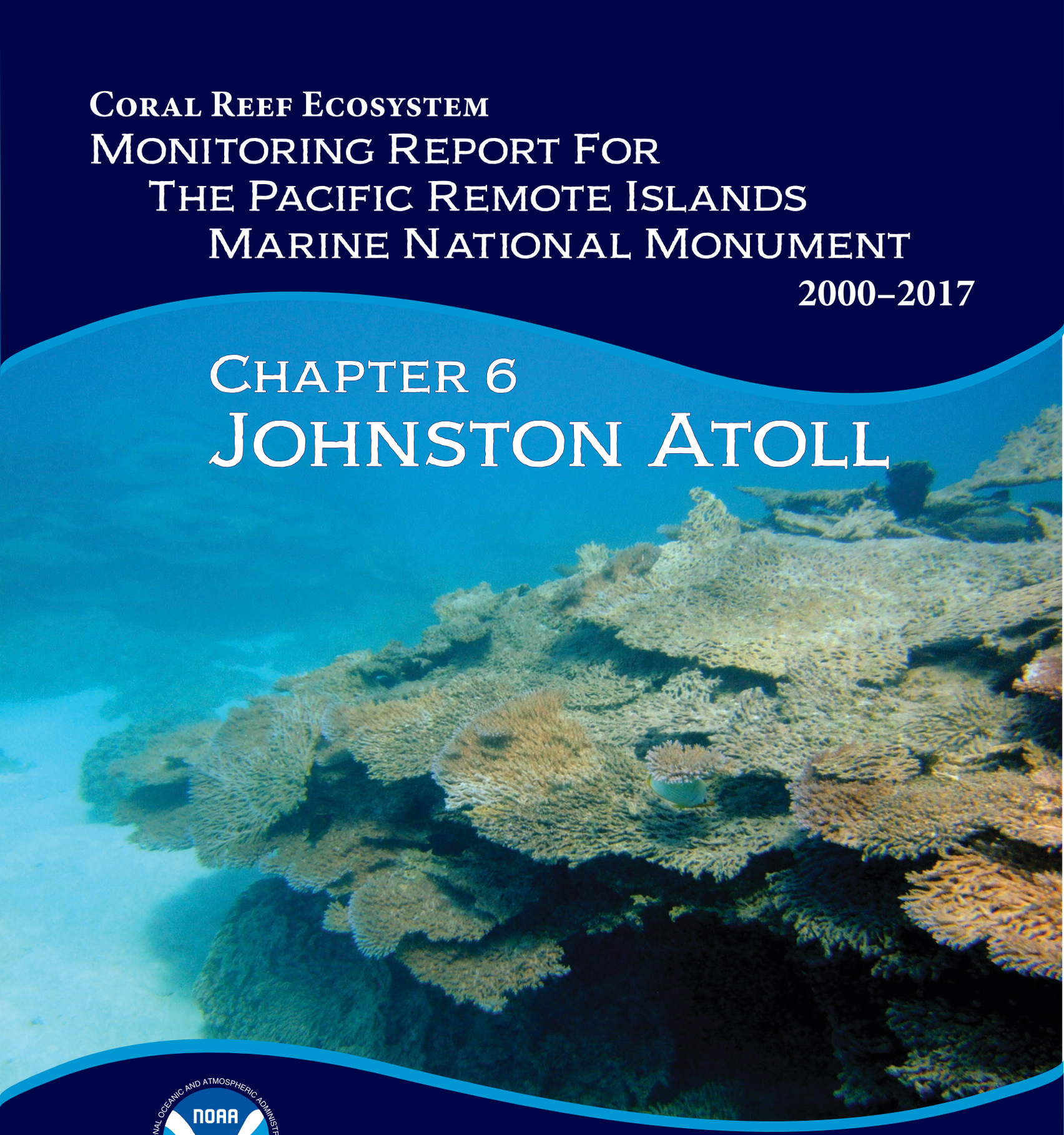
Coral Reef Ecosystem Monitoring Report For The Pacific Remote Islands Marine National Monument

2000–2017

Chapter 6
Johnston Atoll



Ecosystem Sciences Division

Pacific Islands Fisheries Science Center

NOAA FISHERIES

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

Chapter 6: Johnston Atoll

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Citations

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Front Cover: Coral reef at Johnston Atoll. Photo: Marc Nadon, NOAA Fisheries.

Back Cover: Coral reef and array of reef fish at Johnston Atoll. Photo: 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 6: Johnston Atoll



Increasing numbers of seabirds colonize the abandoned relics of military history on Johnston Island while U.S. Fish and Wildlife Service field teams camp among these island residents for 6 months at a time, working to eradicate yellow crazy ants from the refuge.
Photo: Susan White, U.S. Fish and Wildlife Service.

6.1 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

Johnston Atoll is an isolated island located in the central Pacific Ocean at 16°44′N, 169°31′W. Johnston began forming about 70 million years ago, when repeated submarine volcanic eruptions built up layer upon layer of basaltic lava extending up from the seafloor to eventually form an island at the surface (Davis et al. 2002). Over millions of years, the island slowly eroded and subsided as corals around the fringes subsequently grew. Today, Johnston is a broad, shallow platform with an area of about 130 km^2 (50 mi^2) with four islands (Johnston, Sand, North, and East) and a marginal, emergent reef only on the atoll's northwest side (Figure 1). Johnston sits at the northern end of the Line Islands Ridge, although the coral reef biota of Johnston more closely resembles that found in the Hawaiian Archipelago.

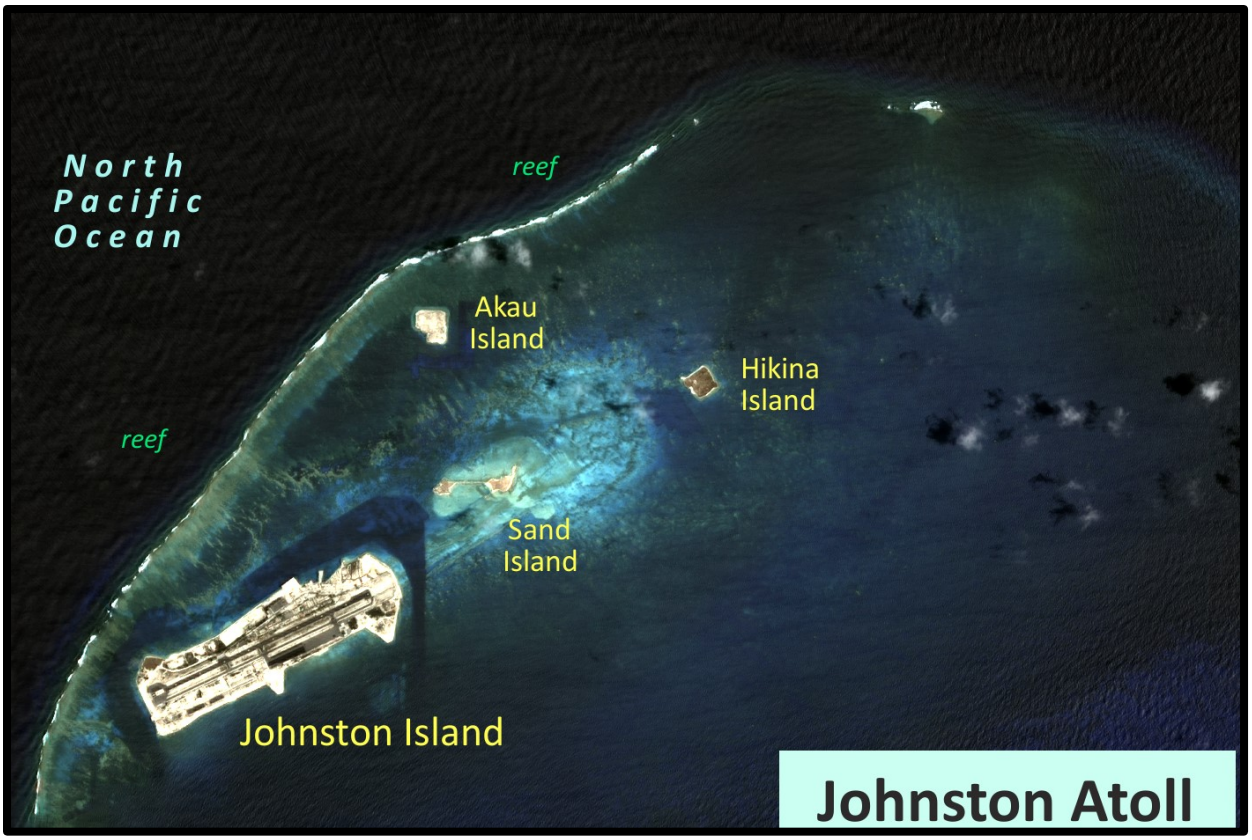


Figure 1. Satellite map of Johnston Atoll, created on January 5, 2016, by Wikipedia User surfsupusa. Source: National Aeronautics and Space Administration.

This chapter provides a compilation of information to assist managers in making informed decisions relating to Johnston Atoll 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 Johnston.

To facilitate discussions about the spatial patterns of ecological and oceanographic observations that appear throughout this chapter, four geographic regions, hereafter referred to as georegions, were defined for Johnston Atoll (Figure 2). Most map-based figures throughout this chapter use the basemap template as shown in Figure 2, which includes land features and the 30 and 100 m depth contours (isobaths).

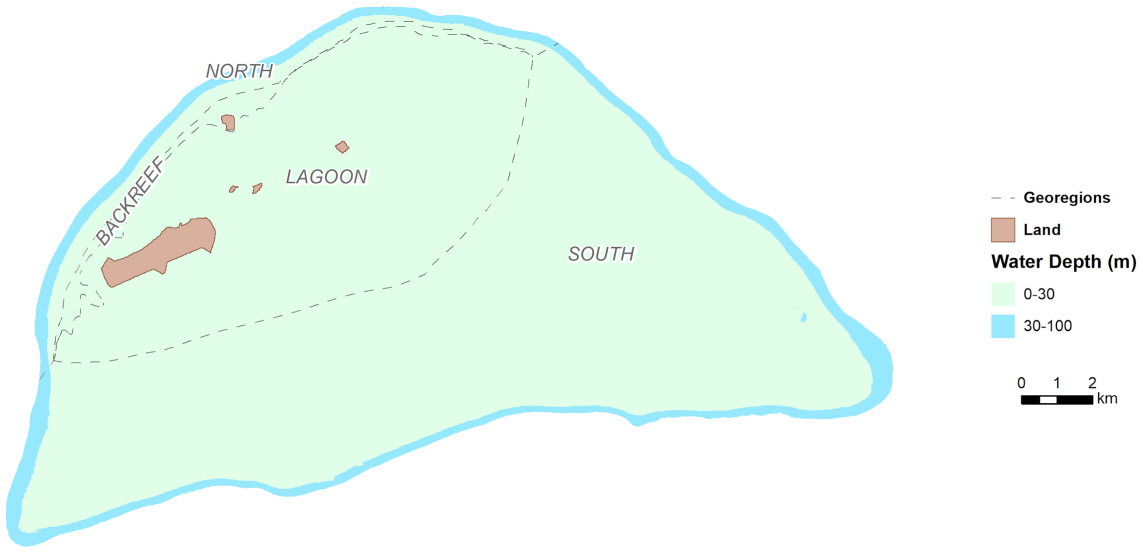


Figure 2. The four geographic regions, or georegions, for Johnston Atoll: North, South, Backreef, and Lagoon.

History and Human Influences

Johnston Atoll never had an indigenous population. The first Western record of the atoll was in 1796 when the American brig *Sally* accidentally grounded on a shoal near the islands. The ship's captain, Joseph Pierpont, published his experience giving an accurate position of Johnston and Sand Islands, but he did not name or lay claim to the area. The islands were not officially named until Captain Charles James Johnston of the Royal Naval ship HMS *Cornwallis* recorded them in 1807 (Findlay 1851).

Citing the Guano Islands Act of 1856, the atoll was claimed by the United States (U.S.) Pacific Guano Company in 1858, which proceeded to nearly deplete the island's guano deposits. The atoll was claimed later that same year by Samuel Allen representing the Kingdom of Hawai'i after requesting authority from King Kamehameha IV. Following the release of the proclamation declaring Johnston part of the Kingdom of Hawaii, King Kamehameha learned of the United States' previous claim to the island and revoked the lease granted to Allen. The atoll was omitted from the list of Hawaiian islands annexed by the United States in 1898. In 1909, Johnston was leased by the Territory of Hawai'i to a private citizen for fifteen years, but was terminated in 1918 due to his unsuccessful attempt to mine the remaining guano and fulfill his lease duties.

The Tanager Expedition, a joint expedition sponsored by the U.S. Department of Agriculture and the Bishop Museum of Hawaii, visited the atoll in 1923. Shortly thereafter in 1926, President Calvin Coolidge designated Johnston and Sand Islands as the Johnston Island Reservation to be manned as a federal bird refuge and placed it under the control of the U.S. Department of Agriculture by Executive Order 4467 (The Conservative Caucus). In 1934, with Executive Order 6935, President Franklin D. Roosevelt placed the islands under the control and jurisdiction of the Secretary of the Navy to establish an air station (President Franklin D. Roosevelt 1934), but the islands were still to be used as a refuge and breeding ground for native birds under the Department of the Interior. The refuge was renamed the Johnston Island National Wildlife

Refuge in 1940. In 1941, Executive Order 8682 established a Naval Defensive Sea area out to 3 nautical miles (President Franklin D. Roosevelt 1941); this is noteworthy, as commercial fishing within that area has been prohibited since that time.

In 1936, the Navy began the first of many changes to enlarge the atoll's land area. Buildings and a boat landing were built on Sand Island, and coral reef was blasted to clear a 1,100 m (3,600 ft) seaplane landing. Further parts of the lagoon were dredged, and the excavated material was used to make a seaplane parking area connecting a causeway to Sand Island. Three seaplane landings were cleared and dredged to a depth of 2.4 m (8 ft). In 1941, construction of an airfield on Johnston Island commenced. A 1,800 m (6,000 ft) runway was built with two 400-man barracks, two mess halls, a cold-storage building, underground hospital, fresh-water plant, water tanks, fuel storage, shop buildings, radio station, and a steel control tower built (United States Bureau of Yards and Docks 1947).

Johnston Atoll was designated as a Naval Defensive Sea Area and Airspace Reservation requiring additional facilities, fuel storage, and water production at the base. In 1943, an additional 4.0 ha (10 acres) of seaplane parking was added. By 1944, Johnston was one of the busiest air transport terminals in the Pacific, as well as a refueling base for submarines.

In addition to the heavy military presence, the U.S. Coast Guard built, operated and maintained a Long Range Aid to Navigation transmitting station on Johnston Atoll from 1957 to 1992. Military satellite and reconnaissance projects continued in the 1960s, including North American Aerospace Defense Command missions, and the U.S. Air Force installed and operated a space camera station on Sand Island (Washington Group International 2012).

Between 1958 and 1963, Johnston Atoll was used as a U.S. nuclear test site for atmospheric and extremely high-altitude nuclear explosions in outer space. Johnston was the location of two nuclear test firings, which detonated 3.8-megaton hydrogen bombs launched to high altitudes by rockets from the atoll. Johnston Island was also used as a launch site for 124 sounding rockets that carried scientific instruments and telemetry equipment. Several nuclear weapon launch failures from Johnston caused serious contamination to the island and surrounding areas with contaminated material being dumped in the ocean or buried in landfills. The lagoon was dredged again during 1963–1964 and used to expand Johnston Island from 89 ha (220 acres) to 253 ha (625 acres), re-contaminating additional portions of the island. This was cleaned up over time.

In the 1970s, Johnston Atoll's military mission was redefined to be a storage and destruction site for chemical weapons. The U.S. Army leased 17 ha (41 acres) to store chemical weapons, including Mustard Gas, Sarin, and Agent Orange. The Army's Johnston Atoll Chemical Agent Disposal System (JACADS) was the first full-scale chemical weapons disposal facility. With construction completed in 1985 (Bourns 1978), it was built to incinerate chemical munitions. By 2000, all of the chemical weapons once stored on Johnston were demilitarized and the agents incinerated at JACADS. The JACADS was demolished in 2003, and the island was stripped of its remaining infrastructure and environmentally remediated (United States Department of Energy 1990). Part of the remediation included burying the site of a 1962 missile explosion, as well as a highly contaminated loading ramp used for loading plutonium-contaminated debris onto small boats for dumping at sea. The Johnston Atoll Plutonium Contaminated Soil Cleanup

Project collected radioactive soil and other contaminated debris, which were buried in a sealed landfill in 2002 (Washington Group International 2012).

In 2009, with Proclamation 8336, President George W. Bush established the PRIMNM to protect and preserve the marine environment around Wake, Baker, Howland, and Jarvis Islands, Johnston and Palmyra Atolls, and Kingman Reef for the proper care and management of the historic and scientific objects therein (National Oceanic and Atmospheric Administration 2009). The Monument lands, waters, and submerged and emergent lands from 0 to 50 nm are cooperatively managed by the U.S. Fish and Wildlife Service (USFWS) and NOAA.

In 2010, a USFWS survey team identified a swarm of yellow crazy ants (*Anoplolepis gracilipes*) that had invaded the island. The yellow crazy ants are particularly destructive to native wildlife necessitating eradication. The "Crazy Ant Strike Team" eradication project was led by the USFWS, and achieved a 99% reduction in ant numbers by 2012. The team continues to work towards a full eradication of the species from the atoll (Woodward 2012).

In 2014, President Barack Obama issued Executive Order 9173 to expand the area of the PRIMNM out to the 200 nautical mile U.S. Exclusive Economic Zone boundary for Wake, Johnston, and Jarvis islands, which are cooperatively managed by NOAA Fisheries and the USFWS (Executive Office of the President 2014).

Johnston Atoll is an unincorporated territory of the United States currently administered by the Air Force, with an on-going intent to turn over administrative jurisdiction to the Department of Interior. In the meantime, the USFWS continues to manage Johnston Atoll as a National Wildlife Refuge with authorization from the Air Force. Public entry into the 12 nautical miles surrounding the atoll is prohibited, though innocent passage through the remaining monument waters is allowed. Limited access for management needs is only by letter of authorization from the U.S. Air Force and Special Use Permit from the USFWS.

Geology and Environmental Influences

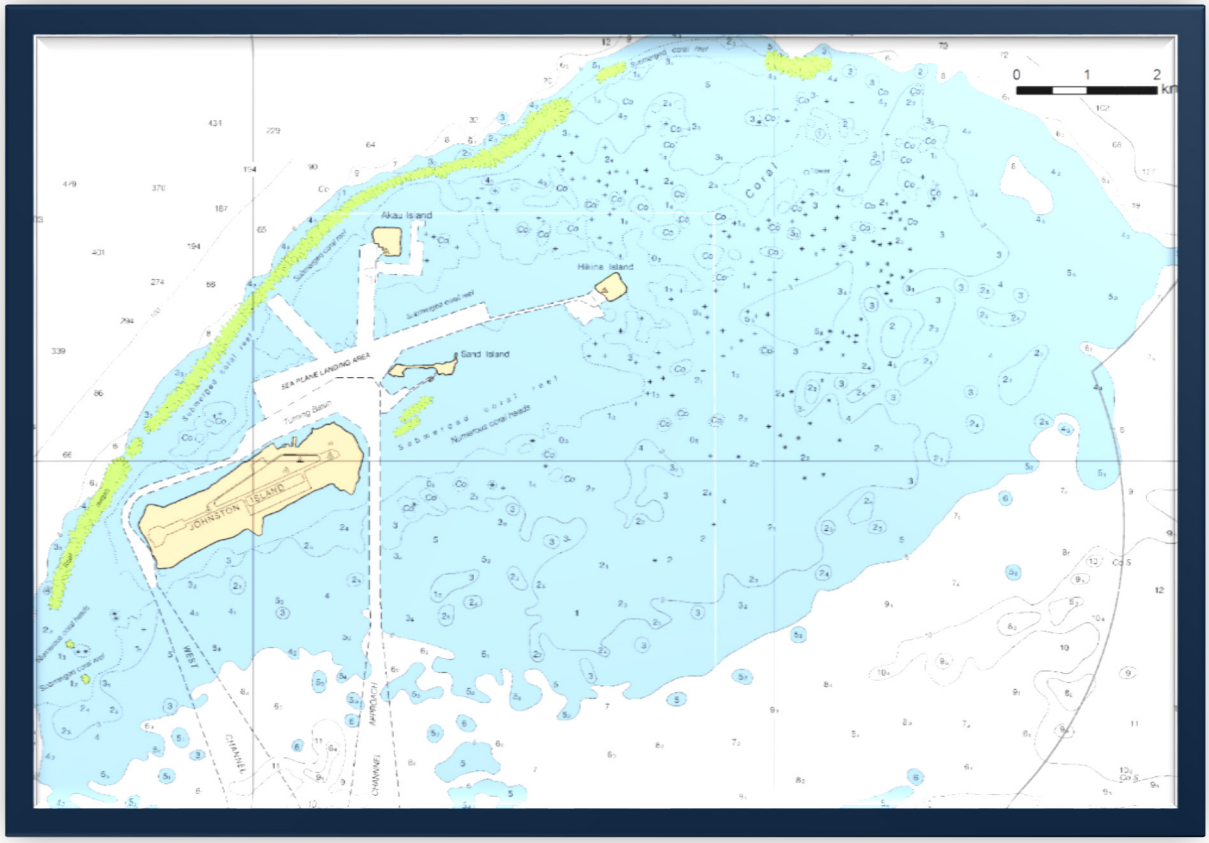
The four islands of Johnston Atoll compose a total land area of 2.67 km^2 (1.03 mi^2). Much of the reef on the southeast portion has subsided. Even though it does not have an encircling reef crest, the reef crest on the northwest portion of the atoll does provide protection for a shallow lagoon with depths ranging from 3 to 10 m. The climate is tropical, but generally dry. Northeast trade winds are consistent, and there is little seasonal temperature variation. With elevation ranging from sea level to 5 m (16 ft), Johnston Island's vegetation consists primarily of scrub and ironwood forests, while Sand, East, and North Islands are mostly flat terrain with low growing vegetation and no natural freshwater sources (United States Fish and Wildlife Service 2017).



Coral reef at Johnston Atoll.
Photo: B. Ruttenberg, NOAA Fisheries.

Benthic Characterization

6.2 Benthic Characterization



NOAA Nautical Chart of Johnston Atoll.
Source: NOAA, 5th Ed., Jul. 2014

In this section, the benthic habitats of Johnston Atoll 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 Johnston Atoll 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 Johnston Atoll during the 2006 Pacific RAMP research cruise using multibeam sonar systems 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 4 and 4,000 m and used to derive mapping products covering approximately 992 km^2. Approximately 163.6 km^2 of the area between 0 and ~30 m depths remained unmapped, either because of time constraints or because the shallower areas around the atoll 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 20 m mid-resolution grid that includes the full extent of the multibeam bathymetric data collected (Figure 3). The data and supporting documentation are available on the Johnston Bathymetry page of the Pacific Islands Benthic Habitat Mapping Center (PIBHMC) website.

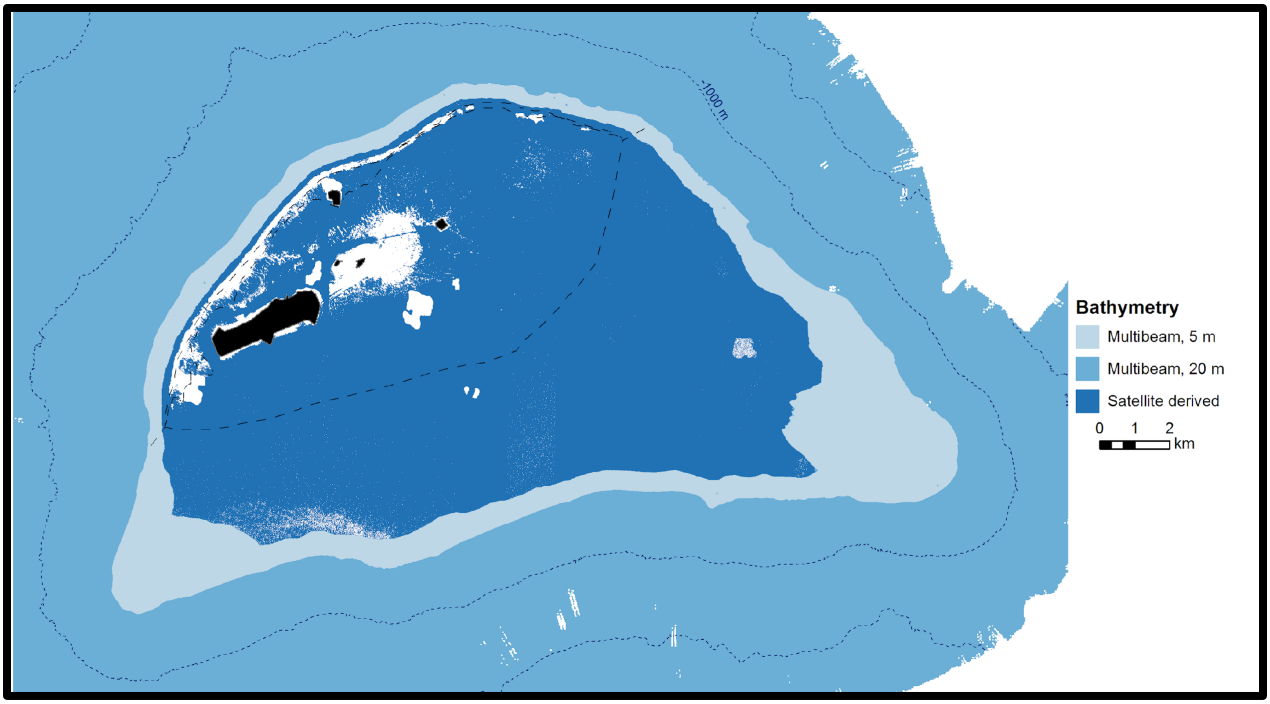


Figure 3. Bathymetric coverage map for Johnston Atoll showing extent of high- (5 m) and mid-resolution (20 m) gridded multibeam data acquired by the Ecosystem Sciences Division (ESD) in 2006 (lighter blues), and estimated bathymetry derived by ESD from satellite imagery (dark blue). The dotted dark blue 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 Johnston Atoll 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 Johnston Backscatter page of the PIBHMC website.

Single-beam Surveys

Single-beam sonar data were acquired around Johnston Atoll from depths between approximately 1 and 368 m in 2012, and between approximately 1 and 138 m depths in 2015, with a soundings error of 0.02 and 0.96 m, respectively (Figure 4).

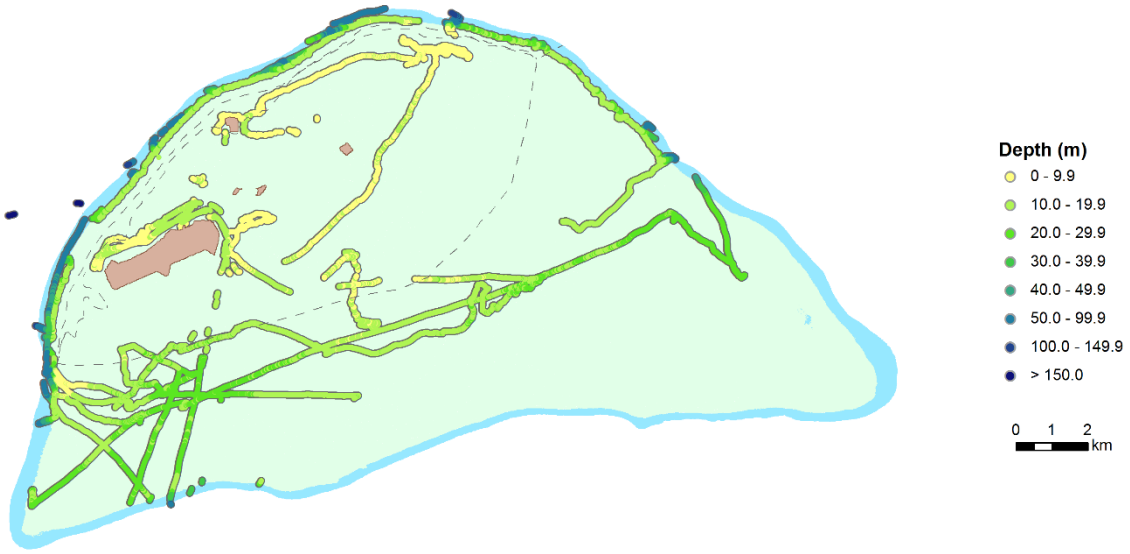


Figure 4. Depth validation data for Johnston Atoll collected by the Ecosystem Sciences Division in 2012 and 2015.

Towed-camera Surveys

Habitat validation data in the form of underwater video and still photographs were acquired in the South georegion of Johnston Atoll from depths between 11 and approximately 100 m by ESD in 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 Johnston Optical Validation page of the PIBHMC website.

Habitat characterization

Satellite-derived Bathymetry

ESD derived estimated depths between 0 and 30 m from IKONOS multi-spectral satellite imagery acquired in 2003 to fill gaps in the shallow-water bathymetric coverage around Johnston Atoll. ESD later derived estimated depths between approximately 0 and 20 m from WorldView-2 satellite imagery acquired in 2014. Depth soundings collected in 2012 and 2015 (Figure 4) were used to validate the satellite-derived depths, resulting in a 77% average agreement between the overlapping soundings and estimated depths. The data and supporting documentation are available on the Johnston Bathymetry page of the PIBHMC website. Though these estimated

depths provide useful information for areas with little or no bathymetric measurements, they have limited use for other mapping purposes. See Figure 3 for the extent of satellite-derived depths generated by ESD that partially filled the bathymetric coverage gap around Johnston.

