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Pacific Reef Assessment and Monitoring Program

Data Report

Ecological monitoring 2015—reef fishes and benthic habitats of the main Hawaiian Islands, Northwestern Hawaiian Islands, Pacific Remote Island Areas, and American Samoa

K. McCoy[1], A. Heenan[1], J. Asher[1], P. Ayotte[1], K. Gorospe[1], A. Gray[1], K. Lino[1], J. Zamzow[1], and I. Williams[2]

1 Joint Institute for Marine and Atmospheric Research
University of Hawaii at Manoa
1000 Pope Road
Honolulu, HI 96822

2 Pacific Islands Fisheries Science Center
National Marine Fisheries Service
NOAA Inouye Regional Center
1845 Wasp Boulevard, Building 176
Honolulu, HI 96818

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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) Coral Reef Ecosystem Program in 2015. This includes the following regions: Northwestern Hawaiian Islands, main Hawaiian Islands, Pacific Remote Island Areas, and American Samoa.

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

Acronyms

CRCP	Coral Reef Conservation Program
CREP	Coral Reef Ecosystem Program (formerly CRED)
NOAA	National Oceanic and Atmospheric Administration
Pacific RAMP	Pacific Reef Assessment Monitoring Program
PMNM	Papahānaumokuākea Marine National Monument
PRIA	Pacific Remote Island Areas
SPC	Stationary Point Count

Contents

Introduction

Background

The Coral Reef Ecosystem Program (CREP) 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), 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 Island Areas (PRIA), which include Johnston and Wake Atolls and the U.S. Line and Phoenix Islands (Figure 1).

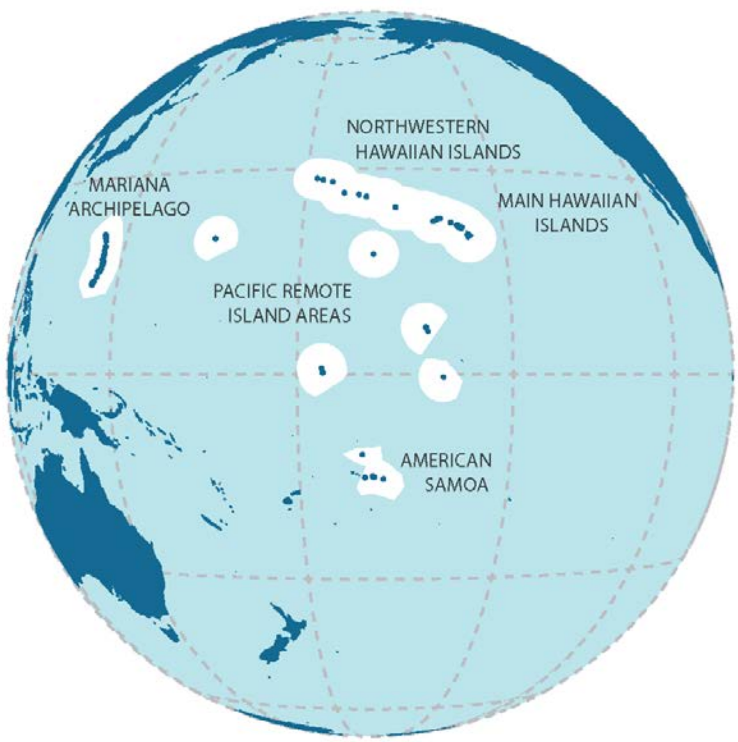

Figure 1 Coral reef areas surveyed by NOAA-CREP for Pacific RAMP. White areas represent the exclusive economic zones for each U.S. Pacific region surveyed.

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

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 a similar survey design 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 CREP. The supplemental PMNM data are included with data shown in this report.

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 2013); these data will be reported in a forthcoming series of complimentary 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 2013 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 snapshot assessments of coral reef assemblages at U.S.-affiliated islands in the Pacific, with the core reporting unit being at the island level (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, in order 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 CREP, but are not a formal part of Pacific RAMP. For instance in February and March of 2015, extra surveys were conducted in the American Samoa Sanctuary in Tutuila (Appendix 7: Baseline Surveys Conducted in 2015 in the National Marine Sanctuary of American Samoa). Extra surveys were also conducted around the main Hawaiian Islands as part of a methods comparison study (Appendix 8: Closed circuit rebreather (CCR) SCUBA comparison study). 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 two years, to once every three years. The sampling design and methods used to monitor coral reef fish species and habitats for Pacific RAMP have also evolved over time. More specifically, from 2000–2006 surveys were conducted at haphazardly located permanent sites using various belt transect methods. During 2007–2009, CREP 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 since 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 fish and associated benthic communities.

Report structure

This report summarizes the reef fish survey data and a subset of the benthic data collected by the Coral Reef Ecosystem Program for Pacific RAMP and for compatible PMNM, NMFS and CRCP survey missions in 2015. During 2015, surveys were conducted in the following regions: Main Hawaiian Islands, Northwestern Hawaiian Islands, Pacific Remote Island Areas, and American Samoa. 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 fish). 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 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. Towed diver survey data is shown from the first year in which it is available at each location (Appendix 2: Number of Surveys per region per year and methods used).

In the final section, the publications that were produced in 2015 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 CREP fish team and relevant to Pacific RAMP fish ecological monitoring work.

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

Methods – stationary point count

Sampling domain and design

The target sampling domain is hardbottom habitat in water shallower than 30m. All islands / atolls within regions are stratified by reef zone (backreef, forereef, lagoon) 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 Mean Preserves on east side of Guam); and "Guam Open West" (Appendix 3: Sectors 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: Sectors 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 Niihau 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 2015.

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. 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	Hardbottom habitat in water less than 30 m depth.
Strata	Reef zone (backreef, forereef, lagoon) 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

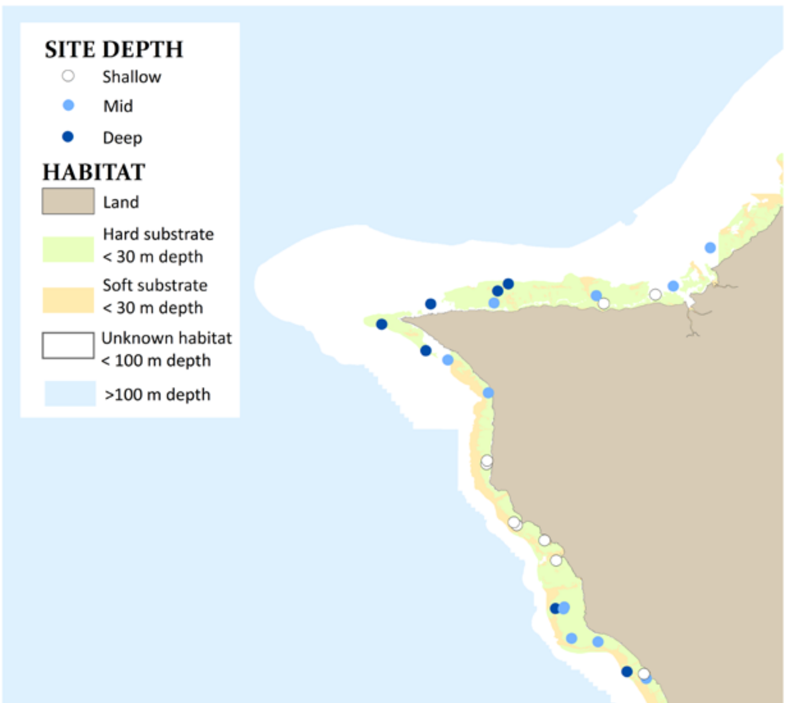

Figure **2**). That is, the latitude and longitude of site locations are randomly drawn from a map of the entire sampling domain.

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 CREP-affiliated Pacific Islands Benthic Habitat Mapping Center, 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 CREP'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 clearly only representative of the areas surveyed (Appendix 4: Samples per sector and strata in 2015). For further details on the methods and maps used to select sites see Williams et al. (2011) or the Coral Reef Ecosystem Program Standard Operating Procedures: Data Collection for Rapid Ecological Assessment Fish Surveys (Ayotte et al. 2015).

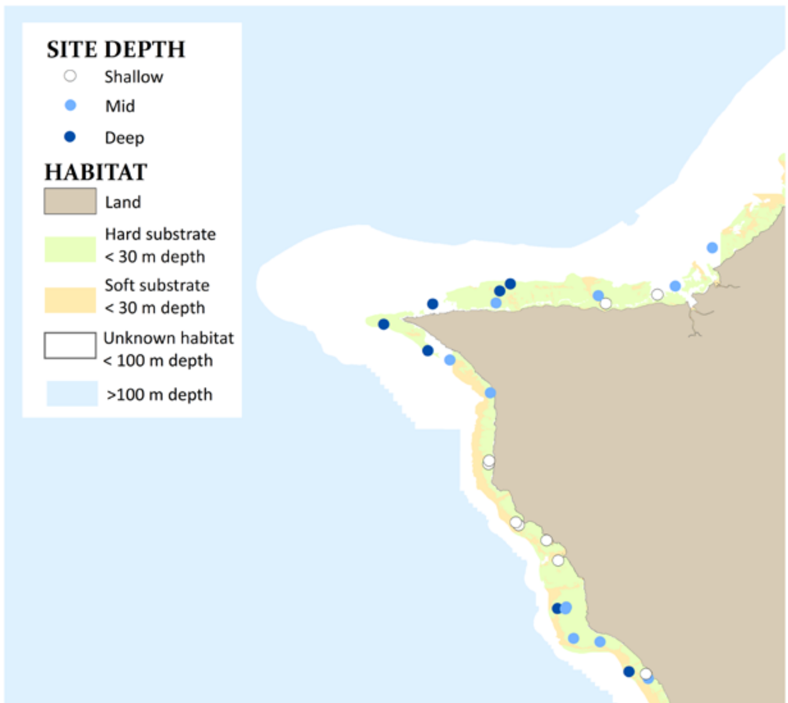

Figure 2 An example of the benthic habitat and depth strata information used in the site selection process. Reef fish survey sites are randomly selected within each depth stratum. Reef fish survey effort is allocated to optimize island-scale biomass estimates. Prior to surveying, a series of primary 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 are 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 underrepresented 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 then 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), 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.

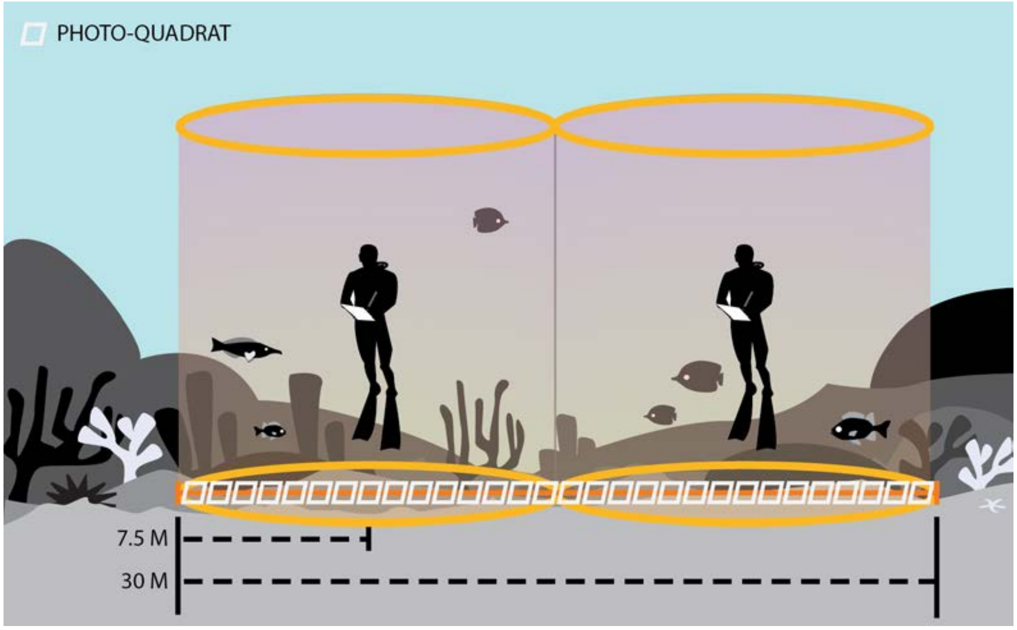

Figure 3 Side view of the stationary point count method. Dive partners count and size fishes within adjacent cylinders measuring 7.5 m in radius. Once the fish survey is complete, divers estimate benthic habitat composition and a benthic photo-transect is collected, spanning the two cylinders.

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 each 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 (e.g., *Tripneustes, Heterocentrotus, Diadema* and *Echinothrix)* and boring (e.g., *Echinometra* and *Echnostrephus*) urchins 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 hardbottom 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).

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 meter 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:

- Ongoing routine training of observers (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 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 2015 are in Appendix 5: SPC Quality control.

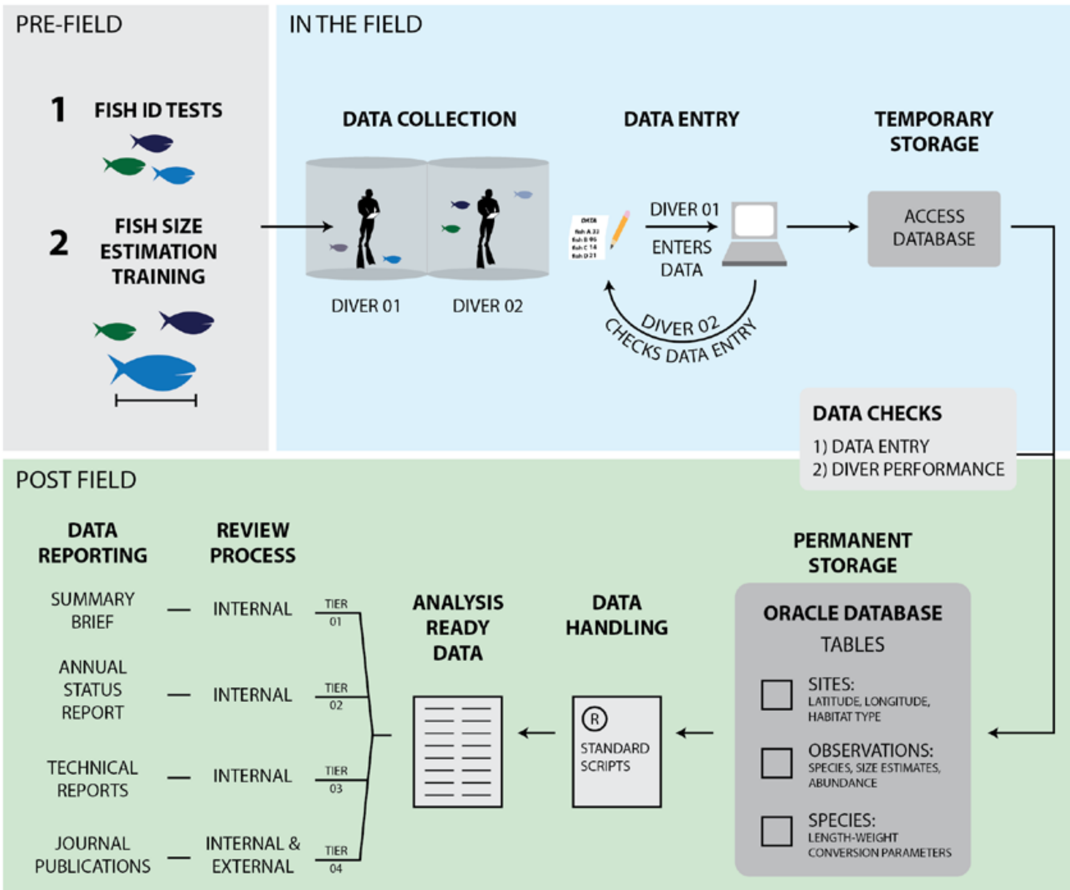

Figure 4 The training, data collection, data processing and reporting phases for Pacific RAMP SPC fish and benthic surveys.

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 10–35, and >35 cm TL.

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 less than 2 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 averaging 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 statuses 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. 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 CREP 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. In order to make it possible to surveys 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 by 0.55 m by 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 minutes in duration, divided into ten 5-minute time segments. One of the divers 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).

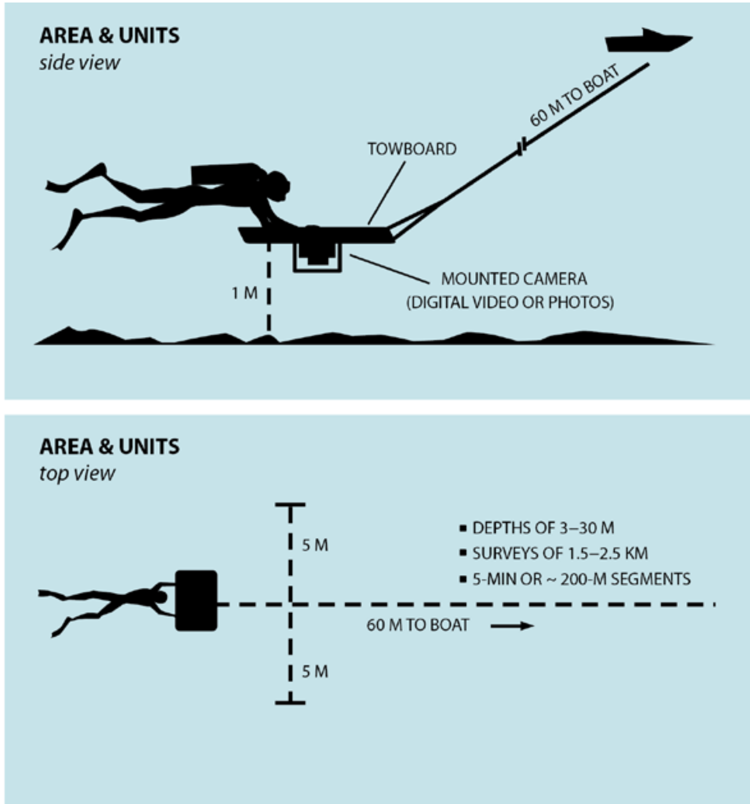

Figure 5 Side view (top) and top view (bottom) of the towed-diver method. Divers count and size fishes within a belt-transect extending 5 m on either side and 10 m in front of the diver.

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 checking 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 given 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 occasionally encountered 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 statuses 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 hardbottom forereef in <30 m) using the same weighting formulas as are used for SPC data.

All data handling and analyses were performed using raw site data extracted from the NOAA CREP 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 fish

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), northern and southern Marianas, Pacific Remote Island Areas, 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 Island Areas (mean ± standard error: 134 ± 5.3 g m^{-2}), followed in decreasing order by the Northwestern Hawaiian Islands (123 ± 6 g m^{-2}), the northern Mariana Archipelago (71 ± 4.7 g m^{-2}), American Samoa (45 ± 2 g m^{-2}), the main Hawaiian Islands (28 ± 1.1 g m^{-2}), and the southern Mariana Archipelago (20 ± 0.8 g m^{-2}) (Figure : 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 statuses and trends section.

Consumer groups

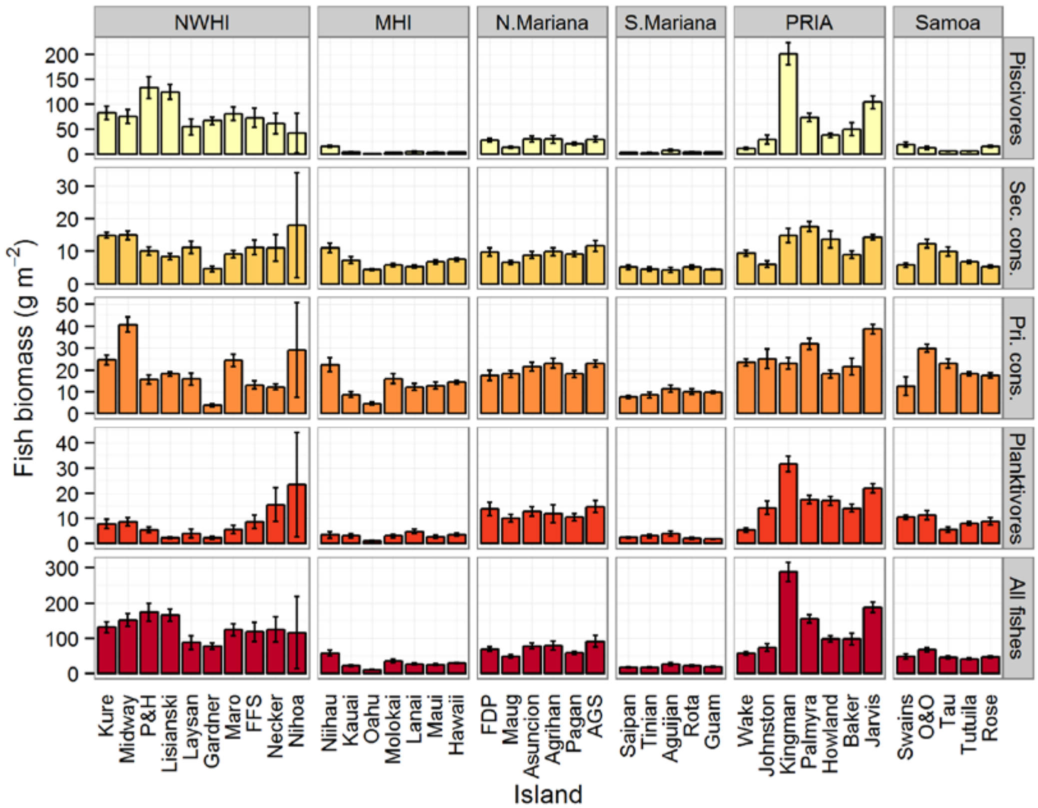

Figure 6 Mean fish biomass by consumer group per US Pacific reef area. Mean fish biomass (± standard error) per consumer group per reef area pooled across survey years (2009–2015). Islands are ordered within region by latitude. See Appendix 4 and Appendix 6 for the sampling density per strata at each island by year. NWHI = Northwestern Hawaiian Islands, MHI = main Hawaiian Islands, N.Mariana = northern Mariana Archipelago, S. Mariana = southern Mariana Archipelago, PRIA = Pacific Remote Island Areas, Samoa = American Samoa, Sec. consumers = secondary consumers (invertivores), Pri. Consumers = primary consumers (herbivores).

Size classes

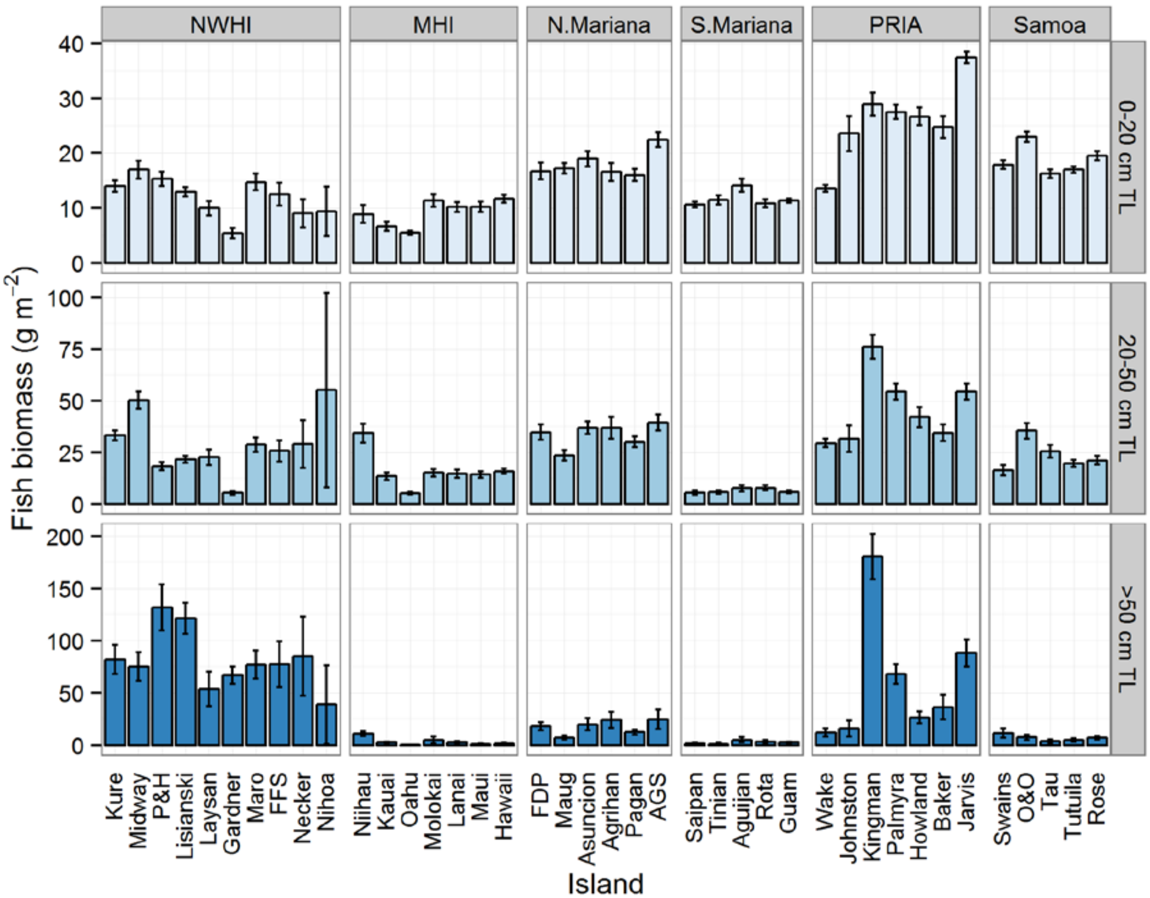

Figure 7 Mean fish biomass per size class per US Pacific reef areas. Mean fish biomass (± standard error) per size class (0–20 cm, 20–50 and > 50 cm in total length (TL)) per reef area pooled across survey years (2009–2015). Islands are ordered within region by latitude. See Appendix 4 and Appendix 6 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, PRIA = Pacific Remote Island Areas, Samoa = American Samoa, 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), PRIA = Pacific Remote Island Areas, Samoa = American Samoa, Sec.consumers = secondary consumers, Pri. Consumers = primary consumers, 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	550	122.7 (6.0)	81.9 (4.5)	8.8 (0.5)	16.5 (0.6)	5.8 (0.8)	12.7 (0.5)	21.9 (1.1)	84.4 (5.1)
MHI	916	27.7 (1.1)	4.2 (0.3)	6.8 (0.3)	11.8 (0.5)	3.3 (0.3)	9.1 (0.3)	14.8 (0.6)	3.3 (0.6)
N.Mariana	376	70.7 (4.7)	24.3 (2.3)	9.7 (0.6)	20.4 (0.8)	14.3 (1.7)	18.1 (0.7)	34 (1.9)	17.4 (2.8)
S. Mariana	507	19.5 (0.8)	3.0 (0.4)	4.7 (0.2)	9.2 (0.4)	2.2 (0.1)	11.2 (0.3)	6.0 (0.5)	2.2 (0.5)
PRIA	686	133.5 (5.3)	63.3 (3.4)	13.5 (0.7)	26.4 (1.1)	20.4 (1.1)	27.1 (0.8)	46.5 (1.9)	58.9 (4.2)
Samoa	766	45.2 (2.0)	8.0 (1.0)	7.5 (0.3)	19.4 (0.6)	8.9 (0.7)	18.2 (0.4)	20.2 (1.0)	6.3 (1.3)

[1] The number of forereef sites surveyed during 2009–2015.

Region and island statuses and trends

This section summarizes SPC data collected at each island in 2009–2015, and towed-diver data summarized at the region level, collected in 2000-2015 (for all regions surveyed in 2015). Towed-diver data is 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 Northwestern Hawaiian Islands (NWHI); main Hawaiian Islands (MHI); American Samoa; and for sub regions of the Pacific Remote Islands Areas (PRIA). The PRIA are an administrative rather than biogeographic region. Therefore, the PRIA 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 – Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and 'reef sharks' (i.e. all Carcharhinidae, Ginglymostomatidae, and Sphyrnidae).

For each island within region, maps illustrate the SPC site level data from the past and most recent surveys and a standard set of graphs show summary information on the fish and benthic community at the island scale. 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 2 size classes, and by consumer group. Mean fish size is also indicated, as well as average percent cover of several major benthic groups: hard coral, macroalgae, and encrusting algae.

Northwestern Hawaiian Islands (NWHI)

French Frigate Shoals (FFS)

French Frigate Shoals were surveyed in 2010 (n =27), 2011 (n = 8), 2012 (n = 15), 2014 (n = 27), and 2015 (n = 8). Three habitats were surveyed: forereef, lagoon, and backreef. 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.

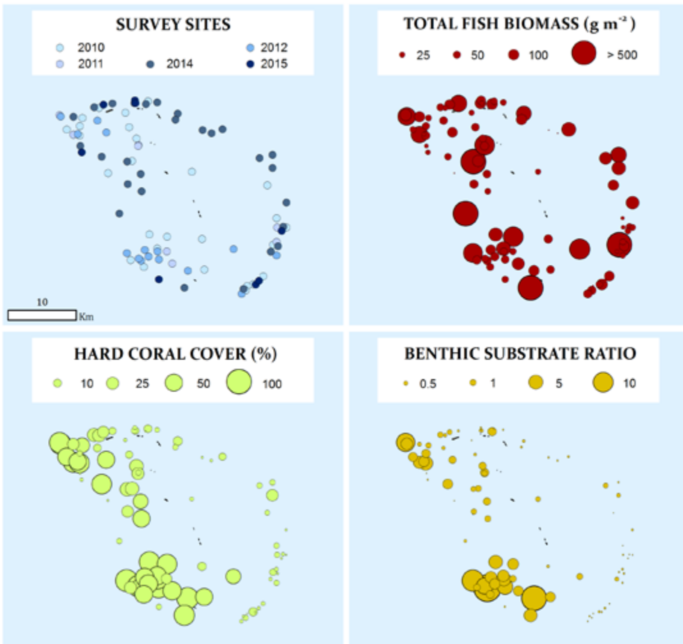

Figure 8 French Frigate Shoals site survey data 2010, 2011, 2012, 2014, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

The forereef habitat was surveyed in 2010 (n = 11), 2011 (n = 2), 2012 (n = 5), 2014 (n = 24) and 2015 (n = 8).

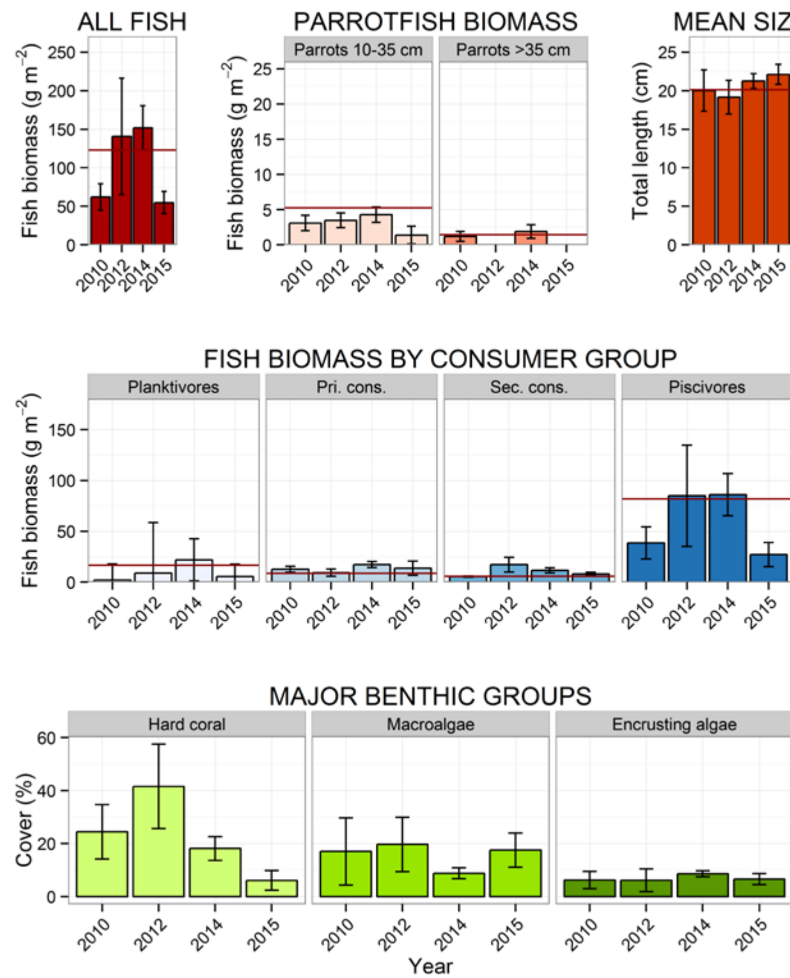

Figure 9 French Frigate Shoals fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos, for forereef habitat only. Only 2 forereef sites were surveyed in 2011, so those data are not included. The Northwestern Hawaiian Islands region mean forereef estimates are plotted for reference (red line).

Kure Atoll

Kure Atoll was surveyed in 2009 (n = 43), 2010 (n = 25), 2012 (n = 20), and 2015 (n = 8).

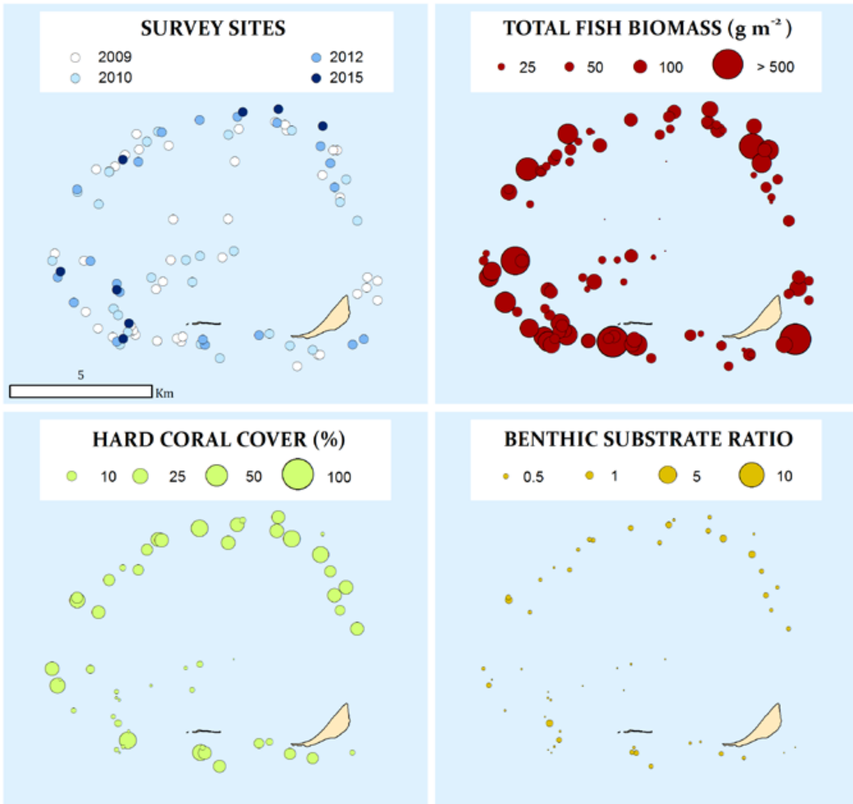

Figure 10 Kure Atoll site survey data 2009, 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

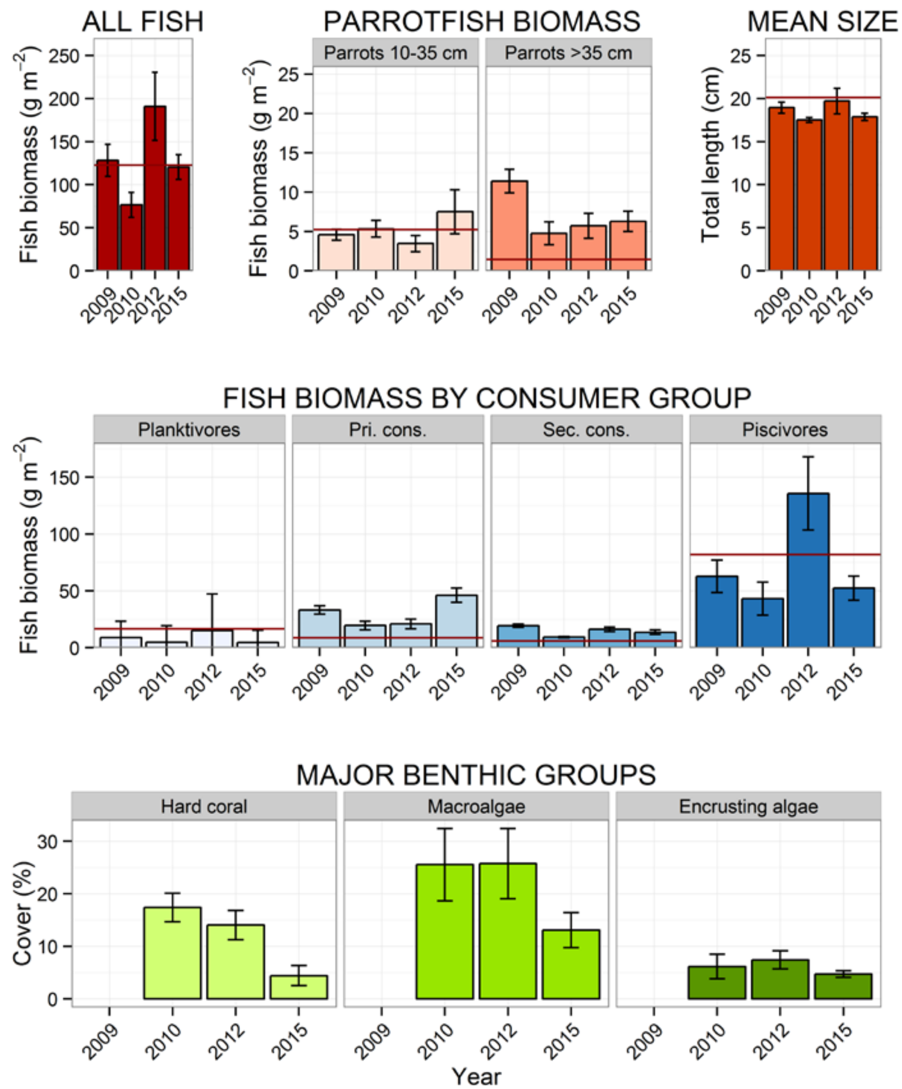

Figure 11 Kure Atoll fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos, for forereef habitat only. The Northwestern Hawaiian Islands region mean forereef estimates are plotted for reference (red line).

