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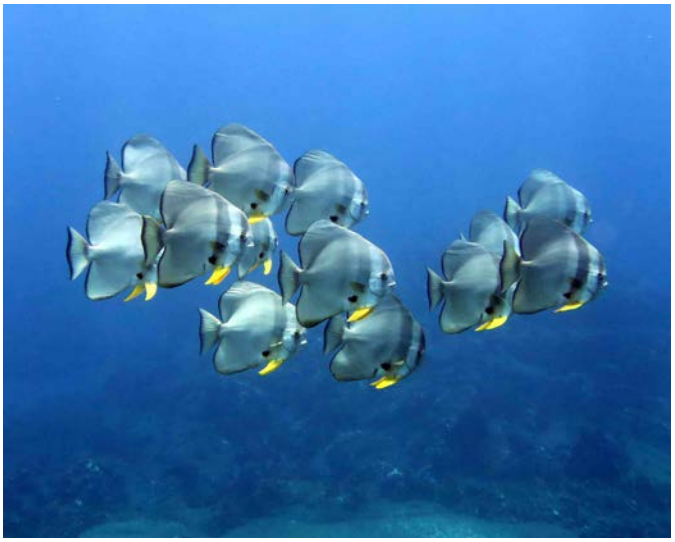
Pacific Reef Assessment and Monitoring Program
Data Report[1]

Ecological monitoring 2017—reef fishes and benthic habitats of the Northwestern Hawaiian Islands, Pacific Remote Islands Marine National Monument, and the Mariana Archipelago



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This report outlines some of the coral reef monitoring surveys conducted by the National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center's (PIFSC) Ecosystem Sciences Division (ESD) in

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2017. This includes the following regions: Northwestern Hawaiian Islands, Pacific Remote Islands Marine National Monument, and the Mariana Archipelago.

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Report template by A. Heenan, maps by P. Ayotte, figures and report compiled by K. McCoy.

Acronyms

BSR	Benthic substrate ratio
CRCP	Coral Reef Conservation Program
ESD	Ecosystem Sciences Division
NCRMP	National Coral Reef Monitoring Program
NOAA	National Oceanic and Atmospheric Administration
Pacific RAMP	Pacific Reef Assessment and Monitoring Program
PMNM	Papahānaumokuākea Marine National Monument
PRIA	Pacific Remote Island Areas
PRIMNM	Pacific Remote Islands Marine National Monument
SPC	Stationary Point Count

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Introduction

Background

The Ecosystem Sciences Division (ESD) established a long-term monitoring program, known as the Pacific Reef Assessment and Monitoring Program (Pacific RAMP) in 2000. Pacific RAMP, which is supported by NOAA's Coral Reef Conservation Program (CRCP) and the Pacific Islands Fisheries Science Center (PIFSC), is tasked with documenting and understanding the status and trends of coral reef ecosystems in the U.S. Pacific. Pacific RAMP monitors reef areas in the following regions: the Hawaiian and Mariana Archipelagos, American Samoa, and the Pacific Remote Islands Marine National Monument (PRIMNM, formerly Pacific Remote Island Areas—PRIA), which include Johnston and Wake Atolls and the U.S. Line and Phoenix Islands (Figure 1).

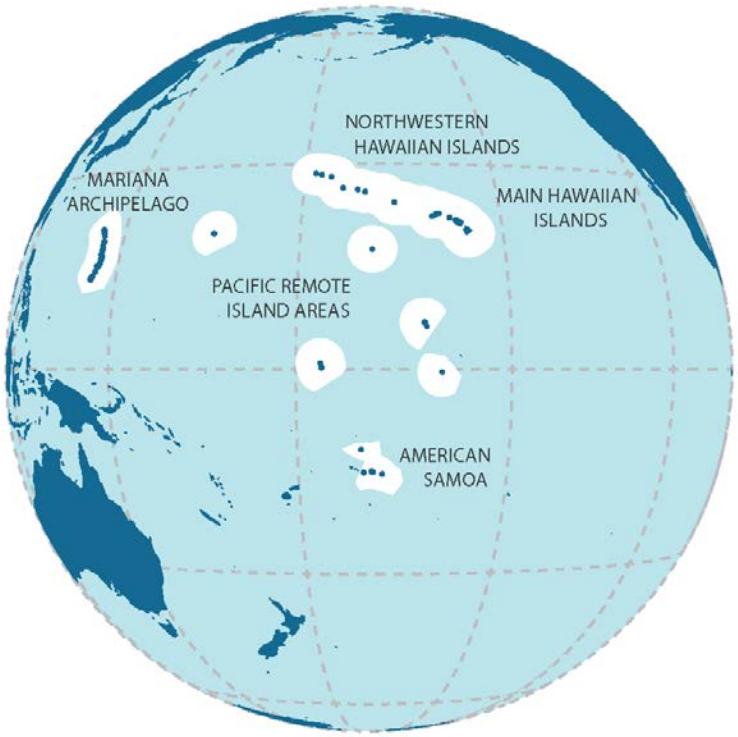

Figure 1. Coral reef areas surveyed by NOAA-ESD for Pacific RAMP. White areas represent the exclusive economic zones for each U.S. Pacific region surveyed.

Pacific RAMP encompasses interdisciplinary monitoring of oceanographic conditions and biological surveys of organisms associated with hard-bottomed habitats in the 0–30-m depth range. From 2000 to 2011, regions were surveyed on a biennial basis, changing to a triennial cycle in 2012 as part of the implementation of NOAA's National Coral Reef Monitoring Program (NCRMP) funded by the NOAA CRCP (NOAA CRCP, 2014).

The NCRMP aims to support integrated, consistent and comparable monitoring of coral reefs across all U.S.-affiliated regions. Partnership and cooperation with other federal and jurisdictional management groups is a core principle of the NCRMP. For example, NOAA's Papahānaumokuākea Marine National Monument (PMNM) conducts a subset of coral reef monitoring surveys in the Northwestern Hawaiian Islands using similar survey designs and methods, with

considerable overlap in observers and database management processes. Data gathered by PMNM is therefore readily merged with data gathered specifically for NCRMP by ESD.

The NCRMP has three themes: biological, climate, and socioeconomic monitoring. Under the biological monitoring theme, the Pacific RAMP collects the following benthic and reef-associated fish data: fish and coral demographic information (species, size, abundance, biomass, disease (coral only), bleaching (coral only)); and information on benthic composition and key species (see Appendix 1: Pacific RAMP data types collected for the biological theme of NCRMP). The focus of this report is 1) the data collected using the stationary point count method to survey the fish assemblage and paired rapid visual assessments of benthic composition and; 2) the towed-diver fish survey (see Section: Methods). The Pacific RAMP collects additional, related benthic data via benthic transects and towed diver surveys (for more information see NCRMP 2014); these data will be reported in a forthcoming series of complementary data reports.

Monitoring scope and historical programmatic changes

Pacific RAMP includes the following biological monitoring objectives:

- Gather information on and document the status and trends of coral reef fishes and benthic assemblages in the U.S. Pacific;
- Provide information on status and trends of coral reef taxa of ecological and economic importance;
- Generate data suitable for tracking and assessing changes in reef assemblages in response to human, oceanographic, or environmental stressors; and
- Generate data suitable for evaluating the effectiveness of specific management strategies, and to support appropriate adaptive management.

These objectives are based on the key monitoring questions for NCRMP and the CRCP support for baseline observations and monitoring (refer to NCRMP 2014 and NOAA CRCP 2009 for more details).

Pacific RAMP involves monitoring over very large spatial scales: ~ 40 islands and atolls spread over thousands of kilometers. The target of Pacific RAMP biological monitoring under NCRMP is to provide periodic snapshot assessments of coral reef assemblages at U.S.-affiliated islands in the Pacific, with the core reporting unit being at the island scale (or sub-island scale for large islands), and as such the survey design and effort are optimized to generate data at the spatial scale of islands and atolls. The NCRMP is therefore explicitly a “wide-but-thin” survey program, with the aim of generating large-scale, regional status and trend information of the Nation’s shallow water (0–30 m) coral reef ecosystems, to provide a broad-scale context and perspective to local jurisdictions and other survey programs.

Additional surveys at smaller spatial scales that are intended to address more local information needs are also occasionally performed by ESD, but are not a formal part of Pacific RAMP; however, none were conducted in 2017. In addition to Pacific RAMP surveys, several agencies (PMNM, National Marine Fisheries Service (NMFS) and CRCP) conducted compatible survey missions, which were incorporated into this report.

In 2012, Pacific RAMP changed from surveying regions once every 2 years, to once every 3 years. The sampling design and methods used to monitor coral reef fish species and habitats for Pacific RAMP have evolved over time. More specifically, from 2000 to 2006 surveys were conducted at haphazardly located permanent sites using various belt transect methods. During 2007 to2009, ESD and PMNM conducted comparative reef fish surveys using both the belt transect and the stationary point count (SPC) methods, and incorporated a stratified random sampling survey design. Survey replication (i.e., the number of sites sampled) greatly increased over this period and this higher level of replication has been maintained (Appendix 2: Surveys per region per year and method used). Following this methods calibration period, from 2009 onwards the SPC method and depth-stratified random sampling were applied routinely in Pacific RAMP for surveying reef fishes and associated benthic communities.

Report structure

This report summarizes the reef fish survey data and a subset of the benthic data collected by the ESD for Pacific RAMP and for compatible PMNM, NMFS and CRCP survey missions in 2017. During 2017, surveys were conducted in the following regions: Northwestern Hawaiian Islands, Pacific Remote Islands Marine National Monument, and the Mariana Archipelago. The status of reef fish assemblages in each region is first described in the wider Pacific context (Section: U.S. Pacific reefs: the status of reef fishes), and later described at the island scale. Given the substantial changes in methods and design used for the reef fish assemblage surveys, this section shows observations collected since 2009, after which point, the reef fish assemblage surveys for Pacific RAMP were consistently conducted using the SPC method under a depth-stratified random sampling design. Towed-diver surveys of large fishes (≥ 50 cm) were designed to generate data at regional or sub-regional scale, and thus we do not generally present island-level summaries of this information. Instead, the towed-diver surveyed data are shown at the regional scale following the SPC reef fish assemblage section.

In the final section, the publications that were produced in 2017 as a result of those surveys are listed; these publications either use the Pacific RAMP fish data or were co-authored by members of the ESD fish team and relevant to Pacific RAMP fish ecological monitoring work.

All data used in this report along with other monitoring data collected by ESD are available upon request to nmfs.pic.credinfo@noaa.gov.

Methods – stationary point count

Sampling domain and design

The target sampling domain is hard-bottom habitat in water shallower than 30 m. All islands / atolls within regions are stratified by reef zone (backreef, forereef, lagoon, protected slope) and depth zone: shallow (0–6 m), mid (6–18 m), and deep (18–30 m). For the large majority of cases, entire islands or atolls are stratified by habitat and depth as described above, however, for populated large islands or where large portions of an island are under fundamentally different levels of management (e.g., inside or outside marine protected areas), there is an additional level of stratification based on "sector" (section of coastline and /or management status). Specifically, Guam is subdivided into three sectors: "Marine Preserve" (being all areas within Guam's Marine Preserve System); "Guam Open East" (areas outside of Marine Preserves on east side of Guam); and "Guam Open West" (Appendix 3: Sector maps). Furthermore, the generally larger, main Hawaiian Islands, and Tutuila, are divided into between 2 and 7 sectors per island, with sector boundaries designed to reflect broad differences in oceanographic exposure, reef structure, and local human population density (Appendix 3: Sector maps). Finally, some of the smaller, more closely spaced islands are always pooled into single reporting and sampling units (i.e., Alamagan, Guguan and Sarigan in the Mariana Archipelago; Ofu and Olosega in American Samoa; and Ni`ihau and Lehua in the main Hawaiian Islands). Due to their small size, these island groups are only ever allocated a limited number of sea days per cruise, and therefore total sampling effort per island is inadequate to report out data at the island level. Details of sectors and sampling effort on survey cruises covered by this report are given in Appendix 4: Samples per sector and strata in 2017.

Table 1. Sampling terms and definitions.

Term	Definition
Sample site data	The average values of estimated observed quantities from the SPC surveys conducted at each site. These are typically derived from a single pair of simultaneous surveys. Sites are tied to geographic coordinates.
Reporting unit	A collection of sample sites, typically an island or atoll, and in some cases small island groups or sectors of larger islands.
Sampling domain	Hard-bottom habitat in water less than 30-m depth.
Strata	Reef zone (backreef, forereef, lagoon, protected slope) Depth zone (shallow 0–6 m[1], mid 6–18 m, deep 18–30 m) Sectors (e.g., management units[2] and stretches of coastline with broadly similar habitat attributes and local human population density[3]).

[1] For practical reasons, sites in which the center point of the survey cylinder is shallower than 1.5 m are not surveyed. [2] For the island of Guam only. [3] Currently only in the main Hawaiian Islands, Tutuila, and Guam.

Site selection

Prior to each survey mission, sample site locations are randomly drawn from geographic information system (GIS) habitat and strata maps (Figure 2). That is, the latitude and longitude of site locations are randomly drawn from a map of the entire sampling domain.

Maps used in the site selection procedure were created using information from the NOAA National Centers for Coastal Ocean Science, reef zones (e.g., forereef) digitized from IKONOS satellite imagery or nautical charts, bathymetric data

from the ESD-affiliated Pacific Islands Benthic Habitat Mapping Center at the University of Hawai`i at Mānoa, and prior knowledge gained from previous visits to survey locations.

During cruise planning, logistic and weather conditions factor into the allocation of monitoring effort around each island or atoll. Prior to the cruises, these constraints determine the area of target habitat from which sites are randomly selected; for instance, one side of an island may be deemed unsurveyable given seasonal wave conditions or ESD's allocation of sea days aboard the NOAA research vessel may curtail the time spent in a particular area. The density of sites that are sampled per stratum is therefore determined by proportionally allocating effort (e.g., the number of sites to be surveyed) based on a weighting factor calculated from the area per stratum per reporting unit and the variance of the target output metrics (e.g., consumer group biomass and total fish biomass; see Section: Fish groupings), combined with what is feasible given the time constraints of ship time allotted per island or atoll.

During field operations on a research cruise, if a site is not suitable (e.g., soft- as opposed to hard-bottomed habitat) or accessible (e.g., due to inclement sea conditions), the dive is aborted and an alternate (backup) site is picked from the randomized list. In some cases, the spatial coverage of sampling sites around the entire area of target sampling domain is incomplete. As such, any inferences about coral reef fish assemblages and habitat made at the island-scale are only representative of the areas surveyed (Appendix 4: Samples per sector and strata in 2017). For further details on the methods and maps used to select sites see Williams et al. (2011) or the Ecosystem Sciences Division Standard Operating Procedures: Data Collection for Rapid Ecological Assessment Fish Surveys (Ayotte et al., 2015).

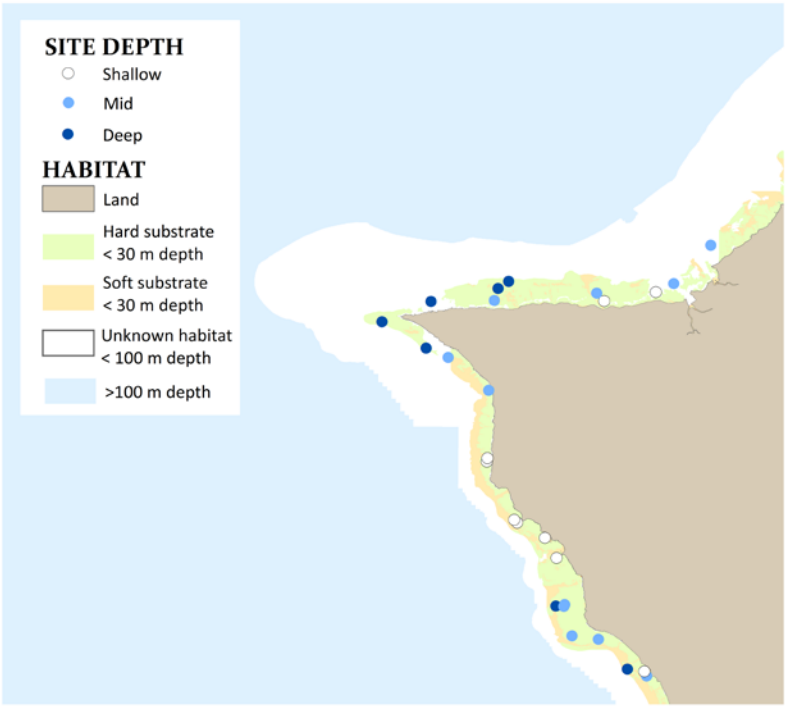

Figure 2. An example of the benthic habitat and depth strata information used in the site selection process. Reef fish survey sites are randomly selected within each depth stratum. Survey effort is allocated to optimize island-scale biomass estimates. Prior to surveying, a series of primary sites are selected. Each circle identifies a site which falls on hard substrata (green) in the three depth strata (see map legend, shallow: 0–6 m, mid: 6–18 m and deep: 18–30 m). An alternate set of depth-stratified sites is also generated in the event that primary sites are not suitable or accessible.

Sampling methods

At each reef fish survey site two types of data are collected; visual counts of the fish assemblage and surveys of the benthic habitat.

Counting and sizing reef fishes

The SPC protocol closely follows that used by Ault and colleagues (Ault et al., 2006) and involves a pair of divers conducting simultaneous counts in adjacent, visually estimated 15-m-diameter cylindrical plots extending from the substrate to the limits of vertical visibility (Figure 3). Prior to beginning each SPC pair, a 30-m line is laid across the substratum. Markings at 7.5 m, 15 m and 22.5 m enable survey divers to locate the midpoint (7.5 m or 22.5 m) and two edges (0 m and 15 m; or 15 m and 30 m) of their survey plots. Each count consists of two components. The first of these is a 5-min species enumeration period in which the diver records the taxa of all species observed within their cylinder. At the end of the 5-min period, divers begin the tallying portion of the count, in which they systematically work through their species listing and record the number and estimated size (total length, TL, to the nearest cm) of each individual fish. The tallying portion is conducted as a series of rapid visual sweeps of the plot, with one species-grouping counted per sweep. To the extent possible, divers remain at the center of their cylinders throughout the count. However, small, generally site-attached and semi-cryptic species, which tend to be under-represented in counts made by an observer remaining in the center of a 7.5-m radius cylinder, are left to the end of the tally period, at which time the observer swims through their plot area carefully searching for those species. In cases where a species is observed during the enumeration period but is not present in the cylinder during the tallying period, divers record their best estimates of size and number observed in the first encounter during the enumeration period and mark the data record as “non-instantaneous.” Surveys are not conducted if horizontal visibility is < 7.5 m, i.e., when observers cannot distinguish the edges of their cylinder (see Ayotte et al., 2015). Biomass per fish is calculated using the standard length-weight equation. Data from the two adjacent SPC surveys are averaged to create a biomass estimate for each site (Section: Data handling), and in cases where more than one SPC paired survey is conducted, data from matched members of each pair are first averaged before pair-specific results are averaged to create site estimates.

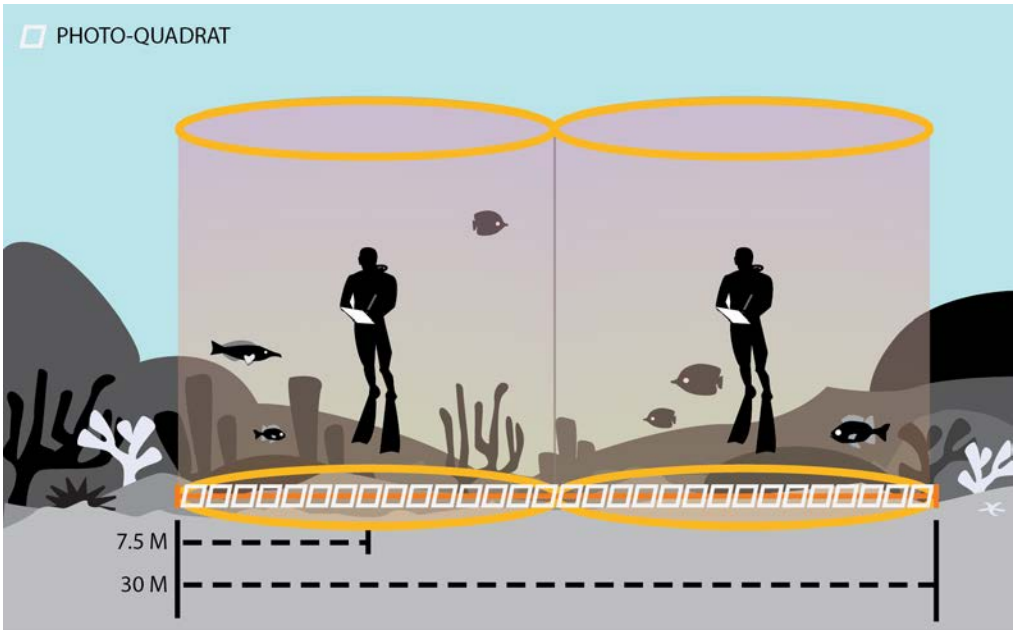

Figure 3. Side view of the stationary point count method. Dive partners count and size fishes within adjacent cylinders measuring 7.5 m in radius. Once the fish survey is complete, divers estimate benthic habitat composition and a benthic photo-transect is collected, spanning the two cylinders.

Assessing benthic habitat characteristics

Two complementary methods are used to assess benthic composition within the same area where fish are surveyed. The first involves divers conducting a rapid visual assessment of the percentage cover of major functional categories of benthic cover and the second involves collecting photo-quadrat images of the benthos taken along the survey transect line that are later analyzed (Figure 3). The rapid visual assessment method provides a coarse but immediate estimate of benthic composition. In contrast, the photo-quadrat surveys provide estimates of benthic composition at a higher taxonomic or functional resolution, but only after substantial post-survey data processing. As with the fish data, benthic data from the two adjacent SPC surveys are averaged to create an estimate per site.

Benthic visual assessment

After completing the fish survey, both divers scan the benthos in their survey cylinder for 2–3 min and visually estimate the percentage cover of encrusting algae, upright macroalgae, hard coral, and sand. Divers also estimate the slope, broad habitat type and structural complexity (Ayotte et al., 2015). Divers record reef habitat complexity by visually estimating the percentage of the cylinder that falls into the following levels of vertical relief: < 0.20 m, 0.20–0.50 m, 0.50–1 m, 1–1.5 m, and > 1.5 m. The abundance of free urchins (e.g., *Tripneustes, Heterocentrotus, Diadema* and *Echinothrix)* and boring urchins (e.g., *Echinometra* and *Echnostrephus*) is also rapidly visually assessed and recorded on a DACOR scale (Dominant, Abundant, Common, Occasional, Rare). Finally, divers identify the broad-scale habitat type for the general area of the survey. The habitat classification scheme follows the geomorphological structures as identified by the Biogeography Branch of the NOAA National Ocean Service National Centers for Coastal Ocean Science. The coral reef and hard-bottom habitat types are: aggregate reef, individual patch reef, aggregated patch reefs, spur and groove, pavement, pavement with sand channels, pavement with patch reefs, sand with scattered coral/rock, reef rubble and rock / boulder (Kendall and Poti, 2011). These visual assessments are used to estimate a benthic substrate ratio (BSR). This ratio indicates the balance between benthic components that contribute to reef accretion (coral and crustose coralline algae) and the other components of the hard-bottom (i.e. non-sand) substrate.

Photo-quadrat survey

With the fish survey and rapid benthic visual assessment completed, one diver takes photographs of the benthos at 1-m intervals along the transect line (30 photographs per site) (Figure 3). A 1-m PVC stick is used to position a digital camera (Canon PowerShot S110, 12.1 megapixel) directly above the substrate to frame an area of ~ 0.7 m^2 per photograph. These images are archived for future analysis.

Our primary benthic assessment method is the photo-quadrat survey because it is a proven standard method and because it allows benthic composition to be identified to a higher resolution. However, due to a lag in analyzing the photo-images, only the visual assessment data are shown in this report. Visual survey data have been shown to be generally comparable to photo-quadrat survey data, with some caveats (McCoy et al., 2015). However, we stress that benthic trends from rapid visual surveys should be considered indicative at best.

Data entry and storage

Data were entered into a Microsoft Access database. Upon completion of the monitoring cruise, all data were migrated to an Oracle database that is stored on a server at the Pacific Islands Fisheries Science Center.

Data quality control

Data quality control is implemented at three main stages:

- Prior to conducting fish surveys for Pacific RAMP, each observer takes the full training course.[2] In between field data collections, observers undergo regular and routine size estimation practice and fish identification tests (Figure 4: Pre-field).
- Checking for errors at the data entry stage (Figure 4: In the field). This occurs on the cruise when observers check the data entered by their dive partner against their datasheet for typing and potential sizing errors. At the

[2] https://www.pifsc.noaa.gov/cred/survey_methods/fish_surveys/rapid_ecological_assessment_of_fish-survey_method_training.php

end of the cruise, a series of error checking scripts are run prior to migrating from the data entry database (Access) to the storage database (Oracle) (Figure 4: Post-field).

- Examining diver estimation accuracy. This occurs during and after the monitoring cruise when diver estimates are compared between dive partner pairs (Figure 4: In the field). Observer comparisons from the regions surveyed in 2017 are in Appendix 5: SPC Quality control: Observer cross-comparison.

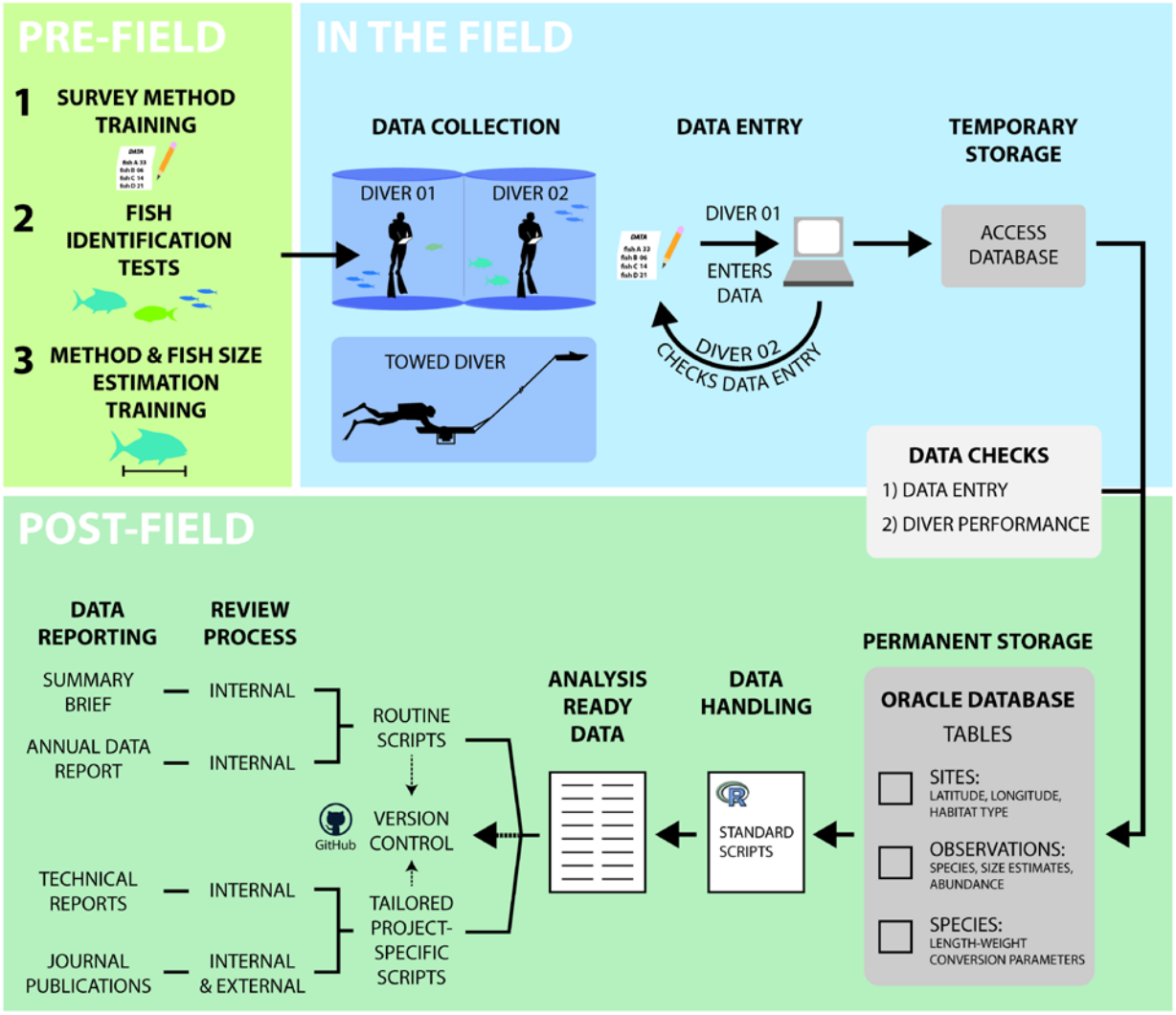

Figure 4. The training, data collection, data processing and reporting phases for Pacific RAMP SPC and towed-diver fish and benthic surveys.