Integrated Bathymetry

ESD's multibeam bathymetry and satellite-derived depths were combined to produce an integrated bathymetric map for Johnston Atoll (Figure 5).

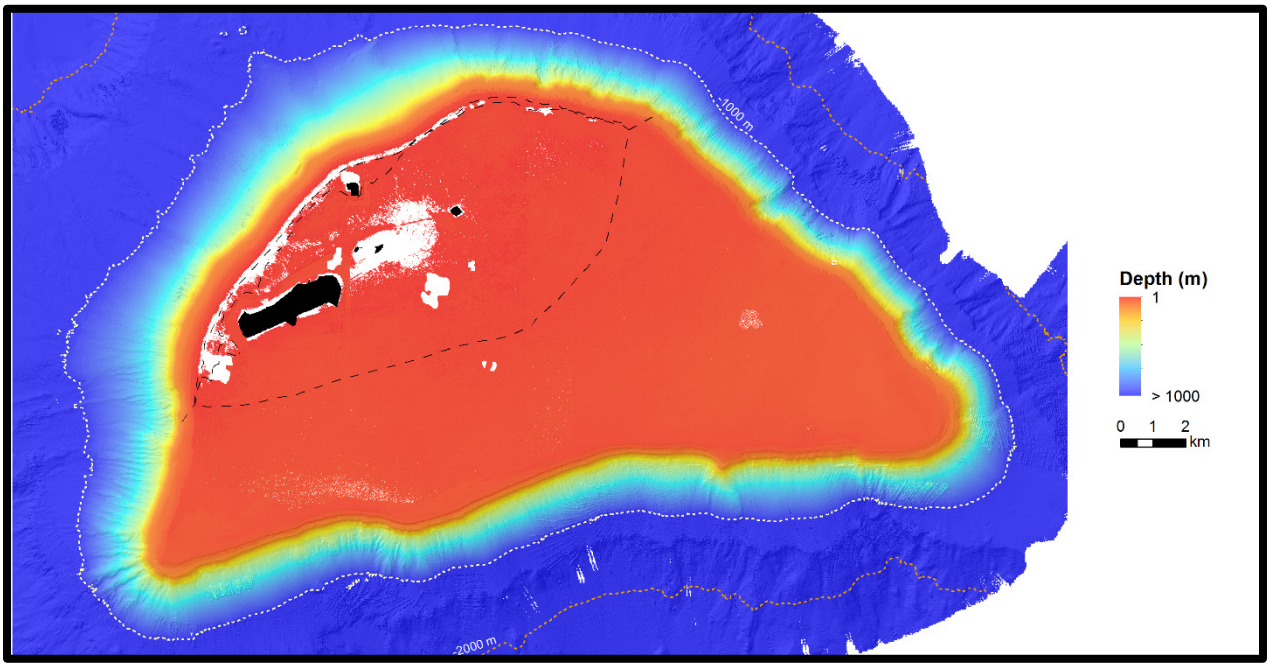


Figure 5. Integrated bathymetric map focusing on depths from 0 to ~1,000 m for Johnston Atoll, with gaps in bathymetric coverage shown in white and land features in black. The dotted lines represent the 1,000 m (white) and 2,000 m (orange) depth contours.

The bathymetric data for Johnston Atoll reveal an atypical, incomplete atoll reef structure. Johnston's unusual geomorphology is characterized by a semicircular emergent barrier reef along the north and west sides of the atoll in the North and South georegions, and the east- and south-facing reefs in the South georegion are submerged. Two prominent terrace systems exist in depths between approximately 10 and 20 m, with the shallower terrace extending approximately 20 km to the east-southeast of the atoll and the other extending approximately 8 km from the island to the southwest corner of the South georegion.

Multiple theories about the incompleteness of the atoll exist. One explanation for the anomaly is the atoll tilted downwards towards the southeast due to extensive mass wasting (structural failure of the seafloor that causes mass movement of sediment deposits). The subsequent uneven loading of the seafloor caused a shift in alignment resulting in the eventual exposure and erosion of the emergent reefs over time. Another theory describes changing sea-level stands, supported by the existence of an extensive, partially narrow and nearly continuous terrace system around the island that provides evidence of multiple sea-level stands over time. However, Maragos et al. (2008) argued the ages of dated carbonate samples taken from the terraces do not support that

theory. The heavily dredged Lagoon georegion ranges in depth from approximately 3 to 10 m. A sunken barge approximately 50 m in length and 3 m in height was located during a mapping mission in 20 m depths on the banktop of the southwest corner of the South georegion. Furthermore, the bathymetric data indicate evidence of extensive mass wasting on the south and northeast sides of the atoll and a broader shelf structure in the north/northwest.

Bathymetric Derivatives

Several geomorphological layers derived from ESD's multibeam bathymetric grids were developed for Johnston Atoll, including slope (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 (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 mid-resolution (20 m) gridded products on the Johnston Seafloor Characterization page of the PIBHMC website. The slope and BPI zones maps clipped to 1,000 m depths are presented here.

Slope

Nearshore 20 m resolution gridded slope values around Johnston Atoll reflect extensive terrace systems in the approximately 10 and 20 m depth ranges in the southeast and southwest corners of the South georegion (Figure 6). These platforms are connected along the southern border of the South georegion, slope gently to approximately 20 m then steeply to approximately 200 m, followed by medium-sloped drop-offs. On the south and east banks of the South and North georegions, steep drop-offs extend beyond 1,000 m depths that display flanks with erosional features. More gradual drop-offs were observed on the west and northwest sides of both georegions.

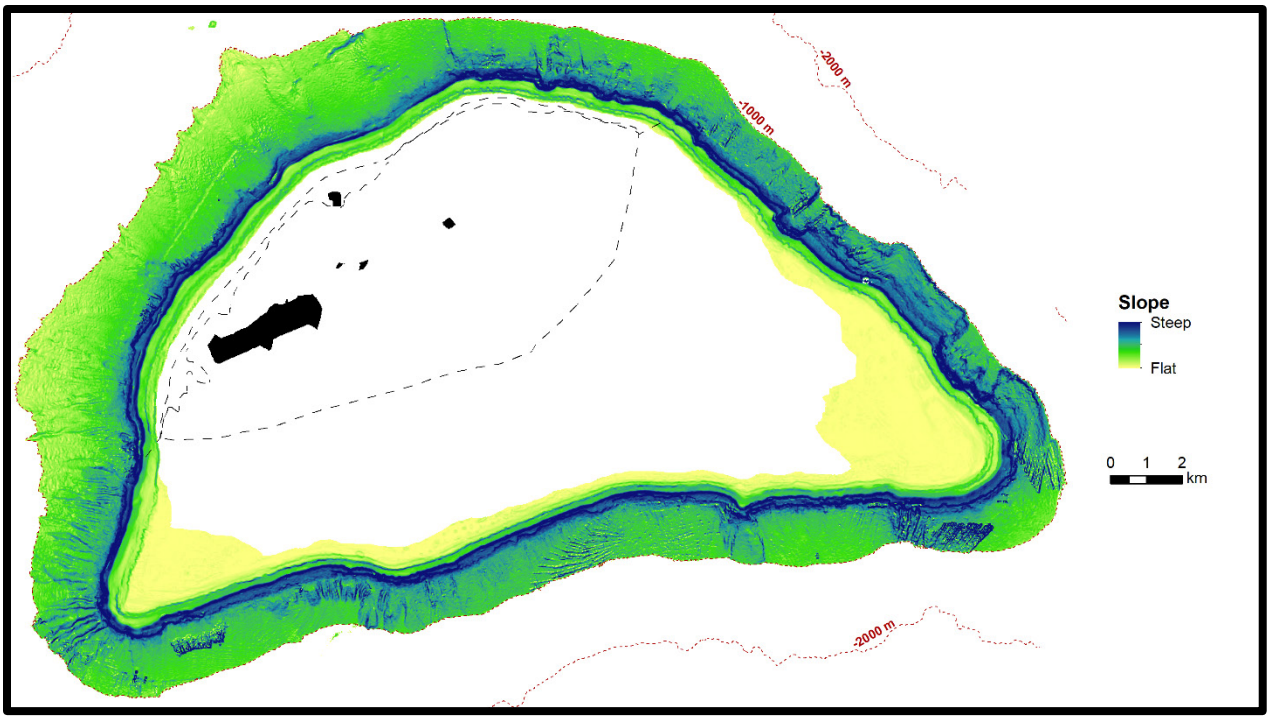


Figure 6. Slope map for Johnston Atoll clipped to 1,000 m depths with land features shown in black. The dotted red lines represent 1,000 m interval depth contours.

Rugosity

A 20 m resolution gridded rugosity map (not shown) is available for Johnston Atoll. 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 advise substrate predictions.

Bathymetric Position Index (BPI)

The 20 m resolution gridded BPI zones map shows the seafloor landscape around Johnston Atoll is predominantly composed of narrow crests (red areas) encircling the atoll and steep slopes (blue areas; Figure 7). Small crests and depressions are found along erosional features on all flanks around the atoll, though they are less prominent in the western area of the North georegion. An extensive flat terrace system located in the southeast and southwest corners of the South georegion is also apparent. The 20 m resolution gridded BPI structures map for Johnston (not shown) shows the finer-scale details of each BPI zone.

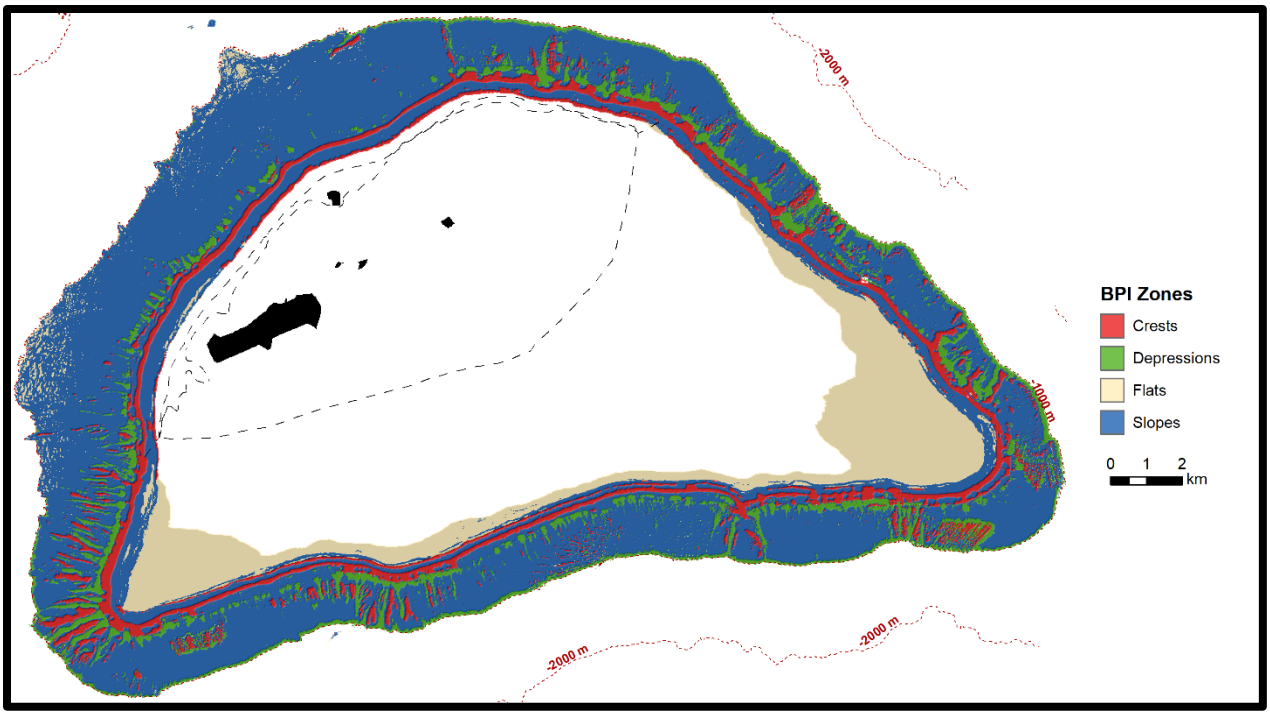


Figure 7. Map of bathymetric position index (BPI) zones for Johnston Atoll clipped to 1,000 m depths with land features shown in black. The dotted red lines represent 1,000 m interval depth contours.

Seafloor Substrate

ESD generated predicted seafloor substrates (i.e., hard or soft bottom) for Johnston Atoll in 2018 (Figure 8). The source data used to produce the substrate map for Johnston for water depths to 1,000 m included multibeam bathymetric and backscatter data from the 2006 *Hi'ialakai* surveys and satellite imagery acquired in 2014 (WorldView-2). The data and supporting documentation are available on the Johnston Seafloor Characterization page of the PIBHMC website.

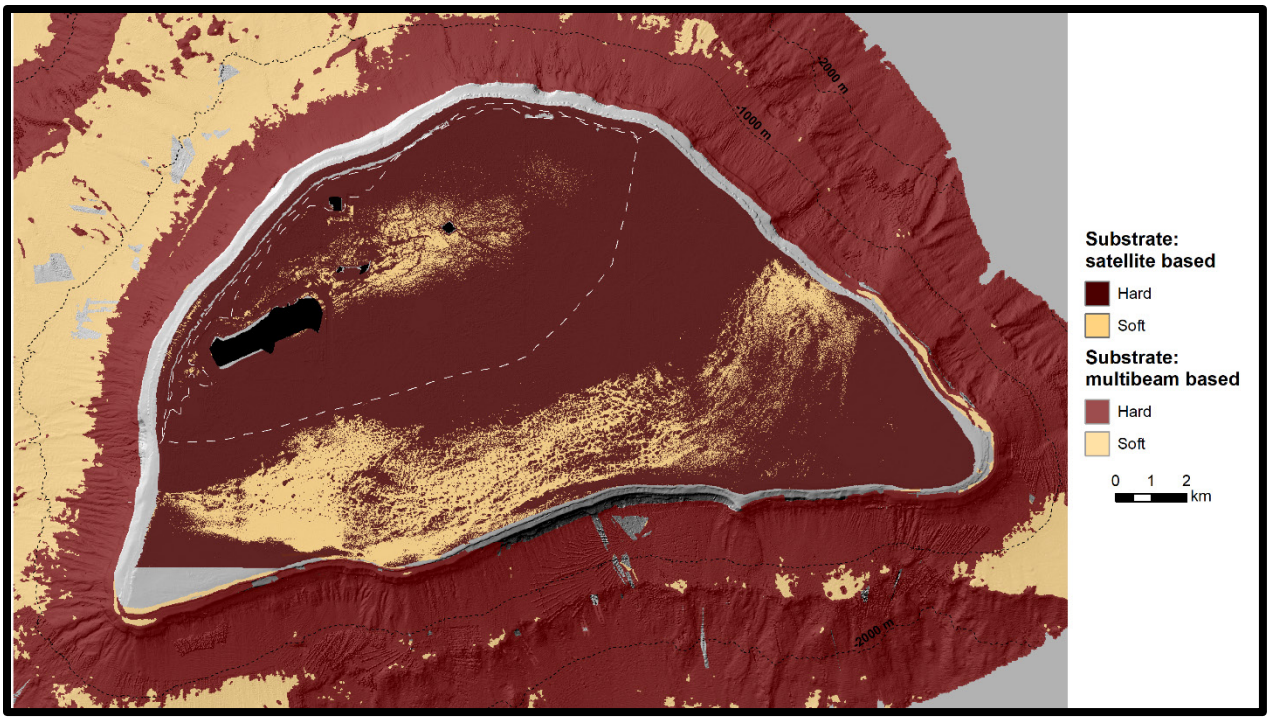


Figure 8. Seafloor substrate map of Johnston Atoll showing hard- and soft-bottom habitats. Depths from ~0 to 30 m were derived from WorldView-2 satellite imagery, and depths >30 m were based on gridded multibeam bathymetric and backscatter data (20 m and 5 m resolution, respectively). The dotted black lines represent 1,000 m interval depth contours. Gaps in substrate coverage are shown in grey and land features in black.

The seafloor surrounding Johnston to 1,000 m depths is predominantly hard substrate with a patch of soft-bottom habitat located in the central Lagoon, a potential sand wave field—with its typical wave-like structural features—within the South georegion, and soft substrates deposited at the bottom of the north/northwest flank in water depths to approximately 750 m and beyond.

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 5 was used to classify depth bins (Figure 9) from 0–1,000 m for Johnston Atoll. 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. These area statistics enable calculation of pertinent population abundance statistics.

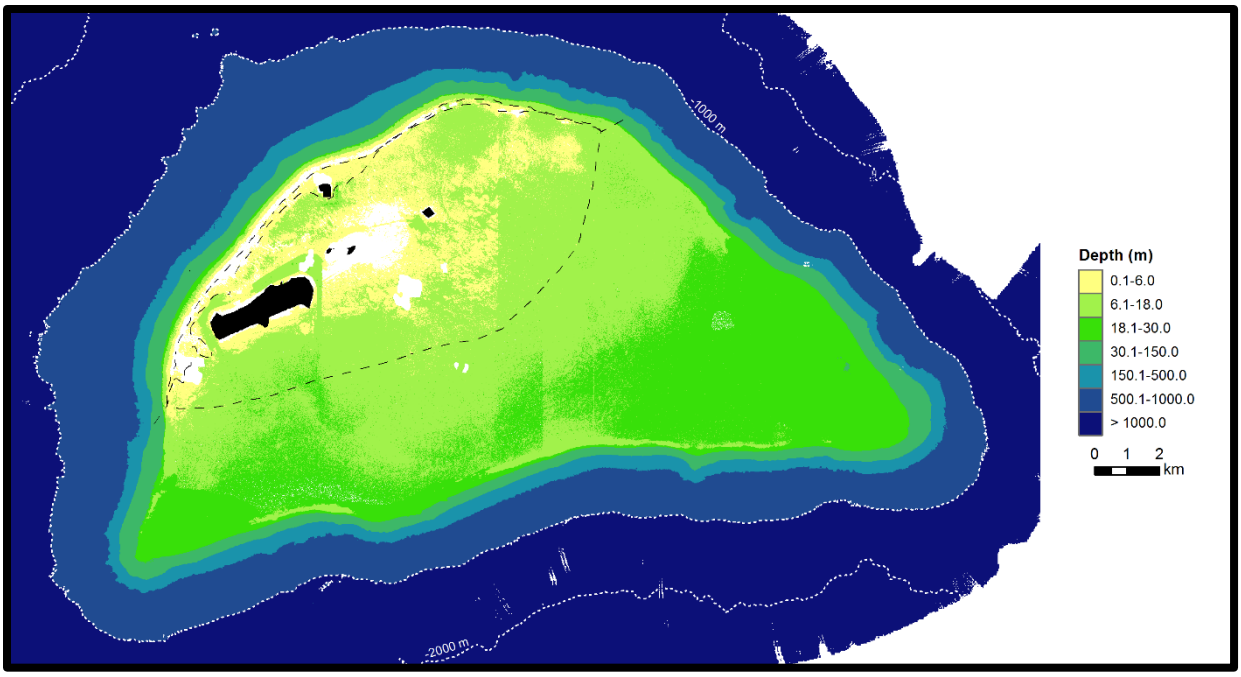


Figure 9. Depth strata map for Johnston Atoll from 0 to 1,000 m, with gaps in bathymetric coverage shown in white and land features in black. The dotted white lines represent 1,000 m interval depth contours.

At Johnston Atoll, 95% of the seafloor between 0 and 30 m depths was mapped, leaving an approximately 9.2 km^2 gap. The map of the seafloor from 30 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 Johnston Atoll. Seafloor area statistics include actual mapped area (km^2) and estimated seafloor area (km^2) based on the integrated bathymetric map for Johnston. Land area is 2.6 km^2.

Depth (m)	Estimated Seafloor (km^2)	Mapped Seafloor (km^2)
>0–6	–	26.1
>6–18	–	92.6
>18–30	–	66.1
Subtotal: >0–30	**194.0**	**184.8**
>30–150	24.0	24.0
>150–500	26.5	26.4
>500–1000	106.7	106.7
Total: >0–1000	**351.2**	**341.9**

Reef Zones

To support the stratified-random design for Pacific RAMP monitoring surveys, reef zones have been delineated for Johnston Atoll, including forereef, protected slope, backreef, lagoon, and land (Figure 10). Satellite imagery was primarily used to manually digitize the zones.



Figure 10. Reef zones for Johnston Atoll.

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 Johnston Atoll, no substrate information existed. As previously discussed, predicted seafloor substrates have since been developed for Johnston and will be incorporated into the survey strata in advance of the Pacific RAMP surveys at Johnston scheduled for 2021. In general, the majority of the nearshore seafloor area around the atoll is a mix of broad hard-bottom areas with significant soft-bottom areas within the Lagoon and South georegions (Figure 8).

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 159.2 km^2 of surveyable seafloor is available within hard-bottom habitats in the 0 to 30 m depth range for all four reef zones (forereef, backreef, protected slope, and lagoon) at Johnston Atoll.



Looking back at the NOAA Ship Hi‘ialakai *during field operations.*
Photo: NOAA Fisheries.

Ocean and Climate Variability

6.3 Ocean and Climate Variability



A subsurface temperature recorder deployed at Johnston Atoll.
Photo: NOAA Fisheries.

Survey Effort and Site Information

By virtue of its location, Johnston Atoll experiences a relatively stable oceanographic regime. Positioned far north of the equator in the central Pacific Ocean, the atoll is removed from the epicenter of the El Niño Southern Oscillation (ENSO) in the eastern and central equatorial Pacific. Johnston is therefore largely sheltered from the dynamic interannual variability in ocean conditions that results from the cycling between warm El Niño events and cool La Niña events every few years. Instead, the atoll's higher latitude creates a stronger seasonal cycle in weather and ocean conditions than is usually observed in the lower latitude reef environments of the PRIMNM, driving intra-annual differences in temperature, salinity, wave exposure, and seawater chemistry that can affect the health and function of coral reef ecosystems. Though less directly impacted by ENSO events, Johnston is positioned along the path of a moderate number of strong tropical cyclones that drive large waves and can significantly influence and damage shallow coral reef habitats.

Johnston Atoll is located at the southern edge of the North Pacific Gyre and sits within the northern boundary of the westward-flowing North Equatorial Current. Oceanographic conditions are also influenced by the eastward-flowing Subtropical Countercurrent and Hawaiian Lee Countercurrent. These countercurrents facilitate water movement between Johnston and the Hawaiian Archipelago to the atoll's east and north, and may create larval transport corridors to both the middle portion of the archipelago near French Frigate Shoals and the lower inhabited islands around Kauai (Kobayashi 2006).

Documenting baseline conditions and natural variability in coral reef environments is critical under the threat of global climate change as concentrations of carbon dioxide in the atmosphere are altering the temperature and chemistry of coral reef habitats. Episodic high temperatures, mostly driven by 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 the 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 shifts in ocean conditions that are occurring 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*, 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, and Figure 15). A summary of the environmental survey efforts around Johnston Atoll from 2004 to 2015 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 oceanographic model products to provide the large-scale climate and oceanographic context for the 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, chlorophyll-*a* (chl-*a*, a proxy for primary productivity) anomalies from the Sea-Viewing Wide Field-of-View Sensor and Moderate Resolution Imaging Spectroradiometer Aqua, tropical cyclone storm tracks from NOAA's Central Pacific Hurricane Center, 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 Johnston Atoll by year, from 2004 through 2015. The following instruments were deployed: sea surface temperature (SST) buoy, subsurface temperature recorder (STR), ecological acoustic recorder (EAR), wave and tide recorder (WTR), calcification accretion unit (CAU), and autonomous reef monitoring structures (ARMS). Conductivity-temperature-depth (CTD) casts, both shallow (near reef) and deep (offshore), have corresponding discrete water samples, shallow (near reef) and deep (offshore). Numbers indicate the quantity of instruments deployed (D) and retrieved (R) as D/R, water samples, and CTD casts. Instruments that were deployed and never retrieved were lost in the field.

Year	Instruments						CTD Casts		Water Samples	
	SST	STR	EAR	WTR	CAU	ARMS	Shallow	Deep	Shallow	Deep
2004	1/-	4/-	–	1/-	–	–	35	–	–	–
2006	1/-	5/4	–	1/1	–	–	39	4	26	20
2008	1/-	6/5	1/-	1/1	–	–	27	7	–	23
2010	1/1	6/5	1/1	1/1	20/-	9/-	23	4	9	20
2012	-/1	9/7	-/1	-/1	25/20	-/9	5	2	10	10
2015	–	6/6	–	–	15/25	–	10	–	11	–
Total	4/2	36/27	2/2	4/4	60/45	9/9	139	17	56	73

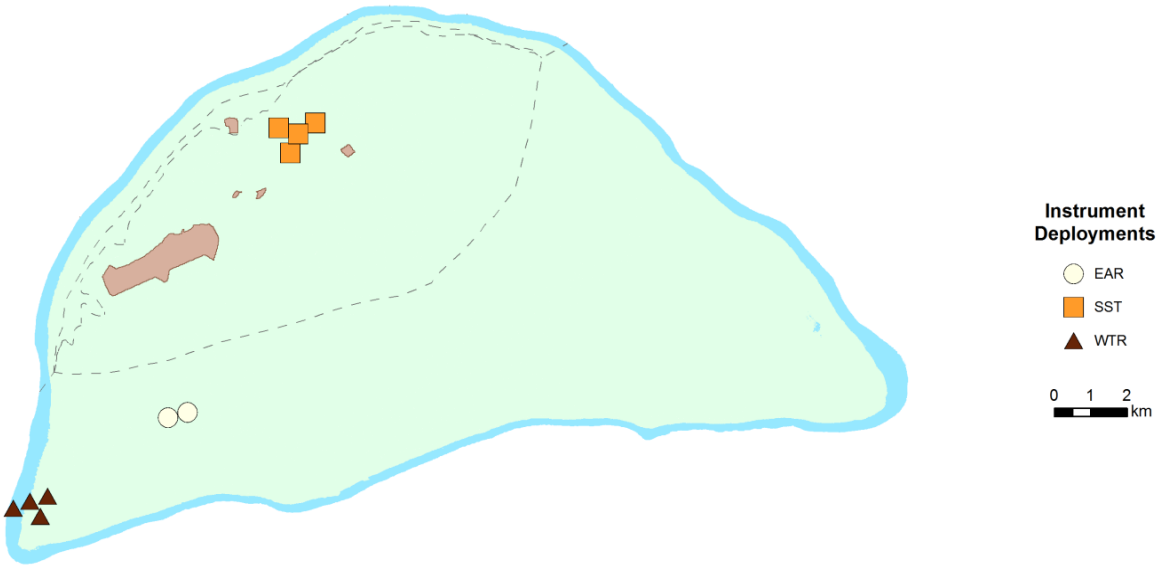


Figure 11. Deployment locations around Johnston Atoll of an ecological acoustic recorder (EAR), sea surface temperature (SST) buoy, and wave and tide recorder (WTR). Instrument deployments at the same location over multiple years have been plotted adjacent to one another and organized around their shared location on the map.

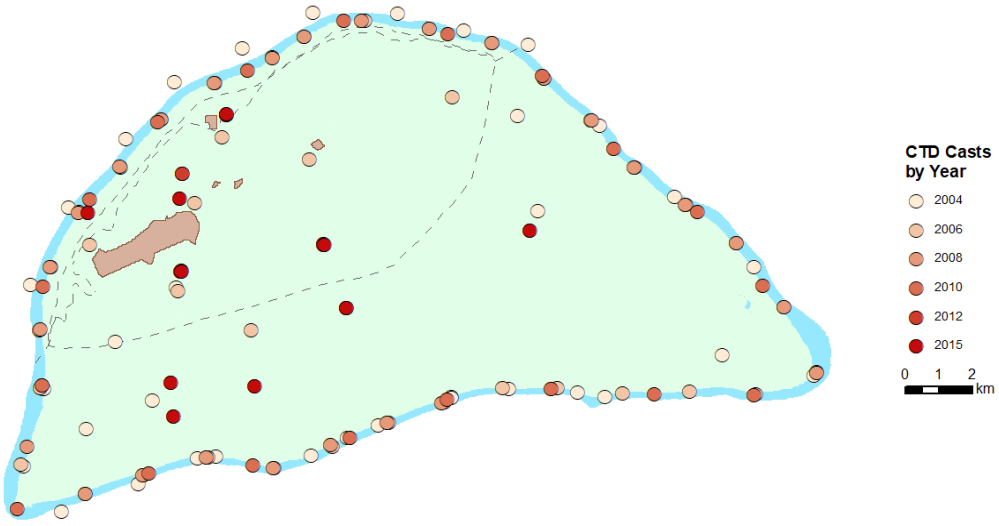


Figure 12. Locations of nearshore conductivity-temperature-depth (CTD) hydrocasts, measuring water column salinity and temperature from the ocean surface to depth of ~30 m around Johnston Atoll. Casts in earlier years (2004–2010) prioritized sampling the entire perimeter of the forereef, while later efforts (2012–2015) focused on permanent instrumentation sites (sites with subsurface temperature recorders, autonomous reef monitoring structures, and/or calcification accretion units).

