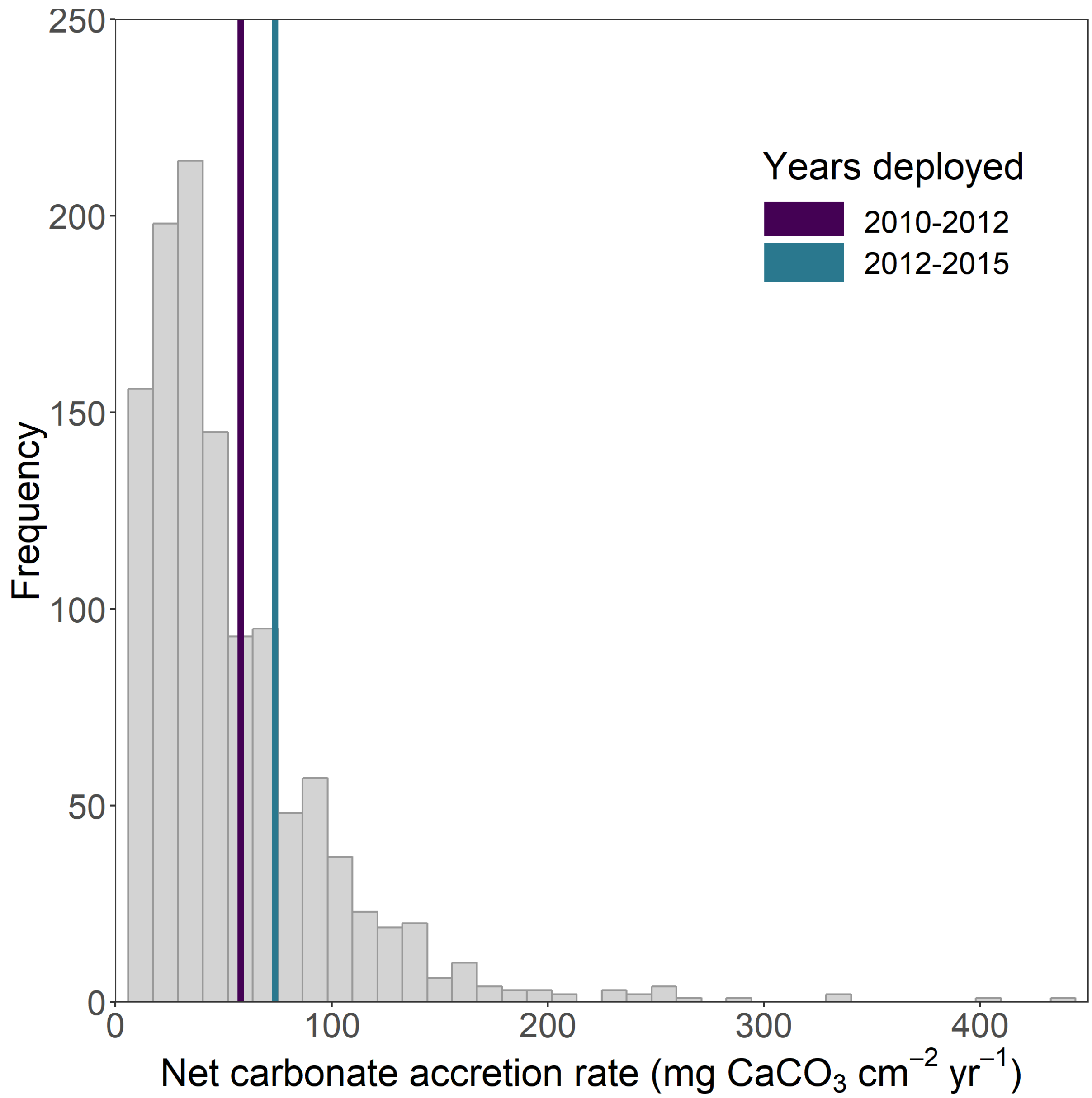


Figure 26. Histogram of all net carbonate accretion rates (mg $CaCO_3$ cm^{-2} yr^{-1}) measured by all calcification accretion units during the period 2010–2017 across the U.S. Pacific Islands region (gray), and median values for 2010–2012 (purple) and 2012–2015 samples for Baker Island (blue).

*A silverspot squirrelfish (*Sargocentron caudimaculatum*) takes refuge under an* Acropora *coral.*
Photo: Kevin Lino, NOAA Fisheries

Coral Reef Benthic Communities

8.4 Coral Reef Benthic Communities

Benthic habitat at Baker Island.
Photo: Morgan Winston, NOAA Fisheries

Survey Effort and Site Information

To characterize benthic habitats and coral populations around Baker Island, data were collected using Rapid Ecological Assessment (REA) surveys and TDS during nine survey efforts conducted between 2001 and 2017 (Table 3). REA surveys at Baker were primarily performed at repeat sites in mid-depth (>6–18 m) through the 2012 surveys, after which a stratified-random sampling (StRS) survey design was adopted to generate more statistically robust island-scale estimates of coral reef benthic community condition. The use of a StRS study design increased the number of survey sites across multiple depth strata (shallow: >0–6 m; mid: >6–18 m; and deep: >18–30 m). The stratified-random sites were more widely and evenly distributed around the island than the former repeat sites (Figure 27). Benthic REA surveys implemented the line-point-intercept (LPI) method from 2006 through 2012, and the photoquadrat method from 2015 through 2017 to estimate percent cover of benthic communities. From 2004 through 2017, the belt-transect (BLT) method was used to estimate the abundance, distribution, condition, and diversity of the coral populations (with progressive updates to the methods detailed in “Chapter 1: Overview”). Photoquadrat surveys were also conducted at fish REA sites over the period

2015–2017, yielding a greater sample size to determine benthic cover. Benthic TDS were conducted primarily around the island perimeter at predominantly mid-depth forereef habitats to estimate the percent cover of benthic functional groups, the density of ecologically or economically important macroinvertebrates, and occurrences of potentially significant ecological events, such as widespread bleaching, outbreaks of disease, and abundance of invasive or nuisance species. Opportunistic benthic surveys between the normal Pacific RAMP survey years (2015 and 2018) were conducted in 2017, specifically to monitor the aftermath of the extreme 2015–2016 El Niño-induced coral bleaching event (Brainard et al. 2018). Due to time limitations during the 2017 survey effort, REA benthic community (i.e., photoquads) and TDS were prioritized; no REA coral population data were collected in 2017.

Table 3. The total number of Rapid Ecological Assessment (REA) survey sites and towed-diver survey (TDS) segments completed by year and strata (if applicable) at Baker Island. Numbers in parentheses (bold) indicate the number of surveys conducted at mid-depths (>6–18 m). *Note: In 2015, REA survey methodology changed from repeat sites to stratified-random sampling (StRS) survey design. StRS sites were located across three depth strata: shallow (S), mid (M), and deep (D). Partial surveys in 2017 were opportunistically conducted to assess the impacts and recovery of coral bleaching experienced during the extreme 2015–2016 El Niño warm event.

		REA	
Year	**TDS**	**Coral Populations**	**Benthic Communities**
2001	37 (**33**)	–	–
2002	19 (**19**)	–	–
2004	76 (**58**)	3	–
2006	87 (**64**)	8	7 (7)
2008	52 (**40**)	4	4 (4)
2010	99 (**91**)	8	7 (7)
2012	100 (**86**)	6	6 (6)
2015*	50 (**44**)	4 (S) 8 (M) 3 (D)	15 (S) 22 (M) 14 (D)
2017*	50 (**41**)	–	9 (S) 8 (M) 6 (D)

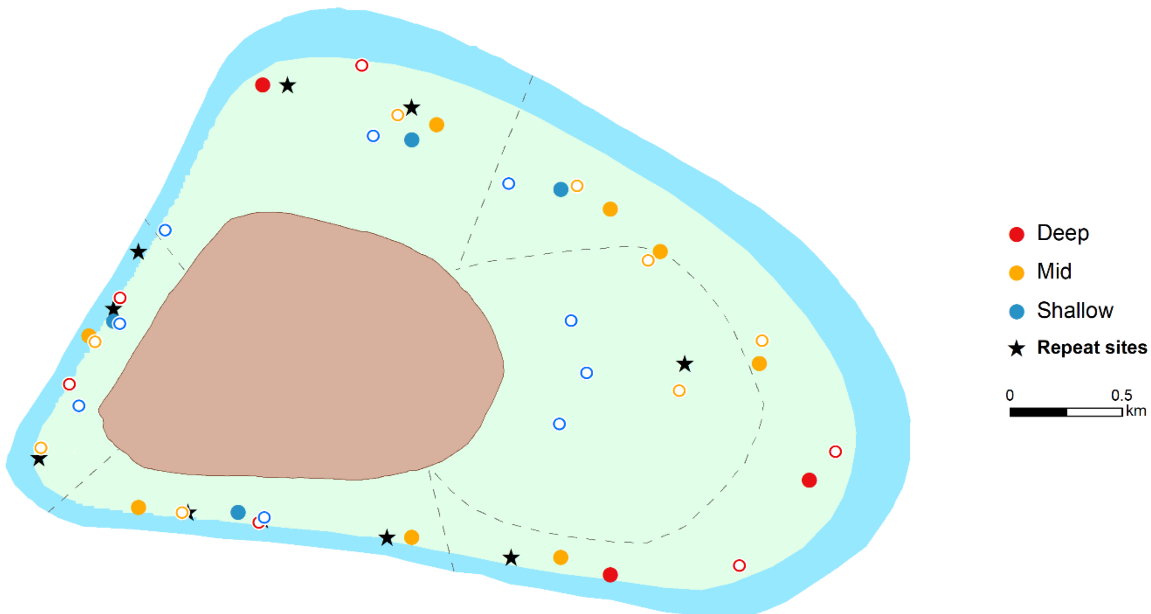


Figure 27. Baker Island benthic Rapid Ecological Assessment survey locations. Repeat sites (stars) were sampled from 2004 through 2012, and stratified-random sampling (StRS) sites were sampled in 2015 (blue, yellow, and red circles for shallow [>0–6 m], mid [>6–18 m], and deep [>18–30 m] depth strata). Photoquadrats for assessing benthic communities were collected at all StRS sites (open circles with white fill and solid circles). Coral population surveys were only conducted at sites indicated by solid circles.

Recent State of Benthic Cover

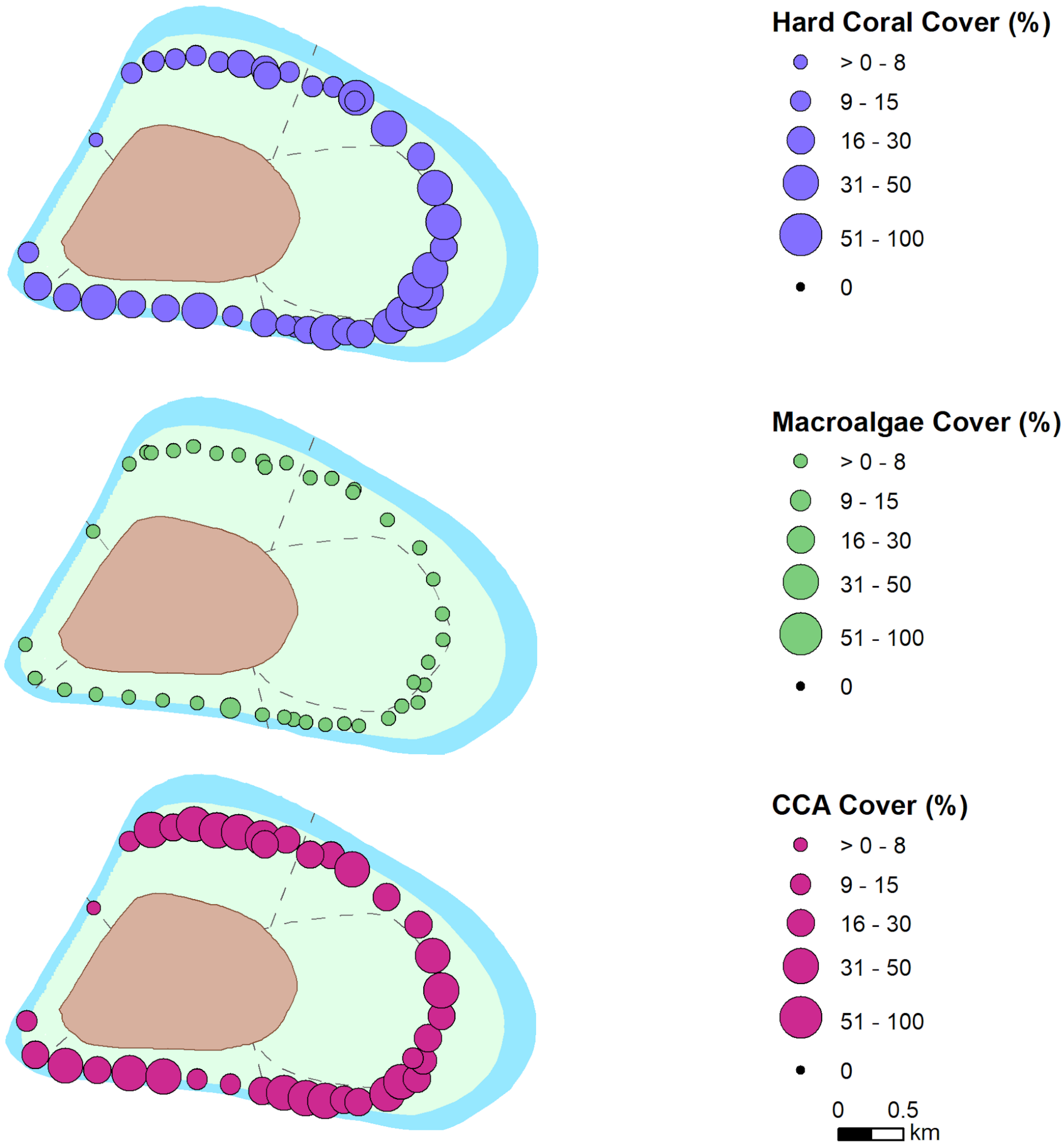


Figure 28. Visual estimates and spatial distributions of benthic cover (%) of mid-depth (>6–18 m) hard coral, macroalgae (including calcified and encrusting macroalgae), and crustose coralline algae (CCA) at Baker Island from towed-diver surveys in 2017.

During mid-depth TDS around Baker Island in 2017 (Figure 28), CCA and hard coral were the dominant benthic functional groups. Mean CCA cover was 25.3% ± 3.4 SE, while mean hard coral cover was slightly lower (mean = 22.2% ± 3.5 SE). Hard coral cover was consistently observed on all tow segments, ranging from 7.5% to 35%; the vast majority of tow segments (95%) had 15% or more coral cover. CCA and hard coral cover were similar in the South and East Terrace georegions, but in the North georegion, CCA tended to dominate. Macroalgae (including encrusting and calcified macroalgae) were consistently low around Baker with nearly 70% of tow segments exhibiting cover values of 0.5% (Figure 28).

