



A Cooperative Multiagency Reef Fish Monitoring Protocol for the Florida and US Virgin Islands Coral Reef Ecosystems

Protocol Narrative Version—2.0



Clockwise from top left: French Angelfish (*Pomacanthus paru*), Queen Triggerfish or Old Wife (*Balistes vetula*), Hogfish (*Lachnolaimus maximus*), a school of Permit (*Trachinotus falcatus*) swimming over divers on Tortugas Bank, Nassau Grouper (*Epinephelus striatus*), Bluehead Wrasse (*Thalassoma bifasciatum*) and in the center a Candy Basslet (*Liopropoma carmabi*)

CLOCKWISE FROM TOP LEFT: UMIAMI / JINGANG LOU, NPS / LEE RICHTER, NPS / ROB WAARA, UMIAMI / JINGANG LUO, NPS / ROB WAARA, UMIAMI / EVAN D'ALESSANDRO, AND IN THE CENTER: NPS / MICHAEL FEELEY

A cooperative multiagency reef fish monitoring protocol for the Florida and US Virgin Islands coral reef ecosystems: Protocol narrative version—2.0

Science Report NPS/SR—2025/327

Michael W. Feeley¹, Marilyn E. Brandt², David R. Bryan², Natalia Zurcher², Alejandro Acosta³, Jerald S. Ault², Jeremiah Blondeau⁴, James A. Bohnsack⁴, Laura Jay W. Grove⁴, Jessica A. Keller³, Vanessa McDonough⁵, Lee Richter¹, Steven G. Smith², Dione W. Swanson⁶

¹ National Park Service
South Florida / Caribbean Network
18001 Old Cutler Road, Suite 419
Palmetto Bay, FL 33157

² University of Miami
Rosenstiel School of Marine, Atmospheric, and Earth Science
4600 Rickenbacker Causeway
Miami, FL 33149

³ Florida Fish and Wildlife Conservation Commission
Fish and Wildlife Research Institute, South Florida Regional Lab
2796 Overseas Highway, Suite 119
Marathon, FL 33050

⁴ National Oceanic and Atmospheric Administration
Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, FL 33149

⁵ Biscayne National Park
9700 SW 328th Street
Homestead, FL 33033

⁶ The Cooperative Institute for Marine and Atmospheric Studies
Rosenstiel School of Marine, Atmospheric, and Earth Science
4600 Rickenbacker Causeway
Miami, FL 33149

Please cite this publication as:

Feeley, M. W., M. E. Brandt, D. R. Bryan, N. Zurcher, A. Acosta, J. S. Ault, J. Blondeau, J. A. Bohnsack, L. J. W. Grove, J. A. Keller, V. McDonough, L. Richter, S. G. Smith, and D. W. Swanson. 2025. A cooperative multiagency reef fish monitoring protocol for the Florida and US Virgin Islands coral reef ecosystems: Protocol narrative version—2.0. Science Report NPS/SR—2025/327. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2310167>

NPS 910/197355, June 2025

The National Park Service Science Report Series disseminates information, analysis, and results of scientific studies and related topics concerning resources and lands managed by the National Park Service. The series supports the advancement of science, informed decisions, and the achievement of the National Park Service mission.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, US Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the US Government.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

This report is available in digital format from the [National Park Service DataStore](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Contents

	Page
Figures.....	vi
Tables.....	vii
Abstract.....	viii
List of Terms or Acronyms.....	ix
Executive Summary.....	xii
Acknowledgments.....	xv
Change History.....	xvi
Revision History Log.....	xvii
1. Introduction.....	1
1.1 Rationale Behind this Document and Underwater Visual Reef Fish Monitoring.....	1
1.2 Fishing Pressure on the Reef.....	2
1.3 Other Pressures on the Reef.....	3
1.4 Fisheries Management.....	4
1.4.1 Florida Keys and Tortugas.....	4
1.4.2 United States Virgin Islands.....	6
2. Background and Objectives.....	9
2.1 Historical Reef Fish Surveys.....	9
2.1.1 Florida Keys and Tortugas.....	9
2.1.2 United States Virgin Islands.....	16
2.2 Measurable Objectives of Monitoring.....	17
2.3 Overview of Monitoring Program.....	18
2.4 Link to Management Decision-Making.....	19
3. Sampling Design.....	21
3.1 Rationale for Selecting This Sampling Design over Others.....	21
3.2 Sampling Domain.....	22
3.2.1 Florida and Tortugas.....	22
3.2.2 United States Virgin Islands.....	23
3.3 Allocation and Site Selection.....	24

Contents (continued)