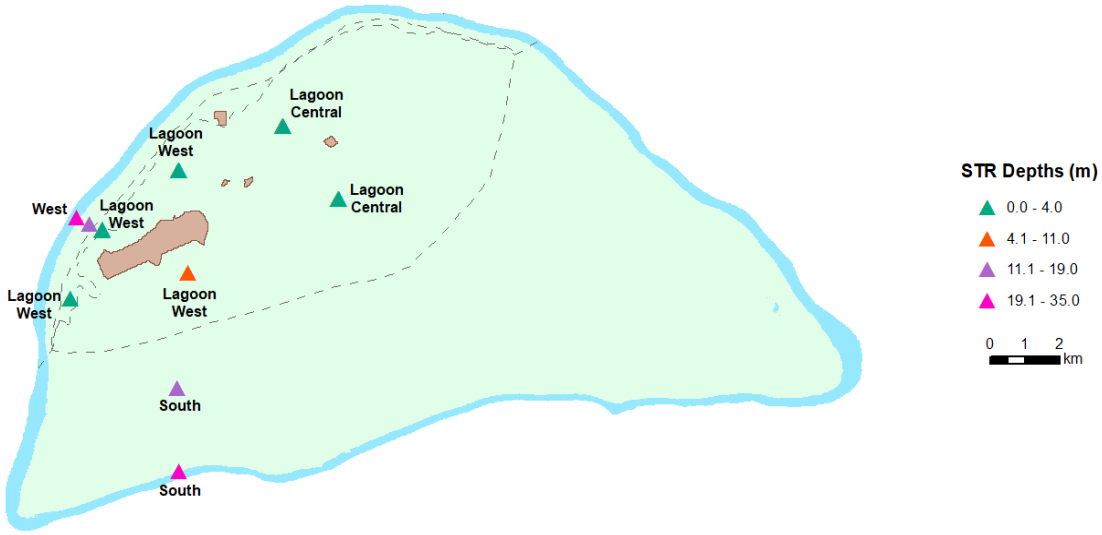


Figure 13. Locations of subsurface temperature recorders (STRs) deployed on the reef substrate in depths ranging from 1 m to 35 m around Johnston Atoll. Multiple STRs may have been collected at the same location over multiple years; however, they are represented by a single marker on the map.

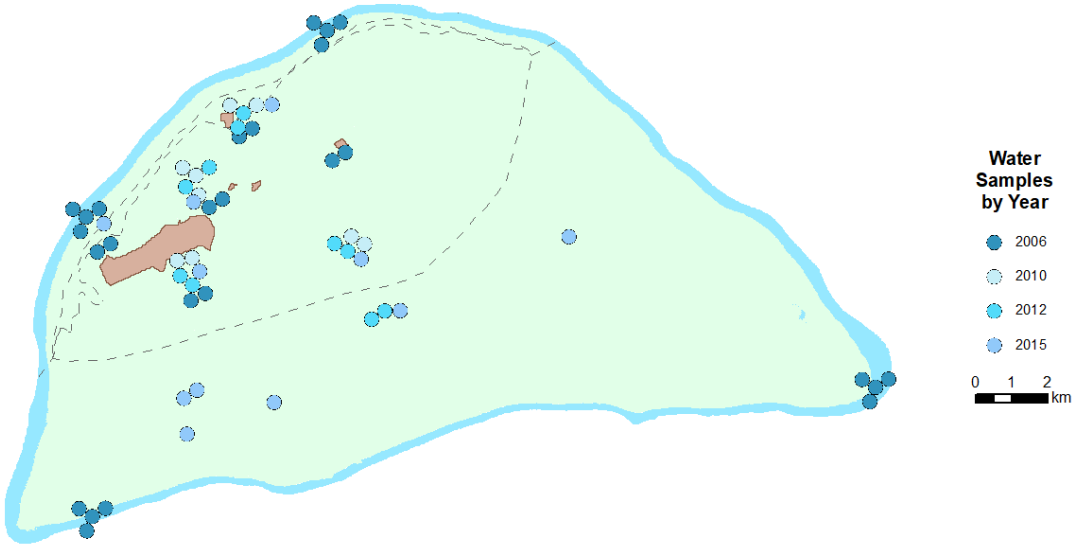


Figure 14. Locations of discrete seawater sample collections from 1 to 35 m depths around Johnston Atoll. Samples were evaluated for various analytes: dissolved inorganic carbon, total alkalinity, chlorophyll-*a*, and dissolved inorganic nutrients. Water samples collected at the same location over multiple years have been plotted adjacent to one another and organized around their shared location on the map. Water sample efforts were largely focused on permanent instrumentation sites (sites with subsurface temperature recorders, autonomous reef monitoring structures, and/or calcification accretion units).

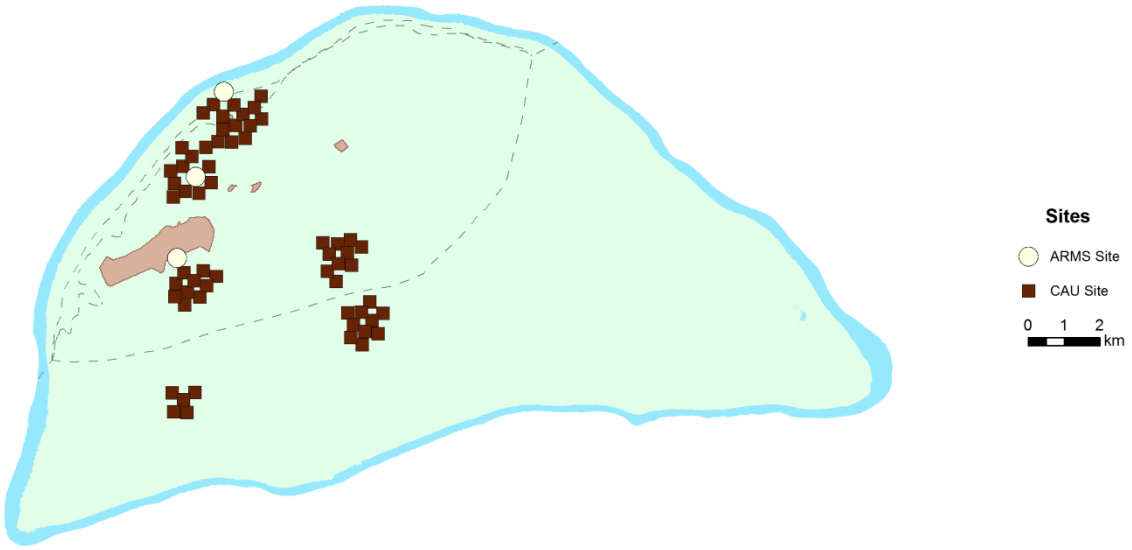


Figure 15. Locations of autonomous reef monitoring structures (ARMS, 3 per site) and calcification accretion units (CAU, 5 per site), deployed on the reef at ~15 m depths around Johnston Atoll. Instrument deployments at the same location over multiple years have been plotted adjacent to one another and organized around their shared location on the map.

Oceanographic Observations

Oceanographic conditions at Johnston Atoll are largely removed from the strong influence of interannual warming and cooling associated with ENSO cycles. The ONI, SST anomalies, DHWs, and chl-*a* anomalies for Johnston from 1981 to 2017 are plotted in Figure 16. The ONI shows the variability and frequency of strong warm (positive, El Niño) and cool (negative, La Niña) SST anomalies in the central equatorial Pacific, with higher SSTs persisting during El Niño warm events and lower SSTs during La Niña cool events (Figure 16). SST anomalies and chlorophyll-*a* concentrations at Johnston do not show a strong correlation with the ONI (Figure 17). Johnston SST anomalies were typically less extreme than the magnitude of temperature change in the central Pacific captured by the ONI, with the exception of the severe El Niño warm event of 2015–2016.

The coral reefs of Johnston Atoll have experienced few episodes of anomalously warm SSTs 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 temperature by 1 °C. SST anomalies above this 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 most significant warming occurred in 2015, during which DHW >8 °C-weeks (Figure 16c). High temperatures at Johnston during this episode were likely driven by the severe 2015–2016 El Niño that was the strongest on record for the central equatorial Pacific (Brainard et al. 2018).

As Johnston is located in the oligotrophic, low-productivity waters of the central portion of the North Pacific gyre, observations of phytoplankton chl-*a* pigment concentrations have been consistently low and were not correlated with ONI (Figure 17b).

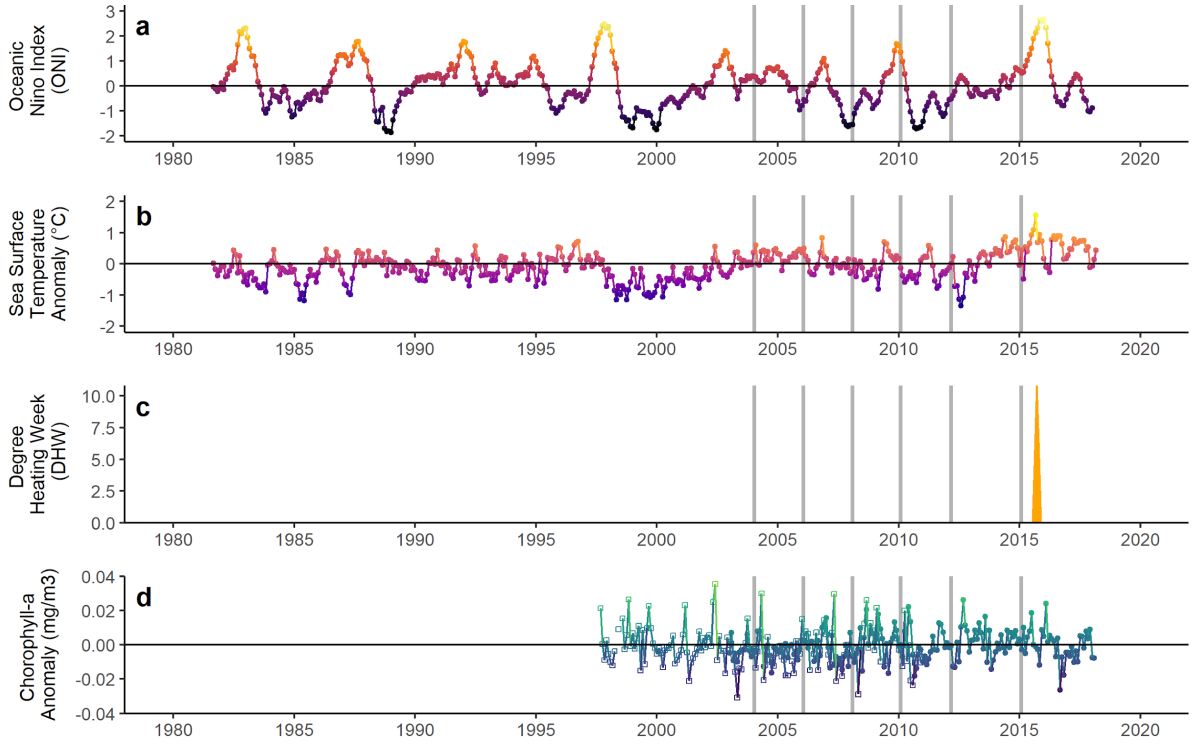


Figure 16. Time series of oceanographic conditions at Johnston Atoll: (a) a 3-month rolling mean of Oceanic Niño Index (ONI) from September 1981 to April 2018 in the El Niño 3.4 region (5°N-5°S, 120°W-170°W), (b) sea surface temperature (SST) anomalies from September 1981 to April 2018, (c) Cumulative Degree Heating Week (DHW) from 1985 to 2017, and (d) phytoplankton chlorophyll-*a* pigment (chl-*a*) concentrations from 1997 to 2017. Available data for ONI, SST, DHW, and chl-*a* were extracted for a box around Johnston (16° 33.8'N to 16° 53.0'N, 169° 40.0'W to 169° 15.2'W). Shading for SST and chl-*a* data indicates the magnitude of the anomaly. The grey vertical bars within each time series denote the occurrence of survey missions to Johnston.

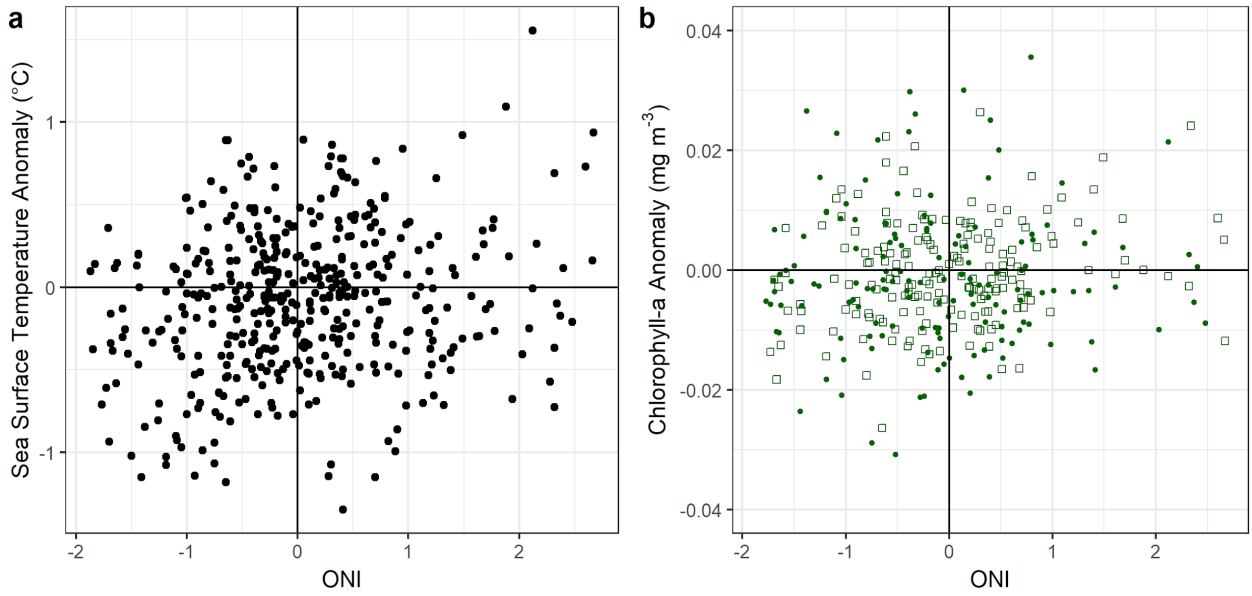


Figure 17. Relationship between monthly-averaged oceanographic conditions at Johnston Atoll: (a) Oceanic Niño Index (ONI) vs. sea surface temperature (SST) anomaly, and (b) ONI vs. satellite-derived chlorophyll-*a* (chl-*a*, Sea-Viewing Wide Field-of-View Sensor in boxes and Moderate Resolution Imaging Spectroradiometer in circles) anomaly data. Available data for ONI, SST anomaly, and chl-*a* were extracted for a box around Johnston (16° 33.8'N to 16° 53.0'N, 169° 40.0'W to 169° 15.2'W).

Water Column Observations

The nearshore water column surrounding Johnston Atoll was generally well-mixed. Figure 18 shows the locations of shallow-water CTD casts that were conducted in January 2006 (39 casts) and January 2010 (23 casts). Cast data documented small differences in seawater temperature, salinity, and density profiles between the survey missions of January 2006 and January 2010, with slightly warmer (about 0.25 °C), slightly less saline, and slightly less dense conditions occurring in 2006 (Figure 19). Temperature, salinity, and density were mostly vertically well-mixed throughout the water column in both years, with some evidence of stratification present in the shallower lagoonal areas. Interestingly, in 2006 the lagoonal waters were cooler and denser than the waters surrounding the forereefs, except at sites 2 and 3, which were similar to the lagoon waters suggesting these may be areas where lagoonal waters discharge to the ocean. In 2010, a shallow (~1 m) freshwater lens appeared at most sites around Johnston, likely indicating recent rainfall.

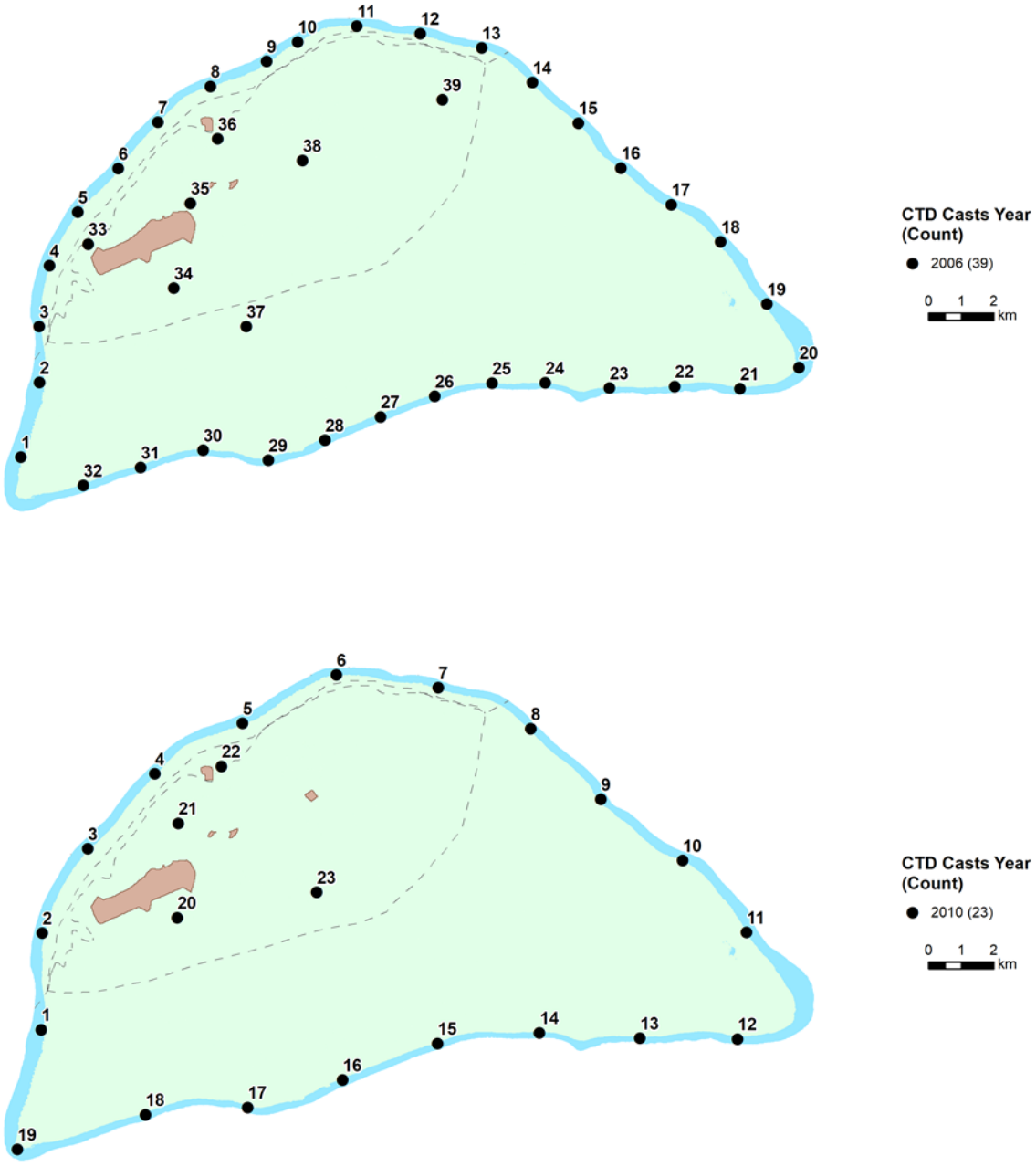


Figure 18. Shallow-water conductivity-temperature-depth (CTD) sampling locations around Johnston Atoll. CTDs were conducted during 2006 (39 casts) and 2010 (23 casts). The casts are numbered sequentially in a clockwise direction.

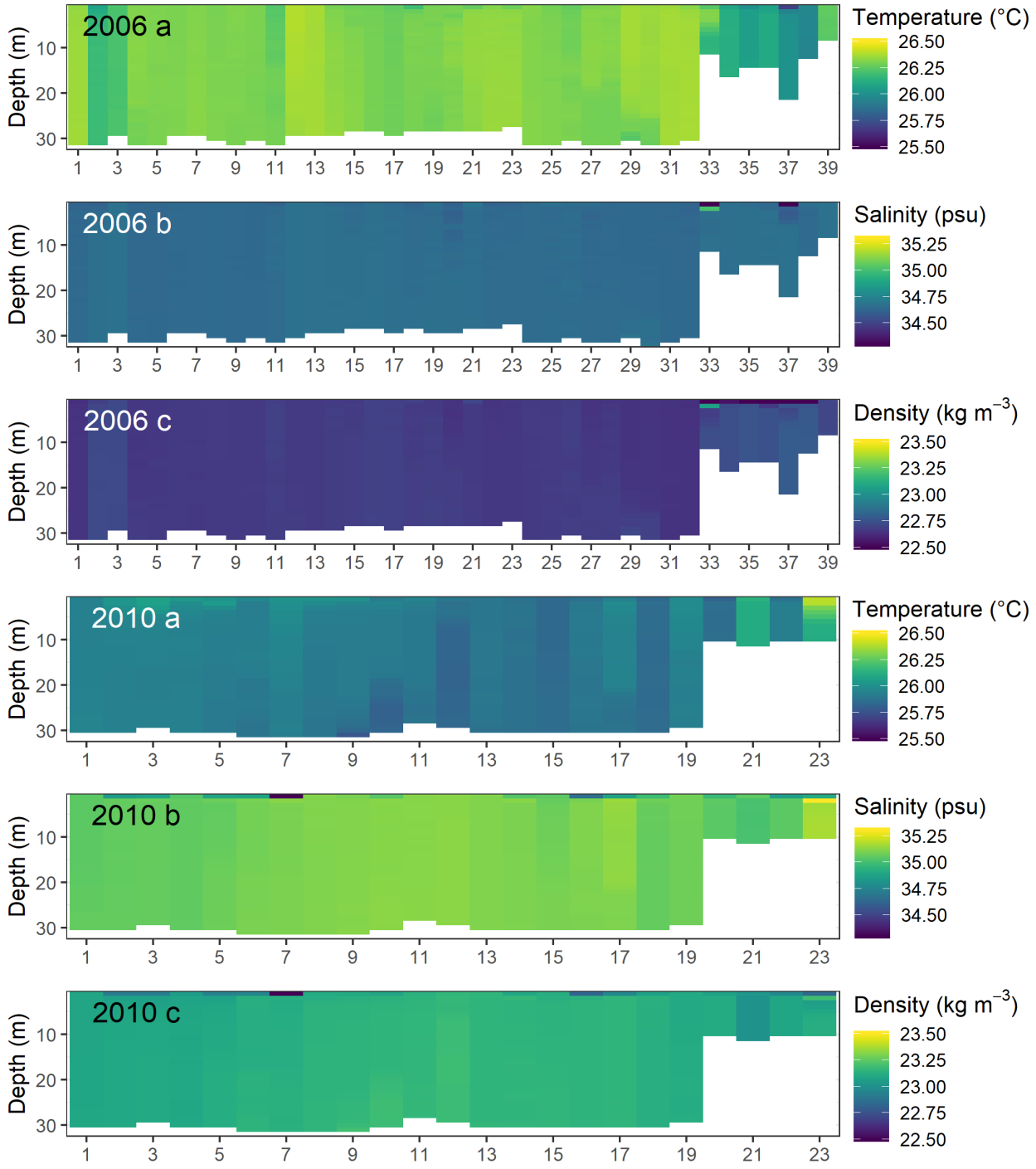


Figure 19. Profiles from shallow-water conductivity-temperature-depth casts around Johnston Atoll in 2006 (top three panels) and 2010 (bottom three panels) for (a) temperature (°C), (b) salinity (psu), and (c) sigma-t density (density of seawater at atmospheric pressure in kg m^{-3} -1,000) from the surface to depths of ~35 m. The casts are numbered sequentially in a clockwise direction around the island (see Figure 18). The top three panels show 2006 profiles 1–39, while the bottom three panels show 2010 profiles 1–23.

Between 2000 and 2015, a total of 34 moored subsurface temperature recorders (STRs) collected temperature time series at depths between 1 and 25 m (Figure 13). This suite of STRs provides in situ vertical thermal structure observations to characterize the temperature regimes influencing the coral reefs at Johnston Atoll at smaller spatial scales and greater depths than is possible using satellite SST data. Johnston reefs are exposed to consistently moderate seasonal temperature oscillations with some inter-annual variability, driving temperatures between 24 °C (during winter) to 29 °C (during summer) (Figure 20). The four georegions of Johnston generally showed homogeneous thermal conditions, both geographically and with depth, indicating a fairly well-mixed system. A cool winter was observed in 2008–2009, and a particularly warm summer occurred in 2014.

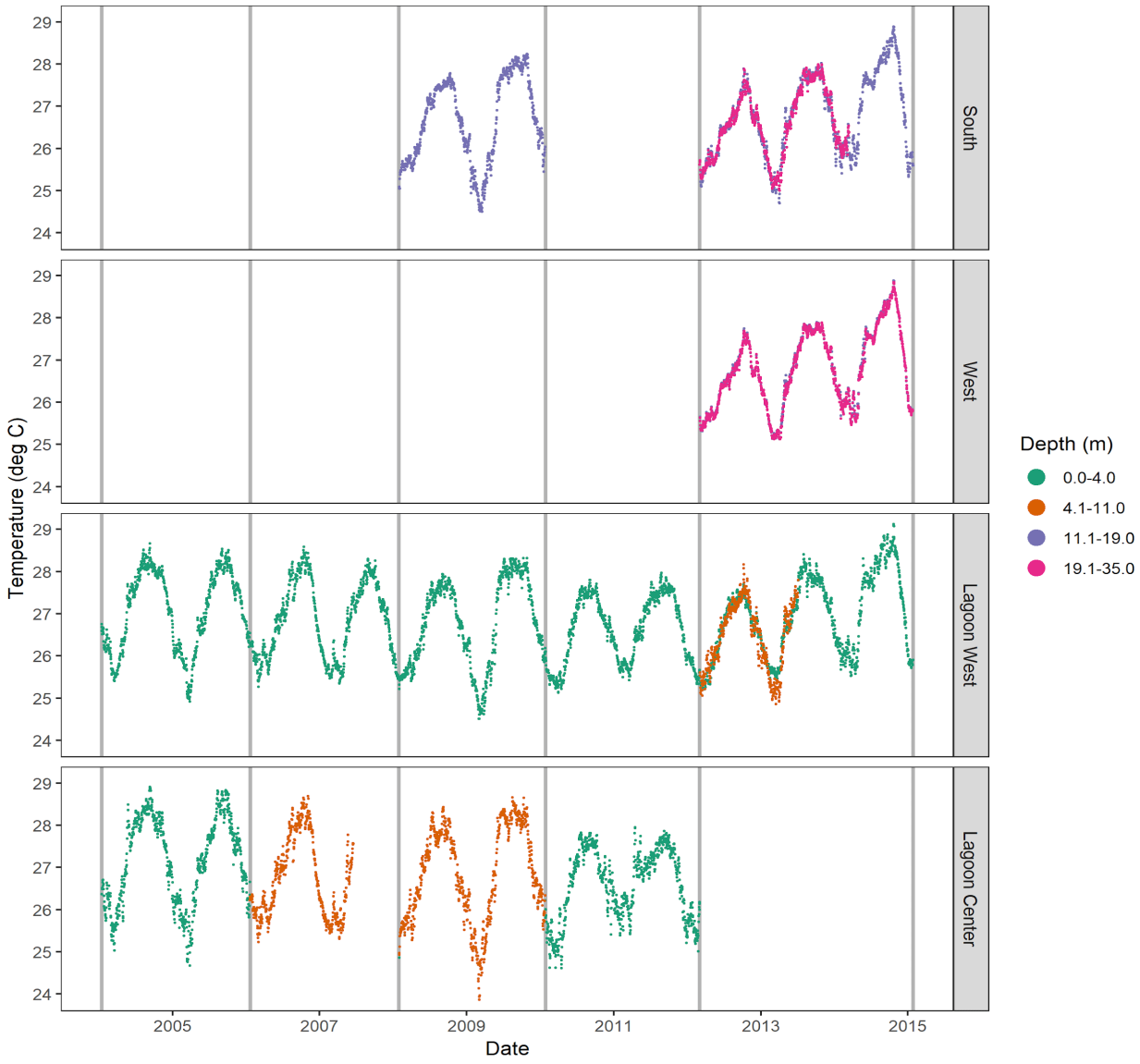


Figure 20. Daily subsurface temperature recorder time-series observations of temperature between 2004 and 2015, collected around Johnston Atoll in the South, West, Lagoon West, and Lagoon Center. Four different depth ranges were defined at each of these locations: 0–4.0 m (green), 4.1–11.0 m (red), 11.1–19.0 m (blue), and 19.1–35.0 m (magenta). The grey vertical bars within each time series denote the occurrence of survey missions to Johnston.

Wave Energy

Ocean wave dynamics strongly influence the environmental conditions of coastal habitats. The energy generated by ocean waves varies over a broad range of time scales, including tidal, multi-day storm events, seasonal, interannual, and decadal. 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 data for Johnston over the period 2010–2016 show noticeable seasonal differences in the approaching wave direction, number of wave observations, and mean wave heights between winter (December–February) and

summer (July–September) (Figure 21). During the winter months, the northwest side of Johnston experienced more waves that had a longer period (the length of time between the passage of wave crests) and height (the vertical distance from trough to crest (Figure 21, left panels). During the summer months, the south and east sides of Johnston were exposed to more waves with both a longer wave period and greater mean wave height (Figure 21, right panels). The mean annual integrated wave power, which includes all seasons over the period from 1979 to 2012, shows that the north-northeast side of Johnston experienced the highest wave power, while the south side appears to have been relatively sheltered (Figure 22).