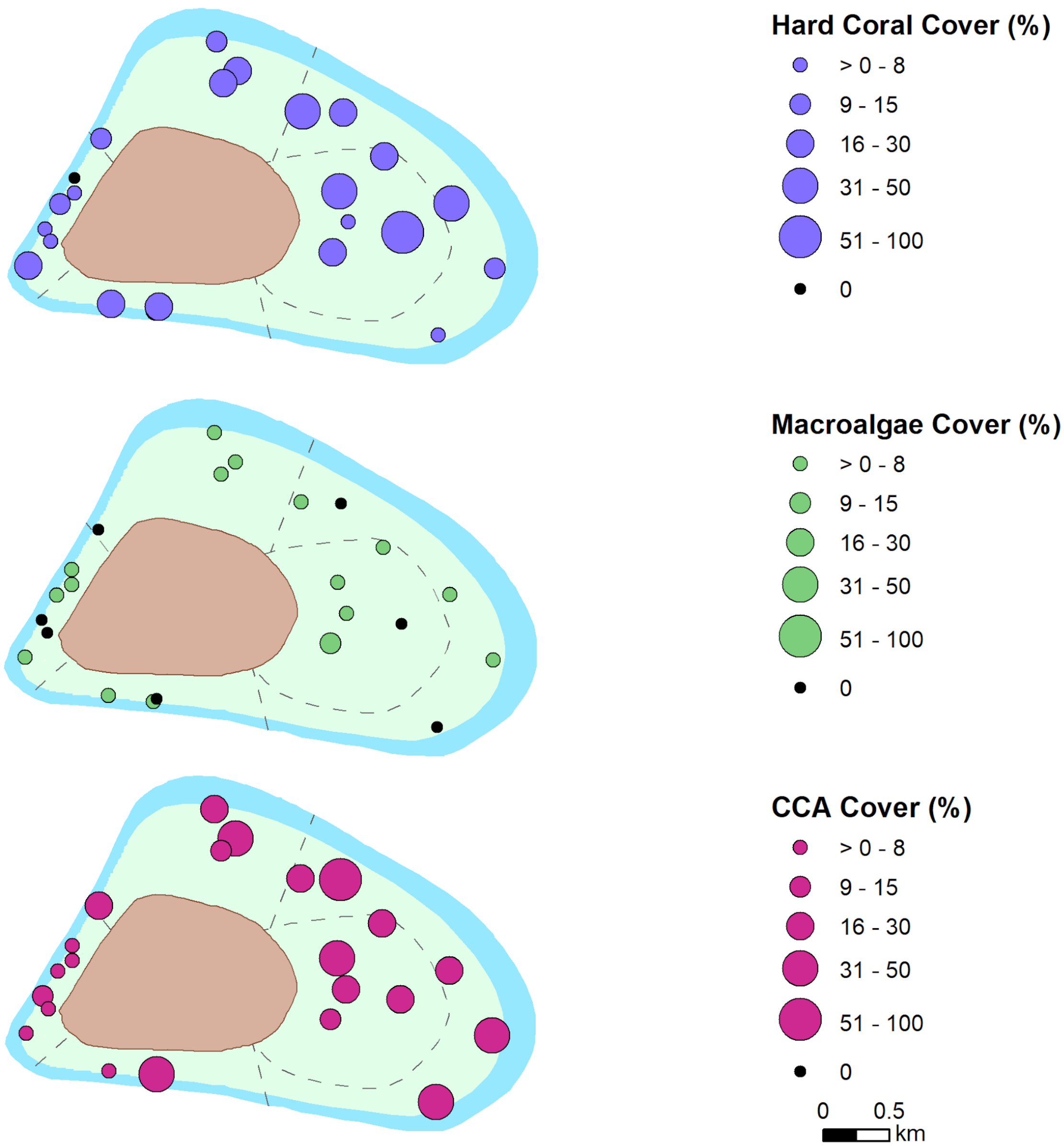


Figure 29. Distributions and site-level estimates of hard coral, fleshy macroalgae (excluding calcified and encrusting macroalgae), and crustose coralline algae (CCA) cover (%) at Baker Island from stratified-random sampling photoquadrat surveys conducted at all depth strata combined (>0–30 m) in 2017.

StRS photoquadrat surveys showed that CCA was the dominant benthic community functional group at Baker Island in 2017 (Figure 29). CCA was present at all sites, with cover ranging between 4% and 52.7% and an island-wide mean of 21.1% ± 2.7 SE (Figure 29). CCA cover increased slightly with depth (Figure 30). Hard coral cover was present at nearly every site (mean = 18.7% ± 3.1 SE) and ranged from 0% to 55.7% cover. Coral cover peaked at mid-depth sites (mean = 26.3% ± 4.8 SE) and declined dramatically at deep sites (mean = 7.6% ± 2.6 SE, Figure 30). Macroalgae were uniformly low around Baker (mean = 1.9% ± 0.7 SE); over 95% of the sites had less than 4% cover (Figure 29). Macroalgae also remained low throughout all depth strata (Figure 30), though cover was highest at the shallow sites (mean = 2.7% ± 1.3 SE), likely due to increased light availability. Whereas CCA and hard coral were relatively dominant in the East Terrace georegion, cover was generally lower in the West georegion. Similar to Howland Island, steep forereef slopes characterize the West georegion of Baker. In this habitat type, steep substrate may limit both light availability and substrate stability for larger colonies thereby contributing to the overall low benthic cover of corals. The mid-depth, shallow-sloped East Terrace and East georegions offer more stable substrate and higher light availability which may help explain the higher coral cover observed in the mid-depths at Baker.

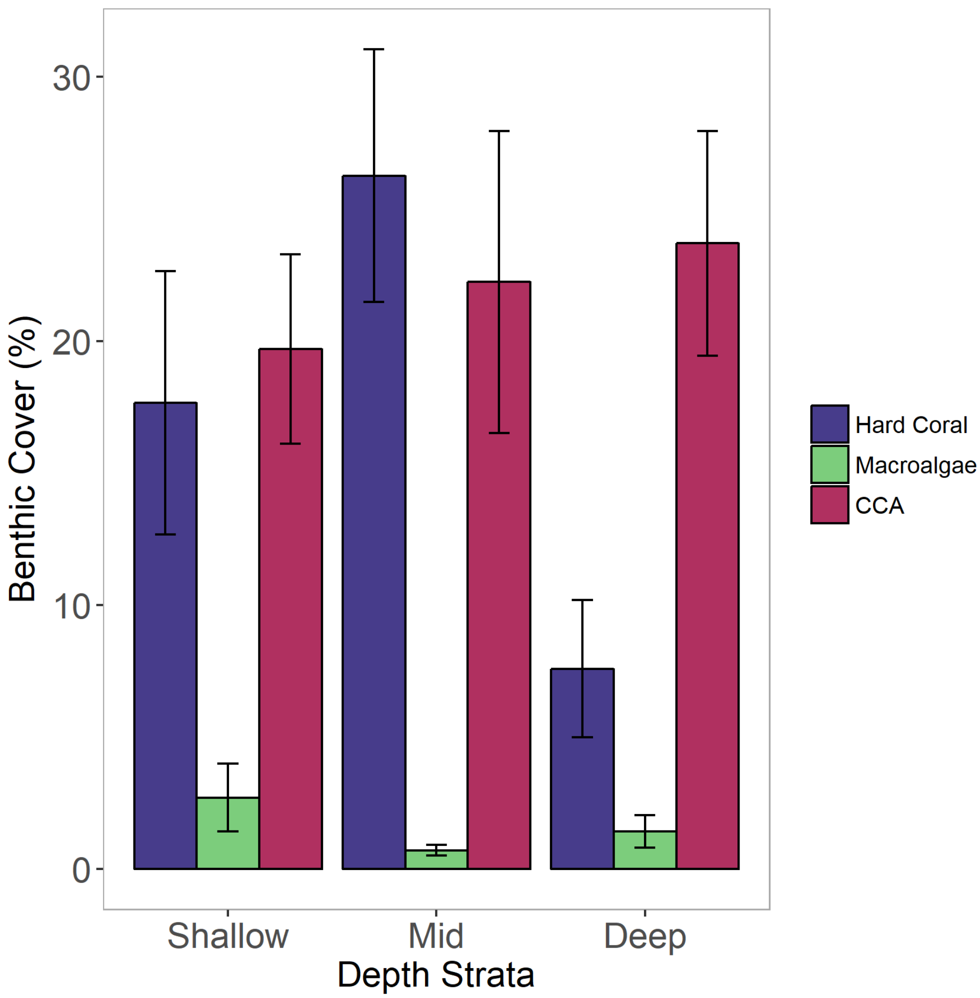


Figure 30. Strata-level mean benthic cover (± 1 SE) at Baker Island by benthic functional groups of hard coral, fleshy macroalgae (excluding calcified and encrusting macroalgae), and crustose coralline algae (CCA) for shallow (>0–6 m), mid (>6–18 m), and deep (>18–30 m) depth strata from stratified-random sampling photoquadrat surveys conducted in 2017.

Time Series of Benthic Cover

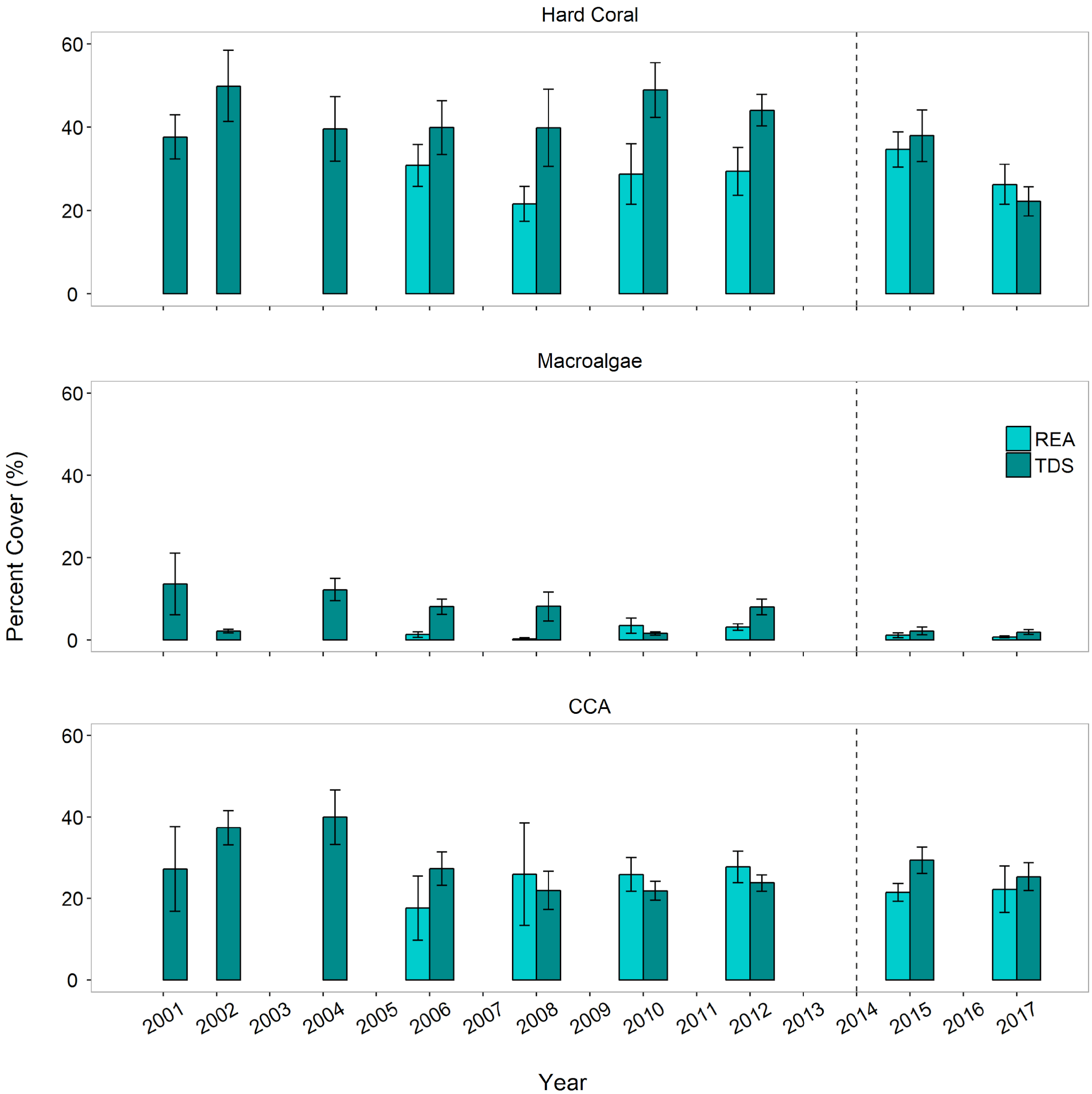


Figure 31. Time series of mean (± 1 SE) hard coral, macroalgae, and crustose coralline algae (CCA) cover (%) at Baker Island by survey method (Rapid Ecological Assessment [REA] and towed-diver [TDS]) conducted at the mid-depth stratum (>6–18 m) from 2001 through 2017. In 2014 (dashed line), REA survey methodology changed from line-point-intercept at repeat sites to photoquadrat surveys at stratified-random sampling sites. *Note: TDS macroalgae data include calcified and encrusting macroalgae; the REA macroalgae data exclude it.