Laysan Island

Laysan Island was surveyed in 2009 (n = 14), 2011 (n = 23), and 2015 (n = 8).

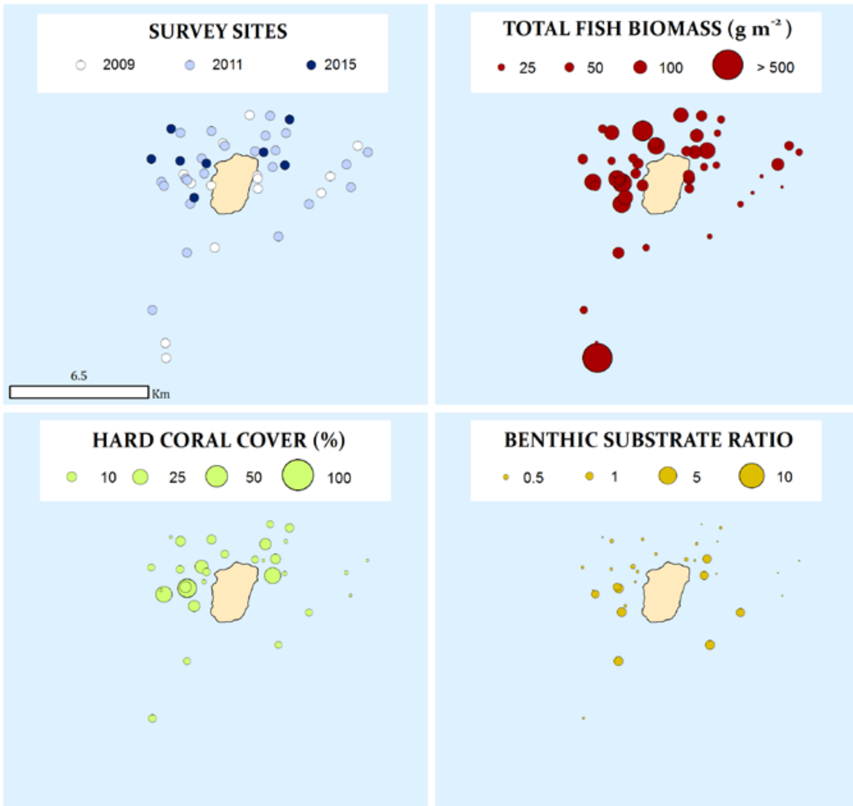

Figure 12 Laysan Island site survey data 2009, 2011, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae /turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

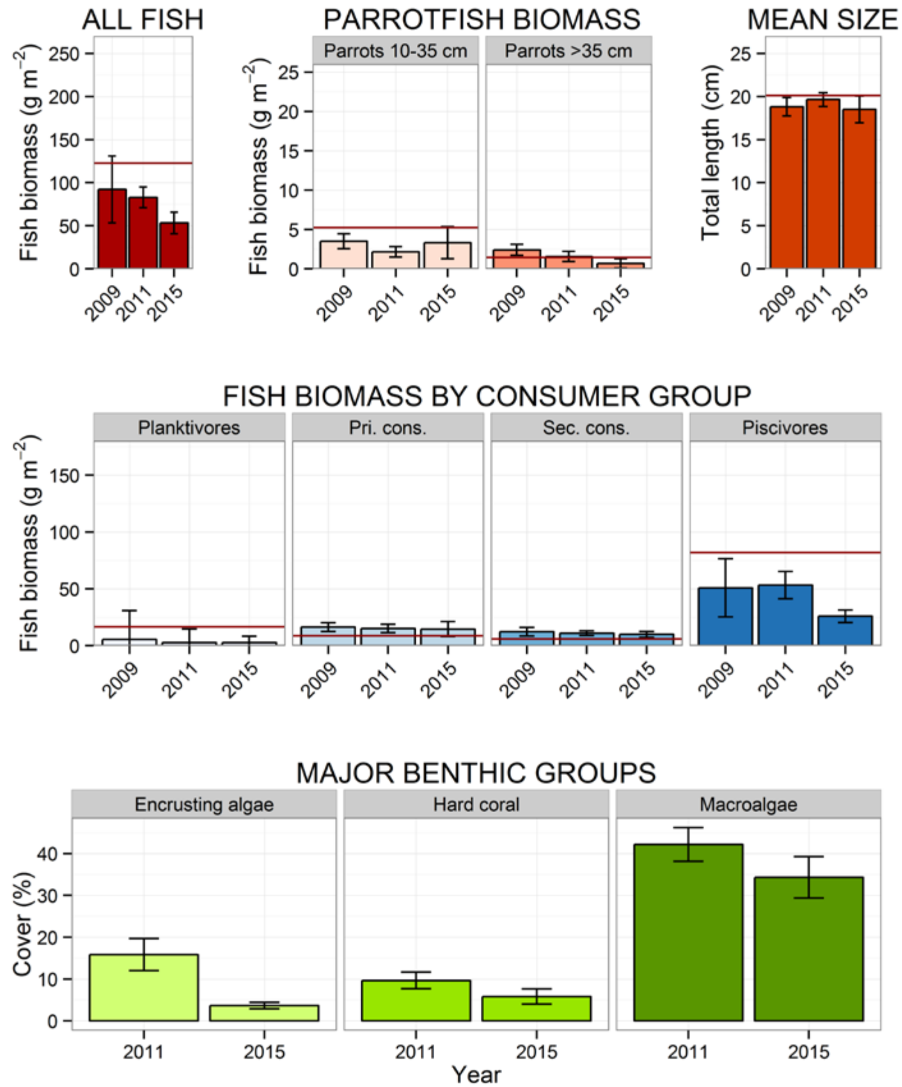

Figure 13 Laysan Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Northwestern Hawaiian Islands region mean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

Lisianski Island

Lisianski Island was surveyed in 2009 (n = 19), 2010 (n = 25), 2011 (n = 9), 2012 (n = 25), 2014 (n = 28), and 2015 (n = 18).

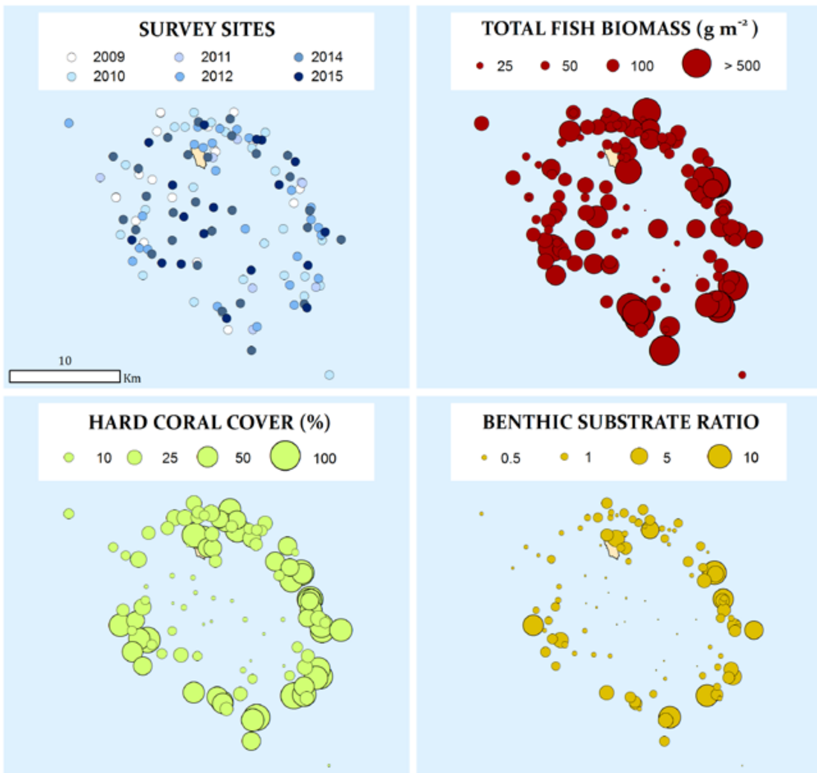

Figure 14 Lisianski Island site survey data 2009, 2010, 2011, 2012, 2014, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

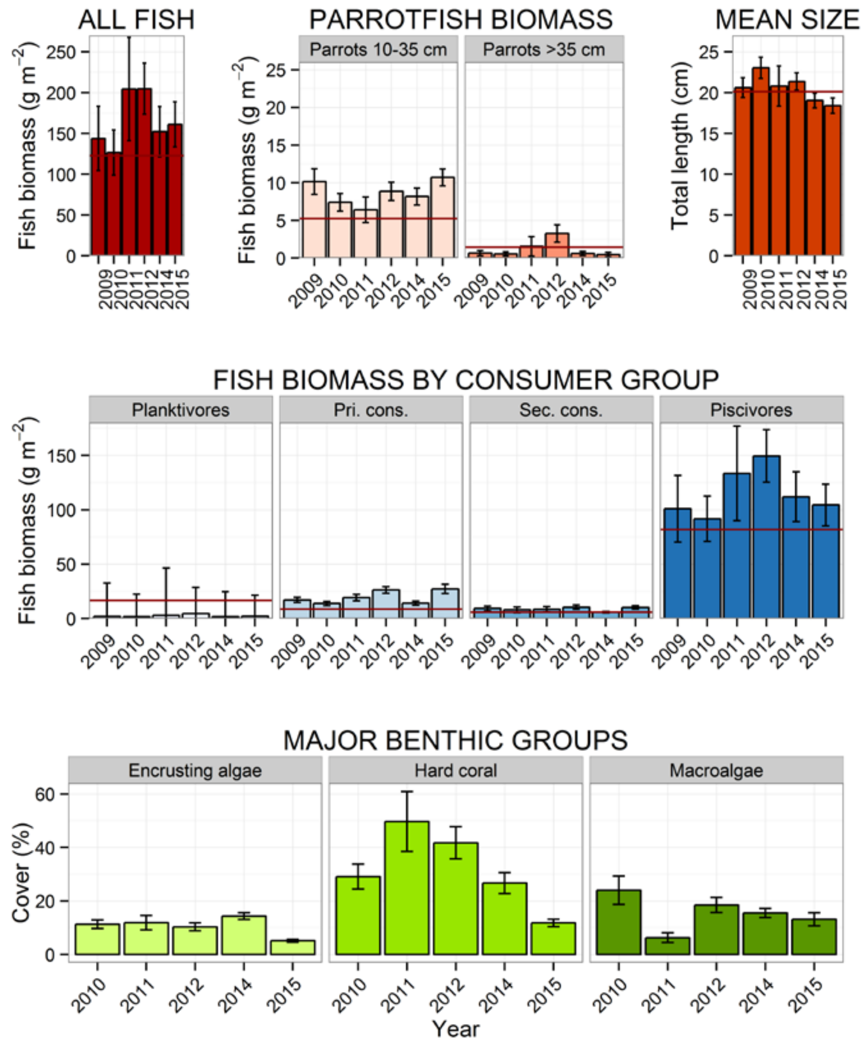

Figure 15 Lisianski Island fish and benthic plots showing the biomass ($g\ m^{-2} \pm SE$) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Northwestern Hawaiian Islands region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

Maro Reef

Maro Reef was surveyed in 2009 (n = 39), 2011 (n = 25), and 2015 (n = 17).

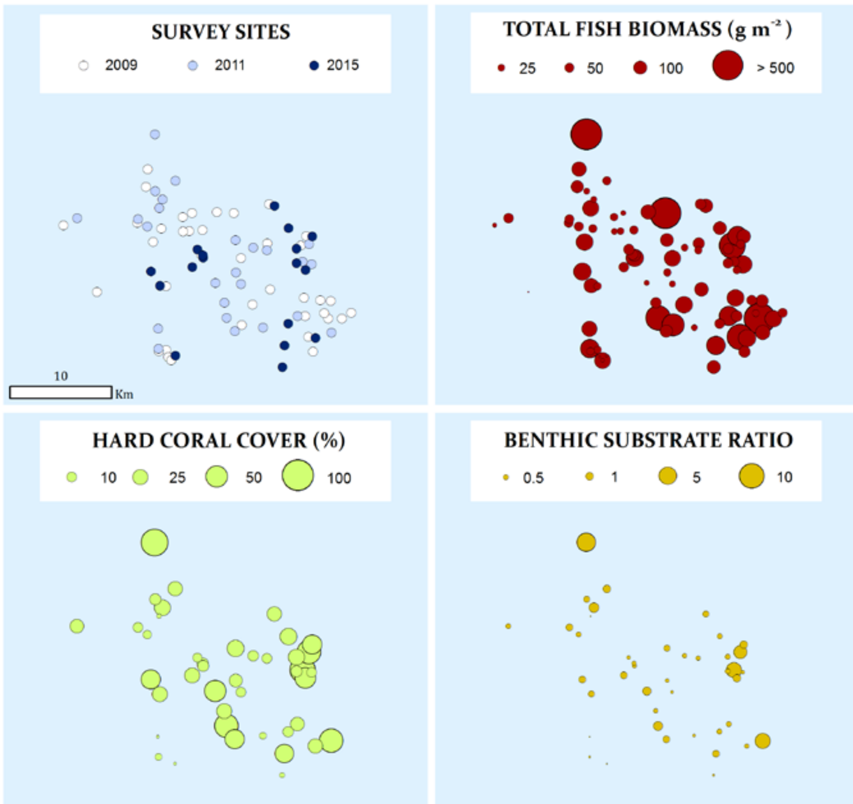

Figure 16 Maro Reef site survey data 2009, 2011, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

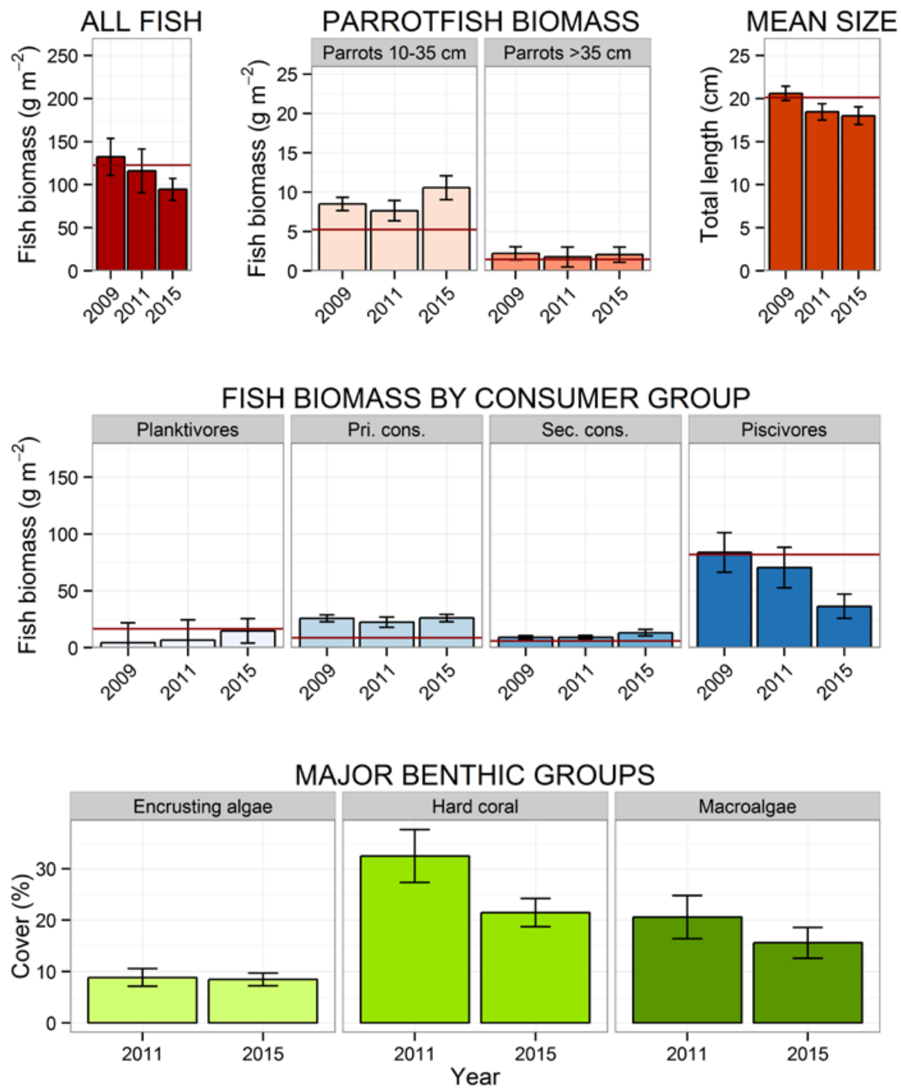

Figure 17 Maro Reef fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for forereef habitat only. The Northwestern Hawaiian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

Midway Island

Midway Island was surveyed in 2009 (n = 53), 2011 (n = 30), 2014 (n = 34), and 2015 (n = 14). Two habitats were surveyed in 2015: forereef and backreef. 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.

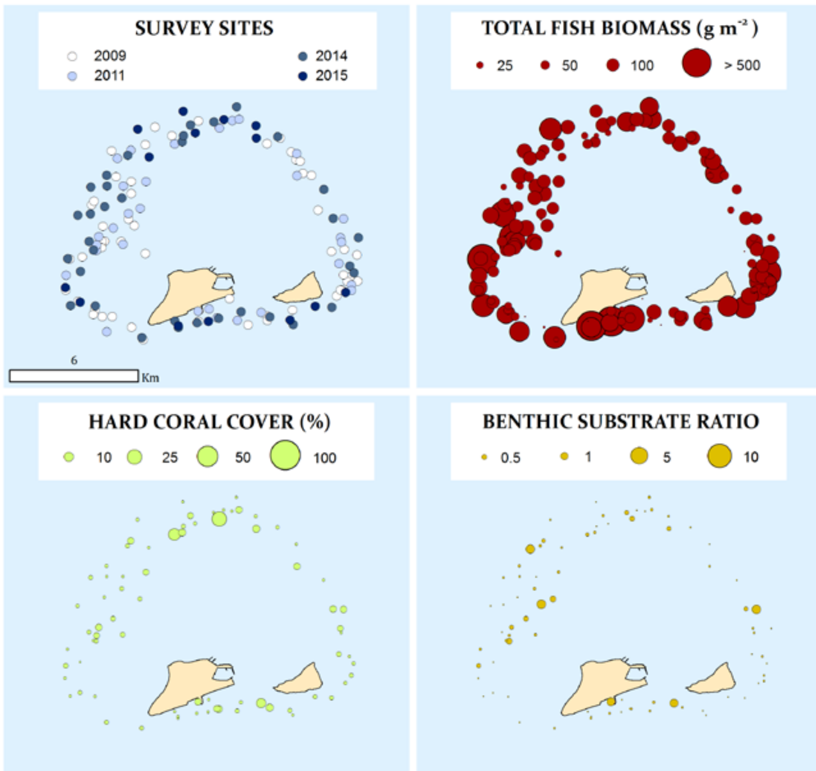

Figure 18 Midway Island site survey data 2009, 2011, 2014, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

The forereef habitat was surveyed in 2009 (n = 31), 2011 (n = 17), 2014 (n = 30), and 2015 (n = 12).

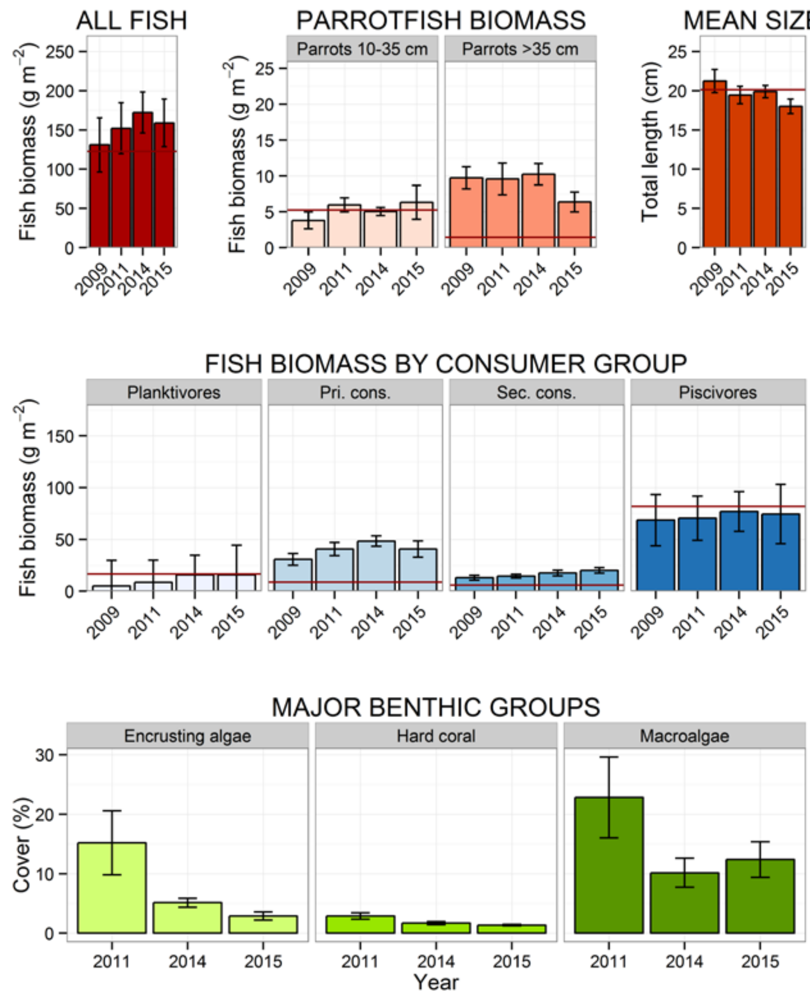

Figure 19 Midway Island fish and benthic plots showing the biomass ($g\ m^{-2} \pm SE$) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for forereef habitat only. The Northwestern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

The backreef habitat was surveyed in 2009 (n = 7), 2011 (n = 5), 2014 (n = 14), and 2015 (n = 2).

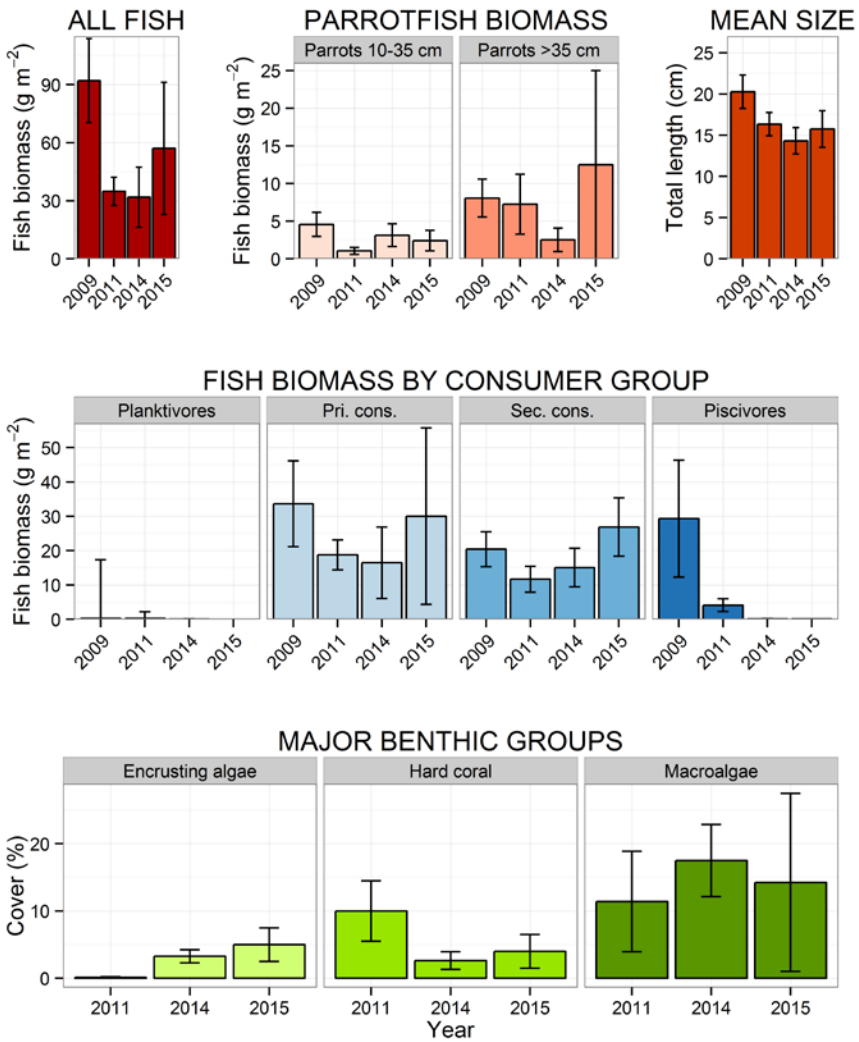

Figure 20 Midway Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for backreef habitat. The Northwestern Hawaiian Islands region mean backreef estimates are not plotted due to small sample size.

Pearl & Hermes Reef

Pearl and Hermes Reef was surveyed in 2010 (n = 41), 2011 (n = 18), 2012 (n = 31), and 2015 (n = 23). Two habitats were surveyed in 2015: forereef and backreef. 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.

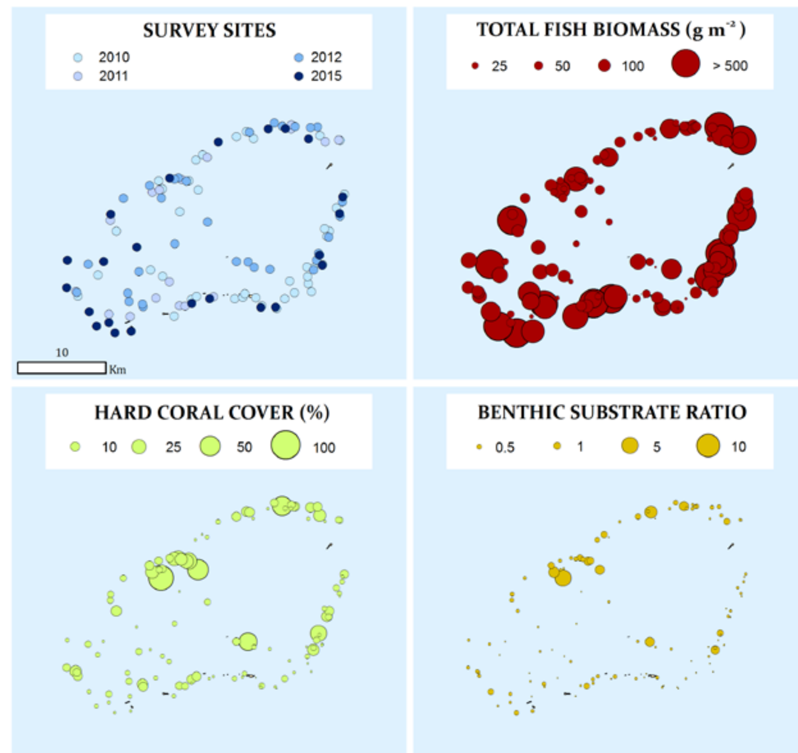

Figure 21 Pearl & Hermes Reef site survey data 2010, 2011, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

The forereef habitat was surveyed in 2010 (n = 24), 2011 (n = 9), 2012 (n = 15), and 2015 (n = 21).

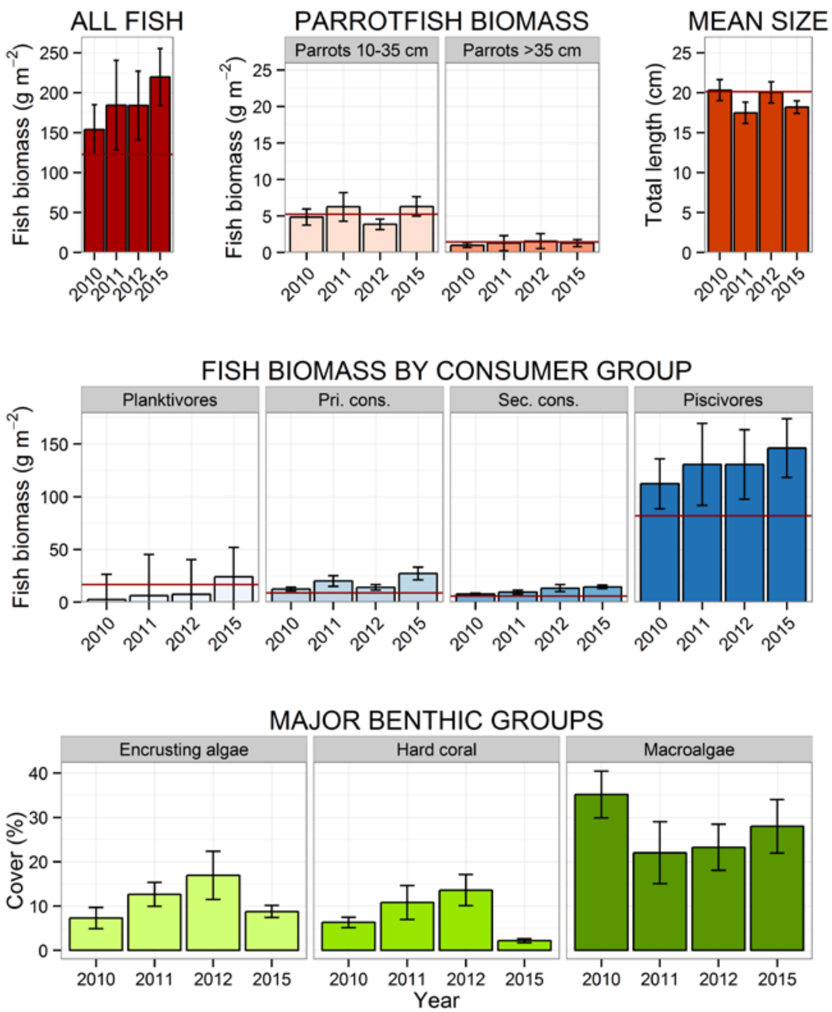

Figure 22 Pearl & Hermes Reef fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for forereef habitat. The Northwestern Hawaiian Islands region mean forereef estimates are plotted for reference (red line).

The backreef habitat was surveyed in 2010 (n = 7), and 2015 (n = 2).

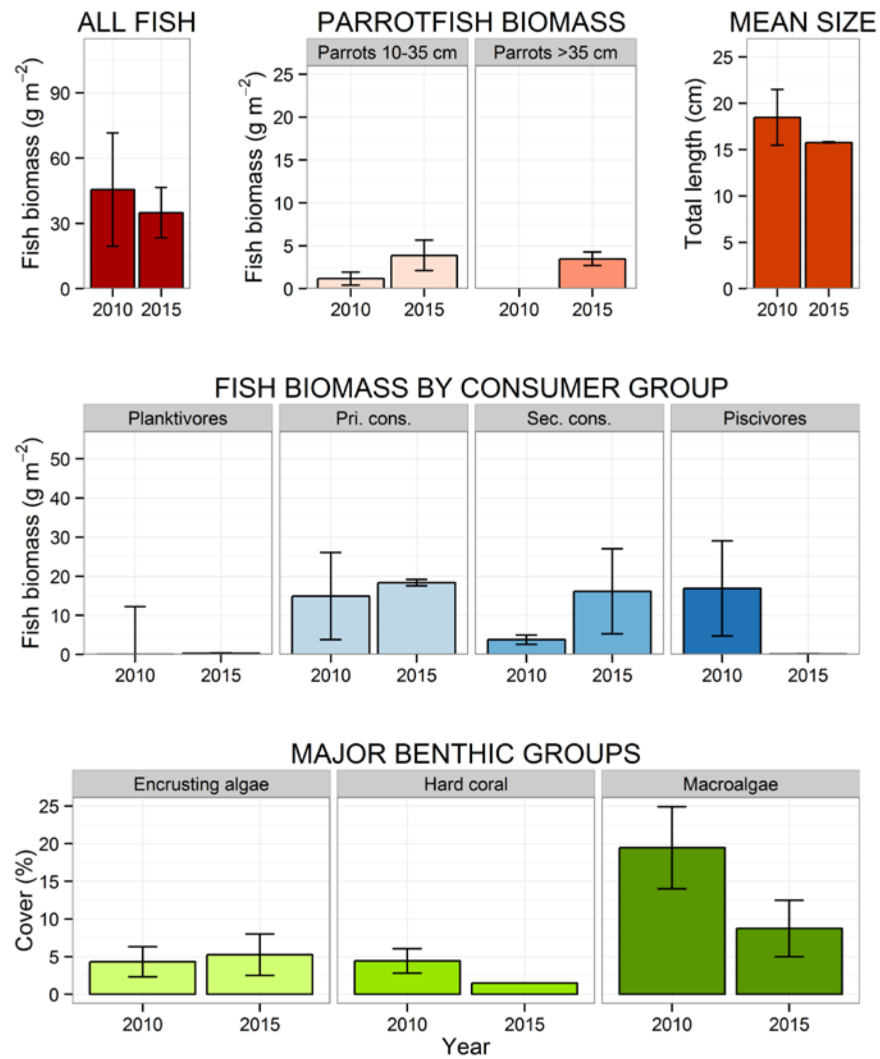

Figure 23 Pearl & Hermes Reef fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for backreef habitat. The Northwestern Hawaiian Islands region mean backreef estimates are not plotted due to small sample size.

Northwestern Hawaiian Islands (NWHI)

Towed divers surveys were conducted in the NWHI in 2000-2004 (n = 77, 10, 43, 71, 55), 2006 (n = 66), 2008 (n = 77), and 2010 (n = 57). Because of low replication and limited spatial coverage in 2001, those data are pooled with 2002 surveys.

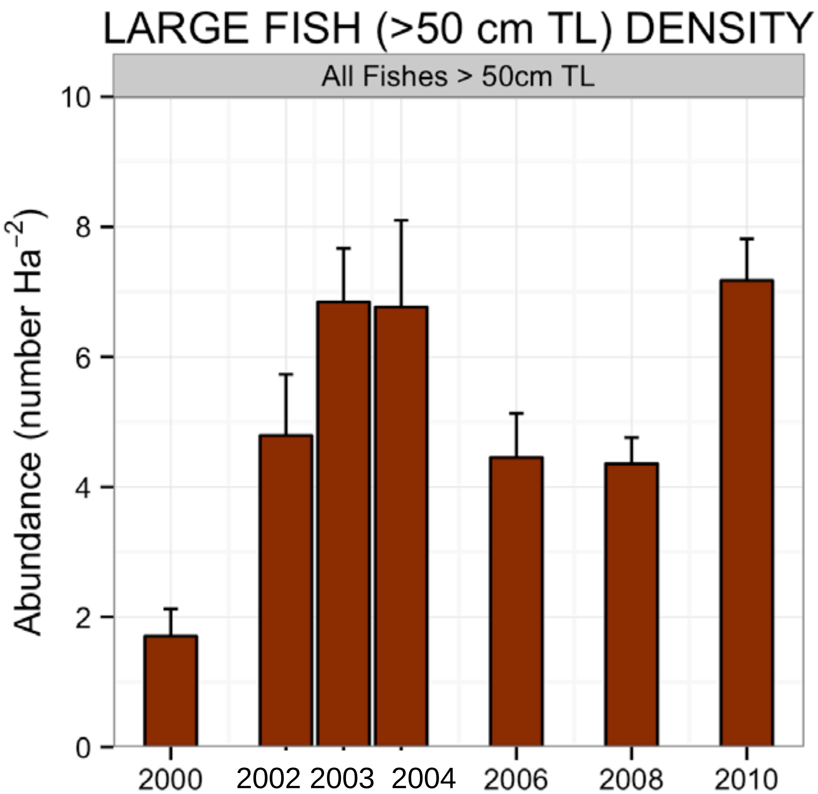

Figure 24 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL surveyed via the towed diver survey method in NWHI.