Data handling

Calculating fish biomass and benthic cover estimates per site

Using the count and size estimate data collected per observer in each replicate survey, the body weight of individual fish is calculated using length-to-weight (LW) conversion parameters, and, where necessary, length-length (LL) parameters (for example, to convert TL to fork length [FL] for species with LW parameters based on FL). LW and LL conversion parameters were taken from FishBase (Froese and Pauly, 2010; Kulbicki et al., 2005). Herein the term "biomass" refers to the aggregate body weight of a group of fishes per unit area (g m^{-2}). Site is the base sample unit and the estimated

biomass of fishes per site is calculated by taking the mean value from the paired SPC surveys. Similarly, the mean percentage cover estimates per benthic functional group and complexity measures are calculated as site-level means.

Fish groupings

In this report, species data are summarized at several different levels: consumer group, size class (only at the region scale), total fish biomass ("all fishes"), parrotfish biomass, and average total length (only at the island level). Consumer groups are: "primary consumers" (herbivores and detritivores); "secondary consumers" (omnivores and benthic invertivores); "planktivores"; and "piscivores," with classifications based on diet information taken largely from FishBase (Froese and Pauly, 2010). The size classes used at the region scale are 0–20, 20–50 and > 50 cm TL. Size classes for parrotfish are 10–30, and > 30 cm TL, as 30 cm is the legal minimum size for fishing on all islands (except Maui).

Generating island-scale estimates from the stratified design

Summary statistics (e.g., mean and variance) of survey quantities (e.g., biomass) are calculated by first averaging values within each stratum before calculating the reporting unit values. A weighted average method to calculate summary statistics is used because survey strata vary in size within each reporting unit.

Estimates of the mean and variance for each survey quantity considered are calculated based on the observed values at sampled sites within each stratum. Then aggregate estimates of the quantities across all strata are calculated using the formulas below. For example, with respect to biomass we have:

(1) pooled mean biomass (*X)* across S strata: $X = \sum_1^S (X_i * w_i)$ and;

(2) pooled variance of mean biomass (*VAR)* across S strata: $VAR = \sum_1^S (VAR_i * w_i^2)$

where X_i is the estimate of mean biomass within stratum *i*, VAR_i is the estimated variance of X_i and w_i is the stratum-weighting factor. Strata weighting factors were based on the size of strata, i.e., if a stratum is 50% of the total area in an island then is weighting factor will be 0.5, and total of all weighting factors in an island sums to 1 (Smith et al. 2011).

In this report, only data from sites surveyed under the stratified sampling design are used, i.e., data collected from 2009 onwards; Appendix 6: Random stratified sites surveyed at each island per year. In the few cases where fewer than two sites were surveyed in a stratum in a reporting period, these sites were removed from the island-scale parameter estimates for that period.

To assess Pacific-wide patterns in reef fish assemblages, statistics of total fish biomass (i.e., all fishes) and biomass within each consumer group and size class (mean and variance) are calculated per island per year and then averaged across years. In the section on U.S. Pacific reefs, summary graphs and metrics were generated from data collected since 2009 (see Section: U.S. Pacific reefs: the status of reef fish).

Island-scale values for total fish biomass (i.e., all fishes) and biomass per consumer group and parrotfish size class (mean and variance) are calculated by year (see Section: Region and island status and trends). For analysis purposes, MHI data from years 2010 and 2012 were pooled, and data from 2013 and 2015 were pooled. This is because the MHI are too large to be fully covered within single years, and hence different sections of coastline are sampled in different years. Data were also pooled for the NWHI for years 2016 and 2017 due to small sample sizes in 2017. Thus far, the time series under the stratified sampling design is too short to infer temporal trends.

All data handling and analyses were performed using raw site data extracted from the NOAA ESD Oracle database, processed using a set of routine processing scripts written in R (R Development Core Team 2011) (Figure 4: post field), and visualized using the ggplot2 package. The site-level data used to generate all figures and summary statistics are available upon request.

Methods – towed-diver surveys

There are a number of important, rare and patchily distributed species that are not well surveyed by comprehensive small-scale survey approaches. This is because encounter rates for those species are usually very low for surveys that do not cover very large areas of reef habitat. Therefore, Pacific RAMP supplements the data gathered by SPC with 'towed-diver' surveys, which involves a pair of divers being towed behind a small boat, and travelling ~2 km in the course one survey. To make it possible to survey fishes over such a large area, and to give a simple criterion for inclusion, towed-diver survey divers record observations on fishes ≥ 50 cm TL, which includes all or most of the adult size range of several groups of conservation and ecological importance, including reef sharks, trevally jacks, humphead wrasse, and bumphead parrotfishes.

Survey design and sampling method

Towed-diver surveys are haphazardly located systematically, with the goal of spreading surveys as widely as possible around the island. To the extent it is feasible, areas of soft-bottom habitat are avoided. The majority of surveys are conducted in 10–20 m of water, with a core target depth of 15 m, dependent on availability of suitable reef habitat in those depths.

Divers are towed using 60-m lines, behind a small boat at a speed of ~1.5 knots, attempting to follow the depth contour (Figure 5). Towboards made of marine polymer sheets measuring 1 m × 0.55 m × 0.02 m are connected to the towlines. Towboards are equipped with continuous depth and temperature recorders, and a tracking GPS on the small boat combined with a layback algorithm allows a survey track, and therefore survey length, to be reconstructed for each survey. Surveys are 50 min in duration, divided into ten 5-min time segments. One diver records benthic information, and the other records the number, size (TL) and species of all fishes ≥ 50 cm (TL) within a belt-transect extending 5 m either side and 10 m in front of the diver, from the bottom to the surface. Fish are identified to the lowest possible taxon and are sized to the nearest cm in TL.

More details of this method are given in Richards et al. 2011.

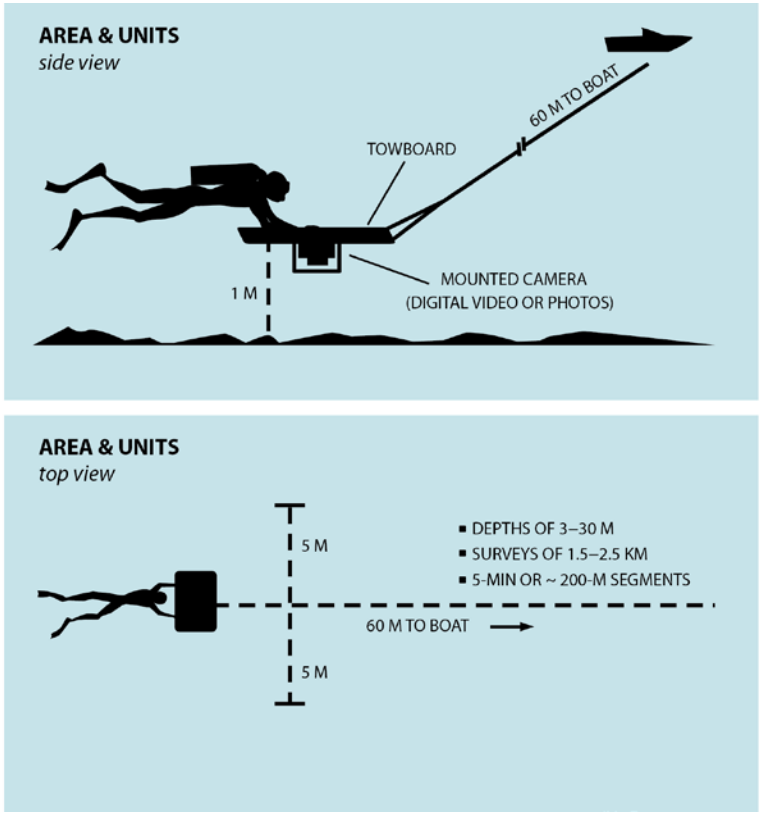

Figure 5. Side view (top) and top view (bottom) of the towed-diver method. Divers count and size fishes within a belt-transect extending 5 m on either side and 10 m in front of the diver.

Data handling and generating regional-scale estimates for towed-diver surveys

As with the SPC data, towed-diver observation data are initially entered into an Access database, and after data entry and quality checks, are transferred into an Oracle database. The Oracle database is linked to a GIS map containing habitat and bathymetric information, as well as the tow survey tracks.

To increase comparability among locations and time periods, only data from tows in forereef habitat with mean depth of between 8 and 20 m are shown here. Information on the number of tows in those and other habitat areas is shown in Appendix 2.

Summary towed diver fish densities are calculated by first calculating a density value per towed-diver survey, i.e., total counted / survey area (= survey length * 10 m). Some species, such as the Bigeye Trevally *Caranx sexfasciatus* and several of the barracuda, are encountered occasionally in schools of several hundred or more individuals. To prevent those occasional observations from overwhelming the longer-term patterns, towed diver data are capped at the 95% percentile for each reporting group and sub-region. Capped tow values are then summarized (i.e., as mean and variance) at island-scale.

Island-scale mean and standard error for total large fish density (i.e., all fishes ≥ 50 cm TL) and density per major family or other grouping – Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and ‘reef sharks’ (i.e., all Carcharhinidae, Ginglymostomatidae, and Sphyrnidae) are calculated by year (see Section: Region and island status and trends). Those summary statistics are converted to regional and sub-regional scales, with data weighted by the amount of reef area per island (all hard-bottom forereef in < 30 m) using the same weighting formulas as are used for SPC data.

All data handling and analyses were performed using raw towed-diver data extracted from the NOAA ESD Oracle database, processed using a set of routine processing scripts written in R (R Development Core Team 2011), and visualized using the ggplot2 package.

U.S. Pacific reefs: the status of reef fishes

This section summarizes variation in reef fish community biomass across the following U.S. Pacific island regions: Northwestern Hawaiian Islands (NWHI), main Hawaiian Islands (MHI), the Mariana Archipelago, Pacific Remote Islands Marine National Monument, and American Samoa. The islands and atolls in the regions surveyed span broad biogeographic, geologic, oceanographic and human-impact gradients. Thus, patterns in the biological community will be influenced by a combination of these factors. There will also be within-island habitat variability that affects the reef fish assemblages surveyed. For instance, several islands have a variety of habitat types, including forereef, lagoon, and backreef habitats and for the purpose of this pan-Pacific comparison, only forereef data are presented.

At the region scale, the highest mean total fish biomass was recorded in the Pacific Remote Islands Marine National Monument (mean ± standard error: 160.5 ± 9.1 g m^{-2}), followed in decreasing order by the Northwestern Hawaiian Islands (117.2 ± 5.0 g m^{-2}), the Northern Mariana Archipelago (70.2 ± 4.1 g m^{-2}), American Samoa (43.8 ± 1.6 g m^{-2}), the main Hawaiian Islands (29.4 ± 1.1 g m^{-2}), and the Southern Mariana Archipelago (19.3 ± 0.8 g m^{-2}) (Figure 6: All fishes). Fish biomass is summarized by consumer group and size class in Figures 6 and 7 and Table 2. The regional mean (± standard error) values for total fish biomass and biomass per size class that are reported in this section are plotted as reference points for visual comparison in the following Region and island status and trends section.

Consumer groups

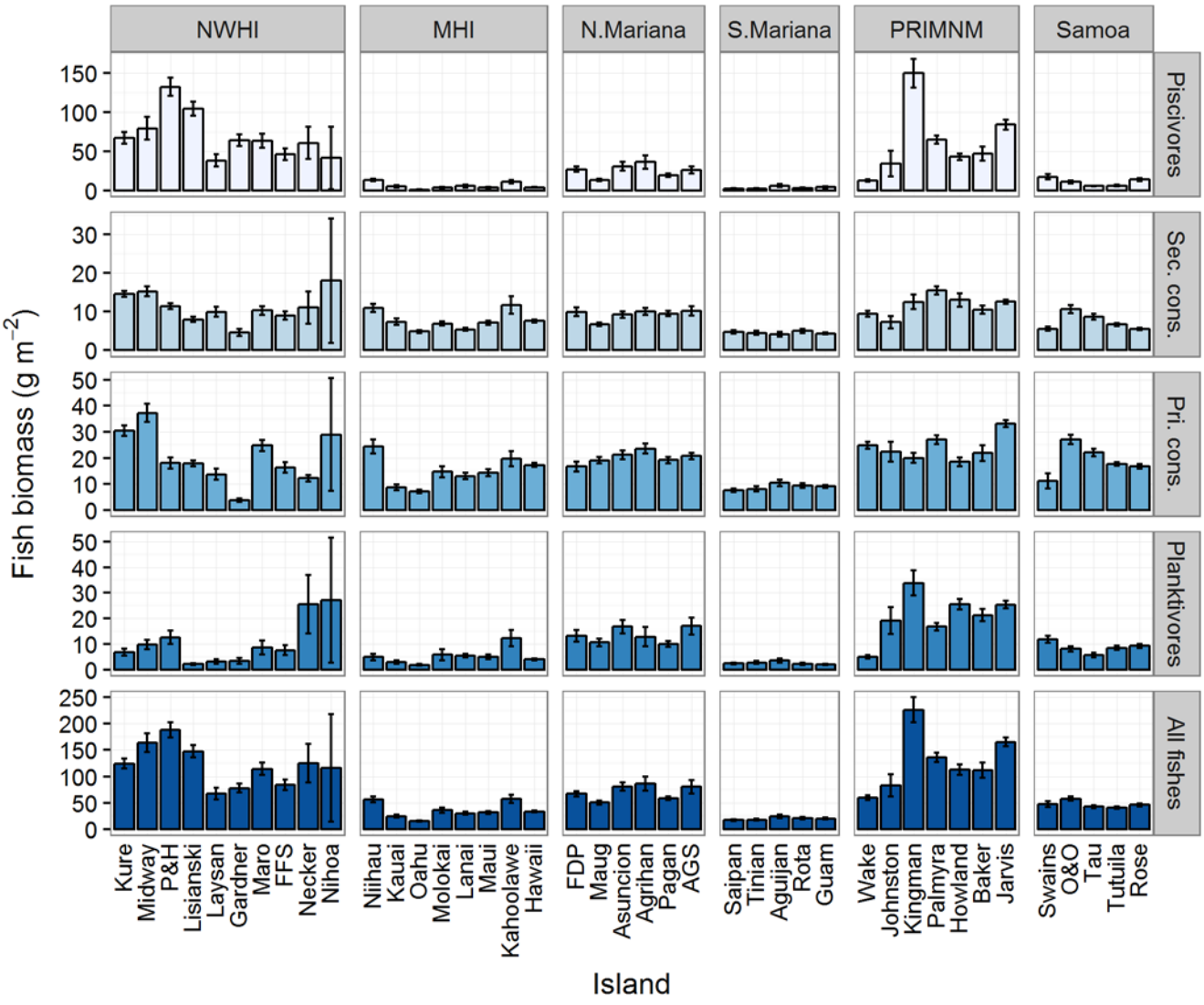

Figure 6. Mean fish biomass by consumer group per US Pacific reef area. Mean fish biomass (± standard error) per consumer group per reef area pooled across survey years (2009–2017). Islands are ordered within region by latitude See Appendix 4 and Appendix 6 for the sampling density per strata at each island by year. NWHI = Northwestern Hawaiian Islands, MHI = main Hawaiian Islands, N. Mariana = Northern Mariana Archipelago, S. Mariana = Southern Mariana Archipelago, PRINMN = Pacific Remote Islands Marine National Monument, Samoa = American Samoa, Sec. consumers = secondary consumers (omnivores and invertivores), Pri. Consumers = primary consumers (herbivores), P&H = Pearl and Hermes, FFS = French Frigate Shoals, FDP = Farallon de Pajaros, AGS = Alamagan, Guguan, and Sarigan islands, O&O = Ofu and Olosega islands.

Size classes

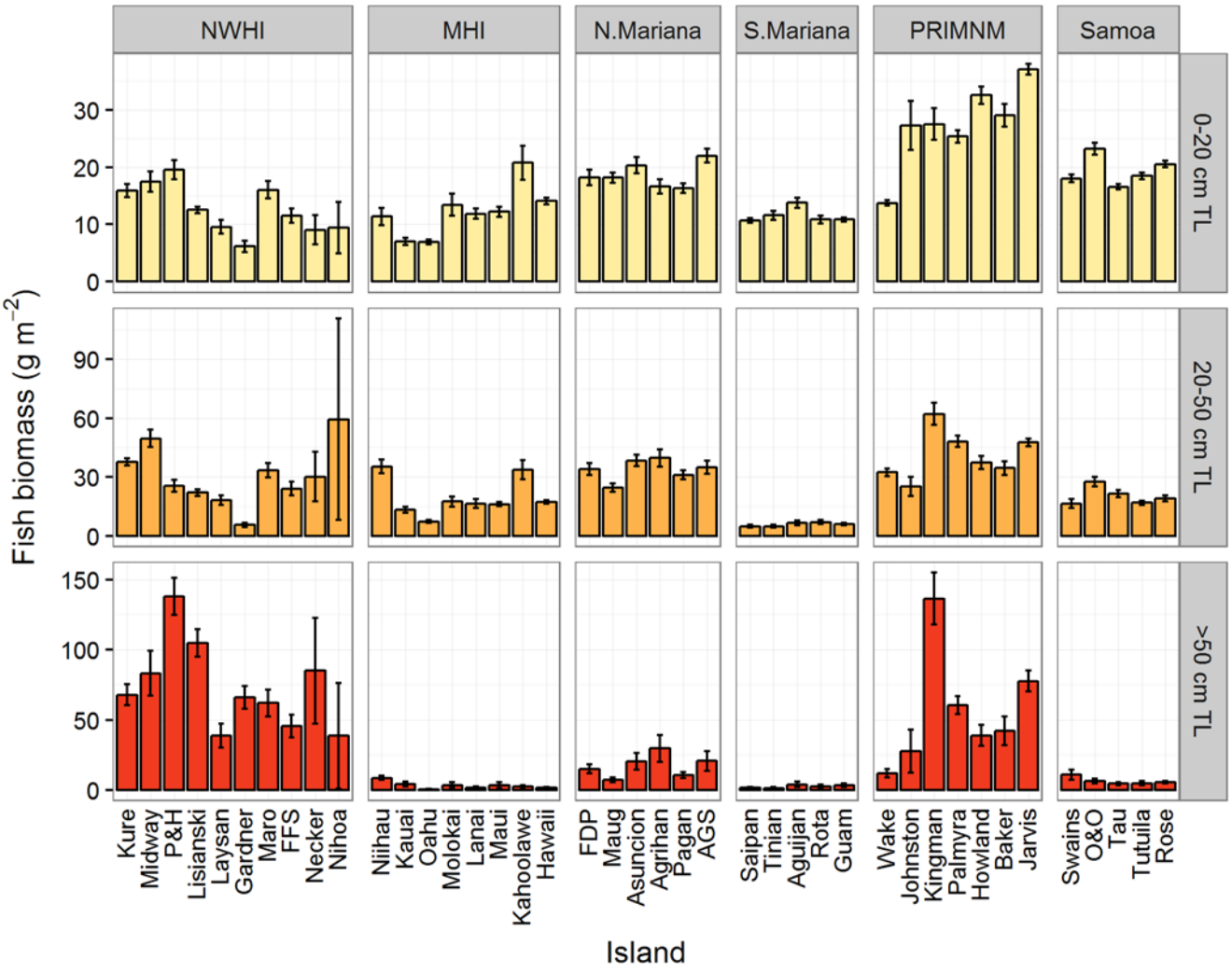

Figure 7. Mean fish biomass per size class per US Pacific reef area. Mean fish biomass (± standard error) per size class (0–20 cm, 20–50 and > 50 cm in total length (TL)) per reef area are pooled across survey years (2009–2017). Islands are ordered within region by latitude. See Appendix 4 and Appendix 6 for the sampling density per strata at each island by year. NWHI = Northwestern Hawaiian Islands, MHI = main Hawaiian Islands, N. Mariana = Northern Mariana Archipelago, S. Mariana = Southern Mariana Archipelago, PRINMN = Pacific Remote Islands Marine National Monument, Samoa = American Samoa, Sec. consumers = secondary consumers (omnivores and invertivores), Pri. Consumers = primary consumers (herbivores), P&H = Pearl and Hermes, FFS = French Frigate Shoals, FDP = Farallon de Pajaros, AGS = Alamagan, Guguan, and Sarigan islands, O&O = Ofu and Olosega islands, TL = total length.

Table 2. Mean fish biomass with standard error in parentheses for all fish biomass, biomass per consumer group and per size class for forereef habitat. NWHI = Northwestern Hawaiian Islands, MHI = main Hawaiian Islands, N. Mariana = Northern Mariana Archipelago (Farallon de Pajaros down to Sarigan), S. Mariana = Southern Mariana Archipelago (Saipan, Tinian, Aguijan, Rota, and Guam), PRIMNM = Pacific Remote Islands Marine National Monument (also called PRIA), Samoa = American Samoa, Sec. consumers = secondary consumers (omnivores and invertivores), Pri. Consumers = primary consumers (herbivores), TL = total length.

Region	Sites[1]	All fishes	Piscivores	Sec. consumers	Pri. consumers	Planktivores	0–20 cm TL	20–50 cm TL	> 50 cm TL
NWHI	817	117.2 (5.0)	78.9 (4.0)	8.3 (0.4)	16.1 (0.6)	5.6 (0.8)	12.1 (0.5)	21.6 (1.1)	79.7 (4.3)
MHI	1167	29.3 (1.1)	4.6 (0.4)	7.0 (0.2)	12.7 (0.5)	3.8 (0.4)	10.2 (0.4)	15.5 (0.7)	3.0 (0.5)
N. Mariana	535	70.2 (4.1)	25.1 (2.3)	9.5 (0.4)	20.5 (0.7)	12.6 (1.2)	17.9 (0.5)	33.8 (1.5)	17.4 (2.7)
S. Mariana	678	19.2 (0.8)	3.5 (0.5)	4.6 (0.2)	8.6 (0.3)	2.3 (0.1)	11.0 (0.2)	5.7 (0.4)	2.5 (0.5)
PRIMNM	770	160.5 (9.1)	90.0 (6.9)	13.2 (0.8)	24.1 (1.0)	23.2 (1.8)	26.7 (1.1)	50.0 (2.3)	82.2 (7.0)
Samoa	949	43.8 (1.6)	7.6 (0.8)	7.5 (0.3)	19.3 (0.6)	8.1 (0.5)	18.8 (0.4)	19.1 (0.8)	5.4 (0.9)

[1] The number of forereef sites surveyed during 2009–2017.

Region and island status and trends

This section summarizes SPC data collected at each island between 2007 and 2017, and towed-diver data summarized at the region level, collected between 2000 and 2017 (for all regions surveyed in 2017). Towed-diver data are intended to generate information on large fishes (≥ 50 cm TL) that has meaning at regional or sub-regional scale. Thus, data summaries are shown for the Northern Mariana Archipelago, Southern Mariana Archipelago, and for sub regions of the Pacific Remote Island Marine National Monument (PRIMNM). The PRIMNM was established by Presidential Proclamation 8336 in January 2009 and expanded by Presidential Proclamation 9173 in September 2014 and are an administrative rather than biogeographic region. Therefore, the PRIMNM islands are reported in the following island groups: the US Phoenix Islands (Howland and Baker); the US Line Islands (Jarvis, Palmyra, Kingman); and for Johnston Atoll alone, as it is located ~ 825 miles south of the MHI and ~ 850 miles from the nearest PRIA islands.

For each region or sub-region, data shown are annual means of total large fish (≥ 50 cm TL) density, as well as density per major family or other grouping. Specifically, annual biomass is shown for 6 groupings: Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and 'reef sharks' (i.e. all Carcharhinidae, Ginglymostomatidae, and Sphyrnidae). These fish families are the most frequently recorded, but with reef sharks pooled into a single category as low numbers of Ginglymostomatidae, and Sphyrnidae make it infeasible to report those separately.

For each island within a region, maps illustrate the SPC site-level data from 2010–2017 (2007–2009 site locations can be found in earlier reports, but are not shown in this report to prevent overcrowding of the maps), and a standard set of graphs show summary information on the fish and benthic community at the island scale for each year-grouping. On each fish biomass graph, a reference line indicates the region wide mean estimate, provided as a relevant regional comparison for island-level estimates. Fish biomass is shown for each year surveyed of all fish, parrotfish in two size classes, and by consumer group. Total fish, consumer group and parrotfish biomass are core NCRMP indicators (NOAA NCRMP 2014). Large parrotfishes are believed to be important grazers, so parrotfish biomass is separately reported for 2 size groups: large (> 30 cm TL) and small (10–30 cm TL) fishes. Mean size per island and year is also reported, as mean size can be a useful indicator of fishing pressure; fishes smaller than 10 cm are excluded from that to reduce noise from variable levels of recent recruitment.

Benthic visual estimates were not incorporated into the surveys until 2010. The most common functionally important major benthic groups are reported as yearly average percent cover: hard coral, macroalgae, and encrusting algae.

Northwestern Hawaiian Islands (NWHI)

NWHI data were pooled into 3-year periods as the archipelago is now visited for NCRMP once every 3 years. Pooling data into 3-year periods allows us to present temporal data in a consistent fashion and to incorporate supplementary data gathered during PMNM survey cruises in non-NCRMP years. NWHI mean lagoon and protected slope estimates are not plotted due to small sample sizes.

French Frigate Shoals (FFS)

French Frigate Shoals was surveyed in 2010–12 (n = 50), 2013–15 (n = 34), 2016–17 (n = 83). Three habitats were surveyed: forereef, lagoon, and protected slope. The biomass is shown for each habitat by all fish, parrotfish, and consumer group. Average total length and the major benthic groups are also shown for each habitat type.

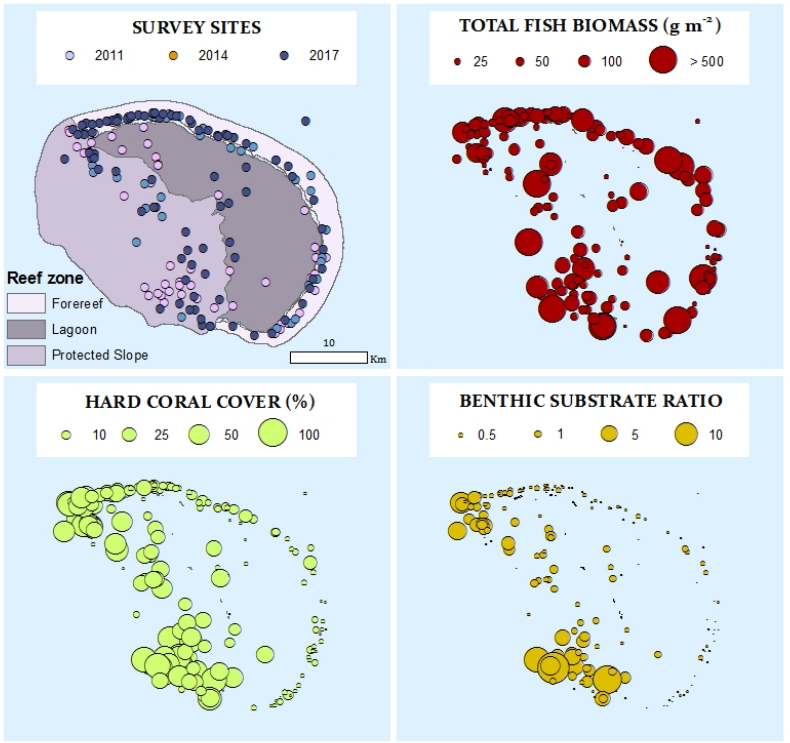

Figure 8. French Frigate Shoals site survey data for 2010–12, 2013–15, and 2016–17 identified by year and reef zone (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

The forereef habitat was surveyed in 2010–12 (n = 12), 2013–15 (n = 22), 2016–17 (n = 58).