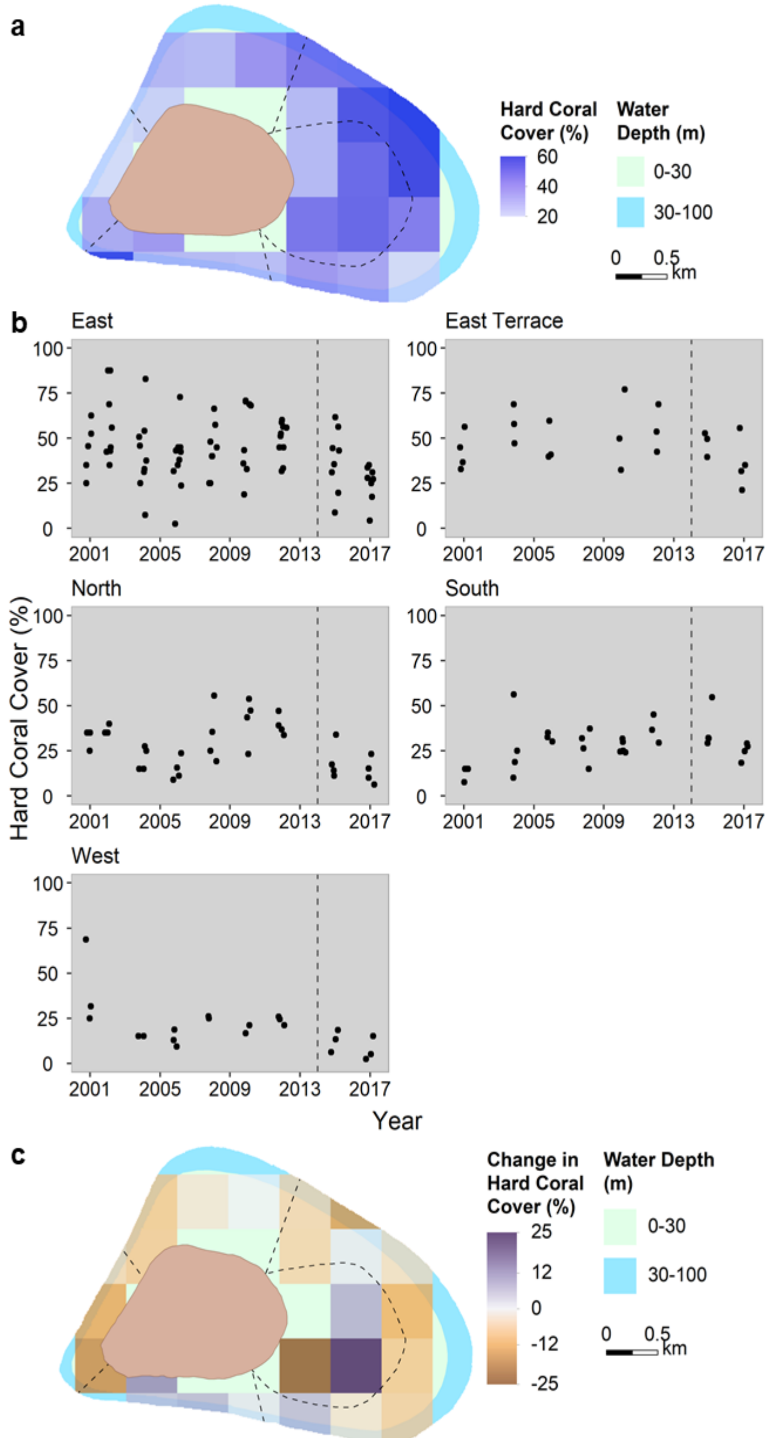


Figure 32. Spatial patterns and temporal trends of gridded (500 m × 500 m) mean coral cover at Baker Island across survey years (2001–2017) and methods (towed-diver, line-point-intercept (LPI), and stratified-random sampling (StRS) benthic and fish photoquadrats): (a) mean hard coral cover per 500 m by 500 m grid cell across all survey years; (b) time series of hard coral cover by georegion; and (c) temporal change in hard coral cover per 500 m by 500 m grid cell, only including cells with at least a 10-year span of data and at least 3 observation years. In 2014 (dashed line), Rapid Ecological Assessment survey methodology changed from LPI at repeat sites to photoquadrat surveys at StRS sites.

At mid-depths, both REA and TDS methods recorded relatively stable hard coral cover from 2001 to 2015, followed by a moderate decline after following the 2015–2016 El Niño (Figure 31). CCA cover was relatively stable and macroalgae cover was uniformly low throughout 2001–2017 (Figure 31). There was a conspicuous decline in hard coral cover from 2015 (pre-El Niño) to 2017, whereby REA photoquadrat surveys showed a 24% decrease and TDS showed a 42% decrease. There was also a reduction in hard coral cover estimates from the REA LPI surveys from a mean of 30.1% (± 0.1 SE) in 2006 to a mean of 21.6% (± 0.04 SE) in 2008, possibly related to the warm and cold SST anomalies over the period 2005–2008.

The decline in hard coral cover following the 2015–2016 El Niño, was observed across most georegions (Figure 32b). The greatest loss of coral cover occurred in the East georegion, where coral cover was the highest (Figure 32a, b), yet variable, in the early 2000s. The decadal trend analysis showed that changes in coral cover over time in the East Terrace georegion were spatially variable, with localized areas of increases and decreases (Figure 32c).

Macroalgae cover was low across years, with consistently higher TDS estimates than REA survey estimates (Figure 31), likely because early estimates of macroalgae in TDS included turf algae. The TDS showed a decrease in macroalgae cover over time, except for a slight increase in 2012. Macroalgae cover estimates from 2015 to 2017 using REA photoquadrats and TDS were similar and remained low (<3%).

Though spatially variable among sites, CCA cover was relatively stable island-wide over time (Figure 29, Figure 31). Estimates of CCA cover from TDS peaked in 2004 (mean = 40% ± 6.7 SE) and declined in subsequent years. Estimates of CCA from REA increased 57% from 2006 to 2012, but with substantial variability associated with 2006 and 2008 estimates, suggesting that those differences were not significant.

Time Series of Algal Disease

No algal diseases were observed on the reefs surrounding Baker Island during REA surveys from 2006 through 2015.

Recent Coral Abundance

In 2015, a total of 20 coral genera were observed at Baker Island (Figure 33). Island-scale colony abundance estimates were generated from the REA transect colony densities extrapolated over the area of hard bottom habitat found in the survey strata (0–30 m). These total abundance estimates indicate that fast-growing *Acropora* dominated the coral community prior to the 2015–2016 El Niño event, especially in the shallow stratum where greater light availability likely led to increased coral growth (Figure 34). At Baker, *Acropora* tended to form large thickets, which has driven the high density and abundance of this genus. Although spatially variable, cover of *Acropora* represented over half the coral cover in each of the three depth strata surveyed. Both adult and juvenile coral communities at Baker were largely composed of *Acropora*.

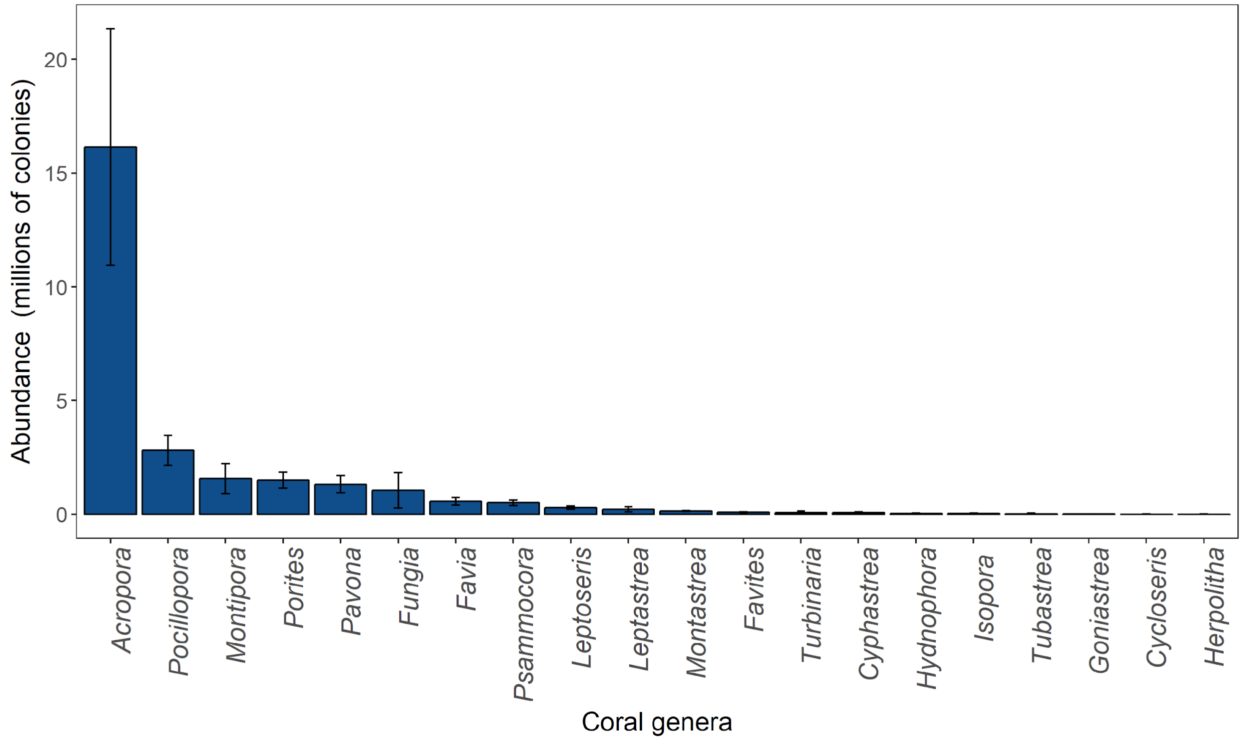


Figure 33. Island-scale abundance (± 1 SE) estimates by coral genera for all depth strata combined (>0–30 m) at Baker Island from Rapid Ecological Assessment surveys conducted in 2015.

While the density of total adult scleractinians in 2015 was similar across strata (Figure 34), hard coral cover based upon photoquadrat surveys was highest at mid-depth sites and declined dramatically at deep sites (Figure 30). This suggests that larger colonies were found in the mid-depths yielding the greater coral cover value, while smaller corals were found in the deep stratum. These patterns reflect changes in the coral community composition with depth (Figure 34), and likely reflect slower growth in the light-limited deep stratum. *Pocillopora*, a genus of small to moderately sized branching corals, had higher densities with increasing depth and was the most abundant of all scleractinians in the deep stratum. *Pavona*, *Montipora*, and *Porites*—genera typically abundant across the PRIMNM—had low densities in the shallow stratum, perhaps due to space limitation by the fast-growing *Acropora*. As *Acropora* density declined with depth, *Pavona* and *Porites* densities increased; density of *Montipora* remained low across depth strata. A table showing total generic richness of hard corals in the PRIMNM can be found in Appendix A of “Chapter 9: PRIMNM in the Pacific-wide Context.”

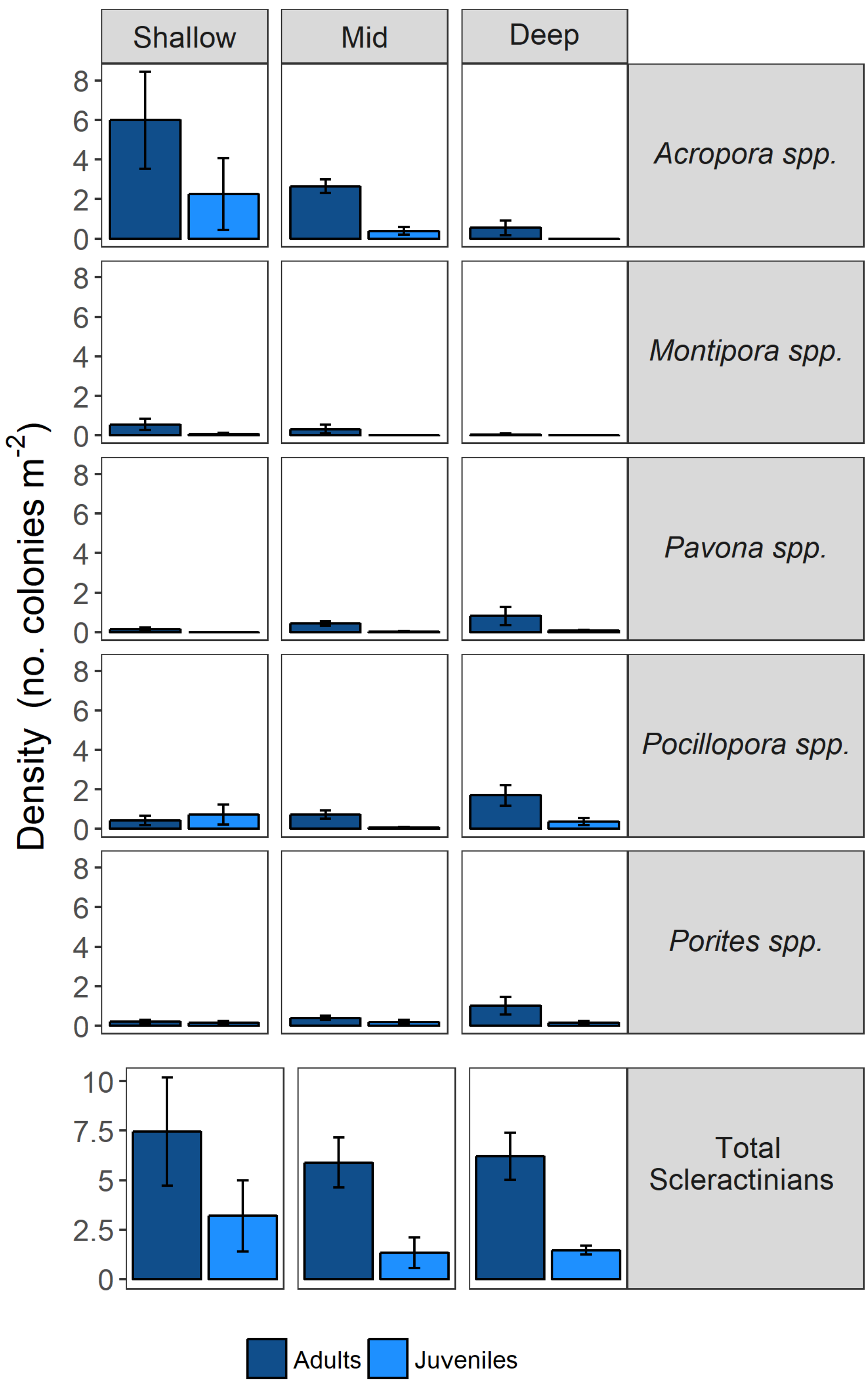


Figure 34. Mean (± 1 SE) adult and juvenile colony density from Rapid Ecological Assessment surveys conducted at Baker Island in 2015 at shallow (>0–6 m), mid (>6–18 m), and deep (>18–30 m) depth strata for five coral genera generally abundant in the Pacific Remote Islands Marine National Monument (*Acropora* spp., *Montipora* spp., *Pavona* spp., *Pocillopora* spp., and *Porites* spp.).

Time Series of Coral Abundance and Condition

Colony density varied over time from 2010 to 2015 (Figure 35), though large variances within survey years. The change in survey design between 2012 and 2015 necessitates caution when interpreting the increase in colony density observed in 2015 following the reduction seen from 2010 to 2012. Interestingly, there was not a concurrent decrease in coral cover from 2010 to 2012 based on either towed-diver or REA surveys. In 2015, smaller-sized colonies dominated the size-frequency distribution (Figure 36), with density decreasing with increasing size class.

Partial coral mortality (as old dead) doubled from 2010 to 2012 (Figure 37a). The 2010 bleaching event (mean prevalence of coral bleaching = 36.4% ± 5.8 SE) (Figure 37b) was the most likely driver of this increase in partial mortality as the prevalence of coral diseases and chronic health conditions was uniformly low over time (<1% in all years). Expectedly, recent dead was the highest during the 2010 bleaching event and decreased over time, together with the prevalence of rapid tissue loss diseases.

Unfortunately, the lack of demographic surveys in 2017 precludes a comprehensive assessment of the effects of the 2015–2016 El Niño event at Baker Island. Based on the hard coral cover losses recorded by the StRS photoquadrat surveys, we expect commensurate changes in coral colony densities and size-structure.

