Pacific Reef Assessment and Monitoring Program
Data Report

Ecological monitoring 2019—Reef fishes and benthic habitats of the main Hawaiian Islands

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This report outlines some of the coral reef monitoring surveys conducted by the National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center's (PIFSC) Ecosystem Sciences Division (ESD) in 2019 in the main Hawaiian Islands.

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Report, figures, and maps compiled by K. McCoy.

Acronyms

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

Contents

Introduction

Background

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

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

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

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

The NCRMP has three themes: biological, climate, and socioeconomic monitoring. Under the biological monitoring theme, the Pacific RAMP collects the following benthic and reef-associated fish data: fish and coral demographic information (species, size, abundance, disease (coral only), and 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). This report focuses on the data collected using the stationary point count method to survey the fish assemblage and paired rapid visual assessments of benthic composition (see Section: Methods). The Pacific RAMP collects additional, related benthic data via benthic transects (for more information see NCRMP 2014), which are not included in this report.

Monitoring scope and historical programmatic changes

Pacific RAMP includes the following biological monitoring objectives:

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

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

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

In 2012, Pacific RAMP changed from surveying regions once every 2 years to once every 3 years. In addition to routine coral reef monitoring, a stand-alone reef fish survey also surveyed most islands in American Samoa in 2016. The sampling design and methods used to monitor coral reef fish species and habitats for Pacific RAMP have evolved over time. More specifically, from 2000 to 2006, surveys were conducted at haphazardly located permanent sites using various belt transect methods. During 2007 to 2009, ESD and PMNM conducted comparative reef fish surveys using both the belt transect and the stationary point count (SPC) methods, and incorporated a stratified random sampling survey design. Survey replication (i.e., the number of sites sampled) greatly increased over this period, and this higher level of replication has been maintained (Appendix 2: Surveys per region per year and method used). Following this methods calibration period, from 2009 onwards, the SPC method and depth-stratified random sampling were applied routinely in Pacific RAMP for surveying reef fishes and associated benthic communities.

Report structure

This report summarizes the reef fish survey data and a subset of the benthic data collected by the ESD for Pacific RAMP survey missions in 2019. During 2019, surveys were conducted in the main Hawaiian Islands. The status of reef fish assemblages is first described in the wider Pacific context (Section: U.S. Pacific reefs: the status of reef fishes), and later described at the island scale. By collecting data using the same methods over time, we are able to look at time series. For the regional comparison, data from 2009–2019 were averaged. Even though the ESD began collecting data in 2000, given the substantial changes in methods and design used for the reef fish assemblage surveys, this section shows observations collected since 2009. After this point, surveys were consistently conducted using the SPC method under a depth-stratified random sampling design.

In the final section, the publications that were produced in 2019 as a result of those surveys are listed; these publications either use the Pacific RAMP fish data, or were co-authored by ESD members listed as co-authors on this report and are relevant to Pacific RAMP's ecological monitoring of fishes.

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

Methods

Sampling domain and design

The target sampling domain is hard-bottom habitat in water shallower than 30 m. All islands/atolls within regions are stratified by reef zone (backreef, forereef, lagoon, protected slope) and depth zone: shallow (>0–6 m)[1], mid (>6–18 m), and deep (>18–30 m). The areas surveyed in the main Hawaiian Islands are all considered 'forereef', and are further stratified into sectors per island, with sector boundaries designed to reflect broad differences in oceanographic exposure, reef structure, and local human population density (Appendix 3: Sector maps). Some of the smaller, more closely spaced islands are always pooled into single reporting and sampling units (i.e., Niʻihau and Lehua). Due to their small size, these island groups are only 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 2019.

Table 1. Sampling terms and definitions.

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

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.

[1] For practical reasons, sites in which the center point of the survey cylinder is shallower than 1.5 m are not surveyed.

Maps used in the site selection procedure were created using information from the NOAA National Centers for Coastal Ocean Science, reef zones (e.g., forereef) digitized from IKONOS satellite imagery or nautical charts, bathymetric data from the ESD-affiliated Pacific Islands Benthic Habitat Mapping Center at the University of Hawaiʻi at Mānoa, and prior knowledge gained from previous visits to survey locations.

During cruise planning, logistics and weather conditions factor into the allocation of monitoring effort around each island or atoll. Prior to the cruises, these constraints determine the area of target habitat from which sites are randomly selected; for instance, one side of an island may be deemed unsurveyable given seasonal wave conditions or ESD's allocation of sea days aboard the NOAA research vessel may curtail the time spent in a particular area. The density of sites that are sampled per stratum is therefore determined by proportionally allocating effort (e.g., the number of sites to be surveyed) based on a weighting factor calculated from the area per stratum per reporting unit and the variance of the target output metrics (e.g., consumer group biomass and total fish biomass; see Section: Fish groupings), combined with 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-bottom habitat) or accessible (e.g., inclement sea conditions), the dive is aborted and an alternate (backup) site is picked from the randomized list. In some cases, the spatial coverage of sampling sites around the entire area of target sampling domain is incomplete. As such, any inferences about coral reef fish assemblages and habitat made at the island-scale are only representative of the areas surveyed (Appendix 4: Samples per sector and strata in 2019). For further details on the methods and maps used to select sites, see Williams et al. (2011) or the Ecosystem Sciences Division Standard Operating Procedures: Data Collection for Rapid Ecological Assessment Fish Surveys (Ayotte et al. 2015).

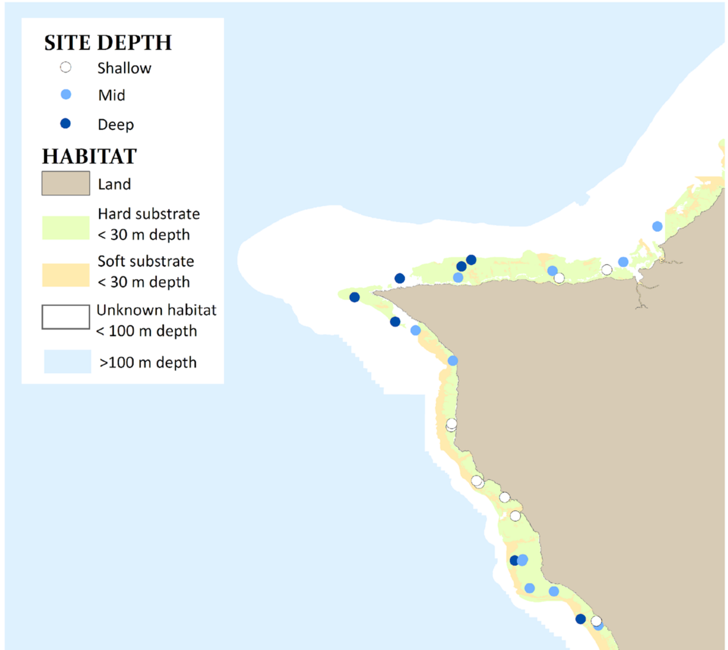

Figure 2. An example of the benthic habitat and depth strata information used in the site selection process. Reef fish survey sites are randomly selected within each depth stratum. Survey effort is allocated to optimize island-scale biomass estimates. Prior to surveying, a series of primary sites are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

Sampling methods

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

Counting and sizing reef fishes

The SPC protocol closely follows that used by Ault and colleagues (Ault et al. 2006) and involves a pair of divers conducting simultaneous counts in adjacent, visually estimated 15-m-diameter cylindrical plots extending from the substrate to the limits of vertical visibility (Figure 3). Prior to beginning each SPC pair, a 30-m line is laid across the substratum. Markings at 7.5, 15, and 22.5 m enable survey divers to locate the midpoint (7.5 or 22.5 m) and two edges (0 and 15 m or 15 and 30 m) of their survey plots. Each count consists of two components. The first of these is a 5-minute species enumeration period in which the diver records the taxa of all species observed within their cylinder. At the end of the 5-minute period, divers begin the tallying portion of the count, in which they systematically work through their species list and record the number and estimated size (total length, TL, to the nearest cm) of each individual fish. The tallying portion is conducted as a series of rapid visual sweeps of the plot, with one species-grouping counted per sweep. To the extent possible, divers remain at the center of their cylinders throughout the count. However, small, generally site-attached and semi-cryptic species, which tend to be under-represented in counts made by an observer remaining in the center of a 7.5-m radius cylinder, are left to the end of the tally period, at which time the observer swims through their plot area carefully searching for those species. In cases where a species is observed during the enumeration period but is not present in the cylinder during the tallying period, divers record their best estimates of size and number observed in the first encounter during the enumeration period and mark the data record as "non-instantaneous." Beginning in 2012, divers also recorded observations of fishes that were first seen inside the cylinders at some point between 5 and 30 minutes into the survey. However, for consistency across time periods, those additional observations were not used in this report. 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).

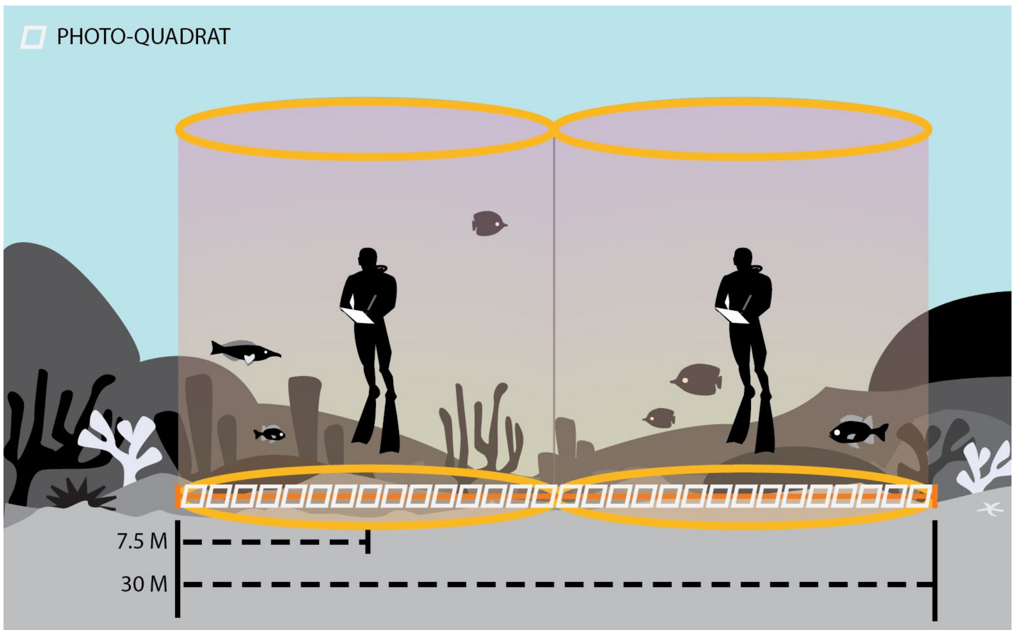

Figure 3. Side view of the stationary point count method. Dive partners count and size fishes within adjacent cylinders measuring 7.5 m in radius. Once the fish survey is complete, divers estimate benthic habitat composition and a benthic photo-transect is collected, spanning the two cylinders.