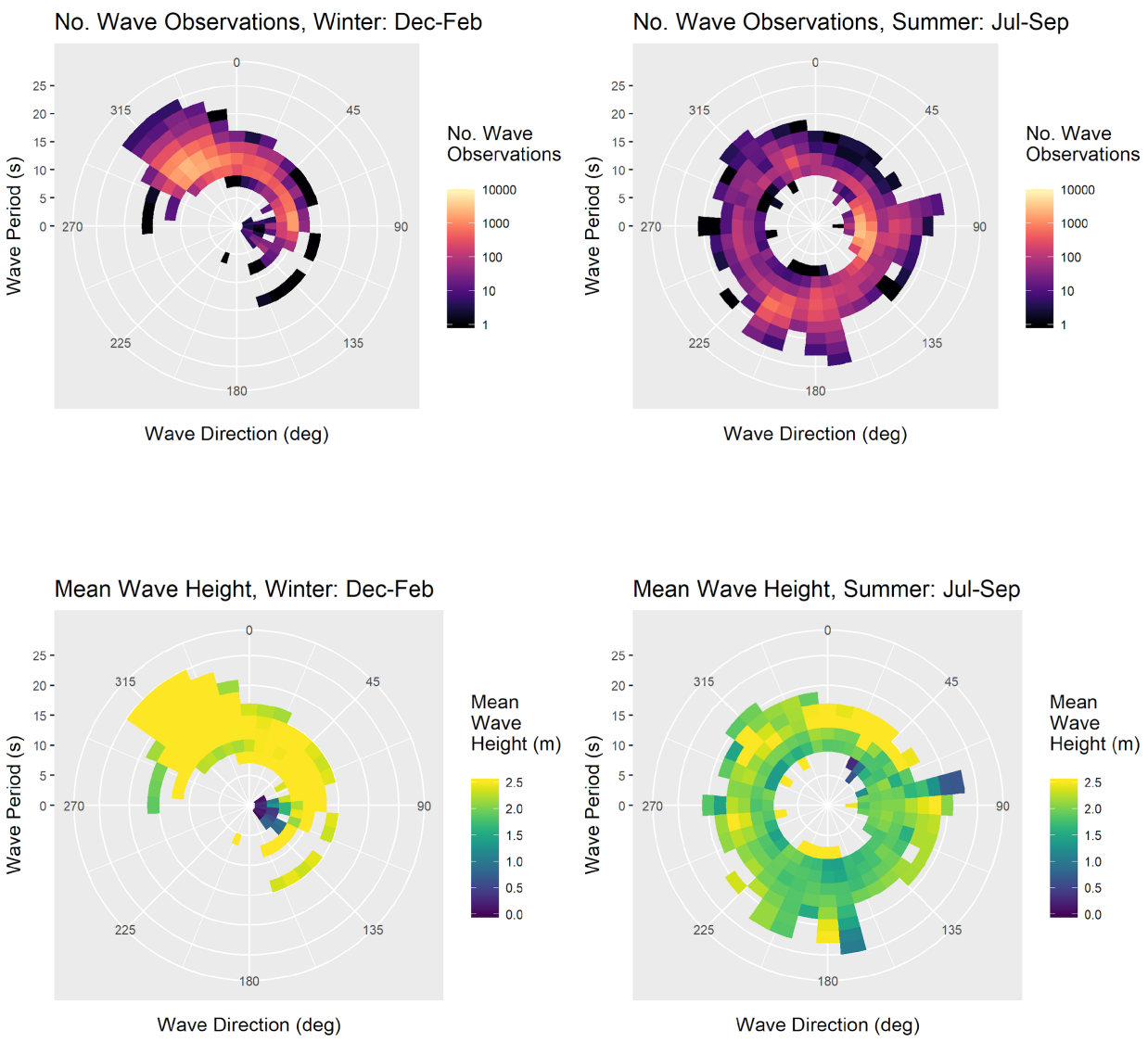


Figure 21. WaveWatch III data from 2010–2016. Top panels: Polar plot of the percent of wave observations coming from different directions between December–February (left), and between July–September (right). Bottom panels: Polar plot of derived mean wave height between December–February (left), and between July–September (right). The position of wave data around the 360-degree circle (in 10-degree bins) displays the direction from which the waves hitting Johnston Atoll travel. Zero degrees indicate that waves arrive from due north and 180 degrees 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.



Figure 22. Mean annual integrated wave power (MWhr/m) calculated at the 15 m depth contour of Johnston Atoll. Data from 1979 to 2012 correspond to modified WaveWatch III by coastline shadowing using the incident wave swath method.

In addition to seasonal and annual patterns, Johnston Atoll is located along the storm tracks of numerous tropical cyclones that generate episodic high-wave energy events that can influence shallow water coral reef communities. Since 1972, nine tropical cyclones of hurricane strength approached within 200 nm of Johnston, six within 50 nm of the atoll (Figure 23). In 1994, Hurricane John passed within 15 nm of Johnston with winds of 150 kt.

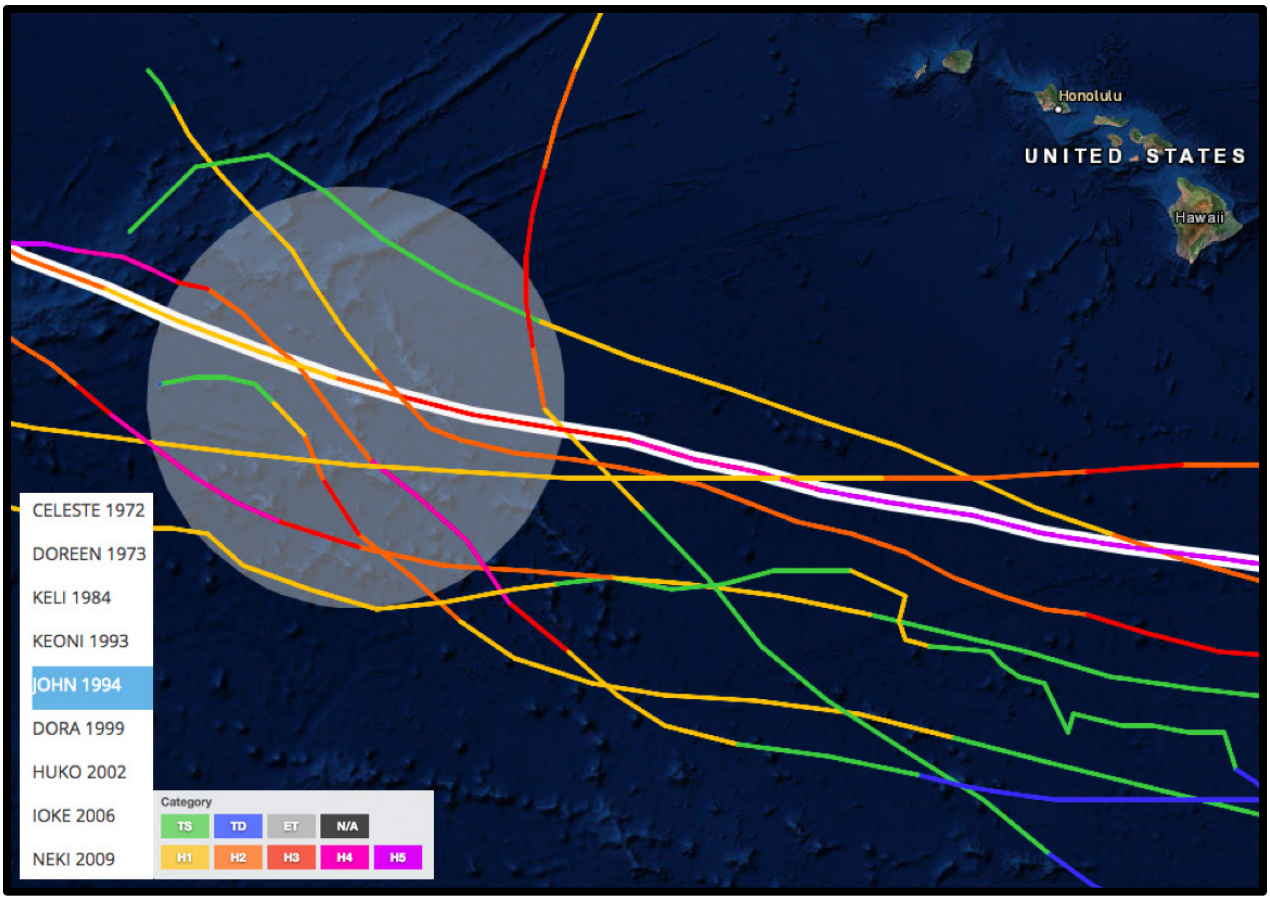


Figure 23. Tropical cyclone storm tracks that reached hurricane status within 200 nm of Johnston Atoll over the period from 1972 to 2017. Hurricane names and years are shown in legend. Hurricane John is highlighted with white background. Trackline colors reflect hurricane category on the Saffir-Simpson scale: H1 (64–82 kt), H2 (83–95 kt), H3 (96–112 kt), H4 (113–136 kt) and H5 (>137 kt). Data from NOAA's Central Pacific Hurricane Center provided by the NOAA Office of Coastal Management at https://coast.noaa.gov/hurricanes/.

Carbonate Chemistry

Aragonite saturation state (Ω_A) is a measure of 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.

The majority of our discrete water sampling effort at Johnston Atoll took place at the same time each year (usually in January). As a result, it is not possible to describe seasonal patterns in seawater carbonate chemistry. The values of Ω_A in the nearshore waters around Johnston were weakly modulated by large-scale ocean climate variability, coral reef metabolic processes (such

as calcification-dissolution relationships at specific reef systems), and local variability in water quality. The overall highest median values in Ω_A and pH were measured during the January 2010 survey mission, followed by 2015 and 2012. The median Ω_A values for the reef waters around Johnston were noticeably lower than the median of values observed by ESD across the U.S. Pacific Islands region (Figure 24), likely because many of the water sampling sites were in lagoonal habitats having longer residence times than the more typical forereef habitats dominant at other islands surveyed. The pH values for the reef waters around Johnston were near the median of values observed by ESD across the U.S. Pacific Islands region for all years (Figure 24).

There were not large spatial differences in carbonate chemistry across years; however, Ω_A values in the Lagoon and South georegions tended to be lower than those measured in the North and Backreef georegions (Figure 25). This spatial pattern may have resulted from the generally north-to-south flow of water across the forereef and into the lagoon during water sampling periods, where the pH and Ω_A of the oceanic water moving southward across the reef were driven down by the metabolic processes of calcification and respiration. The impacts of these reef metabolic processes on carbonate chemistry were likely magnified by longer residence times in the relatively shallow lagoon.

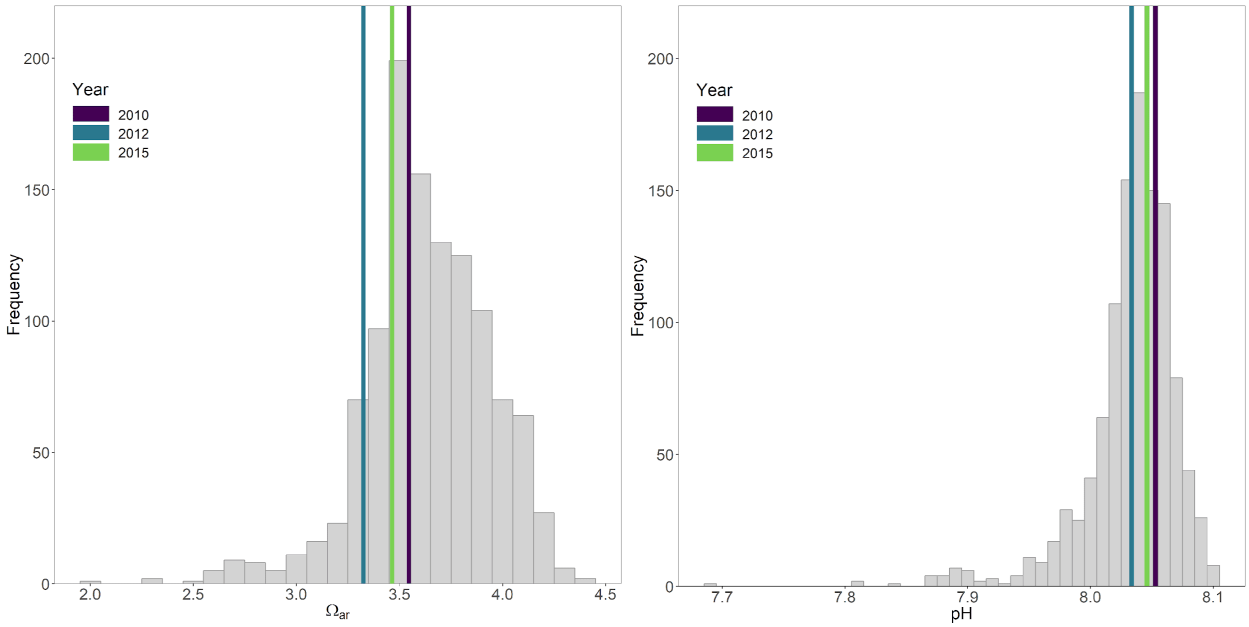


Figure 24. Histogram of all aragonite saturation state (Ω_A; left) and pH (right) values measured from discrete seawater samples across the U.S. Pacific Islands region from 2010 to 2017 (gray). Overlaid vertical bars show the medians of Johnston Atoll data in 2010 (purple), 2012 (blue), and 2015 (green).

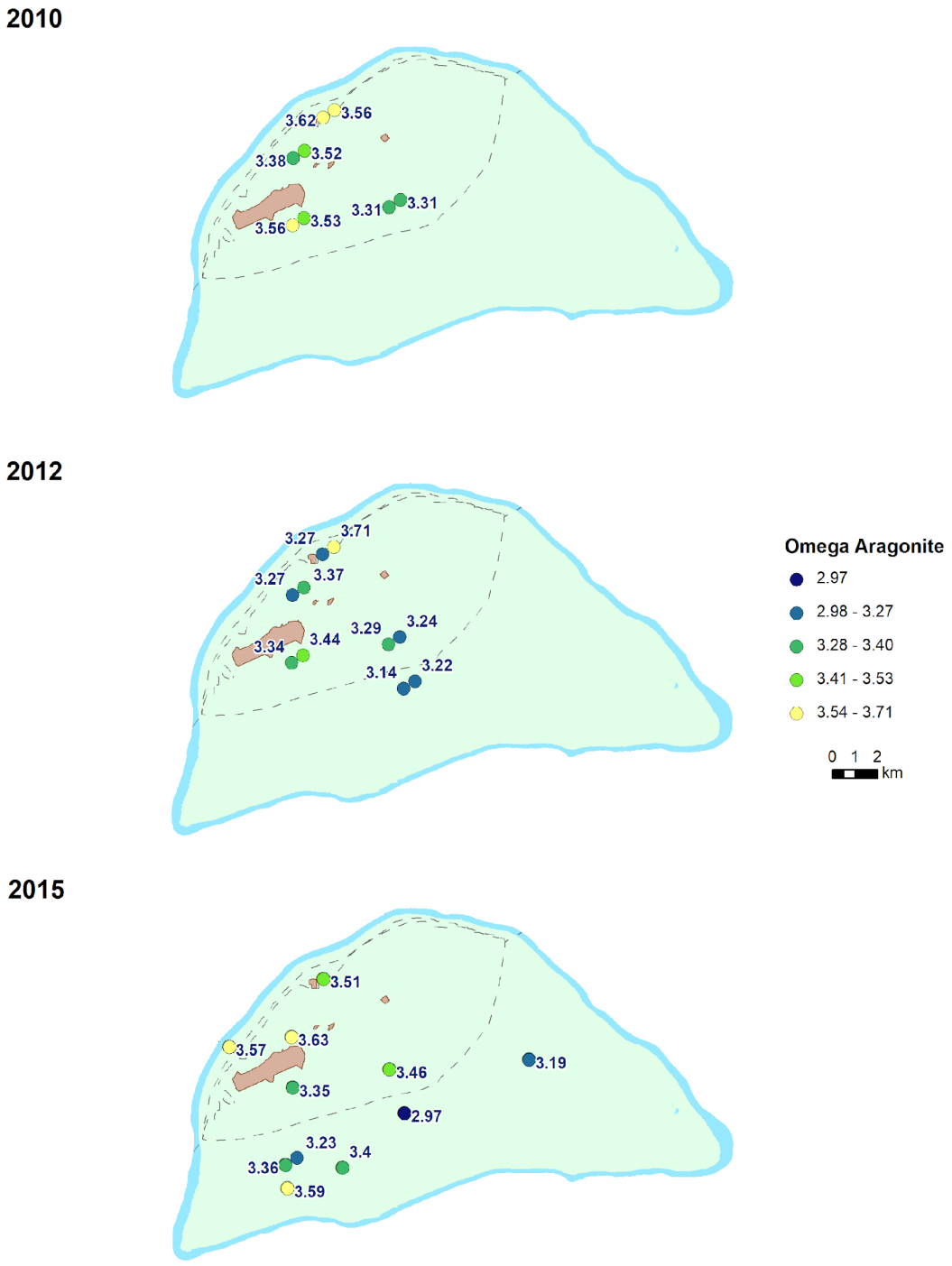


Figure 25. Spatial distribution of aragonite saturation state (Ω_A) observations during 2010, 2012, and 2015 around Johnston Atoll.

Net Carbonate Accretion

Calcification accretion units (CAUs) are simple, two-plate fouling structures that are staked to the reef substrate for 2–3 years, 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 a proxy for the net rate of $CaCO_3$ accretion 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 dynamic nearshore environmental conditions. In particular, calcification rates of corals and CCA are sensitive to changes in carbonate chemistry and decrease 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 Johnston Atoll to assess spatial and temporal variability in reef accretion rates. At the three repeat CAUs sites (JOH-09, JOH-11, and JOH-12), the site-level mean carbonate accretion rates were surprisingly consistent across years, though they varied spatially (Figure 26). The lowest mean accretion rate was observed in the one shallow backreef site, JOH-10, and the highest mean accretion rate was observed in slightly deeper water in the South georegion. Compared to the rest of the Pacific, accretion rates at Johnston were lower than most other reefs (Figure 27). This may have been due to both relatively low Ω_A and low overall productivity of the surrounding oligotrophic environment.

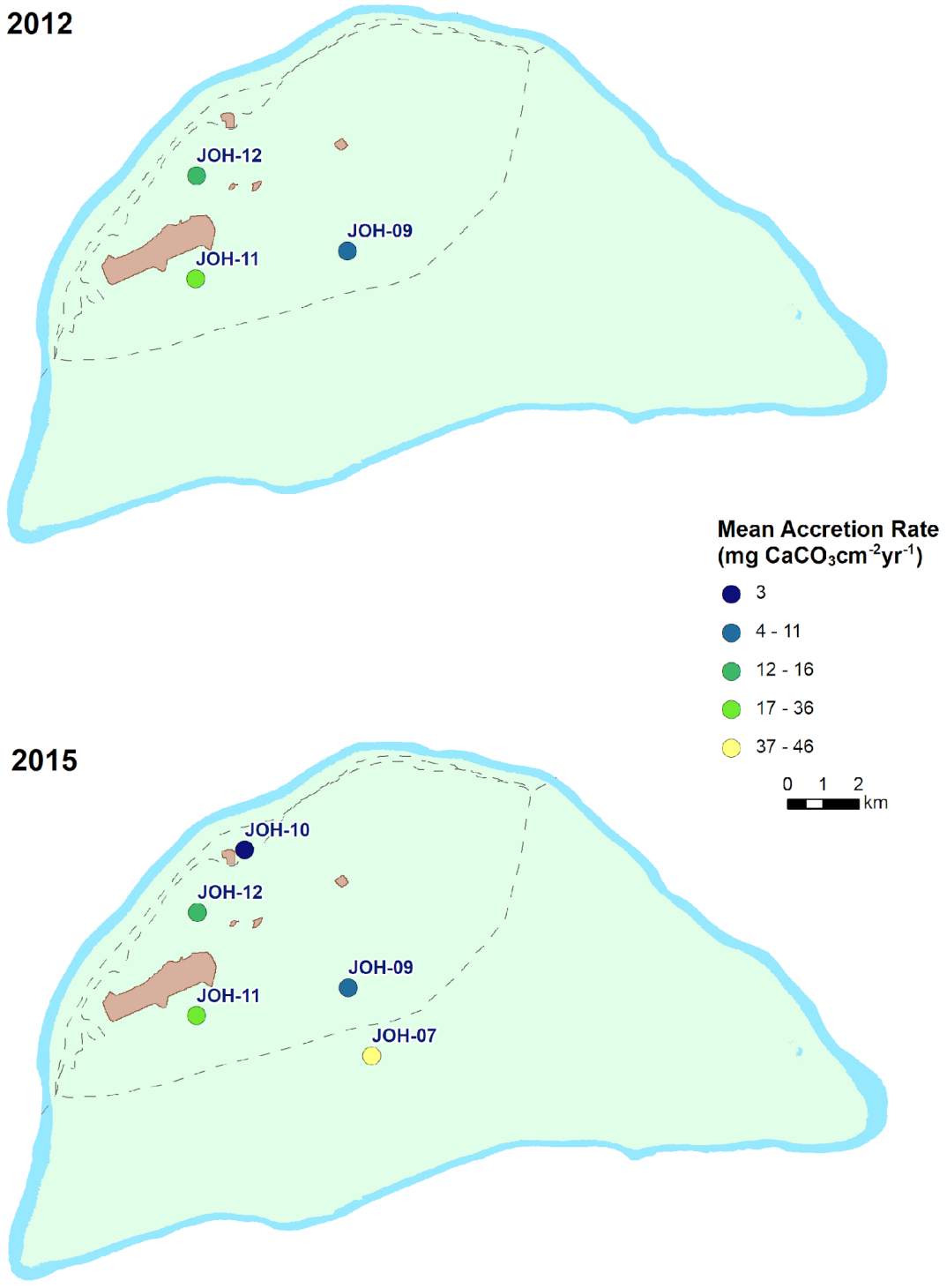


Figure 26. Spatial distribution of mean carbonate accretion rate (mg $CaCO_3$ cm^{-2} yr^{-1}) at Johnston Atoll during 2010–2012 (top) and 2012–2015 (bottom). The calcification accretion units are labeled by location code.

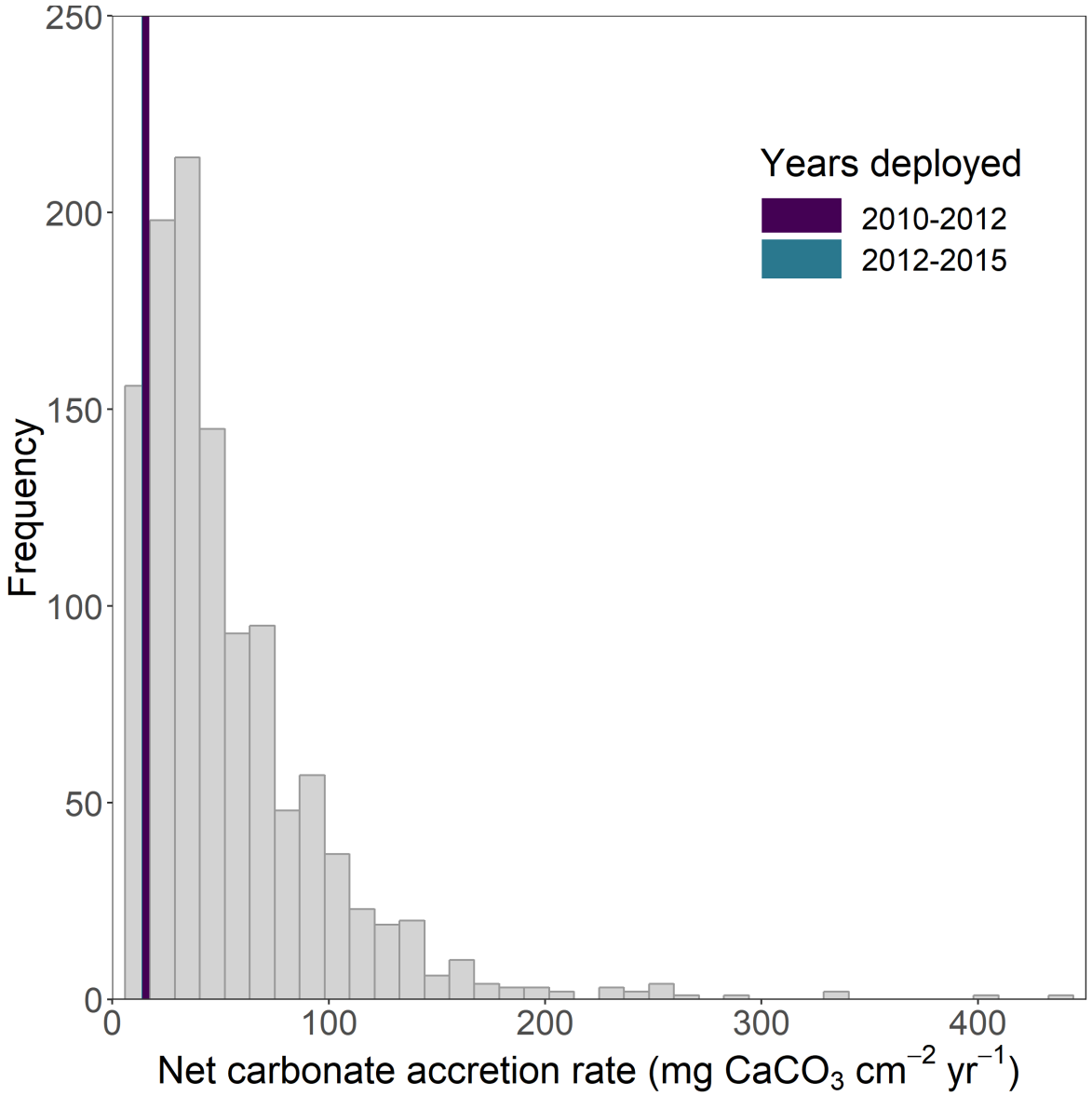
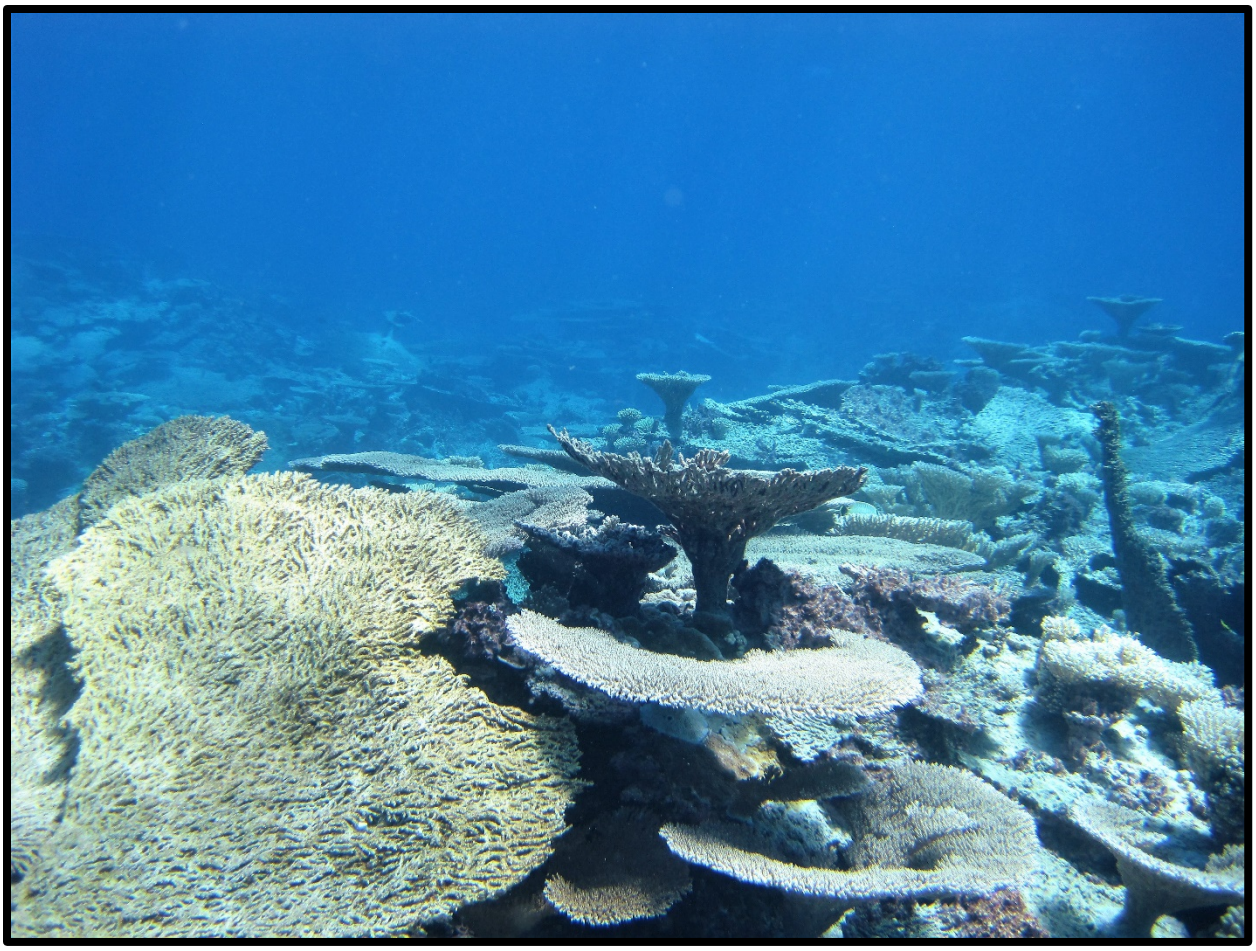


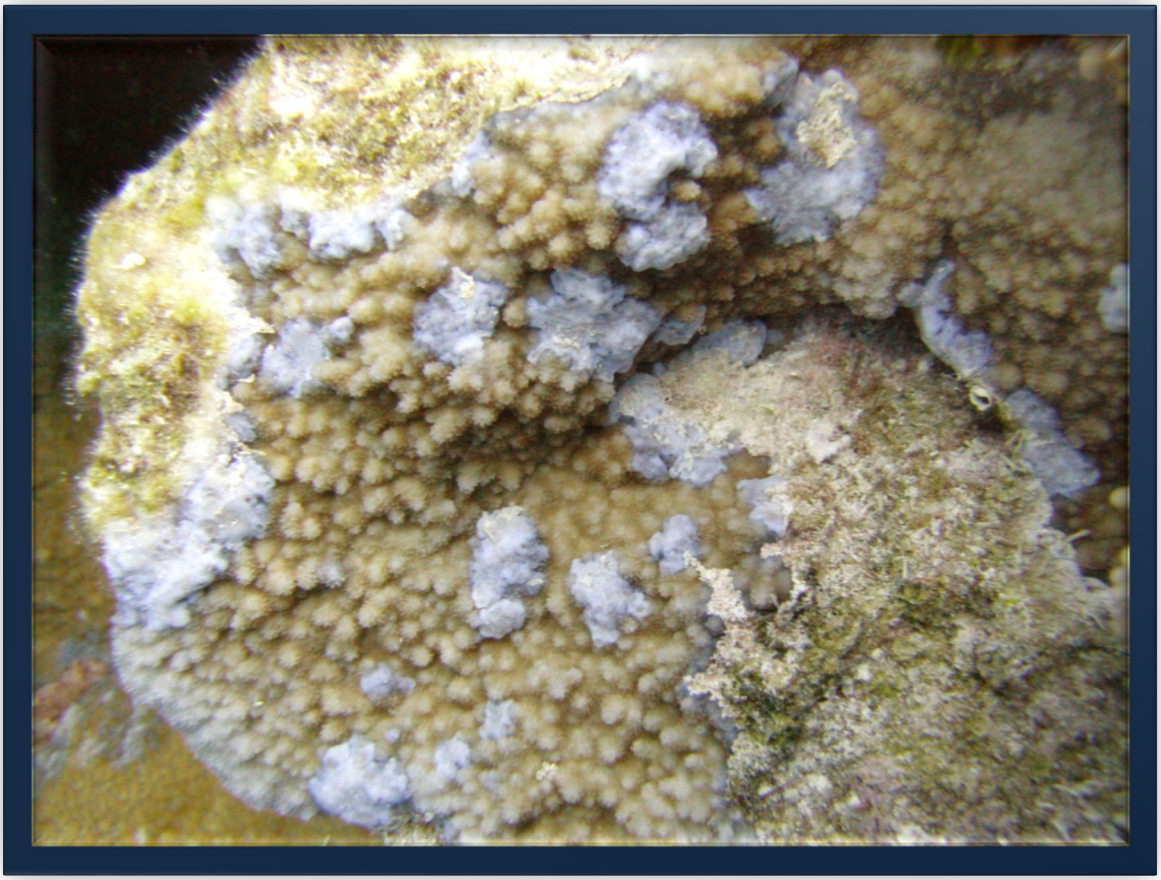
Figure 27. Histogram of all net carbonate accretion rates (m $CaCO_3$ cm^{-2} yr^{-1}) measured by all calcification accretion units during the period 2010–2017 across the U.S. Pacific Islands region (gray), and median values for 2010–2012 (purple) and 2012–2015 (blue) samples for Johnston Atoll.