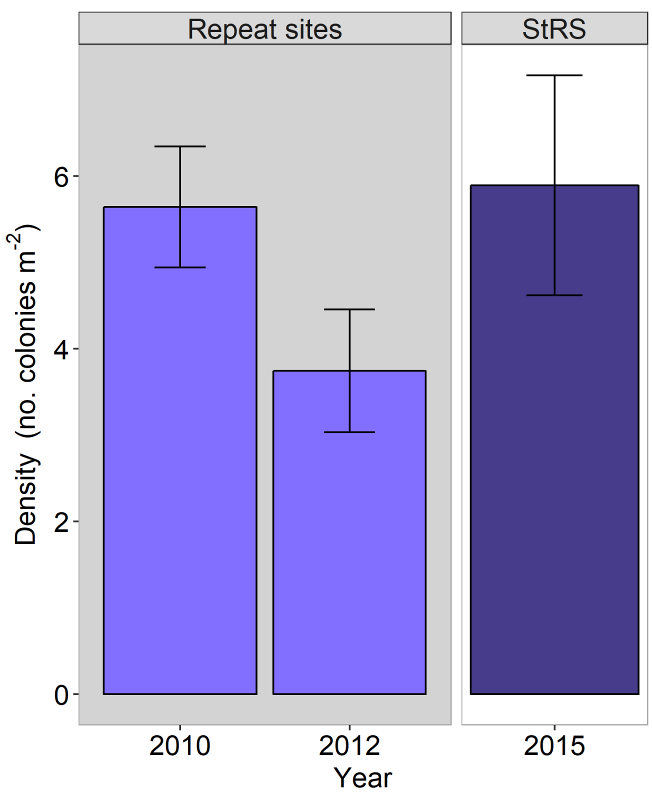


Figure 35. Time series of mean adult colony density (± 1 SE) at Baker Island, from mid-depth (>6–18 m) strata Rapid Ecological Assessment surveys by survey design, repeat sites or stratified-random sampling (StRS), conducted from 2010 through 2015.

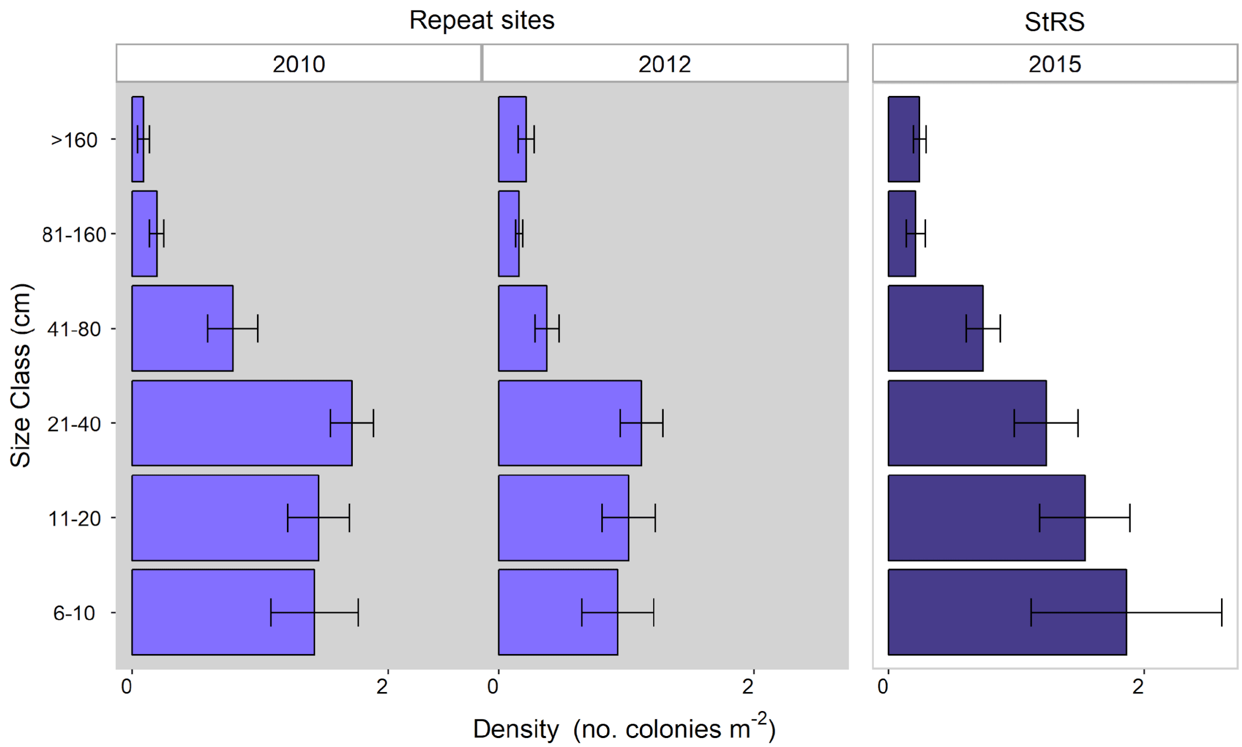


Figure 36. Time series of mean adult colony density (± 1 SE) at Baker Island by size class from mid-depth (>6–18 m) strata Rapid Ecological Assessment surveys by survey design, repeat sites or stratified-random sampling (StRS), conducted from 2010 through 2015.

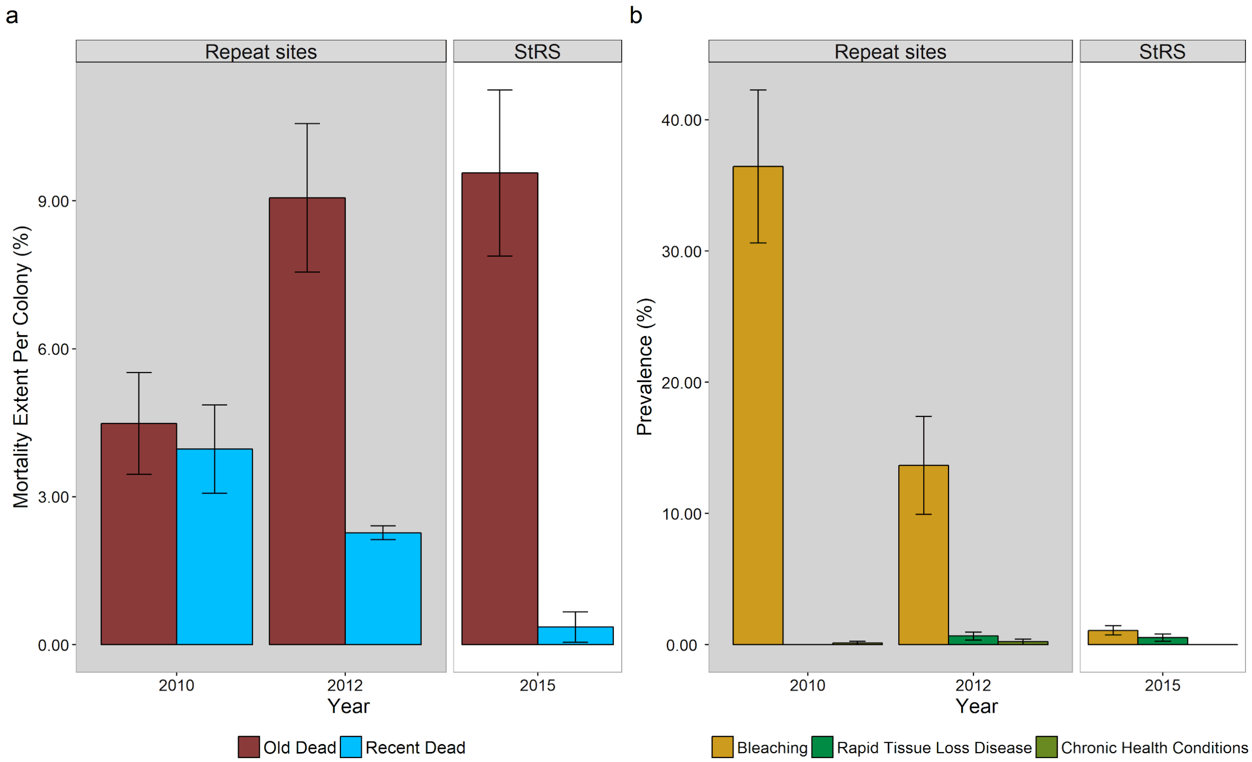


Figure 37. Time series of mean (± 1 SE) (a) percent partial coral mortality and (b) prevalence of bleaching, rapid tissue loss diseases, and chronic health conditions at Baker Island based on mid-depth (>6–18 m) strata Rapid Ecological Assessment surveys by survey design, repeat sites or stratified-random sampling (StRS), conducted from 2010 to 2015.

Benthic Macroinvertebrates

Of the macroinvertebrates surveyed during TDS around Baker Island, urchins had the widest spatial distribution (Figure 38) and were observed during all survey years. Overall, tow segments had low but consistent urchin densities over time, with fewer than 5 individuals per 100 m^2 observed in 97% of the segments where urchins were present. Interestingly, no urchins were observed in the northwest tip area in the North georegion during any of the survey years. Tow segment urchin densities were highest in 2012, with a peak tow segment having 46.9 urchins per 100 m^2. The consistently low macroalgae cover on reefs around Baker over time (Figure 28, Figure 31) may have been due to the stable, herbivorous urchin population.

The majority of sea cucumbers were reported in 2012, and tended to be most abundant in the West and South georegions. Sea cucumber density per tow segment peaked in the West georegion (2.3 individuals per 100 m^2). Lowest densities of sea cucumbers were observed in the East and East Terrace georegions. Based on the benthic cover estimates collected during TDS, sea cucumbers favored habitats with substrate characterized by high hard coral cover (≥45%) and an amalgam of sand or coral rubble.

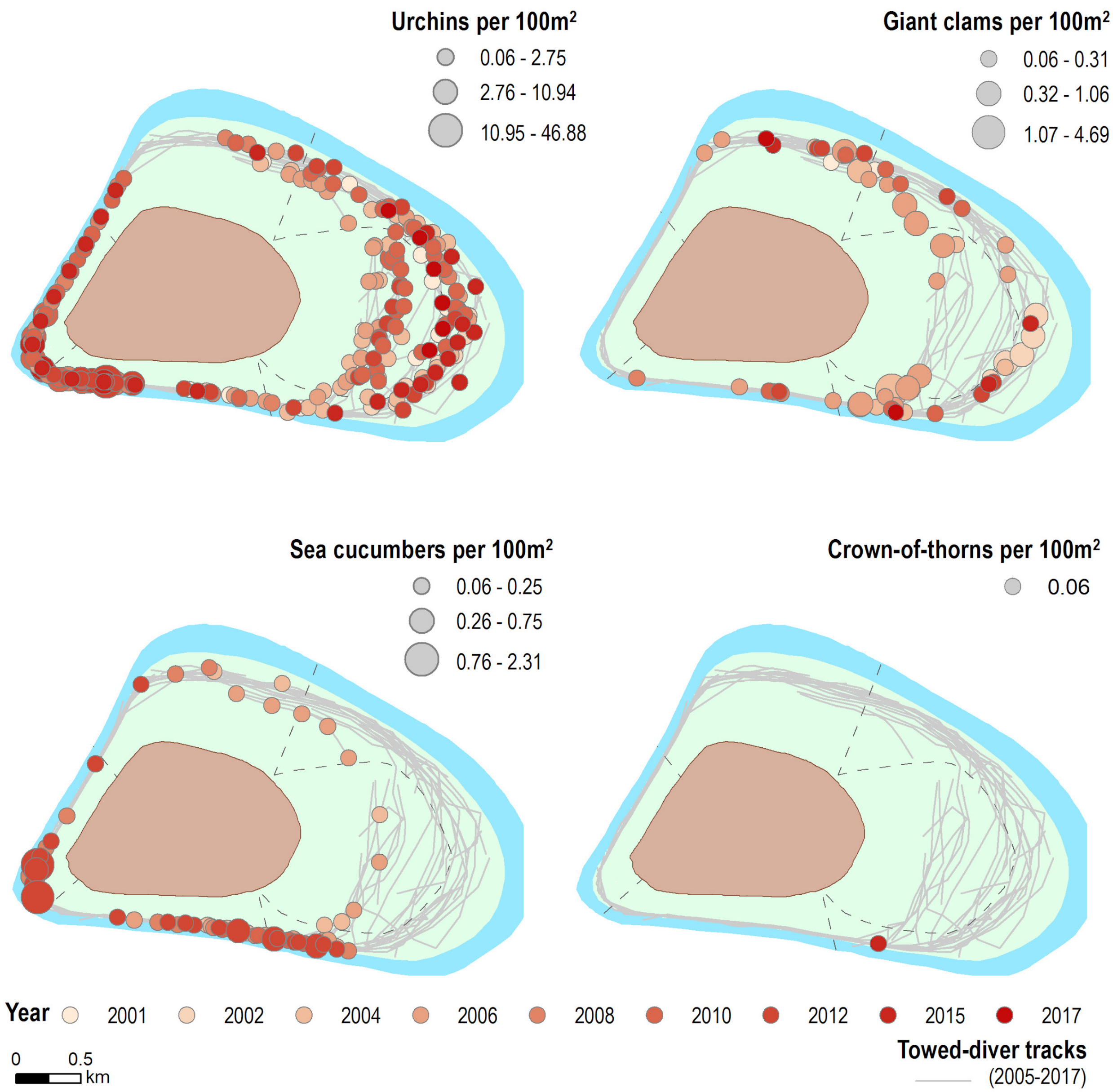


Figure 38. Density of conspicuous, ecologically- or economically-important macroinvertebrates (urchins, giant clams, sea cucumbers, and crown-of-thorns seastars) observed per segment from benthic towed-diver surveys (TDS) conducted throughout all depth strata (>0–30 m) around Baker Island from 2001 through 2017. Sea cucumber observations were discontinued from TDS in 2014.

Giant clams—currently under status review (Federal Register 2017)—were broadly distributed around Baker Island, but were conspicuously absent from the steep forereef substrates of the West georegion (Figure 38).

Observations of crown-of-thorns sea stars were exceptionally rare at Baker Island, with only a single individual being recorded during a single tow segment in 2015 (0.1 individuals per 100 m^2). For perspective, 570 tow segments surveying an area of approximately 1.14×10^6 m^2 have been completed over the period from 2001 through 2017.

Colorful anthias are in such abundance at Baker Island, it can be difficult to see the reef.
Photo: Andrew Gray, NOAA Fisheries.