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.

Benthic visual assessment

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

Photo-quadrat survey

With the fish survey and rapid benthic visual assessment completed, one diver takes photographs of the benthos at 1-m intervals along the transect line (30 photographs per site; Figure 3). A 1-m PVC stick is used to position a digital camera (Canon PowerShot G9X, 20.2 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 photos, 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 custom data entry application built with Oracle Application Express, and stored in an Oracle mission-specific database. Upon completion of the monitoring cruise, all data were migrated to an existing master Oracle database that is stored on a server at the Pacific Islands Fisheries Science Center.

Data quality control

Data quality control is implemented at three main stages:

- Prior to conducting fish surveys for Pacific RAMP, each observer takes the full training course.[2] In between field data collections, observers undergo regular and routine size estimation practice and fish identification tests (Figure 4: Pre-field).
- Checking for errors at the data entry stage (Figure 4: In the field). This occurs on the cruise when observers check the data entered by their dive partner against their datasheet for typing and potential sizing errors. At the end of the cruise, a series of error checking scripts are run prior to migrating from the mission Oracle database to the master Oracle database (Figure 4: Post-field).
- Examining diver estimation accuracy. This occurs during and after the monitoring cruise when diver estimates are compared between dive partner pairs (Figure 4: In the field). Observer comparisons from the regions surveyed in 2017 are in Appendix 5: SPC Quality control: Observer cross-comparison.

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

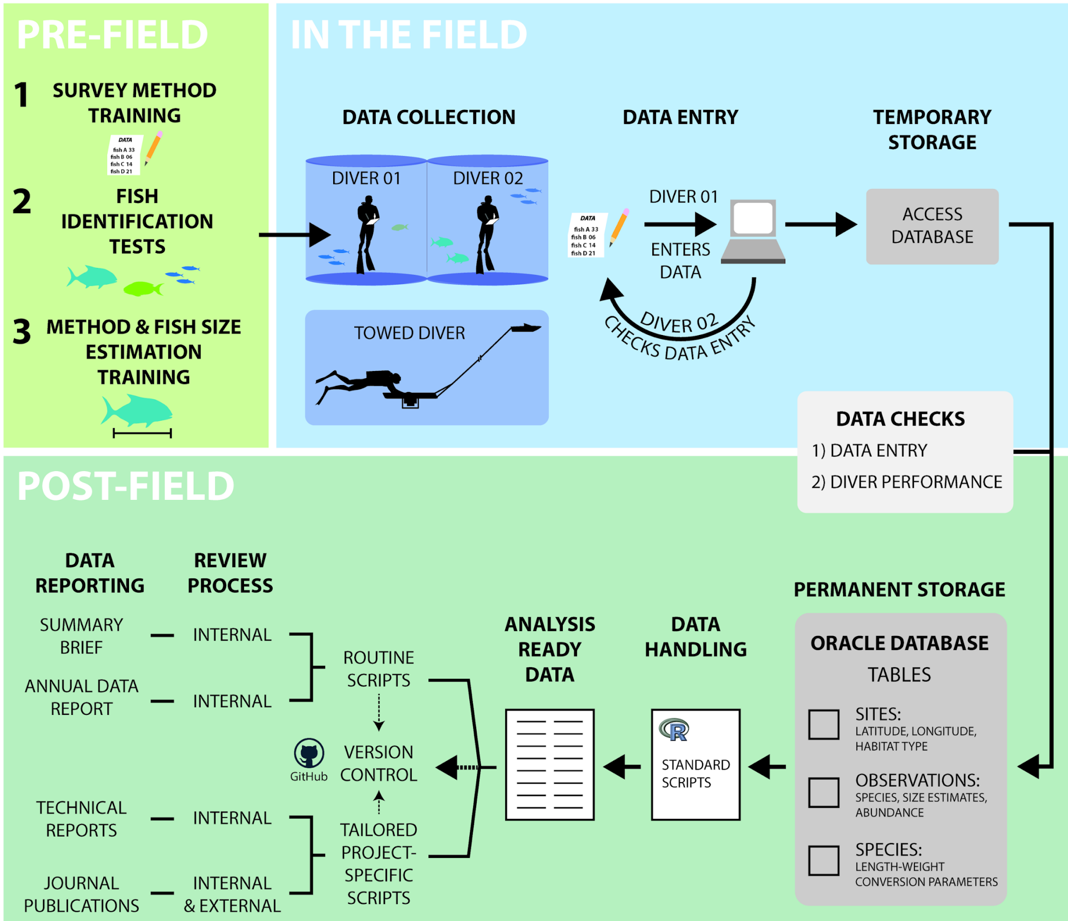

Figure 4. The training, data collection, data processing, and reporting phases for Pacific RAMP SPC surveys.

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). Biomass per fish is calculated using the standard length-weight equation. 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, and in cases where more than one SPC paired survey is conducted, data from matched members of each pair are first averaged before pair-specific results are averaged to create site estimates. Similarly, the mean percentage cover estimates per benthic functional group and complexity measures are calculated as site-level means.

Fish groupings

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

Generating island-scale estimates from the stratified design

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

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

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

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

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 habitat area surveyed at an island, its 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 rare cases where fewer than two sites were surveyed in a stratum during a reporting period, these sites were removed from the island-scale parameter estimates for that period.

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

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

All data handling and analyses were performed using raw site data extracted from the NOAA ESD Oracle database, processed using a set of routine processing scripts written in R (R Development Core Team 2011; Figure 4: post field), and visualized using the ggplot2 package (Wickham 2016). The site-level data used to generate all figures and summary statistics are available upon request.

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

This section summarizes variation in reef fish community biomass across the following U.S. Pacific island regions: Northwestern Hawaiian Islands (NWHI), main Hawaiian Islands (MHI), the Mariana Archipelago, Pacific Remote Islands Marine National Monument (PRIMNM), 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 contain 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 (2009–2019) was recorded in the Pacific Remote Islands Marine National Monument (mean ± standard error: 130.5 ± 4.9 g m^{-2}), followed in decreasing order by the Northwestern Hawaiian Islands (116.1 ± 5.0 g m^{-2}), the Northern Mariana Archipelago (70.2 ± 4.1 g m^{-2}), American Samoa (47.3 ± 1.4 g m^{-2}), the main Hawaiian Islands (29.9 ± 1.0 g m^{-2}), and the Southern Mariana Archipelago (19.1 ± 0.8 g m^{-2}; Figure 5: All fishes). Fish biomass is summarized by consumer group and size class in Figures 5 and 6 and Table 2. The regional mean (± standard error) values for total fish biomass and biomass per size class that are reported in this section are plotted as reference points for visual comparison in the following Region and island status and trends section.