Coral reef at Johnston Atoll.
Photo: NOAA Fisheries.

Coral Reef Benthic Communities

6.4 Coral Reef Benthic Communities



Conspicuous and colorful skeletal growth anomalies on a Montipora *coral colony.*
Photo: Bernardo Vargas-Angel, NOAA Fisheries.

Survey Effort and Site Information

Data to characterize benthic habitats and the coral populations around Johnston Atoll were collected using Rapid Ecological Assessment (REA) surveys and towed-diver surveys (TDS) during eight survey efforts conducted between 2004 and 2015 (Table 3). REA surveys at Johnston were primarily performed at repeat sites at mid-depth (>6–18 m) for the five survey efforts from 2004 through 2012. In 2015, a stratified-random sampling (StRS) design was adopted to generate more statistically robust island-scale estimates of coral reef benthic communities. The use of a StRS study design allowed for an increased number of survey sites across multiple depth strata (shallow: >0–6 m; mid: >6–18 m; and deep: >18–30 m)—though no shallow strata habitats were surveyable at Johnston. The stratified-random sites were more widely and evenly distributed around the atoll than the former repeat sites (Figure 28). For comparability with other reef ecosystems in the PRIMNM, coral demography survey estimates from backreef and lagoon sites were excluded. Benthic REA surveys implemented the line-point-intercept (LPI) method from 2006 through 2012 and the photoquadrat method in 2015 to

estimate the percent cover of benthic communities. Photoquadrat surveys were also conducted at fish REA sites in 2015, yielding a greater sample size to determine benthic cover. The belt-transect (BLT) method was used from 2006 through 2015 to estimate the abundance, distribution, condition, and diversity of the coral populations (with progressive updates to the methods detailed in "Chapter 1: Overview"). 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 conspicuous ecologically- or economically-important macroinvertebrates, and occurrences of potentially significant ecological events, such as widespread bleaching and disease outbreaks.

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 Johnston Atoll. Numbers in parentheses (bold) indicate the number of surveys conducted at mid-depth (>6–18 m). *Note: In 2015, REA survey methodology changed from repeat sites to stratified-random sampling (StRS). StRS sites were located across three depth strata: shallow (S), mid (M), and deep (D).**

Year	TDS	REA	
		Coral Populations	Benthic Communities
2004	235 (**142**)	–	–
2006	238 (**147**)	4	4
2008	90 (**66**)	–	–
2010	198 (**142**)	3	3
2012	171 (**147**)	2	2
2015*	146 (**96**)	6 (M) 3 (D)	16 (M) 17 (D)

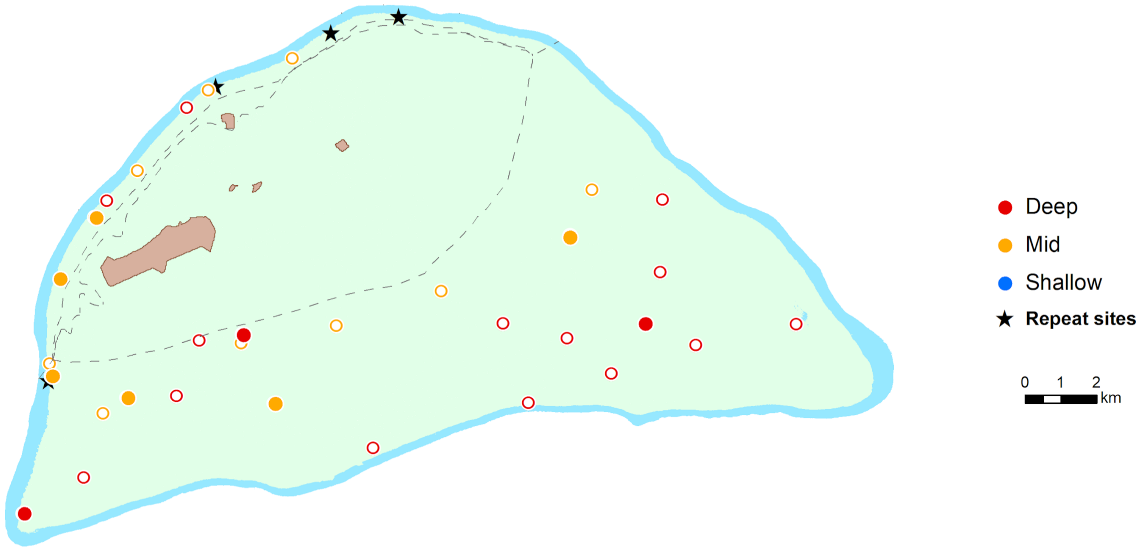


Figure 28. Johnston Atoll benthic Rapid Ecological Assessment surveys locations. Repeat sites (stars) were sampled from 2004 through 2012, and stratified-random sampling (StRS) sites were sampled in 2015 (blue, yellow, and red circles for shallow [>0–6 m], mid [>6–18 m], and deep [>18–30 m] depth strata, respectively). No shallow sites were surveyed at Johnston. Photoquadrats for assessing benthic communities were collected at all StRS sites (open circle with white fill and solid circles). Coral population surveys were only conducted at sites indicated by solid circles.

Recent State of Benthic Cover

The benthic community surveyed using TDS (Figure 29) and StRS (Figure 30) methods at Johnston Atoll revealed large similarities in cover, although there was greater variability in cover estimates derived from StRS surveys, possibly reflecting the greater diversity of depths and habitats sampled using this methodology. Hard coral was present in each tow segment and StRS site, and both methods estimated slightly higher coral cover in the south than the north. Coral cover on tow segments (mean = 6.7% ± 1.6 SE) ranged from 0.5% to 25%, but 78% of segments had cover less than 10%. Coral cover was slightly higher according to StRS estimates (mean = 9.5% ± 1.3 SE), albeit with a narrower and lower range than the tow segments (0.3% to 16%). Both methods showed that macroalgal cover was low and ranged from 0% to 8%, where 87% of tow segments and 88% of StRS sites had ≤2.5% cover (mean = 2.7% ± 0.5 SE and mean = 1.3% ± 0.5 SE, respectively). StRS surveys revealed low spatial variability in macroalgae cover across the forereef. The functional group with the highest benthic cover at Johnston was CCA, which ranged from 0.5% to 69% (mean = 18.4% ± 4.4 SE) on tow segments with the highest values found in the South georegion. StRS sites had a comparable range and mean of CCA to the tow surveys (range: 0% to 67%; mean = 15.5% ± 3.0 SE) and also found sites in the South georegion had the highest CCA cover.

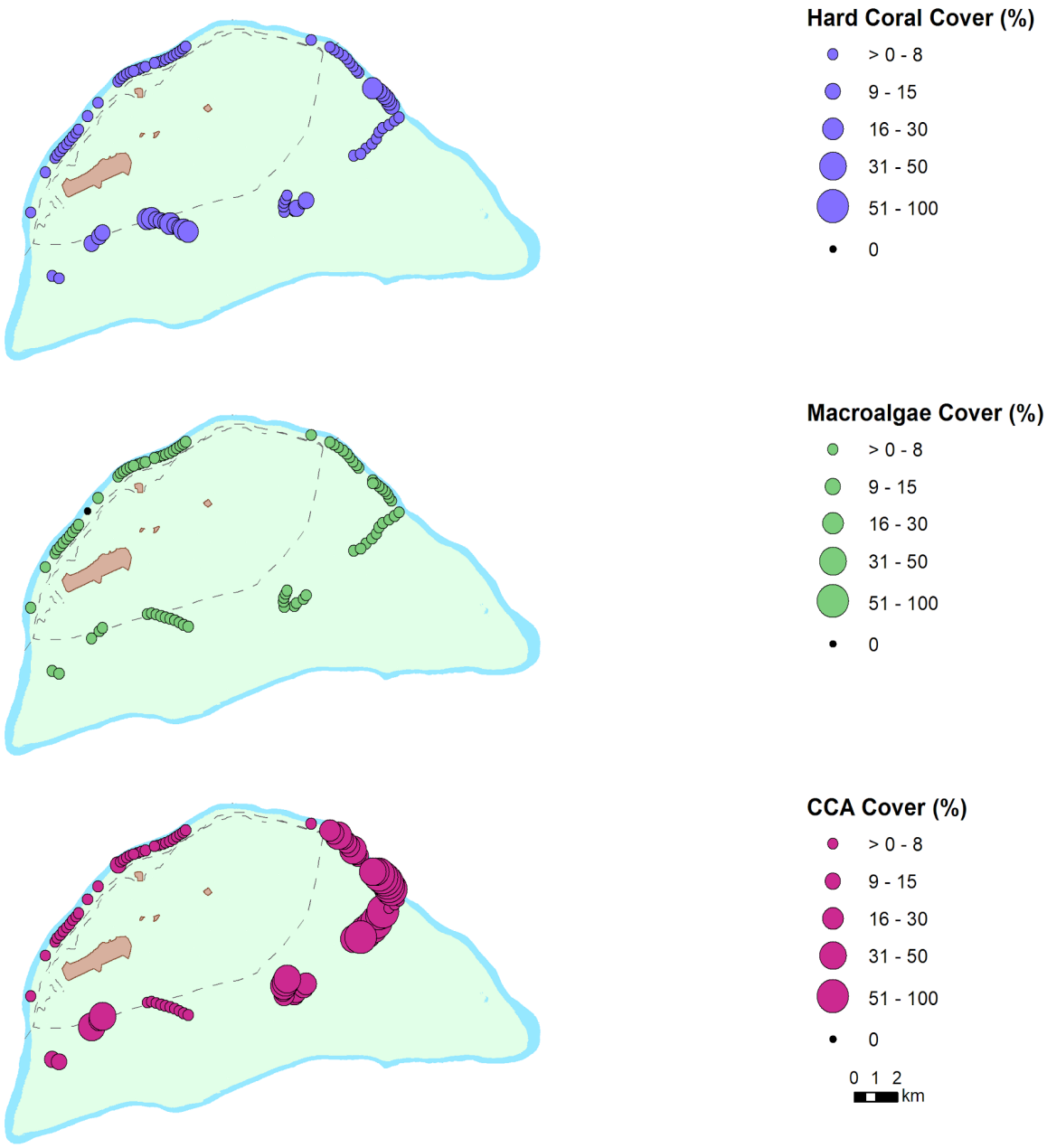


Figure 29. Visual estimates and spatial distribution of mid-depth (>6–18 m) forereef hard coral, macroalgae, and crustose coralline algae (CCA) cover (%) at Johnston Atoll from towed-diver surveys in 2015.

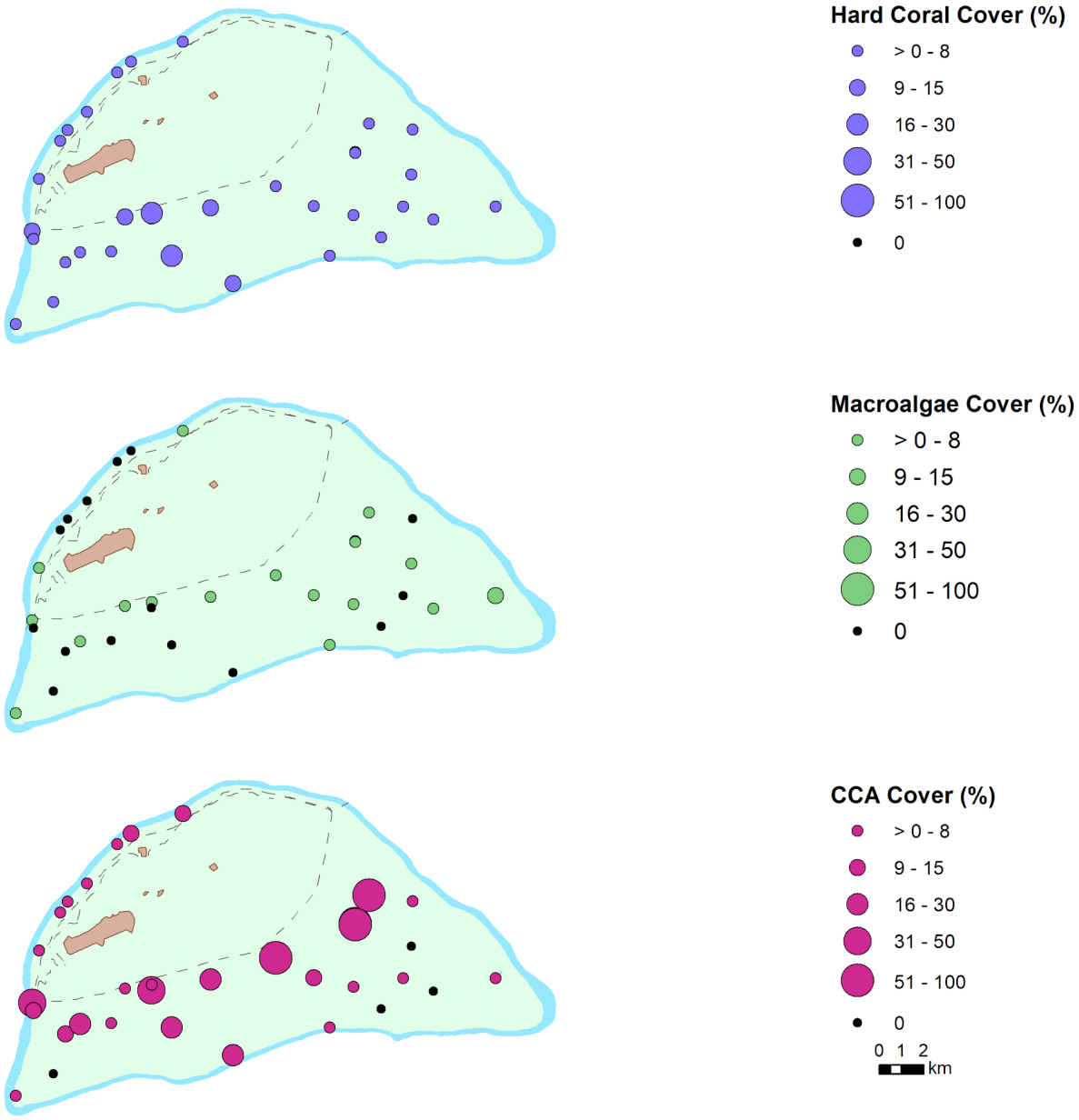


Figure 30. Site-level estimates of hard coral, fleshy macroalgae (excluding calcified and encrusting macroalgae), and crustose coralline algae (CCA) cover (%) at Johnston Atoll from stratified-random sampling photoquadrat surveys conducted at all forereef depth strata combined (>0–30 m) in 2015.

CCA cover based upon StRS estimates was highest in the mid-depth stratum (mean = 28.4% ± 4.7 SE); among the highest observed across the PRIMNM islands in 2015, yet declined sharply with depth (Figure 31). Hard coral cover was consistently low in both the mid and deep strata (≤5%), as was macroalgae cover (≤1%). Turf algae (not shown) dominated the benthos in both the mid-depth (mean = 45.9% ± 4.7 SE) and deep strata (mean = 76.4% ± 4.5 SE).

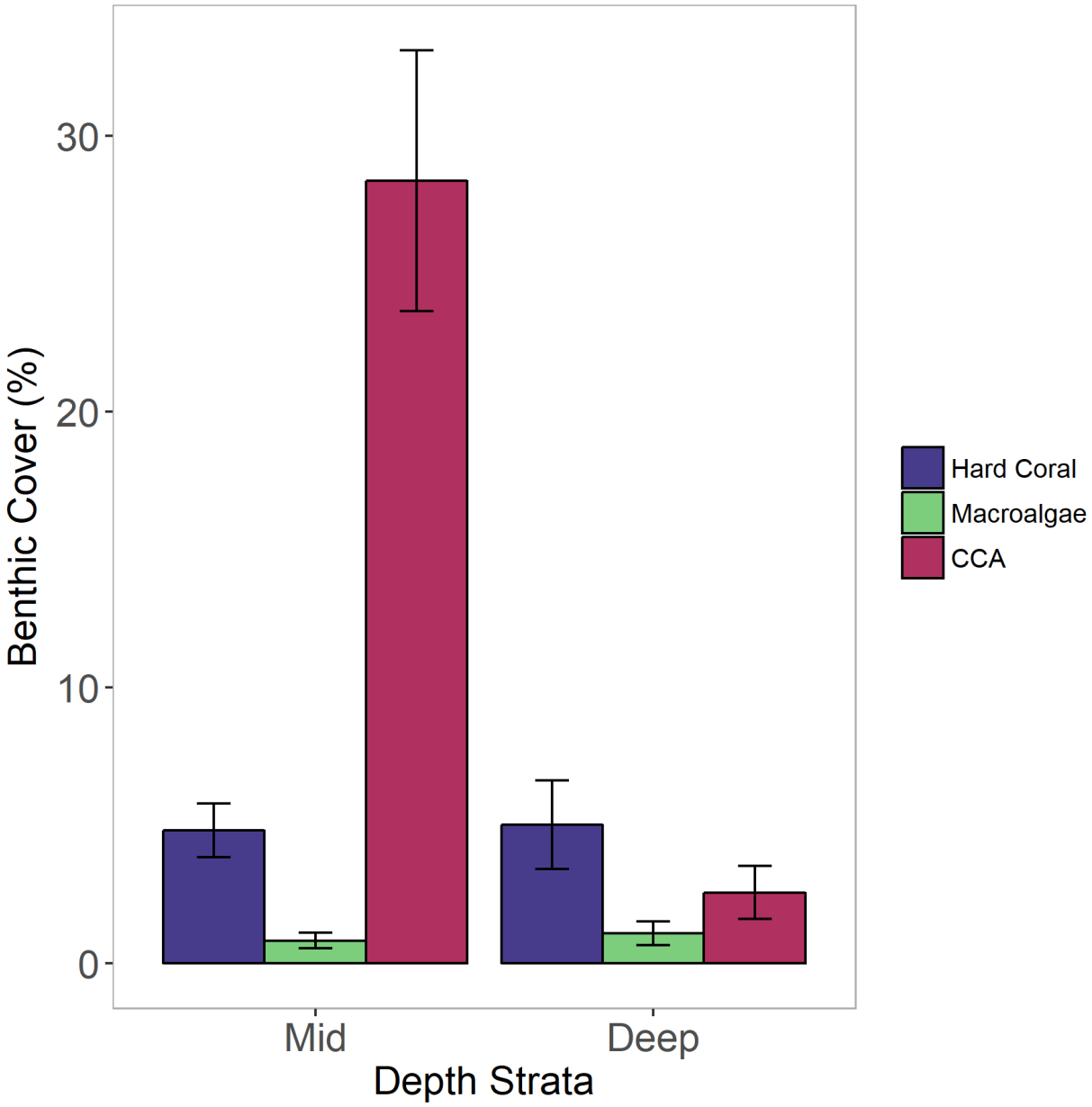


Figure 31. Strata level mean benthic cover (±1 SE) at Johnston Atoll by benthic functional groups of hard coral, fleshy macroalgae (excluding calcified and encrusting macroalgae), and crustose coralline algae (CCA) for shallow (>0–6 m), mid (>6–18 m), and deep (>18–30 m) depth strata from stratified-random photoquadrat surveys conducted in 2015. No shallow sites were surveyed at Johnston.

Time Series of Benthic Cover

Based on both towed-diver and REA surveys, mean hard coral cover remained low (<18%) throughout the survey period from 2004 to 2015 (Figure 32). Localized areas of higher coral cover (20–30%) were observed when spatial data are averaged across all survey years (Figure 33a). Estimates of decadal change in coral cover revealed areas of localized decline within the North georegion, though a similar analysis of the South georegion was not possible due to

limited data (Figure 33b). Consistent with survey results from other islands in the PRIMNM, TDS estimates of mean island-wide macroalgae cover (which include fleshy macroalgae and calcified and encrusting macroalgae) tended to be greater than estimates acquired using the LPI and photoquadrat methods (which exclude calcified and encrusting macroalgae). Macroalgae cover appeared to decline over time according to TDS estimates, peaking in 2004 (mean = 28.6% ± 5.4 SE) and steadily dropping through 2015 (mean = 2.7% ± 0.5 SE; Figure 32). Benthic communities at Johnston were dominated by CCA and turf algae over all survey years. Contrary to the estimates of macroalgae cover, CCA cover was frequently higher based on REA surveys than TDS. REA estimates of CCA cover peaked in 2010 (mean = 57.7% ± 5.6 SE). Turf algae cover (not shown) peaked in 2015 (mean = 45.9% ± 4.7 SE), and was lowest in 2010 (mean = 12.5% ± 5.9 SE).

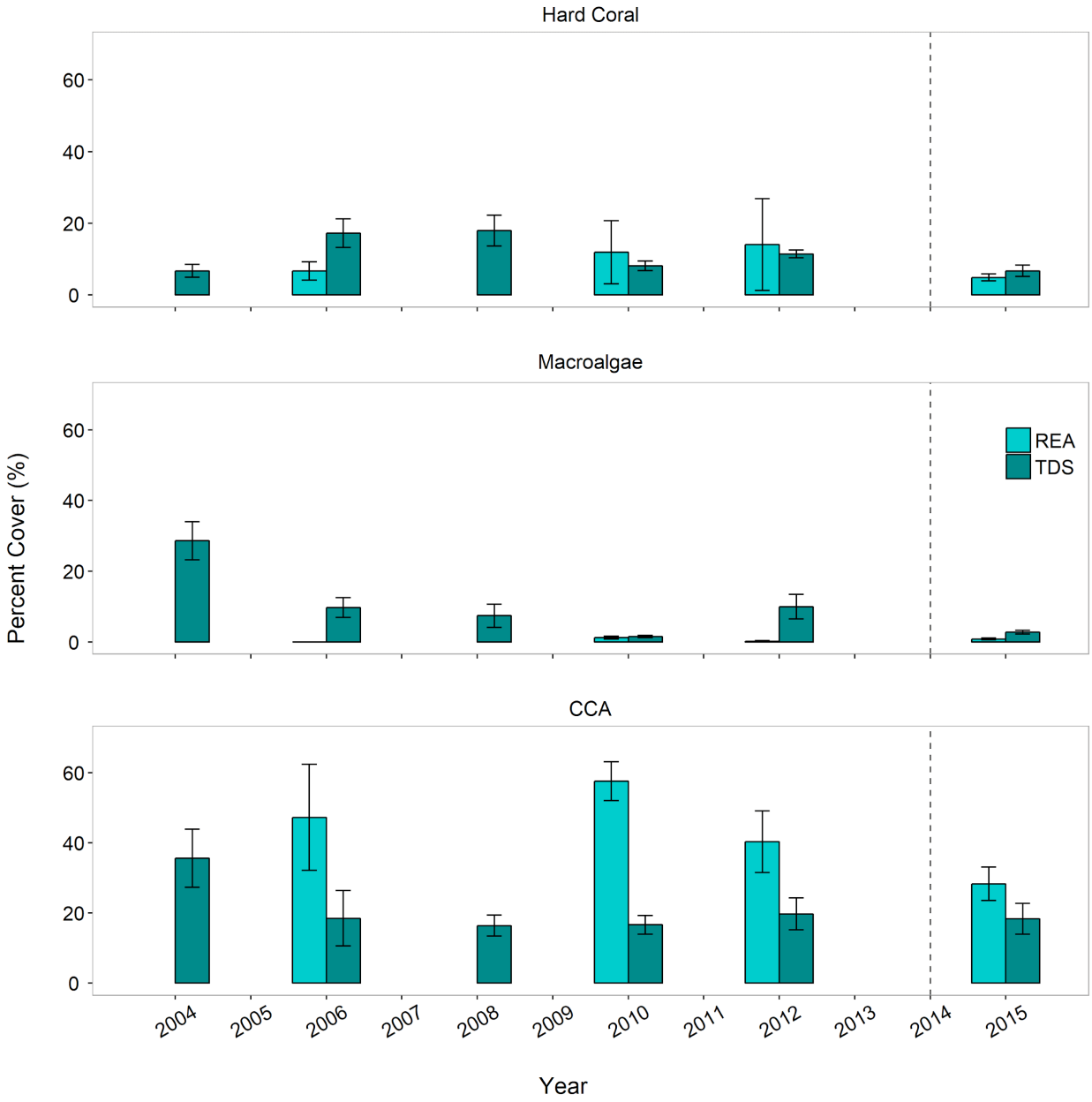


Figure 32. Time series of mean (± 1 SE) hard coral, macroalgae, and crustose coralline algae (CCA) cover (%) at Johnston Atoll by survey method (Rapid Ecological Assessment [REA] and towed diver survey [TDS]) conducted at the mid-depth stratum (>6–18 m) from 2004 to 2015. In 2014 (dashed line), REA survey methodology changed from line-point-intercept at repeat sites to photoquadrat surveys at stratified-random sampling. *Note: TDS macroalgae data include calcified and encrusting macroalgae; the REA macroalgae data exclude it.