Microbiota

8.5 Microbiota

The reef microbiota facilitates the cycling of essential nutrients by breaking down organic materials released by photosynthetic picoplankton (e.g., cyanobacteria) and benthic macroorganisms (corals and macroalgae). Habitats dominated by reef-building organisms (i.e., stony corals and calcified algae), such as Baker Island, illustrate a functional role that suppresses the energetic losses through microbial catabolism and promotes trophic transfer of energetic resources, carbon and inorganic nutrients, into metazoan food webs. This function is observed through the low microbial standing stocks in the water column and high turnover rates of microbial populations on reefs compared to the surrounding oceanic waters. Reef water samples were collected from all RAMP sites across the U.S. Pacific Islands Region beginning in 2008, with the first PRIMNM samples measured in 2009 (i.e., Wake and Johnston Atolls) and 2010 (i.e., Jarvis, Howland, and Baker Islands, Palmyra Atoll, and Kingman Reef). The assessment and monitoring of the reef microbiota paired with data collected on benthic and pelagic macro-biota across the entire U.S. Pacific Islands region, allow for characterization of coral reefs from a molecular to an ecosystem scale.

Microbial Composition and Diversity

Microbial communities in reef waters were collected from RAMP sites across all U.S. Pacific Islands from 2012 to 2014. Reef water samples were processed for molecular identification of microbial populations using metagenomic sequencing. Microbial community composition at Baker Island is characterized by mid to higher than average community diversity (measured using the Shannon Index, a metric of both species richness and evenness) on average compared to other U.S. islands across the Pacific (Figure 39). The community structure of the microbes at Baker reflects the complex and nutrient-rich organic material released by coral-dominated systems and the enhanced niche space characteristic of intact reef habitats, which promote biodiversity across macro- and microbiota.

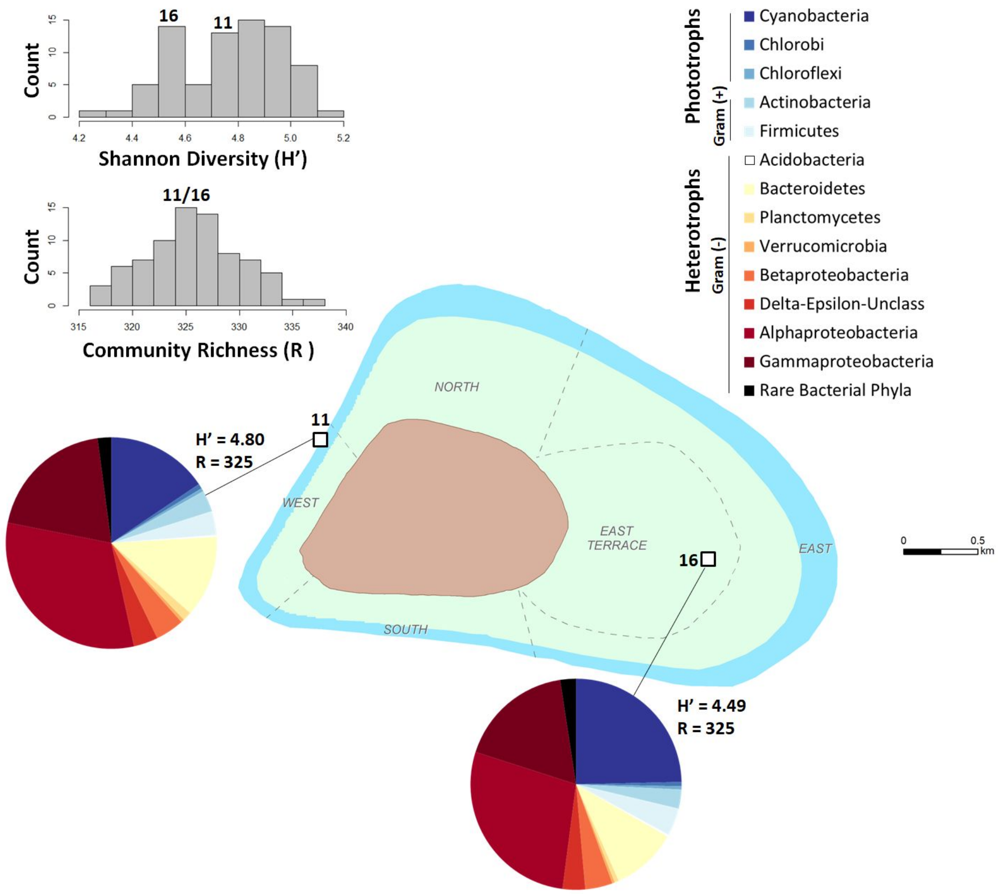


Figure 39. Microbial composition and diversity at Baker Island. The microbial taxonomic groups are shown at Phylum Level. Delta-Epsilon-Unclass, Deltaproteobacteria, Epsilonproteobacteria and Unclassified Proteobacteria are all combined. Community Richness and Diversity were calculated at the Genus Level. H', Shannon Index. R, Rarified Richness. Comparison of microbial diversity at two Baker reefs collected in 2012 (Sites 11 and 16) overlaid on a histogram of all Richness and Diversity.

Microbial Biomass on Reefs

Microbial biomass at Baker Island and other remote equatorial islands that experience equatorial and topographic upwelling (e.g., Howland and Jarvis) is higher than on remote atolls that do not experience strong upwelling (Figure 40). Reef degradation towards algae-dominated states promotes greater cell biomass and higher proportions of fast growing heterotrophic taxa (as observed on the main Hawaiian Islands), which exhibit more microbial biomass in the overlying reef waters (i.e., Baker in 2015 = 29 mg m^{-3} and Oahu in 2008 = 153 mg m^{-3}, respectively). The associated changes in microbial community structure and growth strategies when benthic community composition shifts from corals to algae shunts much more of the energy produced by the system towards decomposition pathways with enhanced respiration of organic compounds to carbon dioxide. This phenomenon is referred to as microbialization.

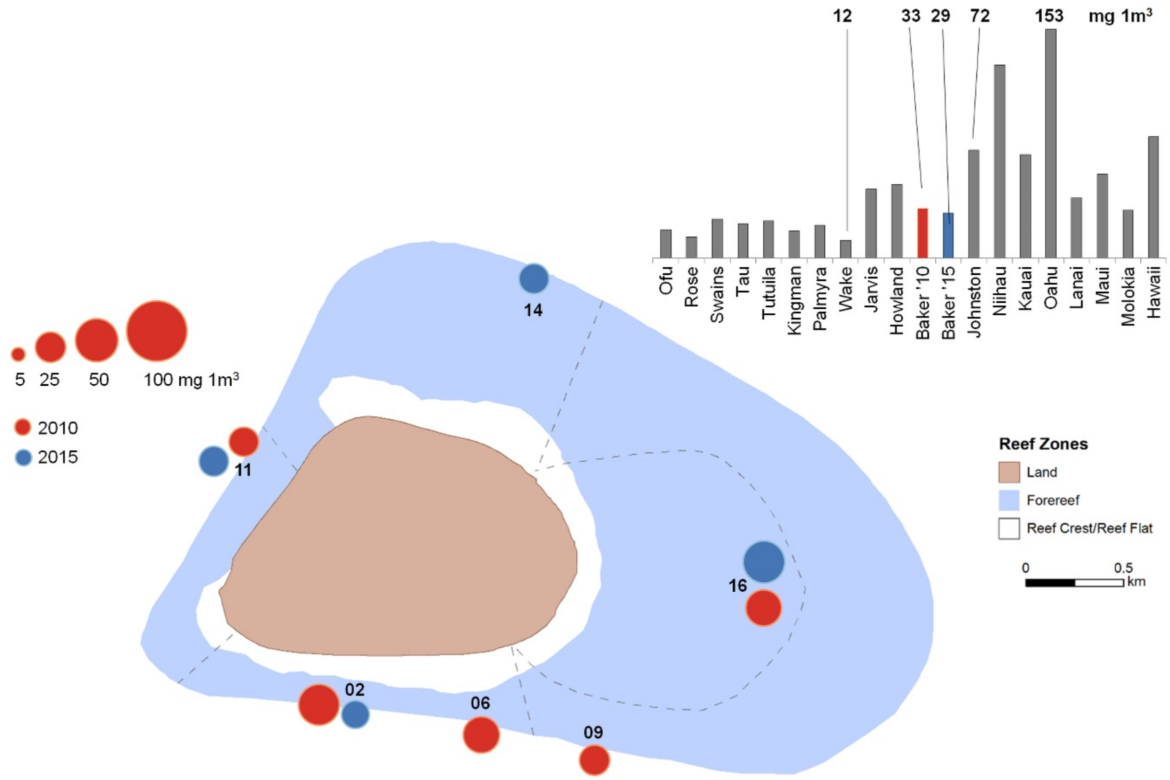


Figure 40. Microbial biomass collected at Baker Island in 2010 and 2015 (n = 15). Cell volume is estimated based on measurements of cell length and width and cell abundances enumerated using epi-fluorescent microscopy. Biomass is reported as milligrams per cubic meter (mg m^3). The 2010 data were published in McDole et al. (2012).

*Clown fish (*Amphiprion clarkii*) peeking out from among sea anemone tentacles at Baker Island.*
Photo: Jeanette Clark, NOAA Fisheries.

Reef Fishes

8.6 Reef Fishes

Parrotfish and bumphead wrasse at Baker Island.
Photo: Andrew Gray, NOAA Fisheries

Survey Effort and Site Information

Reef fishes at Baker Island were surveyed on nine occasions between 2001 and 2017 (Table 4). Surveys were a mix of comprehensive small-area surveys (belt-transect [BLT] or stationary point count [SPC]), and broad-scale (~2.2 km) towed-diver surveys (TDS), focusing on large-bodied fishes (>50 cm total length).

BLTs, which were utilized between 2001 and 2008, were conducted at haphazardly-located, mostly mid-depth (~10–15 m) forereef sites (Figure 41). In 2008, Pacific RAMP initiated the transition from BLT surveys to the current SPC survey method and at the same time moved to a stratified-random sampling (StRS) survey design encompassing all hard-bottom habitats in < 30 m depth (Figure 41). Since that time, there have also been concerted efforts to increase the number of survey sites per visit, with 20 or more sites being surveyed during visits from 2010 onward, compared to 8 or fewer through 2008 (Table 4). One consequence of the shift in survey design is that SPC sites have been much more widely distributed around the island than were BLT surveys—including encompassing reef habitats around the eastern edge of the island that had been only lightly surveyed previously. Since the transition to SPC, many more sites have been located in the East Terrace habitat (Figure 41). Because of some inconsistency in the application of the BLT survey method in the program's earliest years, data from before 2003 are not used to generate quantitative estimates, such as density. Thus, the time series shown were primarily built from TDS for the period 2001 to 2017, and SPC surveys conducted between 2010 and 2015.

Table 4. Reef fish survey effort at Baker Island. Data are number of surveys by year and method. Towed-diver surveys (TDS) were ~2 km long by 10 m wide transects (~20,000 m^2), typically in mid-depth forereef habitats, and were focused on fishes >50 cm total length (TL). In contrast, belt-transect (BLT) and stationary point count (SPC) survey divers count all fishes within relatively smaller areas of reef (~360-600 m^2).

	All Fishes		Large Fish (>50 cm TL)
Year	BLT	SPC	TDS
2001	6	–	2
2002	6	–	2
2004	6	–	6
2006	8	–	6
2008	4	4	8
2010	–	21	9
2012	–	24	10
2015	–	36	5
2017	–	–	5

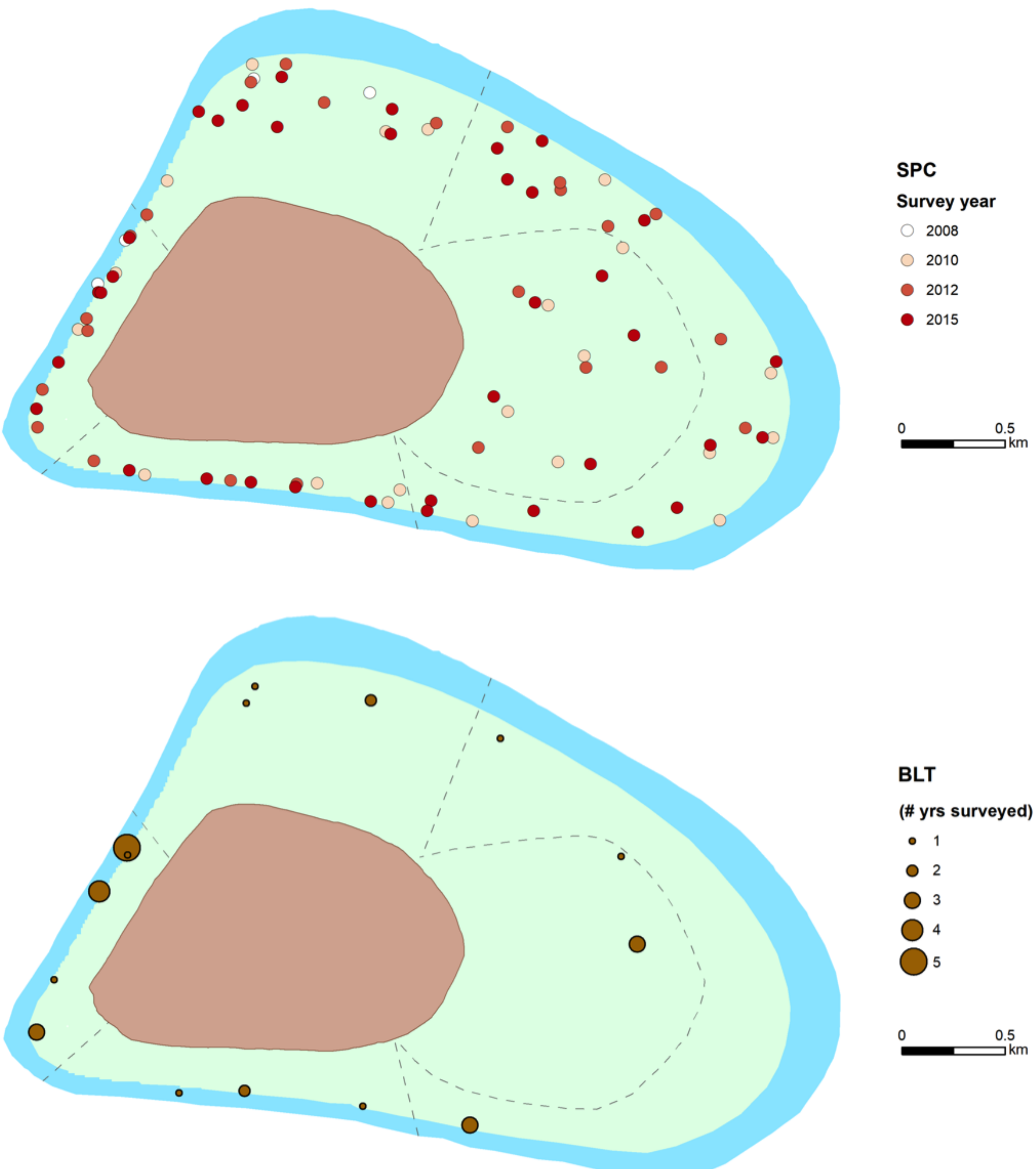


Figure 41. Location of stationary point count (SPC, top) and belt-transect (BLT, bottom) sites at Baker Island. Survey year for SPC sites, which were not revisited, is distinguished by color. BLT survey sites were generally revisited during multiple survey years, and the total number of times each site has been surveyed is indicated by the size of the bubble.