Consumer groups

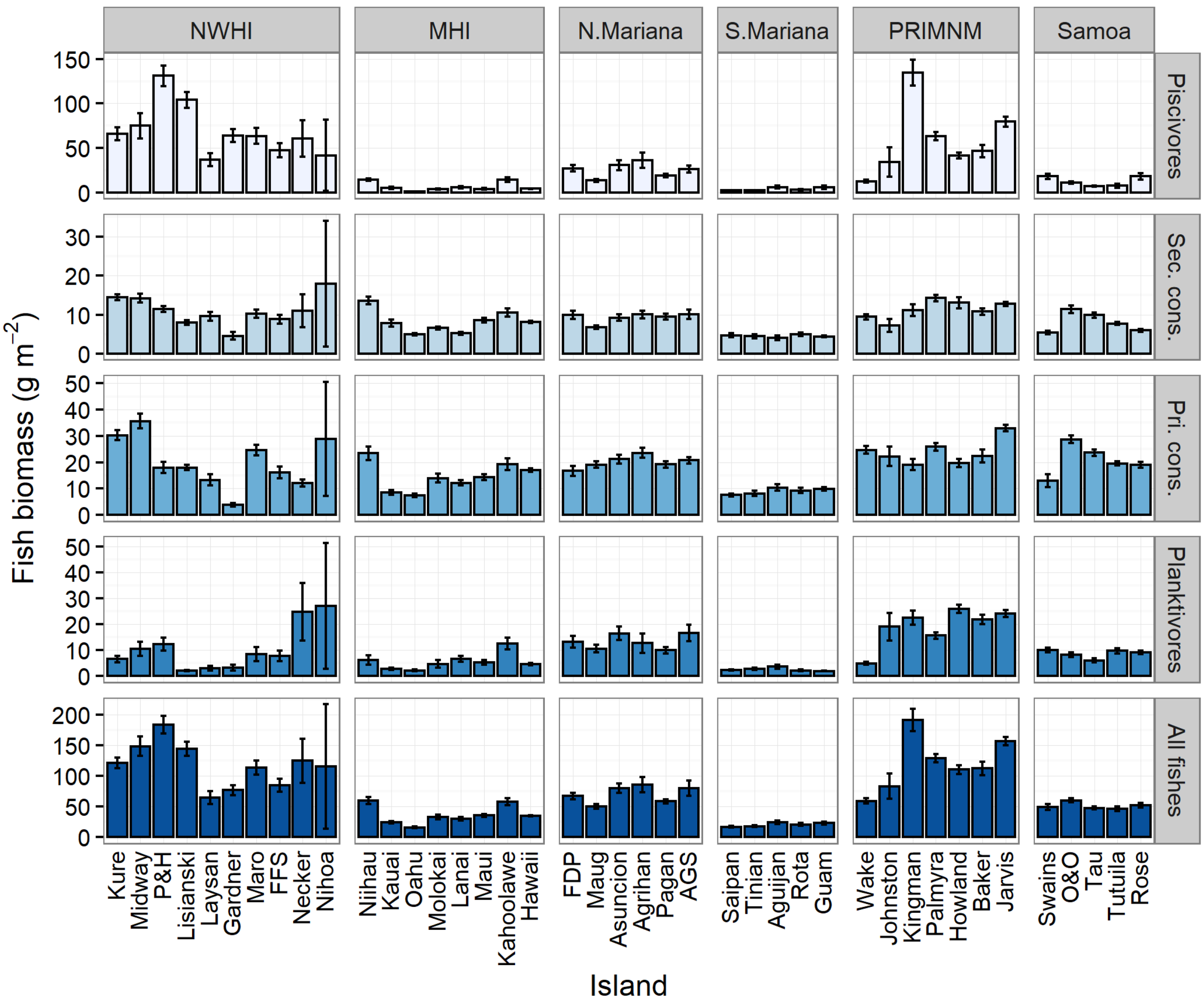

Figure 5. Fish biomass by consumer group per U.S. Pacific reef area. Mean fish biomass (± standard error) per consumer group per reef area pooled across survey years (2009–2019). Islands are ordered within region by latitude See Appendix 4 and Appendix 6 for the sampling density per strata at each island by year. NWHI = Northwestern Hawaiian Islands, MHI = main Hawaiian Islands, N. Mariana = Northern Mariana Archipelago, S. Mariana = Southern Mariana Archipelago, PRINMN = Pacific Remote Islands Marine National Monument, Samoa = American Samoa, Sec. cons. = secondary consumers (omnivores and invertivores), Pri. cons. = primary consumers (herbivores), P&H = Pearl and Hermes, FFS = French Frigate Shoals, FDP = Farallon de Pajaros, AGS = Alamagan, Guguan, and Sarigan islands, O&O = Ofu and Olosega islands.

Size classes

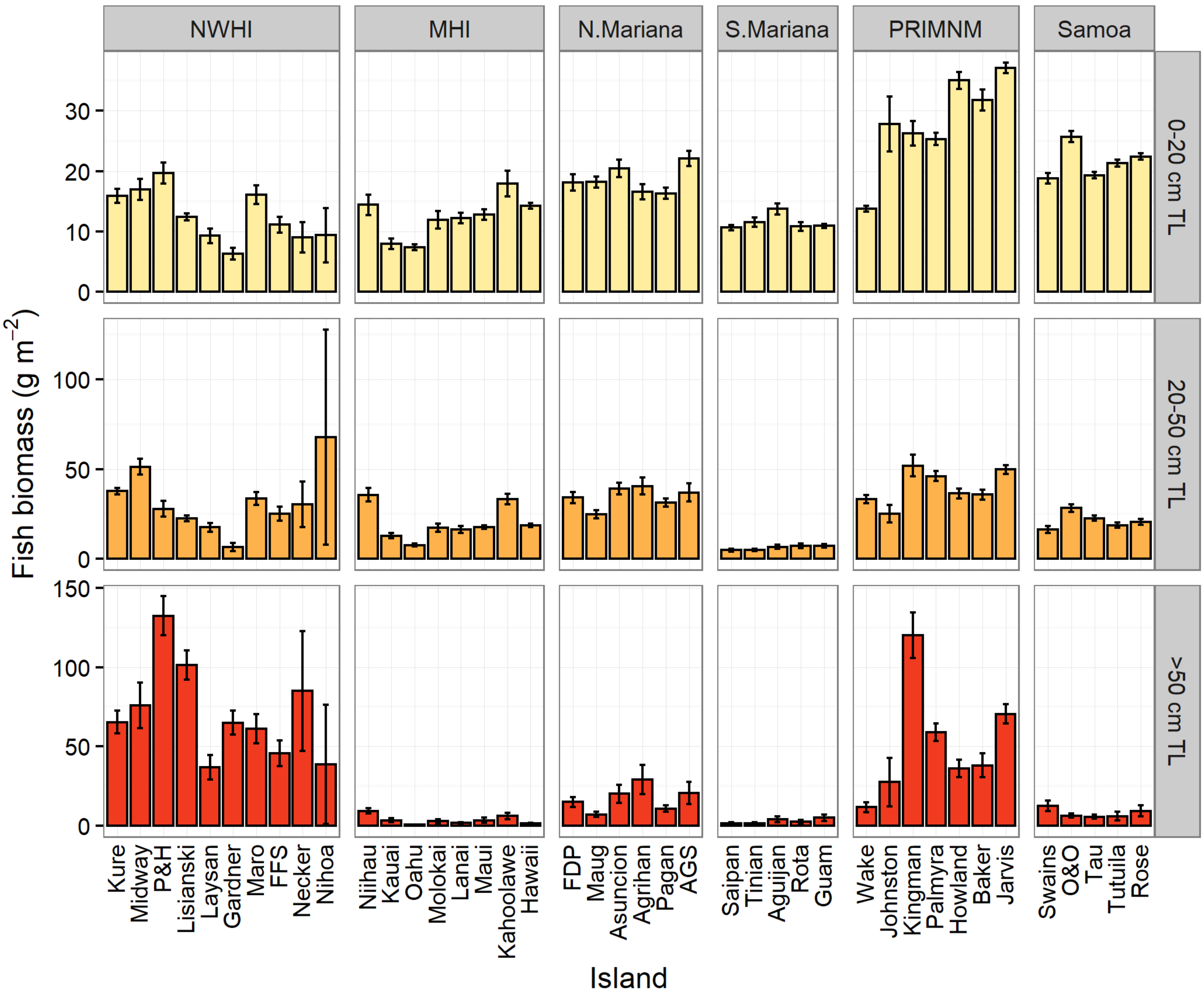

Figure 6. Fish biomass per size class per U.S. Pacific reef area. Mean fish biomass (± standard error) per size class (0–20, 20–50, and >50 cm total length (TL)) per reef area are pooled across survey years (2009–2019). Islands are ordered within region by latitude. See Appendix 4 and Appendix 6 for the sampling density per strata at each island by year. NWHI = Northwestern Hawaiian Islands, MHI = main Hawaiian Islands, N. Mariana = Northern Mariana Archipelago, S. Mariana = Southern Mariana Archipelago, PRINMN = Pacific Remote Islands Marine National Monument, Samoa = American Samoa, P&H = Pearl and Hermes, FFS = French Frigate Shoals, FDP = Farallon de Pajaros, AGS = Alamagan, Guguan, and Sarigan islands, O&O = Ofu and Olosega islands.

Table 2. Mean fish biomass (2009–2019) with standard error in parentheses for all fishes, consumer groups and per size classes surveyed in forereef habitat only. NWHI = Northwestern Hawaiian Islands, MHI = main Hawaiian Islands, N. Mariana = Northern Mariana Archipelago, S. Mariana = Southern Mariana Archipelago, PRIMNM = Pacific Remote Islands Marine National Monument, Samoa = American Samoa, Sec. consumers = secondary consumers (omnivores and invertivores), Pri. consumers = primary consumers (herbivores), TL = total length.

Region	Sites	All fishes	Piscivores	Sec. consumers	Pri. consumers	Planktivores	0–20 cm TL	20–50 cm TL	>50 cm TL
NWHI	775	116.1 (5.0)	78.8 (4.0)	8.3 (0.4)	16 (0.6)	5.6 (0.7)	12 (0.5)	21.7 (1.1)	78.7 (4.3)
MHI	1449	29.9 (1.0)	4.8 (0.3)	7.5 (0.2)	12.5 (0.4)	4 (0.3)	10.7 (0.4)	15.9 (0.6)	2.8 (0.4)
N. Mariana	535	70.2 (4.1)	25.1 (2.3)	9.5 (0.4)	20.5 (0.7)	12.4 (1.2)	17.9 (0.5)	33.8 (1.5)	17.4 (2.7)
S. Mariana	666	19.1 (0.8)	3.5 (0.5)	4.5 (0.2)	8.5 (0.4)	2.2 (0.1)	10.9 (0.2)	5.6 (0.4)	2.5 (0.5)
PRIMNM	895	130.5 (4.9)	66.4 (3.4)	12.7 (0.5)	24.7 (0.9)	17.6 (0.9)	26.3 (0.7)	41.2 (1.5)	60.5 (3.8)
Samoa	1119	47.3 (1.4)	8.0 (0.6)	8.4 (0.3)	21.2 (0.5)	8.4 (0.5)	21.3 (0.4)	20.2 (0.8)	5.3 (0.8)

Region and island status and trends

This section summarizes SPC data collected at each island between 2010 and 2019, when comparable methods were used. For each island within a region, maps illustrate the SPC site-level data from 2015–2019 (2007–2012 site locations can be found in earlier reports, but are not shown in this report to prevent overcrowding of the maps), and a standard set of graphs shows summary information on the fish and benthic community at the habitat and island scale for each year-grouping, starting with 2010. On each fish biomass graph for the forereef habitat, a reference line indicates the region-wide mean estimate across all surveyed years, provided as a relevant regional comparison for island-level estimates. Fish biomass estimates are shown for each year surveyed of all fish, parrotfish in two size classes, and by consumer group. Total fish, consumer group and parrotfish biomass are core NCRMP indicators (NOAA NCRMP 2014). Large parrotfishes are believed to be important grazers, so parrotfish biomass is separately reported for two size groups: large (>30 cm TL) and small (10–30 cm TL) fishes. Mean size per island and year is also reported, as mean size can be a useful indicator of fishing pressure; fishes smaller than 10 cm are excluded from that to reduce noise from variable levels of recent recruitment.