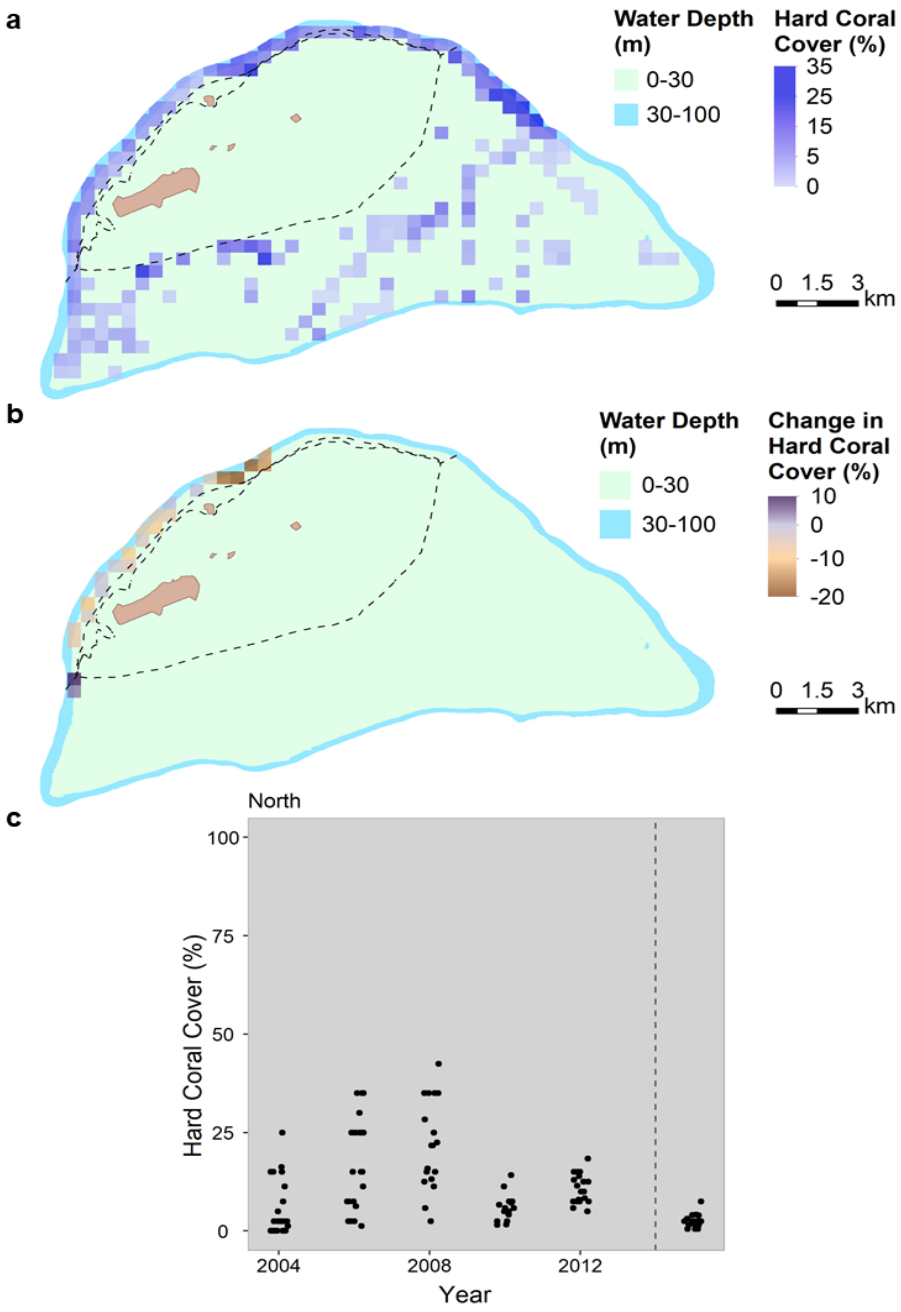


Figure 33. Spatial patterns and temporal trends of gridded (500 m × 500 m) mean coral cover at Johnston Atoll across survey years (2001–2015) and methods (towed-diver survey, line-point-intercept (LPI), and stratified-random sampling (StRS) benthic and fish photoquadrats). (a) Mean hard coral cover per 500 m by 500 m grid cell across all survey years; (b) 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; and (c) time series of hard coral cover in the North georegion only due to limited temporal data in the South georegion. In 2014 (dashed line), Rapid Ecological Assessment survey methodology changed from LPI at repeat sites to photoquadrat surveys at StRS sites.

Time Series of Algal Disease

No CCA disease was observed at Johnston Atoll during REA surveys.

Recent Coral Abundance

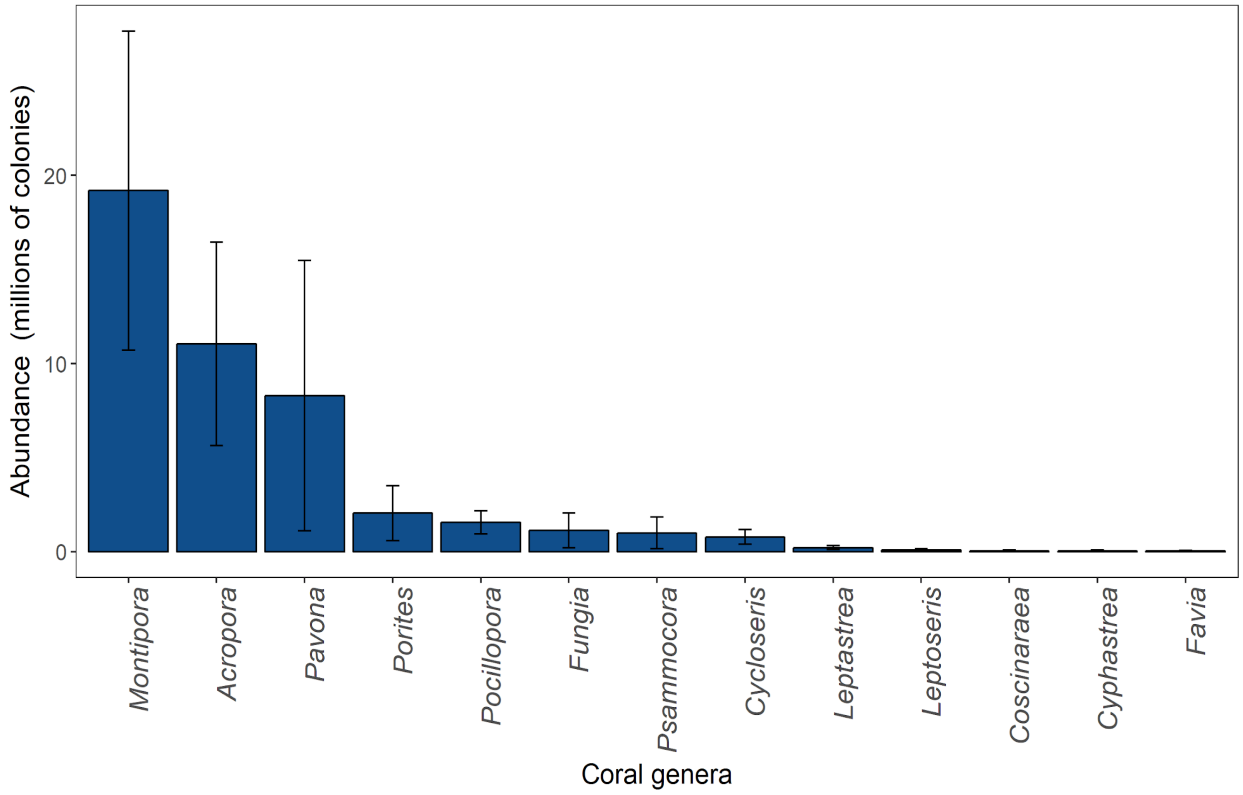


Figure 34. Island-scale abundance (±1 SE) estimates of coral genera for all depth strata combined (>0–30 m) at Johnston Atoll from Rapid Ecological Assessment surveys conducted in 2015.

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). In 2015, a total of 13 coral genera were enumerated at Johnston Atoll. Total abundance estimates indicated that *Montipora* was the dominant genus and *Favia* was the least abundant (Figure 34). Presence of *Acropora retusa*—a species listed under the Endangered Species Act (ESA)—was confirmed (Kenyon 2011).

Adult *Montipora* densities were high among both mid and deep strata (Figure 35). Interestingly, juvenile densities were similar to adult densities in both mid and deep strata for all of the most common genera in the PRIMNM except *Pavona* (Figure 35). The mid-depth coral community was largely composed of adult *Montipora, Acropora,* and *Pavona*, while the deep coral community was largely composed of *Montipora*, *Acropora,* and *Porites* (Figure 35). Despite the low percent cover of hard coral at Johnston Atoll in 2015 (Figure 31), colony density remained comparable to other coral communities across the PRIMNM in 2015. For example, Johnston's adult coral density at the mid-depth strata (mean = 7.0 colonies/m^2 ± 1.8 SE) was similar to that

at Howland Island (mean = 7.1 colonies/m^2 ± 1.2 SE) and higher than that at Baker Island (mean = 5.9 colonies/m^2 ± 1.3 SE). Johnston's adult density for the deep strata was higher than densities at Baker, Howland, and Jarvis Island in 2015. Juvenile coral density at Johnston's mid-depth stratum (mean = 5.8 colonies/m^2 ± 1.5 SE) was higher than estimates from all other islands in the PRIMNM surveyed in 2015 except for Kingman Reef, and in the deep stratum, juvenile density was highest overall (mean = 11.0 colonies/m^2 ± 4.2 SE). Low coral cover coupled with higher coral density indicates a greater occurrence of smaller sized colonies at Johnston, as corroborated by the size structure data (Figure 37). These smaller colonies may reflect coral morphology responding to light limitations at mid and deep depths (shallow strata were not surveyable at Johnston during the 2015 surveys, in contrast to the other PRIMNM islands) and/or a shift in community composition at Johnston where small-bodied colonies comprised a greater proportion of the coral community (i.e., the absence of large table *Acropora* colonies and a greater proportion of small-sized branching *Acropora, Pocillopora,* and *Pavona* species). 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."

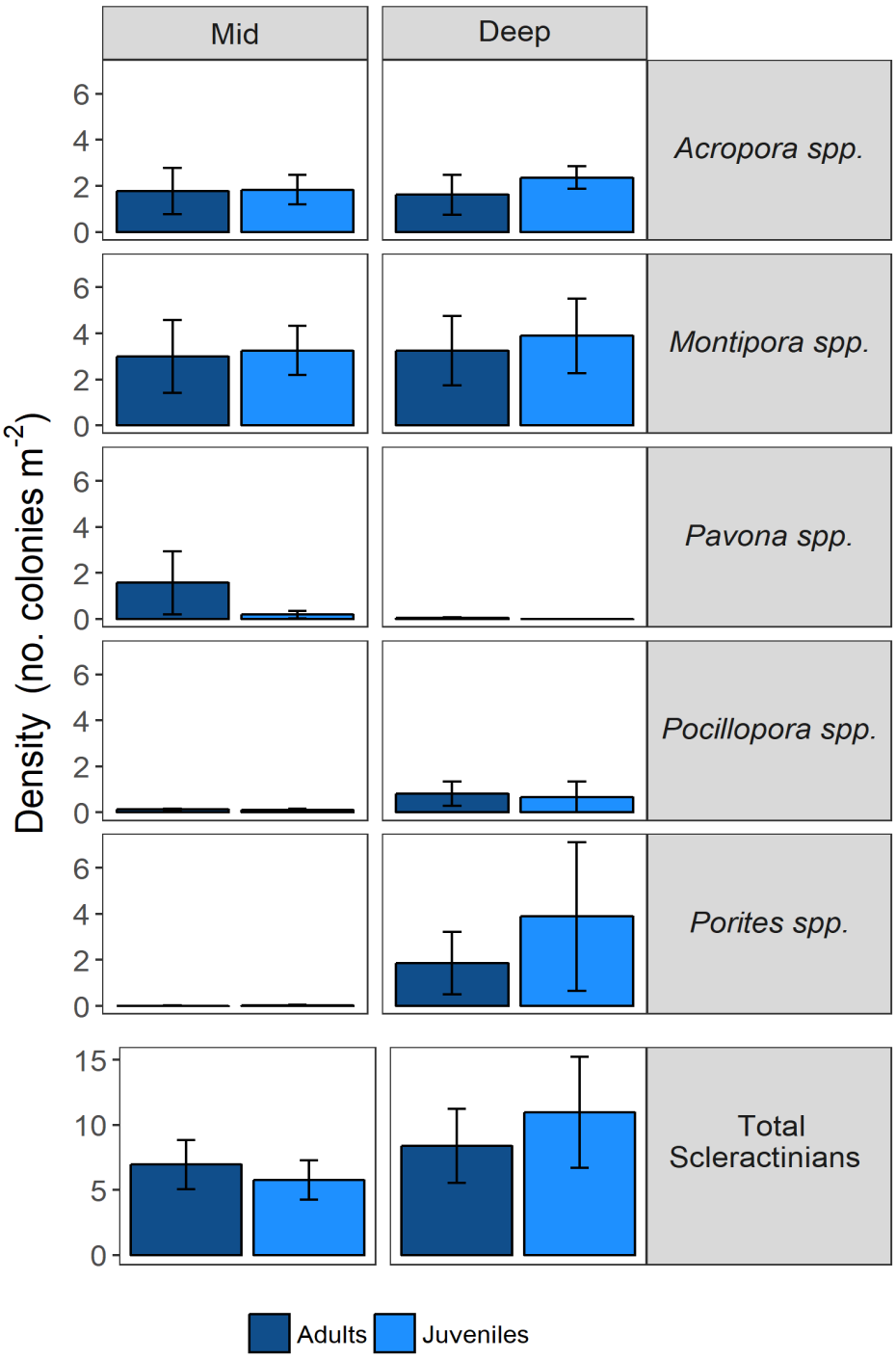


Figure 35. Mean (± 1 SE) adult and juvenile colony density from Rapid Ecological Assessment surveys conducted at Johnston Atoll in 2015 at mid- (>6–18 m) and deep- (>18–30 m) depth strata for five coral generally abundant in the Pacific Remote Islands Marine National Monument (*Acropora* spp., *Montipora* spp., *Pavona* spp., *Pocillopora* spp., and *Porites* spp.) to facilitate comparison among islands.

Time Series of Coral Abundance and Condition

Over time, adult colony density at Johnston Atoll appeared to slightly decrease; however, differences among survey years are not likely statistically significant given the large error associated with each estimate (Figure 36). In all three survey years, the density of colonies decreased as their size increased (Figure 37). Maximum colony sizes observed at Johnston were smaller than at other islands in the PRIMNM, with no colonies larger than 160 cm in diameter and only one colony observed in the 81–160 cm size class bin.

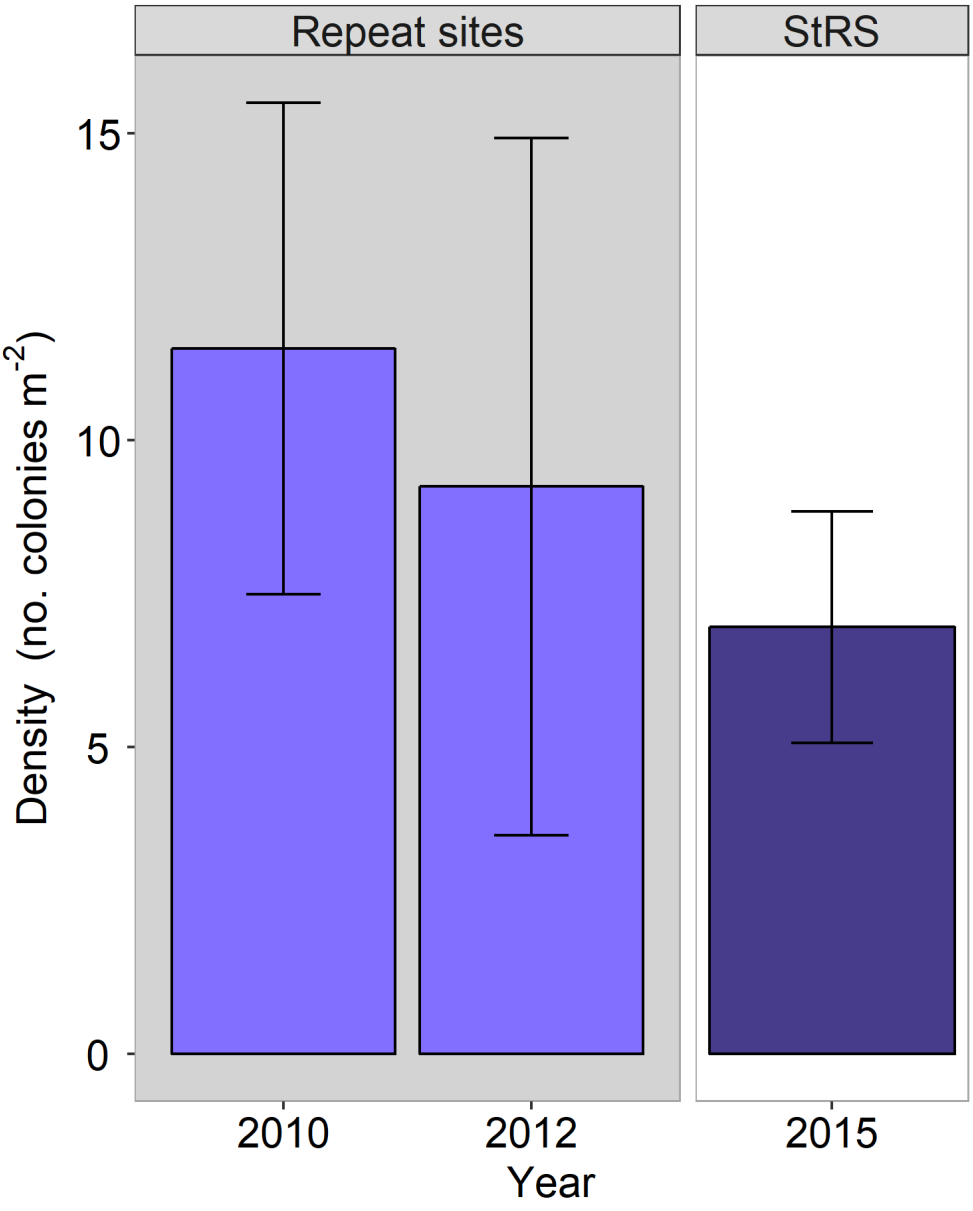


Figure 36. Time series of mean adult colony density (±1 SE) at Johnston Atoll, from mid-depth (>6–18 m) strata Rapid Ecological Assessment surveys by survey design, repeat sites or stratified-random sampling (StRS), conducted from 2010 through 2015.

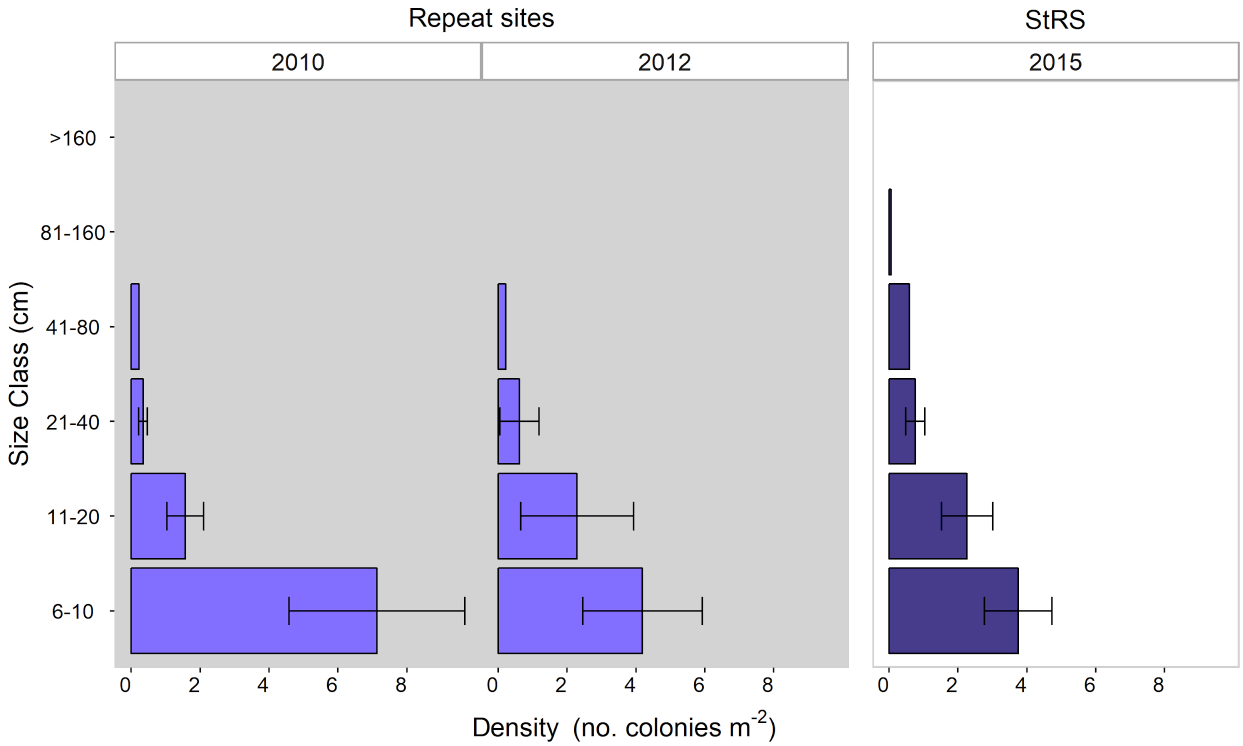


Figure 37. Time series of mean adult colony density (±1 SE) at Johnston Atoll by size class from mid-depth (>6–18 m) strata Rapid Ecological Assessment surveys by survey design, repeat sites or stratified-random sampling (StRS), conducted from 2010 to 2015.

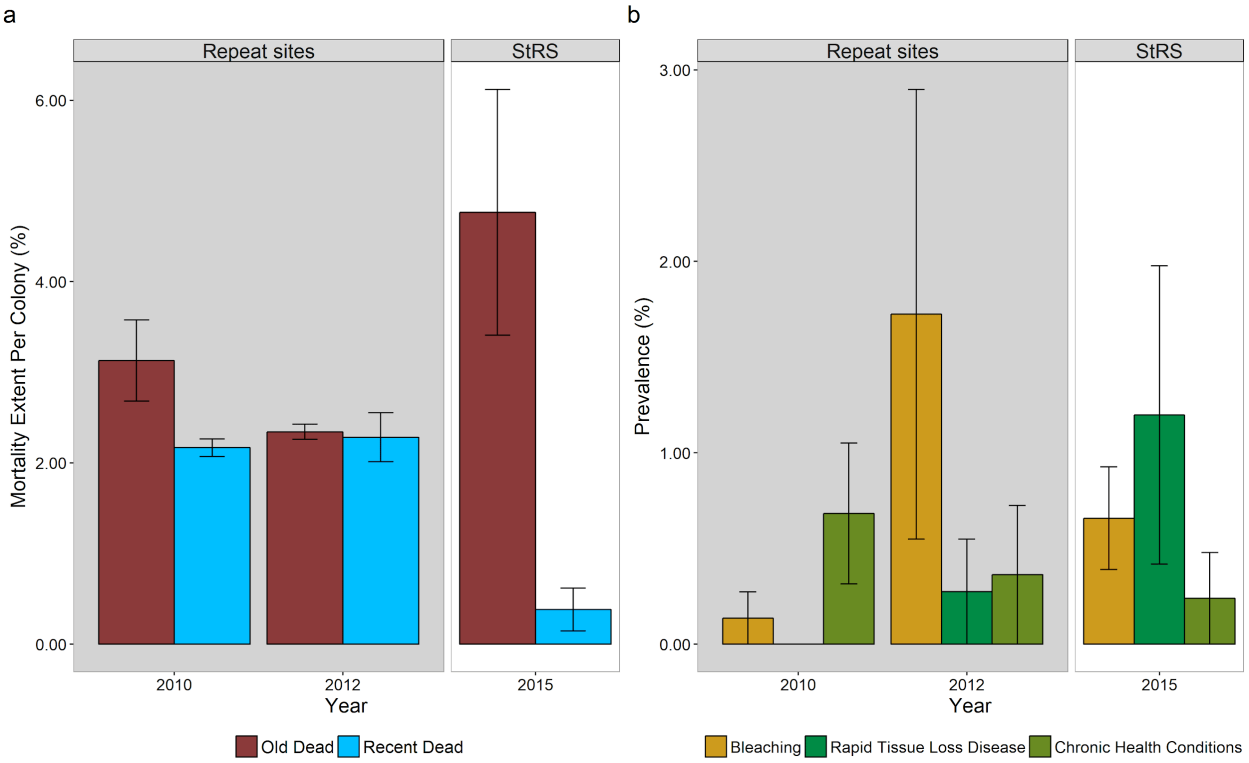


Figure 38. Time series of mean (±1 SE) (a) percent partial coral mortality and (b) prevalence of bleaching, rapid tissue loss diseases, and chronic health conditions at Johnston Atoll based on mid-depth (>6–18 m) strata Rapid Ecological Assessment surveys by survey design, repeat sites or stratified-random sampling (StRS), conducted from 2010 to 2015.

Partial mortality was notably low (~5% or less) overall across the three survey years; likely reflecting the low prevalence of mass coral bleaching or disease observed (Figure 38). Recent mortality showed little change from 2010 to 2012, and dropped to a mean of 0.4 % (±0.2 SE) in 2015. The rise in mean old mortality observed in 2015 may have been caused by mild bleaching observed in 2012, when prevalence was highest (mean = 1.7% ± 1.2 SE). However, given that bleaching remained at background levels (1–2%), other drivers may be implicated in the rise of old mortality. The prevalence of chronic health conditions was low during all survey years, remaining below 1%. Prevalence of rapid tissue loss diseases was also low; absent in 2010, and increasing from 2012 to 2015 (mean = 1.2% ± 0.8 SE).

Benthic Macroinvertebrates

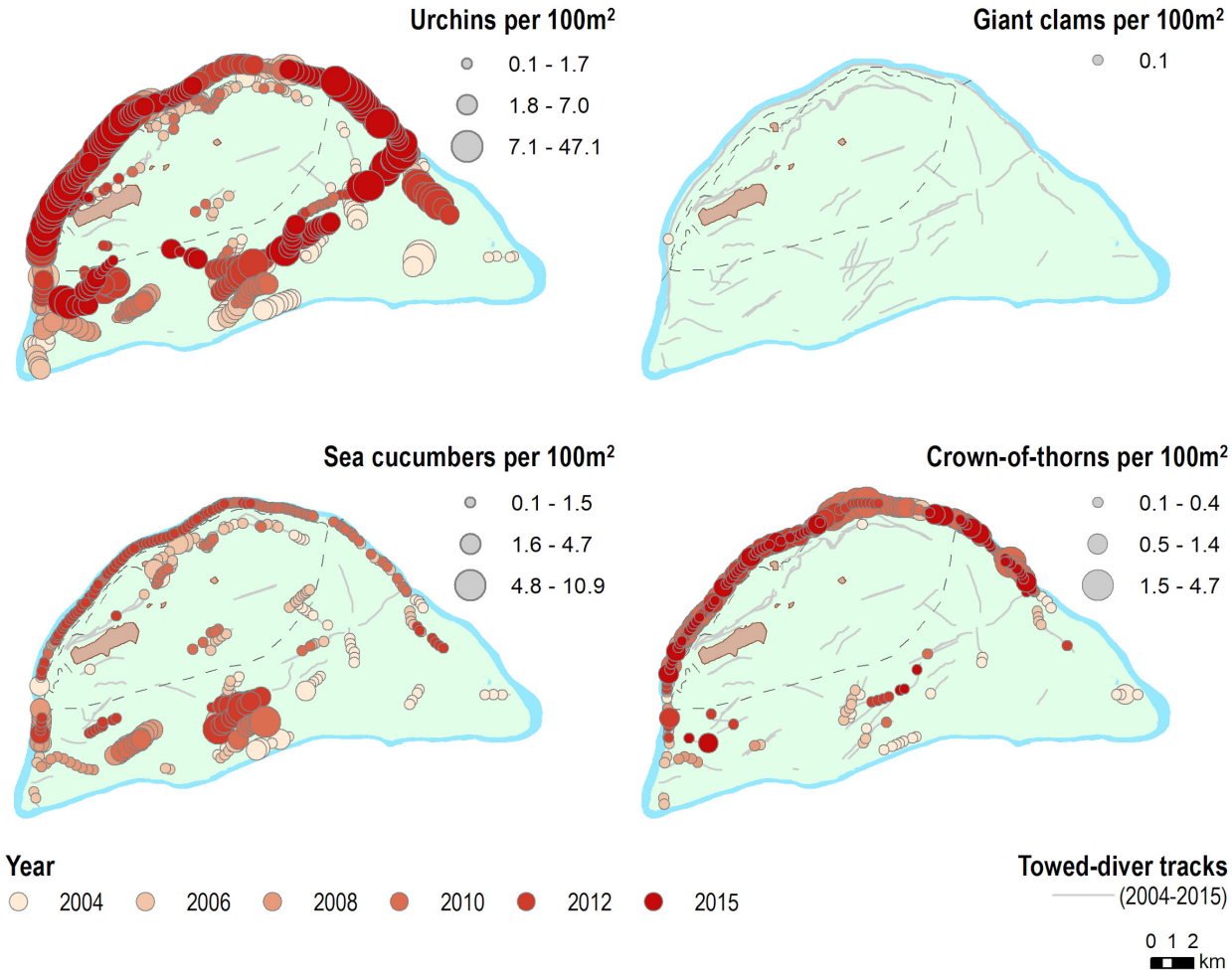


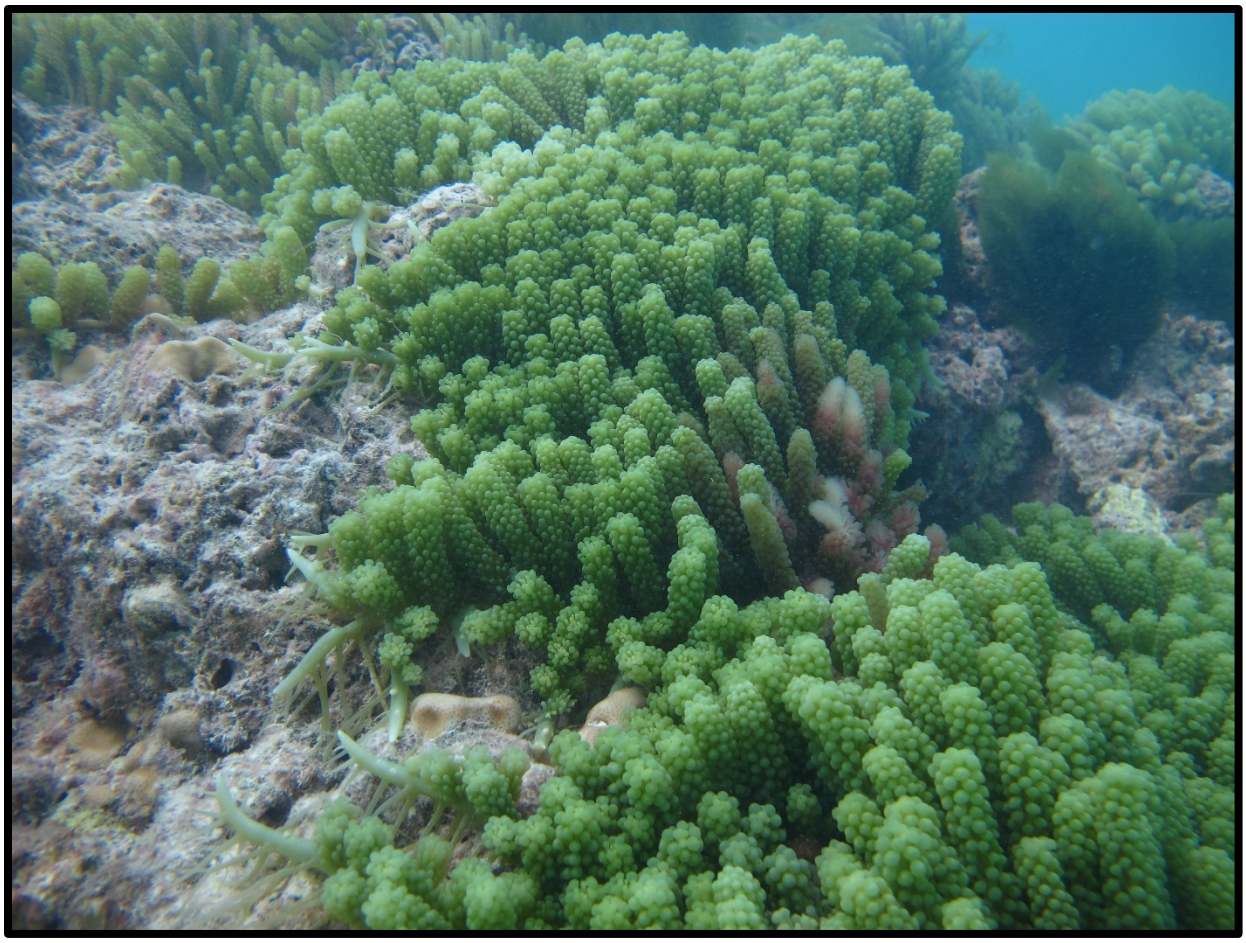
Figure 39. Density of conspicuous ecologically- or economically-important macroinvertebrates (urchins, giant clams, sea cucumbers, and crown-of-thorns sea stars) observed per segment from benthic towed-diver surveys (TDS) conducted throughout all depth strata (>0–30 m) around Johnston Atoll from 2004 to 2015. Sea cucumber observations were discontinued from TDS in 2014.