Distribution of Reef Fish Biomass and Abundance

Total reef fish biomass was highest in the West and East georegions and relatively low at sites in the East Terrace georegion (Figure 42). Biomass across all trophic groups was high at West georegion sites, whereas East georegion sites appeared to support high biomass of piscivores and planktivores (Figure 42).

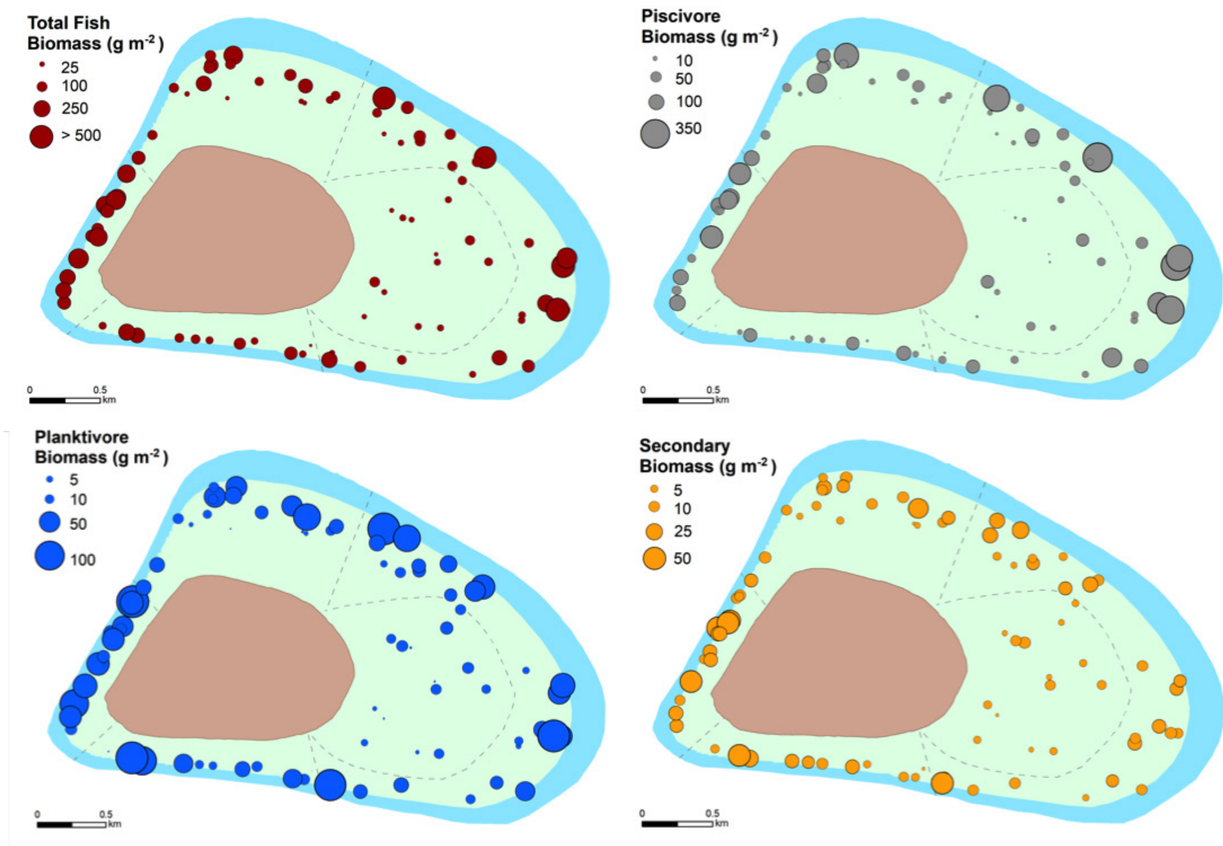
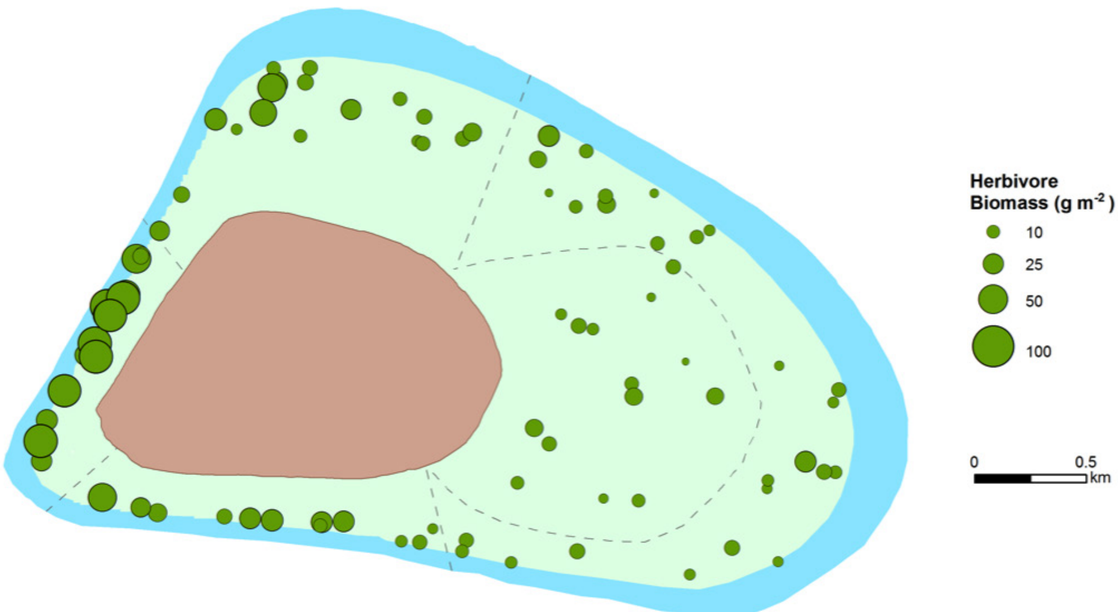


Figure 42. Biomass maps of Total Fish (top left), Planktivore (bottom left), Piscivore (top left) and Secondary Consumer Groups (bottom right) from stationary point count surveys around Baker Island over the period from 2008 through 2015. Secondary consumers include corallivores, omnivores, and invertivores, including many abundant and generally small-bodied species.

Although common on all outer forereef areas, small-bodied planktivores were notably abundant in the East and West georegions. For the two most abundant species, Whitley's splitfin (*Luzonichthys whitleyi*) and Bartlett's anthias (*Pseudanthias bartlettorum*), it was very common for several hundred individuals of each species to be recorded in a single SPC survey. Other major contributors to planktivore biomass at Baker Island included the sleek (*Naso hexacanthus*) and bignose (*N. unicornis*) unicornfishes and soldierfishes (Family Holocentridae). Planktivore biomass was notably lower at East Terrace georegion sites compared to the outer forereef (Figure 42).

Herbivore biomass was considerably higher in the West georegion, driven by high biomass of both parrotfishes and surgeonfishes (Figure 43). Across the island, dominant herbivore species included the whitecheek and striped-fin surgeonfishes (*Acanthurus nigricans* and *Ctenochaetus marginatus*), as well as the ember (*Scarus rubroviolaceus*) and bridled (*S. frenatus*) parrotfishes. Higher herbivore biomass in the West georegion was in part due to higher biomass of those common species, but also due to encounters with large schools, comprised of hundreds of individuals of the convict surgeonfish (*Acanthurus triostegus*) and lined surgeonfish (*Acanthurus lineatus*) at shallow water sites. Sites in the East and Eastern Terrace georegions had low biomass of herbivores (Figure 43).



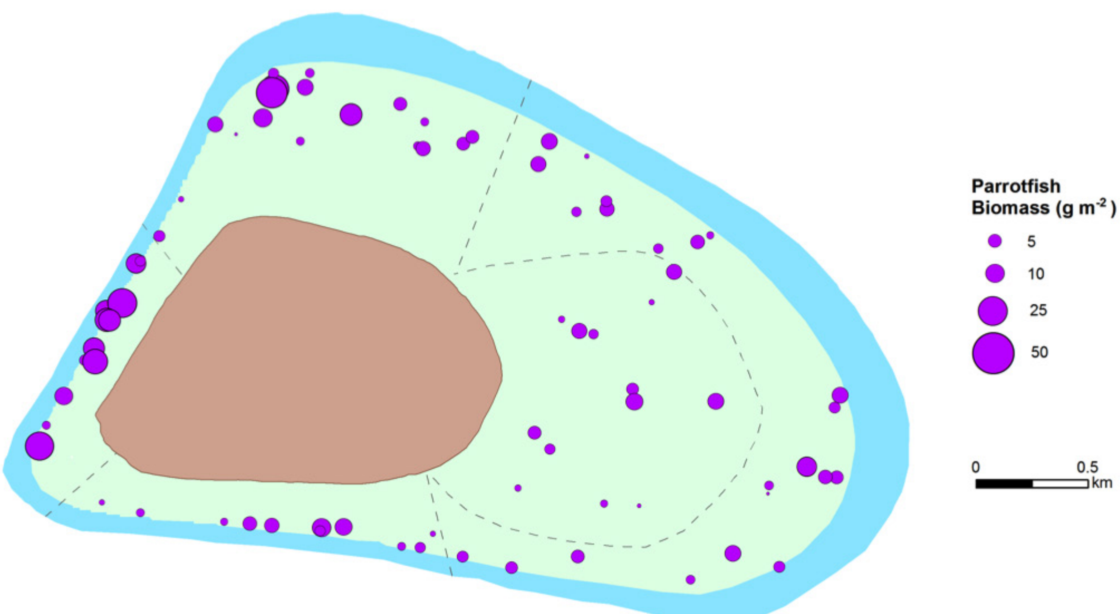
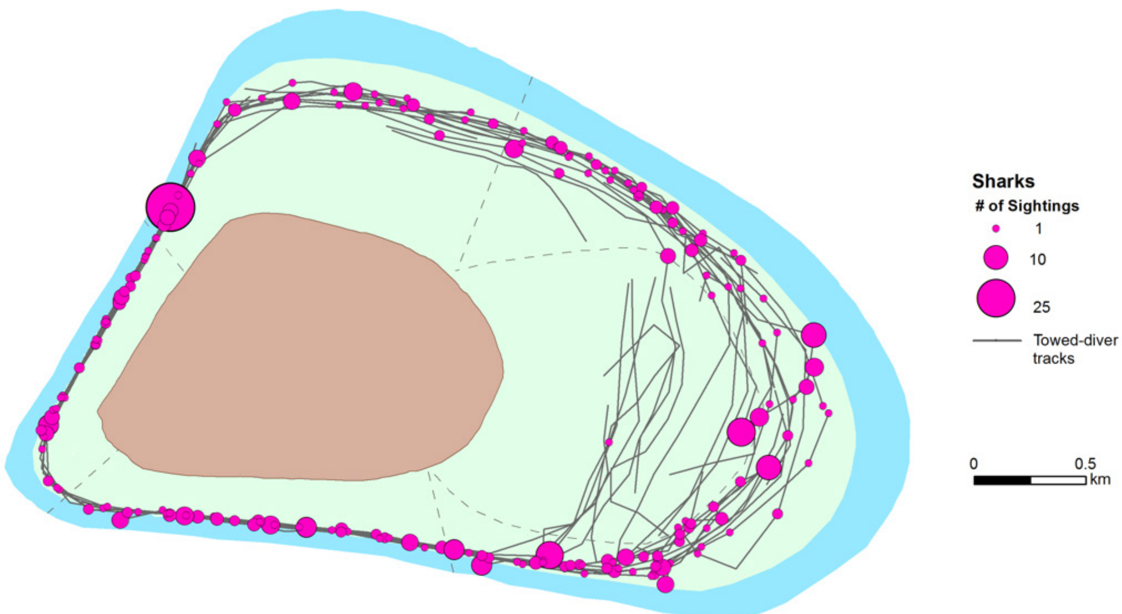


Figure 43. Total Herbivore (top) and Parrotfish (bottom) biomass from stationary point count surveys over the period 2008 through 2015 at Baker Island.



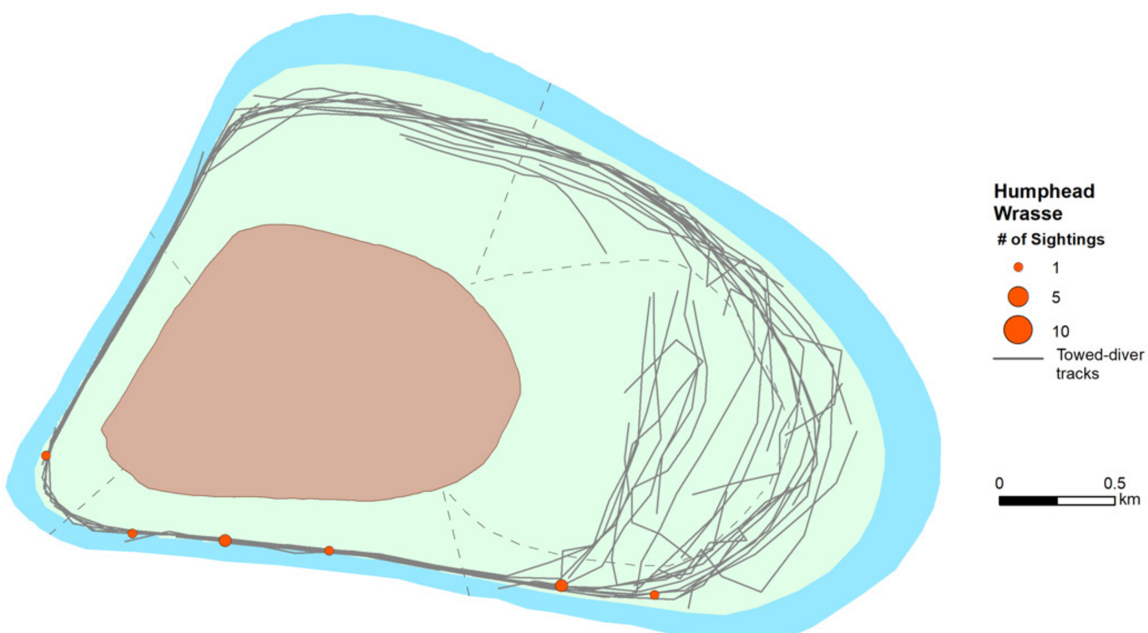


Figure 44. Towed-diver survey sightings of sharks (top) and humphead wrasse (bottom) at Baker Island during the period from 2001 through 2017.

Gray reef sharks (*Carcharhinus amblyrhynchos)* were the most commonly observed shark species in all Baker Island georegions, followed by whitetip reef sharks (*Triaenodon obesus*). Overall, sharks were observed during nearly 40% of all TDS segments (~220 m long sub-units of the survey), varying from more than 60% of all segments in the West georegion to less than 10% of segments in the East Terrace georegion (Figure 44).