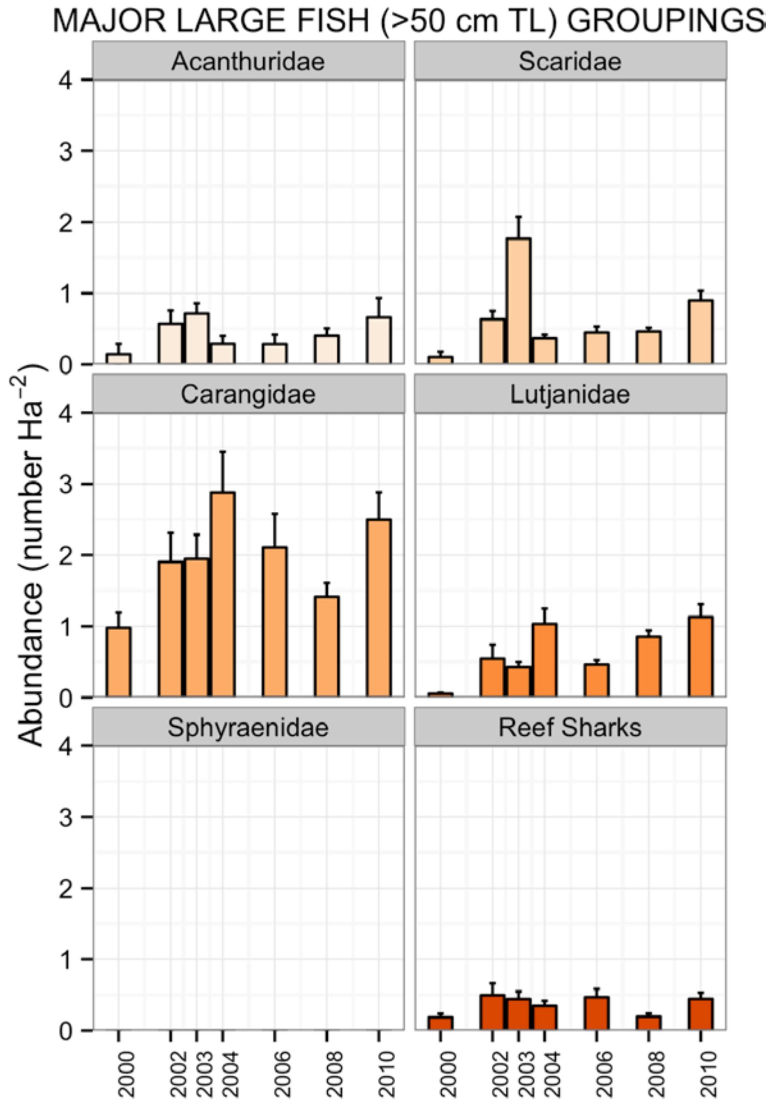

Figure 25 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL for family groups Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and reef sharks in the NWHI.

main Hawaiian Islands (MHI)

Hawaii Island

SPC surveys were conducted in Hawaii Island in 2010 (n = 43), 2013 (n = 58), and 2015 (n= 97).

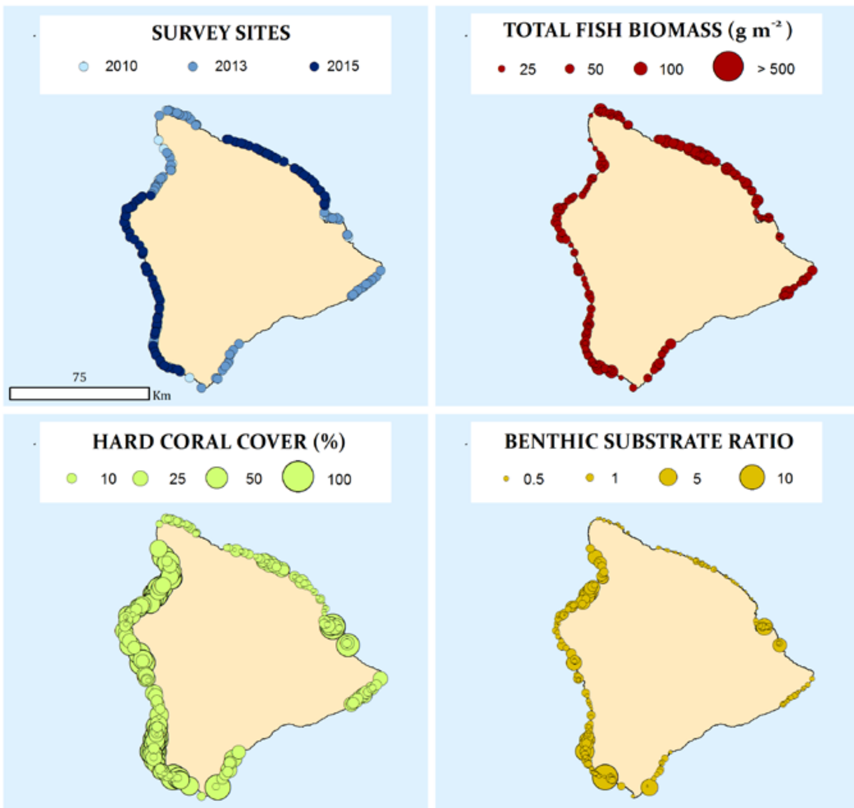

Figure 26 Hawaii Island site survey data 2010, 2013 and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on a reef.

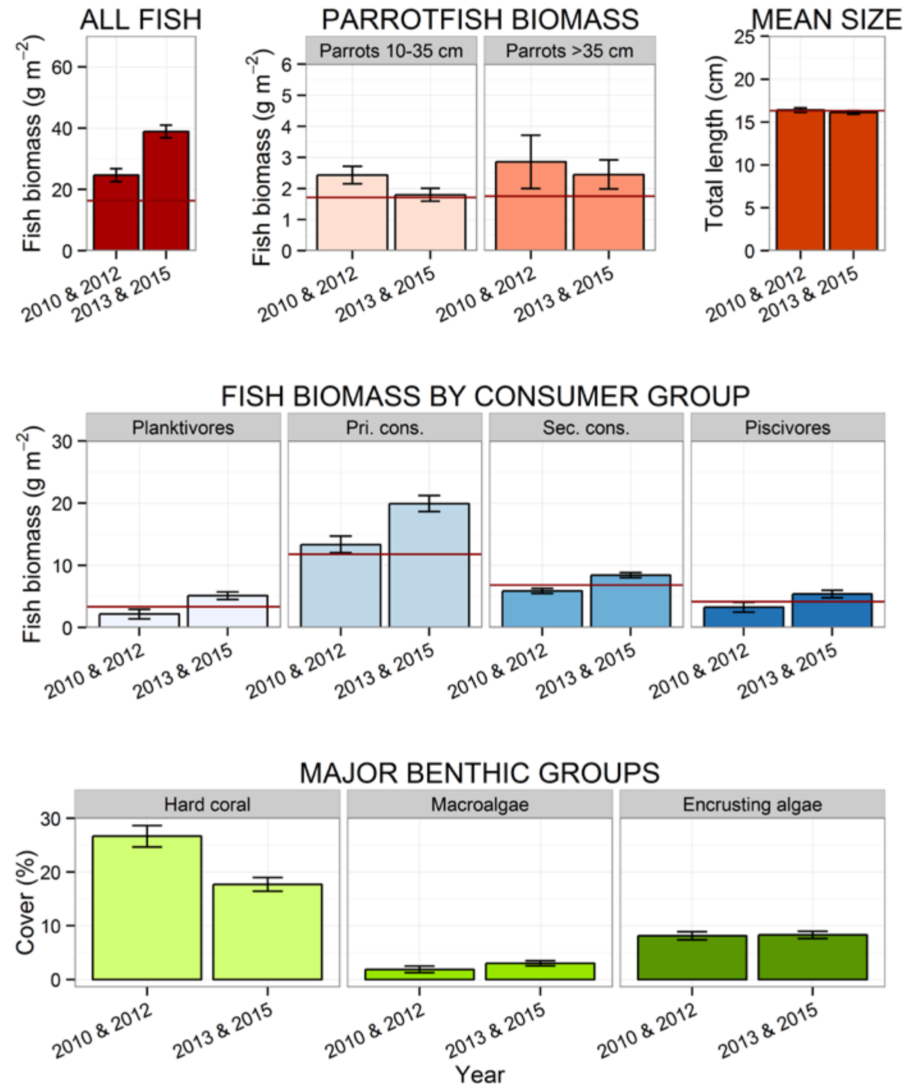

Figure 27 Hawaii Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The main Hawaiian Islands region mean estimates are plotted for reference (red line).

Kauai Island

Kauai Island was surveyed in 2010 (n = 26), 2013 (n = 37), and 2015 (n = 20).

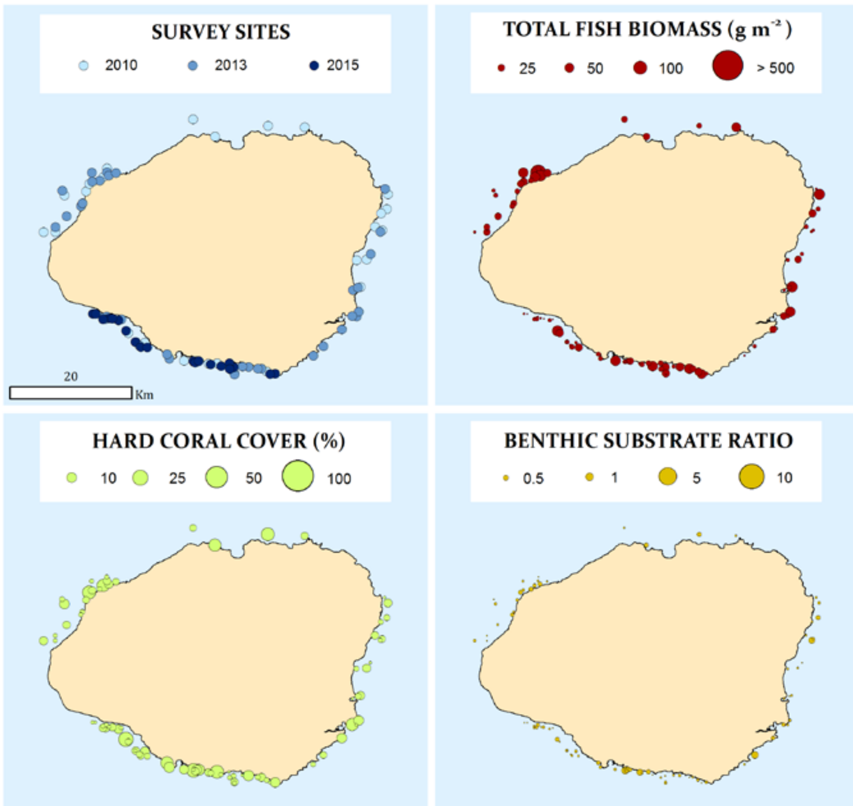

Figure 28 Kauai Island site survey data 2010, 2013, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

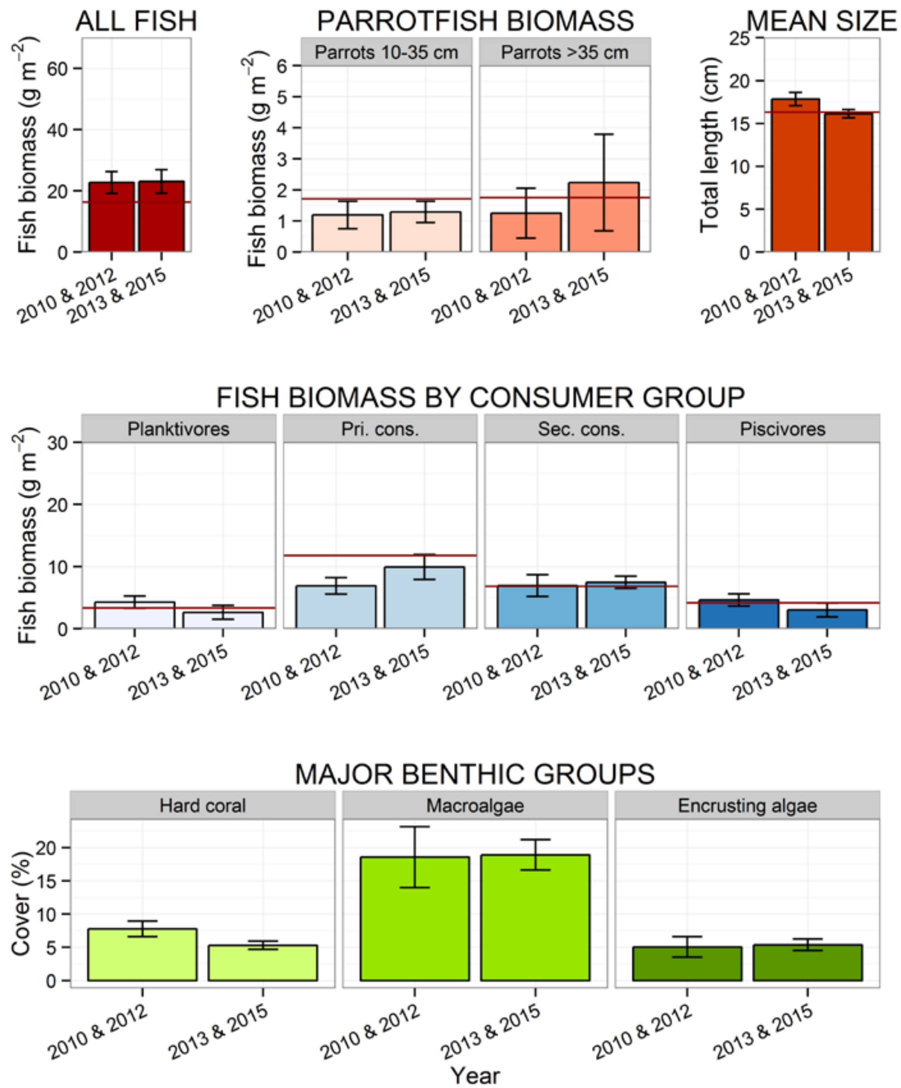

Figure 29 Kauai Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The main Hawaiian Islands region mean estimates are plotted for reference (red line).

Lanai Island

Lanai Island was surveyed in in 2010 (n = 16), 2012 (n = 29), 2013 (n = 29), and 2015 (n= 15).

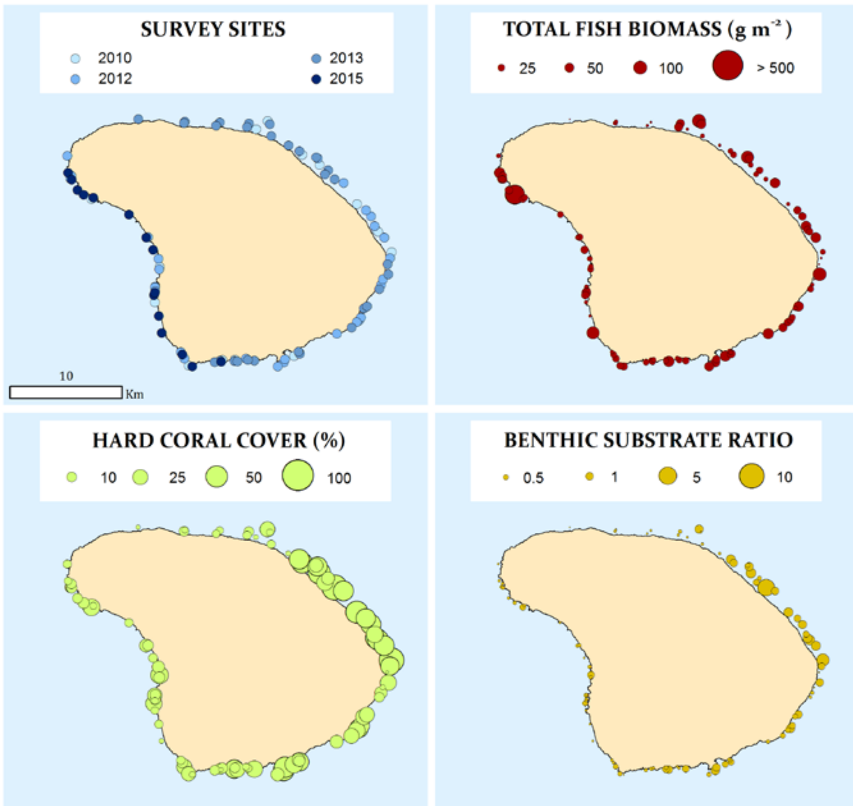

Figure 30 Lanai Island site survey data 2010, 2012, 2013, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

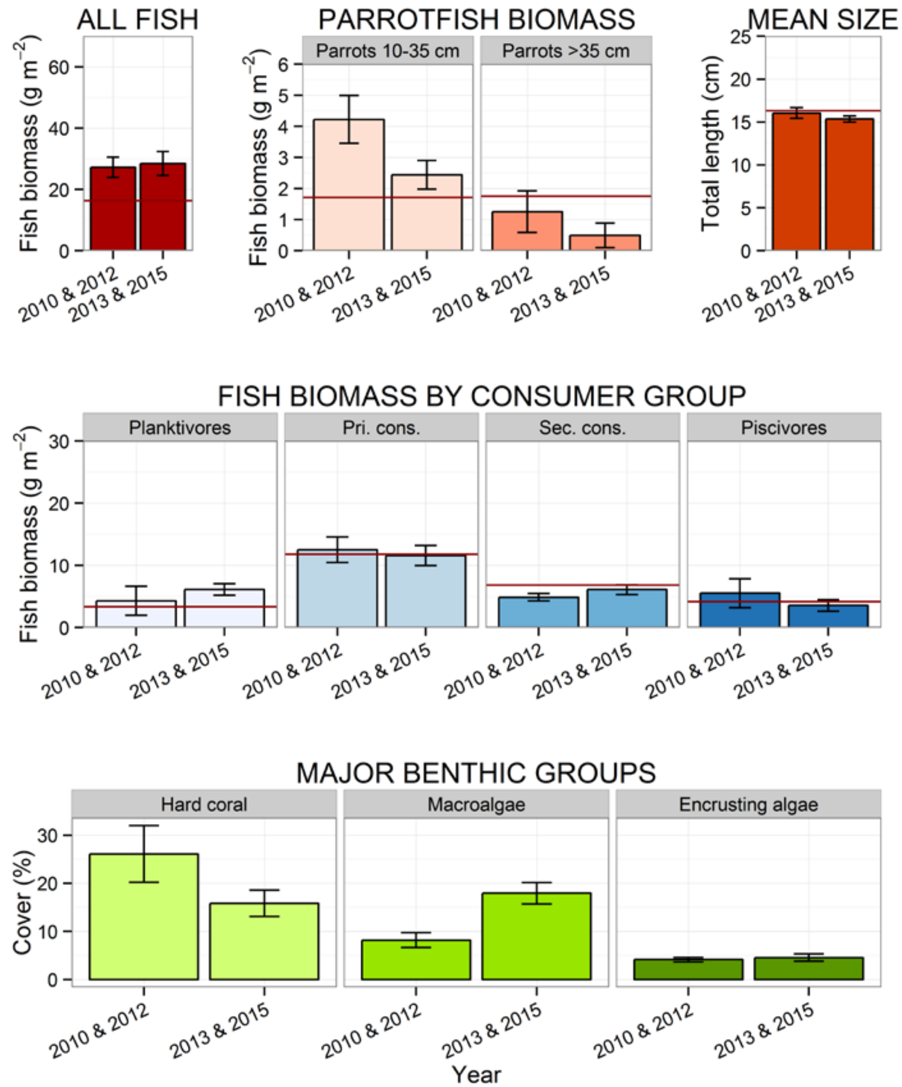

Figure 31 Lanai Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The main Hawaiian Islands region mean estimates are plotted for reference (red line).

Maui Island

Maui Island was surveyed in 2010 (n = 33), 2011 (n = 49), 2012 (n = 34), and 2015 (n = 30).

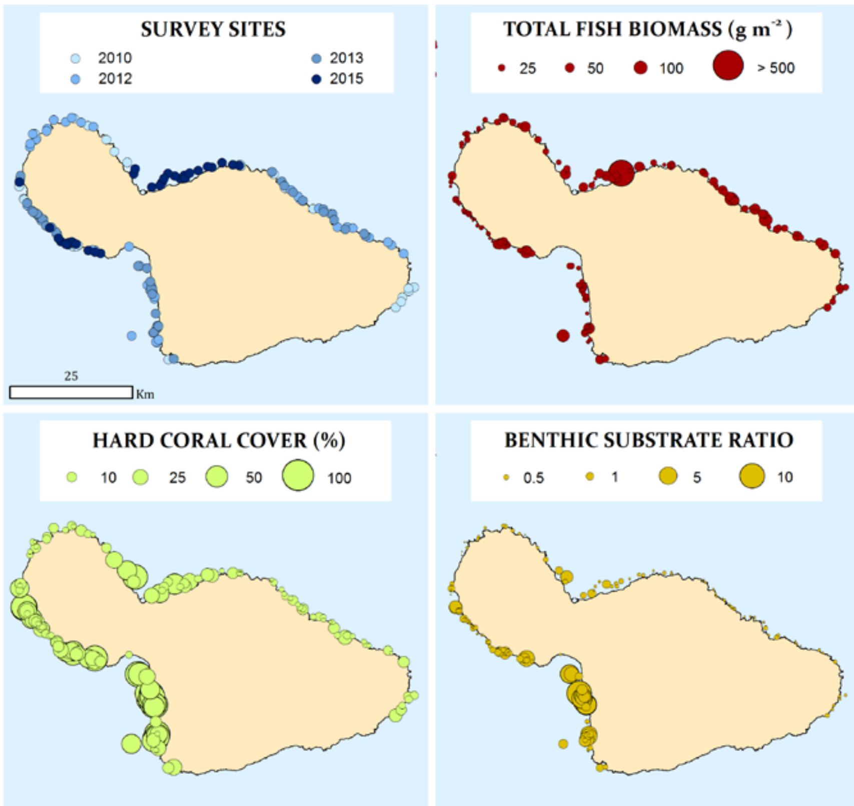

Figure 32 Maui Island site survey data 2010, 2011, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

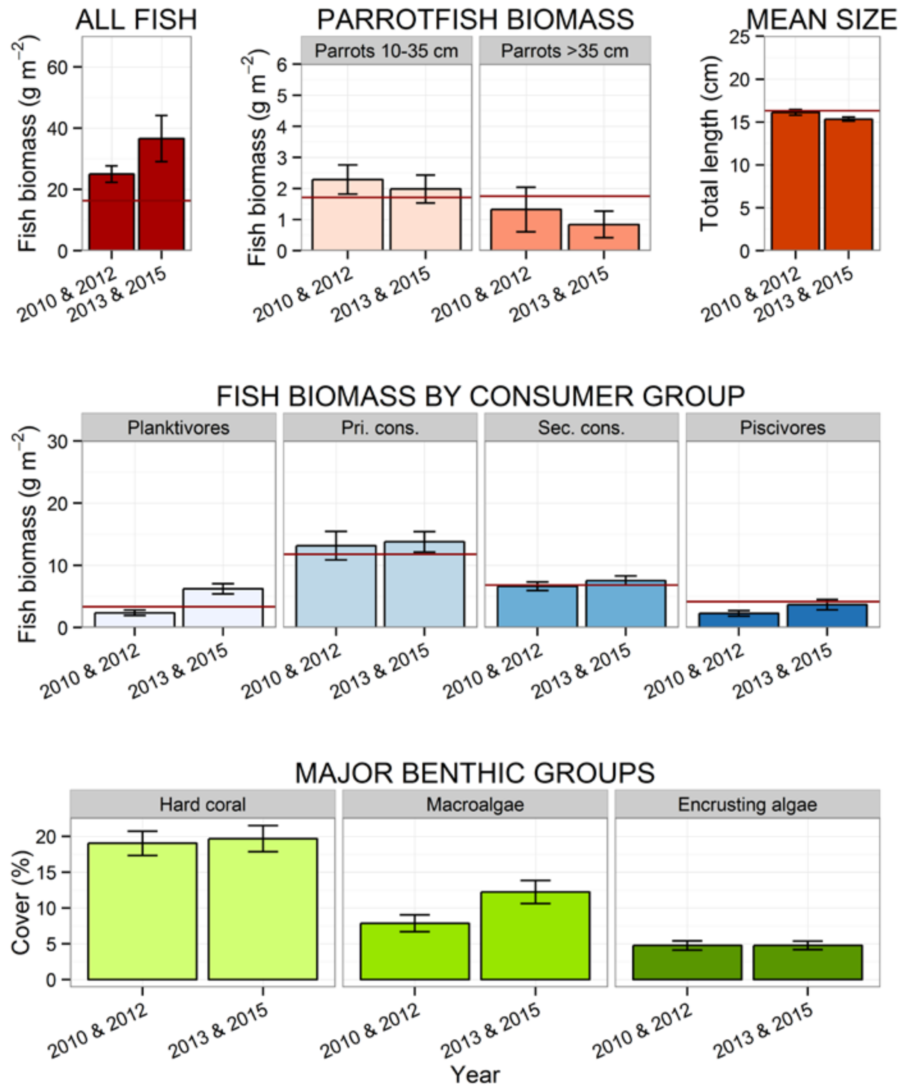

Figure 33 Maui Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The main Hawaiian Islands region mean estimates are plotted for reference (red line).

Molokai Island

Molokai Island was surveyed in 2010 (n = 10), 2012 (n = 50), 2013 (n = 39), and 2015 (n = 48).

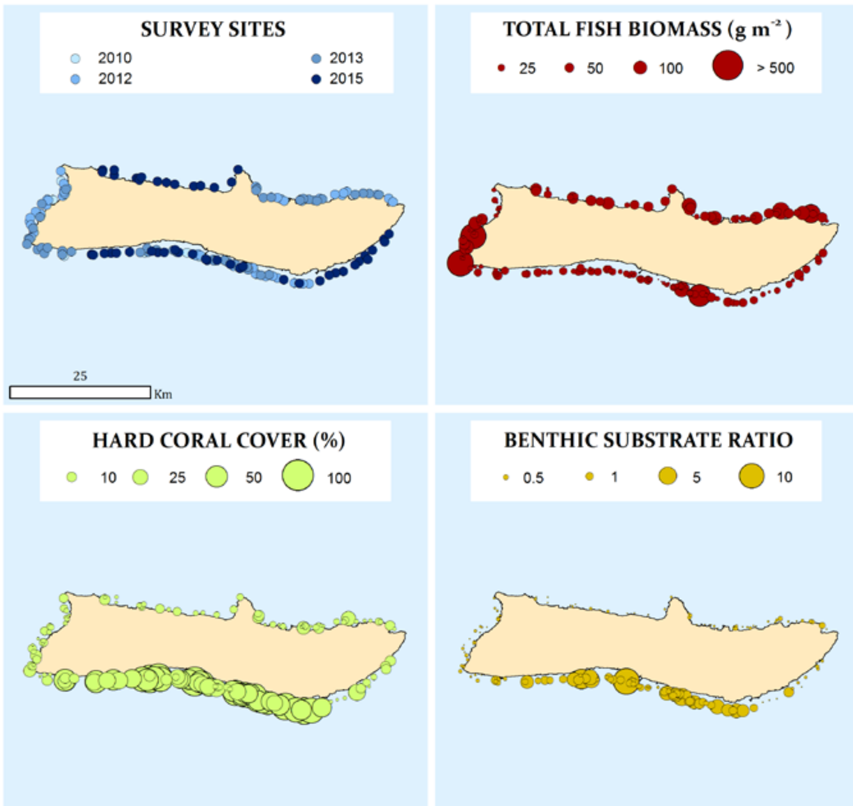

Figure 34 Molokai Island site survey data 2010, 2012, 2013, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

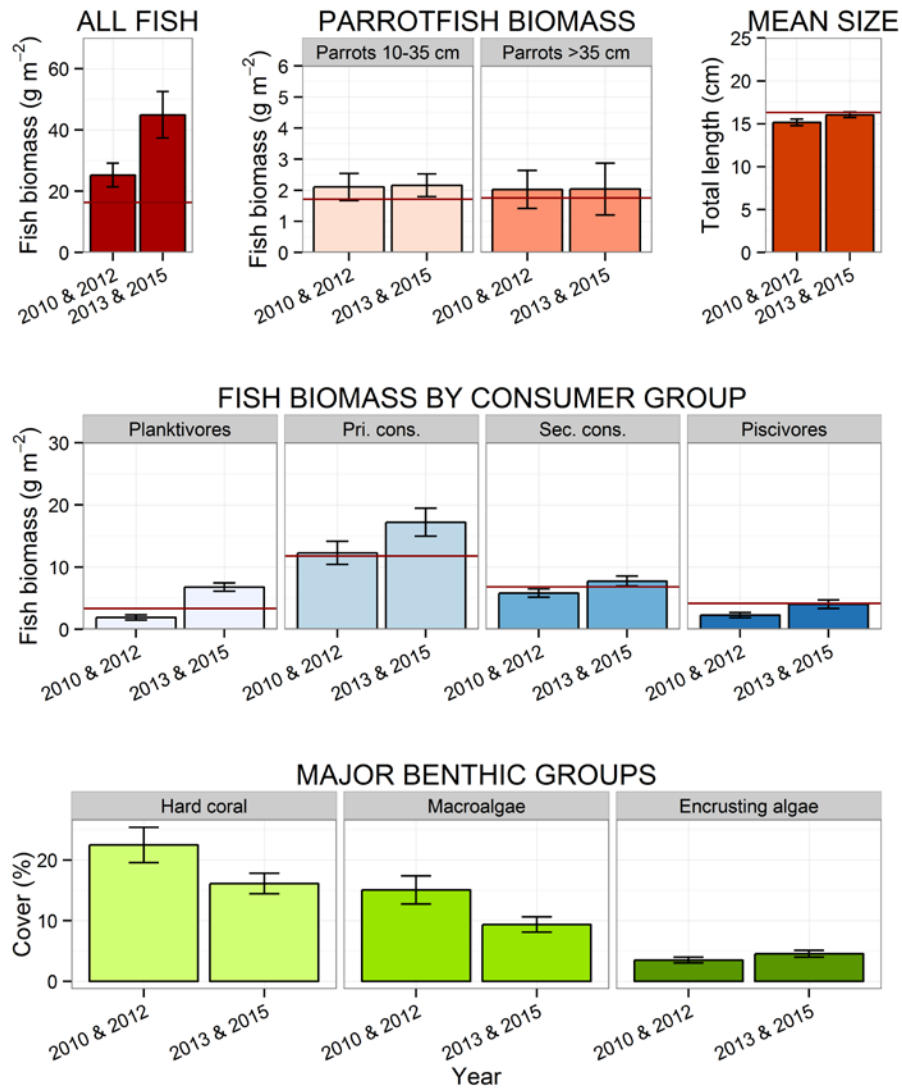

Figure 35 Molokai Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The main Hawaiian Islands region mean estimates are plotted for reference (red line).

Niihau Island

Niihau Island was surveyed in 2010 (n = 16), 2013 (n = 26), and 2015 (n = 49).

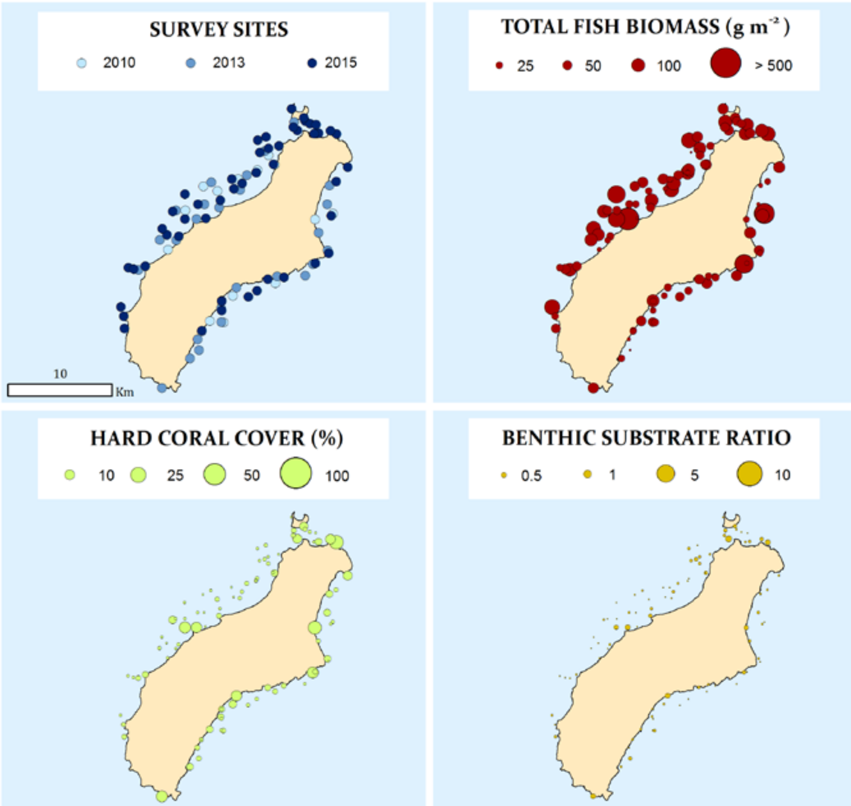

Figure 36 Niihau Island site survey data 2010, 2013, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

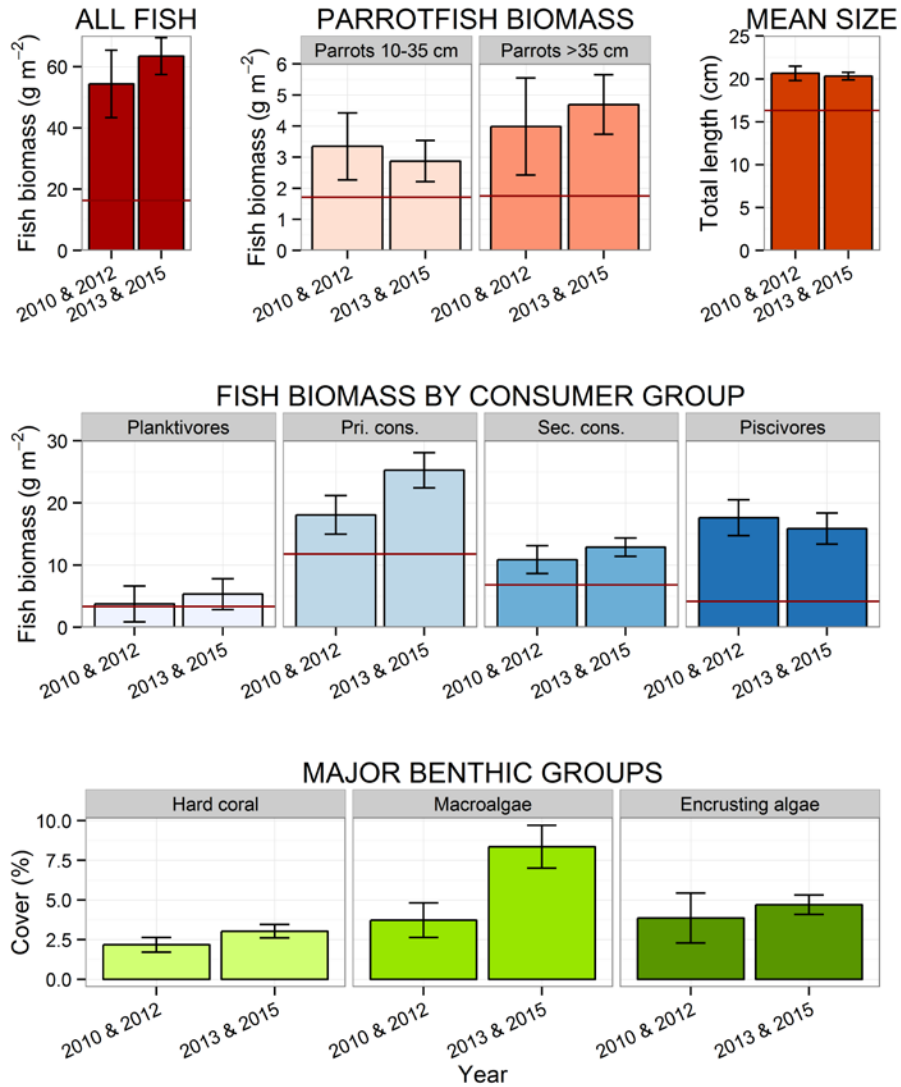

Figure 37 Niihau Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The main Hawaiian Islands region mean estimates are plotted for reference (red line).

Oahu Island

Oahu Island was surveyed in 2010 (n = 40), 2012 (n = 35), 2013 (n = 64), and 2015 (n = 35).