Main Hawaiian Islands (MHI)

Hawai‘i Island

SPC surveys were conducted in Hawai‘i Island in 2010 (n = 43), 2013 (n = 58), 2015 (n = 97), 2016 (n = 59), and 2019 (n = 73).

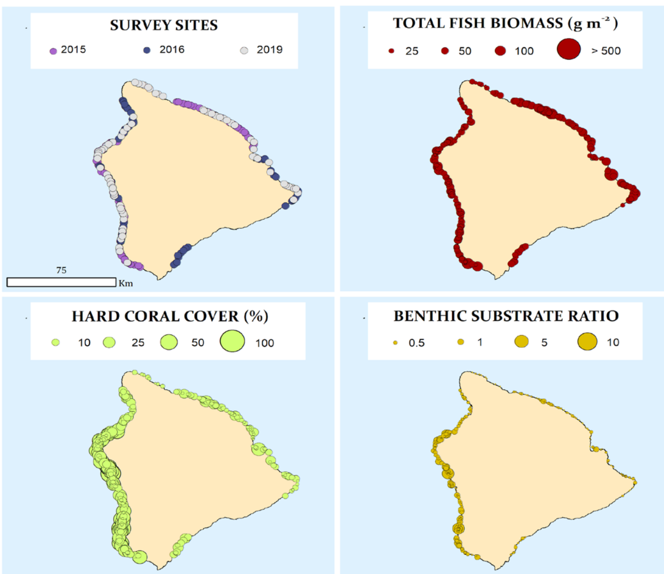

Figure 7. Hawai‘i Island site survey data for 2015, 2016, and 2019. Site location identified by year, total fish biomass recorded at each site, hard coral cover (%) assessed by rapid visual assessment, and benthic substrate ratio [hard coral + crustose coralline algae ⁄ (100 − hard coral + crustose coralline + sand)].

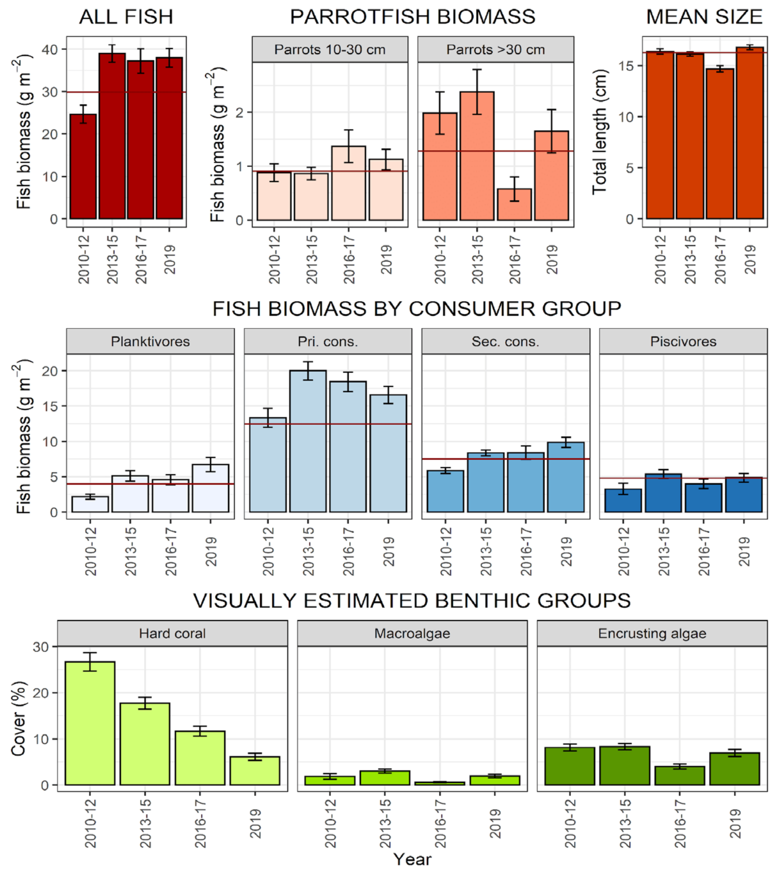

Figure 8. Hawai‘i Island fish and benthic plots. Biomass (g m^{-2} ± SE) of all fishes observed, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The MHI region mean estimates of fish biomass are plotted for reference (red line).

Kahoʻolawe Island

Kahoʻolawe Island was surveyed in 2016 (n = 24), and 2019 (n = 20). Prior years did not include surveys of Kahoʻolawe due to safety hazards that were mitigated in 2016. This island is an important reference in the MHI as it provides an unpopulated reference for the surrounding populated islands.

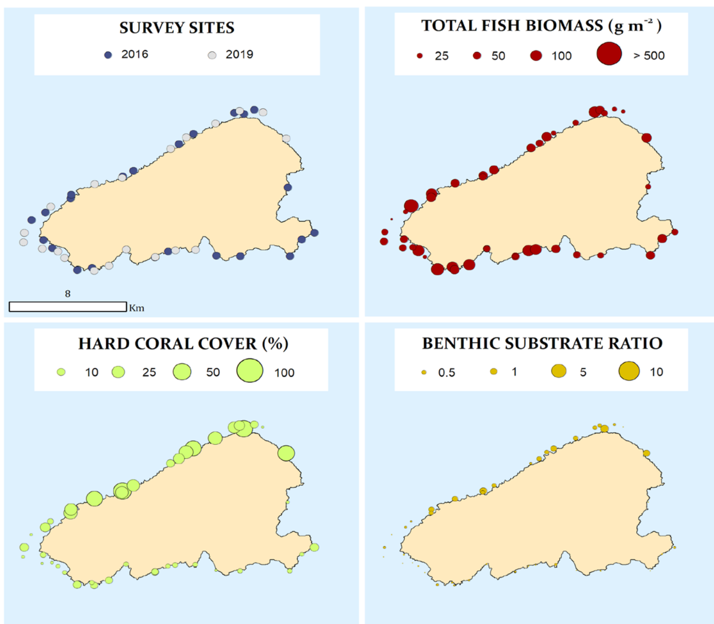

Figure 9. Kahoʻolawe Island site survey data. Kahoʻolawe Island site survey data.

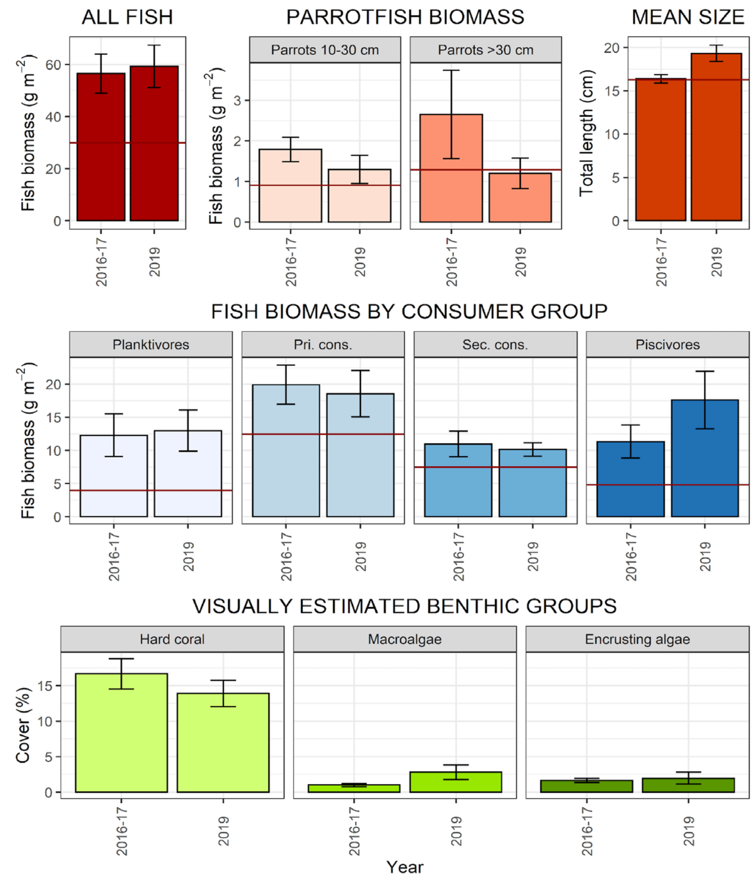

Figure 10. Kahoʻolawe Island fish and benthic plots. Biomass (g m^{-2} ± SE) of all fishes observed, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The MHI region mean estimates of fish biomass are plotted for reference (red line).

Kaua'i Island

Kaua'i Island was surveyed in 2010 (n = 26), 2013 (n = 37), 2015 (n = 20), 2016 (n = 30), and 2019 (n = 22).

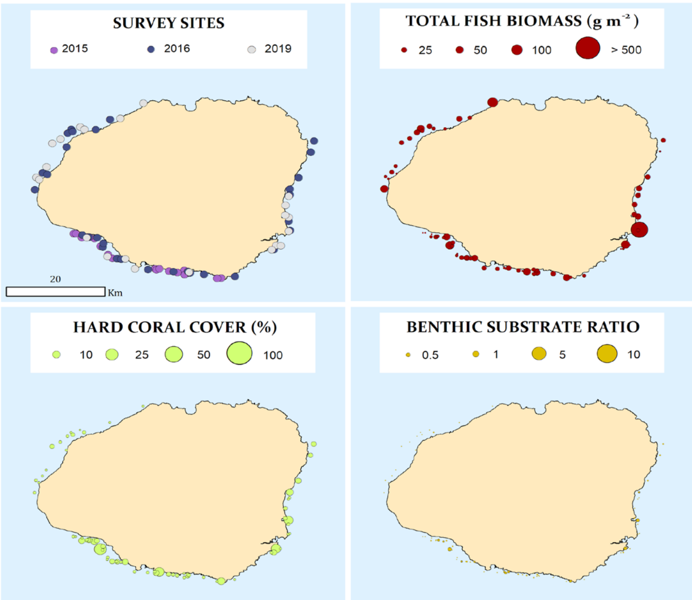

Figure 11. Kaua'i Island site survey data for 2015, 2016, and 2019. Site location identified by year, total fish biomass recorded at each site, hard coral cover (%) assessed by rapid visual assessment, and benthic substrate ratio [hard coral + crustose coralline algae ⁄ (100 − hard coral + crustose coralline + sand)].