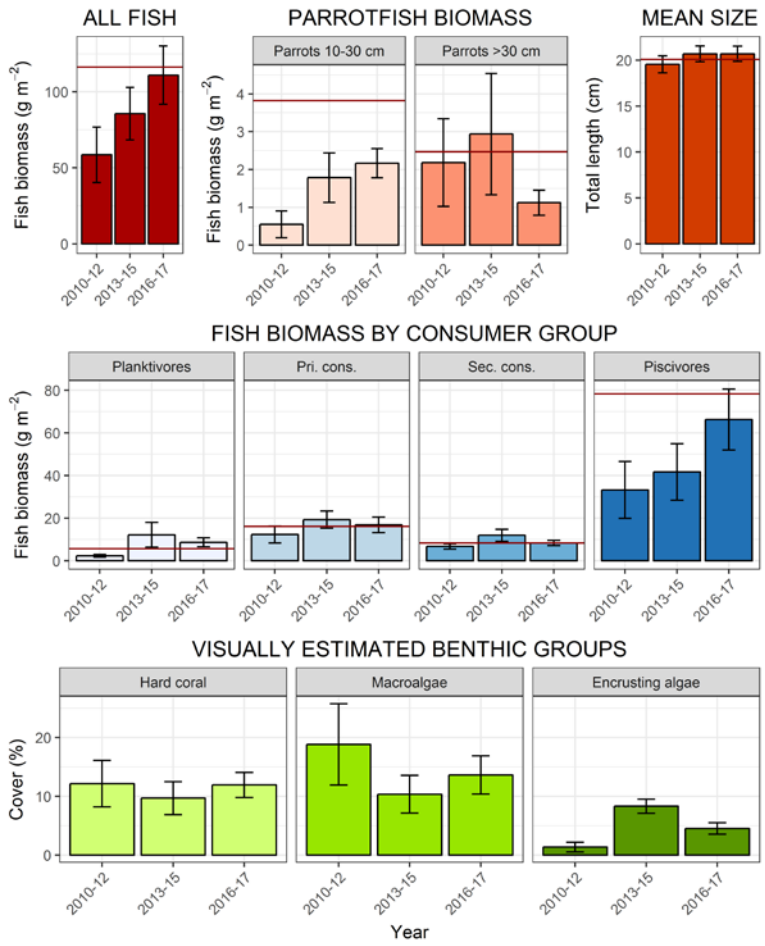

Figure 9. French Frigate Shoals fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos, for forereef habitat only. The NWHI region mean forereef estimates are plotted for reference (red line).

The lagoon habitat was surveyed in 2010–12 (n = 15), 2013–15 (n = 2), 2016–17 (n = 7).

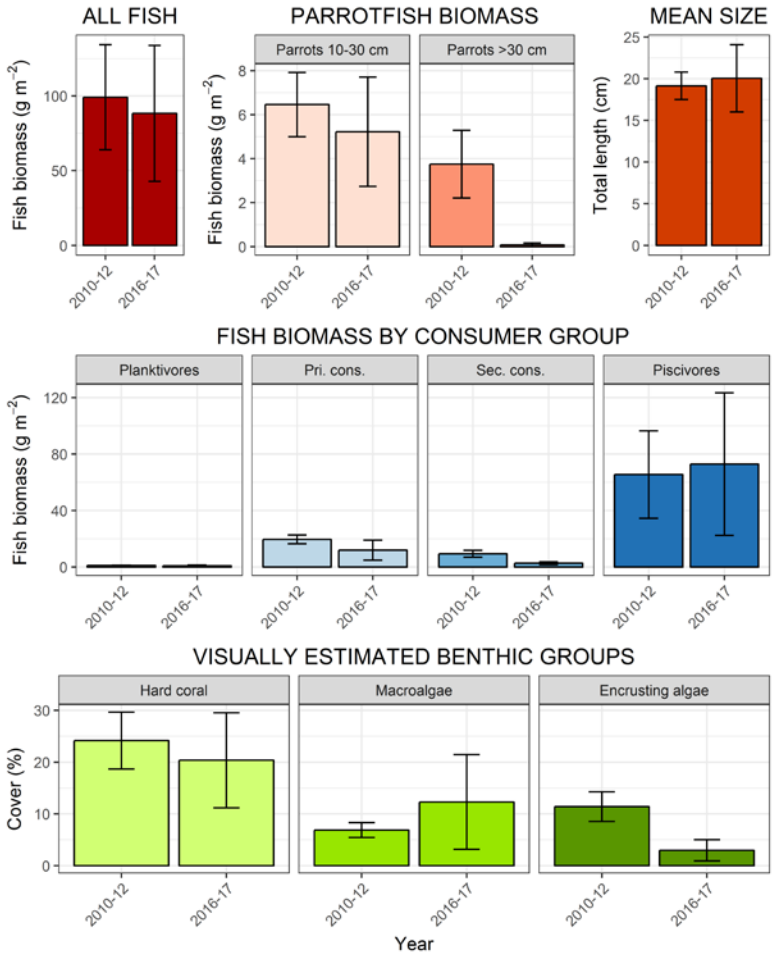

Figure 10. French Frigate Shoals fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos, for lagoon habitat only. Only 2 sites were surveyed in 2013–15, so that time frame is not shown.

The protected slope habitat was surveyed in 2010–12 (n = 23), 2013–15 (n = 10), 2016–17 (n = 18).

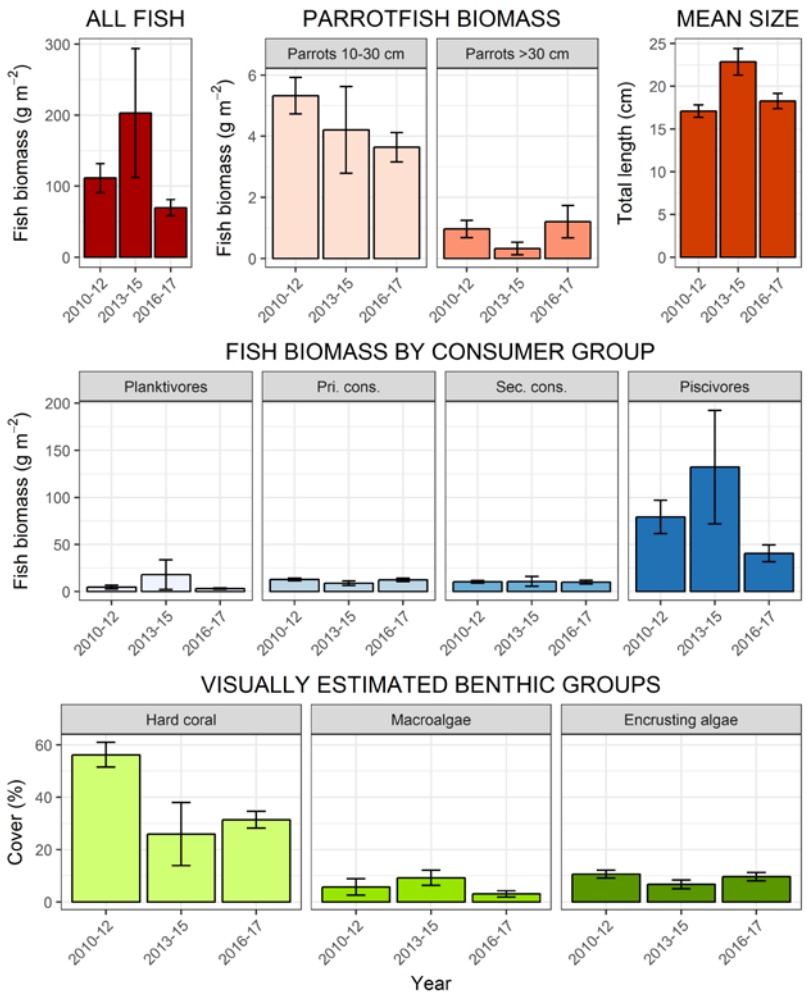

Figure 11. French Frigate Shoals fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos, for protected slope habitat only.

Kure Atoll

Kure Atoll was surveyed in 2007–09 (n = 38), 2010–12 (n = 39), 2013–15 (n = 8), 2016–17 (n = 49).

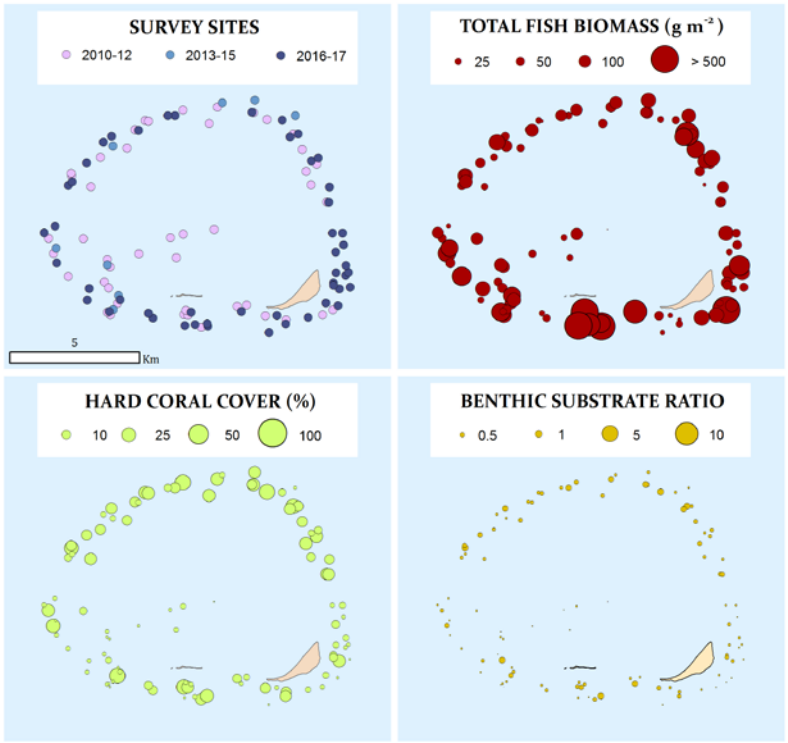

Figure 12. Kure Atoll site survey data for 2010–12, 2013–15, and 2016–17 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

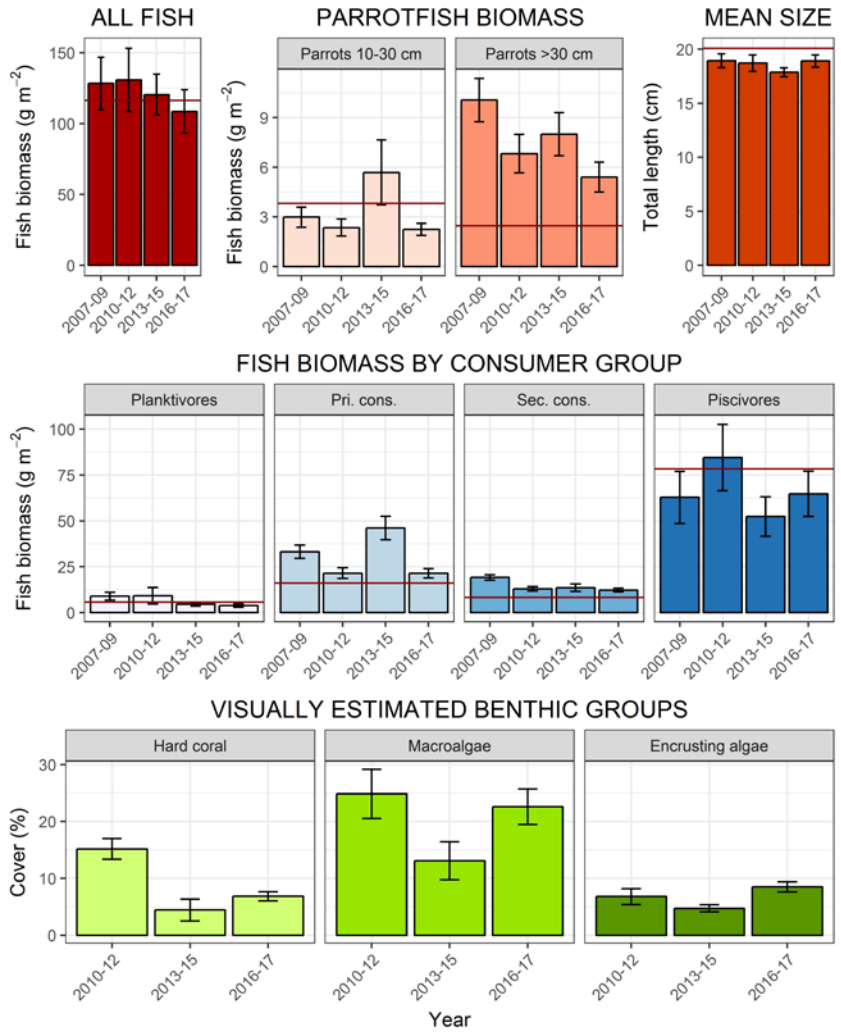

Figure 13. Kure Atoll fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The NWHI region mean forereef estimates are plotted for reference (red line).

Laysan Island

Laysan Island was surveyed in 2007–09 (n = 14), 2010–12 (n = 23), 2013–15 (n = 8), 2016–17 (n = 17).

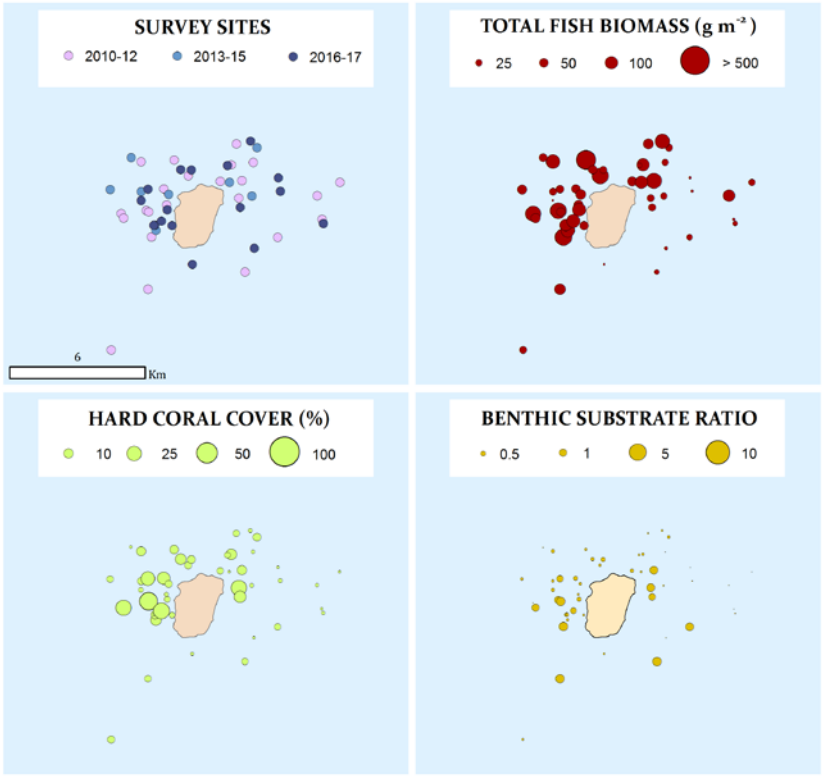

Figure 14. Laysan Island site survey data for 2010–12, 2013–15, and 2016–17 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

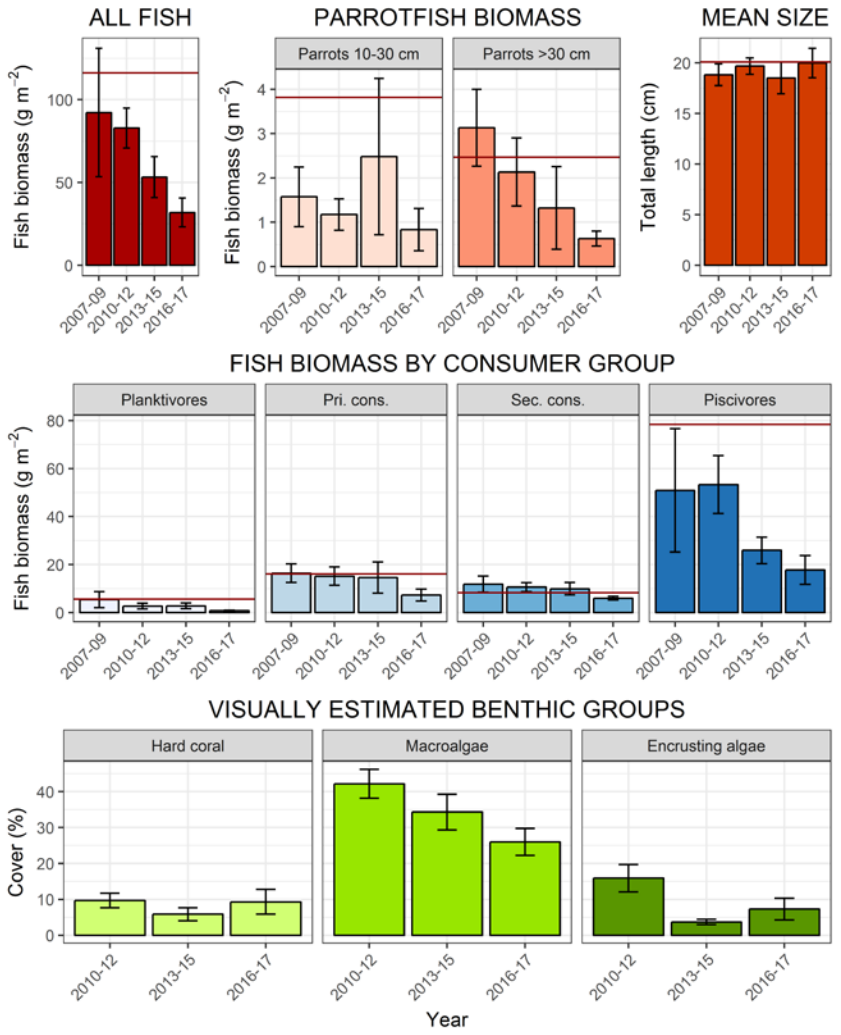

Figure 15. Laysan Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The region mean forereef estimates are plotted for reference (red line).

Lisianski Island

Lisianski Island was surveyed in 2007–09 (n =19), 2010–12 (n = 59), 2013–15 (n = 46), 2016–17 (n = 66).

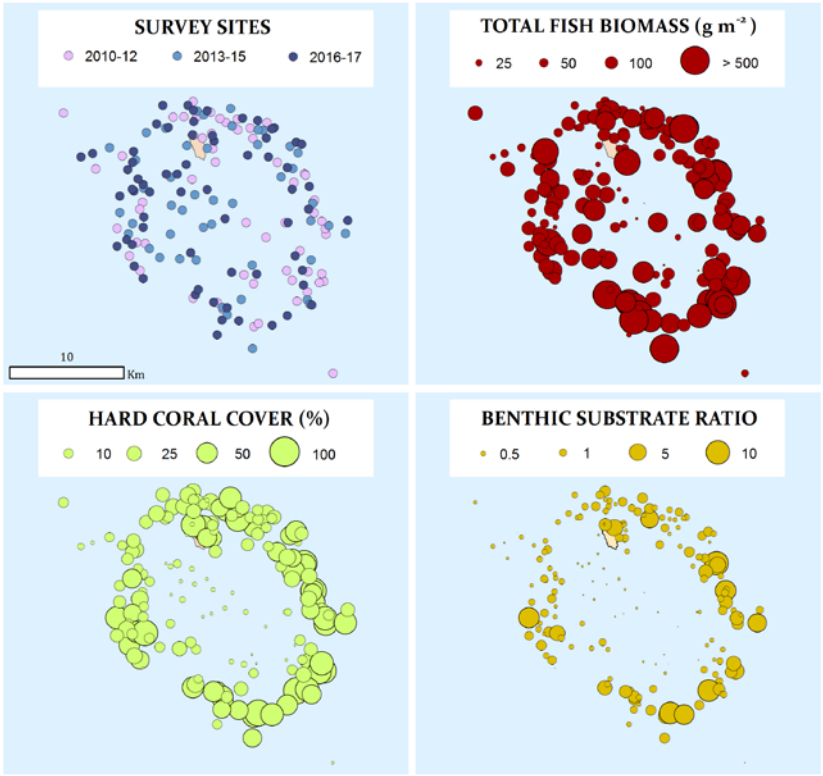

Figure 16. Lisianski Island site survey data for 2010–12, 2013–15, and 2016–17 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

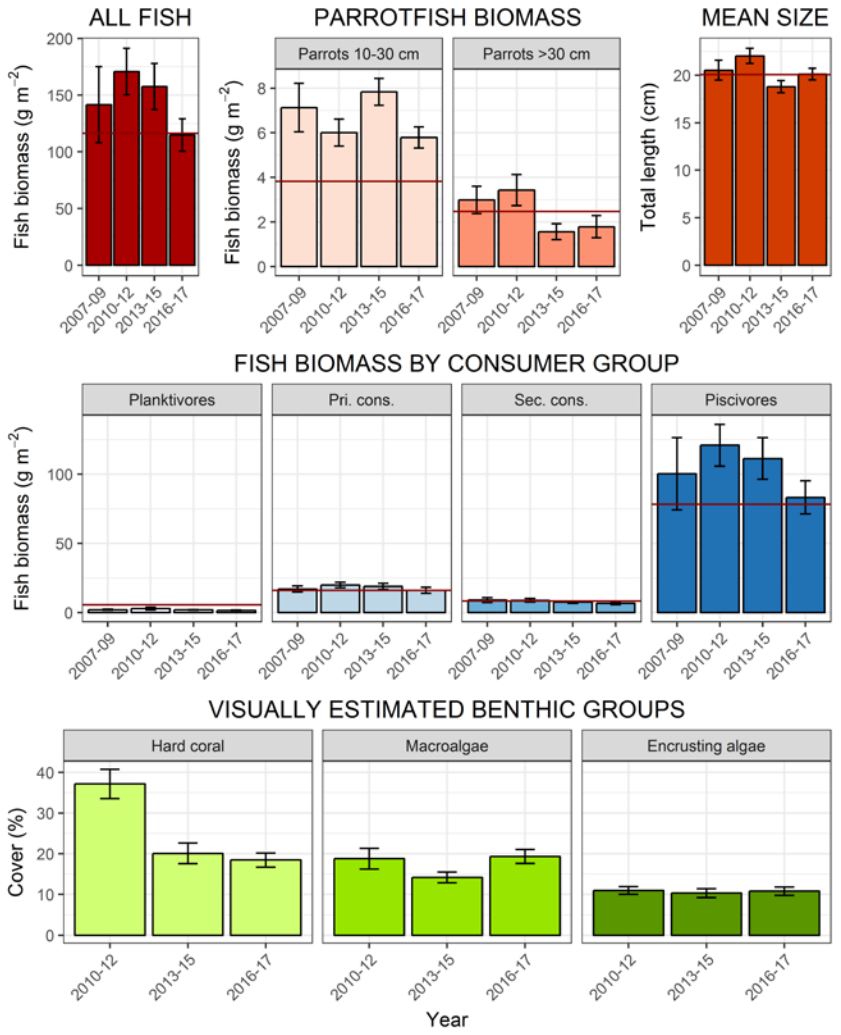

Figure 17. Lisianski Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The NWHI region mean estimates are plotted for reference (red line).

Midway Islands

Midway was surveyed 2007–09 (n = 46), 2010–12 (n = 25), 2013–15 (n = 42), 2016–17 (n = 12).

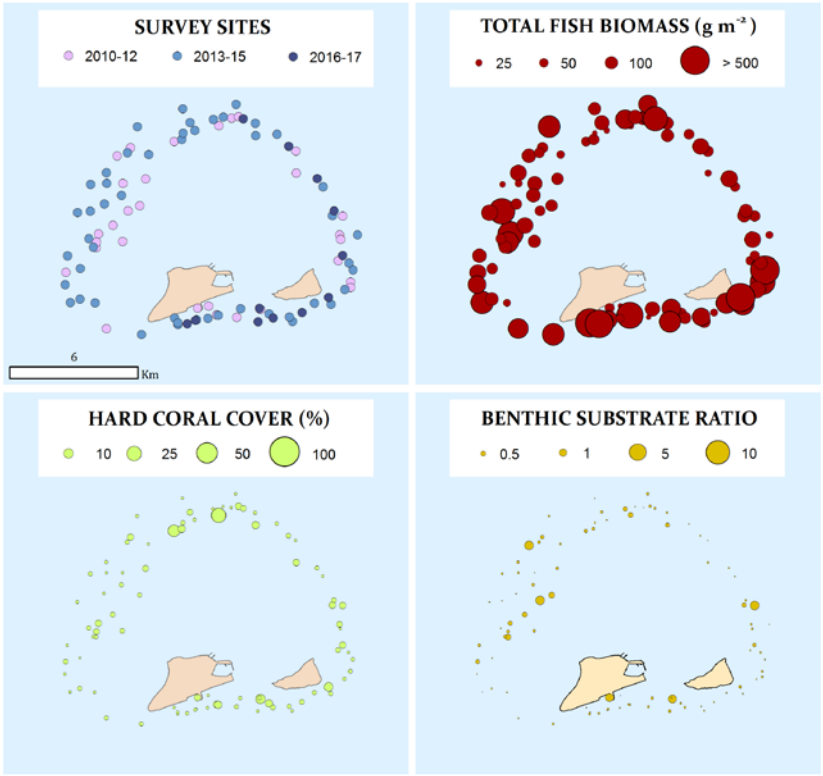

Figure 18. Midway Islands site survey data for 2010-12, 2013-15, and 2016-17identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate rat (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

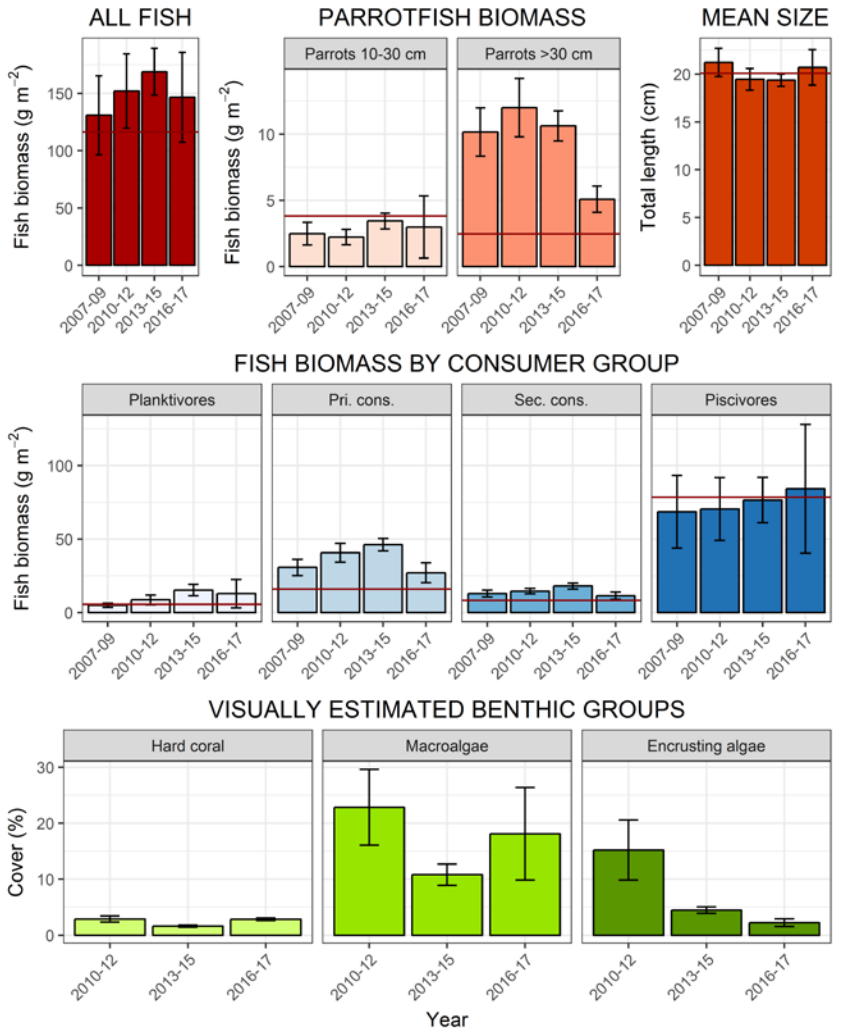

Figure 19. Midway Islands fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos, for forereef habitat only. The NWHI region mean forereef estimates are plotted for reference (red line).

Pearl and Hermes Reef

Pearl and Hermes Reef was surveyed in 2010–12 (n = 82), 2013–15 (n = 21), 2016–17 (n = 81).