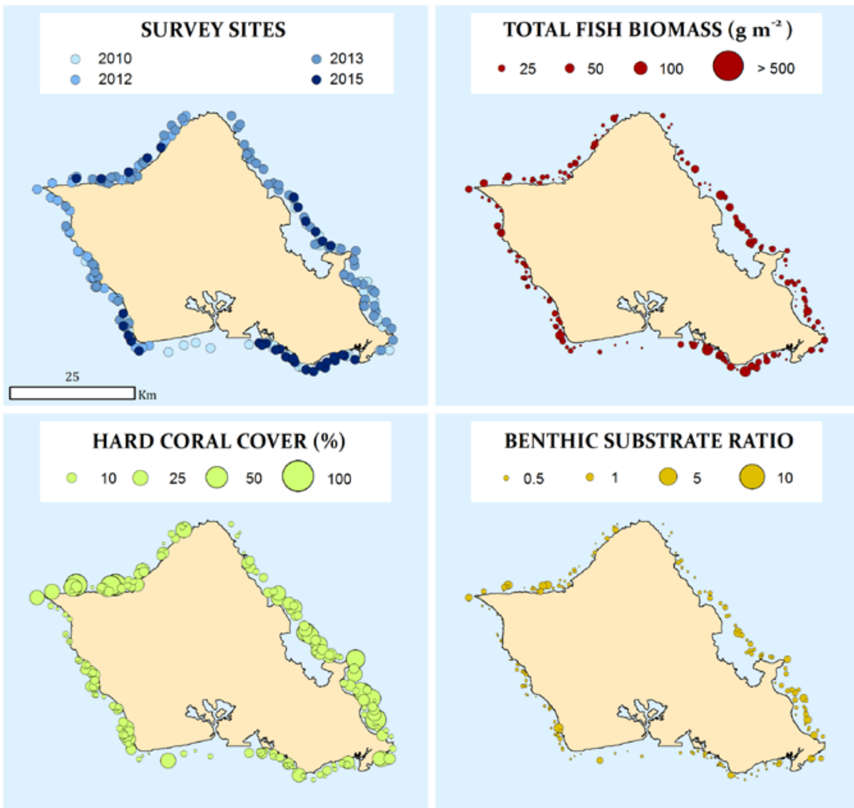

Figure 38 Oahu Island site survey data 2010, 2012, 2013, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

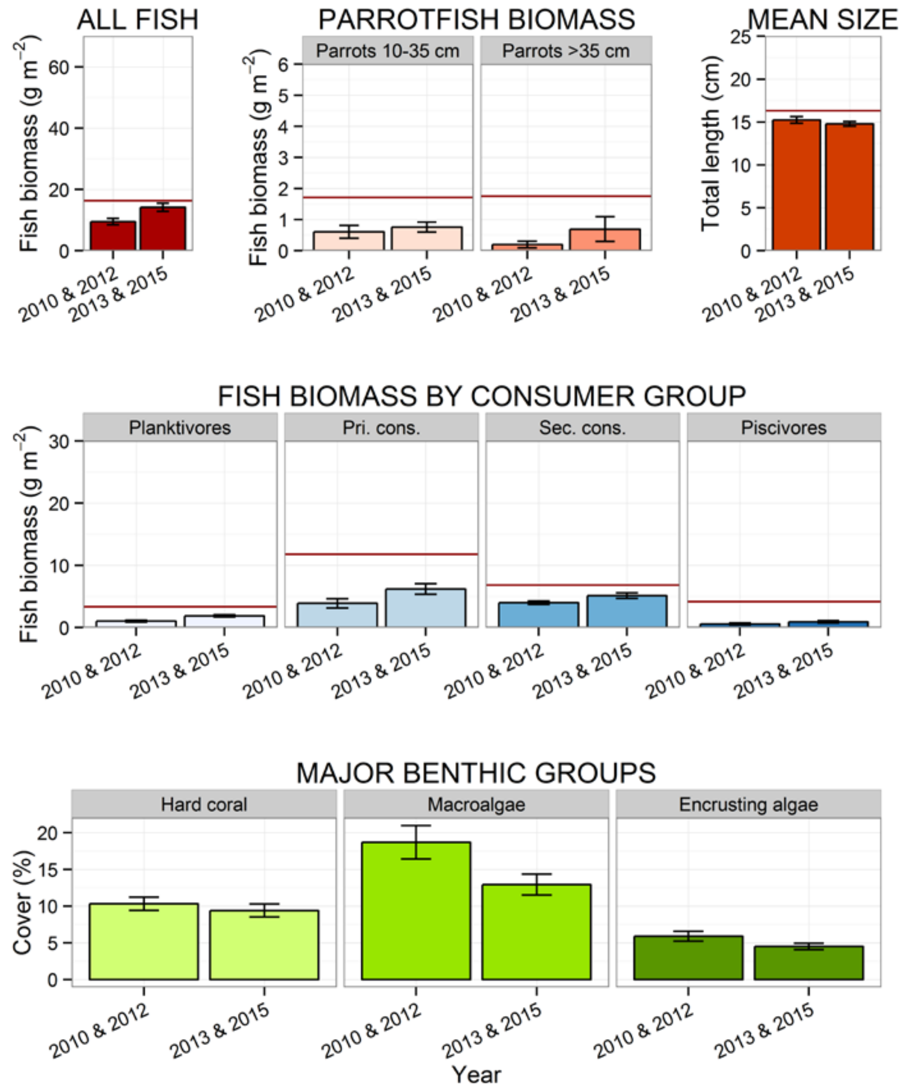

Figure 39 Oahu Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The main Hawaiian Islands region mean estimates are plotted for reference (red line).

main Hawaiian Islands (MHI)

Towed diver surveys were conducted in the MHI in 2005 (n = 80), 2006 (n = 110), 2008 (n = 144), and 2010 (n= 122).

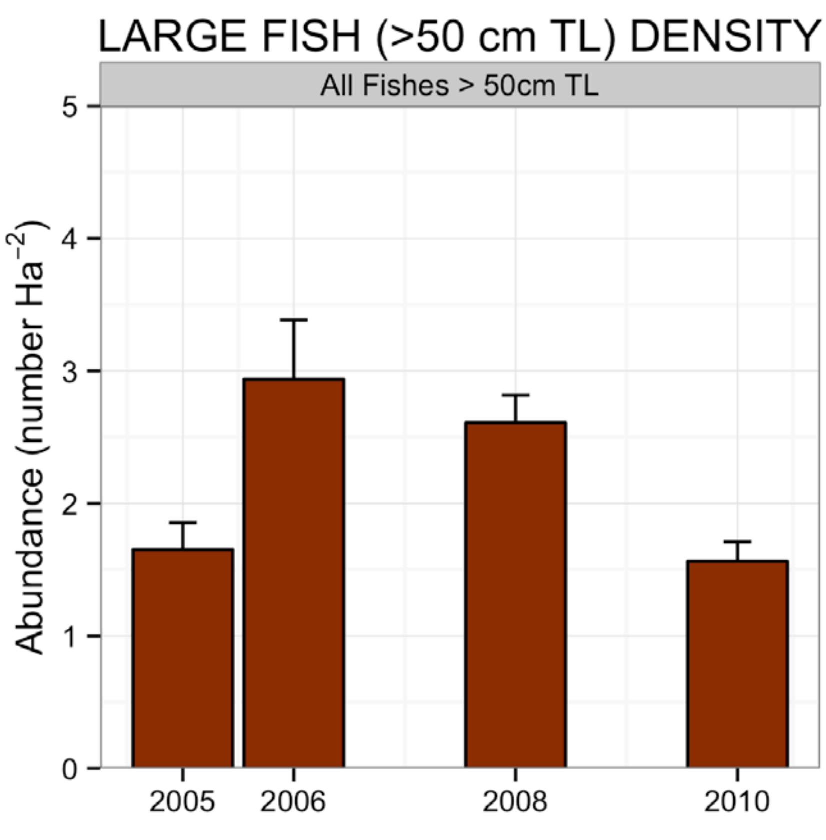

Figure 40 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL surveyed via the towed diver survey method in MHI.

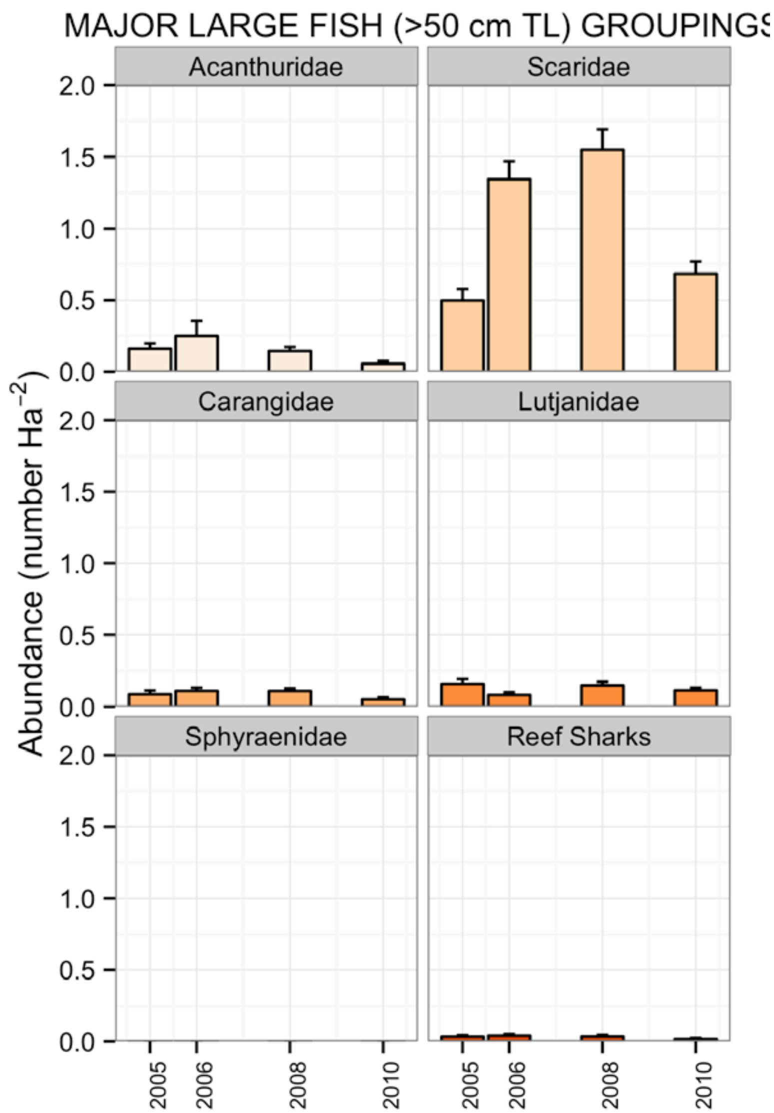

Figure 41 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL for family groups Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and reef sharks in the MHI.

Pacific Remote Islands Areas (PRIA)

Johnston Atoll

Johnston Atoll was surveyed in 2010 (n = 39), 2012 (n = 35), and 2015 (n = 31). Two habitats were surveyed in 2015: forereef and lagoon. 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.

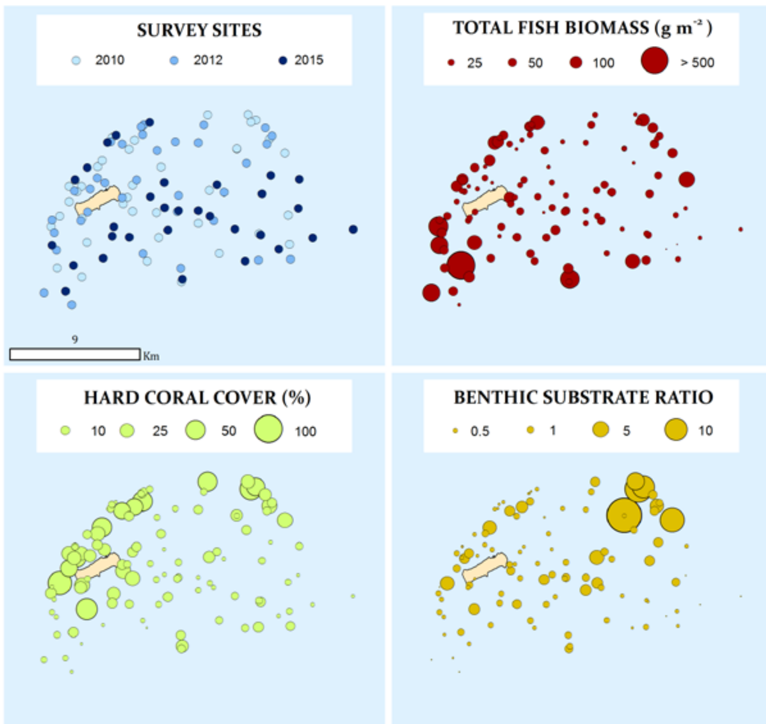

Figure 42 Johnston Atoll site survey data 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

Johnston Atoll forereef was surveyed in 2010 (n = 8), 2012 (n = 9), and 2015 (n = 23).

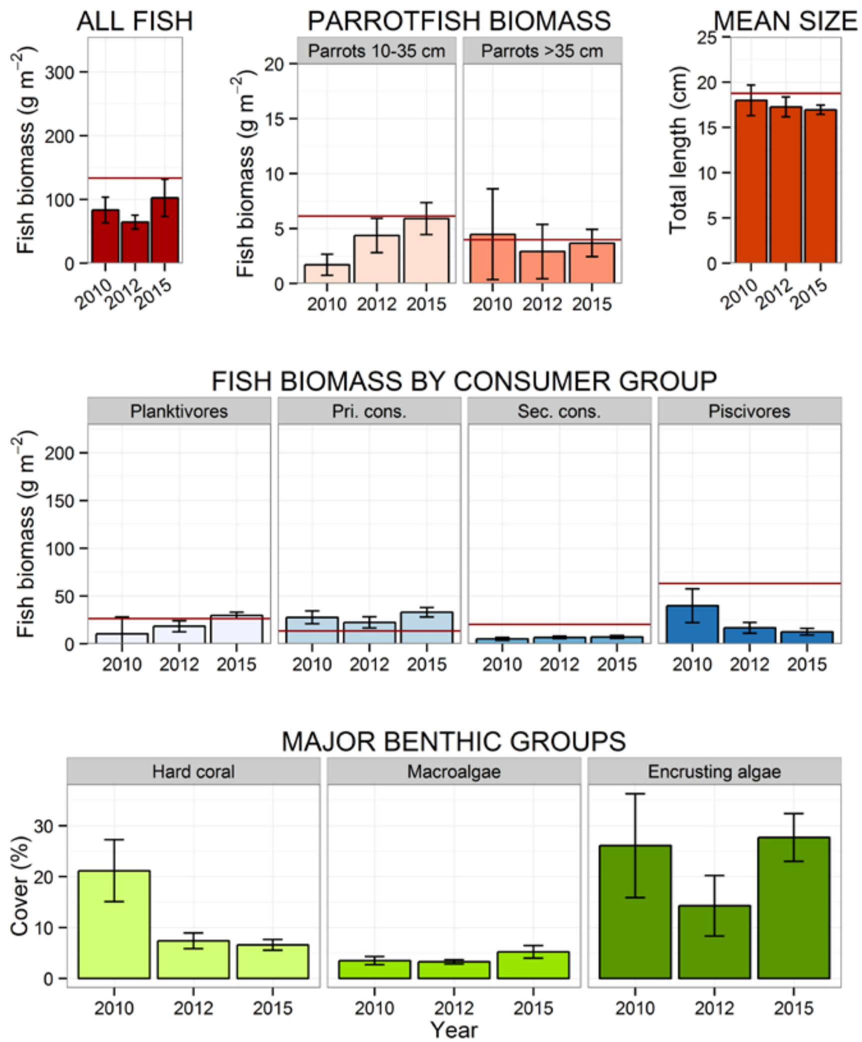

Figure 43 Johnston Atoll fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for forereef habitat. The Pacific Remote Island Areas region mean estimates are plotted for reference (red line).

Johnston Atoll lagoon was surveyed in 2010 (n = 20), 2012 (n =19), and 2015 (n = 8).

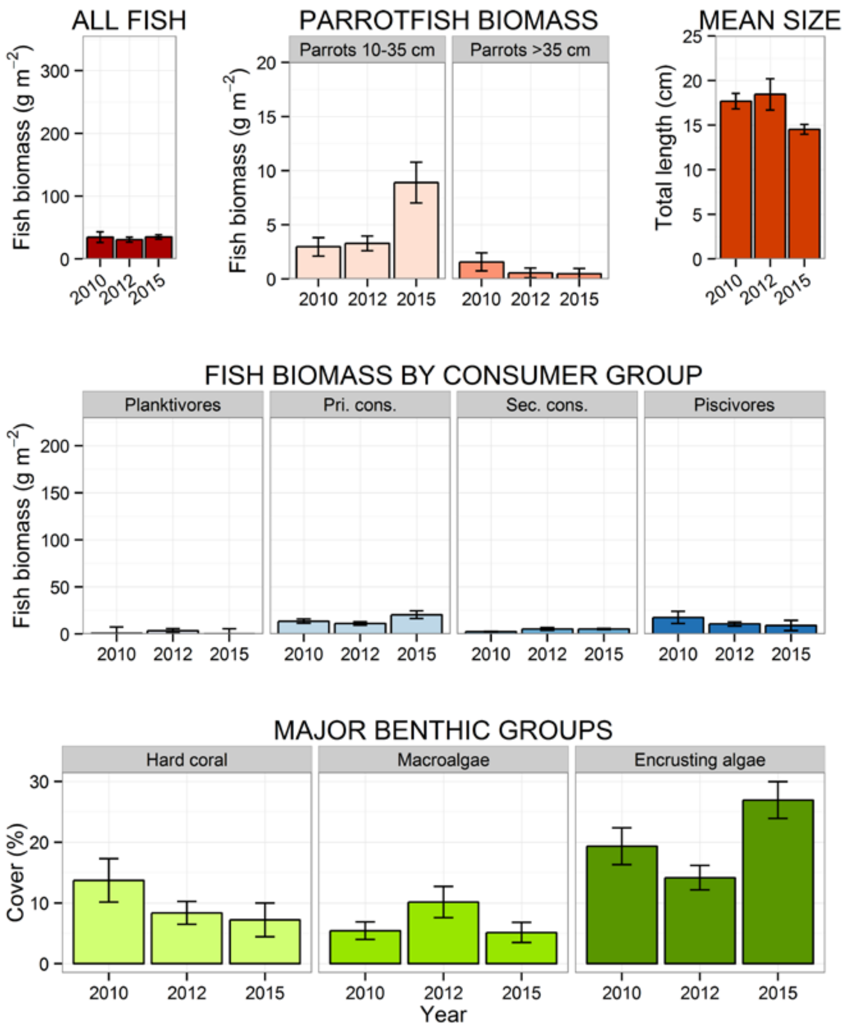

Figure 44 Johnston Atoll fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for lagoon habitat. The Pacific Remote Island Areas region mean lagoon estimates are not plotted due to small sample size.

Pacific Remote Islands Areas (PRIA) – Johnston Atoll

Towed divers surveys were conducted at Johnston Atoll in 2004 (n = 14), 2006 (n = 10), 2008 (n = 8), 2010 (n = 10), 2012 (n = 14) and 2015 (n = 14).

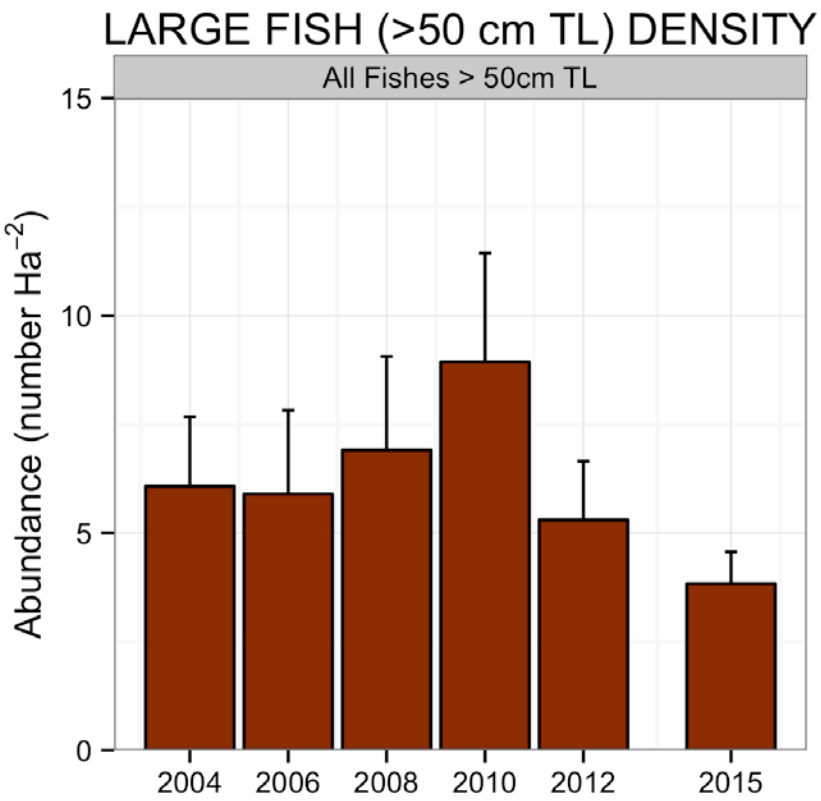

Figure 45 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL surveyed via the towed diver survey method in Johnston Atoll.

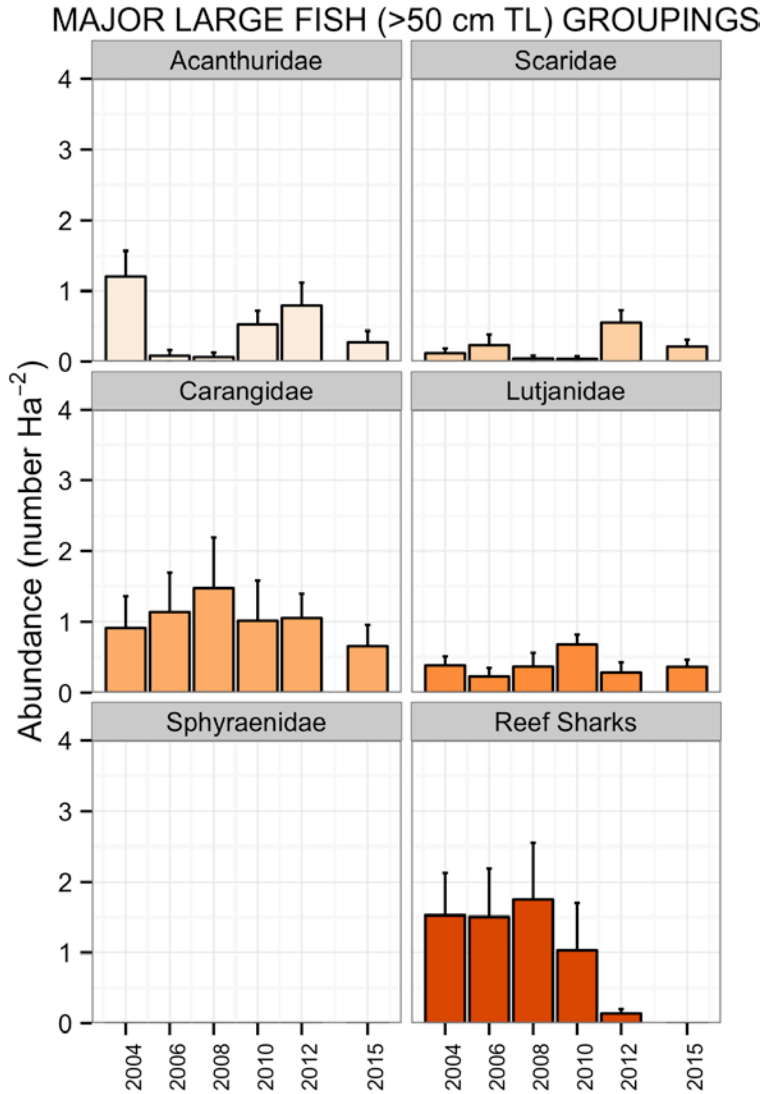

Figure 46 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL for family groups Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and reef sharks at Johnston Atoll.

Baker Island

Baker Island was surveyed in 2010 (n = 21), 2012 (n = 24), and 2015 (n = 36).

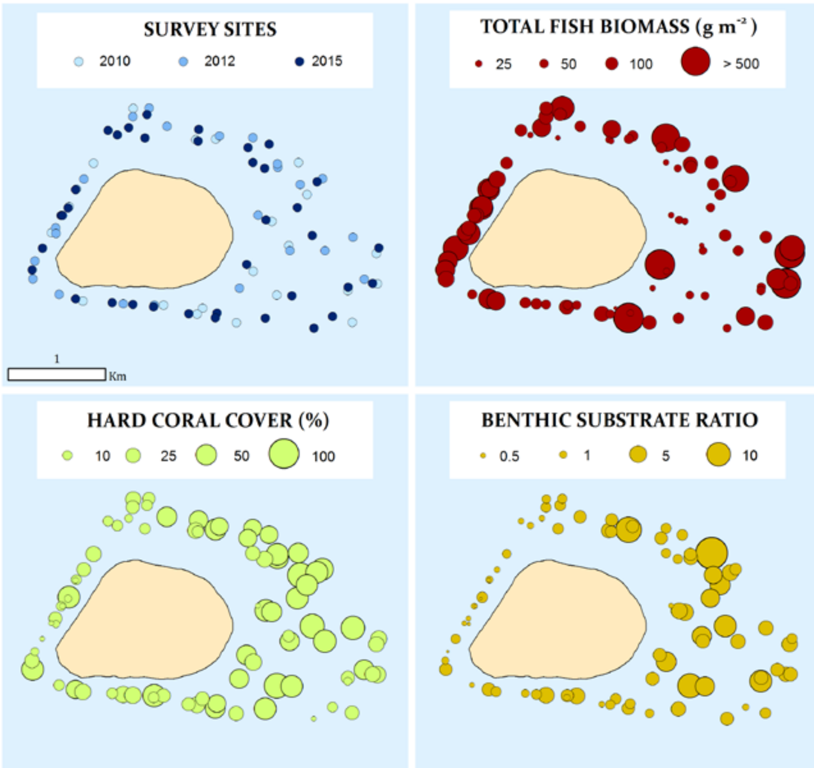

Figure 47 Baker Island site survey data 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

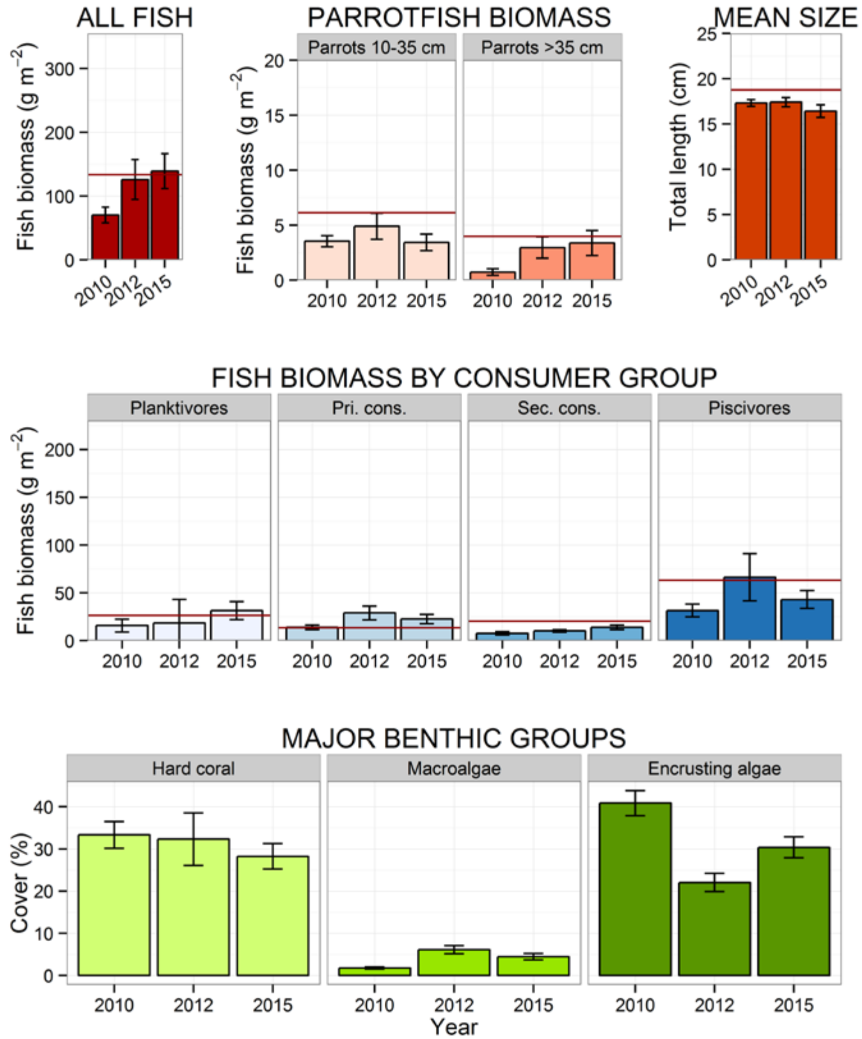

Figure 48 Baker Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Pacific Remote Island Areas region mean estimates are plotted for reference (red line).

Howland Island

Howland Island was surveyed in 2010 (n = 16), 2012 (n = 39), and 2015 (n = 35).

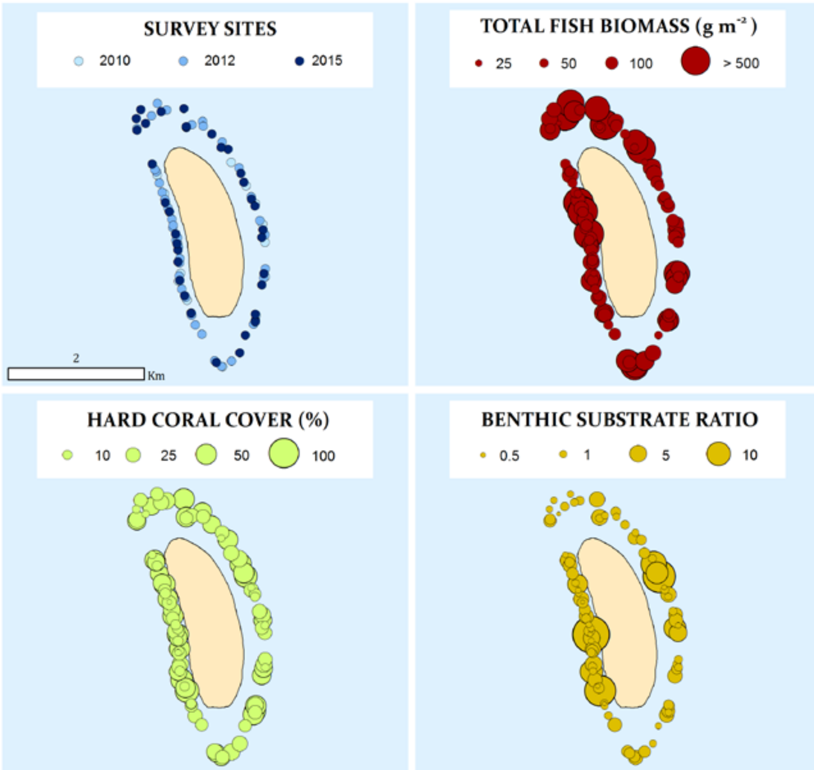

Figure 49 Howland Island site survey data 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

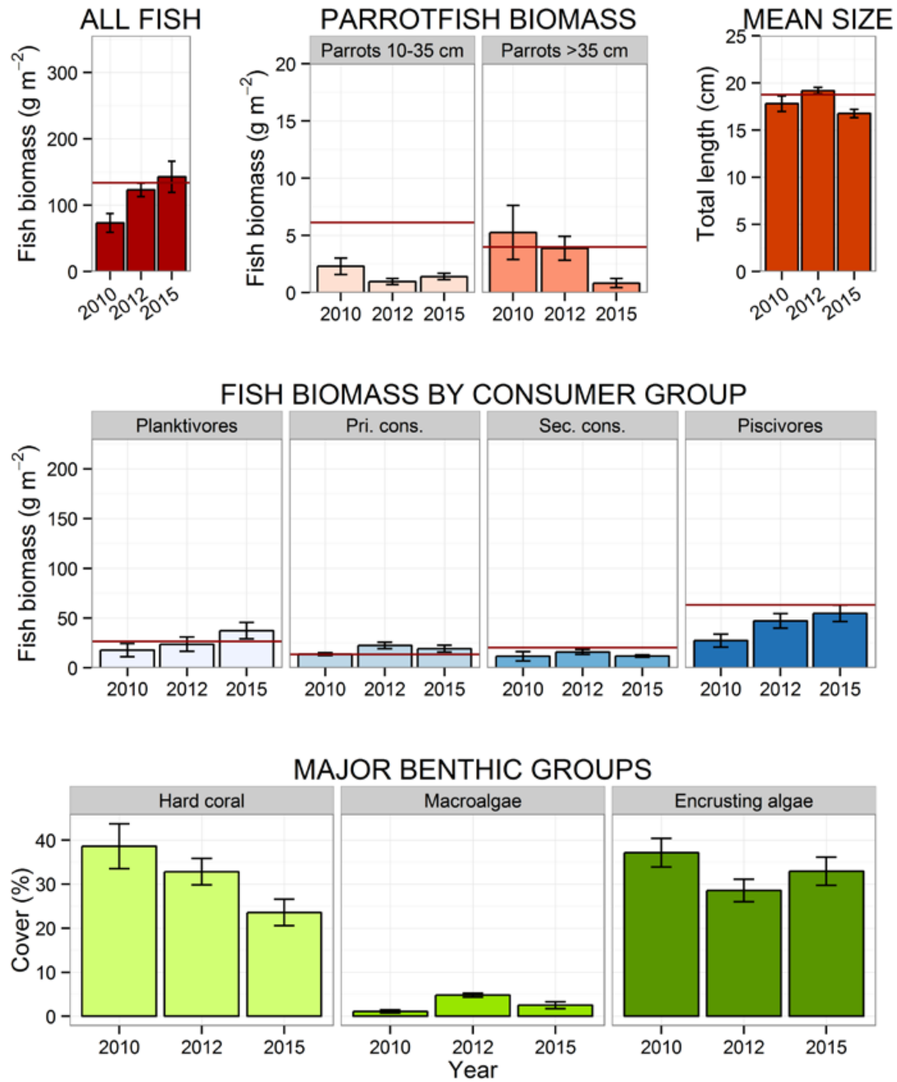

Figure 50 Howland Island fish and benthic plots showing the biomass ($g\ m^{-2} \pm SE$) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The benthic estimates are pooled across all years. The Pacific Remote Island Areas region mean estimates are plotted for reference (red line).

Pacific Remote Islands Areas (PRIA) – Howland and Baker (US Phoenix Islands)

Towed divers surveys were conducted in the US Line Islands in 2001-2 (n = 10), 2004 (n = 16), 2006 (n = 13), 2008 (n = 15), 2010 (n = 19), 2012 (n = 20) and 2015 (n = 10). Because of very low numbers of surveys in 2001 and 2002, data from those years is pooled into a single value (shown as 2002 below).

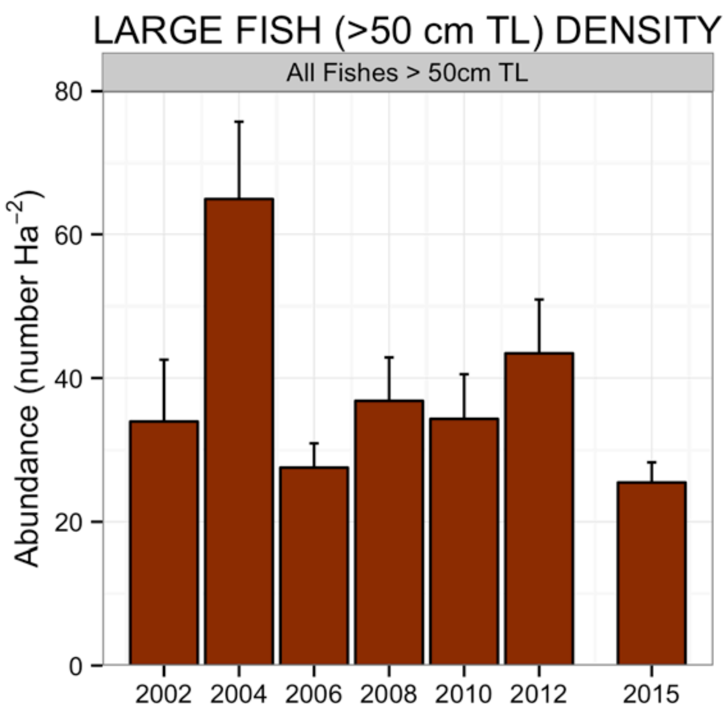

Figure 51 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL surveyed via the towed diver survey method in the US Phoenix Islands.