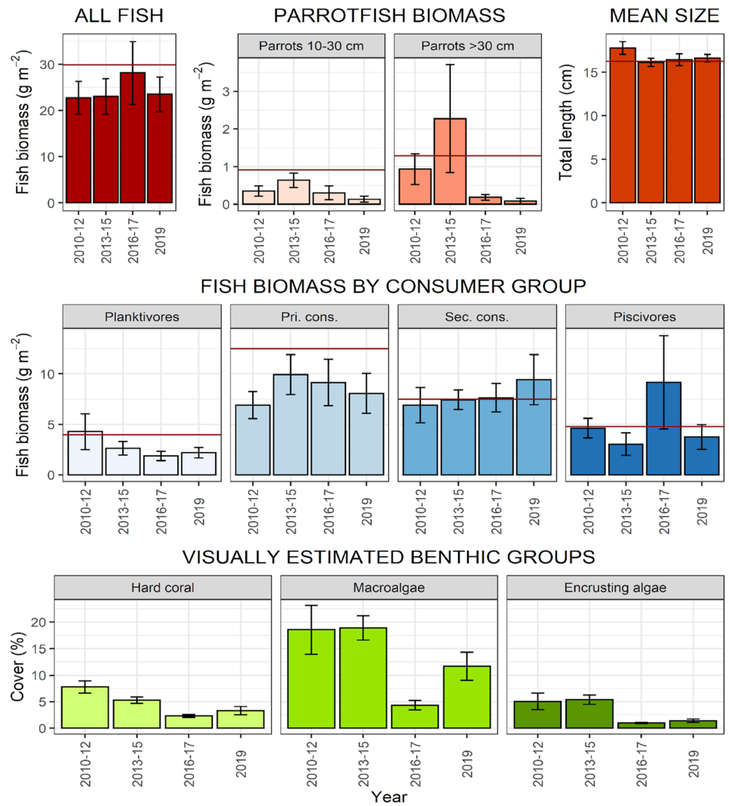

Figure 12. Kaua'i Island fish and benthic plots. Biomass (g m^{-2} ± SE) of all fishes observed, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The MHI region mean estimates of fish biomass are plotted for reference (red line).

Lana'i Island

Lana'i Island was surveyed in in 2010 (n = 16), 2012 (n = 29), 2013 (n = 29), 2015 (n = 15), 2016 (n = 26), and 2019 (n = 27).

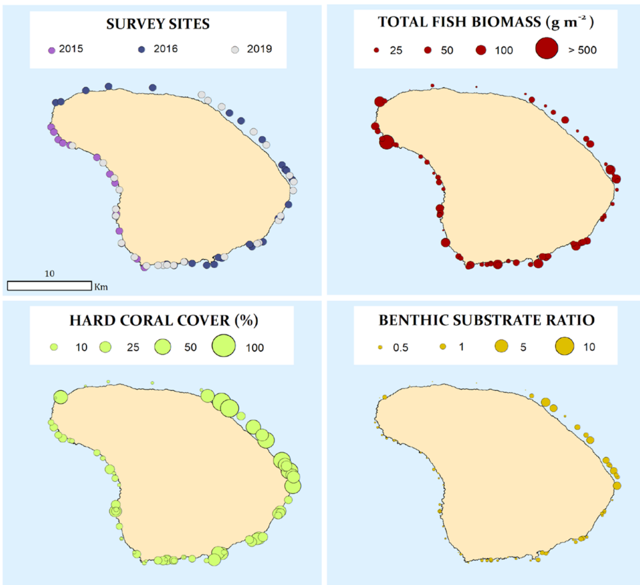

Figure 13. Lana'i Island site survey data for 2015, 2016, and 2019. Site location identified by year, total fish biomass recorded at each site, hard coral cover (%) assessed by rapid visual assessment, and benthic substrate ratio [hard coral + crustose coralline algae / (100 − hard coral + crustose coralline + sand)].

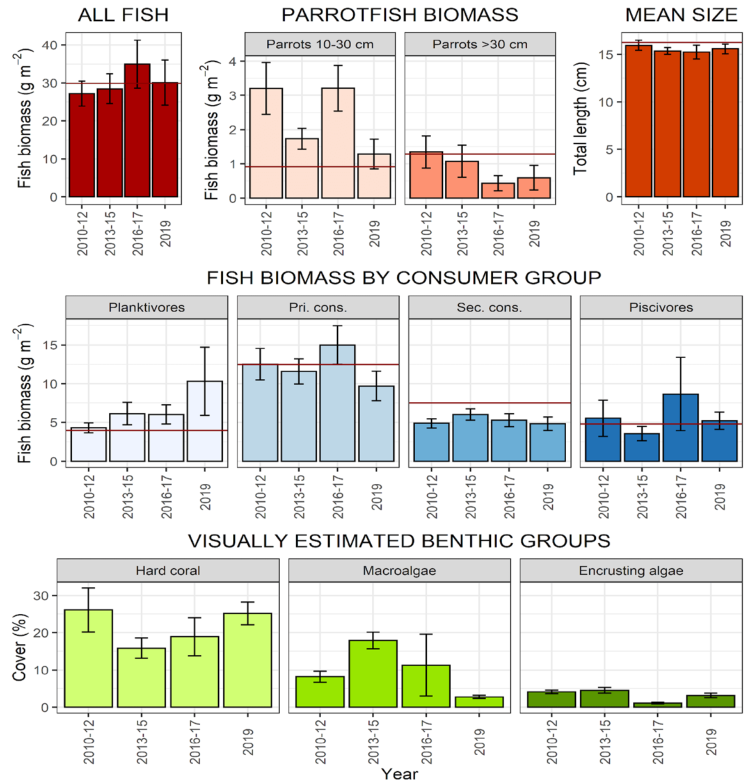

Figure 14. Lana'i Island fish and benthic plots. Biomass (g m^{-2} ± SE) of all fishes observed, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The MHI region mean estimates of fish biomass are plotted for reference (red line).

Maui Island

Maui Island was surveyed in 2010 (n = 33), 2012 (n = 49), 2013 (n = 34), 2015 (n = 30), 2016 (n = 28), and 2019 (n = 42).

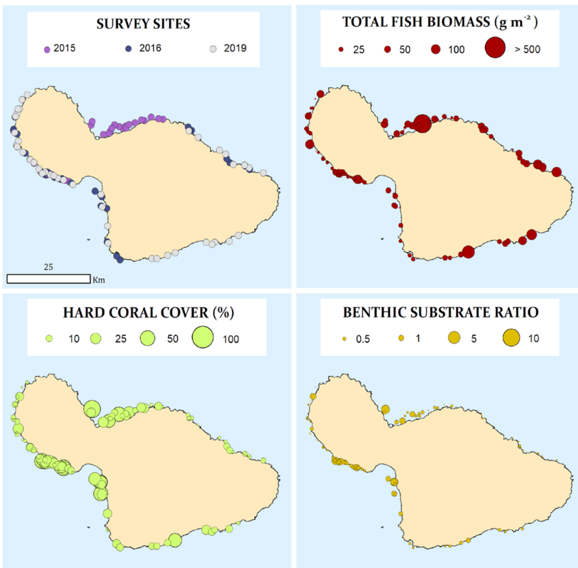

Figure 15. Maui Island site survey data for 2015, 2016, and 2019. Site location identified by year, total fish biomass recorded at each site, hard coral cover (%) assessed by rapid visual assessment, and benthic substrate ratio [hard coral + crustose coralline algae / (100 − hard coral + crustose coralline + sand)].

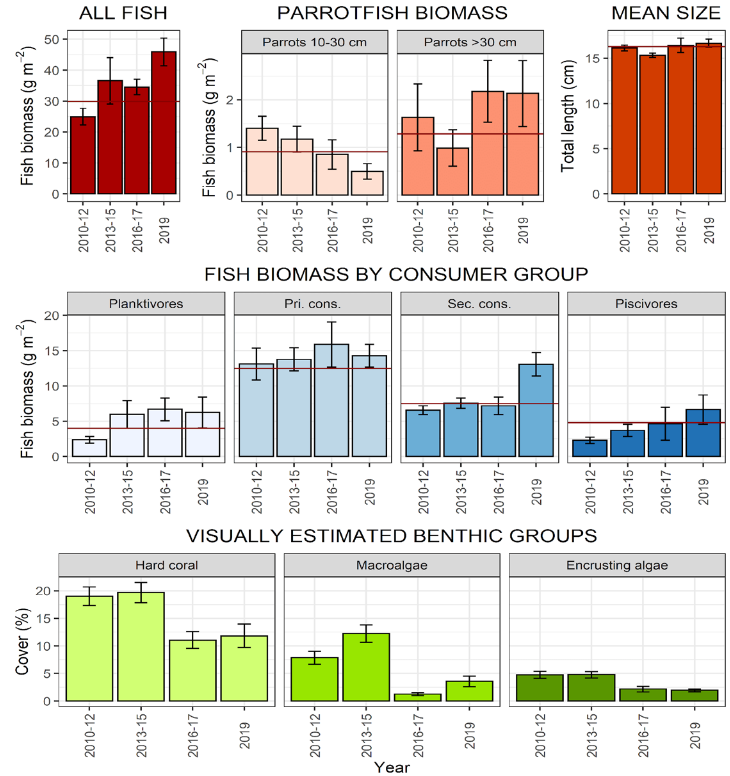

Figure 16. Maui Island fish and benthic plots. Biomass ($g\ m^{-2} \pm SE$) of all fishes observed, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The MHI region mean estimates of fish biomass are plotted for reference (red line).

Molokaʻi Island

Molokaʻi Island was surveyed in 2010 (n = 10), 2012 (n = 50), 2013 (n = 39), 2015 (n = 48), 2016 (n = 23), and 2019 (n = 41).