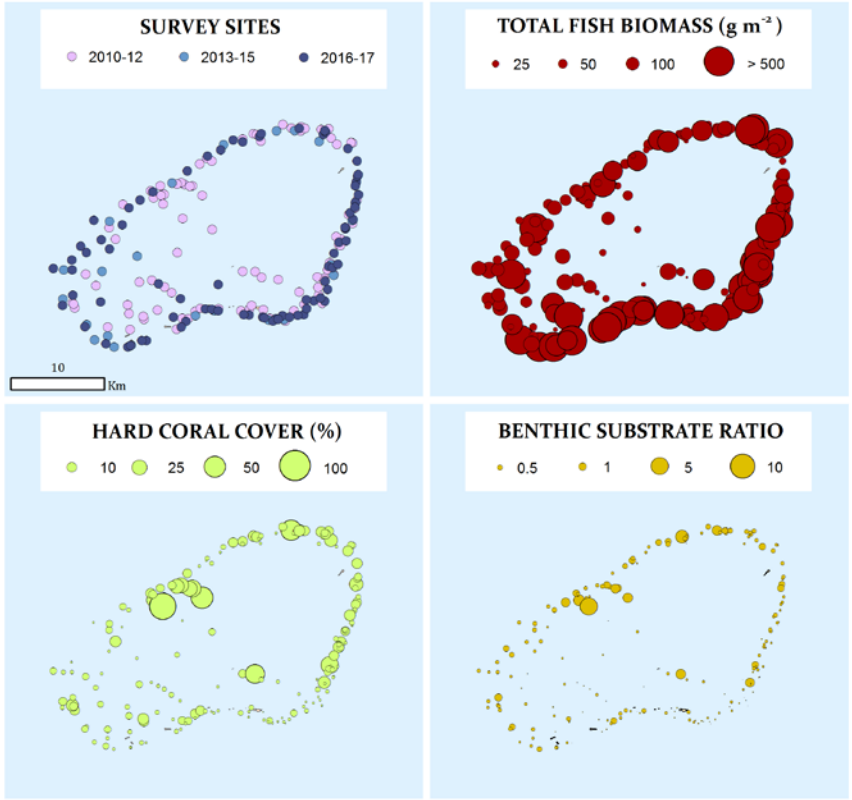

Figure 20. Pearl and Hermes Reef site survey data for 2010–12, 2013–15, and 2016–17 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

The forereef habitat was surveyed in 2010–12 (n = 48), 2013–15 (n = 21), 2016–17 (n = 76).

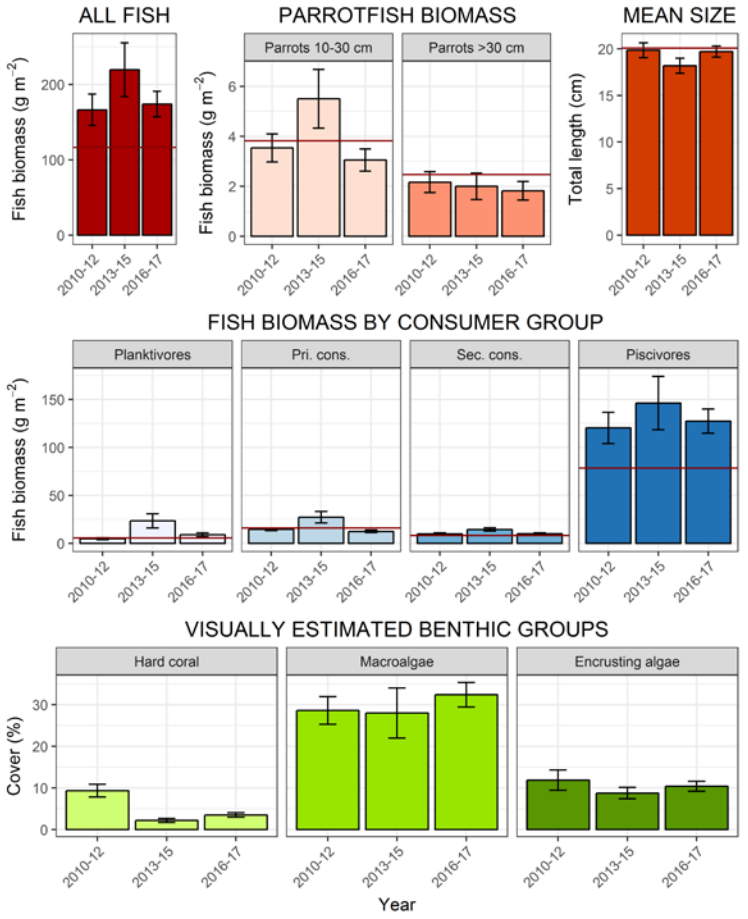

Figure 21. Pearl & Hermes Reef fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos, for forereef habitat only. The NWHI region mean forereef estimates are plotted for reference (red line).

The lagoon habitat was surveyed in 2016–17 (n = 5).

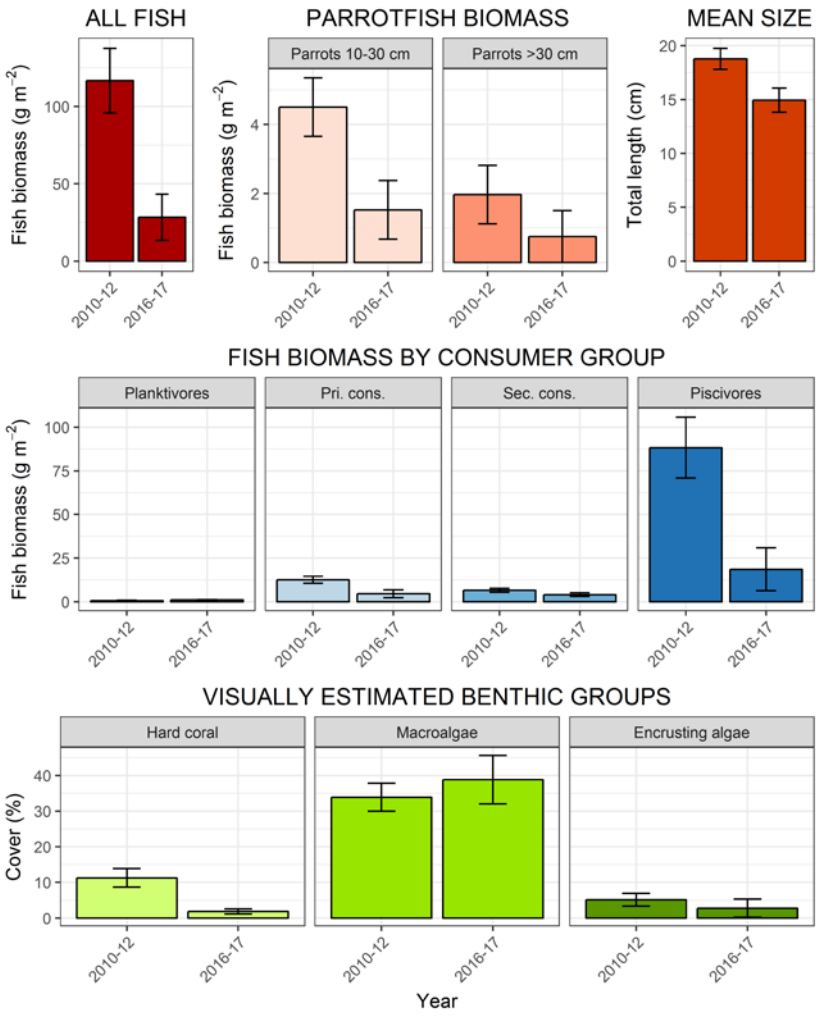

Figure 22. Pearl & Hermes Reef fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos, for lagoon habitat only. The lagoon was not sampled in 2013–15.

Pacific Remote Islands Marine National Monument (PRIMNM)

Wake Island

Wake Island was surveyed in 2009 (n = 29), 2011 (n = 30), 2014 (n = 45), and 2017 (n = 53).

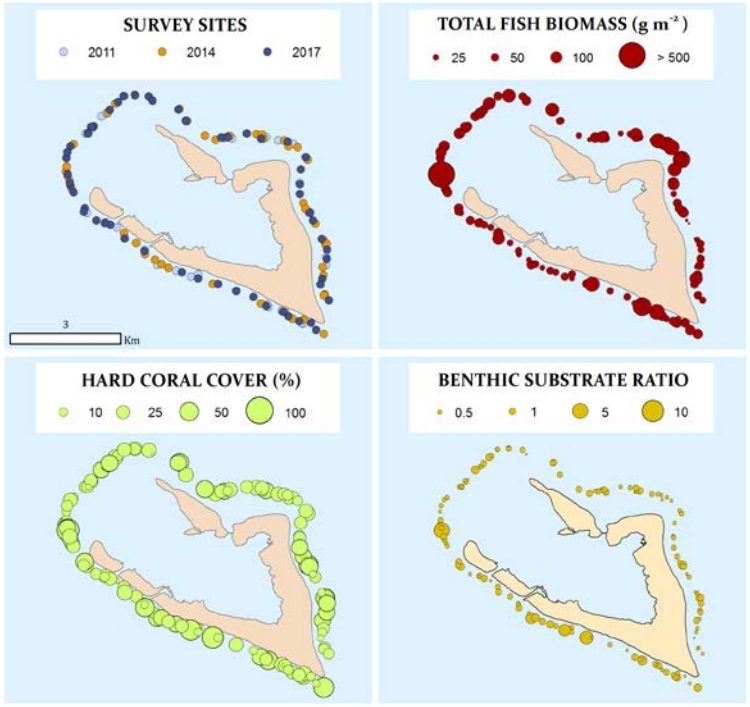

Figure 23. Wake Island site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

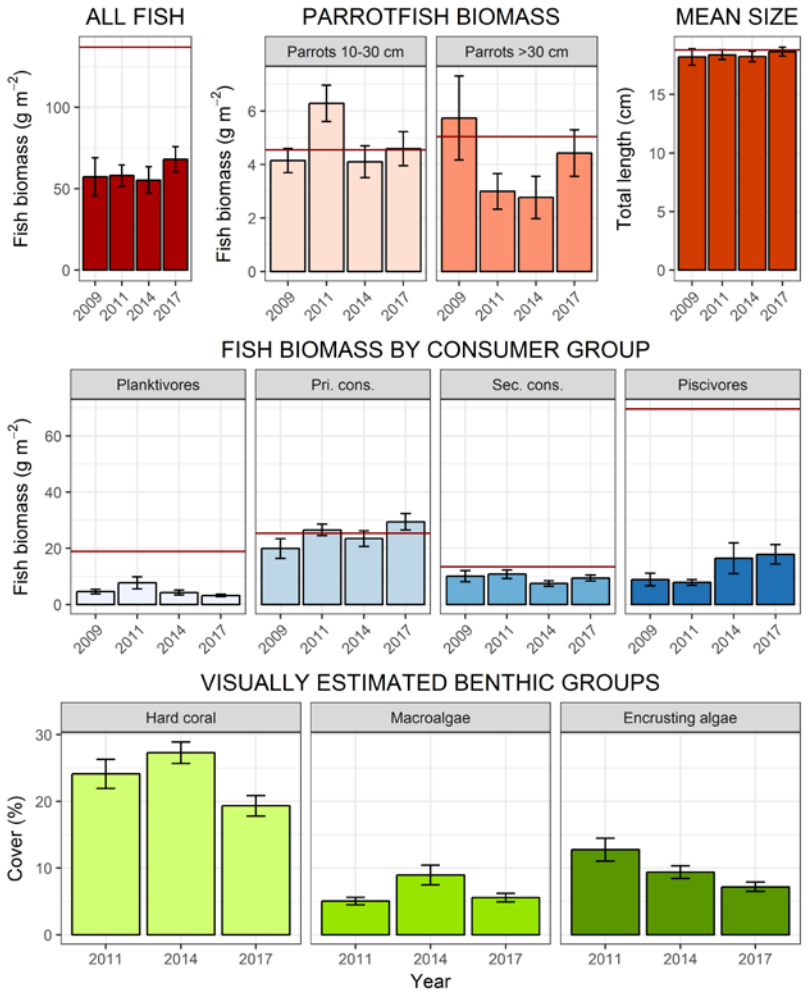

Figure 24. Wake Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The benthic estimates are pooled across all years. The Pacific Remote Islands Marine National Monument region mean estimates are plotted for reference (red line).

Jarvis Island

Jarvis Island was surveyed in 2010 (n = 30), 2012 (n = 42), 2015 (n = 62), 2016 (n = 30), and 2017 (n = 28).

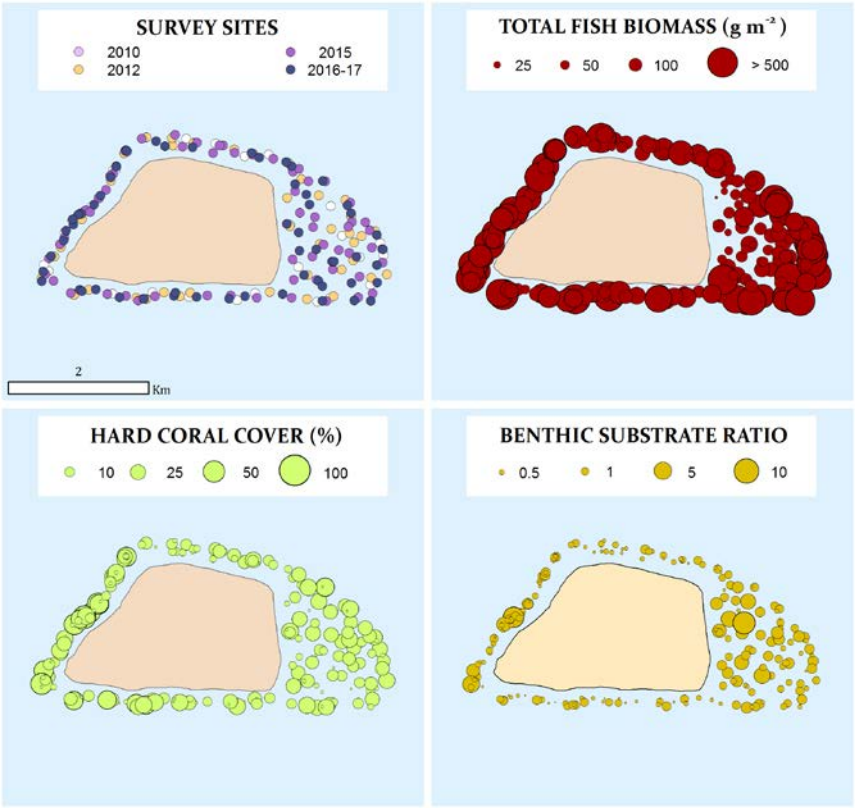

Figure 25. Jarvis Island site survey data for 2010, 2012, 2015, 2016, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

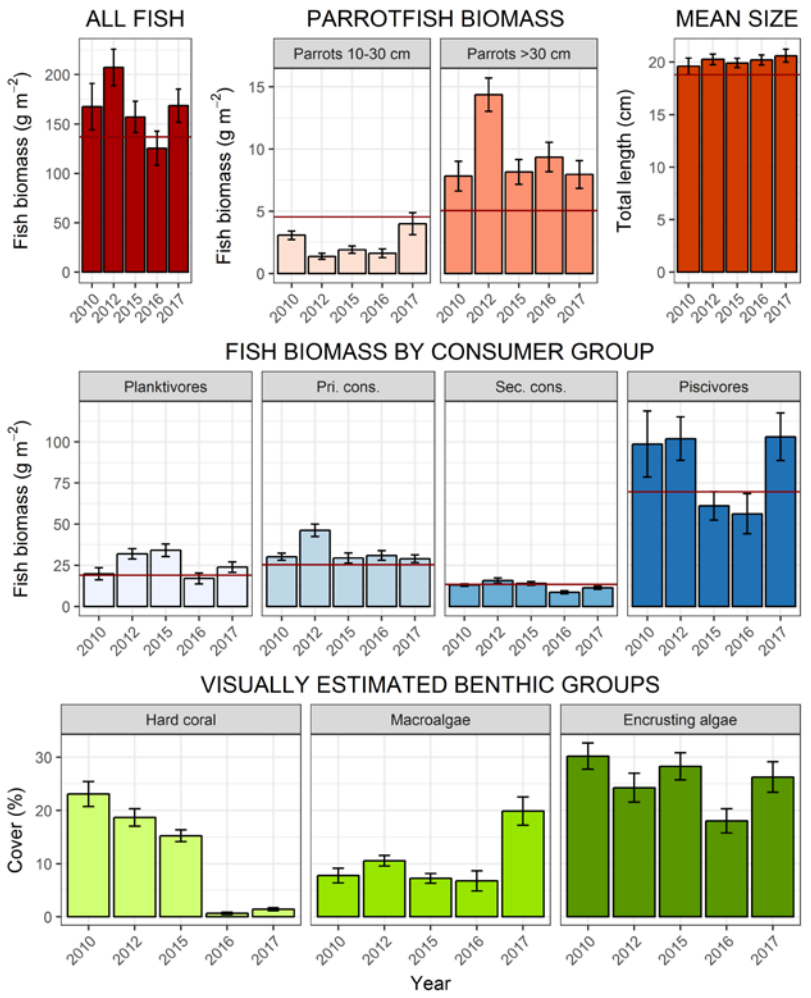

Figure 26. Jarvis Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The benthic estimates are pooled across all years. The Pacific Remote Islands Marine National Monument mean estimates are plotted for reference (red line).

Pacific Remote Islands MNM (Wake Island, Phoenix Islands: Howland and Baker)

Towed-diver surveys were conducted at Wake Island in 2005 (n = 13), 2007 (n = 18), 2009 (n = 13), 2011 (n = 14), 2014 (n = 10), and 2017 (n = 9).

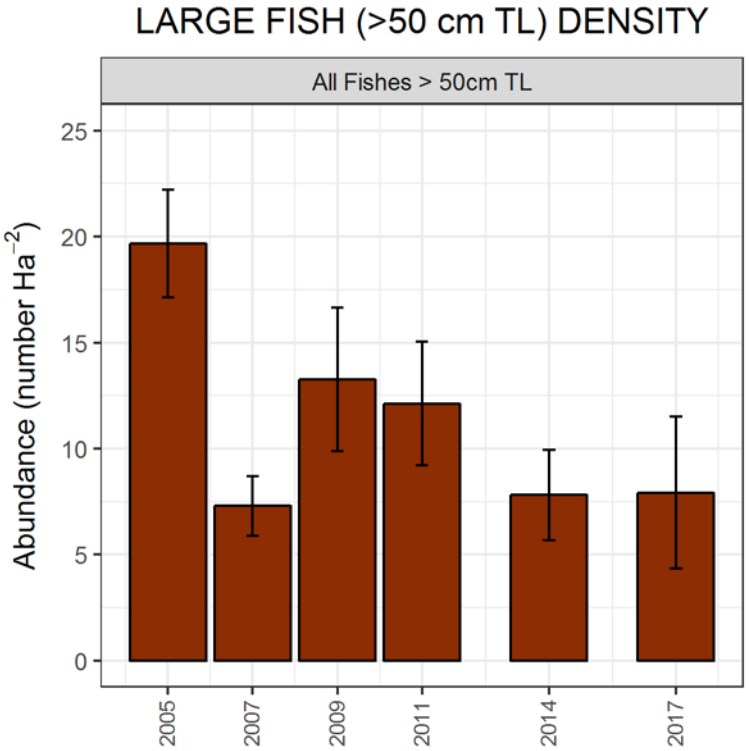

Figure 27. Mean density (number Ha^{-2} ± SE) of fishes ≥ 50 cm TL surveyed via the towed-diver survey method at Wake Island.

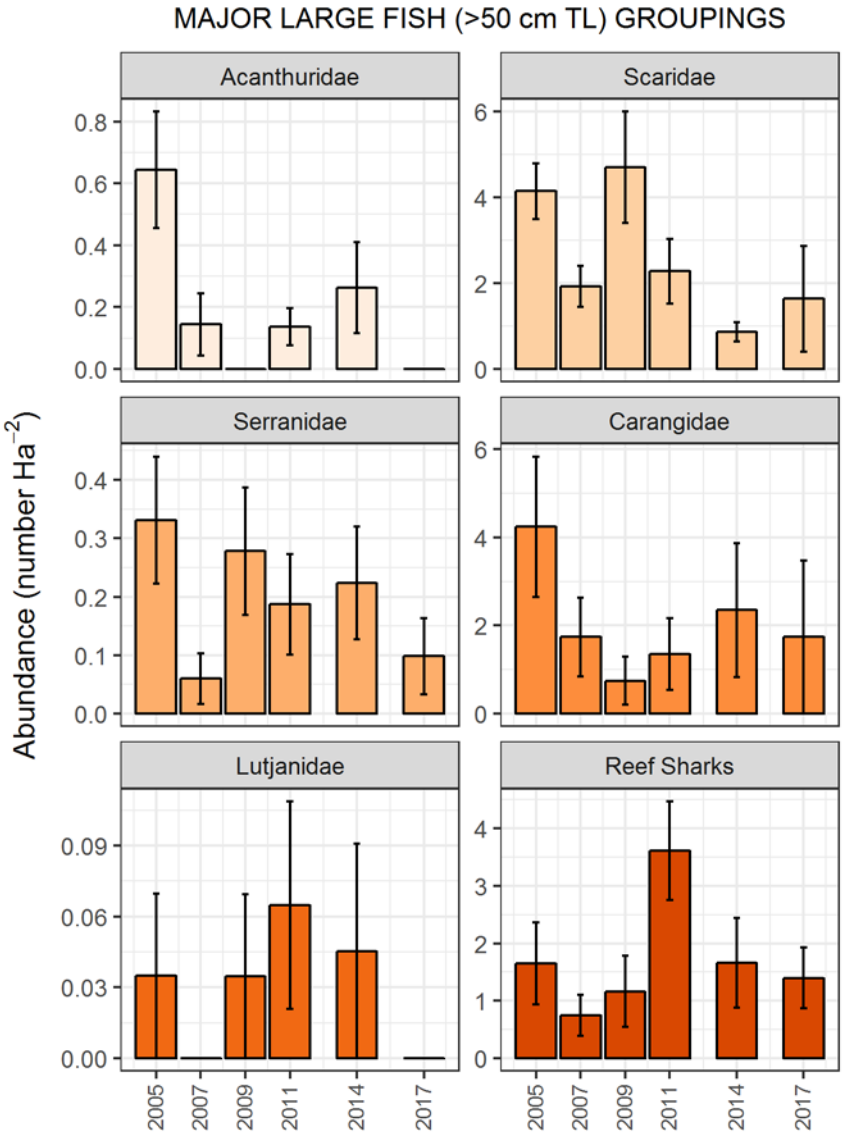

Figure 28. Mean density (number Ha^{-2} ± SE) of fishes ≥ 50 cm TL surveyed via the towed-diver survey method at Wake Island.

Towed-diver surveys were conducted at the Phoenix Islands in 2002 (n = 10), 2004 (n = 16), 2006 (n = 13), 2008 (n = 15), 2010 (n = 19), 2012 (n = 20), 2015 (n = 10), and 2017 (n = 10).

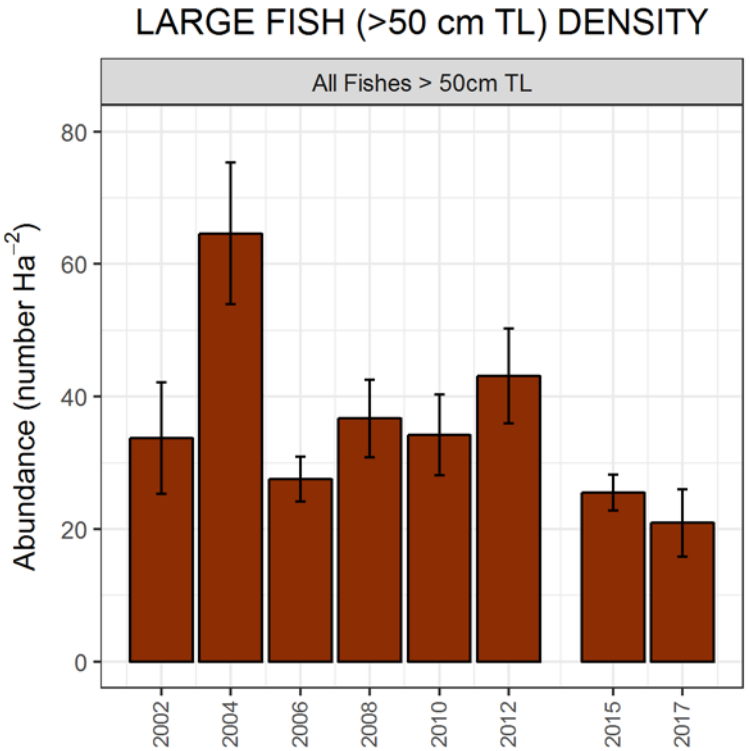

Figure 29. Mean density (number Ha^{-2} ± SE) of fishes ≥ 50 cm TL surveyed via the towed-diver survey method at the Phoenix Islands.

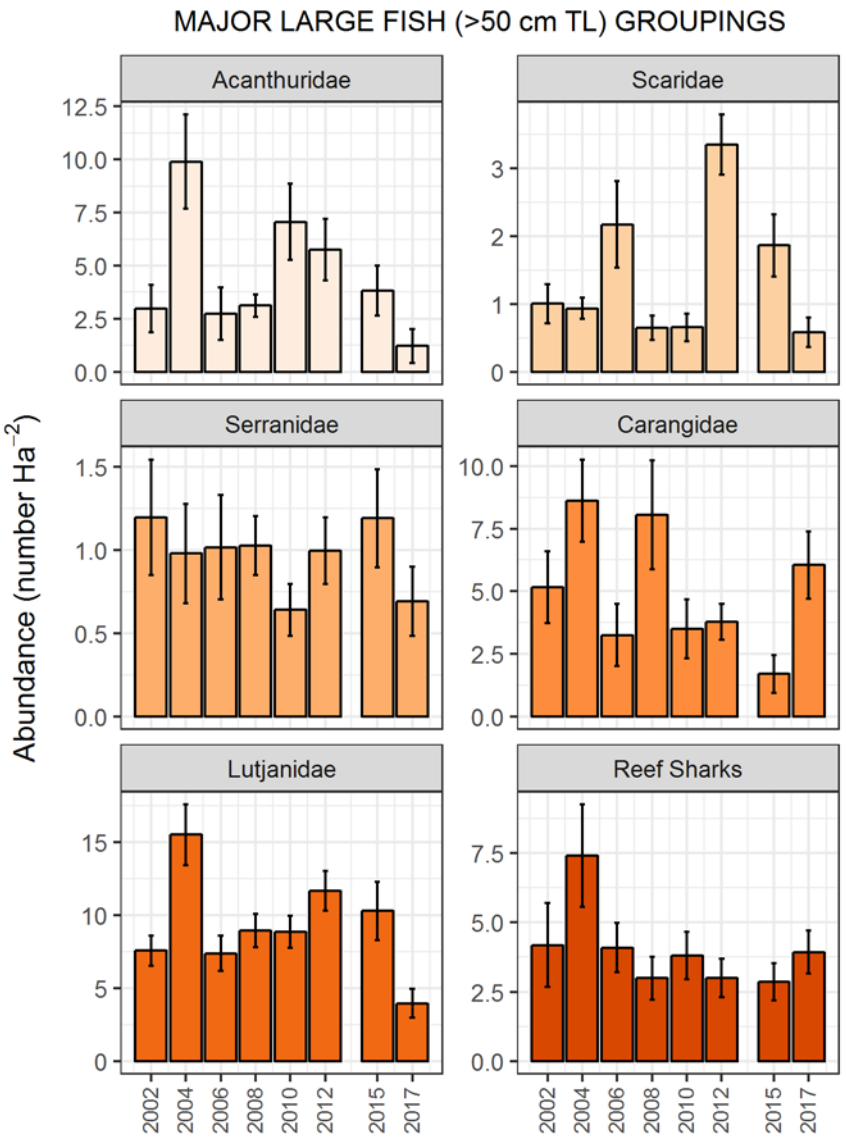

Figure 30. Mean density (number Ha^{-2} ± SE) of fishes ≥ 50 cm TL for family groups Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and reef sharks at the Phoenix Islands.

Northern Mariana Archipelago

Agrihan

Agrihan Island was surveyed in 2009 (n = 14), 2011 (n = 20), and 2017 (n = 19). Agrihan was not surveyed during 2014 due to time restrictions.