Urchin densities were temporally and spatially stable around Johnston Atoll (Figure 39). Urchins were observed in all survey years and in every tow segment around all sides of the atoll, averaging 4.3 individuals per 100 m^2. The highest density of urchins observed was 47.1 individuals per 100 m^2 in 2015.

Ten species of Tridacninae giant clams were petitioned for listing as endangered or threatened under the ESA and are currently under review by NOAA Fisheries (National Oceanic and Atmospheric Administration 2017). Sightings of giant clams at Johnston have been exceptionally rare, with only one individual sighting (in the western forereef in 2004) occurring during the course of 1078 TDS segments covering approximately 2×10^6 m^2 of habitat over the period 2004–2015 (Figure 39).

Sea cucumbers were observed in all survey years (2004–2012) until surveys were discontinued in 2014 (Figure 39). The highest density of sea cucumbers observed was 10.9 individuals per 100 m^2 (in 2010 and 2012), though the majority of density estimates were less-than or equal to 1 individuals per 100 m^2. Though sea cucumbers were broadly distributed spatially around Johnston, densities were greatest in the South georegion.

Unlike the spatial distribution of sea cucumbers, crown-of-thorns sea stars (COTS) had the highest densities along the forereefs of the North georegion (Figure 39). Though COTS were observed during all survey years, the maximum COTS density reached 4.7 individuals per 100 m^2 within several segments during the 2010 surveys. However, across all survey years, 96% of the TDS segments had COTS densities ≤1 individuals per 100 m^2—below reported outbreak values (Pratchett and Caballes 2014).



Benthic habitat at Johnston Atoll.
Photo: B. Ruttenberg, NOAA Fisheries.

Microbiota

6.5 Microbiota



Coral reef and reef fish at Johnston Atoll.
Photo: NOAA Fisheries.

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). Beginning in 2010, the assessment and monitoring of the reef microbiota at Johnston Atoll were incorporated with data collected on benthic and pelagic macrobiota, allowing for characterization of coral reef ecosystems from a molecular to an ecosystem scale across the entire U.S. Pacific.

Microbial Composition and Diversity

No microbial community composition or diversity information are available for Johnston Atoll.

Microbial Biomass on Reefs

Habitats dominated by reef building organisms (i.e., stony corals and calcified algae), such as Pacific Remote Islands and Atolls (e.g., Wake and Palmyra), illustrate a functional role that

suppresses 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. Microbial biomass at Johnston Atoll is higher than at other remote atolls (e.g., Rose and Palmyra) and at remote equatorial islands (Jarvis, Howland, and Baker; Figure 40). Non-calcifying benthic organisms, like fleshy macro and turf algae (observed in higher abundances on human-impacted reef systems), release high amounts of bioavailable dissolved organic carbon and select for larger, fast growing microbial communities that utilize these higher energetic organic resources to sustain their greater metabolic demands. Reef degradation towards algae-dominated states promotes greater cell biomasses 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., Johnston 2010 = 72 mg m^{-3} and Oahu 2008 = 153 mg m^{-3}). 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.

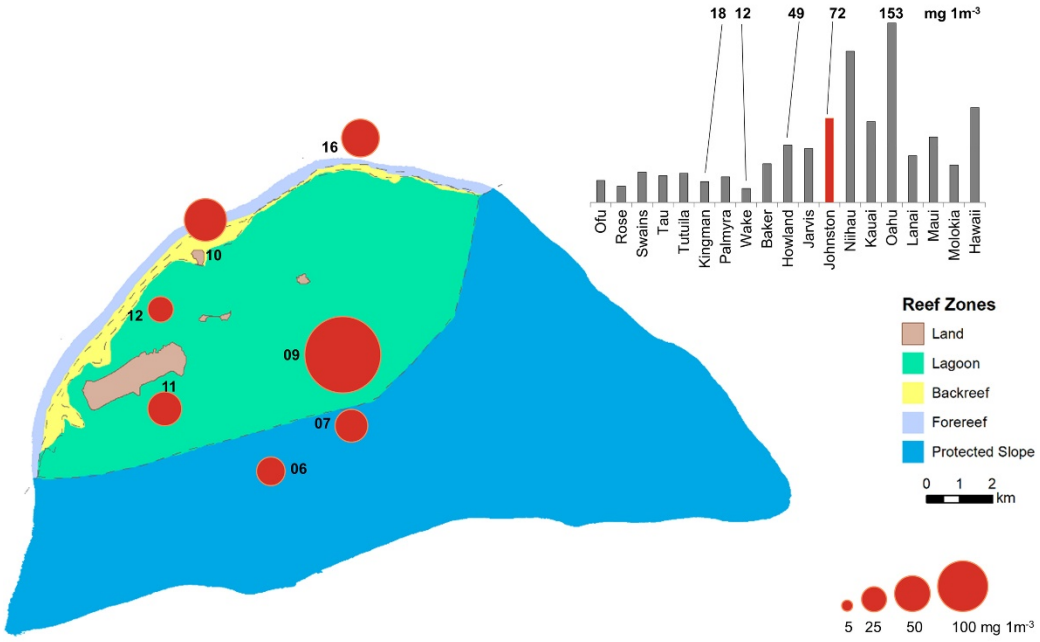
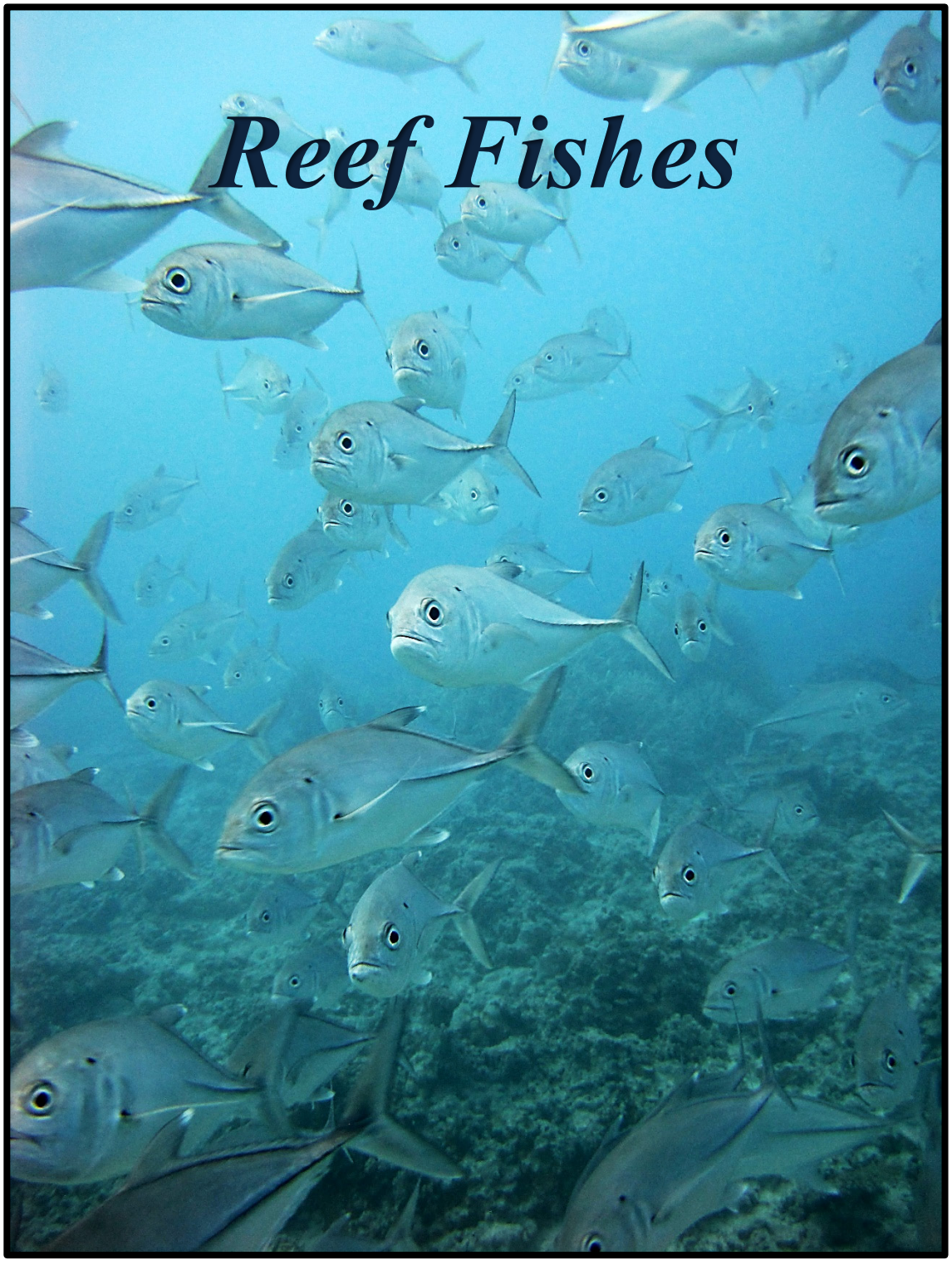


Figure 40. Microbial biomass collected at Johnston Atoll in 2010 and (n = 7). Cell volume is estimated based on measurements of cell length and width and cell abundances enumerated using epi-fluorescent microscopy. Biomass is reported as milligrams per cubic meter (mg m^{-3}). The data were published in McDole et al. (2012).



*A school of bigeye jacks (*Caranx sexfasciatus*).*
Photo: NOAA Fisheries.

6.6 Reef Fishes



A spotted eagle ray swims above the reef at Johnston Atoll.
Photo: NOAA Fisheries.

Survey Effort and Site Information

Reef fishes at Johnston Atoll were surveyed on 6 occasions during the period from 2004 through 2015 (Table 4). In each case, 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).

TDS were conducted primarily around the outer reef areas, especially in the North georegion which has distinct forereef habitat where large fishes tend to be most abundant (Figure 44). BLTs, which were utilized between 2004 and 2008, were mostly conducted at haphazardly located mid-depth (~10–15 m) sites, particularly within the Lagoon georegion (Figure 41). In 2008, Pacific RAMP began the transition from BLT surveys to the current SPC approach, and at the same time moved to a stratified-random survey design that encompasses hard-bottom habitats shallower than 30 m (Figure 8). Since that time, there has also been a concerted effort to increase the number of survey sites per visit. A minimum of 31 sites have been surveyed during every

visit since 2010, compared to 18 or fewer prior to 2010 (Table 4). One consequence of the shift in survey design is that SPC sites have been much more widely distributed spatially around the island than were the earlier BLT surveys, including encompassing reef habitats that had not been surveyed previously (Figure 41). BLT data gathered at the time of moving to the stratified-random design in 2008 cannot be meaningfully compared with earlier BLT data gathered at fixed locations. Unfortunately, for operational reasons, it was not possible to conduct sufficient SPC surveys in 2010 for data to be comparable with later years. Thus, time series are primarily built from TDS from 2004 to 2015 and from SPC surveys conducted from 2010 to 2015.

Table 4. Reef fish survey effort. 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 in which divers counted only fishes >50 cm total length (TL). In contrast, belt-transect (BLT) and stationary point count (SPC) survey divers attempted to count all fishes within small areas of reef (~400 m^2).

	All Fishes		Large Fish (>50 cm TL)
Year	BLT	SPC	TDS
2004	12	–	16
2006	18	–	16
2008	12	12	9
2010	–	39	14
2012	–	35	13
2015	–	31	14

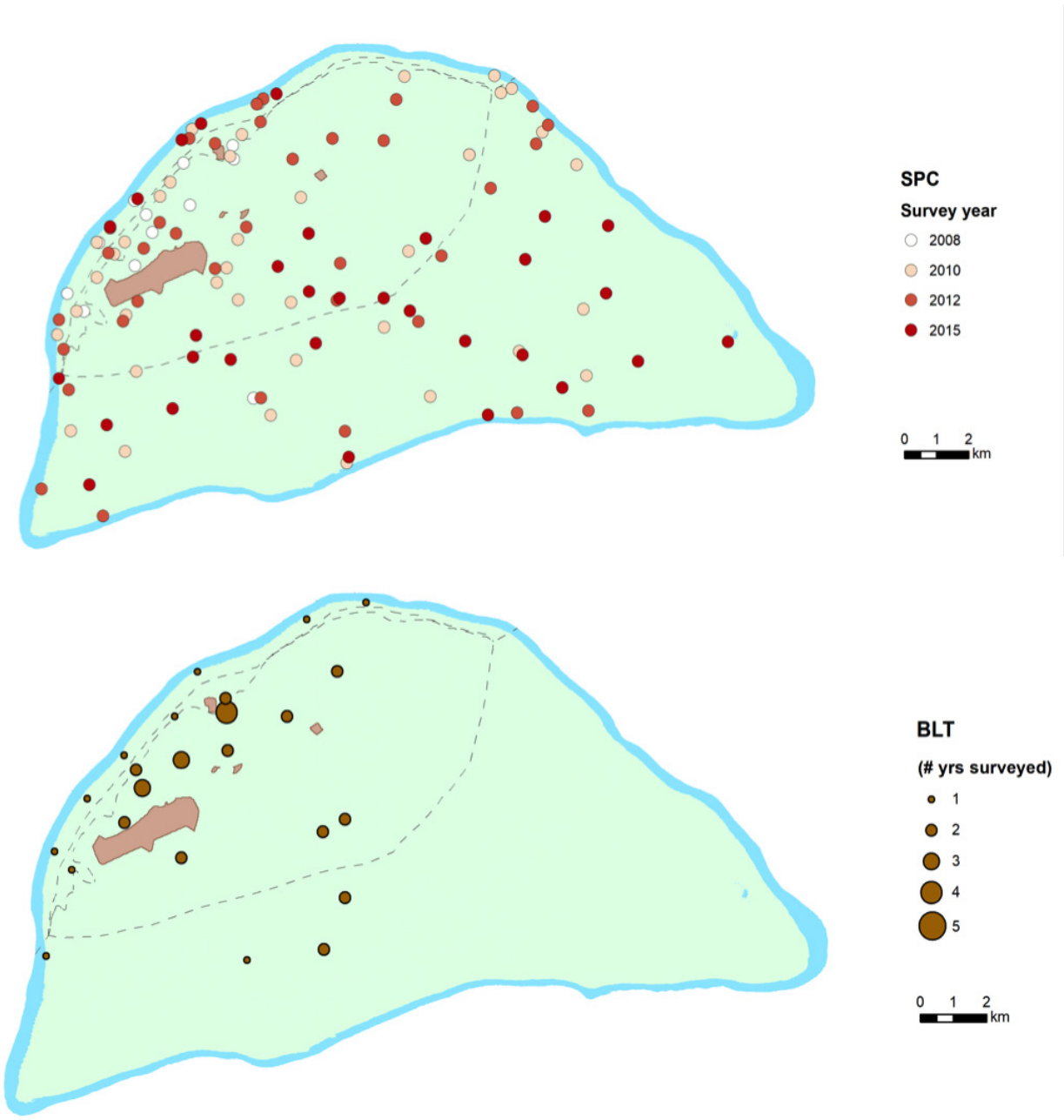


Figure 41. Location of stationary point count (SPC, top) and belt-transect (BLT, bottom) sites at Johnston Atoll. SPC sites were not revisited, and for those the survey year is distinguished by color. BLT survey sites were generally revisited during multiple survey years, and for those the total number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

Distribution of Reef Fish Biomass and Abundance

Reef fish biomass was generally highest on outer forereef habitats in the North and South georegions (Figure 42). That pattern was largely driven by higher biomass of planktivores and piscivores in those areas (Figure 42).

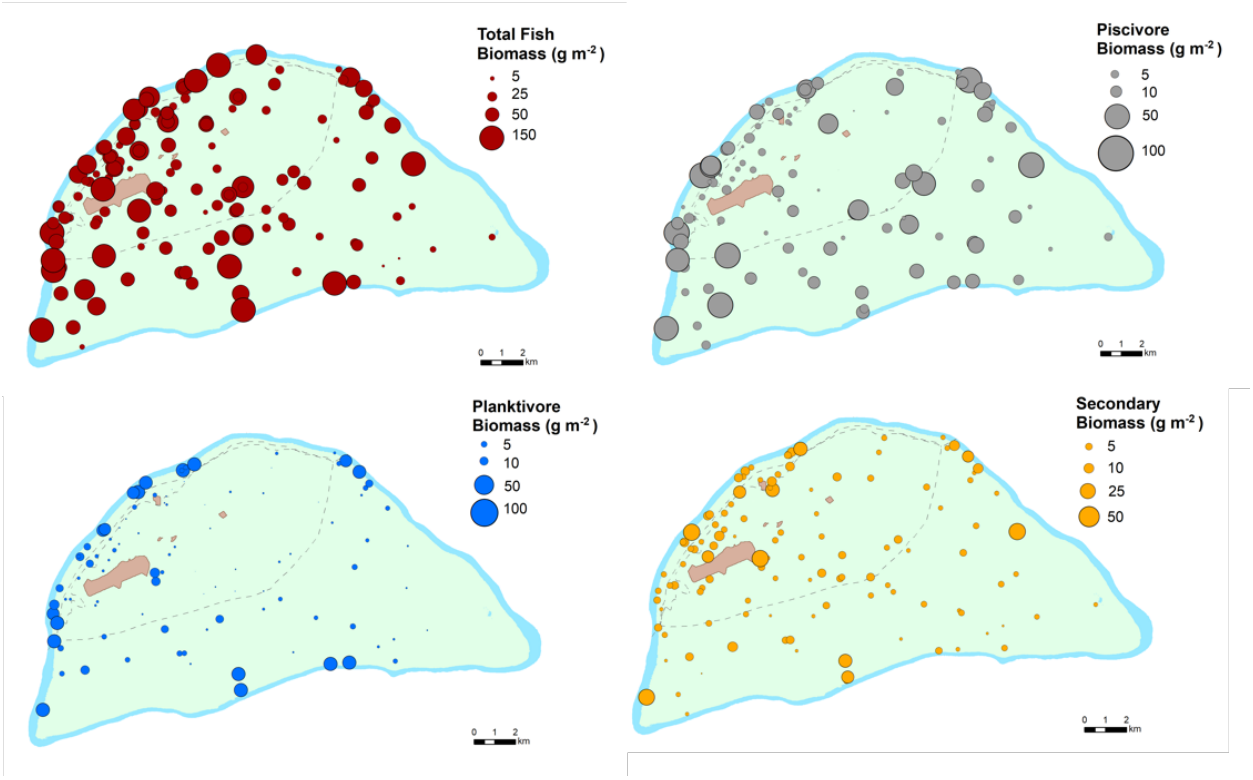


Figure 42. Biomass maps of Total Fish, Planktivore, Piscivore, and Secondary Consumer Groups from stationary point count surveys around Johnston Atoll over the period 2008 through 2015. Secondary consumers include corallivores, omnivores, and invertivores; all groups contain many abundant and generally small-bodied species.

Planktivore biomass was very low in Backreef and Lagoon georegions (Figure 42), with higher biomass in other georegions due to relatively large numbers of soldierfish (*Myripristis* spp.) in the North georegion and sleek unicornfish (*Naso hexacanthus*) in the South georegion.

Total herbivore biomass tended to be relatively low at sites in the Backreef georegion (Figure 43). Parrotfish biomass was dominated by three species: the daisy parrotfish (*Chlorurus sordidus*), spectacled parrotfish (*C. perspicillatus*), and ember parrotfish (*S. rubroviolaceus*), with daisy parrotfishes commonly observed in all georegions. The other two species were less abundant in the Backreef georegion.

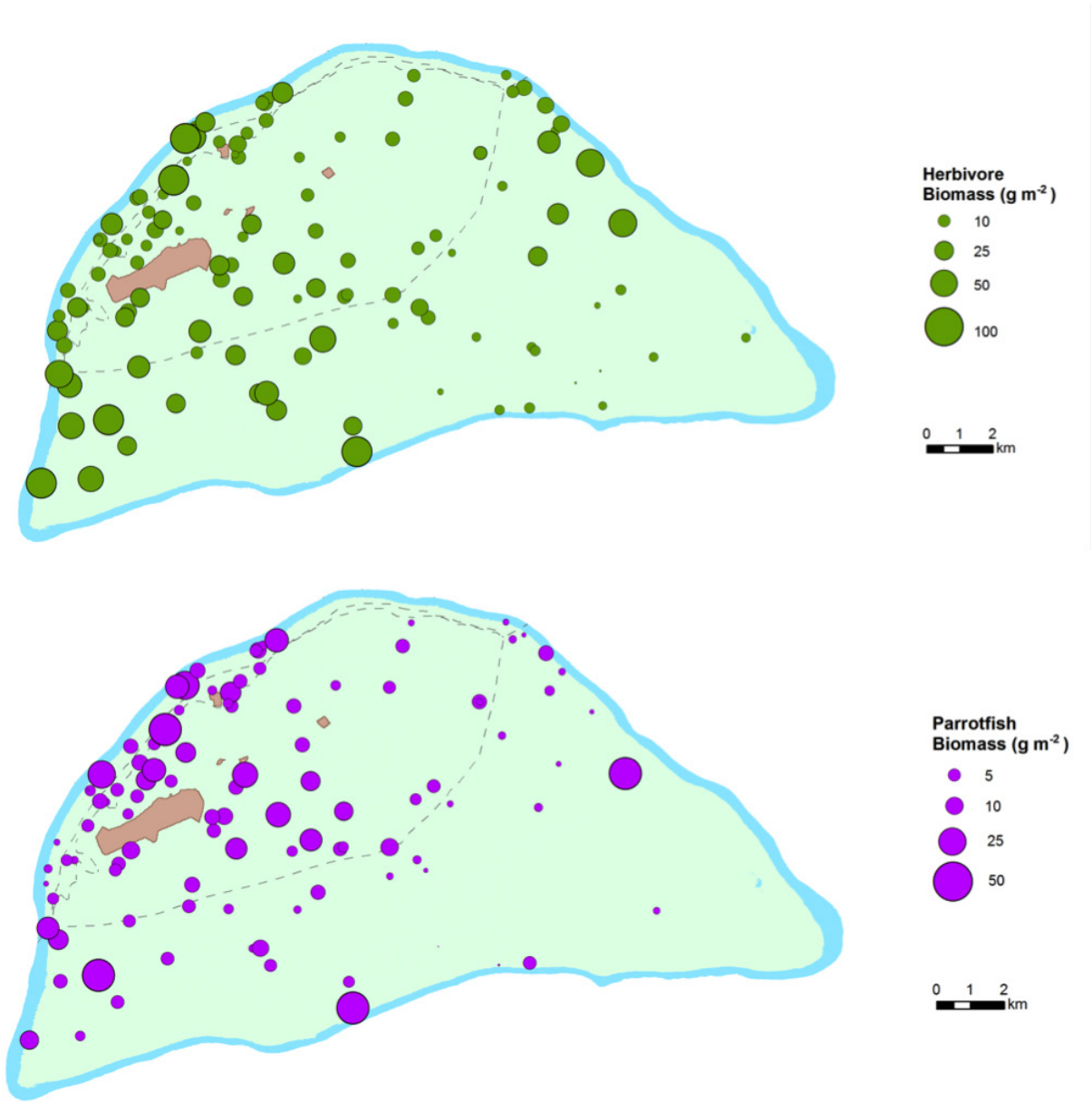


Figure 43. Total Herbivore and Parrotfish biomass at Johnston Atoll from stationary point count surveys over the period from 2008 through 2015.

Gray reef sharks (*Carcharhinus amblyrhynchos*) were the most commonly observed shark species at Johnston Atoll. Encounters were much more frequent on outer reefs in the North georegion, where they were observed on 16% of all towed-diver segments (~220 m long sub-units of the survey, Figure 44). Sharks were only rarely encountered during TDS in Backreef and Lagoon georegions (~1% of all towed-diver segments in those georegions).

Other predatory species contributing to Johnston Atoll piscivore biomass included the bluefin trevally (*Caranx melampygus*), the black jack (*Caranx lugubris*), and the green jobfish (*Aprion virescens*).



Figure 44. Sightings of sharks at Johnston Atoll during towed-diver surveys over the period from 2001 through 2015.

Distribution of Other Species of Interest

Manta rays (*Mobula* spp.) were observed on only two occasions during TDS at Johnston Atoll (Figure 45). Though giant manta rays (*Mobula birostris*) are listed as threatened under the ESA, it is important to recognize that towed divers cannot readily and reliably distinguish between the giant manta and the reef manta, *Mobula alfredi*, which is not listed under the ESA. Green sea turtles (*Chelonia mydas*), which are listed as threatened under the ESA, have been recorded at Johnson on five occasions, all in relatively shallow water (<8 m deep) close to Johnston Island (Figure 45). No hawksbill sea turtles (*Eretmochelys imbricata*) have been recorded by survey divers at Johnston.