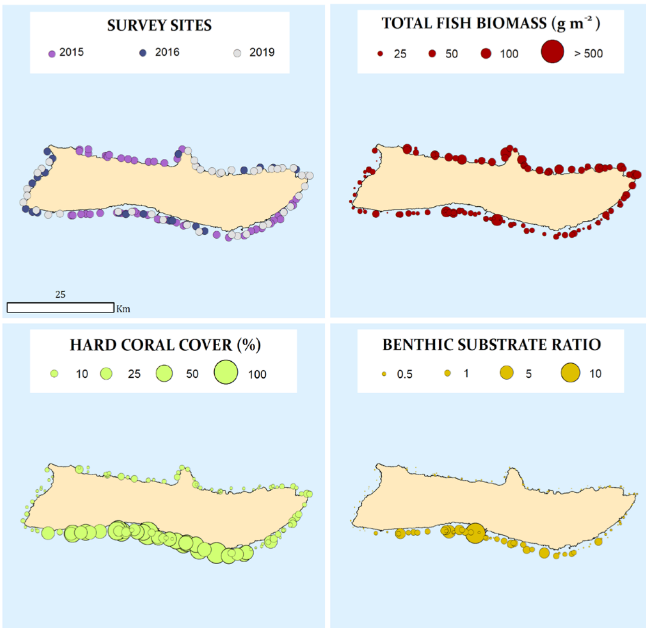

Figure 17. Molokaʻi Island site survey data for 2015, 2016, and 2019. Site location identified by year, total fish biomass recorded at each site, hard coral cover (%) assessed by rapid visual assessment, and benthic substrate ratio [hard coral + crustose coralline algae ⁄ (100 − hard coral + crustose coralline + sand)].

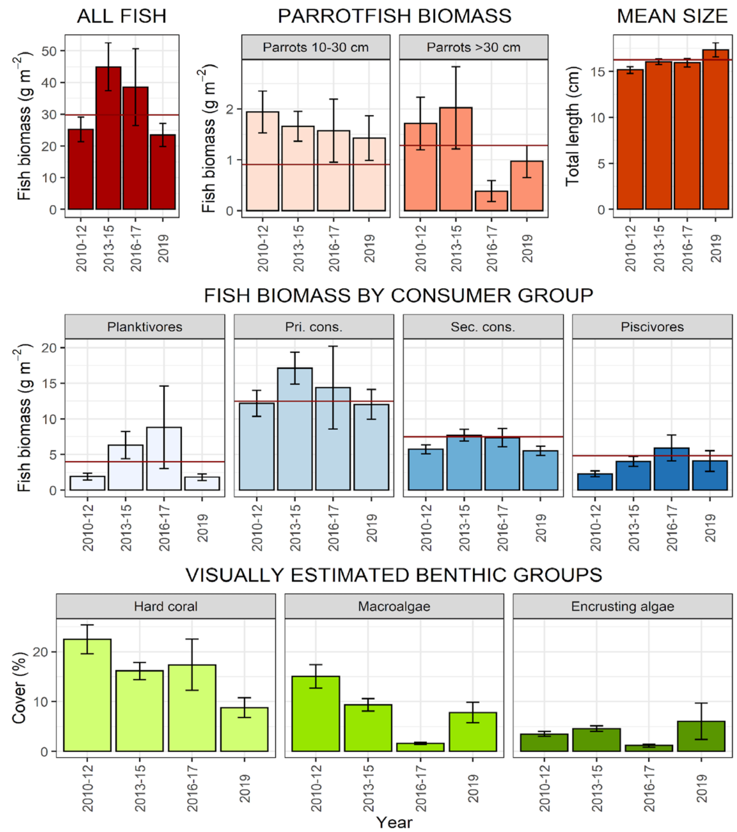

Figure 18. Molokaʻi Island fish and benthic plots. Biomass (g m^{-2} ± SE) of all fishes observed, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The MHI region mean estimates of fish biomass are plotted for reference (red line).

Ni‘ihau Island

Ni‘ihau Island was surveyed in 2010 (n = 16), 2013 (n = 26), 2015 (n = 49), 2016 (n = 12), and 2019 (n = 17).

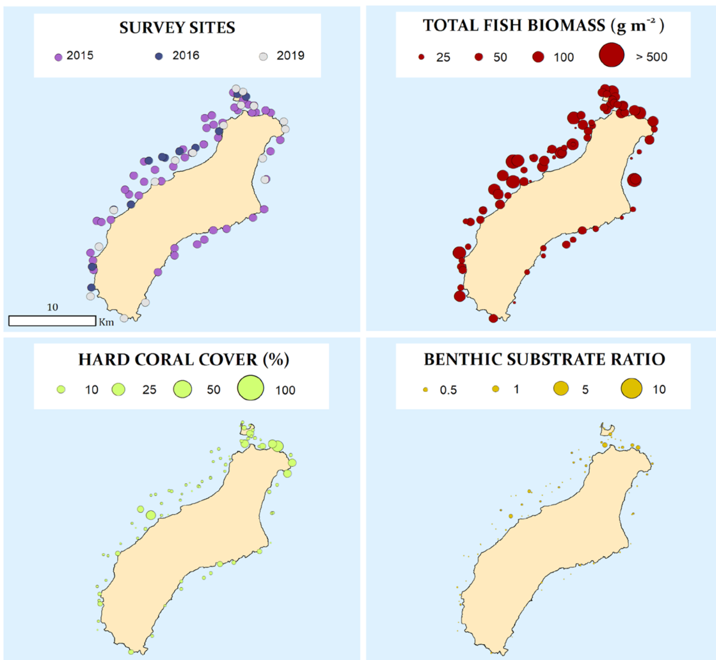

Figure 19. Ni‘ihau Island site survey data for 2015, 2016, and 2019. Site location identified by year, total fish biomass recorded at each site, hard coral cover (%) assessed by rapid visual assessment, and benthic substrate ratio [hard coral + crustose coralline algae / (100 − hard coral + crustose coralline + sand)].

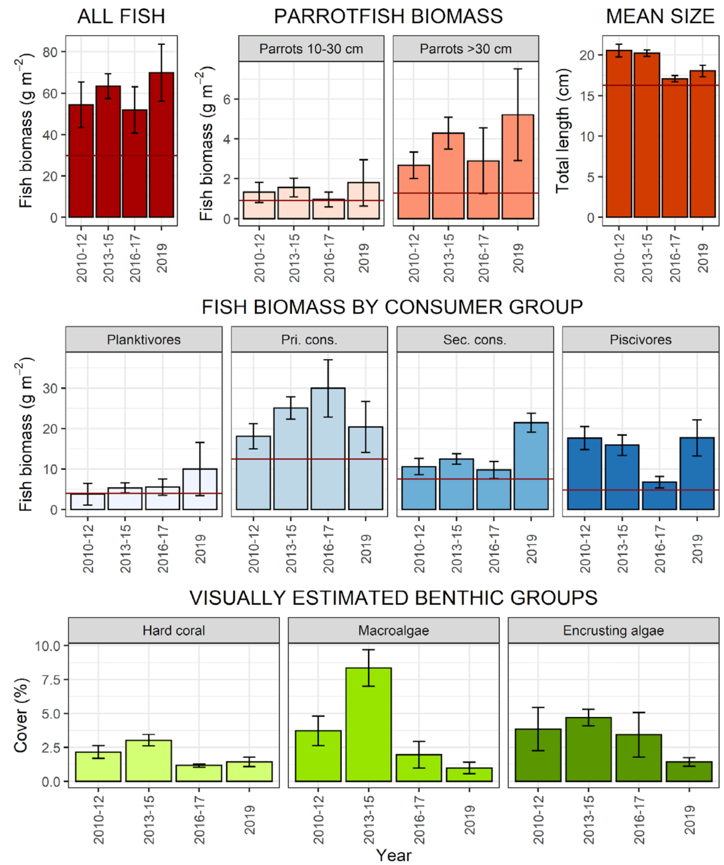

Figure 20. Ni‘ihau Island fish and benthic plots. Biomass (g m^{-2} ± SE) of all fishes observed, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The MHI region mean estimates of fish biomass are plotted for reference (red line).

O‘ahu Island

O‘ahu Island was surveyed in 2010 (n = 40), 2012 (n = 35), 2013 (n = 64), 2015 (n = 35), 2016 (n = 54), and 2019 (n = 50).

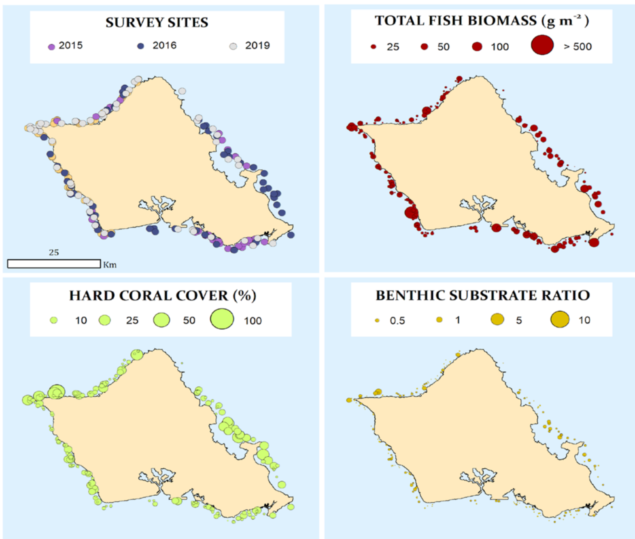

Figure 21. O‘ahu Island site survey data for 2015, 2016, and 2019. Site location identified by year, total fish biomass recorded at each site, hard coral cover (%) assessed by rapid visual assessment, and benthic substrate ratio [hard coral + crustose coralline algae ∕ (100 − hard coral + crustose coralline + sand)].