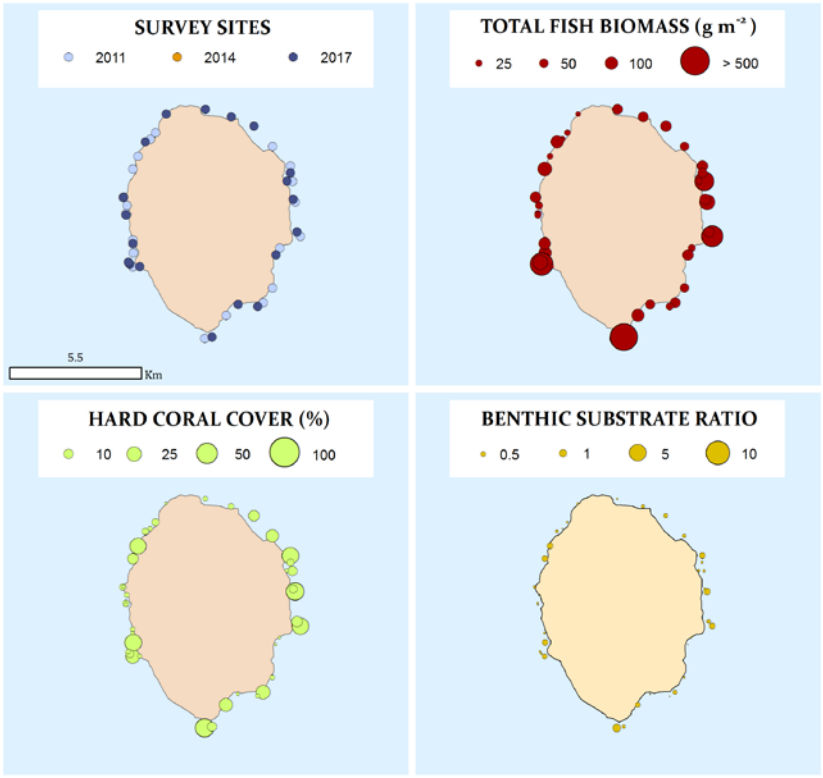

Figure 31. Agrihan Island site survey data for 2011, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

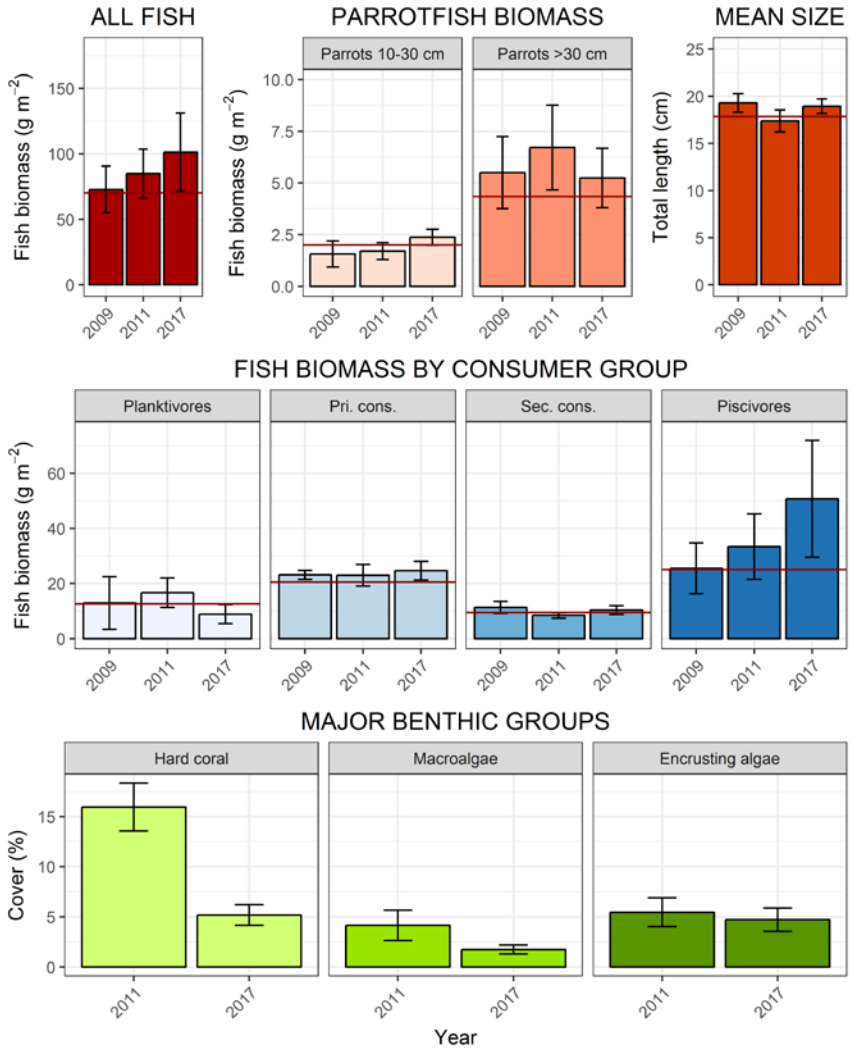

Figure 32. Agrihan Islands fish and benthic plots showing the biomass (g m–2 ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Northern Mariana region mean estimates are plotted for reference (red line).

Asuncion Island

Asuncion Island was surveyed in 2009 (n = 13), 2011 (n = 20), 2014 (n = 21), and 2017 (n = 19).

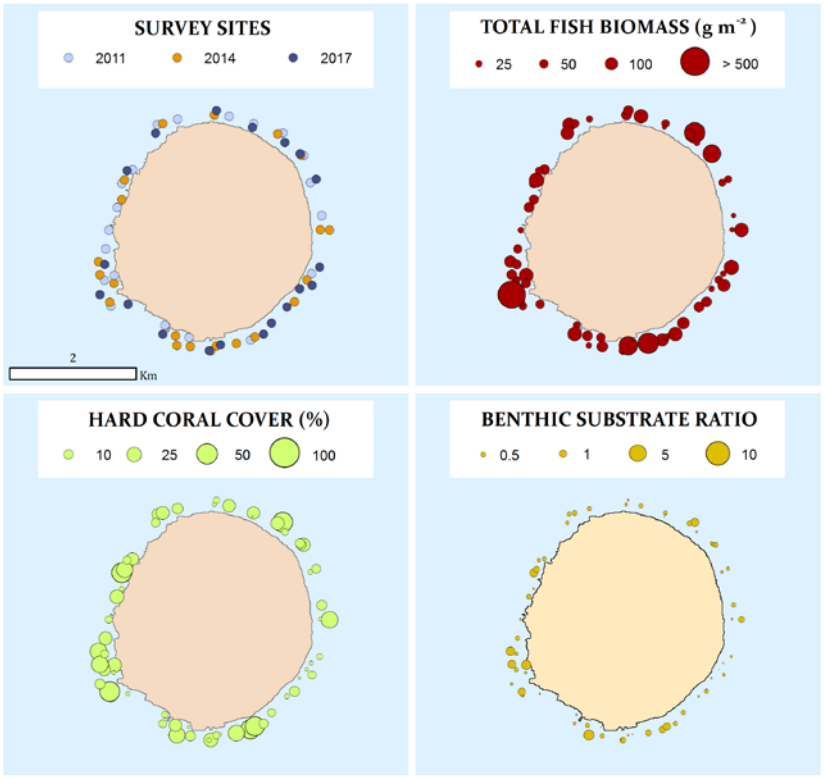

Figure 33. Asuncion Island site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

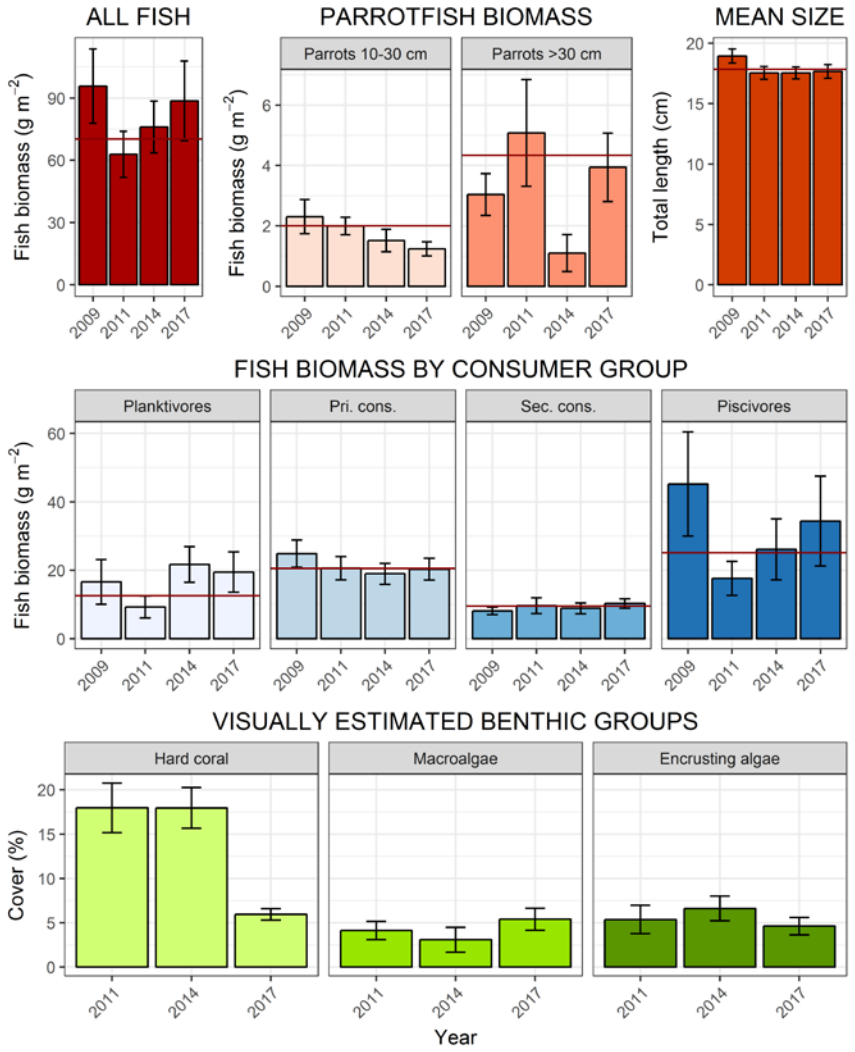

Figure 34. Asuncion Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Northern Mariana region mean estimates are plotted for reference (red line).

Farallon de Pajaros Island

Farallon de Pajaros Island was surveyed in 2009 (n = 7), 2011 (n = 12), 2014 (n = 11), and 2017 (n = 16).

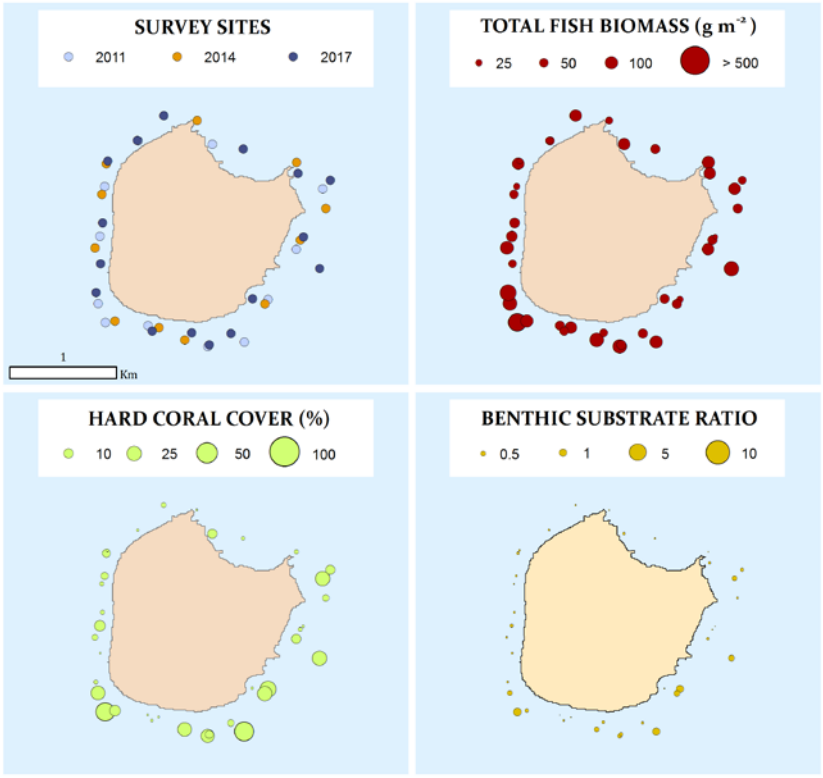

Figure 35. Farallon de Pajaros Island site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

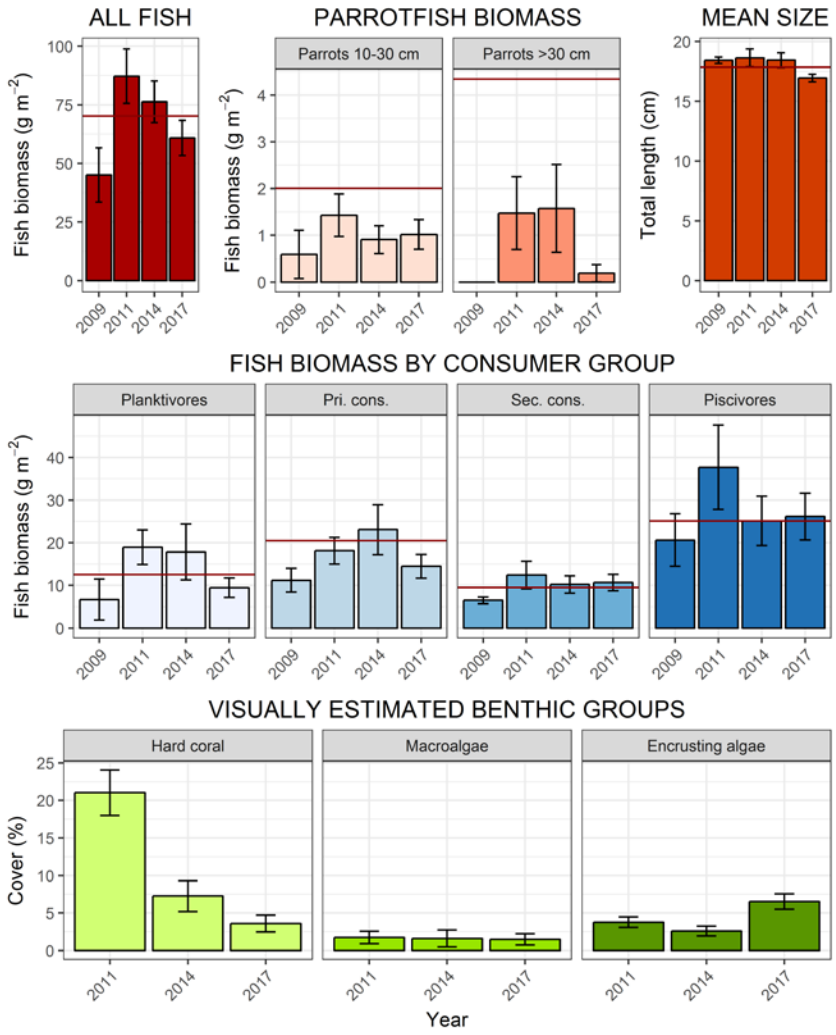

Figure 36. Farallon de Pajaros Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for forereef habitat. The Northern Mariana region mean estimates are plotted for reference (red line).

Maug Islands

Maug Islands were surveyed in 2009 (n = 21), 2011 (n = 30), 2014 (n = 40), and 2017 (n = 38).

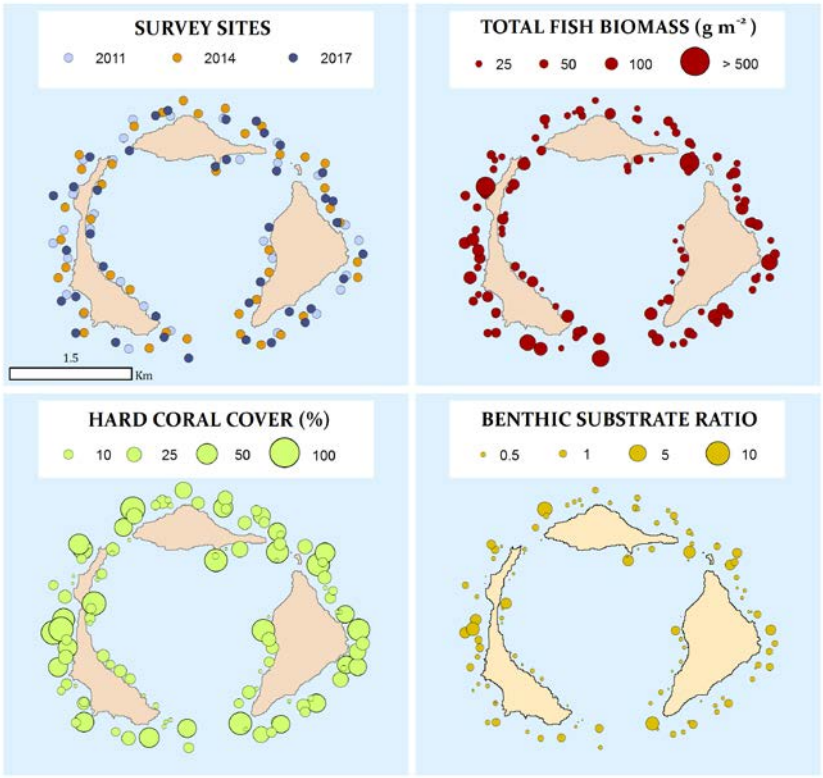

Figure 37. Maug Islands site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae plus sand)) (bottom right).

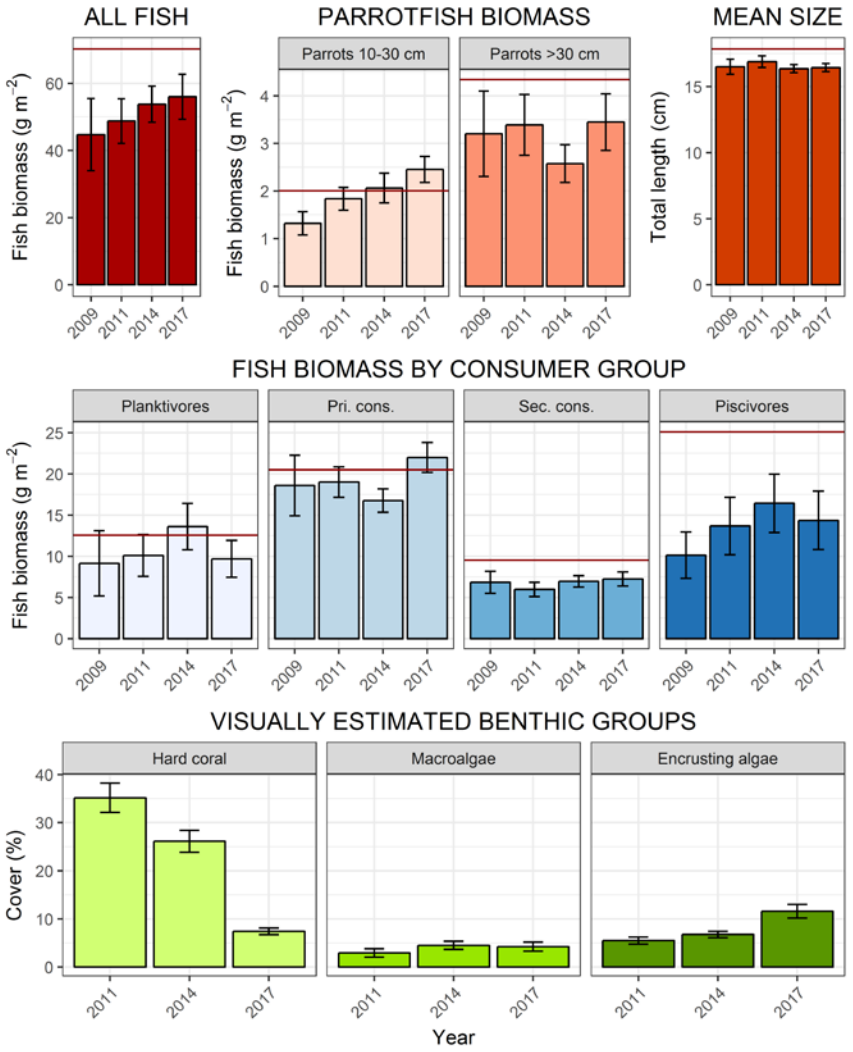

Figure 38. Maug Islands fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Northern Mariana region mean estimates are plotted for reference (red line).

Pagan Island

Pagan Island was surveyed in 2009 (n = 21), 2011 (n = 29), 2014 (n = 43), and 2017 (n = 40).

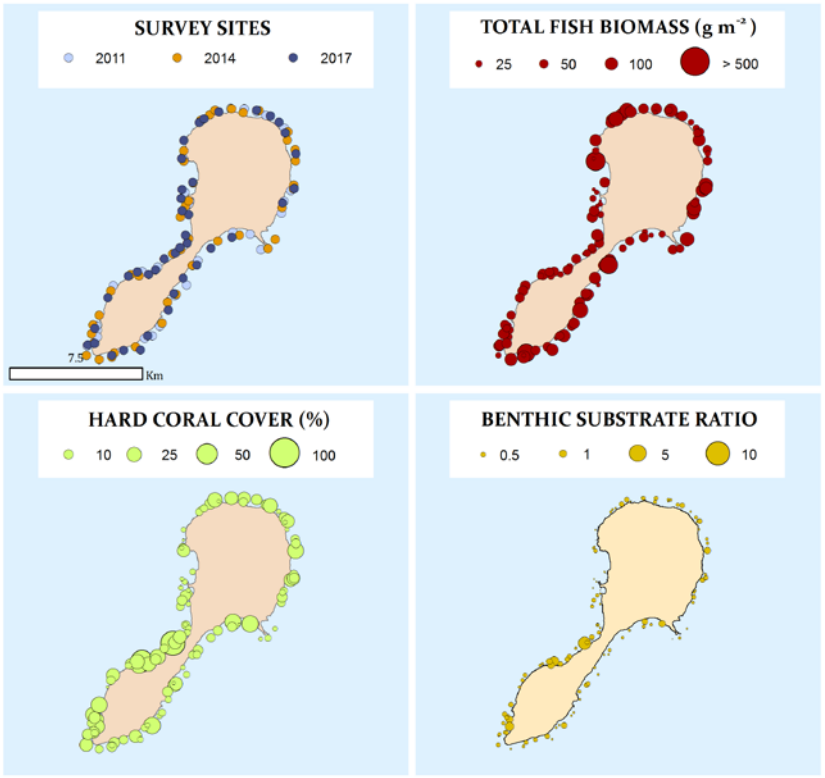

Figure 39. Pagan Island site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae plus sand)) (bottom right).

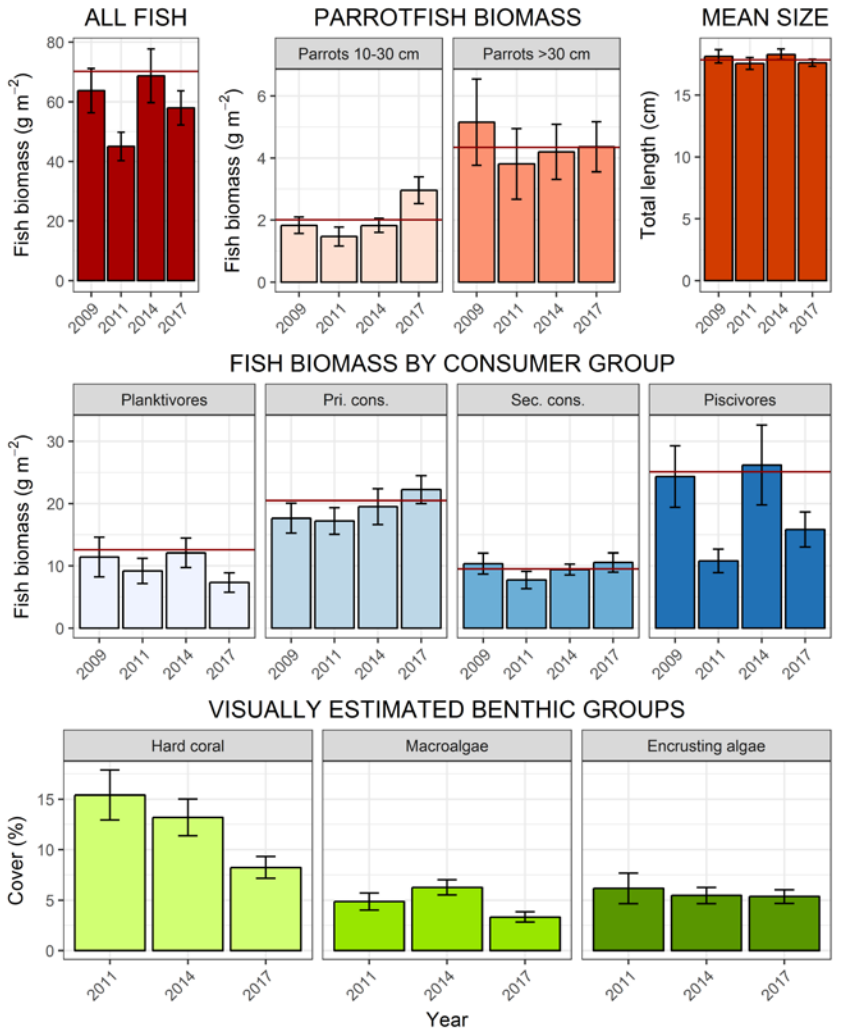

Figure 40. Pagan Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Northern Mariana region mean estimates are plotted for reference (red line).

Alamagan, Guguan, and Sarigan Islands (AGS)

These three islands were combined for analysis purposes due to proximity and small size. Alamagan, Guguan, and Sarigan Islands were surveyed in 2009 (n = 19), 2011 (n = 24), 2014 (n = 33), and 2017 (n = 18).

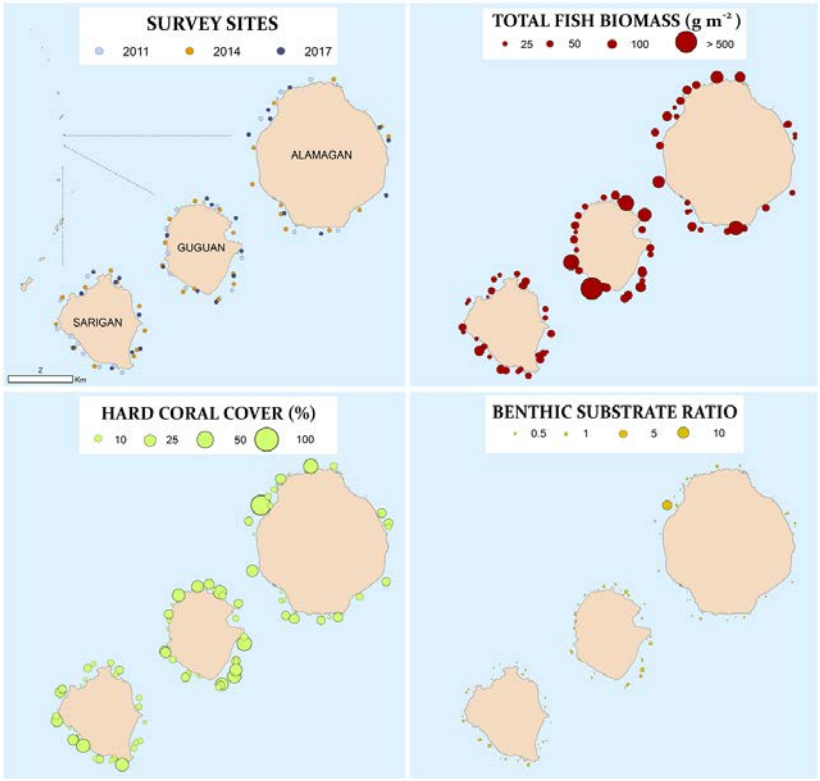

Figure 41. Alamagan, Guguan, and Sarigan Islands site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

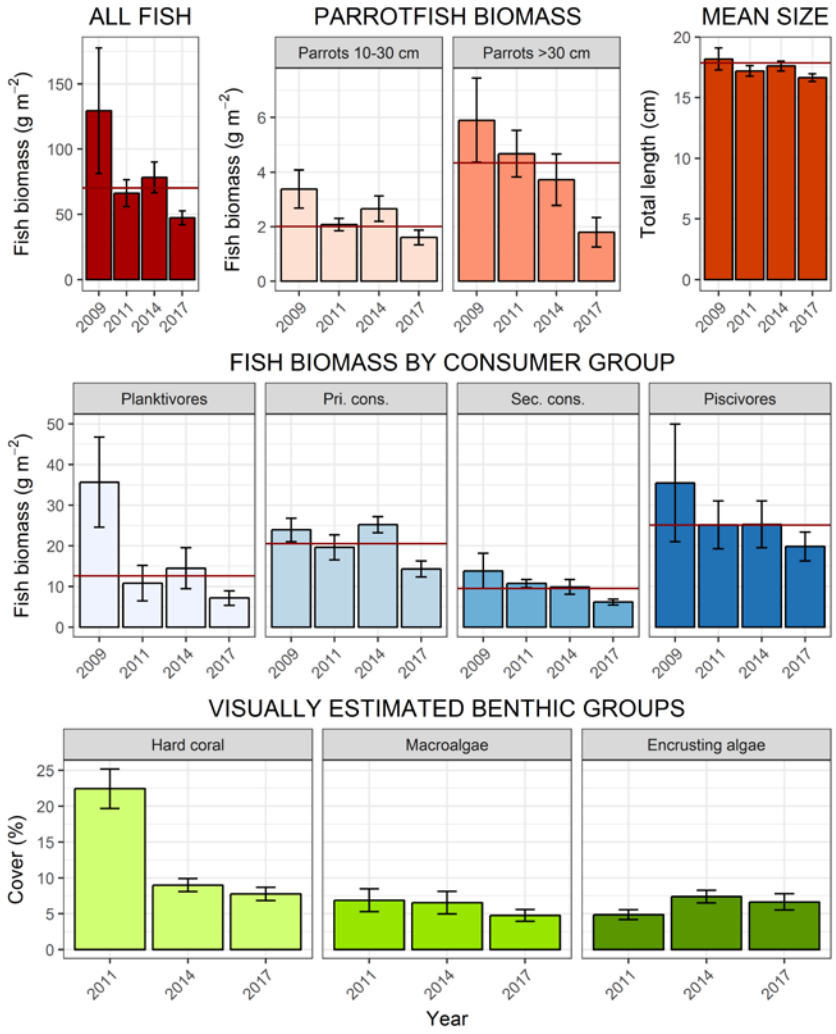

Figure 42. Alamagan, Guguan, and Sarigan Islands fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Northern Mariana region mean estimates are plotted for reference (red line).