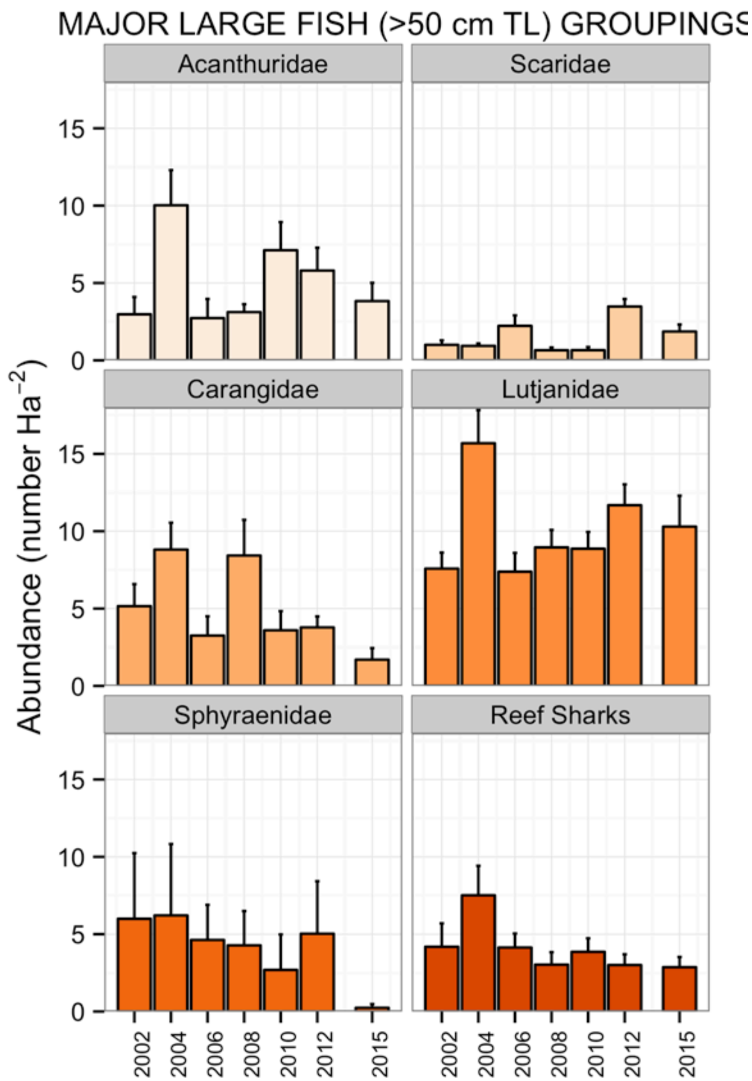

Figure 52 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL for family groups Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and reef sharks in the US Phoenix Islands.

Jarvis Island

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

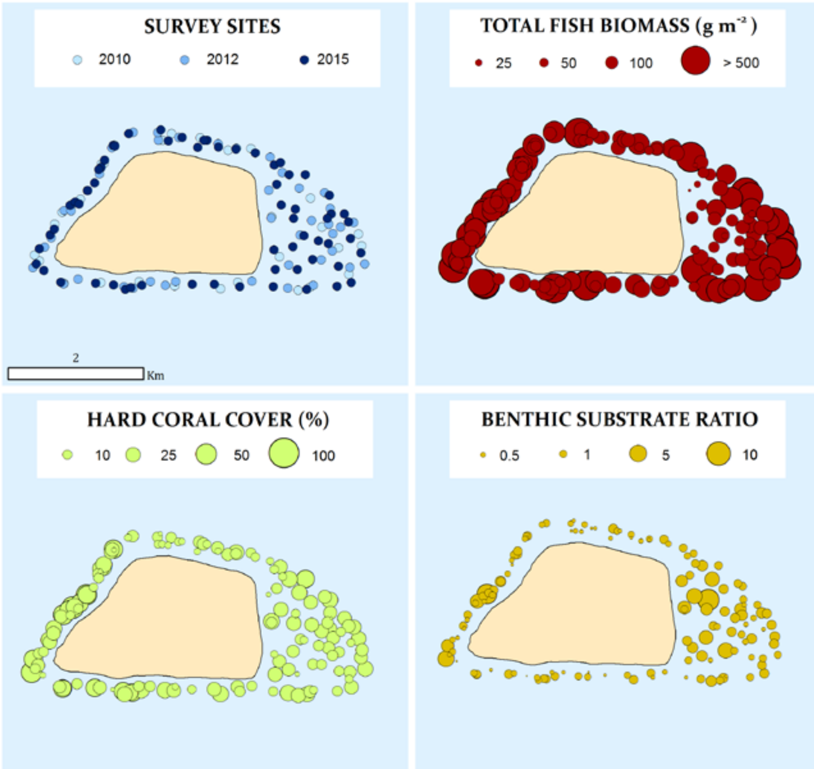

Figure 53 Jarvis Island site survey data 2009, 2011, and 2014 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

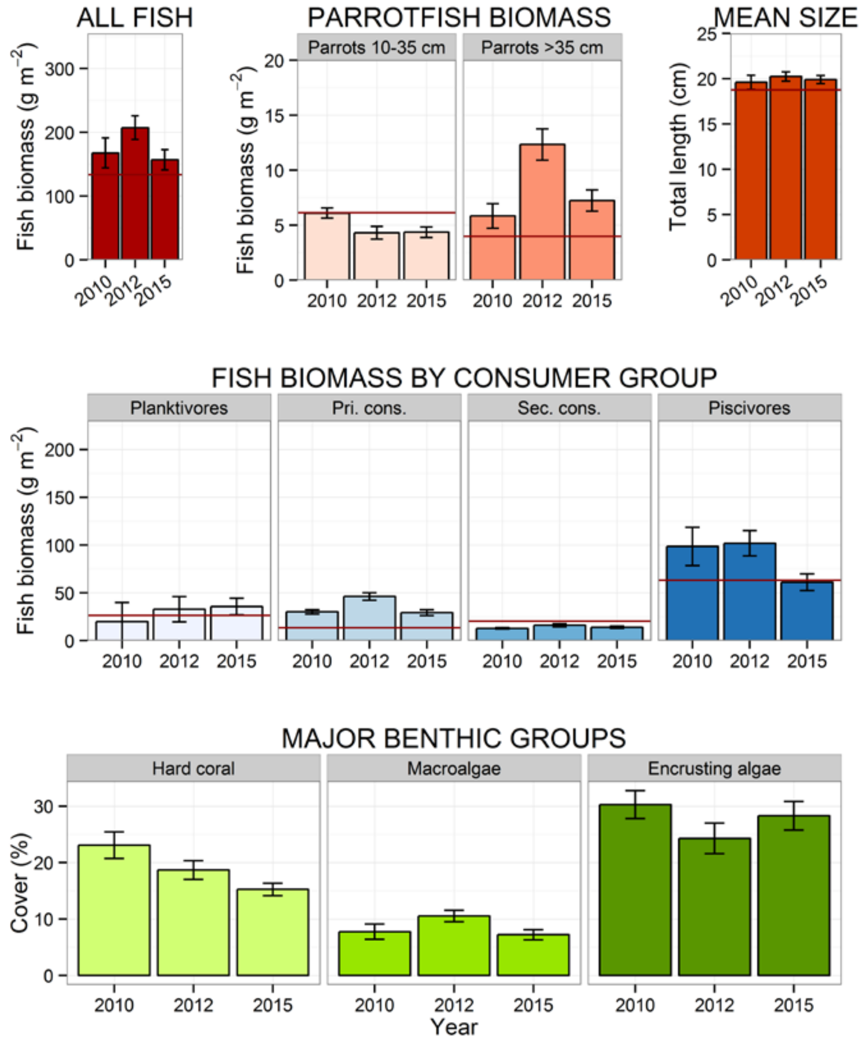

Figure 54 Jarvis Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The benthic estimates are pooled across all years. The Pacific Remote Island Areas region mean estimates are plotted for reference (red line).

Kingman Reef

Kingman Reef was surveyed in 2010 (n = 33), 2012 (n = 49), and 2015 (n = 49). Three habitats were surveyed: forereef, lagoon, and backreef. 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.

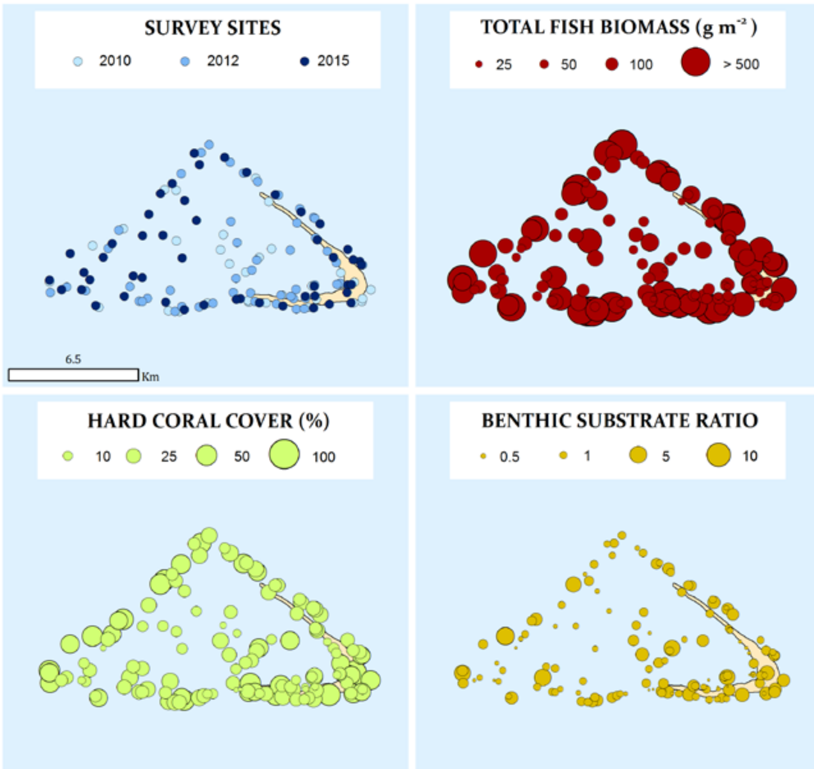

Figure 55 Kingman Reef site survey data 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

Kingman forereef was surveyed in 2010 (n = 33), 2012 (n = 49), and 2015 (n = 49).

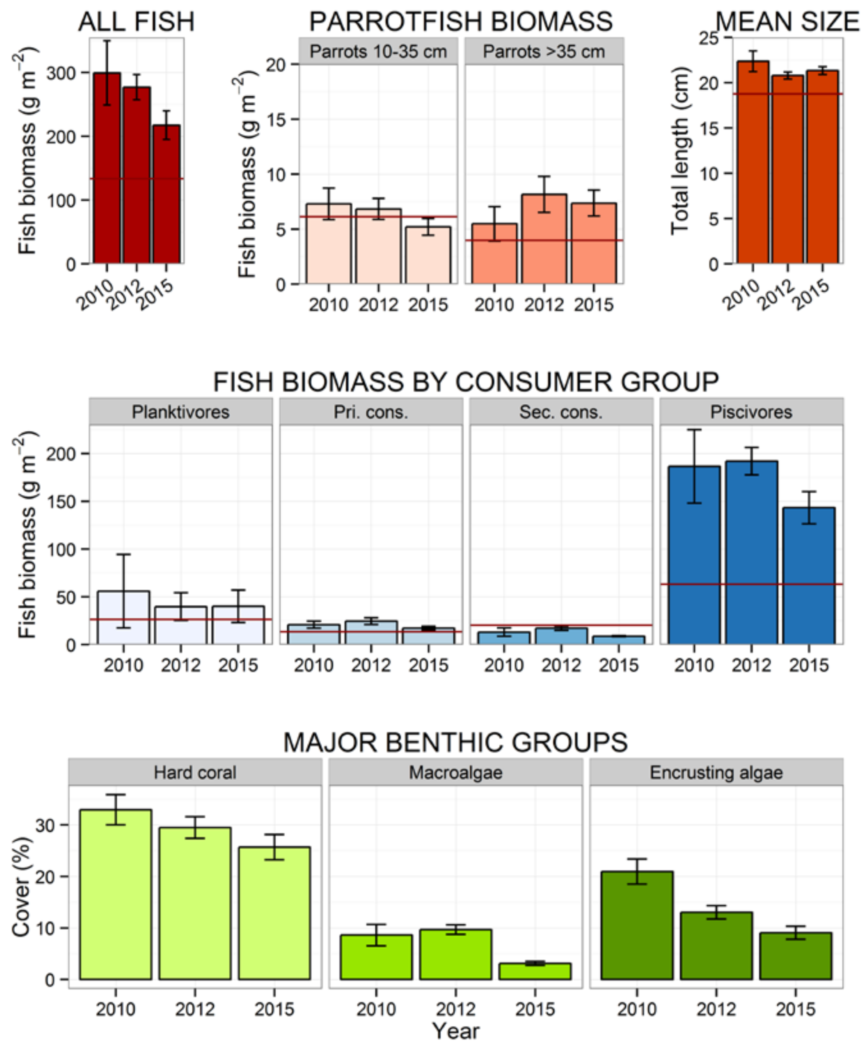

Figure 56 Kingman Reef fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for forereef habitat. The Pacific Remote Island Areas region mean estimates are plotted for reference (red line).

Kingman backreef was surveyed in 2010 (n = 33), 2012 (n = 49), and 2015 (n = 49).

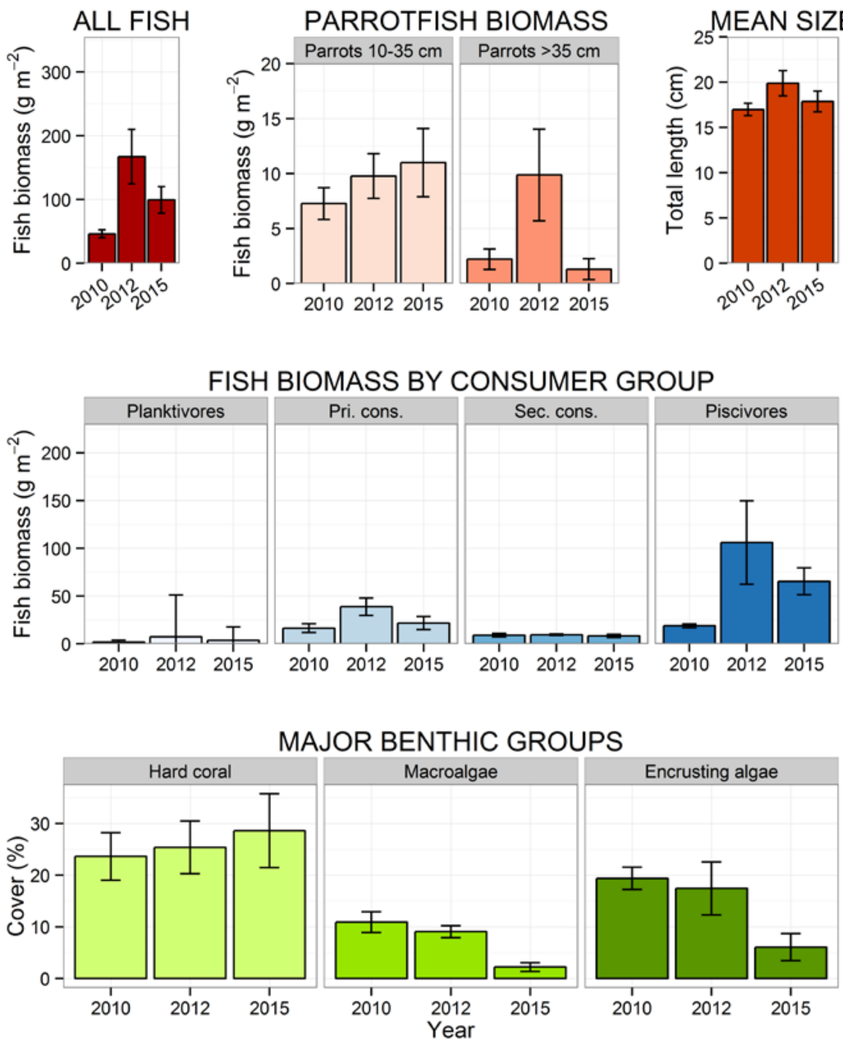

Figure 57 Kingman Reef fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for backreef habitat. The Pacific Remote Island Areas region mean backreef estimates are not plotted due to small sample size.

Kingman lagoon was surveyed in 2010 (n = 33), 2012 (n = 49), and 2015 (n = 49).

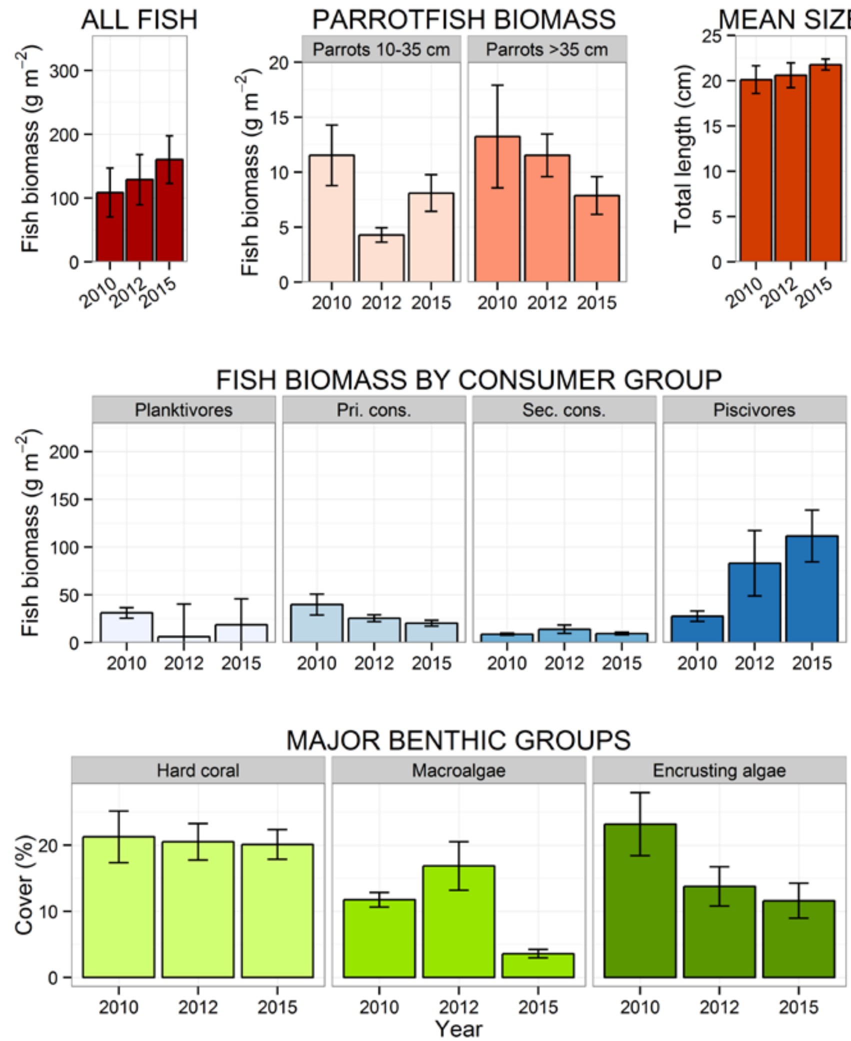

Figure 58 Kingman Reef fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well

as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for lagoon habitat. The Pacific Remote Island Areas region mean lagoon estimates are not plotted due to small sample size.

Palmyra Atoll

Palmyra Atoll was surveyed in 2010 (n = 40), 2012 (n = 42), and 2015 (n = 78).

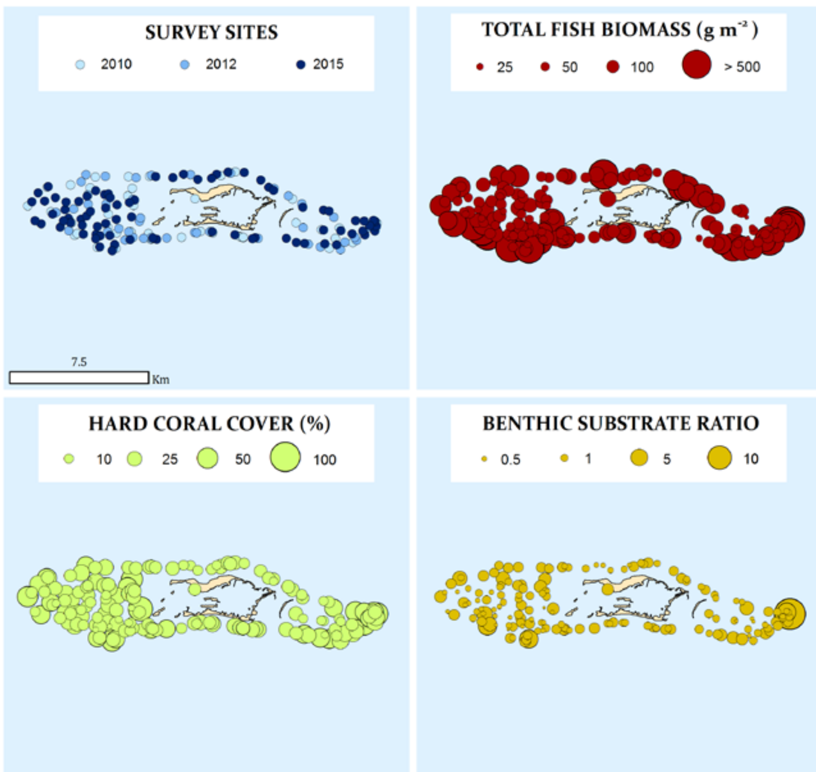

Figure 59 Palmyra Atoll site survey data 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

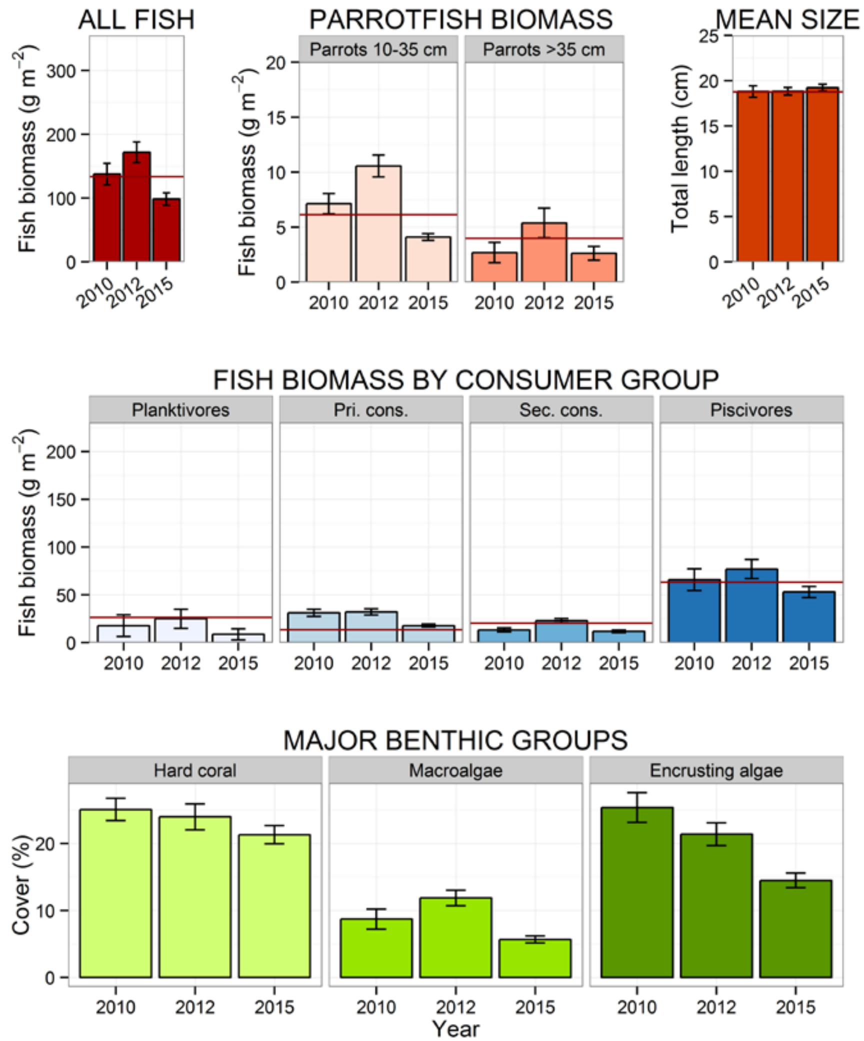

Figure 60 Palmyra Atoll fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The Pacific Remote Island Areas region mean estimates are plotted for reference (red line).

Pacific Remote Islands Areas (PRIA) – Palmyra, Jarvis, Kingman (US Line Islands)

Towed divers surveys were conducted in the US Line Islands in 2001-2 (n = 26), 2004 (n = 42), 2006 (n = 41), 2008 (n = 45), 2010 (n = 47), 2012 (n = 44) and 2015 (n = 37). Because of very low numbers of surveys in 2001 and 2002, data from those years is pooled into a single value (shown as 2002 below).

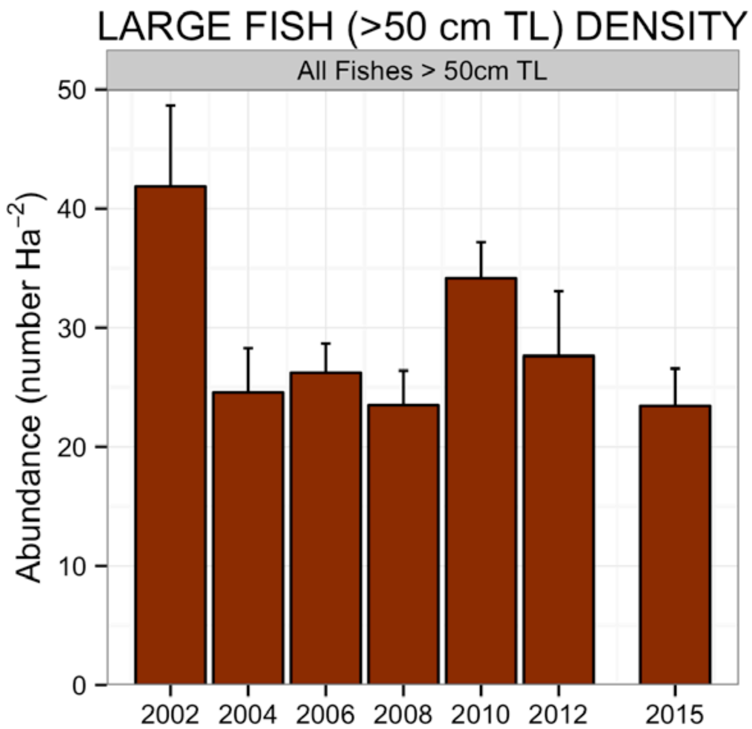

Figure 61 Mean density (number $Ha^{-2} \pm SE$) of fishes ≥ 50cm TL surveyed via the towed diver survey method in the US Line Islands.

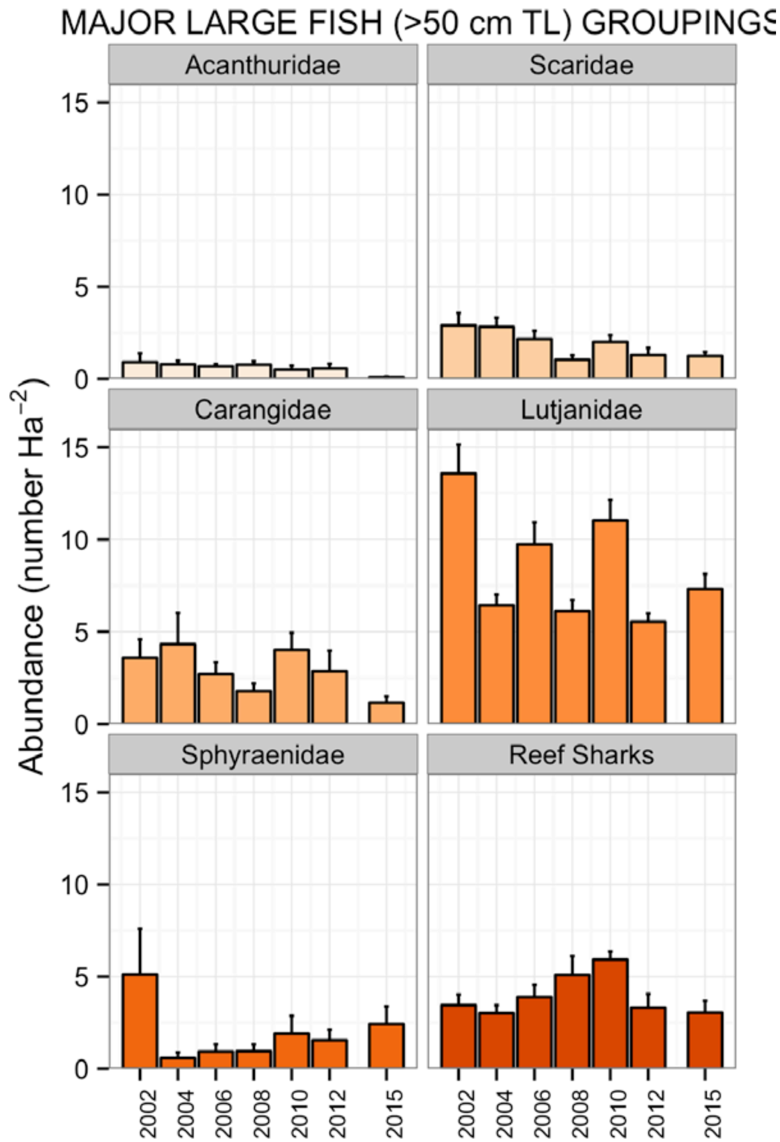

Figure 62 Mean density (number $Ha^{-2} \pm SE$) of fishes ≥ 50cm TL for family groups Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and reef sharks in the US Line Islands.

American Samoa

Ofu and Olosega Islands

Ofu and Olosega Islands were surveyed in 2010 (n = 30), 2012 (n = 30), and 2015 (n = 52). Due to their proximity, these islands are analyzed together.

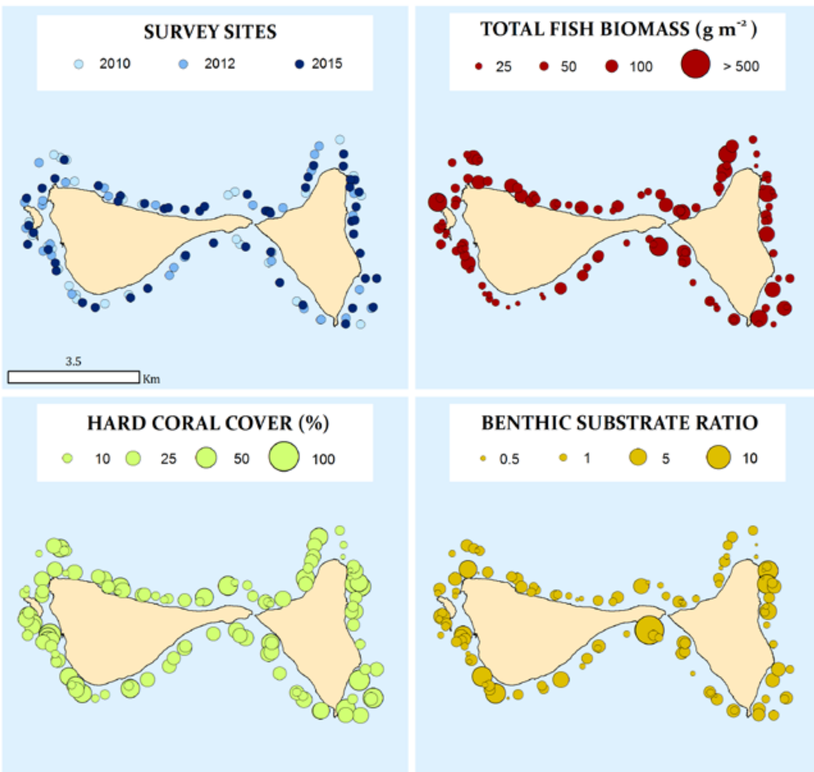

Figure 63 Ofu and Olosega Islands site survey data 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

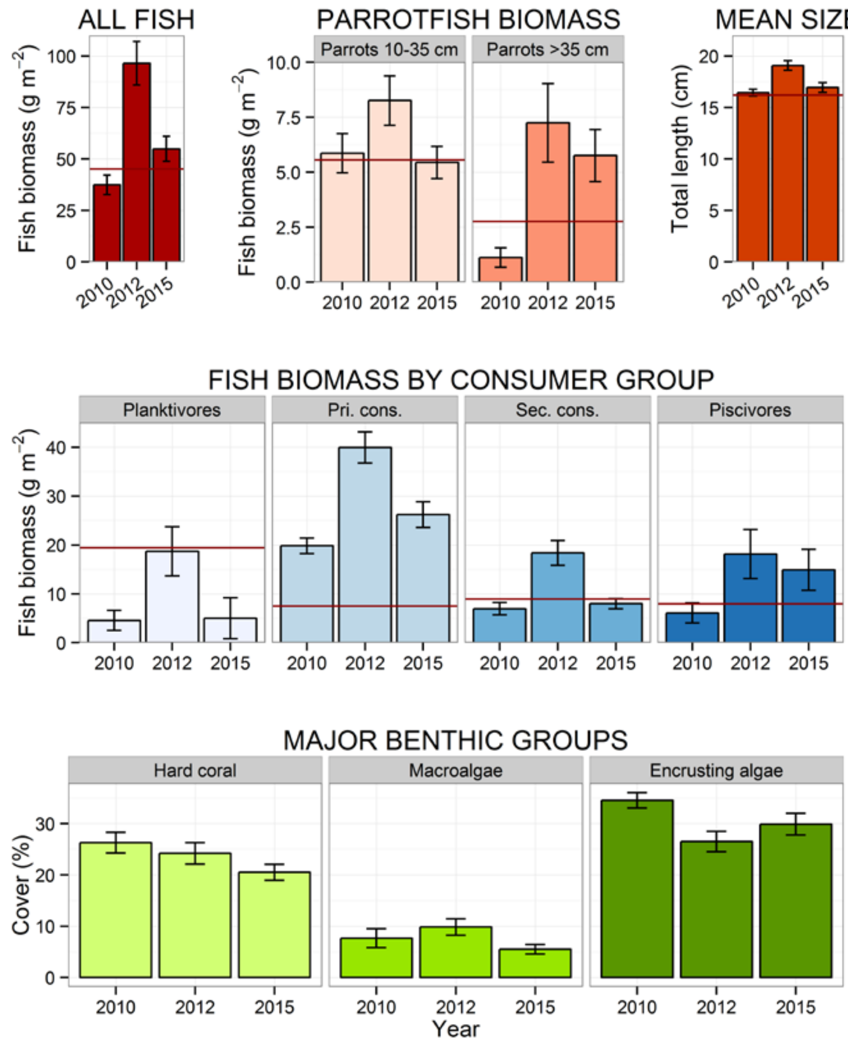

Figure 64 Ofu and Olosega Islands fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The American Samoa region mean estimates are plotted for reference (red line).

Rose Atoll

Rose Atoll was surveyed in 2010 (n = 34), 2012 (n = 48), and 2015 (n = 47). Three habitats were surveyed: forereef, lagoon, and backreef. 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.

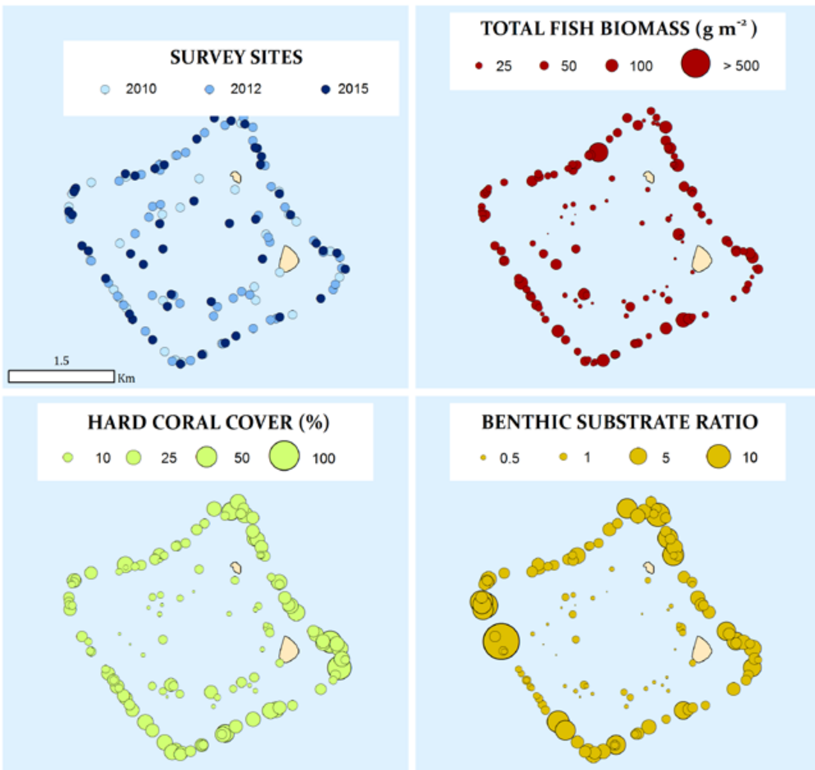

Figure 65 Rose Atoll site survey data 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

Rose Atoll forereef was surveyed in 2010 (n = 24), 2012 (n = 33), and 2015 (n = 37).