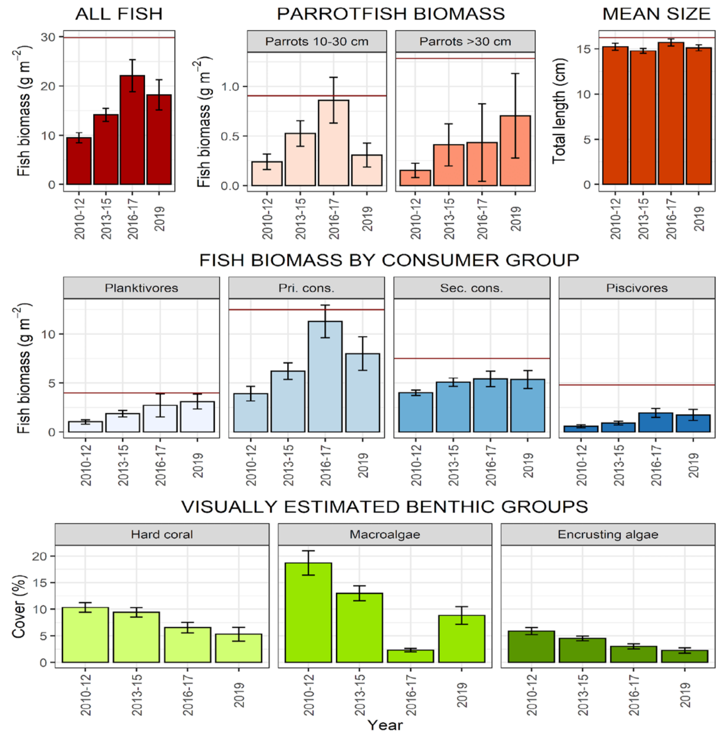

Figure 22. O‘ahu Island fish and benthic plots. Biomass (g m^{-2} ± SE) of all fishes observed, per parrotfish size class (top) and per consumer group (middle), as well as mean size (TL cm, top) and the percentage cover (± SE) of the benthos. The MHI region mean estimates of fish biomass are plotted for reference (red line).

Publications, information products, and data requests 2019

The following products published in 2019 were produced using biological data collected during Pacific RAMP and related monitoring surveys.

Blogs

Sea Tales: Monitoring Coral Reef Ecosystems throughout the Hawaiian Archipelago. https://www.fisheries.noaa.gov/science-blog/sea-tales-monitoring-coral-reef-ecosystems-throughout-hawaiian-archipelago

Reports

Gove JM, Lecky J, Walsh WJ, Ingram RJ, Leong K, Williams I, Polovina J, Maynard J, Whittier R, Kramer L, et al. 2019. West Hawaiʻi integrated ecosystem assessment ecosystem status report. Pacific Islands Fisheries Science Center, PIFSC Special Publication, SP-19-001, 46 p. https://doi.org/10.25923/t3cc-2361.

McCoy K, Asher J, Ayotte P, Gray A, Lino K, Kindinger T, Williams I. 2019. Pacific Reef Assessment and Monitoring Program, data report: ecological monitoring 2018—reef fishes and benthic habitats of the Pacific Remote Islands Marine National Monument and American Samoa. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-19-008, 46 p. https://doi.org/10.25923/0rg6-y073.

Nadon MO. 2019. Stock Assessment of Guam Coral Reef Fish. 2019. 2019. U.S. Dept. of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-82, 107 p. https://doi.org/10.25923/pyd6-7k49.

Scientific publications

Jouffray J-B, Wedding LM, Norstrom AV, Donovan MK, Williams GJ, Crowder LB, Erickson AL, Friedlander AM, Graham NAJ, Gove JM, Kappel CV, Kittinger JN, Lecky J, Oleson KLL, Selkoe KA, White C, Williams ID, Nystrom M. 2019. Parsing human and biophysical drivers of coral reef regimes. Proceedings of the Royal Society B: Biological Sciences. 286:1896. https://doi.org/10.1098/rspb.2018.2544. https://doi.org/10.1098/rspb.2018.2544.

Williams ID, Couch C, Beijbom O, Oliver T, Vargas-Angel B, Schumacher B, Brainard R. 2019. Leveraging automated image analysis tools to transform our capacity to assess status and trends on coral reefs. Frontiers in Marine Science. https://doi.org/10.3389/fmars.2019.00222.

Vargas-Ángel B, Huntington B, Brainard RE, Venegas R, Oliver T, Barkley H, et al. 2019. El Niño-associated catastrophic coral mortality at Jarvis Island, central Equatorial Pacific. Coral Reefs. https://doi.org/10.1007/s00338-019-01838-0.

Weijerman M, Grüss A, Dove D, Asher J, Williams I, Kelley C, et al. 2019. Shining a light on the composition and distribution patterns of mesophotic and subphotic fish communities in Hawai‘i. Mar Ecol Prog Ser. https://doi.org/10.3354/meps13135.

Chung AE, Wedding LM, Meadows A, Moritsch MM, Donovan MK, Gove J, et al. 2019. Prioritizing reef resilience through spatial planning following a mass coral bleaching event. Coral Reefs 38: 837–850. https://doi.org/10.1007/s00338-019-01812-w.

Darling ES, McClanahan TR, Maina J, Gurney GG., Graham NAJ, Januchowski-Hartley F, et al. 2019. Social–environmental drivers inform strategic management of coral reefs in the Anthropocene. Nat Ecol Evol. https://doi.org/10.1038/s41559-019-0953-8.

McClanahan T, Schroeder R, Friedlander A, Vigliola L, Wantiez L, Caselle J, et al. 2019. Global baselines and benchmarks for fish biomass: comparing remote reefs and fisheries closures. Mar Ecol Prog Ser, 612, 167–192. https://doi.org/10.3354/meps12874.

Chung AE, Wedding LM, Green AL, Friedlander AM, Goldberg G, Meadows A, et al. 2019. Building Coral Reef Resilience through Spatial Herbivore Management. Front Mar Sci 6. https://doi.org/10.3389/fmars.2019.00098.

Fish and benthic data requests

In 2019: 14 requests.

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Kulbicki M, Guillemot N, Amand M. 2005. A general approach to length-weight relationships for New Caledonian lagoon fishes. Cybium, 29(3): 235–252.

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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 Benthic percent cover Benthic key species (presence/absence) Rugosity	Paired 18-m coral demographic transects Paired 15-m photoquadrat transects 2000 × 10 m towed-diver survey	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.
Fish	Fish abundance, size, and species Fish key species	Paired 15-m-diameter stationary point count (SPC) surveys ~2000 × 10 m^2 towed-diver survey		

Appendix 2: Surveys per region per year and method used

Table A2-1. The number of belt transect and SPC sites surveyed per region per year. From 2000 to 2006 the belt transect method was used to survey coral reef fishes. During the calibration period that took place from 2006–2008, surveys were conducted using both the belt and the stationary point count (SPC) method. The SPC data collected prior to 2009 are 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	2000-2005	2006-2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Region Method	**Belt**	**Belt & SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**	**SPC**
N. Mariana	80	36	135	-	135	-	-	148	-	-	159	-	-
S. Mariana	59	60	116	-	219	-	-	198	-	-	172	-	-
Main HI	73	243	-	184	-	163	287	-	294	257	-	-	292
NWHI*	298	366	203	118	141	91	-	89	96	182	92	-	-
PRIMNM	125	272	42	179	30	231	-	45	291	30	81	190	-
Am. Samoa	100	283	-	241	-	223	-	-	339	185	-	185	-

Appendix 3: Sector maps

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 A3-1).

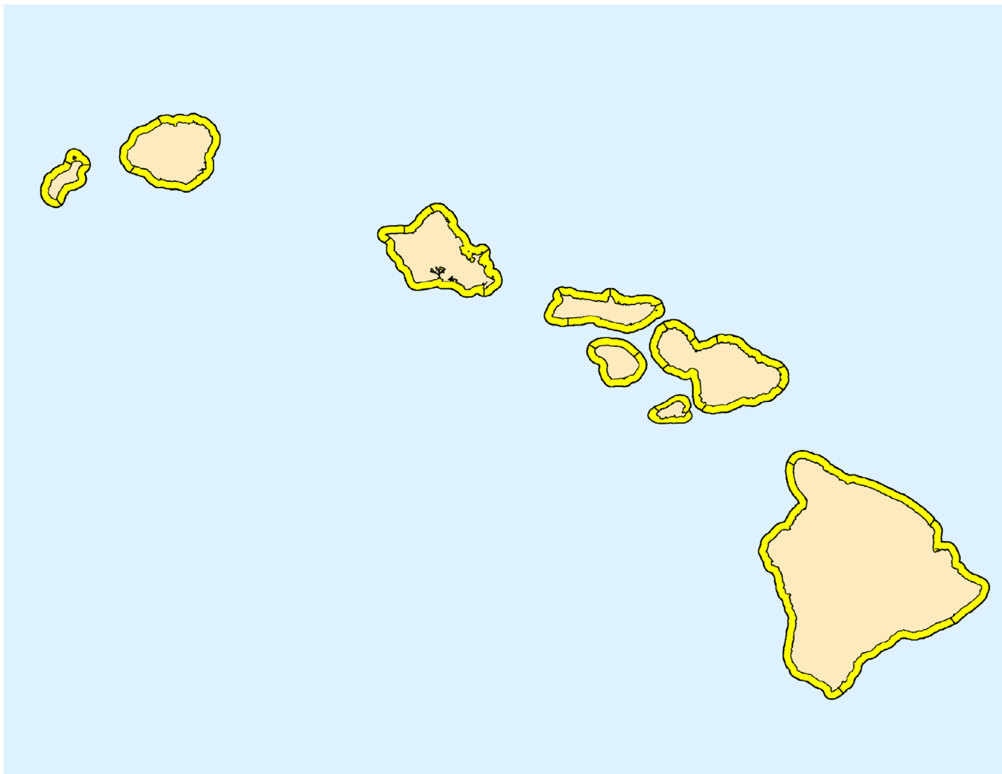

Figure A3-1. The sectors of the main Hawaiian Islands. Sectors are broadly based on wave exposure, habitat complexity and local human population density.

Appendix 4: Samples per sector and strata in 2019

Table A4-1. The number of sites surveyed per depth strata and the sector used to pool 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 the main Hawaiian Islands, islands are broken down into smaller sectors. D = deep (>18–30 m), M = mid (>6–18 m), S = shallow (>0–6 m).