Northern Mariana Archipelago

Towed-diver surveys were conducted in the N. Mariana Archipelago in 2003 (n = 77), 2005 (n = 55), 2007 (n = 57), 2009 (n = 57), 2011 (n = 55), 2014 (n = 35), and 2017 (n = 59).

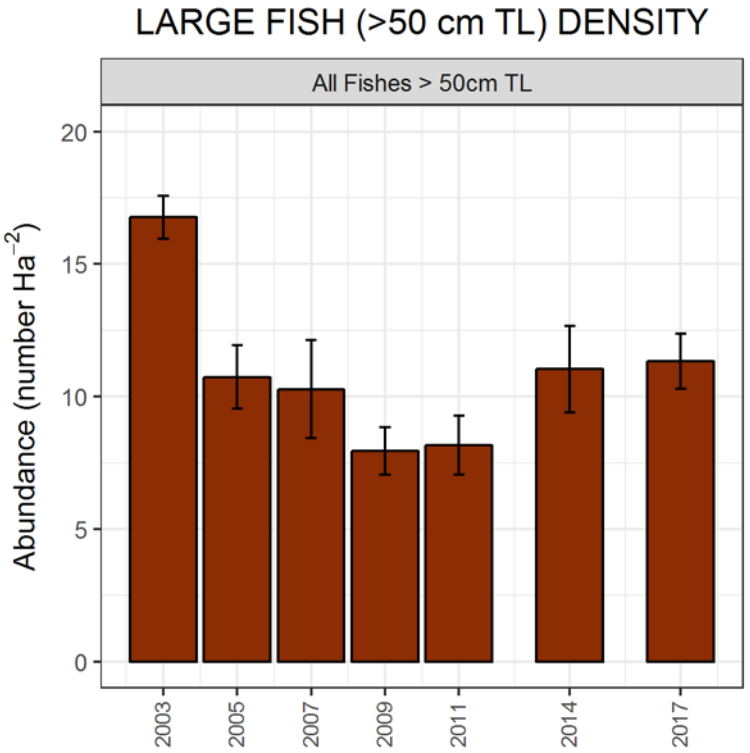

Figure 43. Mean density (number Ha^{-2} ± SE) of fishes ≥ 50 cm TL surveyed via the towed-diver survey method in the N. Mariana Archipelago.

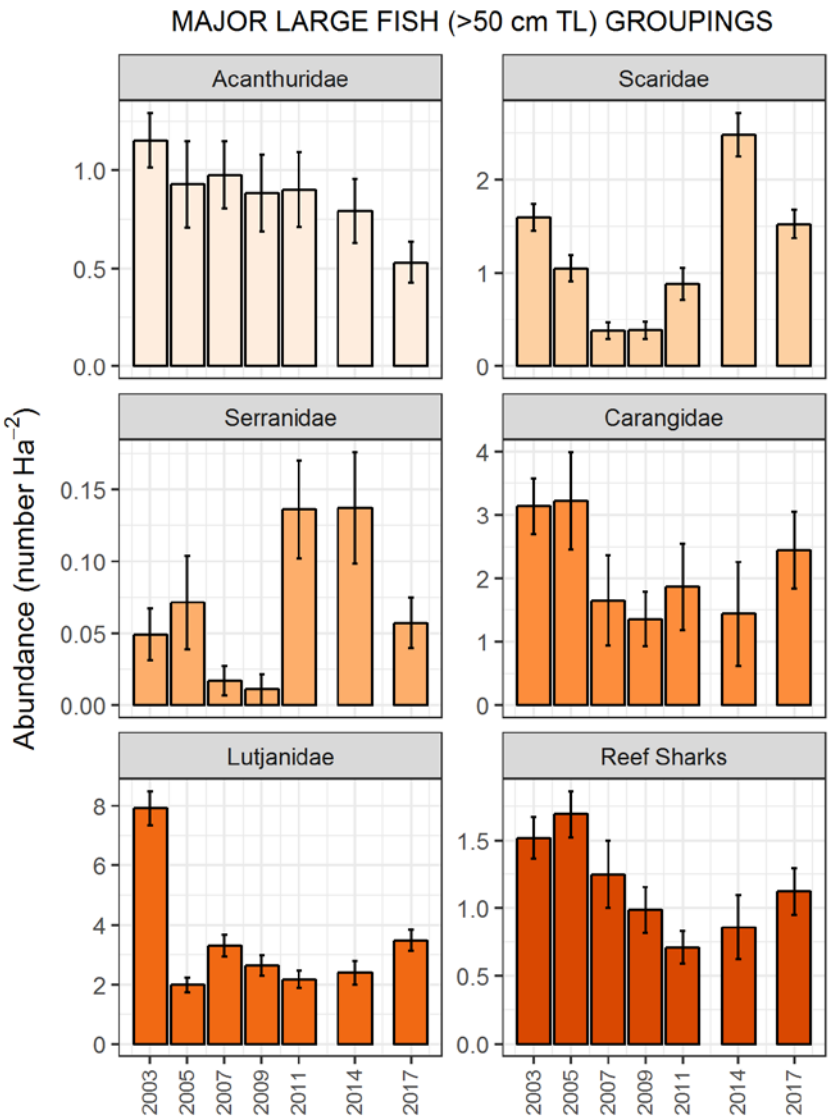

Figure 44. Mean density (number Ha^{-2} ± SE) of fishes ≥ 50 cm TL for family groups Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and reef sharks in the N. Mariana Archipelago.

Southern Mariana Archipelago

Aguijan Island

Aguijan Island was surveyed in 2009 (n = 6), 2011 (n = 13), 2014 (n = 10), and 2017 (n = 17).

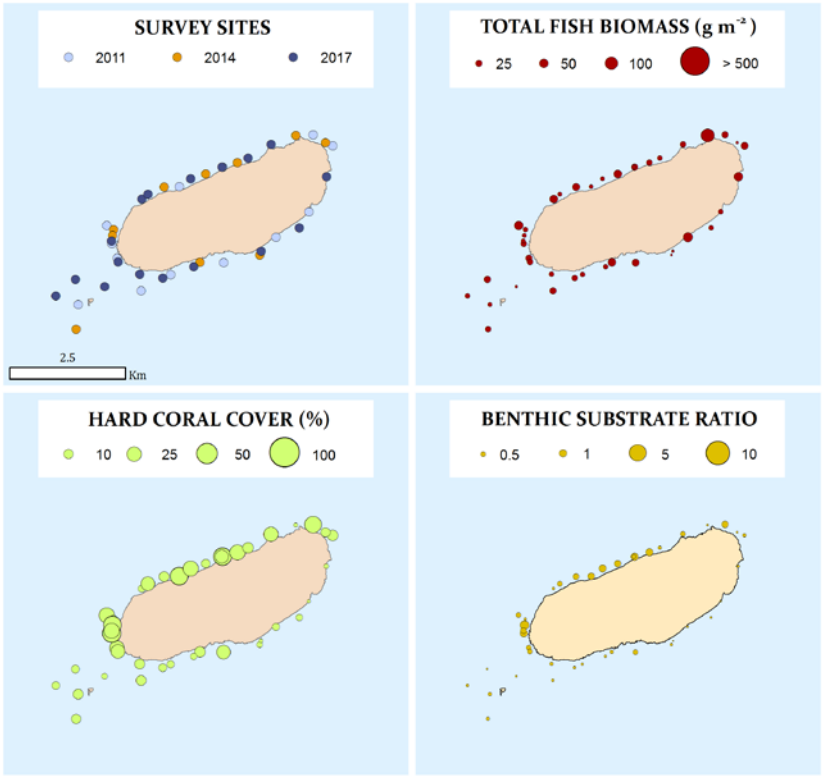

Figure 45. Aguijan Island site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae plus sand)) (bottom right).

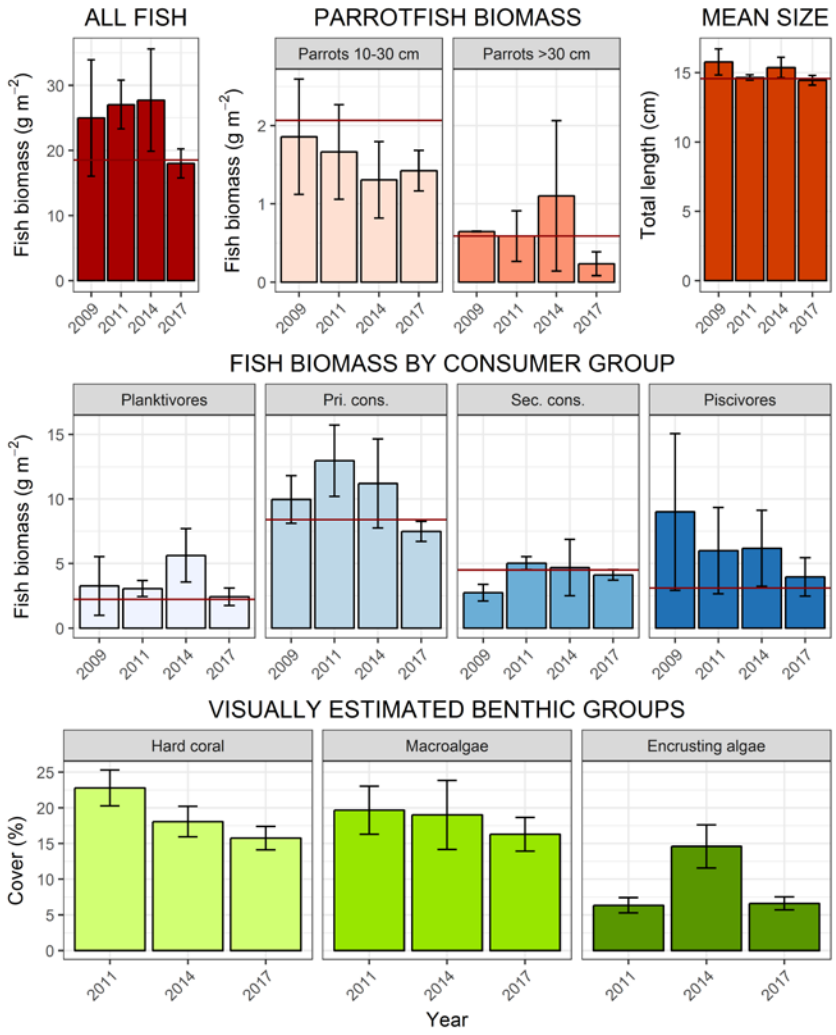

Figure 46. Aguijan Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Southern Mariana region mean estimates are plotted for reference (red line).

Guam Island

Guam Island was surveyed in 2009 (n = 25), 2011 (n = 133), 2014 (n = 104), and 2017 (n = 66).

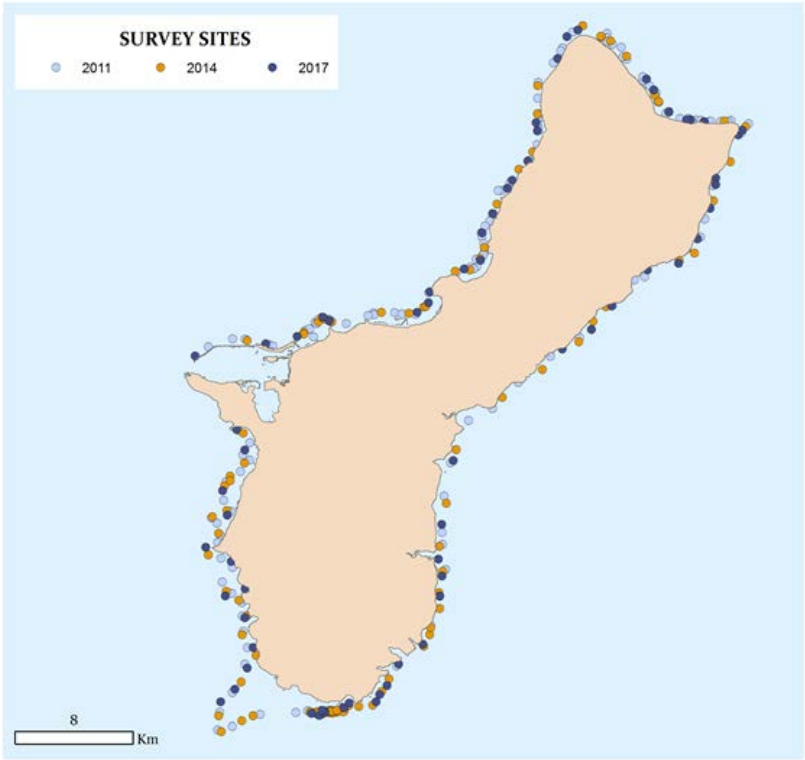

Figure 47. Guam Island site survey data for 2011, 2014, and 2017, identified by year.

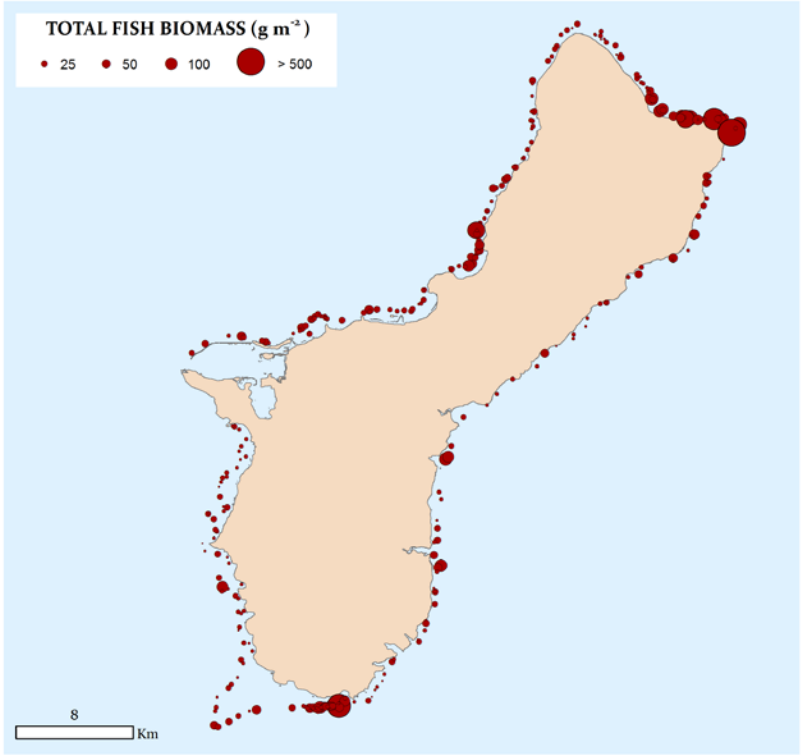

Figure 48. Total fish biomass recorded at each site per year.

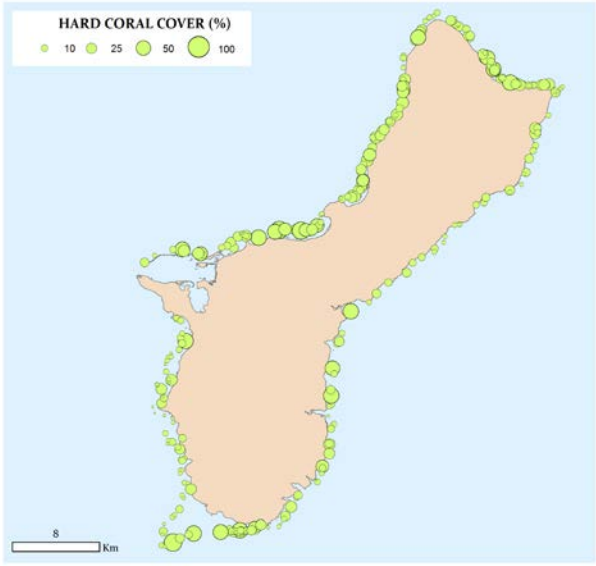

Figure 49. Hard coral cover (%) assessed by rapid visual assessment.

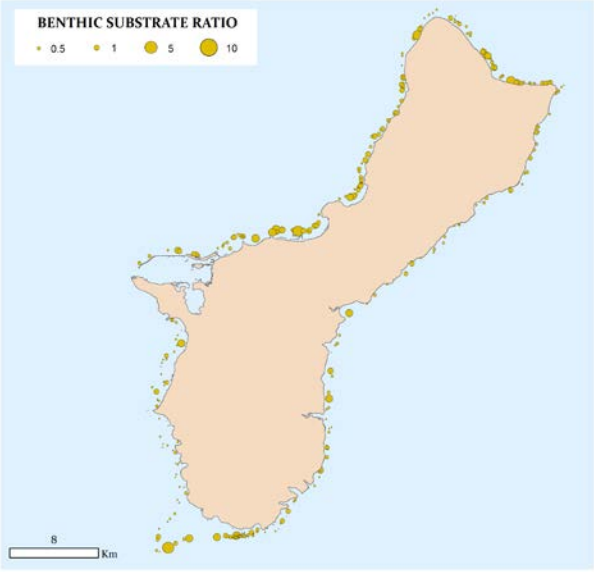

Figure 50. Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)).

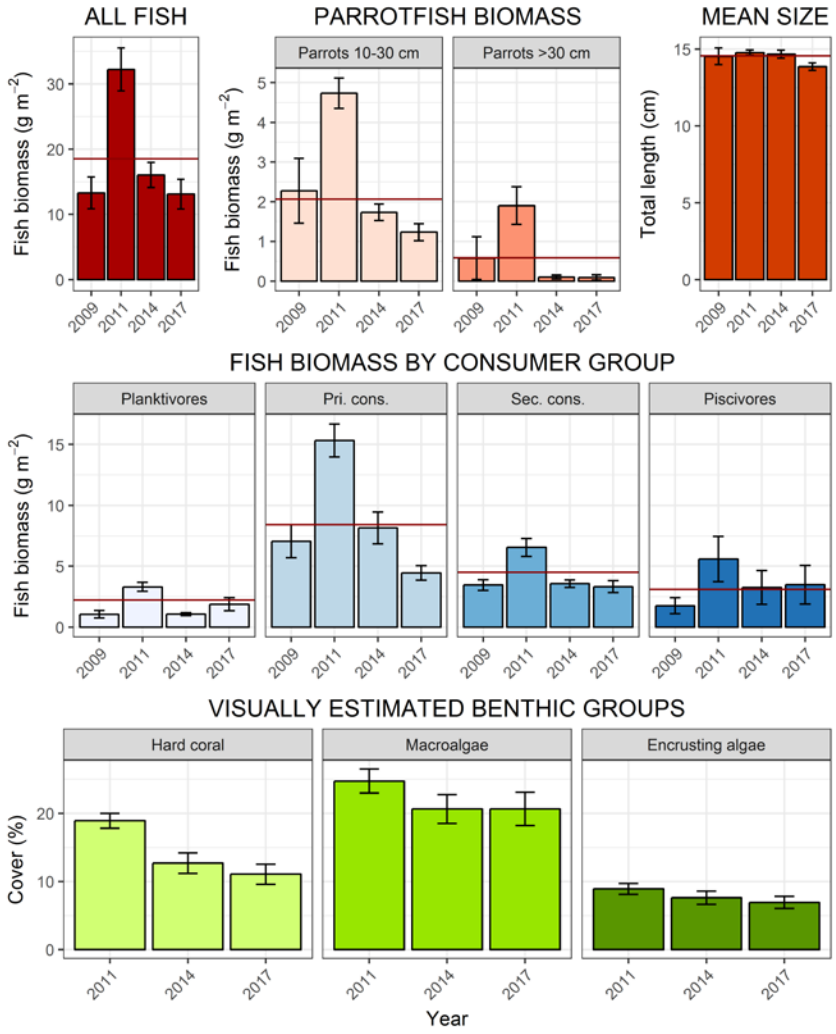

Figure 51. Guam Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Southern Mariana region mean estimates are plotted for reference (red line).

Rota Island

Rota Island was surveyed in 2009 (n = 14), 2011 (n = 24), 2014 (n = 28), and 2017 (n = 28).

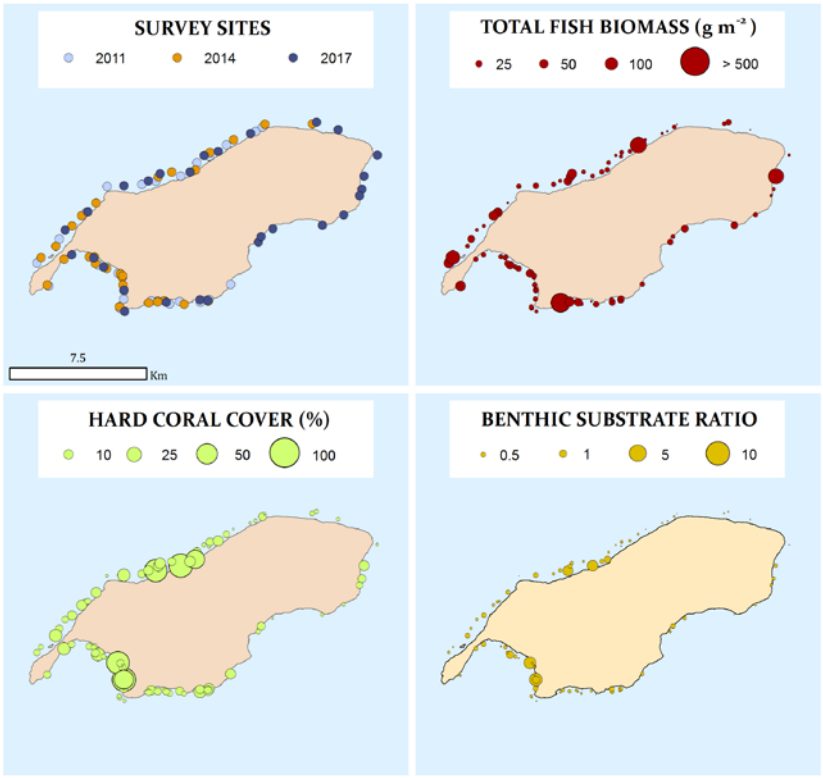

Figure 52. Rota Island site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae plus sand)) (bottom right).

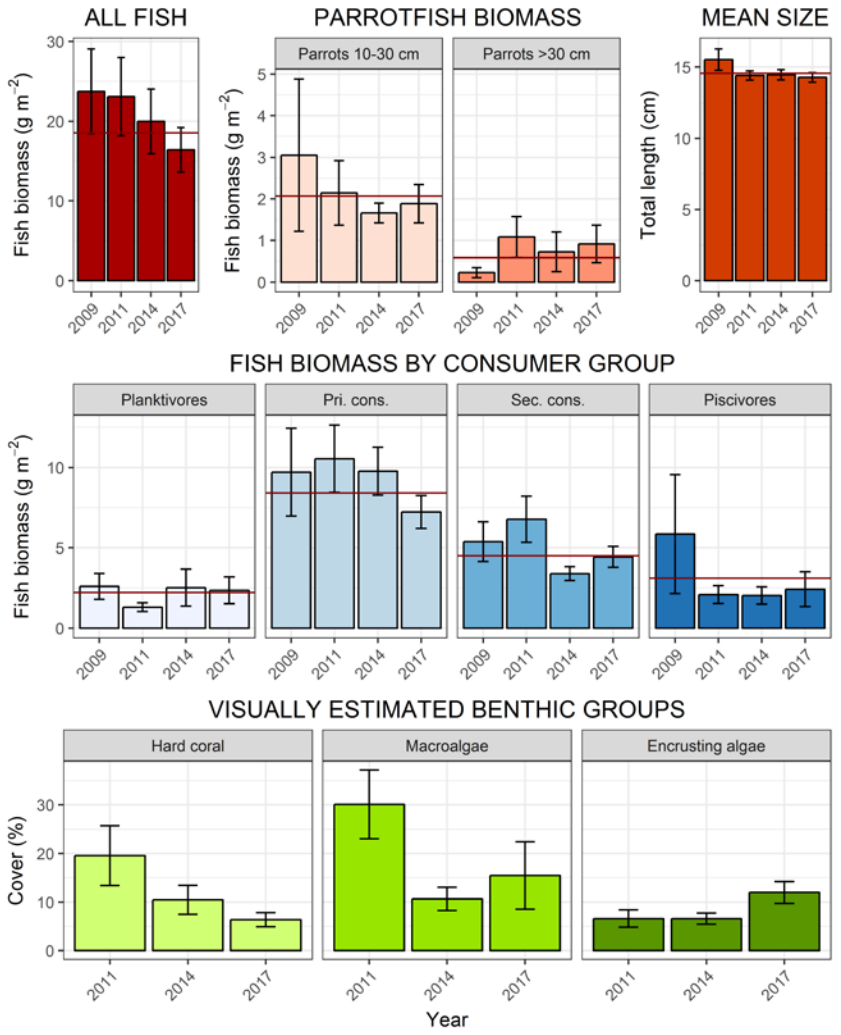

Figure 53. Rota Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Southern Mariana region mean estimates are plotted for reference (red line).

Saipan Island

Saipan Island was surveyed in 2009 (n = 22), 2011 (n =30), 2014 (n = 48), and 2017 (n = 37).

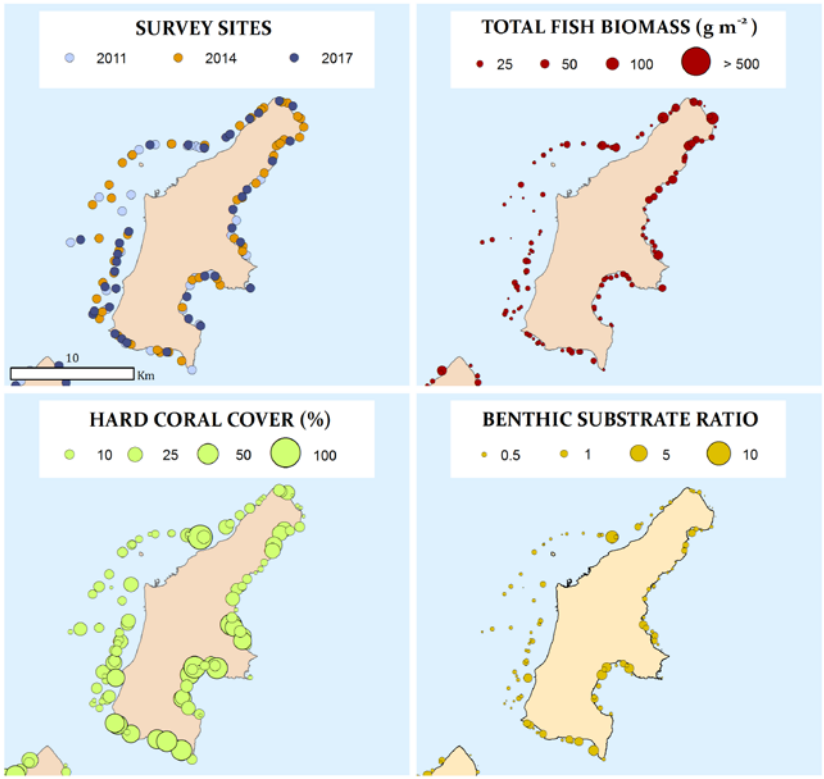

Figure 54. Saipan Island site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae / 100 – (hard coral plus crustose coralline algae plus sand)) (bottom right).