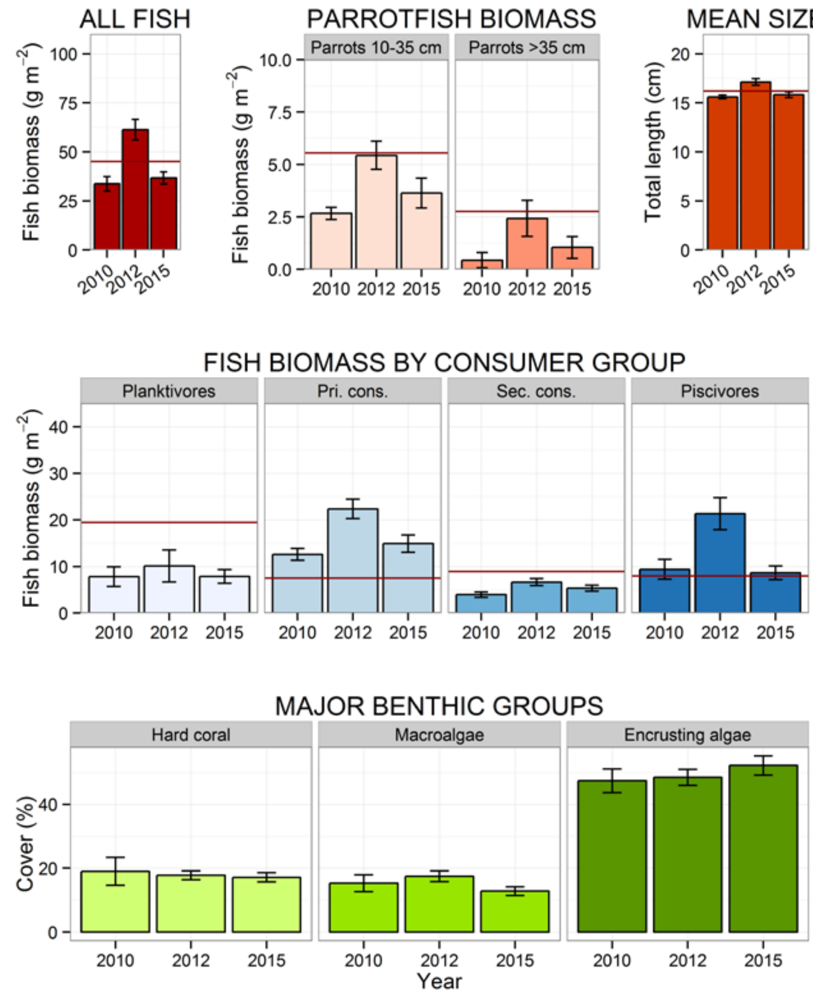

Figure 66 Rose Atoll fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for forereef habitat. The American Samoa region mean estimates are plotted for reference (red line).

Rose Atoll backreef was surveyed in 2010 (n = 6), 2012 (n = 15), and 2015 (n = 5).

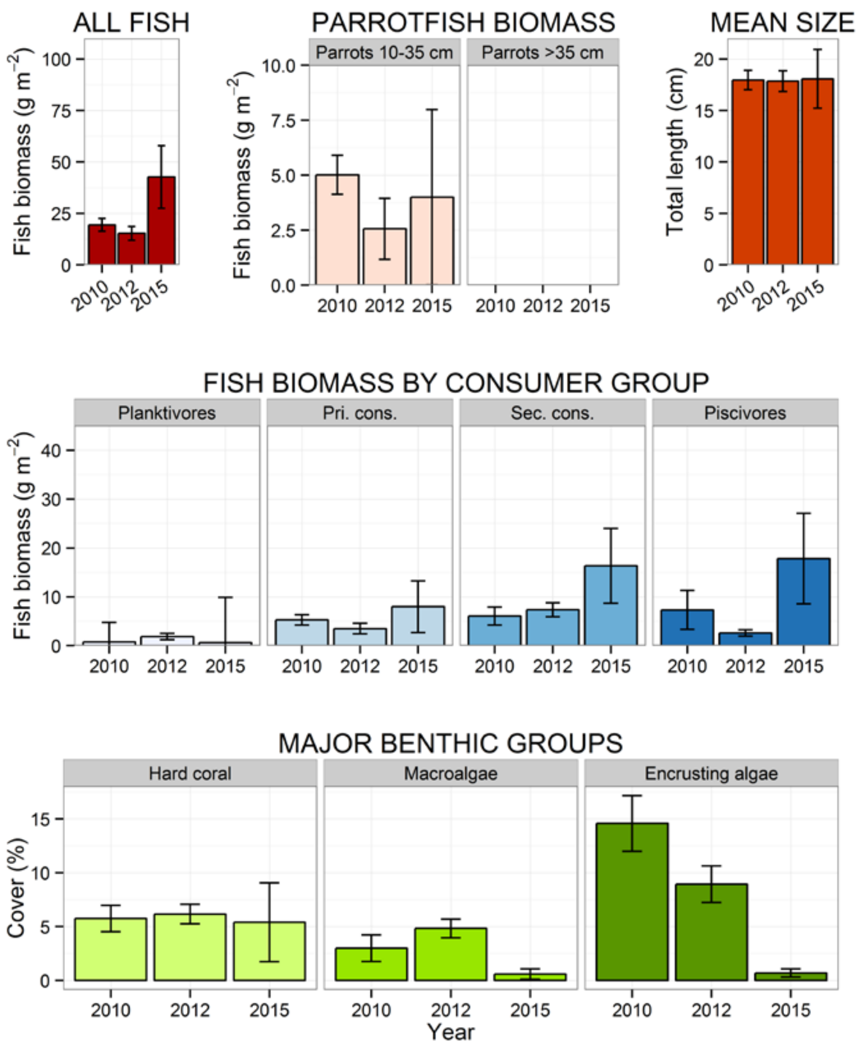

Figure 67 Rose Atoll fish and benthic plots showing the biomass (g m−2 ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for backreef habitat. The American Samoa region mean backreef estimates are not plotted due to small sample size.

Rose Atoll lagoon was surveyed in 2010 (n = 4), and 2015 (n = 5).

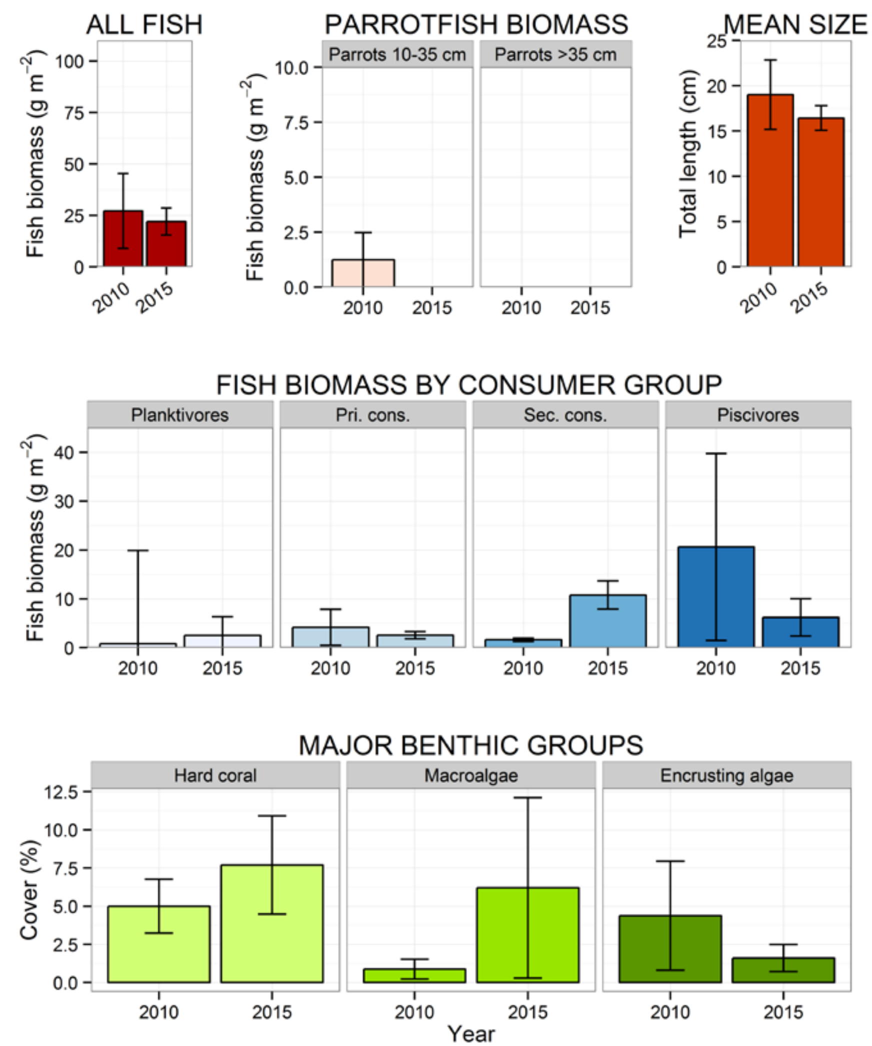

Figure 68 Rose Atoll fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos for lagoon habitat. The American Samoa region mean backreef estimates are not plotted due to small sample size.

Swains Island

Swains Island was surveyed in 2010 (n = 24), 2012 (n = 38) and 2015 (n = 32).

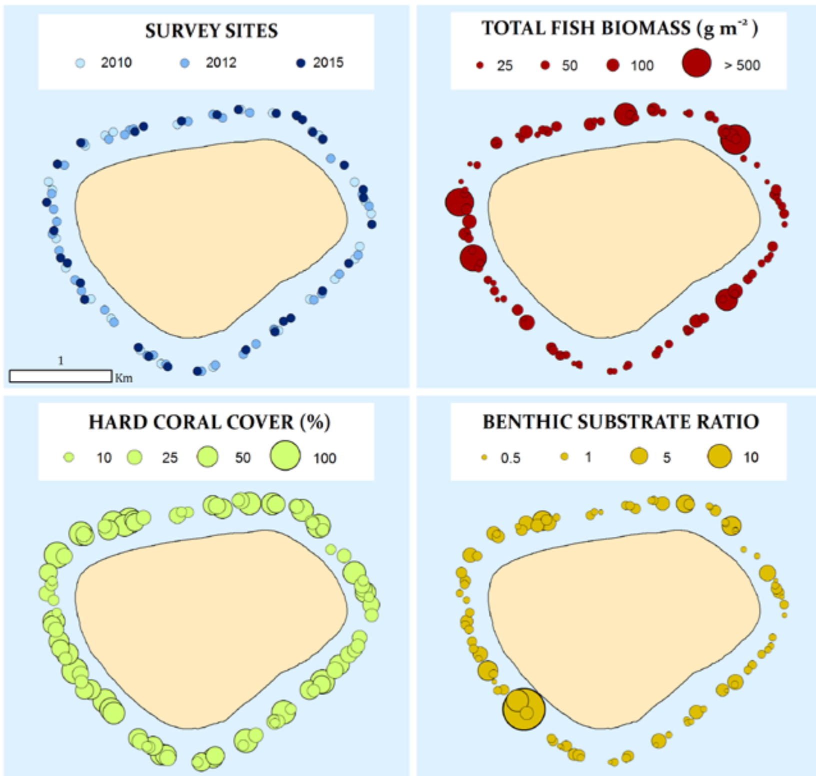

Figure 69 Swains Island site survey data 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

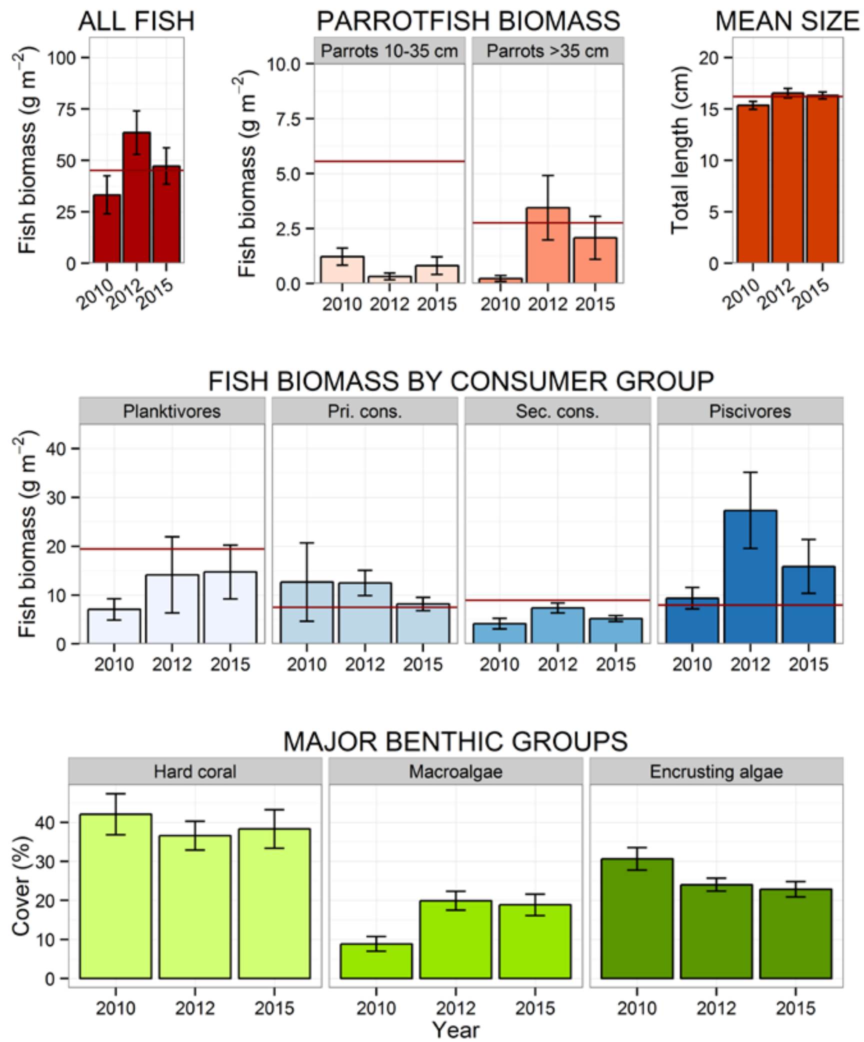

Figure 70 Swains Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The American Samoa region mean estimates are plotted for reference (red line).

Tau Island

Tau Island was surveyed in 2010 (n = 24), 2012 (n = 22) and 2015 (n = 46).

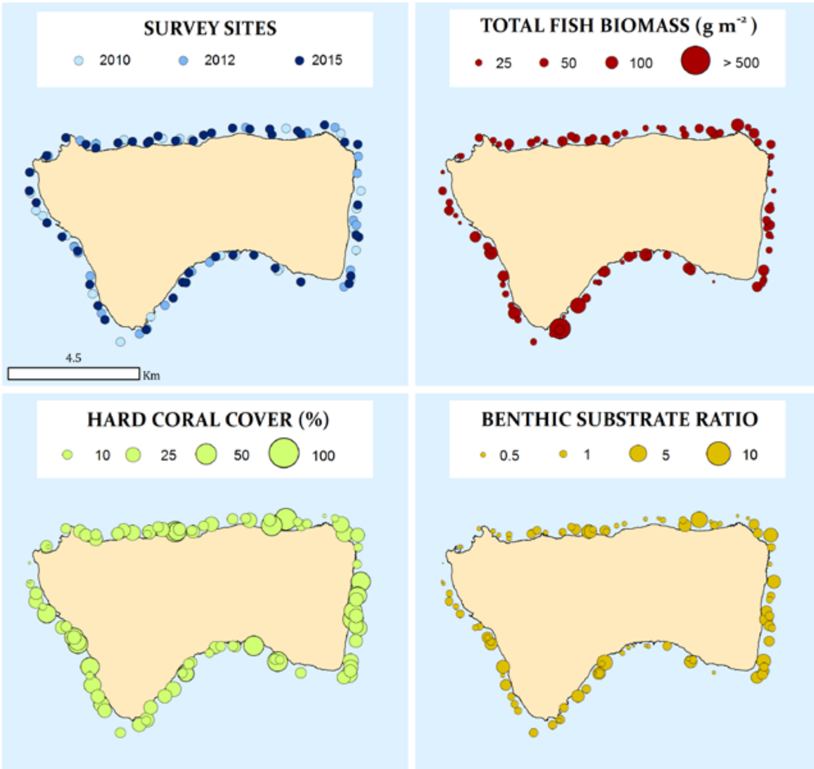

Figure 71 Tau Island site survey data 2010, 2012, and 2015 identified by year (top left). Total fish biomass recorded at each site per year (top right). Hard coral cover (%) assessed by rapid visual assessment (bottom left). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom right). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

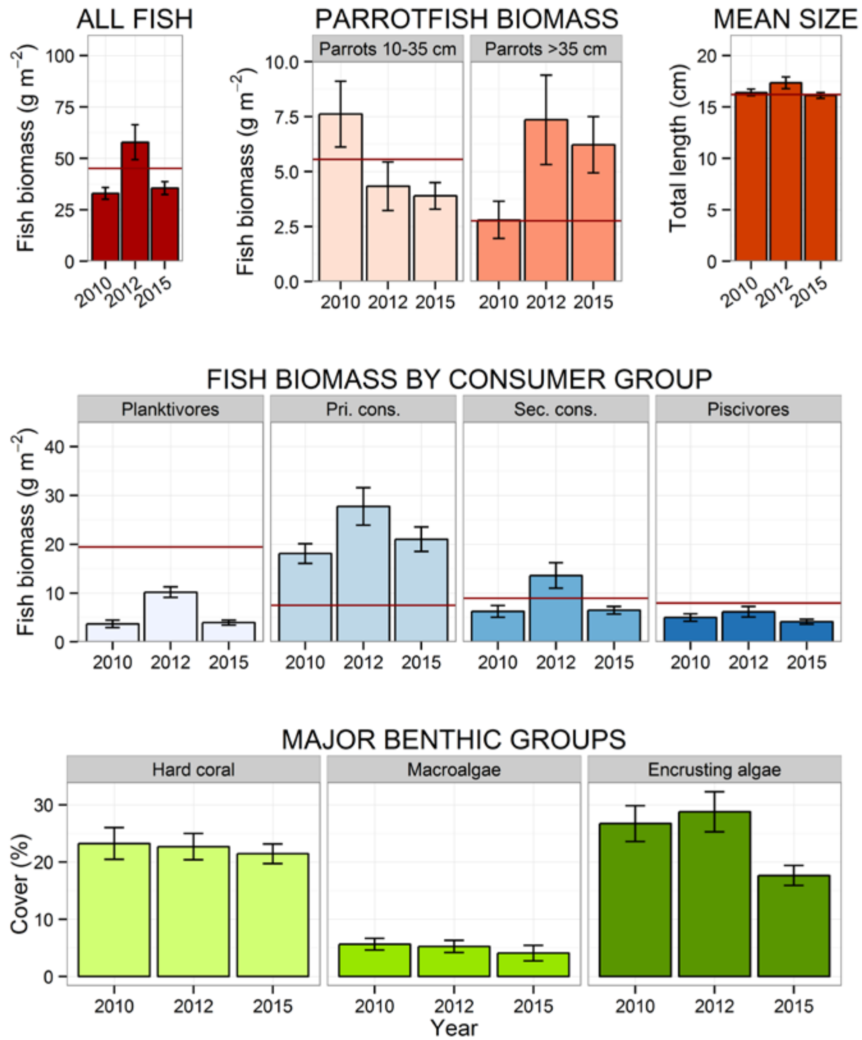

Figure 72 Tau Island fish and benthic plots showing the biomass (g m^{-2} ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The American Samoa region mean estimates are plotted for reference (red line).

Tutuila Island

Tutuila Island was surveyed in 2010 (n = 127), 2012 (n = 85), and 2015 (n = 162).

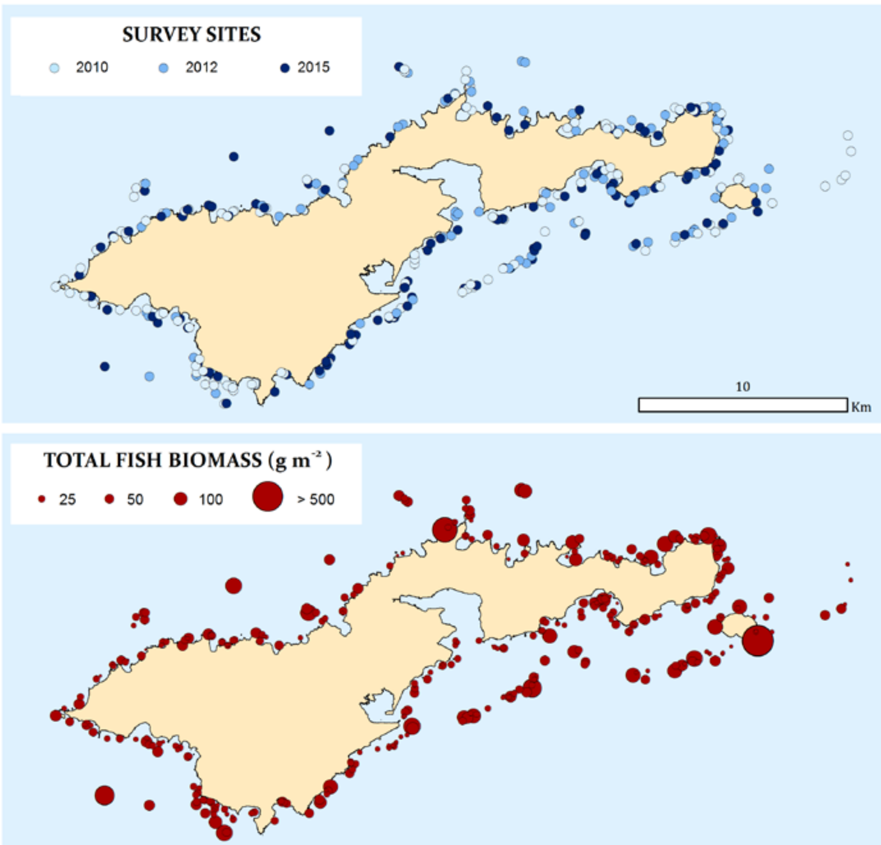

Figure 73 Tutuila Island site survey data 2010, 2012, and 2015 identified by year (top). Total fish biomass recorded at each site per year (bottom).

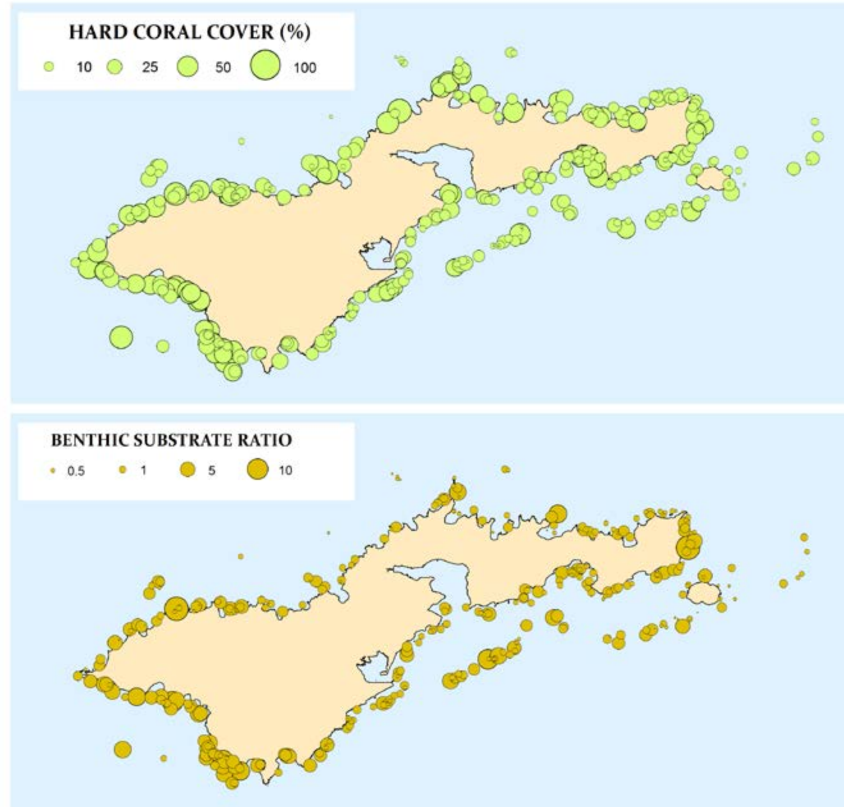

Figure 74 Tutuila Island site survey data 2010, 2012 and 2015. Hard coral cover (%) assessed by rapid visual assessment (top). Benthic substrate ratio (hard coral plus encrusting algae / turf and macroalgae) (bottom). This ratio indicates the balance between the benthic components that contribute to reef accretion (coral and crustose coralline algae) compared to fleshy macroalgae and turf algae that compete for space on the reef.

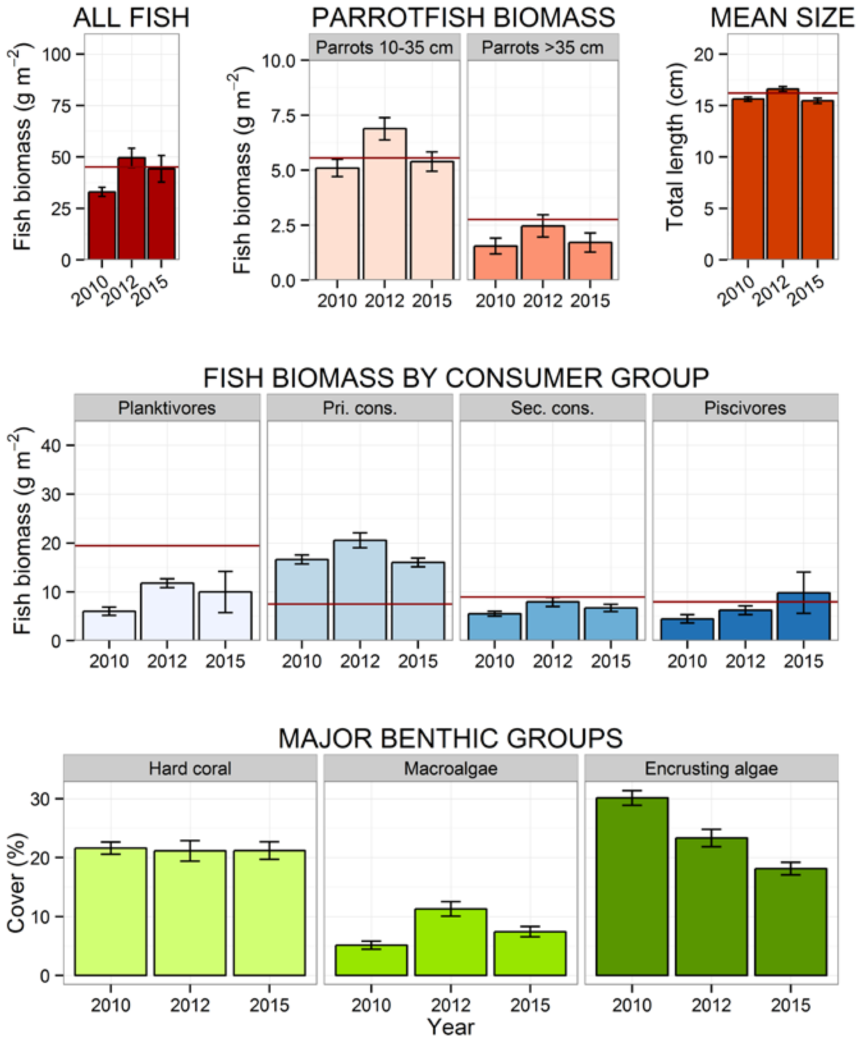

Figure 75 Tutuila Island fish and benthic plots showing the biomass (g m–2 ± SE) of fish observed in total, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The American Samoa region mean estimates are plotted for reference (red line).

American Samoa

Towed divers surveys were conducted in American Samoa in 2002 (n = 42), 2004 (n = 94), 2006 (n = 92), 2008 (n = 99), 2010 (n = 88), 2012 (n = 68) and 2015 (n = 62).

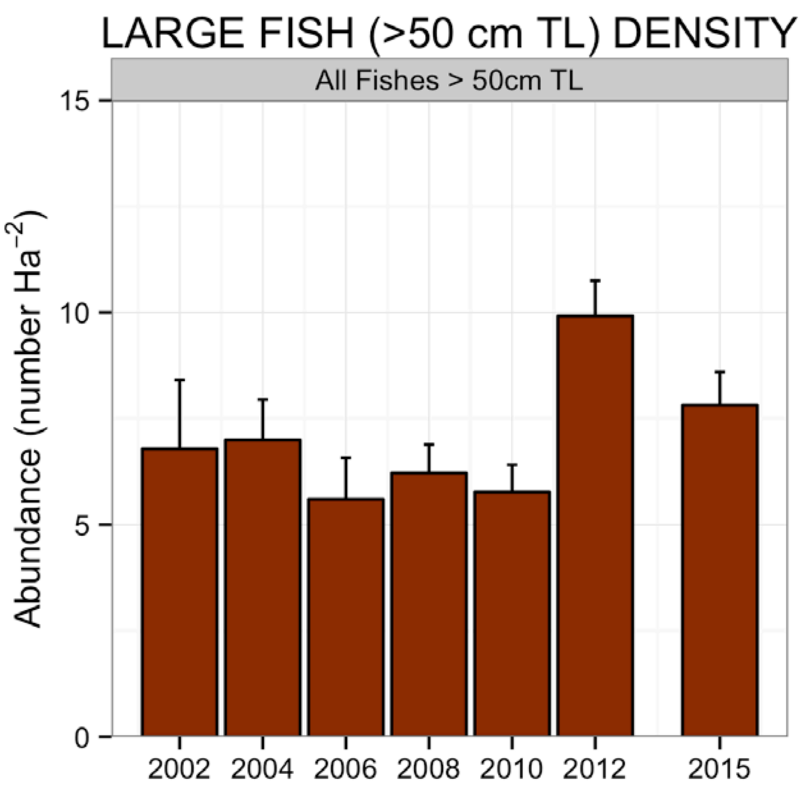

Figure 76 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL surveyed via the towed diver survey method in American Samoa.

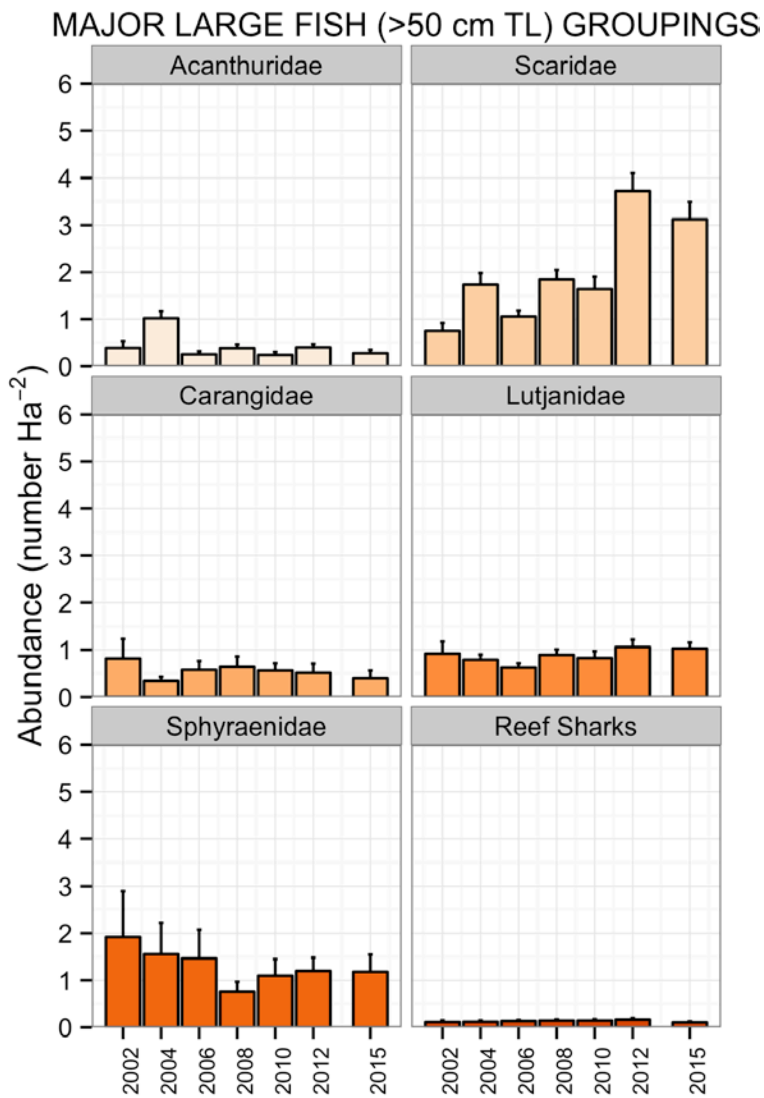

Figure 77 Mean density (number Ha^{-2} ± SE) of fishes ≥ 50cm TL for family groups Acanthuridae, Scaridae, Carangidae, Lutjanidae, Sphyraenidae, and reef sharks in American Samoa.

Publications, information products, and data requests 2015

The following products published in 2015 were either produced using biological data collected during Pacific RAMP and related monitoring surveys, or were coauthored by members of the CREP fish team.

Blogs

Bubbles or not, here we come!
https://pifscblog.wordpress.com/2015/07/08/bubbles-or-not/

Counting Fish: Bubbles or Not? Expedition underway to assess reef fish populations in the Main Hawaiian Islands
https://pifscblog.wordpress.com/2015/06/16/reef-fish-expedition/

How can an ecosystem approach be used to address climate change?
https://pifscblog.wordpress.com/2015/04/23/ecosystem-approach-climate-change/

Five million fish and counting!
https://pifscblog.wordpress.com/2015/04/21/five-million-fish-and-counting/

Four Million Nine Hundred Ninety-Nine Thousand Nine Hundred and Ninety-Nine
https://pifscblog.wordpress.com/2015/04/09/4999999-fish/

Science and technology innovations to promote sustainable fisheries in Southeast Asia and the Coral Triangle
https://pifscblog.wordpress.com/2015/03/09/science-and-technology-report/

Scientists complete coral reef ecosystem monitoring work around the U.S. Phoenix Islands
https://pifscblog.wordpress.com/2015/02/24/coral-reef-ecosystem-monitoring/

Monitoring briefs

Coral Reef Ecosystem Program, Pacific Islands Fisheries Science Center, 2015. Reef fish surveys main Hawaiian Islands, 2015. Fish monitoring brief. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-15-017, 2 p.

Coral Reef Ecosystem Program, Pacific Islands Fisheries Science Center, 2015. Pacific Reef Assessment and Monitoring Program. Fish monitoring brief: Pacific Remote Islands Areas 2015. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-15-012, 2 p.

Coral Reef Ecosystem Program, Pacific Islands Fisheries Science Center, 2015. Pacific Reef Assessment and Monitoring Program. Fish monitoring brief: American Samoa 2015. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-15-008, 2 p.

Reports

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McCoy K, Ayotte P, Gray A, Lino K, Schumacher B, Sudnovsky M, 2015. Coral reef fish biomass and benthic cover along the north coast of Timor-Leste based on underwater visual surveys in June 2013. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-15-004, 18 p. + Appendices. DOI: 10.7289/v5k0728f.

McCoy K, Williams I, Heenan A, 2015. A comparison of rapid visual assessments and photo-quadrat analyses to monitor coral reef habitats. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-15-011, 13 p. + Appendix. DOI: 10.7289/V52805K5.

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Nadon MO, Ault JS, Williams ID, Smith SG, DiNardo GT, 2015. Assessment of Hawaiian coral reef fish populations using a length-based methodology applied to diver survey and fishery data, PLoS ONE 10(8):e0133960. DOI:10.1371/journal.pone.0133960.

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Fish and benthic data requests

In 2015: 52 requests.

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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 × $10m^2$ towed-diver survey		

Appendix 2: Surveys per region per year and method used

Table A2.1. The number of 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). 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	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Region Method	Belt	Belt	Belt	Belt	Belt	Belt	Belt & SPC	Belt & SPC	Belt & SPC	SPC	SPC	SPC	SPC	SPC	SPC	SPC
N. Mariana				42		38		36		135		135			148	
S. Mariana				25		34		30		116		219			198	
Main HI						73	57		186		184		163	287		294
NWHI*	58	18	63	62	57	40	64	155	147	203	118	141	91		89	96
PRIAs		30	34		48	13	67	12	193	42	179	30	231		45	291
Am. Samoa			42		58		61		222		241		223			339

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

Table A2.2 Number of towed-diver surveys per year. Numbers in brackets are tows that were not included when calculating regional annual 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 consistently surveyed consistently throughout the period from which we have data.