Island	Sector	Forereef-D	Forereef-M	Forereef-S
Hawaii	HAW_HAMAKUA	6	9	4
Hawaii	HAW_KONA	6	23	8
Hawaii	HAW_PUNA	7	6	4
Kahoolawe	KAH_NORTH	2	3	3
Kahoolawe	KAH_SOUTH	4	6	2
Kauai	KAU_EAST	4	7	2
Kauai	KAU_NAPALI	3	4	2
Lanai	LAN_NORTH	1	3	1
Lanai	LAN_SOUTH	6	9	7
Maui	MAI_KIHEI	3	4	5
Maui	MAI_LAHAINA	6	3	4
Maui	MAI_NE	3	3	2
Maui	MAI_SE	3	5	1
Molokai	MOL_PALI	6	6	5
Molokai	MOL_SOUTH	1	7	7
Molokai	MOL_WEST	3	4	2
Niihau	NII_EAST	2	1	0
Niihau	NII_LEHUA	2	4	1
Niihau	NII_WEST	2	4	1
Oahu	OAH_EAST	0	1	0
Oahu	OAH_KAENA	4	2	4
Oahu	OAH_NE	3	5	1
Oahu	OAH_NORTH	2	6	3
Oahu	OAH_SOUTH	4	6	9

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 areas. However, if there is no consistent bias in the estimates made by a diver, one would expect the median value of their performance to be close to zero i.e., with estimates in half of the counts being higher than their partner's estimates and half of the counts lower than their partner's estimates. Boxplots of diver performance, therefore, give (1) a strong but general indication of relative bias; if there is no consistent bias, then the median differences between a single diver and their dive partners will be close to zero and (2) an indication of how variable each diver's counts are compared to their dive partners—if a particular diver's performance varies widely compared to their partner's (i.e., several very high and/or several very low counts) that may indicate variability in their performances. 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 Main Hawaiian Islands 2019).

Main Hawaiian Islands 2019

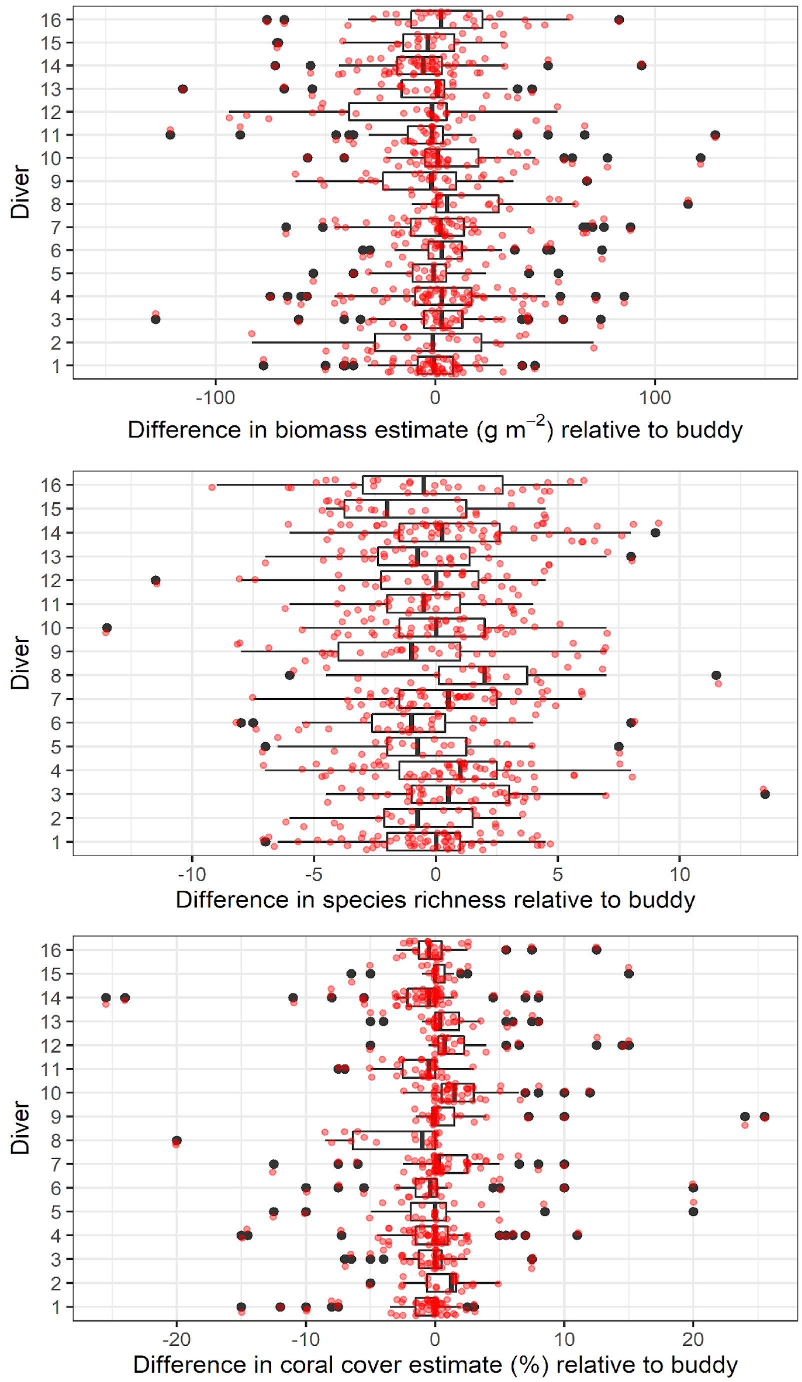

Figure A5-1. Main Hawaiian Islands comparison of observer diver vs diver partner estimates for total fish biomass, species richness, and hard coral cover during 2019 surveys. The boxplot shows the median difference (thick vertical line) in estimates for each diver. The box represents the location of 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).

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

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

Region	Island	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Northwestern HI	Kure	43	25	-	20	-	-	8	39	6	-	-	141
Northwestern HI	Midway	53	-	30		-	34	14	-	10	-	-	141
Northwestern HI	Pearl & Hermes	-	41	18	31	-	-	23	56	20	-	-	189
Northwestern HI	Lisianski	19	25	9	25	-	28	18	40	17	-	-	181
Northwestern HI	Laysan	14	-	23	-	-	-	8	-	11	-	-	56
Northwestern HI	Gardner	-	-	12	-	-	-	-	-	-	-	-	12
Northwestern HI	Maro	39	-	25	-	-	-	17	-		-	-	81
Northwestern HI	French Frigate	-	27	8	15	-	27	8	47	28	-	-	160
Northwestern HI	Necker	13	-	8	-	-	-	-	-	-	-	-	21
Northwestern HI	Nihoa	-	-	8	-	-	-	-	-	-	-	-	8
Main HI	Ni‘ihau	-	16	-	-	26	-	49	12	-	-	17	120
Main HI	Kaua‘i	-	26	-	-	37	-	20	30	-	-	22	135
Main HI	O‘ahu	-	40	-	35	64	-	35	54	-	-	50	278
Main HI	Moloka‘i	-	10	-	50	39	-	48	23	-	-	41	211
Main HI	Lana‘i	-	16	-	29	29	-	15	26	-	-	27	142
Main HI	Maui	-	33	-	49	34	-	30	29	-	-	42	216
Main HI	Kaho‘olawe	-	-	-	-	-	-	-	24	-	-	20	44
Main HI	Hawai‘i	-	43	-	-	58	-	97	24	-	-	73	330
N. Mariana	Farallon de Pajaros	7	-	12	-	-	11	-	59	16	-	-	46
N. Mariana	Maug	21	-	30	-	-	40	-	-	38	-	-	129
N. Mariana	Asuncion	13	-	20	-	-	21	-	-	19	-	-	73
N. Mariana	Agrihan	14	-	20	-	-		-	-	19	-	-	53
N. Mariana	Pagan	21	-	29	-	-	43	-	-	40	-	-	133
N. Mariana	AGS	19	-	24	-	-	33	-	-	27	-	-	103
S. Mariana	Saipan	23	-	30	-	-	48	-	-	37	-	-	138
S. Mariana	Tinian	14	-	19	-	-	19	-	-	24	-	-	76
S. Mariana	Aguijan	6	-	13	-	-	10	-	-	17	-	-	46
S. Mariana	Rota	14	-	24	-	-	28	-	-	28	-	-	94
S. Mariana	Guam	25	-	133	-	-	104	-	-	66	-	-	328
PRIMNM	Wake	29	-	30	-	-	45	-	-	53	-	-	157
PRIMNM	Johnston	-	39	-	35	-	-	31	-	-	-	-	105
PRIMNM	Kingman	-	33	-	49	-	-	49	-	-	40	-	171
PRIMNM	Palmyra	-	40	-	42	-	-	78	-	-	50	-	210
PRIMNM	Howland	-	16	-	39	-	-	35	-	-	29	-	119
PRIMNM	Baker	-	21	-	24	-	-	36	-	-	32	-	113
PRIMNM	Jarvis	-	30	-	42	-	-	62	30	28	39	-	231
Am.Samoa	Swains	-	24	-	38	-	-	32	-	-	30	-	124

Region	Island	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Am.Samoa	Ofu & Olosega	-	30	-	30	-	-	52	11	-	25	-	148
Am.Samoa	Tau	-	24	-	22	-	-	46	50	-	28	-	170
Am.Samoa	Tutuila	-	127	-	85	-	-	162	77	-	81	-	531
Am.Samoa	Rose	-	34	-	48	-	-	47	47	-	21	-	197

Contact us

We are committed to providing ecological monitoring information that is transparent, readily accessible and relevant to the sound management of coral reef resources. For data requests contact: nmfs.pic.credinfo@noaa.gov

Users of this data report, we would welcome your comments on how to improve the utility of this document for future versions. Comments or suggestions on the content of this annual data report may be submitted to nmfs.pic.credinfo@noaa.gov with the subject line addressed: For the Attention of the Fish Team Lead.