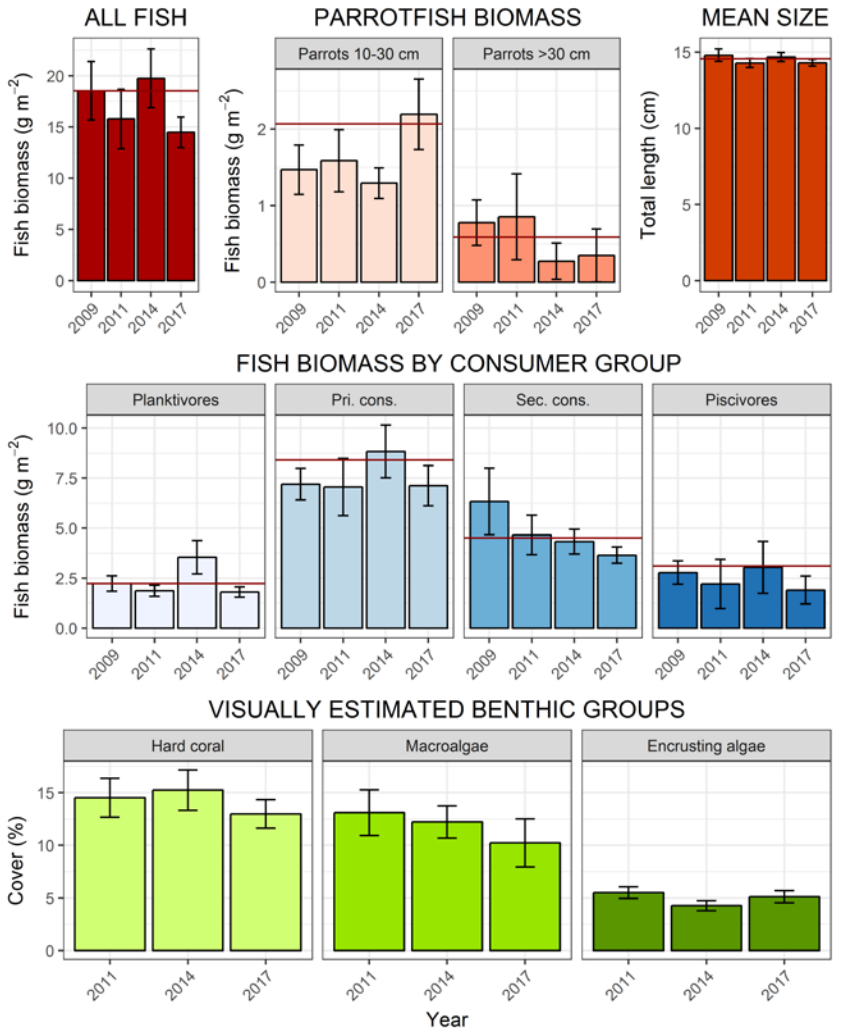

Figure 55. Saipan Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Southern Mariana region mean estimates are plotted for reference (red line).

Tinian Island

Tinian Island was surveyed in 2009 (n = 14), 2011 (n = 19), 2014 (n = 19), and 2017 (n = 24).

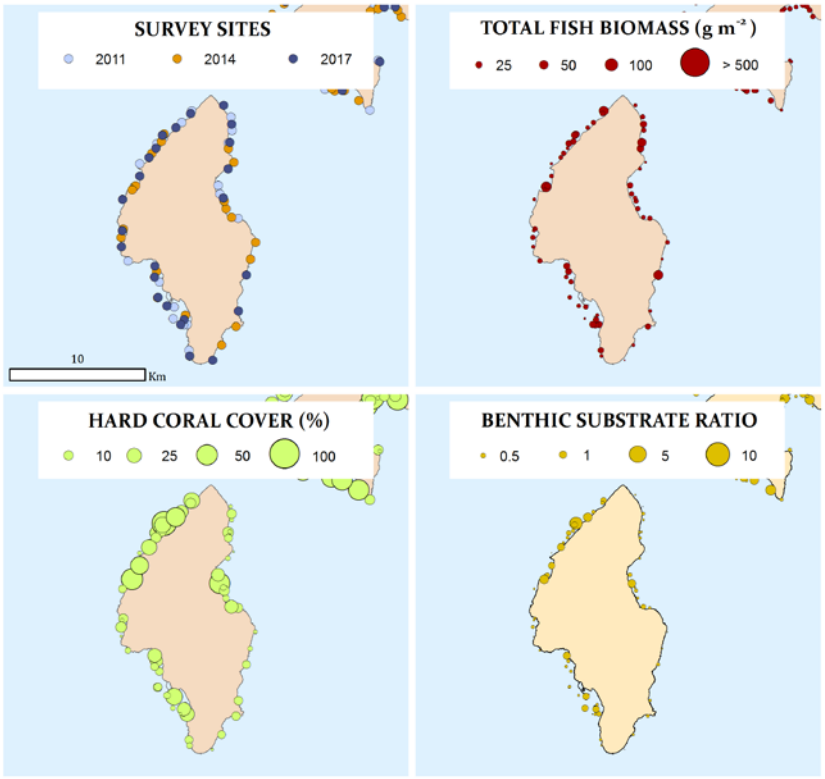

Figure 56. Tinian Island site survey data for 2011, 2014, and 2017 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus crustose coralline algae plus sand)) (bottom right).

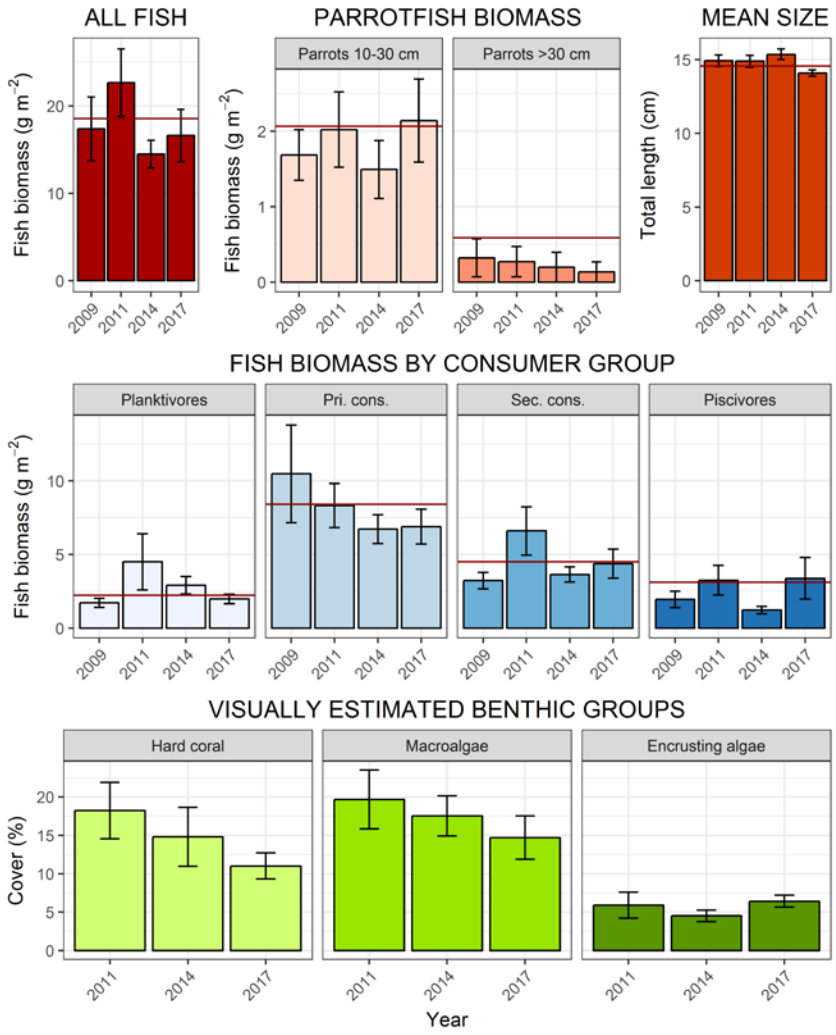

Figure 57. Tinian Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fishes observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Southern Mariana region mean estimates are plotted for reference (red line).

Southern Mariana Archipelago

Towed-diver surveys were conducted in the N. Mariana Archipelago in 2003 (n = 47), 2005 (n = 68), 2007 (n = 56), 2009 (n = 68), 2011 (n = 64), 2014 (n = 67), and 2017 (n = 74).

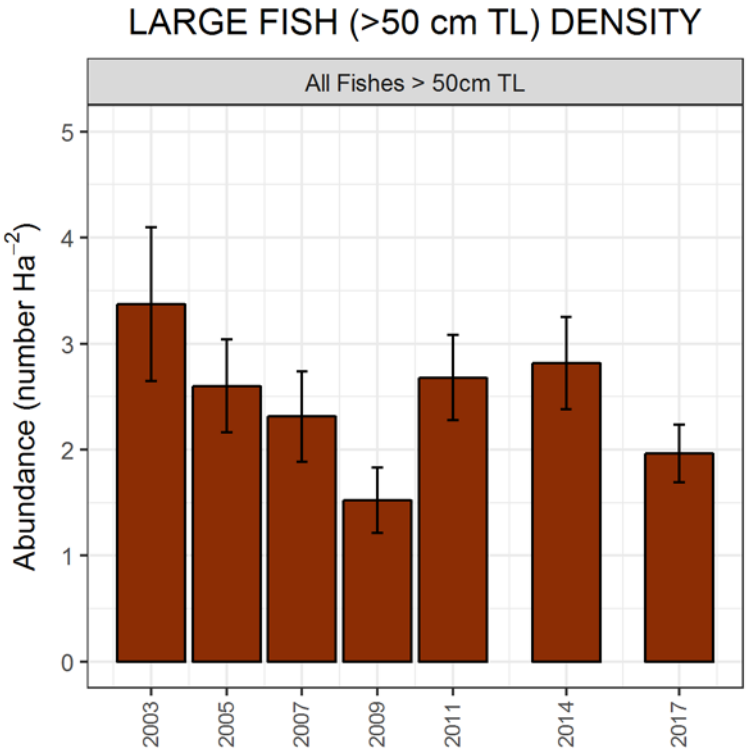

Figure 58. Mean density (number Ha^{-2} ± SE) of fishes ≥ 50 cm TL surveyed via the towed-diver survey method in the S. Mariana Archipelago.

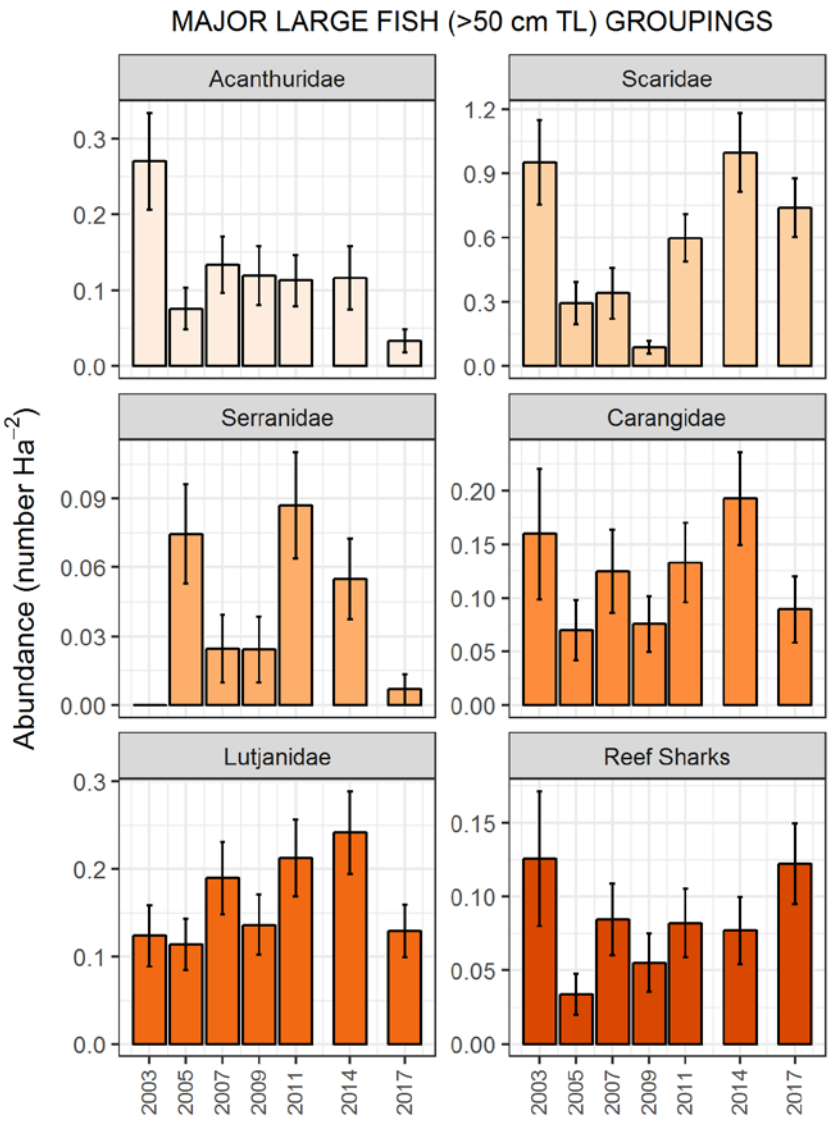

Figure 59. Mean density (number Ha^{-2} ± SE) of fishes ≥ 50 cm TL for family groups Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and reef sharks in the S. Mariana Archipelago.

Publications, information products, and data requests 2017

The following products published in 2017 were either produced using biological data collected during Pacific RAMP and related monitoring surveys, or were coauthored by members of the ESD fish team.

Blogs

A Fish That Shapes the Reef
https://pifscblog.wordpress.com/2017/04/27/fish-shapes-reef/

What happens to reef fish after coral bleaching?
https://pifscblog.wordpress.com/2017/05/08/reef-fish-coral-bleaching/

Monitoring briefs

Coral Reef Ecosystem Program, Pacific Islands Fisheries Science Center, NOAA Fisheries 2017. Pacific Reef Assessment and Monitoring Program Fish monitoring brief: Northwestern Hawaiian Islands, 2016. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-17-030, 2 p doi:10.7289/V5/DR-PIFSC-17-030.

Reports

Gorospe KD, and Acoba, T, 2017. A survey design performance analysis examining linkages between reef fish assemblages and benthic morphologies in the main Hawaiian Islands. NOAA Tech. Memo. NMFS-PIFSC-64, 35 p. https://doi.org/10.7289/V5/TM-PIFSC-64.

Heenan A, Gorospe K, Levine A, Raynal J, Lawrence A, 2017. Linking local and national data to improve marine managed area monitoring and data quality in Tutuila, American Samoa: a feasibility report. Pacific Islands Fisheries Science Center, PIFSC Working Paper, WP-17-001, doi: 10.7289/V5/WP-PIFSC-17-001.

McCoy K, Heenan A, Asher J, Ayotte P, Gorospe K, Gray A, Lino K, Zamzow J, Williams I, 2017. Pacific Reef Assessment and Monitoring Program. Data report : ecological monitoring 2016 : reef fishes and benthic habitats of the main Hawaiian Islands, Northwestern Hawaiian Islands, Pacific Remote Island Areas, and American Samoa. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-17-001, 66 p. doi:10.7289/V5/DR-PIFSC-17-001.

Scientific publications

Asher JM, Williams ID, & Harvey E, 2017. Mesophotic Depth Gradients Impact Reef Fish Assemblage Composition and Functional Group Partitioning in the Main Hawaiian Islands. Frontiers in Marine Science, 4, 98.

Asher JM, Williams ID., & Harvey ES, 2017. An assessment of mobile predator populations along shallow and mesophotic depth gradients in the Hawaiian Archipelago. Nature Scientific Reports, 7(1), 3905.

Boyle S, De Anda V, Koenig K, O'Reilly E, Schafer M, Acoba T, Dillon A, Heenan A, Oliver T, Swanson D, et al 2017. Coral reef ecosystems of the Pacific Remote Islands Marine National Monument: a 2000-2016 Overview. Pacific Islands Fisheries Science Center, PIFSC Special Publication, SP-17-003, 66 p. doi:10.7289/V5/SP-PIFSC-17-003.

Friedlander A, Donovan MK, Samoulis K, Williams ID, Brown EK, Conklin EJ, DeMartini E, Rodgers KS, Spartks RT, Walsh JW, 2017. Human‐induced gradients of reef fish declines in the Hawaiian Archipelago viewed through the lens

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Heenan A, Williams ID, Acoba T, DesRochers A, Kosaki RK, Kanemura T, Nadon MO, Brainard RE, 2017. Long-term monitoring of coral reef fish assemblages in the Western central Pacific. Scientific Data, 4:170176, doi: 10.1038/sdata.2017.176.

Kelly ELA, Eynaud Y, Williams ID, Sparks RT, Dailer ML, Sandin SA, & Smith JE, 2017. A budget of algal production and consumption by herbivorous fish in an herbivore fisheries management area, Maui, Hawaii. *Ecosphere*, *8*(8), e01899. http://doi.org/10.1002/ecs2.1899.

Robinson JPW, Williams ID, Edwards AM, McPherson J, Yeager L, Vigliola L., … Baum JK, 2017. Fishing degrades size structure of coral reef fish communities. *Global Change Biology*, *23*(3), 1009–1022. http://doi.org/10.1111/gcb.13482.

Weijerman M, Gove J, Williams ID, Walsh WJ, Minton D, Polovina J, *in press*, Evaluating management strategies to optimize ecosystem services provided by coral reefs**,** Ecological Applications.

Yeager LA, Deith M, McPherson JM, Williams ID, Baum JK, 2017. Scale dependence of environmental controls on the functional diversity of coral reef fish communities.

Fish and benthic data requests

In 2017: 31 requests.

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Ault JS, Smith SG, Bohnsack JA, Luo J, Harper DE, and McClellan DB, 2006. Building Sustainable Fisheries in Florida's Coral Reef Ecosystem: Positive Signs in the Dry Tortugas. Bulletin of Marine Science, 78 (3): 633-654.

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Appendices

Appendix 1: Pacific RAMP data types collected for the biological theme of NCRMP

Theme	Indicator	Method	Spatial sampling	Temporal scale
Benthos	Coral demographics and condition: species, abundance, size, bleaching, disease, mortality	Paired 18-m coral demographic transects	Stratified random sampling optimized for commercially and ecologically important fish and coral species in shallow (0–30 m) hard bottom areas. Strata include depth, habitat type, and management zone.	Surveys conducted every 3 years, all surveys generally conducted within the same 3-month season.
	Benthic percent cover	Paired 15-m photoquadrat transects		
	Benthic key species (presence/absence)	2000 × 10 m towed-diver survey		
	Rugosity			
Fish	Fish abundance, size, and species	Paired 15-m-diameter stationary point count (SPC) surveys		
	Fish key species	~ 2000 × 10 m^2 towed-diver survey		

Appendix 2: Surveys per region per year and method used

Table A2. 1. The number of belt transect and SPC sites surveyed per region per year. From 2000 to 2006 the belt transect method was used to survey coral reef fishes. During the calibration period that took place from 2006–2008, surveys were conducted using both the belt and the stationary point count (SPC) method. The SPC data collected prior to 2009 is not used in this report because sites were not selected based on the randomized depth stratified design (see Section: Methods – stationary point count). Furthermore, during the methods transition period, sites surveyed at the mid-depth strata in 2009 were the haphazardly selected, fixed sites selected in the previous years. Shallow and deep sites were randomly selected. Here we report all data from 2009 onwards, including the non-randomized mid-depth 2009 sites. In the future, these mid-depth sites should be excluded from any time series analysis.

Year	2000-2005	2006-2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Region / Method	**Belt**	**Belt & SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**
N. Mariana	80	36	135	-	135	-	-	148	-	-	159
S. Mariana	59	60	116	-	219	-	-	198	-	-	172
main HI	73	243	-	184	-	163	287	-	294	257	-
NWHI*	298	366	203	118	141	91	-	89	96	182	126
PRIMNM	125	272	42	179	30	231	-	45	291	30	81
Am. Samoa	100	283	-	241	-	223	-	-	339	185	-

*In partnership with NOAA's Papahānaumokuākea Marine National Monument (PMNM), surveys have been conducted in the Northwestern Hawaiian Islands on a more frequent, nearly annual basis.

Table A2. 2. Number of towed-diver surveys per year. Numbers in brackets are tows that were not included when calculating regional summary data, either because they were not in the core habitat (8–20-m deep forereef) or because they were at islands that were not surveyed consistently throughout the period from which we have data.

Island	2000–2001	2002–2003	2004–2005	2006–2007	2008–2009	2010–2011	2012–2013	2014–2016	2017
Agrihan	-	12	5	6	11	10	-	-	10
Alamagan	-	6	6	6	6	3	-	3	6
Anatahan	-	(12)	-	-	-	-	-	-	-
Asuncion	-	6	5	5	5	6	-	5	6
Farallon de Pajaros	-	8	4	4	3	4	-	2	3
Guguan	-	6	2 (1)	5	4	5	-	3	3
Maug	-	13 (3)	11 (1)	9	8	9	-	8	8
Pagan	-	21	17	16	15	14	-	11	19
Sarigan	-	5 (1)	5	6	5	4	-	3	4
Northern Mariana	**-**	**77 (16)**	**55 (2)**	**57**	**57**	**55**	**-**	**35**	**59**
Arakane	-	(6)	(3)	-	-	-	-	-	-
Pathfinder	-	(4)	(3)	-	-	-	-	-	-
Santa Rosa	-	(3)	(3)	-	-	-	-	-	-
Stingray	-	(4)	-	-	-	-	-	-	-
Supply	-	(1)	-	-	-	-	-	-	-
Tatsumi	-	(2)	-	-	-	-	-	-	-
Mariana Banks	**-**	**(20)**	**(9)**	**-**	**-**	**-**	**-**	**-**	**-**
Aguijan	-	4	5 (1)	3	5	4	-	3	6
Guam	-	19	23	19	22	23	-	31	24
Rota	-	12	11	10	11	11	-	8	12
Saipan	-	6	17	16	20	16	-	14	21
Tinian	-	6	12	8	10 (1)	10	-	11	11
Southern Mariana	**-**	**47**	**68 (1)**	**56**	**68 (1)**	**64**	**-**	**67**	**74**
Hawai`i	-	-	-	33	41	37	-	21	-
Kaua`i	-	-	22	13 (2)	18	21 (1)	-	10	-

Island	2000–2001	2002–2003	2004–2005	2006–2007	2008–2009	2010–2011	2012–2013	2014–2016	2017
Kaula	-	-	-	(3)	-	-	-	-	-
Lana`i	-	-	9 (1)	11	12	10	-	6	-
Maui	-	-	11	26 (1)	27	20 (4)	-	17	-
Moloka`i	-	-	7	7	12	11	-	14	-
Ni`ihau	-	-	15	17 (1)	14	9	-	5	-
O`ahu	-	-	16	3	20	14	-		-
MHI	**-**	**-**	**80 (2)**	**110 (7)**	**144**	**122 (5)**	**-**	**67**	**-**
French Frigate	10 (12)	17 (16)	7 (10)	9 (10)	15 (7)	18 (3)	-	22	-
Gardner	(1)	(2)	(2)	-	-	-	-	-	-
Kure	12 (4)	18 (6)	7 (6)	7 (6)	8 (6)	8 (5)	-	13	-
Laysan	6	9	5	5 (1)	5	-	-	12	-
Lisianski	13 (1)	20 (4)	11 (1)	10 (2)	10 (2)	10 (2)	-	-	-
Maro	24 (6)	21	6 (5)	10 (3)	11	-	-	-	-
Midway	-	28 (4)	8 (5)	7 (8)	10 (6)	-	-	-	-
Necker	4	4	-	4	-	-	-	-	-
Nihoa	2	-	-	-	-	-	-	-	-
Pearl & Hermes	17 (7)	32 (22)	20	14 (12)	18 (9)	21 (2)	-	30	-
Raita	(3)	-	-	-	-	-	-	-	-
NWHI	**88 (34)**	**114 (89)**	**55 (38)**	**66 (42)**	**66 (41)**	**57 (12)**	**-**	**77**	**-**
Johnston	-	-	14 (13)	10 (16)	8 (3)	10 (11)	14 (3)	14 (2)	-
Johnston	**-**	**-**	**14 (13)**	**10 (16)**	**8 (3)**	**10 (11)**	**14 (3)**	**14 (2)**	**-**
Jarvis	2	3 (1)	10 (1)	10 (2)	13 (4)	10	7 (2)	6	-
Kingman	1 (5)	6 (5)	15 (3)	12 (10)	12 (9)	13 (8)	16 (5)	12 (4)	-
Palmyra	3 (2)	11 (2)	17 (4)	19 (2)	20 (2)	24 (1)	21 (1)	19 (1)	-
US Line	**6 (7)**	**20 (8)**	**42 (8)**	**41 (14)**	**47 (13)**	**47 (9)**	**44 (8)**	**37 (5)**	**-**
Baker	2	2	7 (1)	7 (3)	8	9	10	5	5
Howland	2	4	9	6 (1)	7	10 (1)	10 (1)	5	5
US Phoenix	**4**	**6**	**16 (1)**	**13 (4)**	**15**	**19 (1)**	**20 (1)**	**10**	**10**

Island	2000–2001	2002–2003	2004–2005	2006–2007	2008–2009	2010–2011	2012–2013	2014–2016	2017
Ofu & Olosega	-	10 (3)	16 (2)	15 (2)	14	14	10	10	-
Rose	-	5 (12)	9 (15)	13 (8)	14 (6)	11 (2)	7 (2)	5 (1)	-
South Bank	-	-	-	-	-	(6)	-	-	-
Swains	-	7 (3)	13 (1)	9	12	8 (1)	7 (3)	6	-
Tau	-	6 (2)	16 (2)	15	15	16	11	12	-
Tutuila	-	14 (1)	40 (3)	40 (4)	44	39	33	29	-
American Samoa	**-**	**42 (21)**	**94 (23)**	**92 (14)**	**99 (6)**	**88 (9)**	**68 (5)**	**62 (1)**	**-**
Wake	-	-	13	18	13	14	-	10	9

Appendix 3: Sector maps

For the majority of islands, the entire island or atoll is stratified by habitat or depth. Guam, Tutuila and the main Hawaiian Islands, however, have an additional level of stratification.

Guam

Guam is subdivided into sectors based on management status (marine preserve or not) and aspect (East or West): thus there are two open sectors: "Guam Open East" (areas outside of Marine Preserves on east side of Guam); and "Guam Open West". Grouping of marine preserve sites – i.e., whether to pool all into a single stratum 'Guam Marine Preserve' or break out at level of some or all individual marine preserves depends on sampling density per year – higher sampling density allows for individual marine preserves to be sectors. In 2014, we pooled MP sites into "Achang MP" (Achang Reef Flat Marine Preserve, due to intensive sampling efforts there); "Marine Preserve" (being all other areas within Guam's Marine Preserve System; Figure A3. 1).

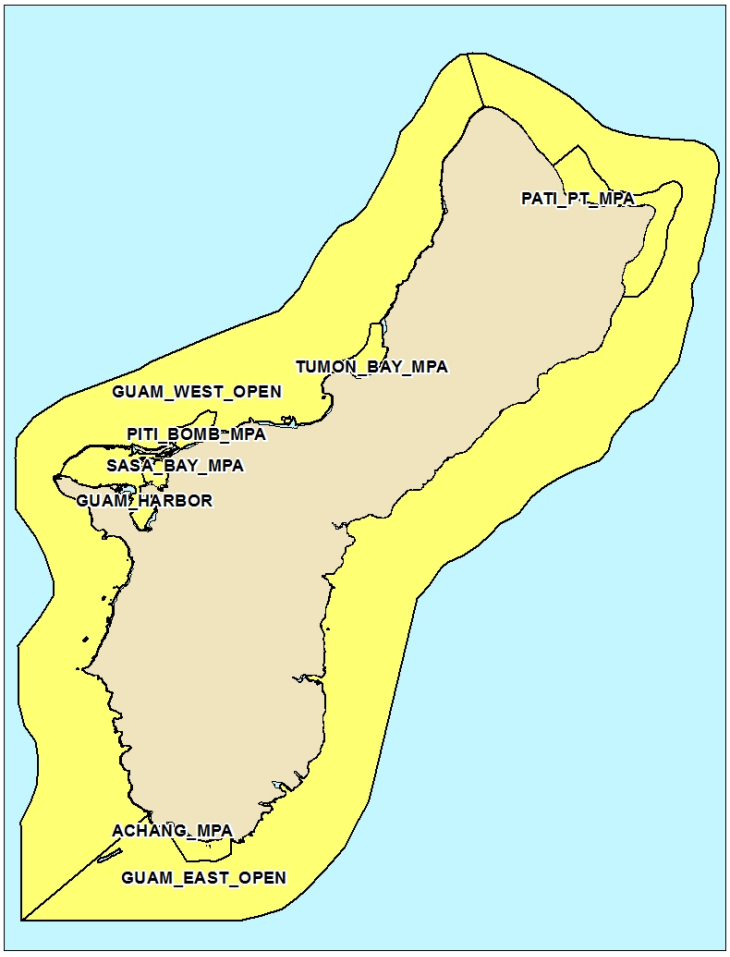

Figure A3. 1. Guam sectors. Sampling is stratified by habitat, depth and the additional sectors based on whether areas are inside or outside Achang Reef Flat MP, the pooled Marine Preserve system, and by the East and West side of the island.