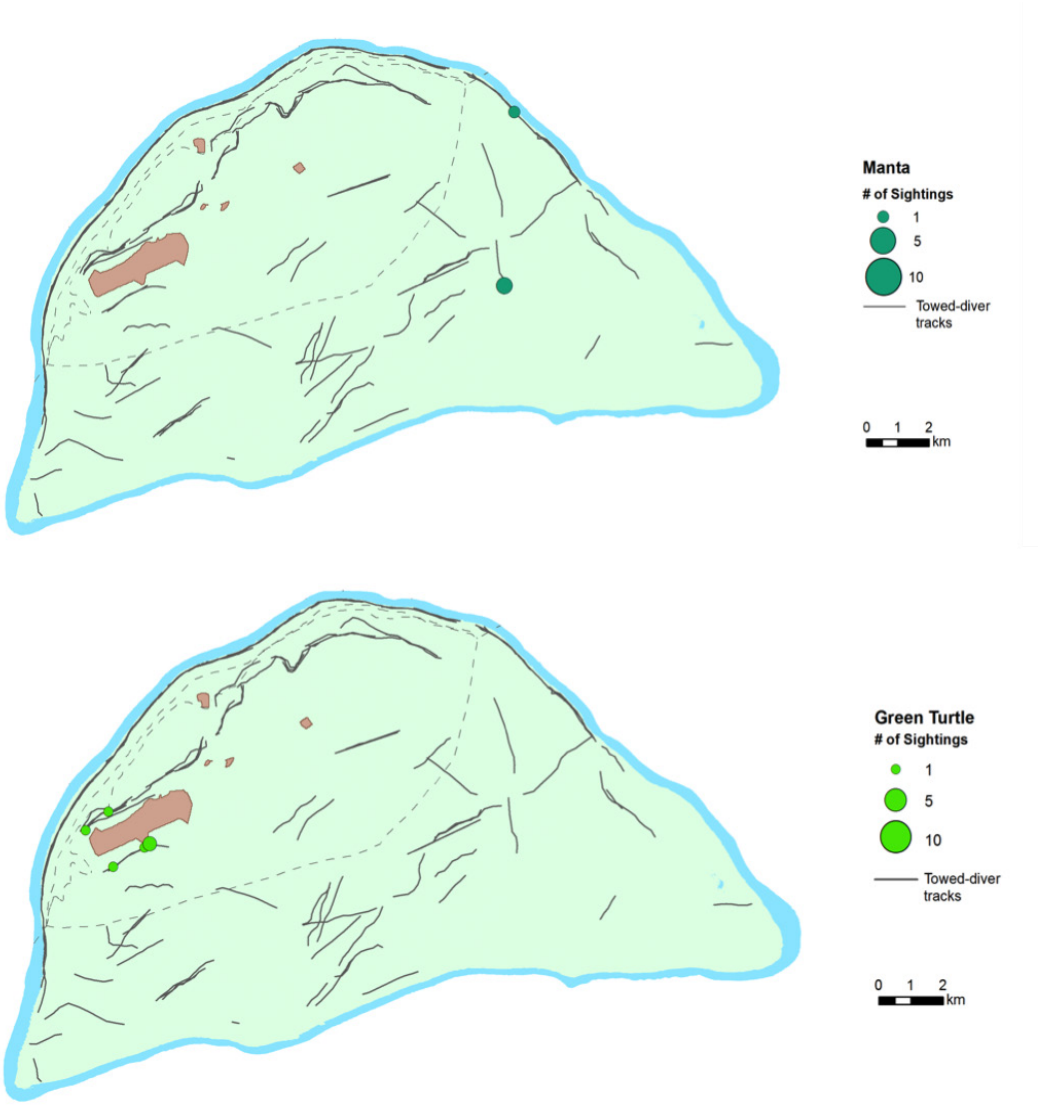


Figure 45. Sightings of manta rays and green sea turtles during towed-diver surveys at Johnston Atoll over the period from 2001 through 2015.

Reef Fish Time Series

Observed biomass of reef fishes over time, incorporating data from both BLT and SPC surveys are shown Figure 46. As is evident from the size of the confidence intervals in early years (2004 and 2006), there were generally an insufficient number of surveys and associated data from those earlier survey periods to identify clear temporal patterns, and there are no clear indications of changes during that earlier time period (Figure 46). Based on the SPC data that were collected between 2010 and 2015, there was some variability in reef fish biomass among years, including low piscivore biomass in 2015 and low planktivore biomass in 2010. There were significant trends between 2010 and 2015, though there appears to have been a general pattern of increasing total reef fish biomass, apparently driven by slight increases in parrotfishes and other herbivores (Figure 46).

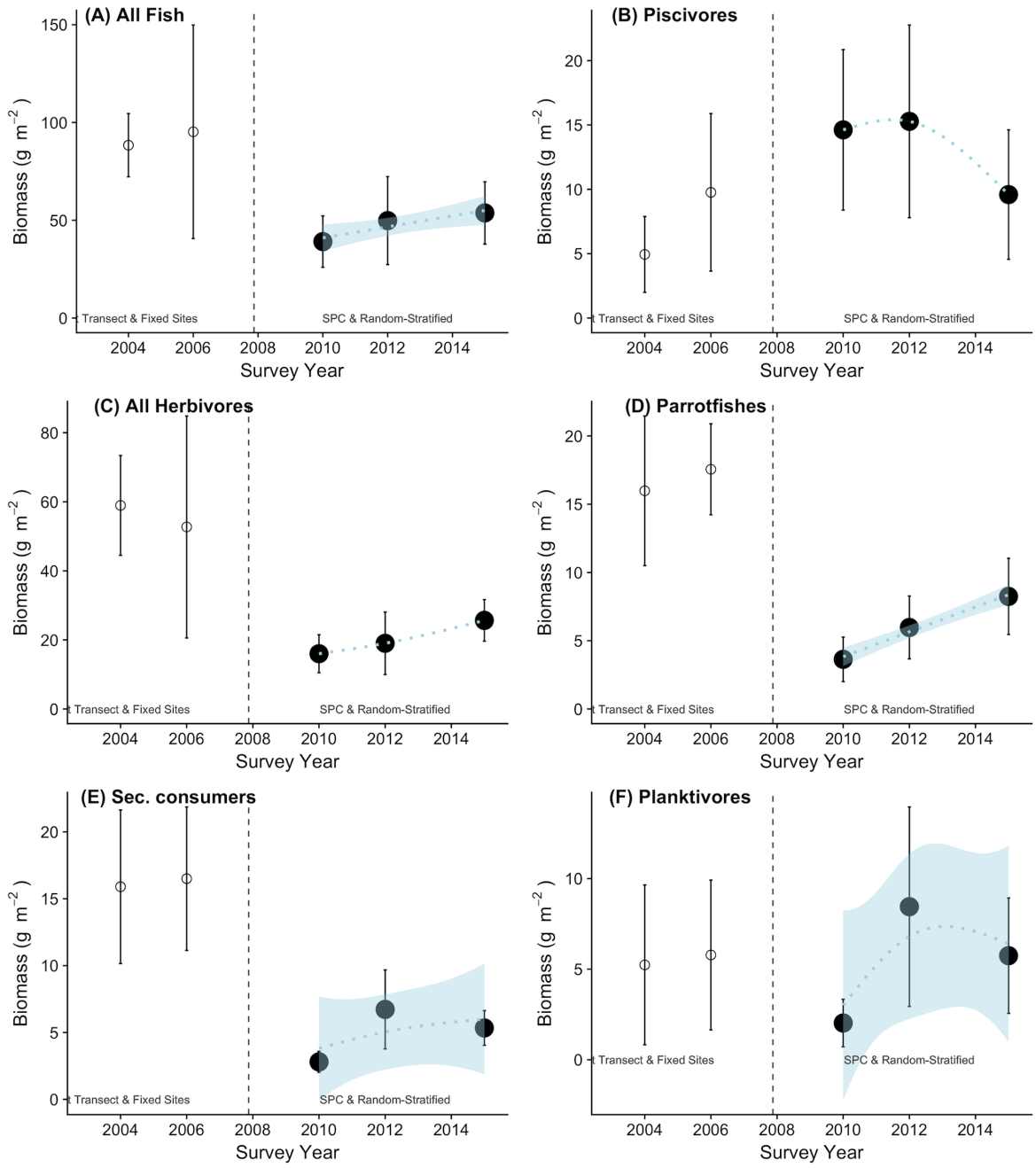


Figure 46. Time series of reef fish biomass at Johnston Atoll. Data are shown for belt-transect surveys conducted at a limited number of mid-depth forereef sites in 2004 and 2006, and stationary point count (SPC) surveys conducted at randomly located sites encompassing all hard-bottom forereef in ≤30 m, during the period from 2008 through 2015. Circles indicate mean values, and vertical error bars represent 95% confidence intervals per time period. The light blue dotted trend line and confidence intervals that have been added for visualization purposes are 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.

Only two groups of large bodied fishes were recorded frequently enough during TDS to show temporal trends: reef sharks and jacks (Figure 47). Although low in 2015, counts of jacks for that

year were well within normal variability for that group (Figure 47). There were, however, clear declines in TDS counts of reef sharks at Johnston Atoll from around 2010 onwards (Figure 47). Specifically, divers conducting TDS recorded between around 40 and 65 reef sharks every year between 2004 and 2008, but only 25 in 2010, 4 in 2012, and 0 in 2015. These findings are in general agreement with SPC surveys, which showed an apparent, though not significant, decline of piscivore biomass in 2015 (Figure 46). However, reef sharks were still observed by SPC survey divers and were recorded as present in the vicinity during 5 of the 31 SPC surveys conducted in 2015. Clearly, reef sharks remain present at Johnston, even relatively abundant when compared to inhabited areas, such as the main Hawaiian Islands, surveyed as part of the Pacific RAMP. It is an inherent limitation of the Pacific RAMP that surveys are restricted to a few days in every 2- or 3-year cycle and thus short-term variability in oceanographic conditions have the potential to influence counts of highly mobile species, such as reef sharks that are able to use a wide range of habitats and depths.

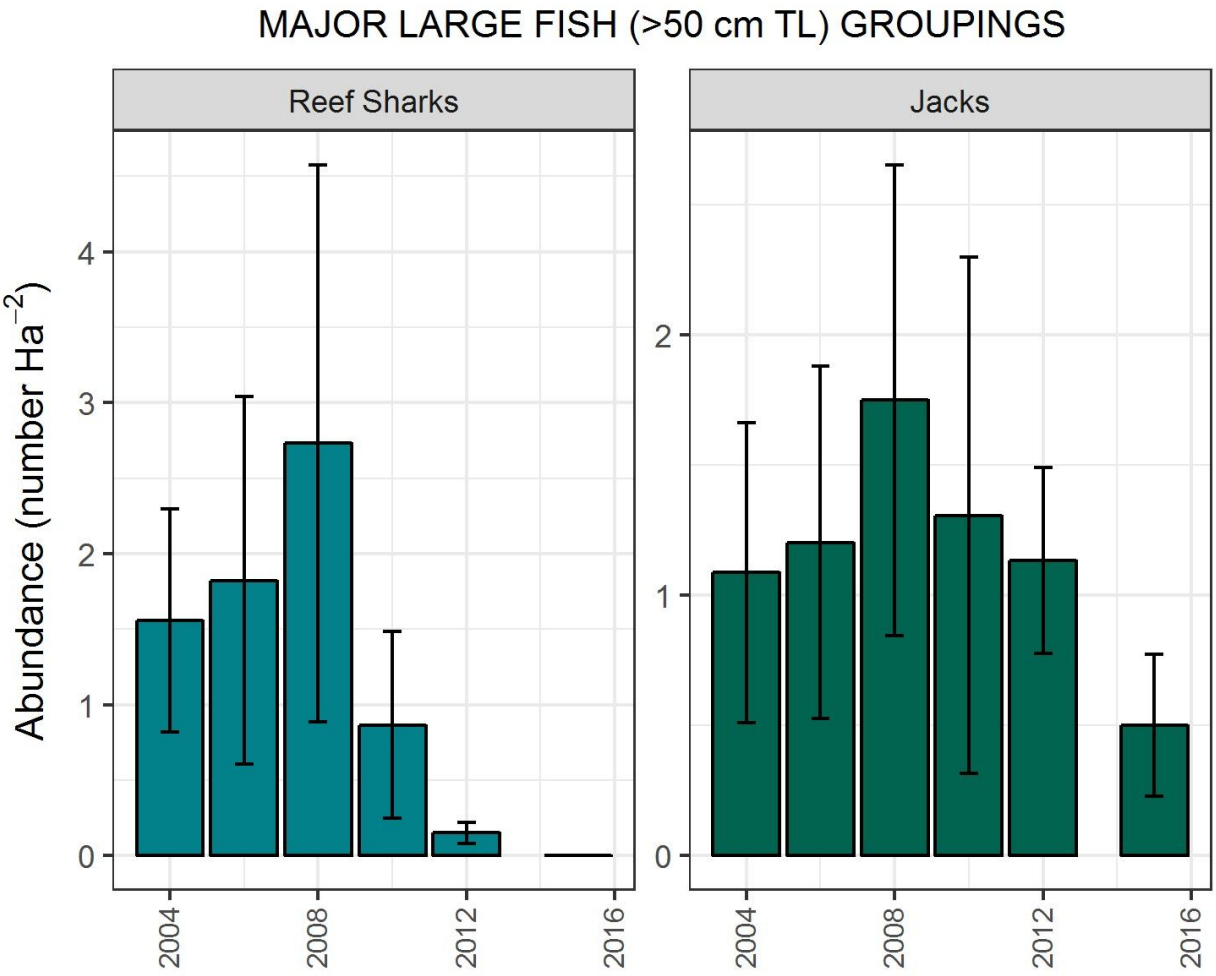


Figure 47. Bar plots by year for reef sharks and jacks from towed-diver survey (TDS) data at Johnston Atoll. In order to increase consistency among years, trends are derived only from TDS >500 m in length, which were conducted in forereef habitats between 10 and 20 m deep. Data shown are mean and standard error.

Species Lists, Encounter Rates, and Diversity

Mean reef fish species richness values at Johnston Atoll ranged between 13 and 21 species of reef fish per SPC survey, averaging approximately 18 species of reef fish per survey (Figure 48). Evenness of reef fish species at Johnston was relatively high for the PRIMNM, ranging between 0.72 and 0.80 (Figure 48). Coral reef fish fauna at Johnston were generally similar to those from Hawaii, which is relatively depauperate compared to other islands and atolls of the PRIMNM; therefore, it is unsurprising that mean reef fish richness was much lower at Johnston. Despite some variability among years, including low recorded diversity of reef fish in 2010, there is no indication of a temporal trend in fish assemblage diversity at Johnston over the period from 2010 through 2015 (Figure 48).

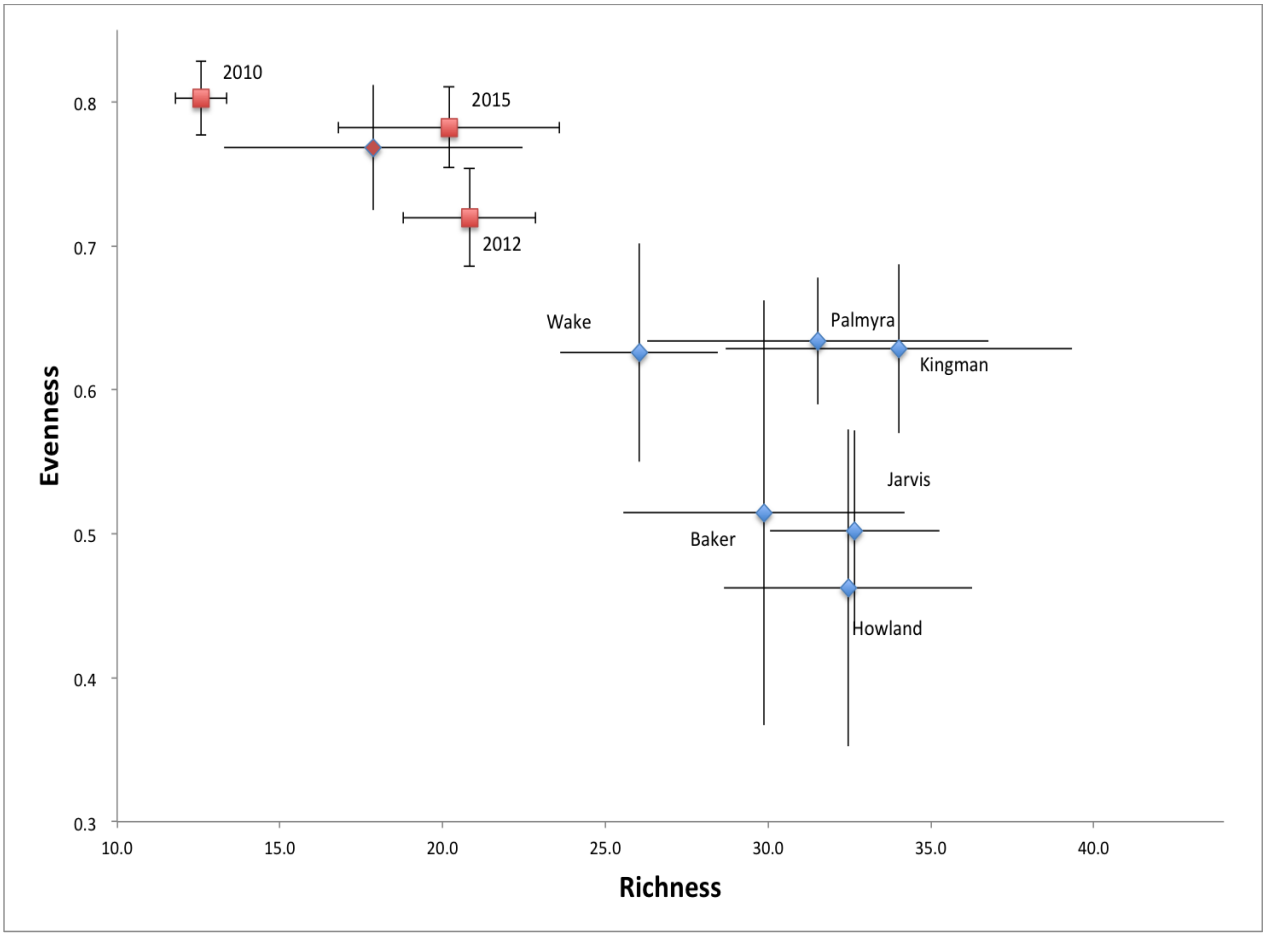


Figure 48. Richness versus evenness for reef fishes at Johnston Atoll and other Pacific Remote Islands Marine National Monument (PRIMNM) locations. Red squares are species richness (the number of species encountered) and evenness (how equally abundance was distributed) values at Johnston by year (± SE). Blue circles represent mean (± SE) richness and evenness values for other islands in the PRIMNM across all survey years. The single red dot represents the mean (± SE) value at Johnston across all survey years. For consistency, only data from forereef sites are included.

Six species of reef fishes recorded during surveys at Johnston Atoll are listed as endangered, vulnerable, or near threatened by the International Union for Conservation of Nature (IUCN)

Red List (International Union for Conservation of Nature 2017). The Chevron butterflyfish (*Chaetodon trifascialis*) that is very closely associated with table *Acropora* corals, was seen during nearly half of all SPC surveys, and the gray reef shark (*Carcharhinus amblyrhynchos*) was recorded as present in the vicinity during 13% of SPC surveys. Other listed species were seen rarely (on one or two of the SPC surveys): eagle ray (*Aetobatus narinari*), Galapagos shark (*Carcharhinus galapagensis*), manta rays (*Mobula* sp., both species of which are IUCN-listed), and orbicular velvetfish (*Caracanthus typicus*). As velvet fish are typically somewhat hidden among branches of *Pocillopora* corals, the only way to properly census those species is to carefully examine all branching corals in dedicated surveys focused on cryptic species. That species was therefore likely to be undercounted using the SPC method employed for Pacific RAMP. Two ESA-listed species have been observed at Johnston Atoll: green sea turtles (*Chelonia mydas*) and *Mobula* sp.—although as noted above, it is not possible for divers to reliably distinguish between the two species: *M. birostris* and *M. alfredi*, and only the former is listed under the ESA. A complete list of fish species observed each year is given in Appendix B of "Chapter 9: Pacific Remote Islands Marine National Monument in the Pacific-wide Context."



Marine Debris

6.7 Marine Debris

Various types of marine debris were sporadically recorded 79 times during benthic TDS at Johnston Atoll from 2004 to 2015 (Figure 49). This does not encompass all debris found at Johnston, given that the surveys were only done haphazardly, and it is also possible that the same debris may have been noted in consecutive survey years. Metal and cable debris made up the majority of the sightings.

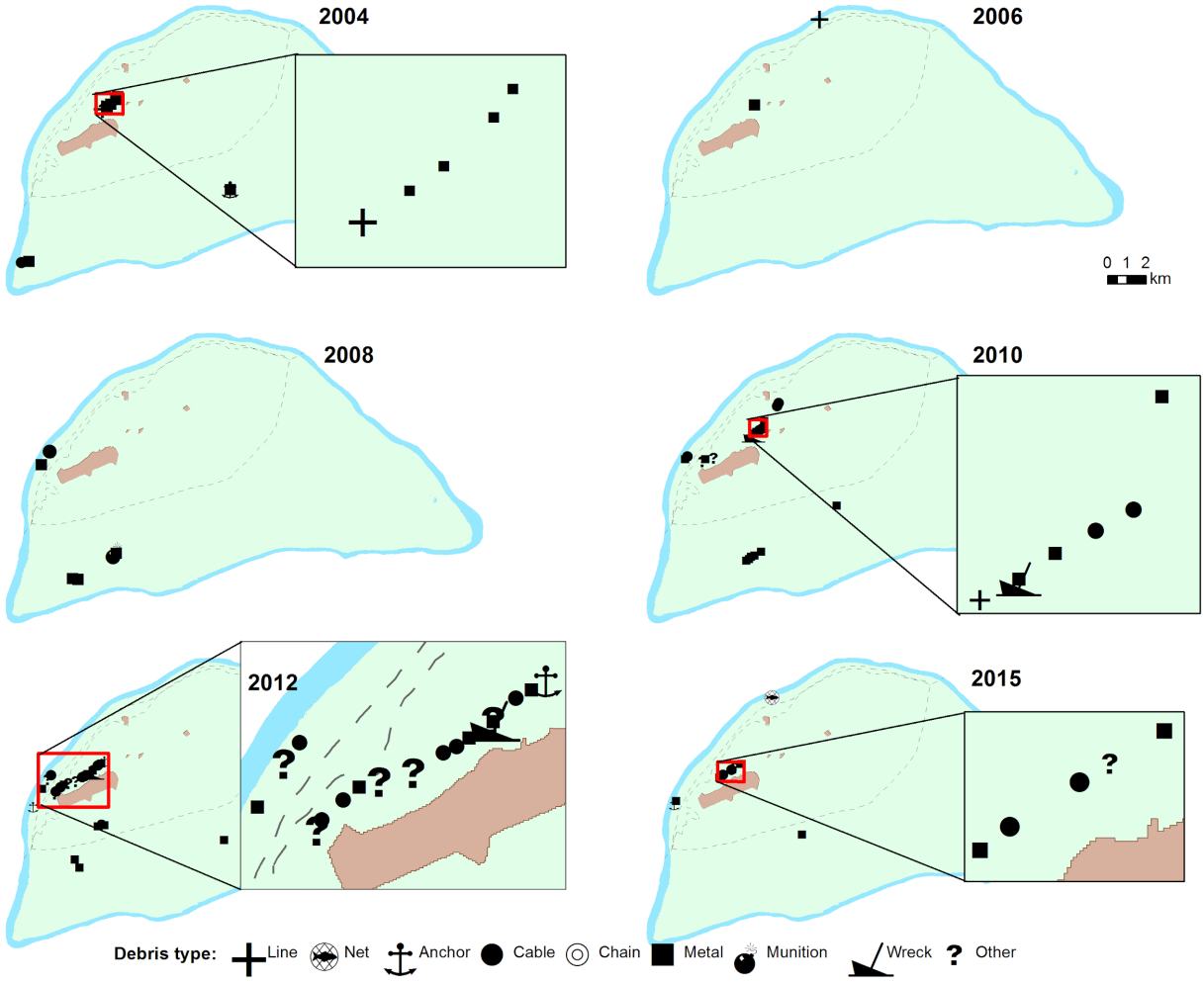


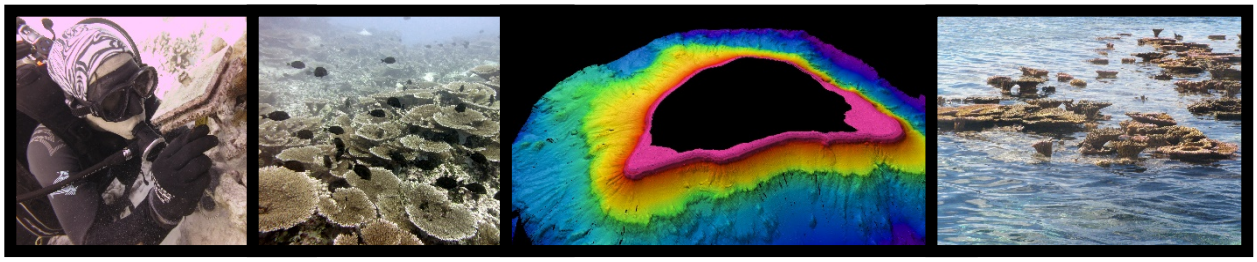
Figure 49. Marine debris sightings. Line, net, anchor, cable, metal, munition, wreck, and miscellaneous (other) debris observed during towed-diver surveys around Johnston Atoll from 2004 through 2015.



A scene with frigate birds at Johnston Atoll.
Photo: Laura Beauregard, U.S. Fish and Wildlife Service.

Ecosystem Integration

6.8 Ecosystem Integration



*Photos left to right at Johnston Atoll: Oceanography diver Jeanette Clark carefully examines serial number during calcification accretion unit recovery; Ringtail surgeonfish (*Acanthurus blochii*) gather over a reef of* Acropora *coral at Johnston Atoll, Photo: Dione Swanson; 3-D multibeam bathymetry of the seafloor surrounding Johnston Atoll, Image Source: Pacific Islands Benthic Habitat Mapping Center; Aerial exposure of the table* Acropora cytherea *colonies in the shallow lagoon habitat during an extreme low tide event, Photo: Bernardo Vargas-Angel. All images courtesy NOAA Fisheries.*

Oceanic Drivers of Benthic and Fish Populations

Due to its location almost 17° north of the equator in the central Pacific Ocean, Johnston Atoll is somewhat protected from the extreme ENSO-related interannual variability in ocean conditions observed in the more equatorial PRIMNM islands. As a result, thermal anomalies and enrichment of nutrients in surface waters typically linked with El Niño events were somewhat muted (when discernible) at Johnston. However, this more northerly location does place Johnston directly in the path of tropical cyclones, as evidenced by the passage of nine hurricanes within 200 nm of Johnston since 1972. Such disturbances can cause fragmentation and damage to corals, and leave altered reefs in their wake. Indeed, across the entire atoll, the benthic community at Johnston was largely characterized by CCA and notably low cover of hard corals (10–15%). Johnston's forereef was also comprised of the fewest coral genera (13) observed in the PRIMNM and the greatest biomass of microbes in the region that was similar to magnitudes observed at islands highly impacted by humans. The extent to which hurricanes have influenced and shaped Johnston's benthic community through time remains unclear. In contrast, juvenile density of hard corals was surprisingly high, perhaps due to greater availability of space for coral settlement via benthic scouring during hurricanes, or an abundance of CCA that may have favored coral recruitment (e.g., Harrington et al. 2004) depending on which CCA species were present. The ESA-listed coral *Acropora retusa* has also been sighted at Johnston (Kenyon 2011). Prevalence of coral diseases at Johnston was relatively high at the small number of site surveys in 2006 (Vargas-Ángel 2009), but has been relatively low (1–2%) in subsequent surveys that included a larger number of sites. Macroalgal cover has remained low at Johnston, possibly from grazing by urchins and herbivorous fishes, both of which appeared to be distributed and relatively abundant across the entire surveyed extent of the atoll.

Although the predominantly oligotrophic waters of Johnston may influence the observed benthic communities of the forereefs at Johnston Atoll, it also seems to some degree that these reefs represent remnants of both direct and indirect impacts of historical human activities, such as dredging in the Lagoon georegion and in the artificial formation of Akua and Hikina Islands, as well as the entire atoll serving as an epicenter for nuclear testing. Corallivorous COTS were

frequently observed in low abundances across Johnston, with individuals present during all TDS yet never recorded in outbreak densities. Importantly, despite a lack of observed coral bleaching across the forereef at Johnston, levels of thermal stress observed during the timespan in which surveys were conducted had yet to reach threshold levels in which coral bleaching would have been expected. During the extreme 2015–2016 El Niño in the central equatorial Pacific, however, sea surface temperatures at Johnston rose to unprecedented levels for this atoll, but there have not been any subsequent Pacific RAMP surveys at Johnston since that thermal event to assess whether there were any significant impacts.

Biomass of reef fishes has remained low across the forereef of Johnston Atoll compared to the rest of the PRIMNM, and island-wide fish communities were disproportionately comprised of large-bodied predators. Although oligotrophic conditions could potentially explain the lower biomass observed across the lower trophic groups of fishes, it is unclear how this top-heavy trophic structure persists. Lastly, one or two manta rays (*Mobula* spp.) were reported over the extent of survey effort from 2004 through 2015, which may have included the ESA-listed *M. birostris* (the only ESA-listed fish species sighted at Johnston).

Spatial Variation within the Atoll

The highest cover of hard corals was observed along the outer southern edge of the Lagoon georegion. This area also had the only observed increase in coral cover across survey years, as well as the only sighting of a single giant clam (*Tridacna gigas*) both occurring in the southeast corner just outside of the Lagoon. Cover of both hard corals and CCA were lower in the North georegion of Johnston Atoll, potentially due to greater exposure of shallow forereef to wave power from intense north swell during the winter months. The North georegion also appeared to support greater fish biomass, and sightings of reef sharks were often concentrated in this area.

As water flowed across the northern forereef and into the Lagoon georegion, decreases in saturation state were evident, perhaps due to a combination of biological activity throughout the forereef and the higher residence time of water in the Lagoon. Observations of remaining reef structure in the Lagoon that consisted mostly of semi-dead table *Acropora* sp. suggests historical dredging altered the composition of forereef communities likely by reducing water circulation and enhancing sedimentation. Where *Acropora* sp. have persisted, localized spikes in fish biomass have also been present.

The green sea turtle (*Chelonia mydas*), which is listed under the ESA, has been observed only around Johnston Island, and humpback whales (*Megaptera novaeangliae*) were sighted in 2004 across Johnston Atoll, including in the Lagoon. These whales were likely a portion of the population that migrates to the Hawaiian Islands during the winter months, given the relatively close proximity between the Hawaiian Archipelago and Johnston.

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