Island	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2014	2015
Agrihan				12		5		6		11		10			
Alamagan				6		6		6		6		3		3	
Anatahan				(12)											
Asuncion				6		5		5		5		6		5	
Farallon de Pajaros				8		4		4		3		4		2	
Guguan				6		2 (1)		5		4		5		3	
Maug				13 (3)		11 (1)		9		8		9		8	
Pagan				21		17		16		15		14		11	

Island	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2014	2015
Sarigan				5 (1)		5		6		5		4		3	
Northern Mariana				**77**		**55 (2)**		**57**		**57**		**55**		**35**	
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	
Guam				19		23		19		22		23		31	
Rota				12		11		10		11		11		8	
Saipan				6		17		16		20		16		14	
Tinian				6		12		8		10 (1)		10		11	
Southern Mariana				**47**		**68 (1)**		**56**		**68 (1)**		**64**		**67**	
Hawaii							33		41		37				
Kauai						22	13 (2)		18		21 (1)				
Kaula							(3)								
Lanai						9 (1)	11		12		10				
Maui						11	26 (1)		27		20 (4)				
Molokai						7	7		12		11				
Niihau						15	17 (1)		14		9				
Oahu						16	3		20		14				
MHI						**80 (2)**	**110**		**144**		**122**				
French Frigate	10 (9)	(3)	11 (4)	6 (12)	7 (10)		9 (10)		15 (7)		18 (3)				
Gardner	(1)			(2)	(2)										
Kure	12 (4)		5 (6)	13	7 (6)		7 (6)		8 (6)		8 (5)				
Laysan	6		4	5	5		5 (1)		5						
Lisianski	13 (1)		6 (4)	14	11 (1)		10 (2)		10 (2)		10 (2)				
Maro	14 (3)	10 (3)	6	15	6 (5)		10 (3)		11						
Midway			11 (4)	17	8 (5)		7 (8)		10 (6)						
Necker	4			4			4								
Nihoa	2														
Pearl & Hermes	17 (7)		(22)	32	20		14		18 (9)		21 (2)				

Island	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2014	2015
Raita		(3)													
NWHI	**78**	**10 (9)**	**43**	**71**	**55**		**66**		**66**		**57**				
Johnston					14		10		8 (3)		10		14 (3)		14 (2)
Johnston					**14**		**10**		**8 (3)**		**10**		**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		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**		**47**		**47 (9)**		**44 (8)**		**37 (5)**
Baker		2	2		7 (1)		7 (3)		8		9		10		5
Howland		2	4		9		6 (1)		7		10 (1)		10 (1)		5
US Phoenix		**4**	**6**		**16 (1)**		**13 (4)**		**15**		**19 (1)**		**20 (1)**		**10**
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**		**94**		**92**		**99 (6)**		**88 (9)**		**68 (5)**		**62 (1)**

Appendix 3: Sectors 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 Mean Preserves on east side of Guam); and "Guam Open West". Grouping of marine preserve sites – i.e. whether to pool all into a single strata '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).

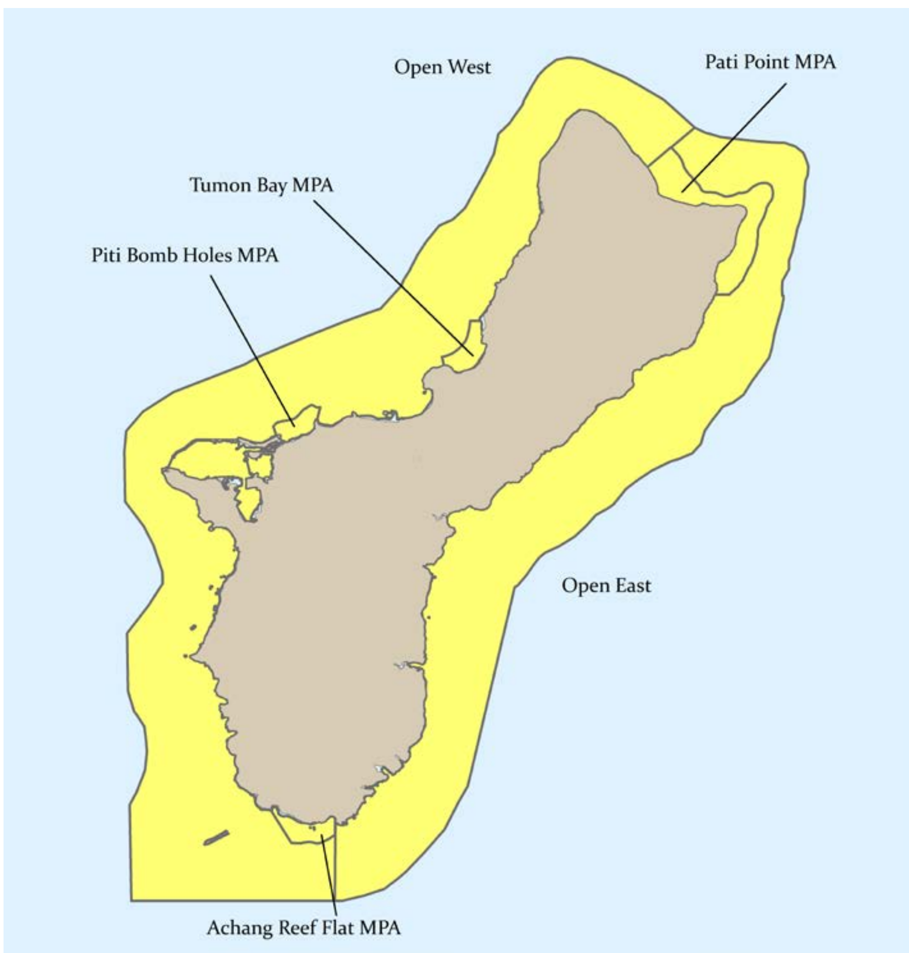

Figure A3.1. Guam sectors. Sampling is stratified by habitat, depth and the additional sectors based on whether areas are inside or outside Achang Reef Flat MP, the pooled Marine Preserve system, and by the East and West side of the island.

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).

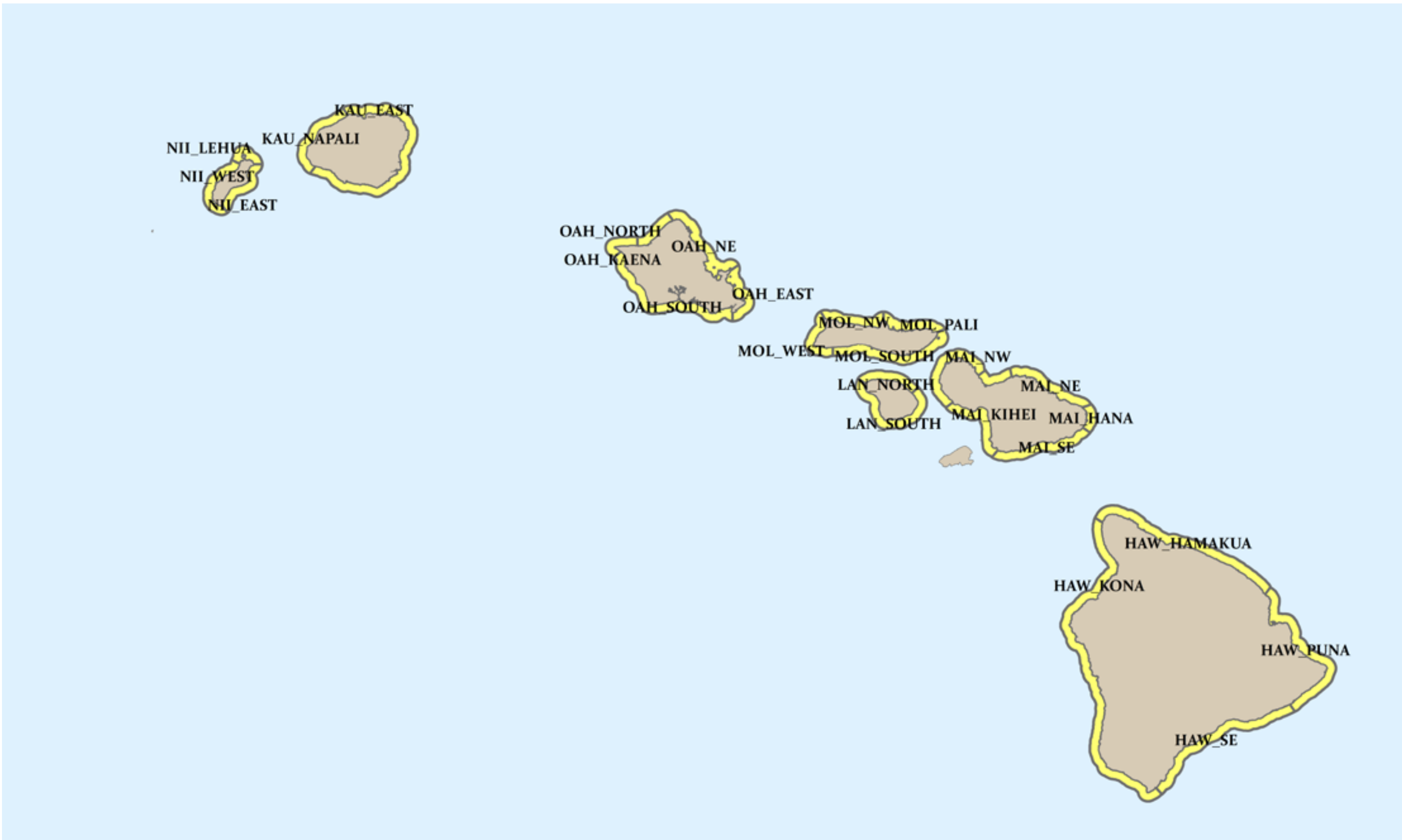

Figure A3.2. The sectors of the main Hawaiian Islands. Sectors are broadly based on wave exposure, habitat complexity and local human population density.

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 2015

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). Backreef site depths were pooled for analysis.

Year	Region	Island	Sector	Backreef-All	Forereef-D	Forereef-M	Forereef-S	Lagoon-All
2013 & 2015	MHI	Hawaii	HAW_HAMAKUA		10	22	7	
2013 & 2015	MHI	Hawaii	HAW_KONA		27	38	16	
2013 & 2015	MHI	Hawaii	HAW_PUNA		8	11	5	
2013 & 2015	MHI	Hawaii	HAW_SE		3	6	2	
2013 & 2015	MHI	Kauai	KAU_EAST		8	29	9	
2013 & 2015	MHI	Kauai	KAU_NAPALI		4	4	3	
2013 & 2015	MHI	Lanai	LAN_NORTH		3	5	7	
2013 & 2015	MHI	Lanai	LAN_SOUTH		5	14	10	
2013 & 2015	MHI	Maui	MAI_KAHULUI		3	6	6	
2013 & 2015	MHI	Maui	MAI_KIHEI		4	9	7	
2013 & 2015	MHI	Maui	MAI_LAHAINA		1	7	6	
2013 & 2015	MHI	Maui	MAI_NE		7	6	2	
2013 & 2015	MHI	Molokai	MOL_NW		6	6	4	
2013 & 2015	MHI	Molokai	MOL_PALI		4	5	4	
2013 & 2015	MHI	Molokai	MOL_SOUTH		9	20	15	
2013 & 2015	MHI	Molokai	MOL_WEST		4	6	4	
2013 & 2015	MHI	Niihau	NII_EAST		8	10	7	
2013 & 2015	MHI	Niihau	NII_LEHUA		6	6	4	
2013 & 2015	MHI	Niihau	NII_WEST		8	16	10	
2013 & 2015	MHI	Oahu	OAH_EAST		4	8	6	
2013 & 2015	MHI	Oahu	OAH_KAENA			2	1	
2013 & 2015	MHI	Oahu	OAH_NE		11	10	6	
2013 & 2015	MHI	Oahu	OAH_NORTH		8	4	4	
2013 & 2015	MHI	Oahu	OAH_SOUTH		8	16	11	
2015	NWHI	French Frigate	French Frigate		3	3	2	
2015	NWHI	Kure	Kure		4	2	2	
2015	NWHI	Laysan	Laysan		3	3	2	
2015	NWHI	Lisianski	Lisianski		8	7	3	
2015	NWHI	Maro	Maro		3	11	3	
2015	NWHI	Midway	Midway	2	4	5	3	
2015	NWHI	Pearl & Hermes	Pearl & Hermes	2	8	10	3	
2015	PRIAs	Baker	Baker		11	14	11	
2015	PRIAs	Howland	Howland		10	13	12	
2015	PRIAs	Jarvis	Jarvis		13	31	18	
2015	PRIAs	Johnston	Johnston		13	10		8
2015	PRIAs	Kingman	Kingman	7	10	20	4	8

Year	Region	Island	Sector	Backreef-All	Forereef-D	Forereef-M	Forereef-S	Lagoon-All
2015	PRIAs	Palmyra	Palmyra		33	30	15	
2015	SAMOA	Ofu & Olosega	Ofu & Olosega		17	27	8	
2015	SAMOA	Rose	ROSE_OTHER	5				5
2015	SAMOA	Rose	ROSE_SANCTUARY		10	21	6	
2015	SAMOA	Swains	SWAINS_OPEN		3	3	3	
2015	SAMOA	Swains	SWAINS_SANCTUARY		5	9	9	
2015	SAMOA	Tau	Tau		16	24	6	
2015	SAMOA	Tutuila	AUNUU_SANCTUARY_B		15	9	3	
2015	SAMOA	Tutuila	FAGATELE_SANCTUARY		6	15	6	
2015	SAMOA	Tutuila	TUT_NE		7	11	6	
2015	SAMOA	Tutuila	TUT_NW		9	5	4	
2015	SAMOA	Tutuila	TUT_SE		14	27	10	
2015	SAMOA	Tutuila	TUT_SW		4	6	5	

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 not 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 divers' 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 American Samoa 2015, Figure A5.2 main Hawaiian Islands 2015, Figure A5.3 Northwestern Hawaiian Islands 2015, Figure A5.4 Pacific Remote Island Areas 2015).

American Samoa 2015

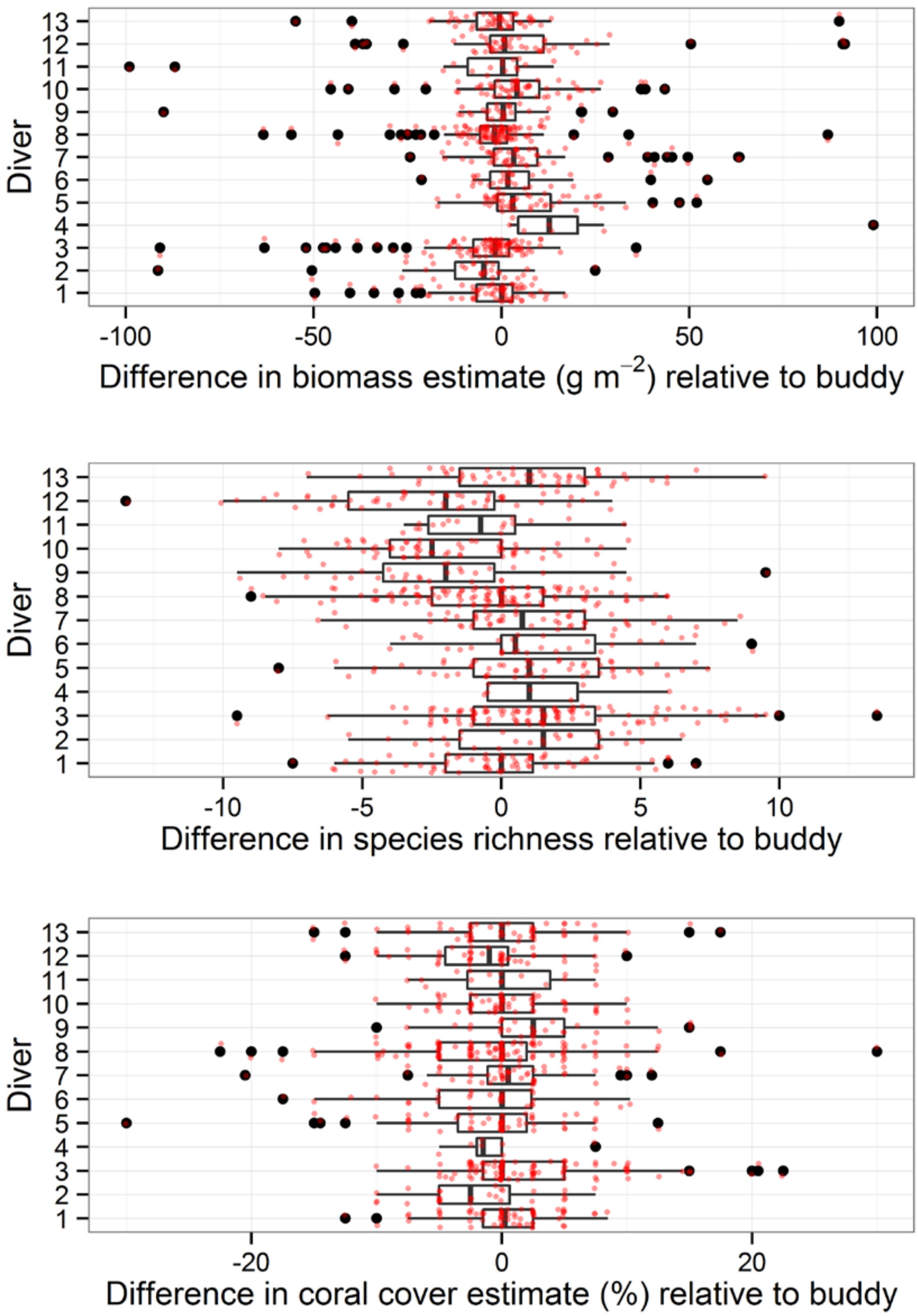

Figure A5.1 American Samoa comparison of observer diver vs dive partner estimates for total fish biomass, species richness and hard coral cover during 2015 surveys. The boxplot shows the median difference (thick vertical line) in estimates for each diver, the box represents the location of 50% of the 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).

main Hawaiian Islands 2015

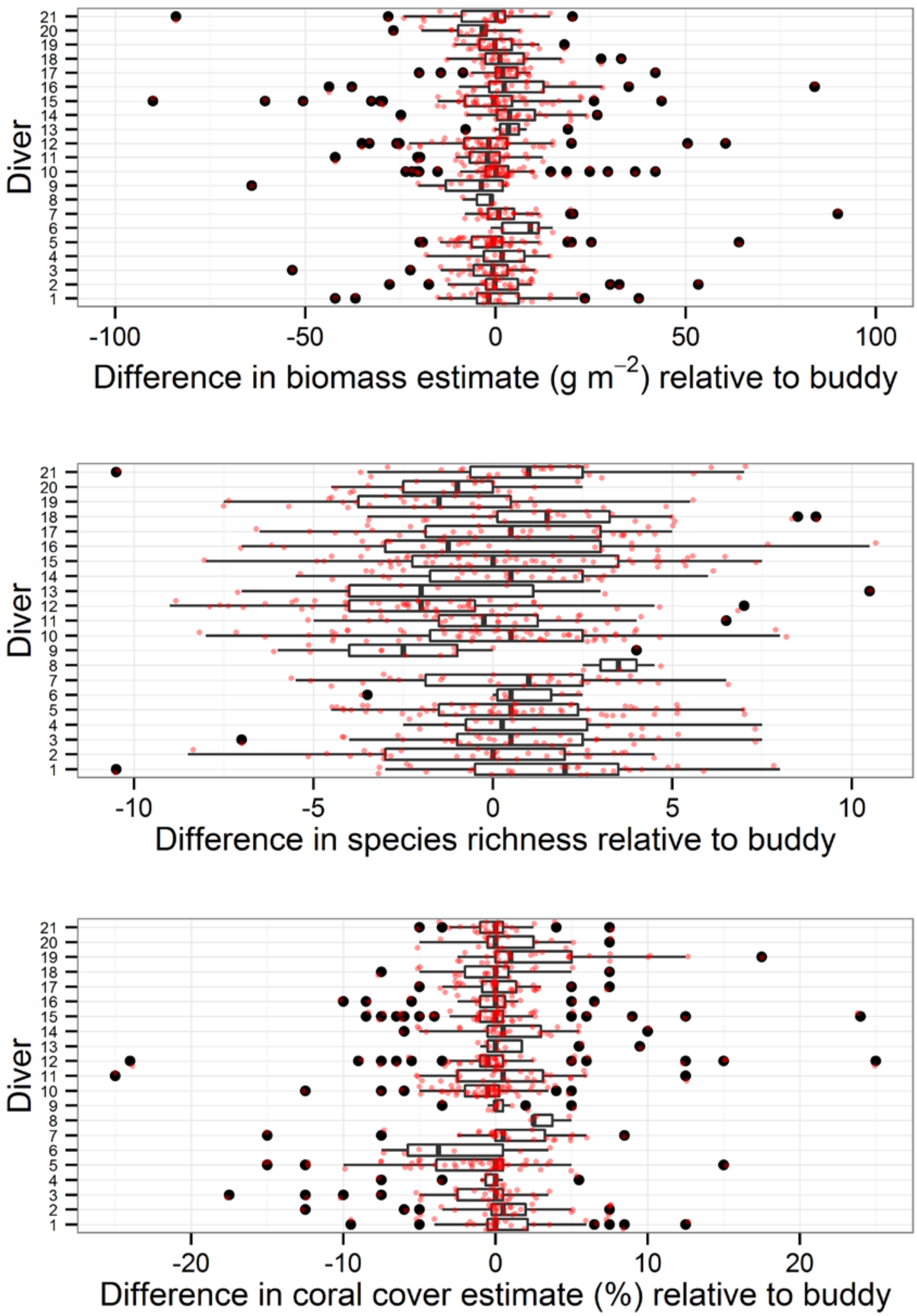

Figure A5.2 Main Hawaiian Islands comparison of observer diver vs diver partner estimates for total fish biomass, species richness and hard coral cover during 2015 surveys. See Figure A5.1 legend for details.

Northwestern Hawaiian Islands 2015

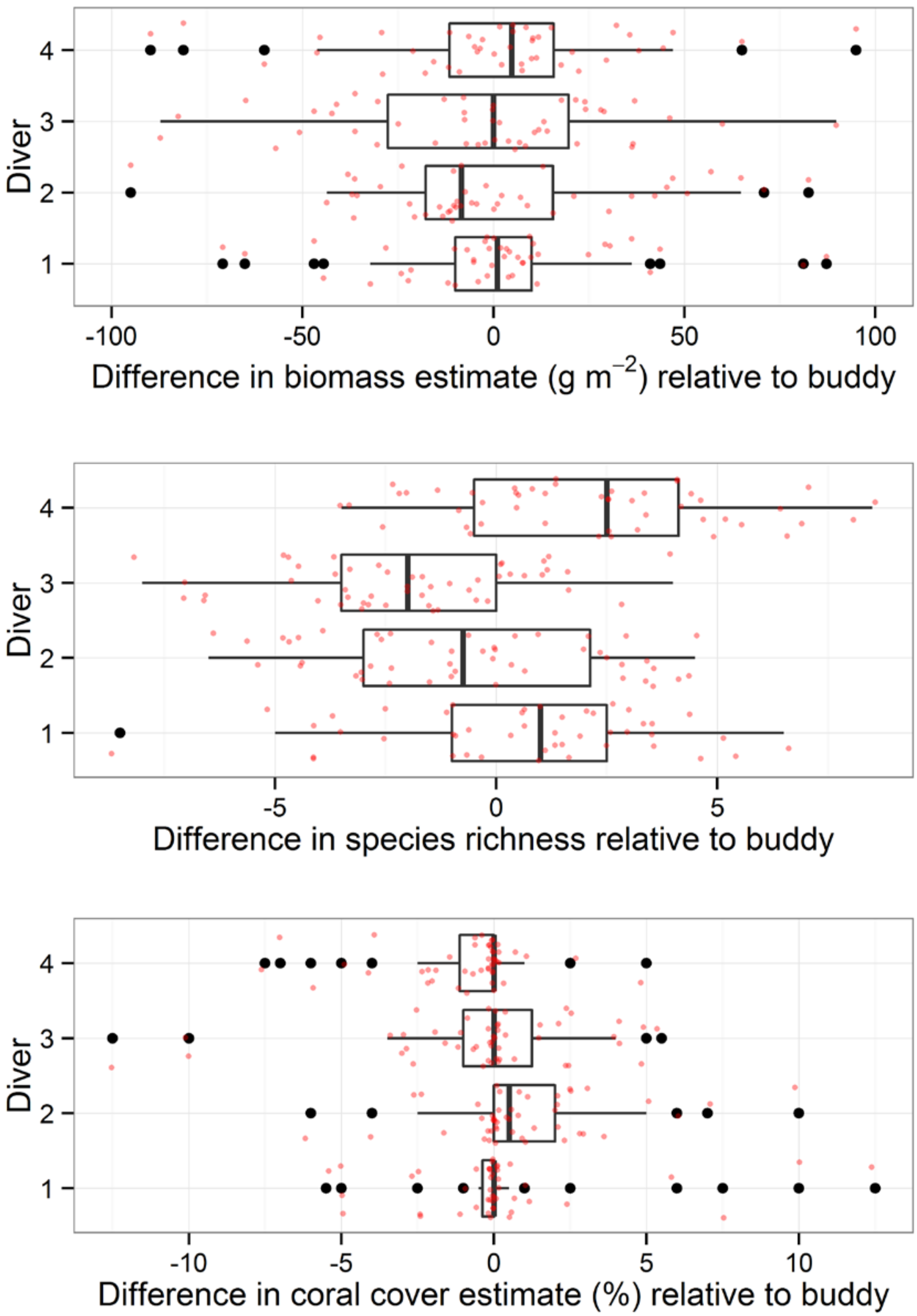

Figure A5.3 Northwestern Hawaiian Islands comparison of observer diver vs dive partner estimates for total fish biomass, species richness and hard coral cover during 2015 surveys. See Figure A5.1 legend for details.

Pacific Remote Island Areas 2015

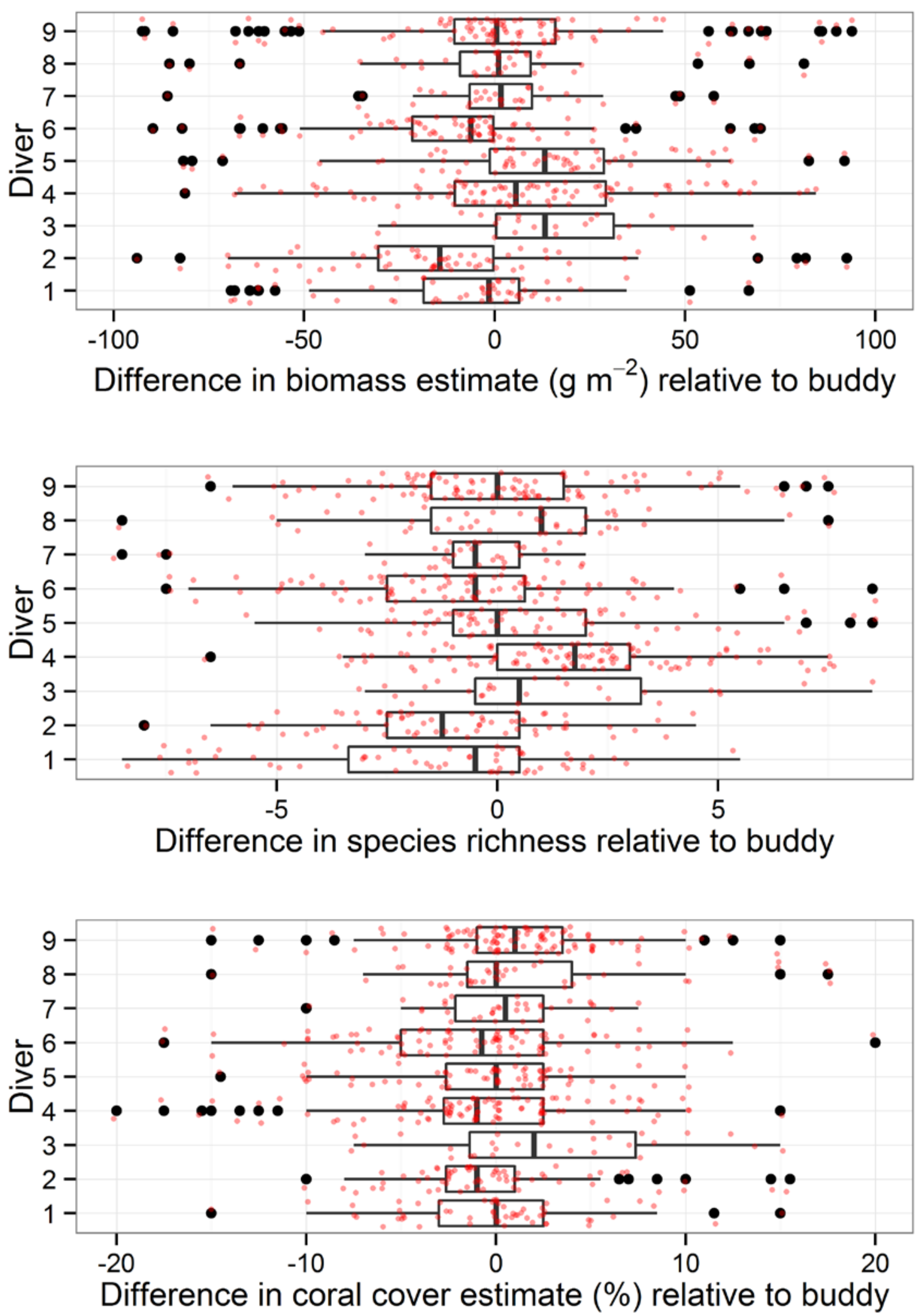

Figure A5.4 Pacific Remote Island Areas comparison of observer diver vs dive partner estimates for total fish biomass, species richness and hard coral cover during 2015 surveys. See Figure A5.1 legend for details.

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	Total
Northwestern HI	Kure	43	25		20			8	96
Northwestern HI	Midway	53		30			34	14	131
Northwestern HI	Pearl & Hermes		41	18	31			23	113
Northwestern HI	Lisianski	19	25	9	25		28	18	124
Northwestern HI	Laysan	14		23				8	45
Northwestern HI	Gardner			12					12
Northwestern HI	Maro	39		25				17	81
Northwestern HI	French Frigate		27	8	15		27	8	85
Northwestern HI	Necker	13		8					21
Northwestern HI	Nihoa			8					8
Main HI	Niihau		16			26		49	91
Main HI	Kauai		26			37		20	83
Main HI	Oahu		40		35	64		35	174
Main HI	Molokai		10		50	39		48	147
Main HI	Lanai		16		29	29		15	89
Main HI	Maui		33		49	34		30	146
Main HI	Hawaii		43			58		97	198
N. Mariana	Farallon de Pajaros	7		12			11		30
N. Mariana	Maug	21		30			40		91
N. Mariana	Asuncion	13		20			21		54
N. Mariana	Agrihan	14		20					34
N. Mariana	Pagan	21		29			43		93
N. Mariana	AGS	19		24			33		76
S. Mariana	Saipan	23		30			48		101
S. Mariana	Tinian	14		19			19		52
S. Mariana	Aguijan	6		13			10		29
S. Mariana	Rota	14		24			28		66
S. Mariana	Guam	25		133			104		262
PRIA	Wake	29		30			45		104
PRIA	Johnston		39		35			31	105
PRIA	Kingman		33		49			49	131
PRIA	Palmyra		40		42			78	160
PRIA	Howland		16		39			35	90
PRIA	Baker		21		24			36	81
PRIA	Jarvis		30		42			62	134
Am.Samoa	Swains		24		38			32	94
Am.Samoa	Ofu & Olosega		30		30			52	112
Am.Samoa	Tau		24		22			46	92
Am.Samoa	Tutuila		127		85			162	374
Am.Samoa	Rose		34		48			47	129

Appendix 7: Baseline surveys conducted in 2015 in the National Marine Sanctuary of American Samoa

Summary

This report summarizes the baseline reef fish surveys conducted as a partnership between the Coral Reef Ecosystem Program (CREP) and the National Marine Sanctuary of Marine Samoa (NMSAS) in February and March of 2015. The Coral Reef Ecosystem Program (CREP) implements the Pacific Reef Assessment and Monitoring Program (RAMP), an ecosystem-scale interdisciplinary coral reef monitoring program. This partnership with NMSAS enabled additional sampling work focused on the marine sanctuaries of American Samoa. Collectively, these surveys provide a baseline assessment of American Samoa's sanctuaries. Furthermore, since the survey method and design are also implemented as part of Pacific RAMP, these data are directly comparable to data from elsewhere in the region. The intention here is to continue this work periodically so that the status of biological communities within sanctuaries can be tracked through time and in comparison to reef areas outside of the sanctuaries.

Methods

The sampling domain for fish and benthic surveys is hardbottom habitat in water less than 30 m. Each island reported here is stratified by reef zone (backreef, forereef, lagoon) and depth zone (0-6 m, 6-18 m, and 18-30 m). In addition, for Tutuila, the sampling domain was also stratified based on section of coastline (i.e., NE, NW, SE, and SW). For each island, the number of sites sampled in each stratum is determined by: (1) a weighting factor that includes both the area per stratum and the variance of the target metric (e.g., total fish biomass density) and (2) logistical issues such as weather conditions and/or time constraints. Prior to each survey mission, the latitude and longitude of site locations are randomly drawn from geographic information system (GIS) habitat and strata maps. Maps of each island's sampling domain are 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 CREP-affiliated Pacific Islands Benthic Habitat Mapping Center, University of Hawai'i at Mānoa, as well as prior knowledge gained from previous visits to survey locations.

Our survey protocol is based on a modified paired stationary point count (SPC) method developed by our colleagues (Ault et al. 2006) and involves a pair of divers conducting simultaneous fish surveys in adjacent, visually estimated 15 m diameter cylindrical plots extending from the substrate to the limits of vertical visibility. Upon reaching a target survey site, a 30 m transect line is laid across the substratum following the depth contour. Divers use the transect line to locate the centers (7.5 m and 22.5 m) and two edges (0 m and 15 m; or 15 m and 30 m) of their survey plots. Each SPC consists of two components: a 5-minute species enumeration period in which divers recorded all species present in or moving through their cylinder, followed by a tallying portion, in which divers systematically record the number and size (total length to nearest cm) of all fishes of each taxon on their list. The tallying portion is conducted as a series of rapid visual sweeps, with one species grouping counted per sweep. The divers' goal is to get a near instantaneous record of fishes present within their cylinder. 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 the size and number observed in their first encounter during the enumeration period and mark the data recorded as "non-instantaneous". Lastly, on completing the fish count, divers visually estimated benthic cover (% cover per functional group, including hard coral) and structural complexity within the SPC cylinders. Details of our specific survey methods can be found in Ayotte et al. (2015).

Here, instantaneous and non-instantaneous data are pooled together. For all surveys, data from the two adjacent cylinders are averaged to obtain a mean value for the site. The biomass density of each fish is then calculated using standard, species-specific, length-weight equations. For each reporting unit presented below (e.g., Rose Sanctuary, Aunuu B, etc.), sites within each stratum are averaged and weighted proportional to stratum area. Weighted averages are then summed across strata to obtain biomass density estimates for each reporting unit.

Results

Fish surveys were conducted between February 15 and March 30, 2015. During this time, researchers conducted a total of 325 fish surveys across eight reporting units: Rose Sanctuary, Swains Sanctuary, Aunuu B, Fagatele Sanctuary, Tau, Ofu & Olosega, Rose Inside Crest, and Tutuila (Table A7.1). Furthermore, Tutuila is broken down into sectors (Figure A7.1).

Table A7.1 – Summary of fish surveys for the sanctuary and non-sanctuary reporting units visited during the American Samoa Reef Assessment and Monitoring Program 2015

Area	Dates Visited	# of Surveys
SANCTUARY UNITS		
ROSE SANCTUARY	MAR 16-19	37
SWAINS SANCTUARY	FEB 15; FEB 18-20	23
AUNUU B	FEB 28; MAR 03; MAR 28-29	27
FAGATELE	FEB 17; MAR 05-07; MAR 30	27
NON SANCTUARY UNITS		
TAU	Mar 15; Mar 20; Mar 23-24	43
OFU & OLOSEGA	Mar 13-14; Mar 21; Mar 25-26	52
ROSE INSIDE CREST	Mar 17-18	10
NE TUTUILA	FEB 27-28; MAR 03-04; MAR 28-29	24

Area	Dates Visited	# of Surveys
NW TUTUILA	MAR 01; MAR 04	18
SE TUTUILA	FEB 26 & 28; MAR 02-03; 07; 12; 27; & 30	49
SW TUTUILA	MAR 05-06; MAR 27	15

Fish biomass density for each of the reporting units described above are reported in two formats: (1) site-level bubble maps by island and (2) comparative bar graphs displaying pooled-up information at the level of each reporting unit. For the comparative bar graphs, we divide Tutuila into four sectors (NE NW, SE, and SW) as shown in Figure A7.1.