The main Hawaiian Islands

The main Hawaiian Islands are divided into between 2 and 7 sectors per island, with sector boundaries based on broad differences in oceanographic exposure, reef structure, and local human population density (Figure A3. 2).

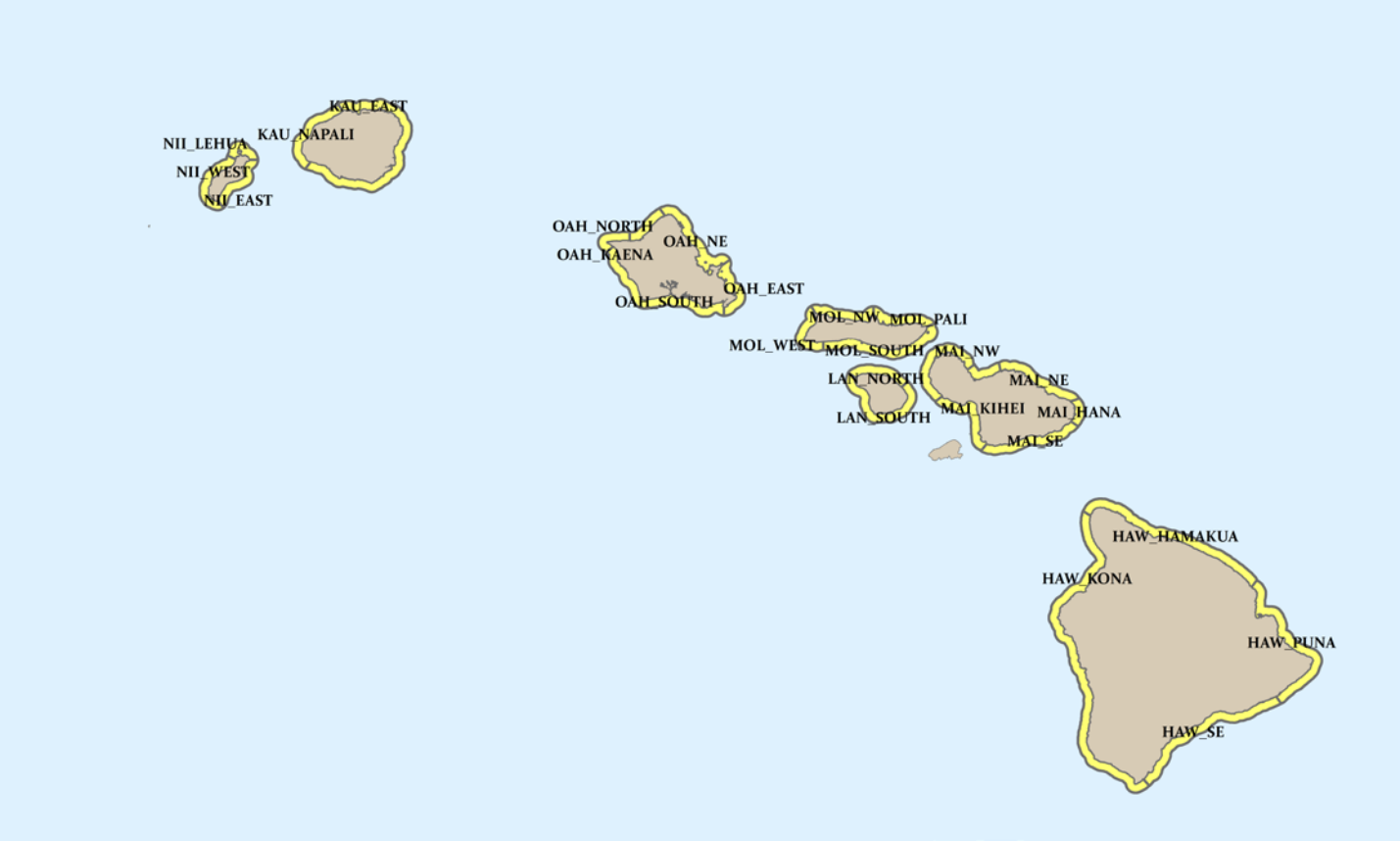

Figure A3. 2. The sectors of the main Hawaiian Islands. Sectors are broadly based on wave exposure, habitat complexity and local human population density.

Tutuila

Tutuila has been divided into 4 main sectors (NE, NW, SE, SW) and with sectors for 2 no-take sanctuary zones (Fagatele Bay, and Aunu'u Zone B) (Figure A3. 3).

Figure A3. 3. Tutuila sectors. Sectors were determined by the Biogeography Branch of the NOAA National Ocean Service National Centers for Coastal Ocean Science.

Appendix 4: Samples per sector and strata in 2017

Table A4. 1. The number of sites surveyed per depth strata and the sector used to pool up the data in island level parameter estimates. For most islands, during the site selection process, the sector area from which site locations are randomly drawn are the islands. In some case, such as Guam, islands are broken down into smaller sectors. D = deep (18–30 m), M = mid (6–18 m), S = shallow (0–6 m). Lagoon site depths were pooled for analysis.

Region	Island	Sector	Forereef-D	Forereef-M	Forereef-S	Lagoon-M	Lagoon-S	Protected Slope-D	Protected Slope-M
NWHI	French Frigate	French Frigate	13	35	10	3	4	10	8
NWHI	Kure	Kure	18	23	8	-	-	-	-
NWHI	Laysan	Laysan	6	9	2	-	-	-	-
NWHI	Lisianski	Lisianski	28	31	7	-	-	-	-
NWHI	Midway	Midway	4	4	4	-	-	-	-
NWHI	Pearl & Hermes	Pearl & Hermes	20	45	11	2	3	-	-
PRIMNM	Jarvis	Jarvis	4	13	11	-	-	-	-
PRIMNM	Wake	Wake	17	22	14	-	-	-	-
S.MARIAN	Aguijan	Aguijan	7	7	3	-	-	-	-
S.MARIAN	Guam	Guam East Open	6	9	4	-	-	-	-
S.MARIAN	Guam	Guam Marine Protected Area	8	7	6	-	-	-	-
S.MARIAN	Guam	Guam West Open	6	9	11	-	-	-	-
S.MARIAN	Rota	Rota	8	14	6	-	-	-	-
S.MARIAN	Saipan	Saipan	17	14	6	-	-	-	-
S.MARIAN	Tinian	Tinian	9	9	6	-	-	-	-
N.MARIAN	Agrihan	Agrihan	8	4	7	-	-	-	-
N.MARIAN	Asuncion	Asuncion	6	9	4	-	-	-	-
N.MARIAN	Farallon de Pajaros	Farallon de Pajaros	5	7	4	-	-	-	-
N.MARIAN	Maug	Maug	12	17	9	-	-	-	-
N.MARIAN	Pagan	Pagan	17	13	10	-	-	-	-
N.MARIAN	AGS	Alamagan	3	3	3	-	-	-	-
N.MARIAN	AGS	Guguan	4	3	2	-	-	-	-
N.MARIAN	AGS	Sarigan	4	2	3	-	-	-	-

Appendix 5: SPC Quality control: Observer cross-comparison

Estimates are compared between dive partner pairs to check for consistency between observers. This can be done for any parameter estimated, but here total fish biomass, species richness (number of unique species counted) and hard coral cover estimates are highlighted, three of the most frequently reported summary metrics from the stationary point count survey data. The difference between the estimates of each diver and those of their dive partner at each site is calculated and referred to here as diver performance. Real differences between dive partners are expected, as divers survey adjacent, not the same cylinder area. However, if there is no consistent bias in the estimates made by a diver, one would expect the median value of their performance to be close to zero i.e. with estimates in half of the counts being higher than their partner's estimates and half of the counts lower than their partner's estimates. Boxplots of diver performance, therefore, give 1) a strong but general indication of relative bias; if there is no consistent bias, then the median differences between a single diver and their dive partners will be close to zero and 2) an indication of how variable each diver's counts are compared to their dive partners – if a particular diver's performance varies extremely widely compared to their dive partners (i.e. several very high and/or several very low counts) that may be an indication of variability in their performance. As dive teams are regularly rotated throughout the course of a survey mission, measures of individual diver's counts reflect their performance relative to the entire pool of other divers participating in those surveys. These boxplots are routinely generated during and after field operations to give divers feedback on their performance relative to their colleagues and are summarized here by region (Figure A5. 1 Northwestern Hawaiian Islands 2017, Figure A5. 2 Pacific Remote Islands Marine National Monument 2017, Figure A5. 3 Norther Mariana Islands 2017, Figure A5. 4 Southern Mariana Islands).

Northwestern Hawaiian Islands 2017

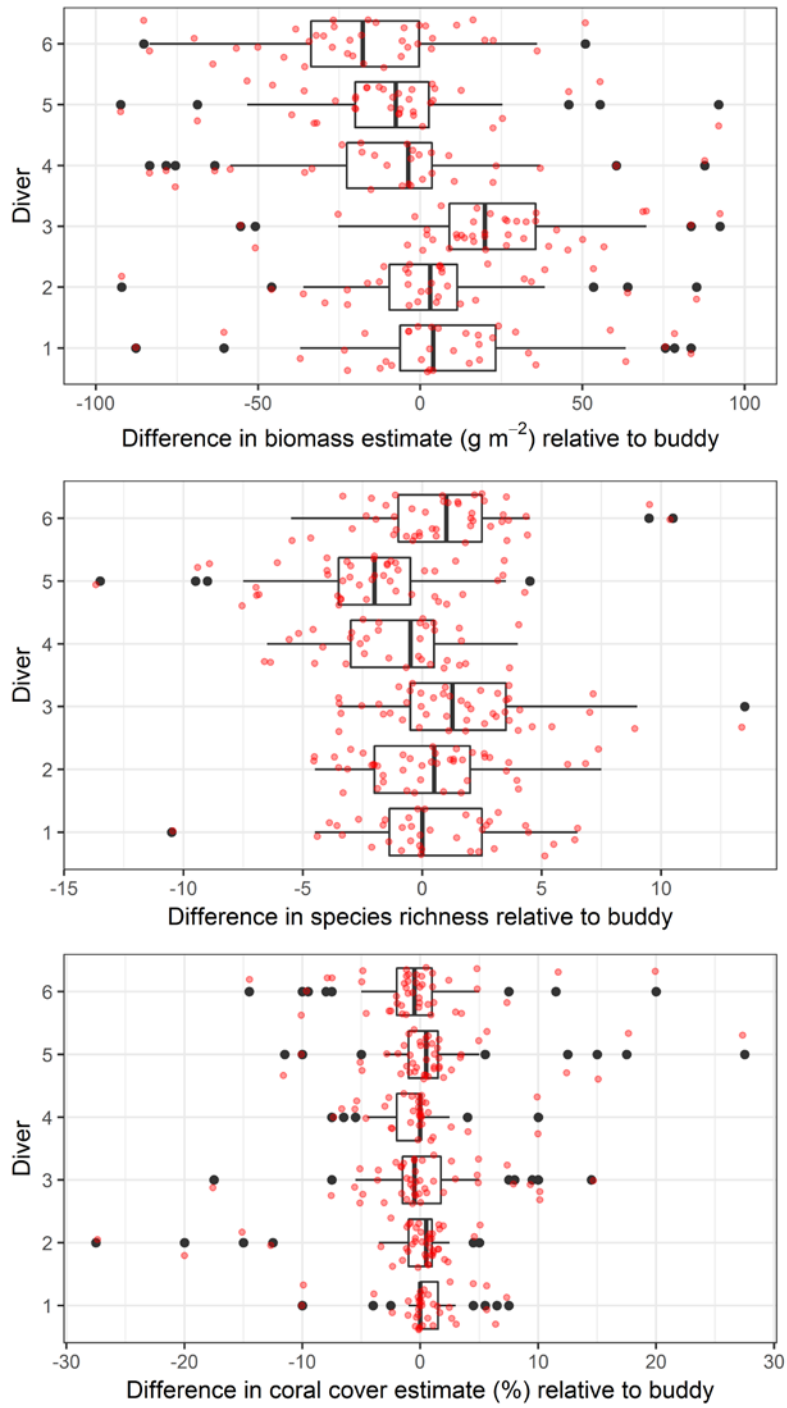

Figure A5. 1. Northwestern Hawaiian Islands comparison of observer diver vs. dive partner estimates for total fish biomass, species richness and hard coral cover during 2017 surveys. The boxplot shows the median difference (thick vertical line) in estimates for each diver, the box represents the location of 50% of the data. Lines extending from each box are 1.5 times the interquartile range which represents approximately 2 standard deviations; points greater than this (outliers) are plotted individually (black dots).

Pacific Remote Islands Marine National Monument 2017

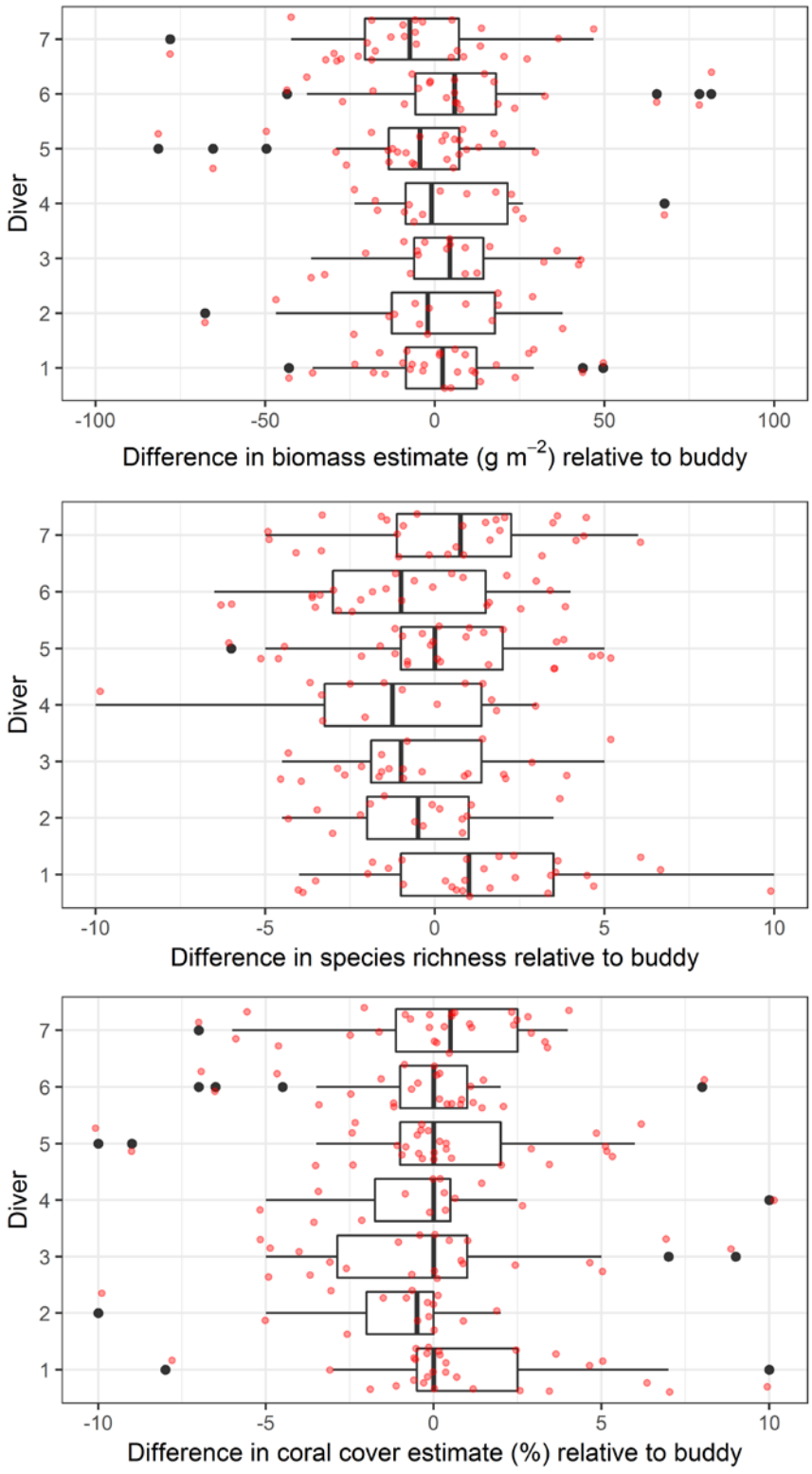

Figure A5. 2. Pacific Remote Islands Marine National Monument comparison of observer diver vs diver partner estimates for total fish biomass, species richness and hard coral cover during 2017 surveys. See Figure A5. 1 legend for details.

Northern Mariana Archipelago 2017

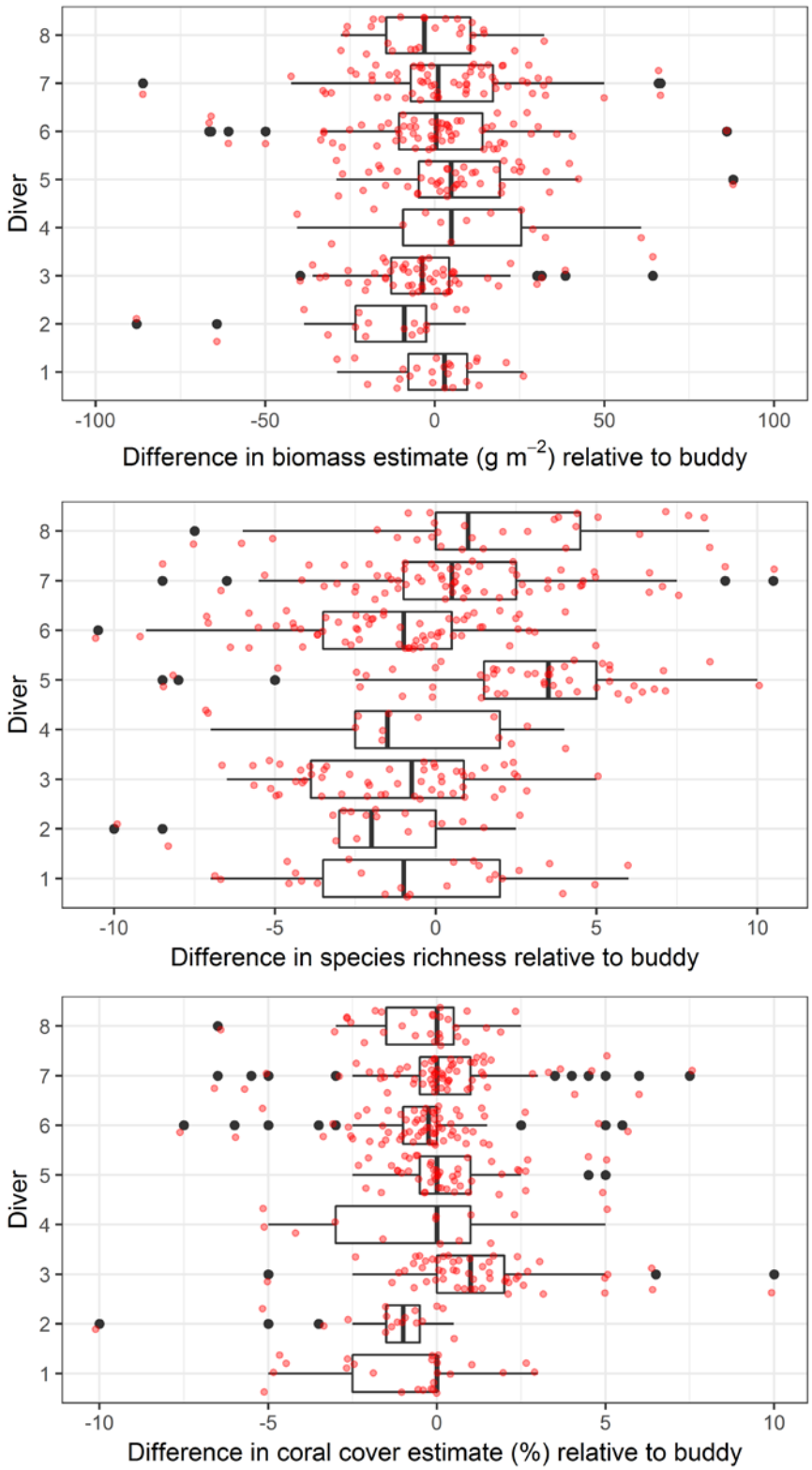

Figure A5. 3. Northern Mariana Archipelago comparison of observer diver vs dive partner estimates for total fish biomass, species richness and hard coral cover during 2017 surveys. See Figure A5. 1 legend for details.

Southern Mariana Archipelago 2017

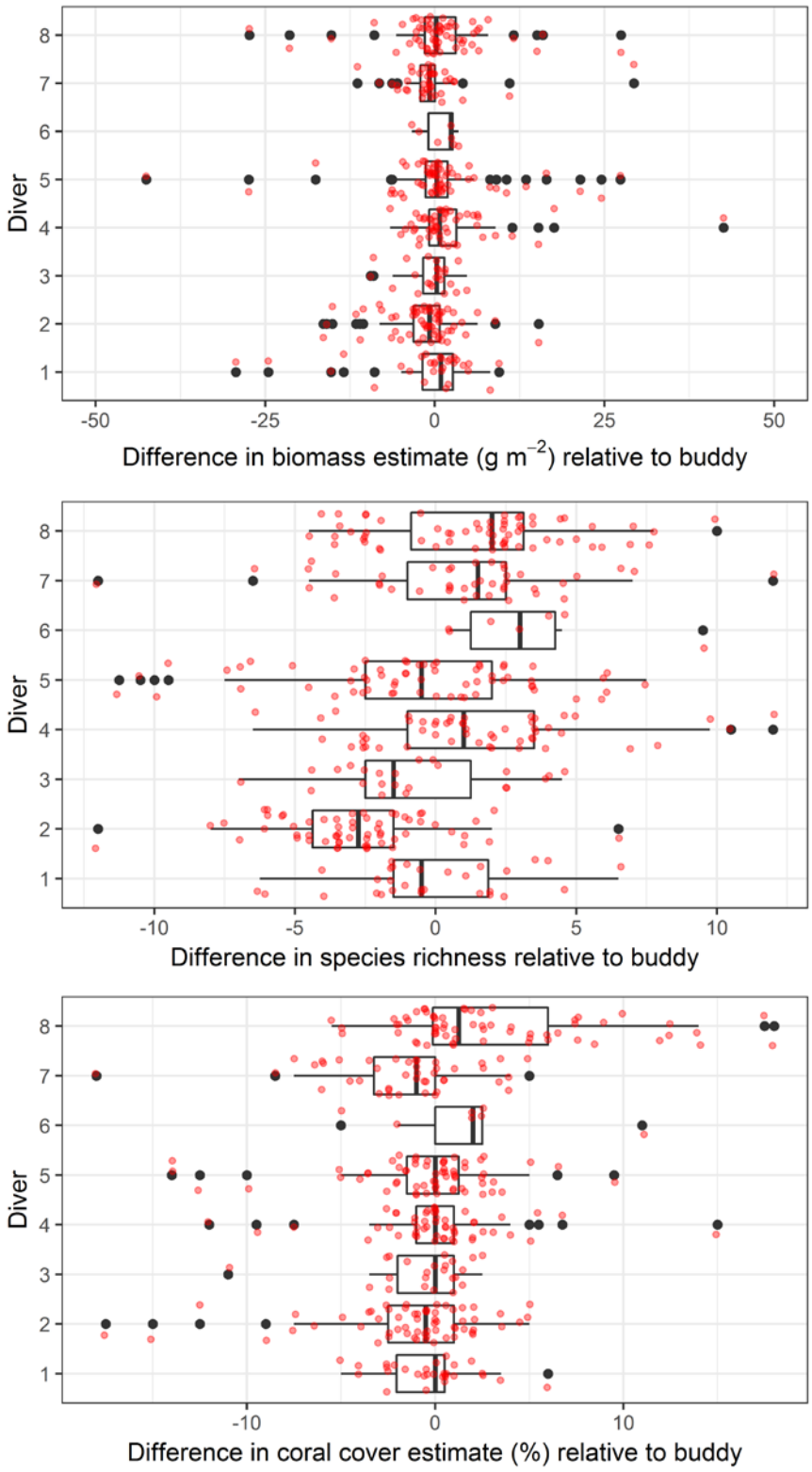

Figure A5. 4. Southern Mariana Islands comparison of observer diver vs dive partner estimates for total fish biomass, species richness and hard coral cover during 2016 surveys. See Figure A5. 1 legend for details.

Appendix 6: Random stratified sites surveyed at each island per year

Table A6. 1. The total number of sites surveyed per island (ordered by region) per year under the depth stratified random sampling design, using the stationary point count method to survey the fish assemblage.

Region	Island	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Northwestern HI	Kure	43	25	-	20	-	-	8	39	10	145
Northwestern HI	Midway	53	-	30		-	34	14	-	12	143
Northwestern HI	Pearl & Hermes	-	41	18	31	-	-	23	56	25	194
Northwestern HI	Lisianski	19	25	9	25	-	28	18	40	26	190
Northwestern HI	Laysan	14	-	23	-	-	-	8	-	9	54
Northwestern HI	Gardner	-	-	12	-	-	-	-	-	-	12
Northwestern HI	Maro	39	-	25	-	-	-	17	-	-	81
Northwestern HI	French Frigate	-	27	8	15	-	27	8	47	36	168
Northwestern HI	Necker	13	-	8	-	-	-	-	-	-	21
Northwestern HI	Nihoa	-	-	8	-	-	-	-	-	-	8
Main HI	Ni`ihau	-	16	-	-	26	-	49	12	-	103
Main HI	Kaua`i	-	26	-	-	37	-	20	30	-	113
Main HI	O`ahu	-	40	-	35	64	-	35	54	-	228
Main HI	Moloka`i	-	10	-	50	39	-	48	23	-	170
Main HI	Lana`i	-	16	-	29	29	-	15	26	-	115
Main HI	Maui	-	33	-	49	34	-	30	29	-	175
Main HI	Kaho`olawe	-	-	-	-	-	-	-	24	-	24
Main HI	Hawai`i	-	43	-	-	58	-	97	24	-	222
N. Mariana	Farallon de Pajaros	7	-	12	-	-	11	-	59	16	46
N. Mariana	Maug	21	-	30	-	-	40	-	-	38	129
N. Mariana	Asuncion	13	-	20	-	-	21	-	-	19	73
N. Mariana	Agrihan	14	-	20	-	-		-	-	19	53
N. Mariana	Pagan	21	-	29	-	-	43	-	-	40	133
N. Mariana	AGS	19	-	24	-	-	33	-	-	27	103
S. Mariana	Saipan	23	-	30	-	-	48	-	-	37	138
S. Mariana	Tinian	14	-	19	-	-	19	-	-	24	76
S. Mariana	Aguijan	6	-	13	-	-	10	-	-	17	46
S. Mariana	Rota	14	-	24	-	-	28	-	-	28	94
S. Mariana	Guam	25	-	133	-	-	104	-	-	66	328
PRIMNM	Wake	29	-	30	-	-	45	-	-	53	157
PRIMNM	Johnston	-	39	-	35	-	-	31	-	-	105
PRIMNM	Kingman	-	33	-	49	-	-	49	-	-	131
PRIMNM	Palmyra	-	40	-	42	-	-	78	-	-	160
PRIMNM	Howland	-	16	-	39	-	-	35	-	-	90
PRIMNM	Baker	-	21	-	24	-	-	36	-	-	81
PRIMNM	Jarvis	-	30	-	42	-	-	62	30	28	192
Am.Samoa	Swains	-	24	-	38	-	-	32	-	-	94
Am.Samoa	Ofu & Olosega	-	30	-	30	-	-	52	11	-	123
Am.Samoa	Tau	-	24	-	22	-	-	46	50	-	142
Am.Samoa	Tutuila	-	127	-	85	-	-	162	77	-	451
Am.Samoa	Rose	-	34	-	48	-	-	47	47	-	176

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