Biomass of jacks tended to be high at outer forereef sites and very low in the East Terrace georegion, with biomass dominated by two species—the bluefin trevally (*Caranx melampygus*) and black jack (*C. lugubris*). The two-spotted red snapper (*Lutjanus bohar*) was the most abundant piscivorous snapper in all georegions.

Humphead wrasses (*Cheilinus undulatus*) were occasionally observed by survey divers around Baker Island (in ~1% of all TDS segments), with most encounters along the southern outer forereef (Figure 44). No encounters with bumphead parrotfishes were recorded during Pacific RAMP surveys at Baker.

Distribution of Other Species of Interest

Manta Rays (*Mobula* spp.) were regularly sighted during TDS at Baker Island—they were observed during approximately 5% of all tow segments. The large majority of those observations were during surveys of the northern and southeastern outer forereefs (Figure 45).

Sea turtles were commonly observed during the TDS—green sea turtles (*Chelonia mydas*) were recorded during approximately 16% of all TDS segments, including approximately 40% of all segments in the South and West georegions (Figure 45). Hawksbill sea turtles (*Eretmochelys imbricata*) were observed during approximately 1% of all segments (Figure 45). Under the U.S. Endangered Species Act (ESA), green sea turtles at Baker Island are within the North Central Pacific distinct population segment (DPS), which are listed as threatened. Hawksbill sea turtles are ESA-listed and endangered throughout their range, thereby including Baker Island.

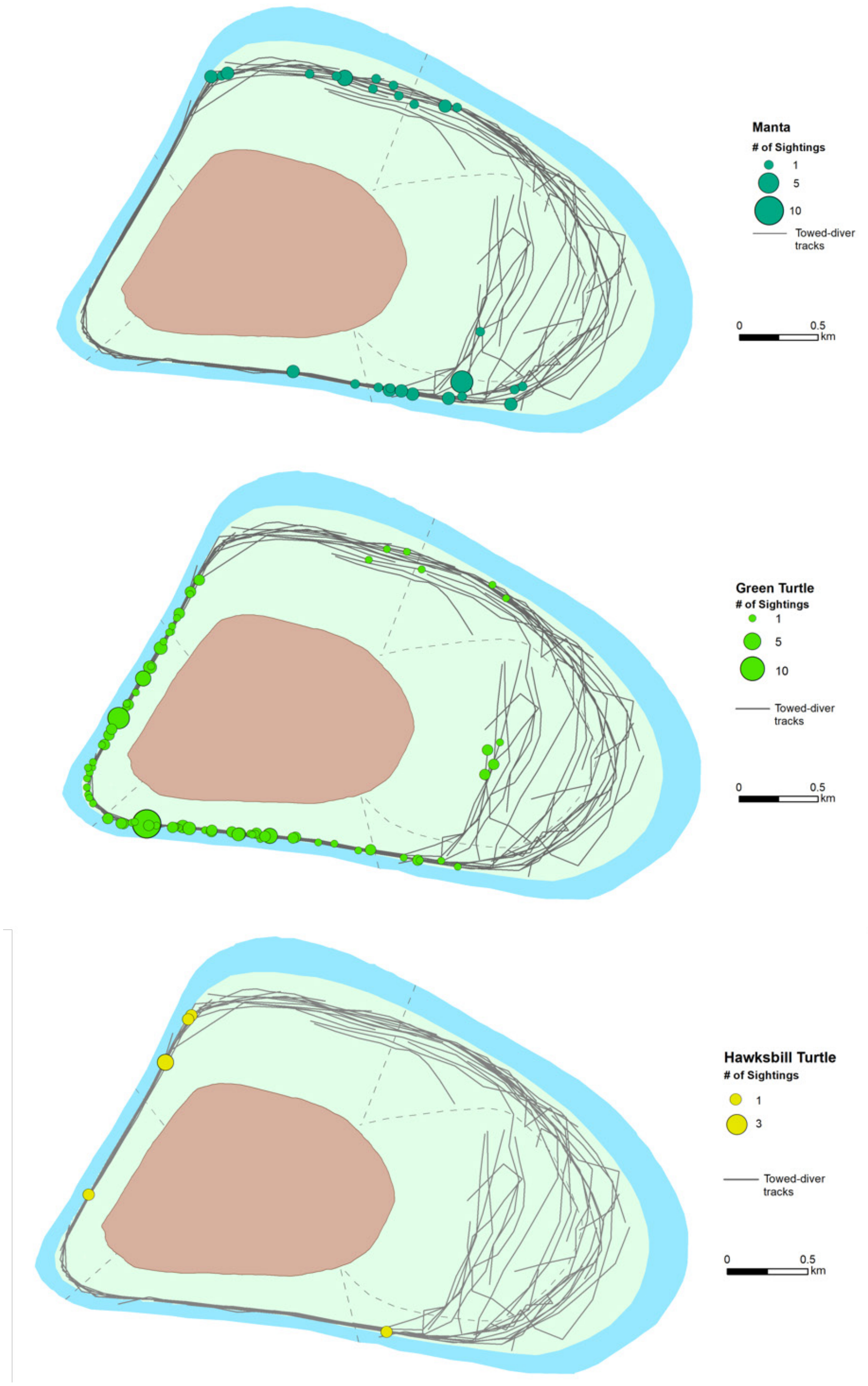


Figure 45. Towed-diver survey sightings of manta rays (top), green sea turtles (middle), and hawksbill sea turtles (bottom) at Baker Island over the period from 2001 through 2017. Green sea turtle sightings include observations recorded as unspecified turtle, as the great majority of sea turtles seen at Baker were green sea turtles.

Reef Fish Time Series

The time series of biomass of reef fishes, incorporating data from both BLT and SPC surveys, are shown in Figure 46. As is evident from the size of the confidence intervals in early years, there were insufficient data from earlier survey periods to statistically identify clear temporal patterns (Figure 46). Based on the SPC data that were collected between 2010 and 2015, mean biomass estimates of several groups of fishes were marginally higher in 2012 and 2015, but the scale of among-year differences is small relative to survey uncertainty within year (Figure 46).

Based on TDS data, there were no clear trends in abundance of sharks, jacks, or large-bodied surgeonfishes at Baker Island (Figure 47). TDS of primarily large motile fishes are prone to high variability among and within years, caused by infrequent encounters with large groups of some of these fishes. For example, in 2004, an aggregation of 38 whitetip reef sharks (*Triaenodon obesus*) was observed at the west end of Baker. In that same year, divers encountered groups of giant trevally (*Caranx ignobilis*) and rainbow runner (*Elagatis bipinnulata*), as well as large numbers of bignose unicornfish (*Naso vlamingii*).

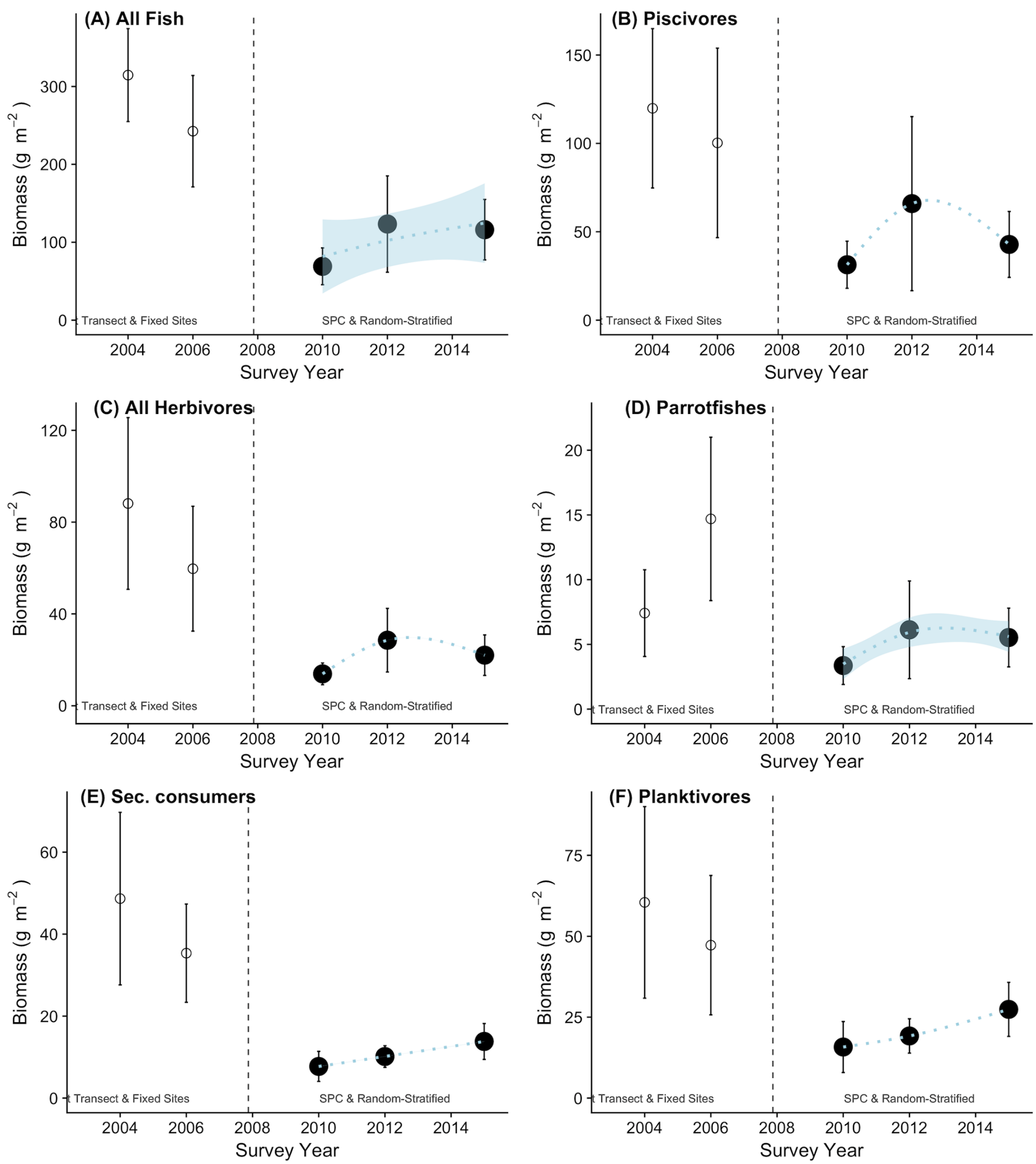


Figure 46. Time series of reef fish biomass at Baker Island. Data are shown for belt-transect surveys conducted at a limited number of mid-depth forereef sites in 2004 and 2006, and stationary point count (SPC) surveys conducted at randomly located sites encompassing all hard-bottom forereef in depths <30 m, over the period from 2010 through 2015. Gray circles indicate mean values, and vertical error bars represent 95% confidence intervals per time period. The light blue dotted trend line and 95% confidence intervals were derived from generalized additive models of biomass against survey year. Biomass values from the different periods cannot be directly compared due to differences in methods and survey locations.

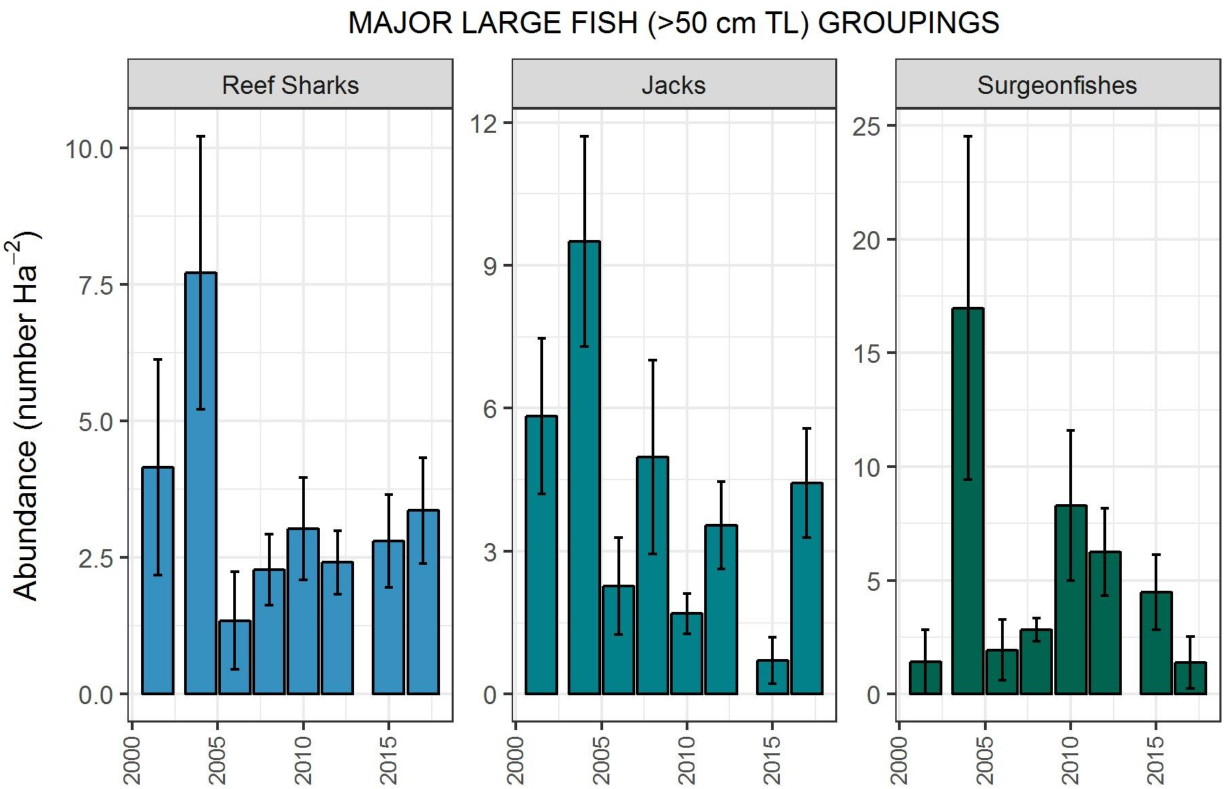


Figure 47. Bar plots by year for reef sharks, jacks, and surgeonfishes from towed-diver surveys (TDS) at Baker Island over the period from 2001 through 2017. Data shown are mean and standard error of abundance. Note that 2001 and 2002 data were pooled due to low sample sizes in those years. In order to increase consistency among years, trends were derived only from TDS >500 m in length, which were conducted in forereef habitats between 10 and 20 m deep.

Species Lists, Encounter Rates, and Diversity

Mean species richness of reef fishes around Baker Island was comparable to other islands of the PRIMNM, averaging 29.9 species per survey. Richness was lower and evenness higher in 2010 than in later years, and although it seems that richness is increasing over time, this is likely due to divers' increased ability to identify species. Therefore, there was no consistent trend in richness or evenness at Baker over the period 2010 through 2015 (Figure 48).