Figure A7.1 – Map displaying the four, non-sanctuary (i.e., open to fishing) reporting units around Tutuila, American Samoa.

The following section (Figures A7.2-A7.5) displays site-level bubble maps, which report on the biomass densities (g m^{-2}) of: all fish, piscivores, fish >50 cm, and *Acanthurus lineatus* (alogo). In addition, we report on visually-estimated, site-level percent hard coral cover (Figure A7.6) and benthic substrate ratio (ratio of the sum of hard coral and crustose coralline algae cover to the sum of macroalgae and turf cover; Figure A7.7).

Three other species of interest to NMSAS, *Selar crumenophthalmus* (big eye scad or atule), *Epinephelus lanceolatus* (giant grouper), and *Bolbometopon muricatum* (bumphead parrotfish), were not encountered in any surveys.

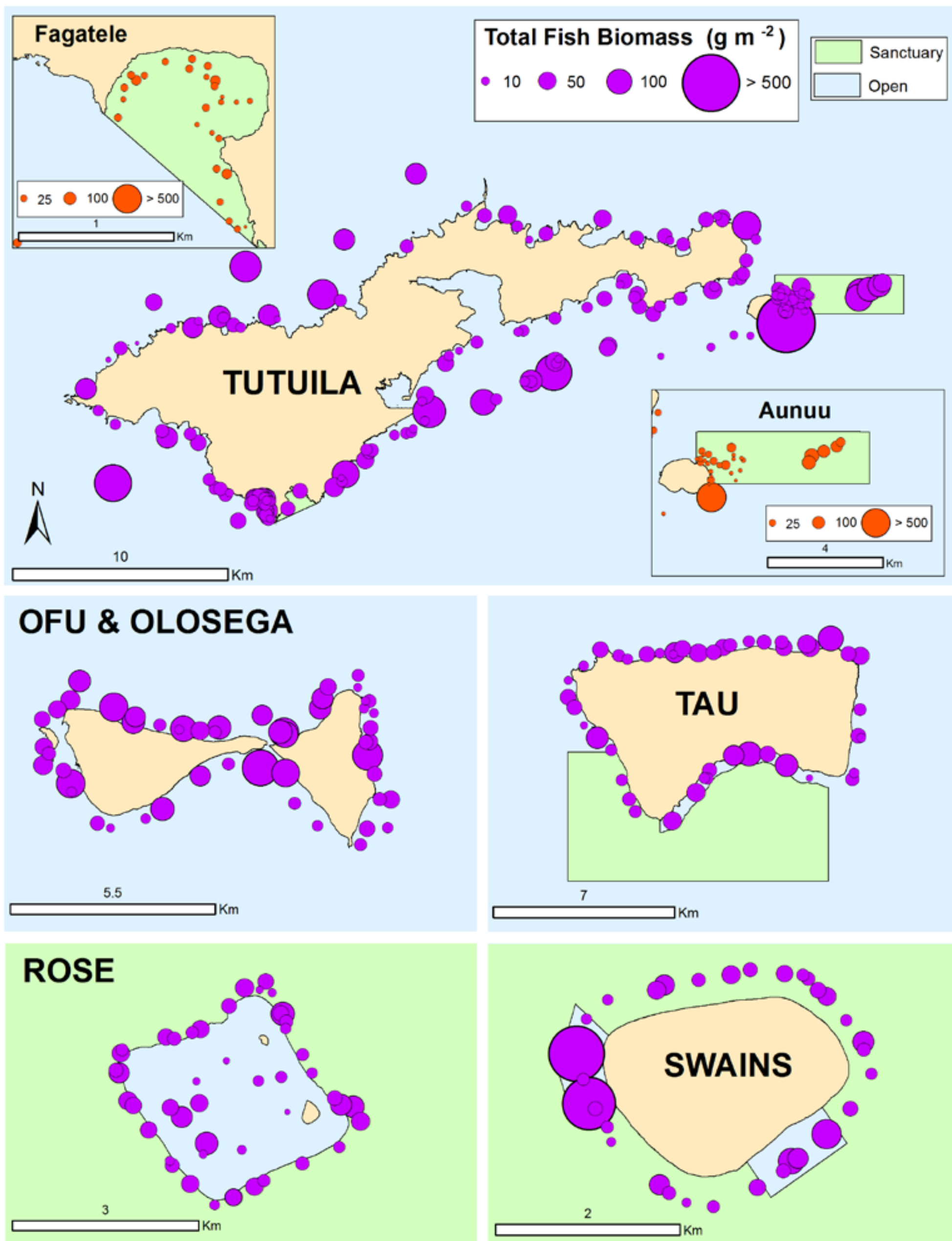

Figure A7.2 – Biomass density of all fishes (g m^{-2}) at each survey site. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

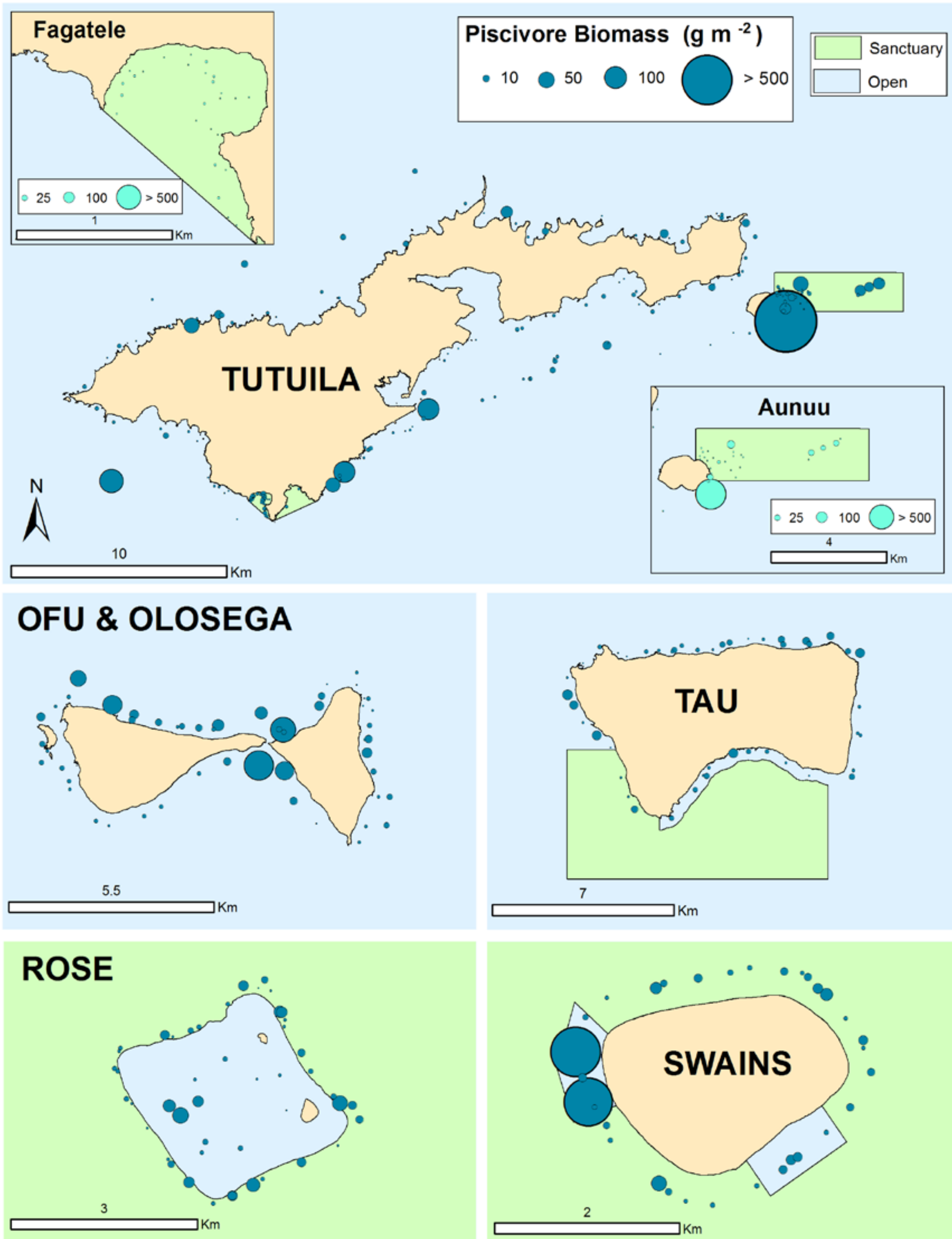

Figure A7.3 – Biomass density of all piscivores (g m^{-2}) at each survey site. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

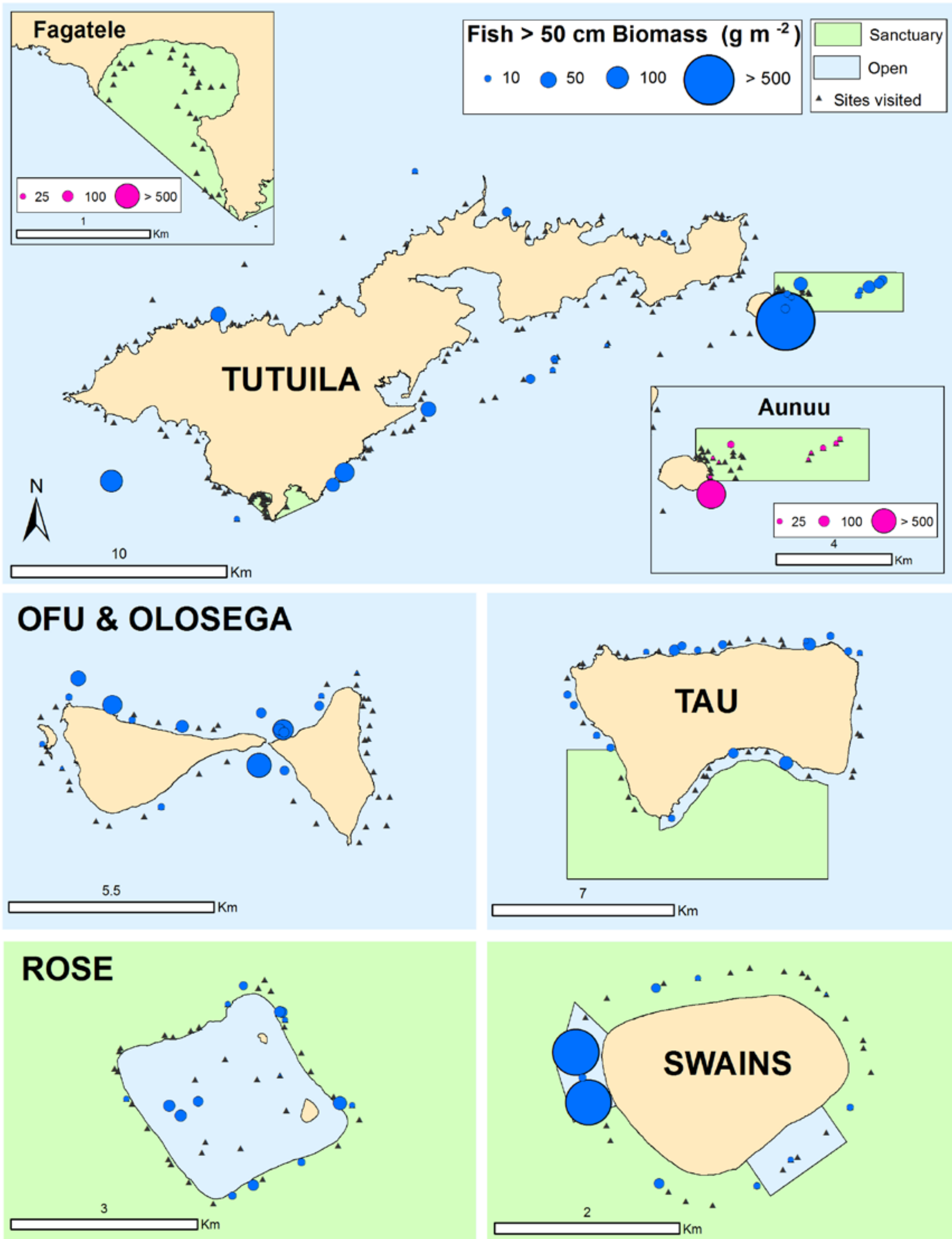

Figure A7.4 – Biomass density of all fish >50 cm (g m^{-2}) at each survey site. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

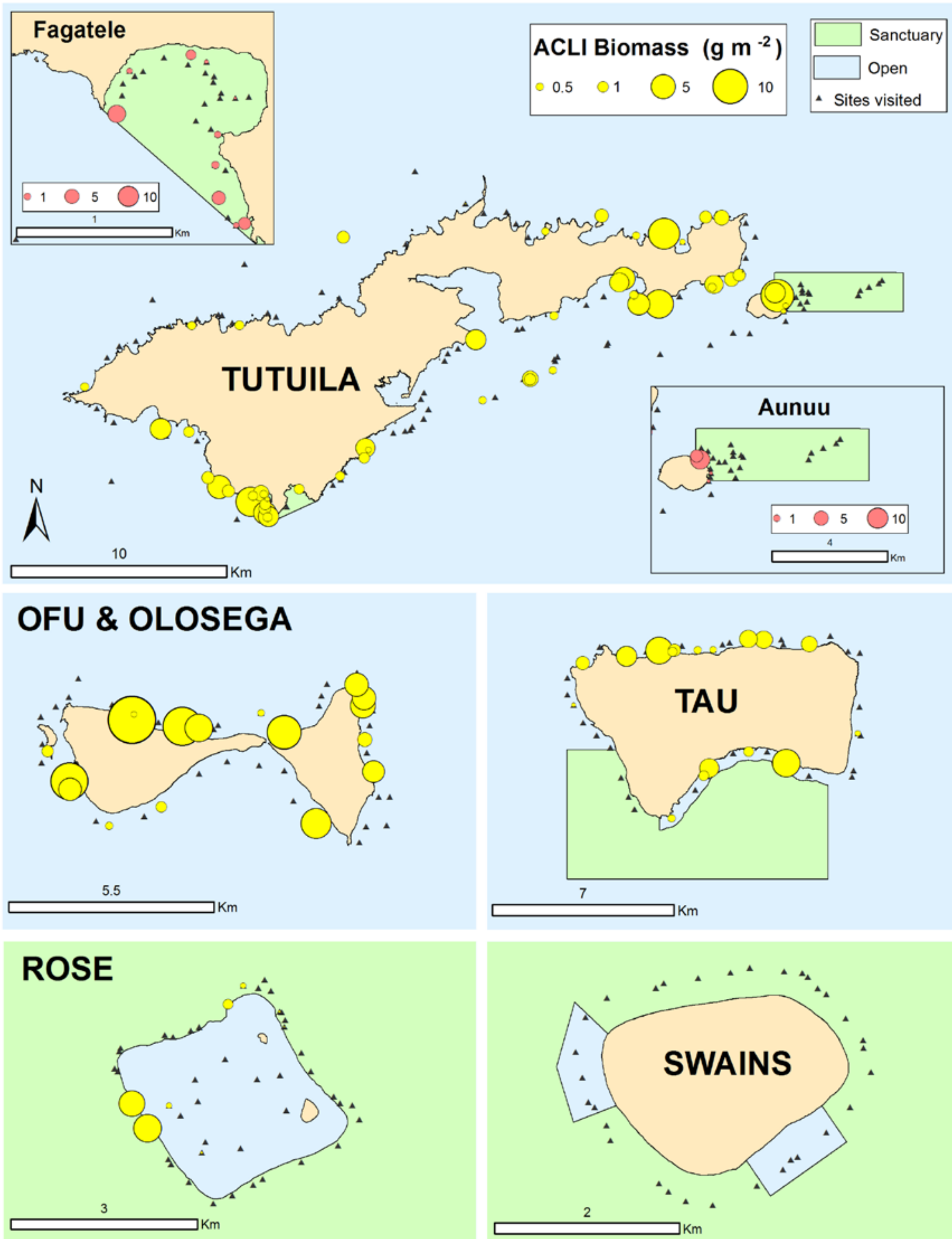

Figure A7.5 – Biomass density of *Acanthurus lineatus* (g m^{-2}) at each survey site. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

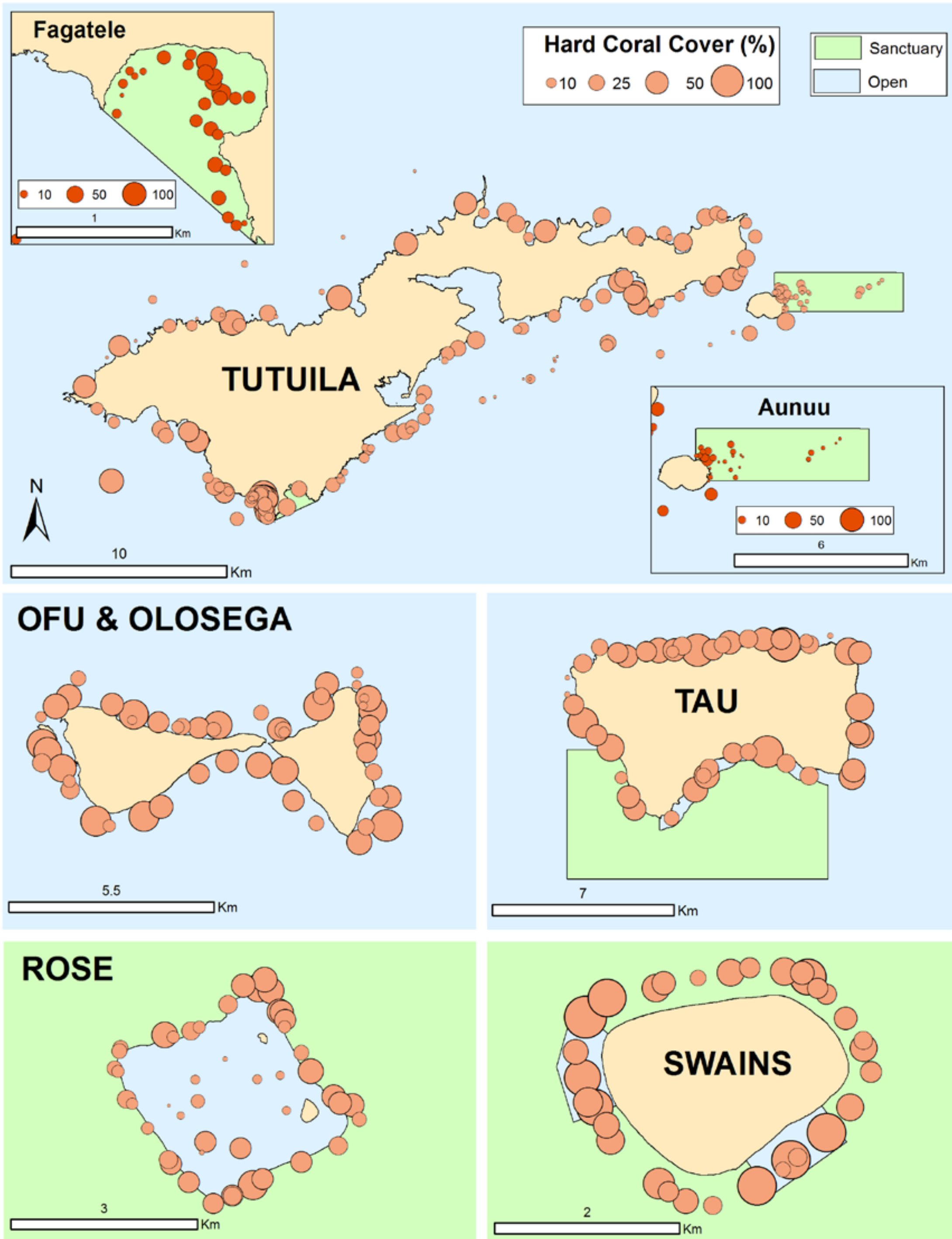

Figure A7.6 – Visual estimates of percent hard coral cover at each survey site. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

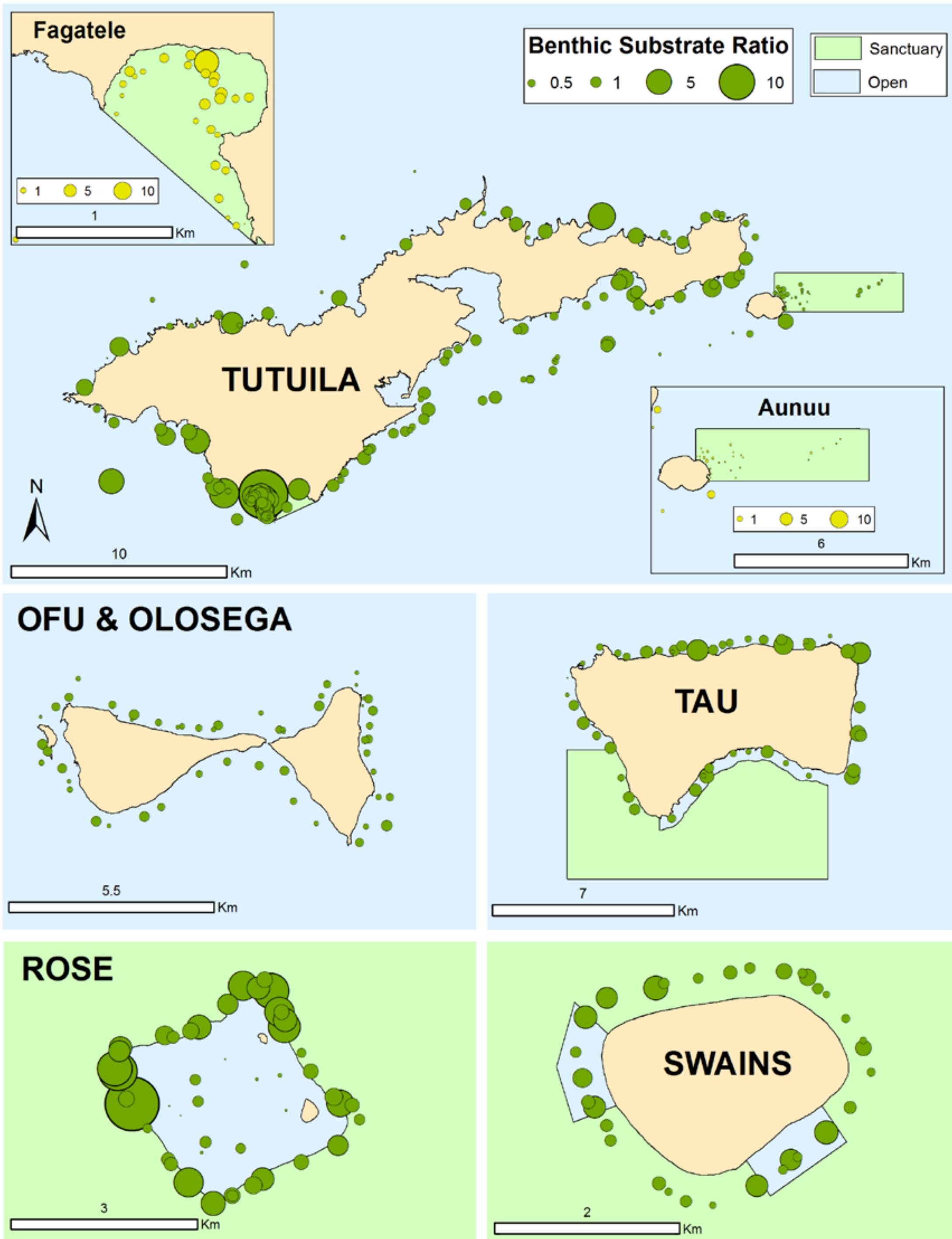

Figure A7.7 – Benthic substrate ratio [i.e., (hard coral + crustose coralline algae) / (macroalgae + turf)] at each survey site. Calculations are based on visual estimates of the percent cover of hard coral, crustose coralline algae, macroalgae, and turf algae. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

In the next section, site-level data are pooled together and displayed as bar graphs comparing the following reporting units: Rose (Inside Crest), Ofu & Olosega, Tau, Aunuu B, Fagatele Sanctuary, Swains Sanctuary, and Rose Sanctuary (Figures A7.8-A7.12). We compare the biomass densities (g m^{-2}) for total fish, piscivores, herbivores, and fish >50 cm, as well as percent hard coral cover across all reporting units. In addition to the graphs displayed below, sector-level data are reported as a table in Appendix C. Finally, it should be noted that the large standard errors (i.e., error bars) for NE Tutuila, particularly for the biomass density estimates of piscivores and fish >50 cm, is entirely driven by a single site found off Aunuu at which a large school of barracudas (*Sphyraena qenie*) was sighted.

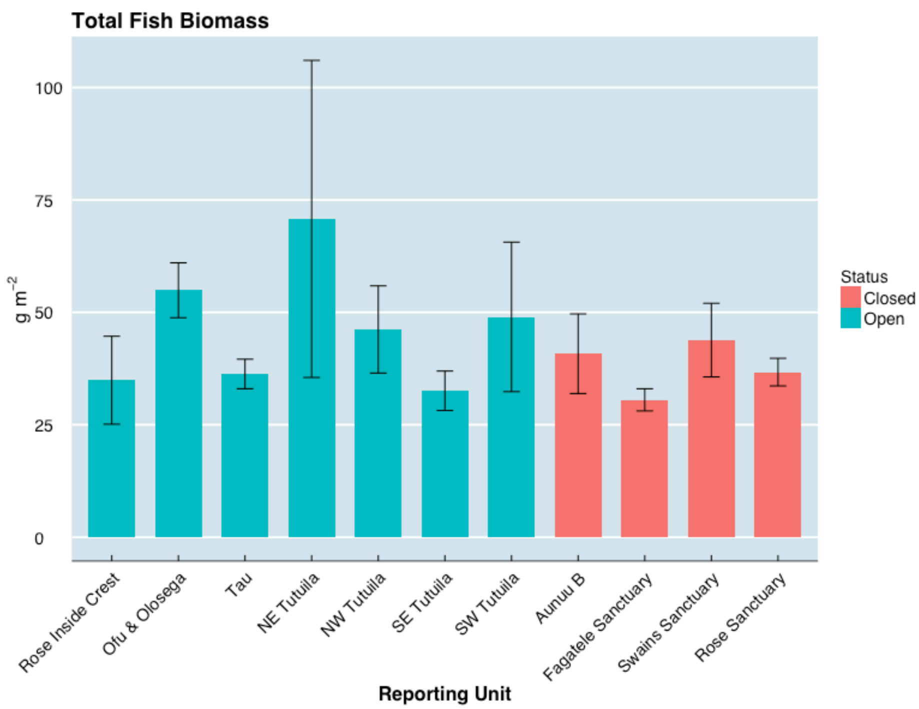

Figure A7.8 – Biomass density of all fishes (g m^{-2}) for different reporting units around American Samoa, including areas that are part of the National Marine Sanctuary of American Samoa. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

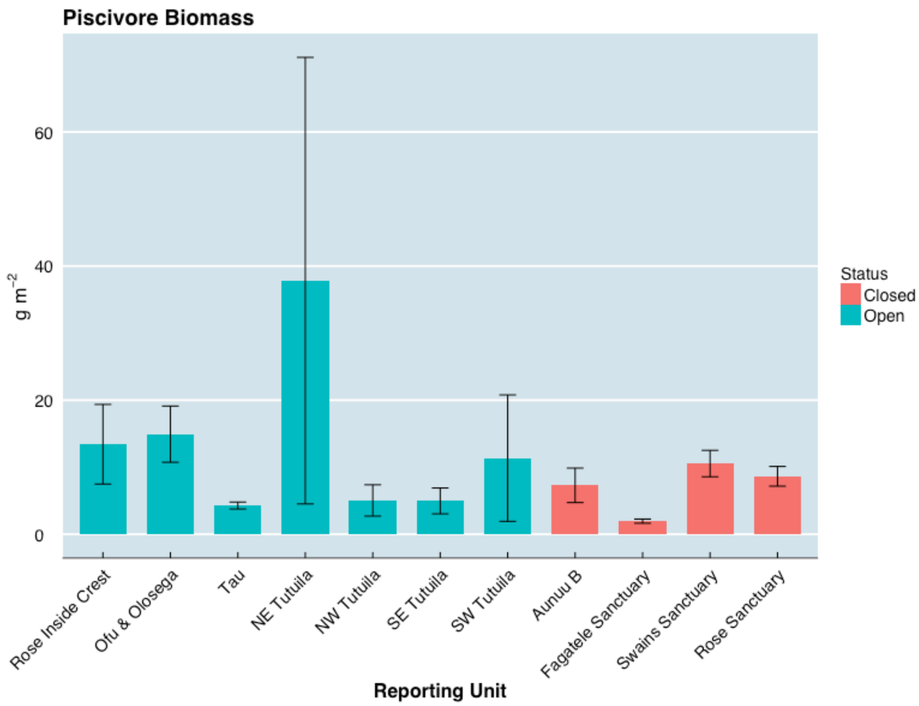

Figure A7.9 – Biomass density of piscivores (g m^{-2}) for different reporting units around American Samoa, including areas that are part of the National Marine Sanctuary of American Samoa. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

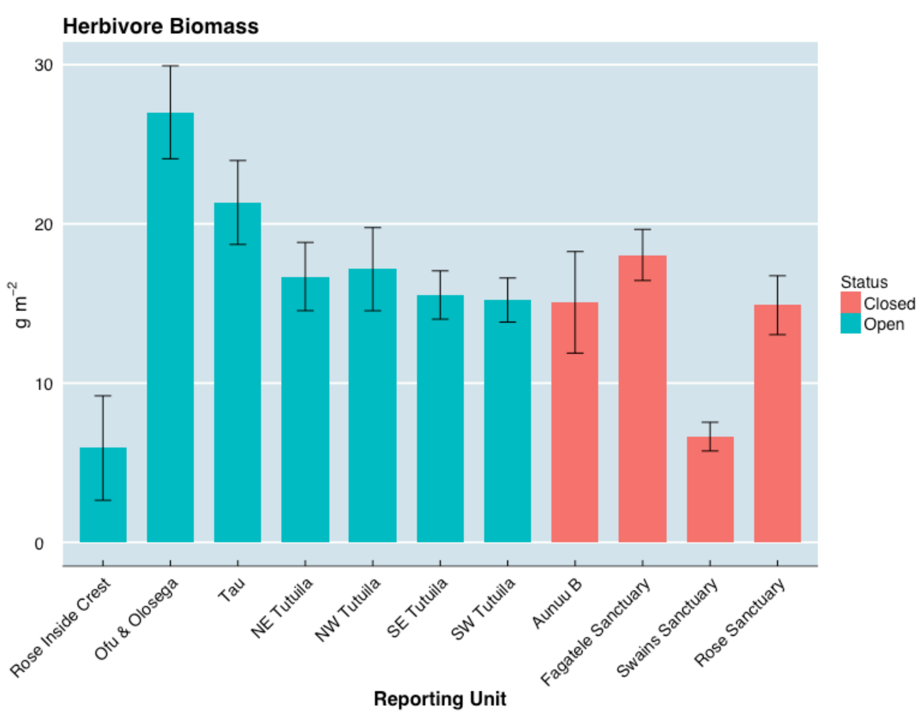

Figure A7.10 – Biomass density of herbivores (g m^{-2}) for different reporting units around American Samoa, including areas that are part of the National Marine Sanctuary of American Samoa. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

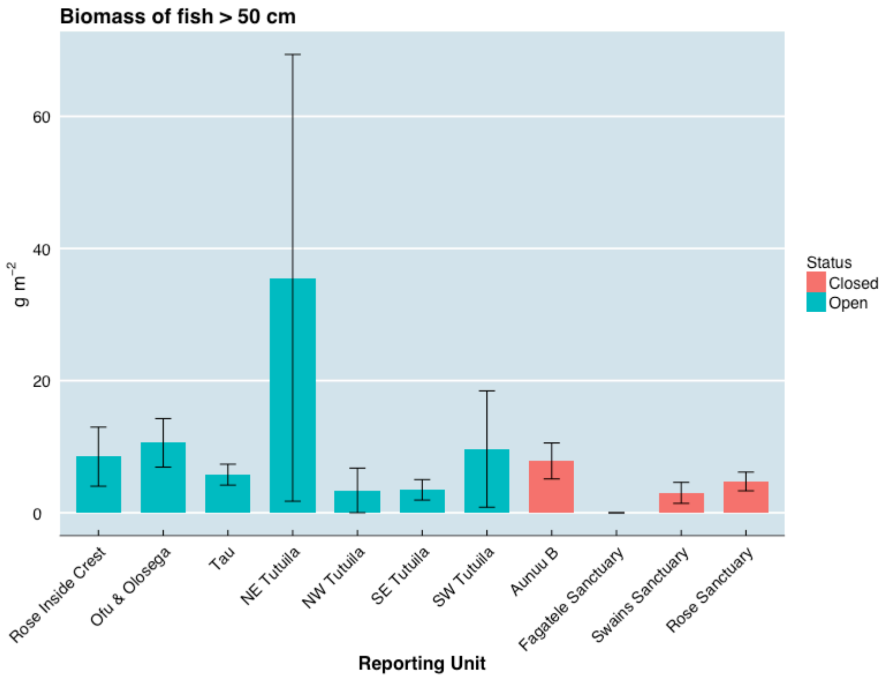

Figure A7.11 – Biomass density of fish >50 cm (g m^{-2}) for different reporting units around American Samoa, including areas that are part of the National Marine Sanctuary of American Samoa. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

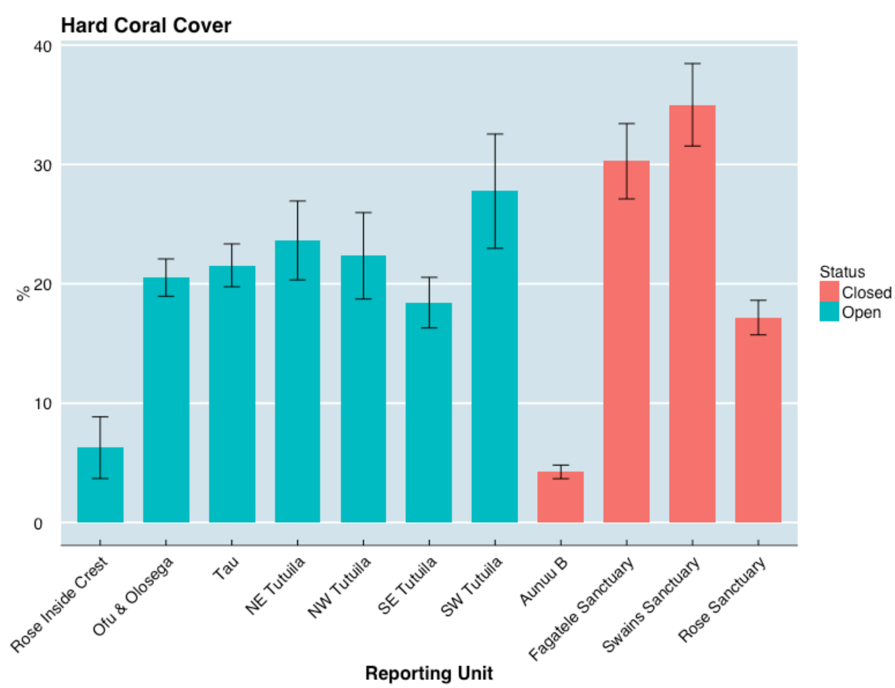

Figure A7.12 – Percent hard coral cover for different reporting units around American Samoa, including areas that are part of the National Marine Sanctuary of American Samoa. Data collected by CREP during the American Samoa Reef Assessment and Monitoring Program 2015.

Appendix 8: Closed circuit rebreather (CCR) SCUBA comparison study

Fish behavior can change depending on survey methods used (Dickens 2011), so it is important for CREP to acknowledge the potential for biases associated with SCUBA surveys while using the SPC methodology. The primary disturbance associated with SCUBA diving is the noisy stream of bubbles produced from divers' exhales, which may attract or repel fish. Closed circuit rebreathers (CCRs) are significantly quieter than SCUBA and eliminate noise and visual disturbances associated with SCUBA by not producing bubbles.

To address issues related to potential SCUBA biases we conducted a comparison between SCUBA and CCR using the SPC method on the main Hawaiian Islands Reef Fish Survey cruise and additional land-based operations on Oahu. Our goal is to better understand biases associated with SCUBA surveys by comparing biomass, abundance and richness between SCUBA and CCR surveys. Results from this study will be analyzed and after internal review will be submitted for publication in a scientific journal.

References

Dickens, L. C., Goatley, C. H. R., Tanner, J. K. & Bellwood, D. R. (2011). Quantifying Relative Diver Effects in

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