As noted above, the green sea turtle (*Chelonia mydas*) and hawksbill sea turtle (*Eretmochelys imbricata*) are ESA-listed, as is the giant manta (*Mobula birostris*). Although divers have regularly observed manta rays at Baker Island, it is not possible for divers to reliably distinguish between the ESA-listed giant manta and the non-listed reef manta (*Mobula alfredi*) during most visual surveys. Also, ESA-listed scalloped hammerhead sharks *(Sphyrna lewini*) were observed at Baker in 2006, 2008, and 2012.

Including manta rays and the scalloped hammerhead, seven species of fish recorded during surveys at Baker Island are listed as endangered, vulnerable, or near threatened by the International Union for Conservation of Nature (IUCN) Red List (IUCN 2017). One of those, the gray reef shark (*Carcharhinus amblyrhynchos*), was frequently observed by divers (e.g., they were recorded as present in the vicinity of more than half of all SPC surveys). Another IUCN-listed species, the Chevron butterflyfish (*Chaetodon trifascialis*), was observed at 28% of all SPC surveys. That species is very closely associated with table *Acropora* corals. Three other listed species, the blacktip reef shark (*C. melanopterus*), the manta ray (both species of manta are IUCN listed), and the spotted eagle ray (*Aetobatus narinari*) were observed on 6–11% of SPC surveys. Humphead wrasse were infrequently observed at Baker in most years (only at 3% of SPC sites), and scalloped hammerhead *(Sphyrna lewini*) have been observed at Baker in some years. A complete list of fish species observed each year is provided in Appendix B of "Chapter 9: Pacific Remote Islands Marine National Monument in the Pacific-wide Context."

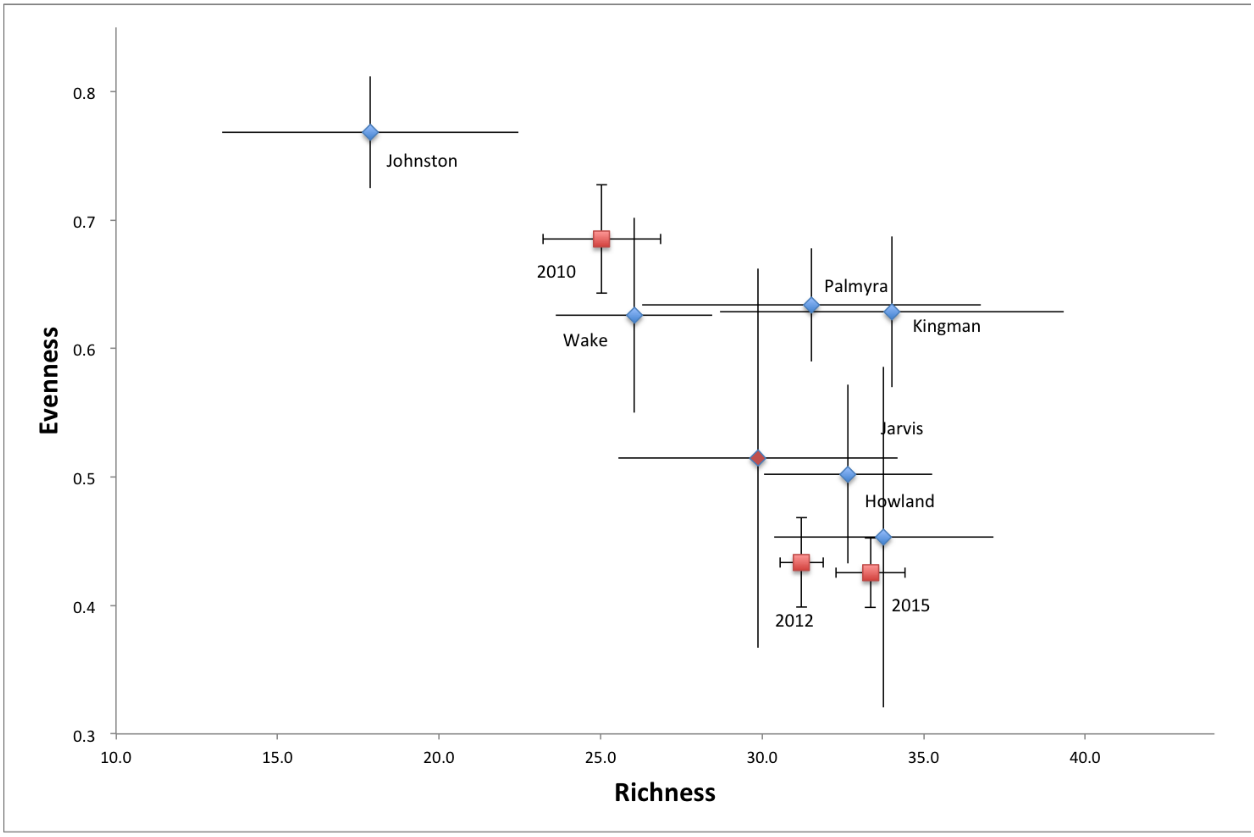


Figure 48. Richness vs evenness. Red squares are species richness (the number of species encountered per survey) and evenness (how equally distributed the total fish abundance was among species) values (± SE) at Baker Island by year. Blue circles represent mean (± SD) of richness and evenness values for other islands in the Pacific Remote Islands Marine National Monument across all years. The single red dot represents the mean values of richness and evenness at Baker across all years. For consistency among locations, only data from forereef areas are included.

Marine Debris

8.7 Marine Debris

A total of 58 observations of marine debris have been recorded sporadically around Baker Island during TDS conducted between 2001 and 2015 (Figure 49). This does not encompass all debris found at Baker, as the surveys did not cover all reef habitats every year. In addition, it is possible that the same debris was noted in different survey years. Chain and anchors made up the majority of the debris sightings at Baker, particularly in the West georegion.

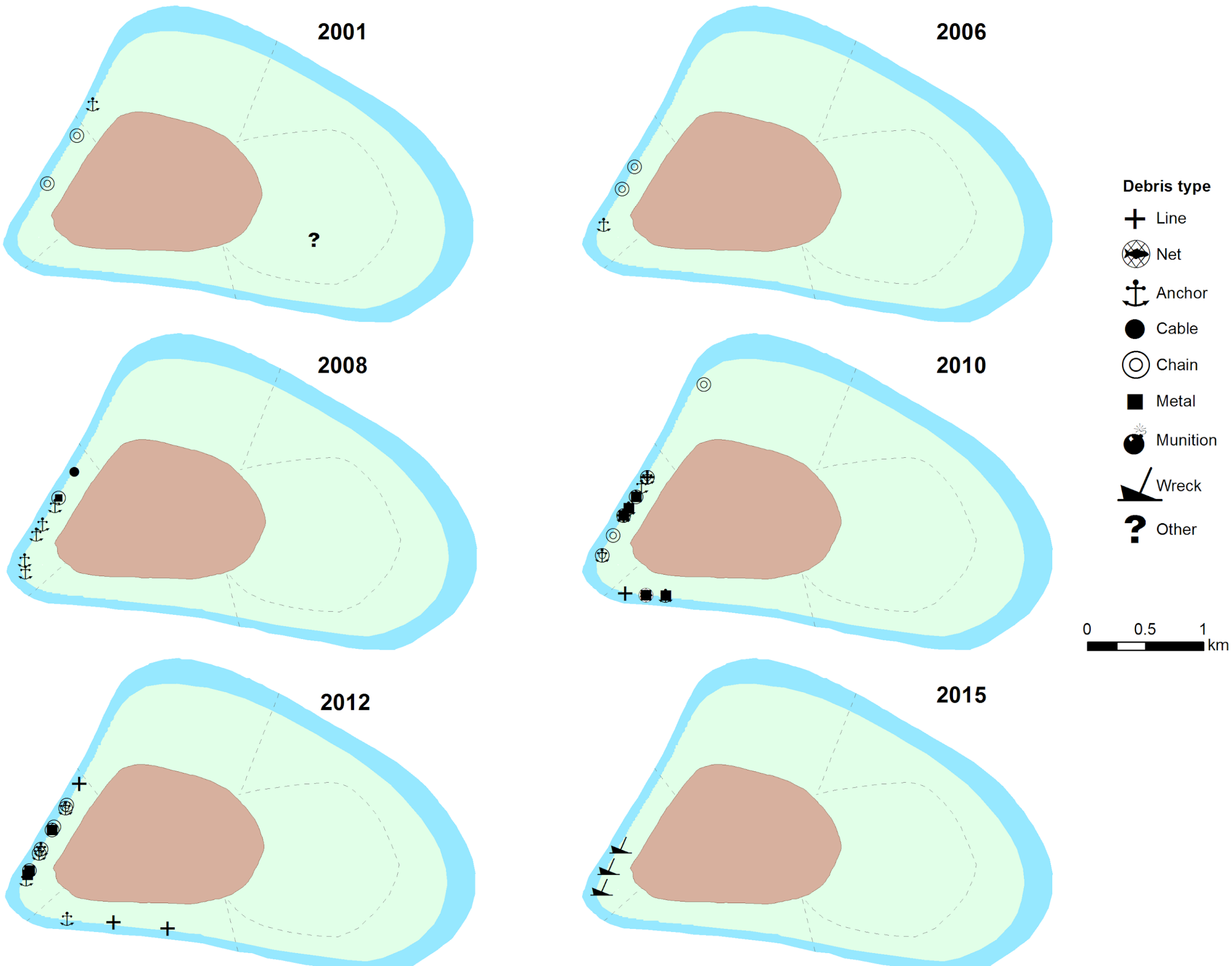


Figure 49. Marine debris sightings during towed-diver surveys at Baker Island between 2001 and 2015. Line, cable, metal, chain, and miscellaneous (other) debris were observed during that time period.

*A school of blackfin barracuda (*Sphyraena qenie*) cruise above the reef at Baker Island.*
Photo: Andrew Gray, NOAA Fisheries.

Ecosystem Integration

8.8 Ecosystem Integration

Photos left to right: Perspective view of Baker Island showing steep slopes on all sides, Image—NOAA Fisheries; A dense thicket of Acropora *spp. on Baker's shallow forereef, Photo: Morgan Winston, NOAA Fisheries; A school of fusiliers (*Caesio teres*) swims over the coral at Baker Island, Photo: Kevin Lino, NOAA Fisheries; A typical reefscape of Baker Island's Eastern terrace, Photo: Ariel Halperin, NOAA Fisheries.*

Oceanic Drivers of Benthic and Fish Populations

Located just north of the equator in the path of both the westward-flowing surface South Equatorial Current (SEC) and the eastward-flowing subsurface Equatorial Undercurrent (EUC), Baker Island is characterized by equatorial and topographic upwelling that varies in strength and intensity across years with ENSO cycles. During La Niña conditions, enhanced upwelling resulted in anomalously cool, nutrient-rich, and biologically productive surface waters that were also lower in pH and aragonite saturation state. In contrast, the reversal of such conditions was evident as upwelling weakened during El Niño events, resulting in warmer temperatures and declines in chl-a concentrations as surface waters shifted toward lower productivity, though higher pH and aragonite saturation states were more favorable for calcification. Island-wide measures from 2001 to 2015 indicated cover of hard coral and CCA remained relatively high and stable with almost complete absence of coral and CCA diseases (<1%), and sampling of reef-associated microbes revealed values of diversity and biomass similar to those observed at other remote islands. Macroalgal cover was uniformly low across surveyed areas of forereef, which may have been maintained by an abundance of grazers, including sea urchins that were typically distributed evenly around the island. The corallivorous crown-of-thorns sea star was sighted only once in 2015 and perhaps remained essentially absent due to a lack of planktonic larval dispersal to this remote and isolated island. Sharks were observed along the extent of outer forereef surveyed by towed divers, including occasional sightings of the scalloped hammerhead (*Sphyrna lewini*), which is listed under the ESA. The hawksbill sea turtle (*Eretmochelys imbricata*), which is also listed under the ESA, was sighted on only 1% of TDS.

Due to Baker Island's location in the western portion of the central equatorial Pacific, oceanographic conditions characteristic of eastern Pacific El Niño events tended to be milder in magnitude than those experienced further east, including during extreme El Niño events. For instance, SST anomalies and thermal stress at Baker were substantially less severe during the extreme 2015–2016 El Niño than at Jarvis Island located approximately 1,850 km (1,000 nm) to the east (Brainard et al. 2018). After this particular bleaching event, hard coral cover at Baker reflected a decrease of only approximately 24% by 2017, compared to a massive decline of 98% at Jarvis. In contrast, the forereef of Baker is more likely to experience the thermal impacts of central Pacific El Niño events. For example, a moderate El Niño that began in 2009 resulted in a series of thermal anomalies in both surface and subsurface temperatures at Baker, and benthic surveys conducted in 2010 revealed a bleaching prevalence of over 30%. Although there has been periodic evidence at Baker of changes to the coral community that can be related to ENSO cycles, there remain no clear patterns of corresponding changes in fish biomass over the 2010–2015 time period.

Spatial Variation within the Island

Prevailing trade wind-driven waves and the surface SEC approach Baker Island from the east, whereas localized topographic upwelling occurs along the leeward side of the island as the eastward-flowing subsurface EUC encounters the steeper western slope, resulting in cool, nutrient-rich surface waters. Fish biomass was typically higher in the forereef areas of both the East and West georegions, with the biomass of both planktivores and piscivores tending to be greater in the nutrient-rich water of the West georegion. Herbivores, such as parrotfishes, surgeonfishes, and ESA-listed green sea turtles (*Chelonia mydas*), have also exhibited greater measures of abundance and occurrence in the West georegion (and South georegion for turtles), despite macroalgal cover that has remained uniformly low around the entire island.

The West georegion has further remained distinct for its absence of giant clams and relatively low cover of hard coral and CCA, perhaps in part due to the steeply-sloped habitat. An invasive corallimorph (*Rhodactis* sp.), however, appears to have proliferated across the benthos off the southwestern end of Baker Island where iron continuously leeches from sources, such as historical shipwrecks and remnant ship anchors. Sea cucumbers were most prevalent in the West and South georegions; areas relatively protected from wave energy. In contrast, distribution of manta rays (*Mobula* spp., potentially including the ESA-listed *M. birostris*) may have been related to movement patterns and foraging activity related to high-current areas, resulting in a greater abundance of sightings in the North georegion and southern area of the East georegion.

The East Terrace georegion of Baker Island consists of a shallow reef shelf with large, dense thickets of *Acropora* spp. interspersed with narrow, wave-carved spur-and-groove channels. Because of the extent of coral thickets, this georegion consistently contained the greatest coral cover, and *Acropora* spp. was appreciably the most abundant genera of coral both island-wide and within the shallow- and mid-depth strata. In contrast, the deep-depth stratum consisted mostly of *Pavona* spp., *Pocillopora* spp., and *Porites* spp. corals. Fish biomass in the East Terrace georegion remained notably low, possibly due to the combination of high wave energy in a shallow habitat or lower productivity and food availability.

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