	Page
3.4 Level of Change That Can Be Detected	27
4. Field Methods	28
4.1 Field Season Preparations and Equipment Setup	28
4.2 Reef Visual Census (RVC) Surveys	28
4.3 Post-mission Equipment Maintenance and Storage	29
5. Data Control	30
5.1 Post-collection Data Handling	30
5.2 Data Entry, Verification and Editing	31
5.3 Data Management	32
5.3.1 Data Assimilation	32
5.3.2 Regional NOAA data sets	32
5.3.3 Metadata and Archiving	32
5.4 Overview of QA/QC	33
5.5 Protected Data	33
6.0 Data Analysis and Reporting	34
6.1 Recommendations for Routine Data Summaries and Statistical Analyses	34
6.2 Iterative Approach to Survey Design	35
7. Personnel Roles, Requirements and Training	36
7.1 Roles and Responsibilities	36
7.2 Qualifications	36
7.3 Training	36
8. Operational Requirements	38
8.1 Annual Workload and Field Schedule	38
8.2 Facility and Equipment Needs	38
8.3 Sequence of Events During Field Season	39
8.4 Frequency and Timing of Sampling	40
8.5 Startup Costs and Budget Considerations	41
8.6 Safety	42

Contents (continued)

	Page
Literature Cited	45

Figures

	Page
Figure 1. Hardbottom habitat, 2016 and 2018 survey locations, and designated management zones of the Upper, Middle and Lower Keys subregions.....	5
Figure 2. Hard bottom habitat, 2016 and 2018 survey locations, and designated management zones of the Florida Keys reef tract in the Tortugas subregion.	6
Figure 3. Hard bottom habitat, 2017 and 2019 survey locations, and designated management zoning of the United States Virgin Islands St. Thomas/St. John region.....	7
Figure 4. Hard bottom habitat, 2017 and 2019 survey locations, and designated management zoning of the United States Virgin Islands St. Croix region including Buck Island Reef National Monument (BUI), Salt River National Historical Park and Ecological Preserve (SARI), St. Croix East End Marine Park (EEMP), Red Hind Closure and Mutton Snapper Closure.	8
Figure 5. RVC diver setting up for an independent scuba-based Reef Fish Visual Census (RVC) survey developed by Bohnsack and Bannerot (1986).....	9
Figure 6. Recommended normalized indices of relative abundance for Yellowtail Snapper from 1991–2017 for stock assessment for the Southeastern United States.	14
Figure 7. Time series (1978–2016) for average length in the exploited phase (L_{bar}) for three exploited reef fish stocks based on four independent survey types including commercial data (TIP), recreational data (MRIP), and RVC exploited phase data (adults > length of capture (L_c)).....	15
Figure 8. Monitoring program flow chart.	19
Figure 9. Flow of data and QA/QC process.....	31

Tables

	Page
Table 1. Revision history log.	xvii
Table 2. Peer reviewed reports, protocols and scientific journal articles published based on the multi-agency reef fish visual census (RVC) protocol.	11
Table 3. Historical survey effort of primary sampling units (<i>n</i>) for reef fish visual census (RVC) stratified random surveys in the Florida Keys, Tortugas and the United States Virgin Islands.	25
Table 4. Historical survey effort of primary sampling units (<i>n</i>) for reef fish visual census (RVC) stratified random surveys in National Parks and no-take marine reserves (NTMR) in Florida and the United States Virgin Islands.	26
Table 5. Example metrics for summary reports that can be calculated from data.	34
Table 6. Projected implementation schedule for reef fish visual census monitoring in Florida and US Virgin Islands.	39
Table 7. Sampling schedule by park.	40
Table 8. SFCN monitoring budget protocol implementation.	41
Table 9. Relevant documents and location on South Florida/Caribbean Network server.	43

Abstract

Reef fish populations play a vital ecological and economic role in the coral reef ecosystems of Florida and the U.S. Virgin Islands (USVI), however, they face significant threats from habitat degradation, rising global temperature, and increased fishing pressures. Traditional fishery-dependent data have proven inadequate for accurately assessing reef fish populations, leading to the development of the *Cooperative Multiagency Reef Fish Monitoring Protocol*. This unified fishery-independent methodology uses visual census techniques to monitor reef fish. The protocol merges long-standing monitoring programs in Florida and the U.S. Virgin Islands, refining over 40 years of research and survey design improvements. Utilizing a single-stage stratified random sampling design, this methodology optimizes data collection by segmenting survey areas into 50×50 meter (164×164 feet) grid cells based on habitat, depth, and management status. Surveys are conducted by region biennially using the Reef Visual Census (RVC) stationary point count method, which allows divers to record fish abundance, size structure, and habitat characteristics. The protocol's objectives include tracking relative fish densities, spatial distributions and size structures of both target and non-target species. The protocol also facilitates the evaluation of marine protected areas (MPAs) and other fishery management regulations. Data collected help assess sustainable fisheries management practices and the impacts of environmental stressors and human activities. Findings from previous surveys indicate significant declines in economically important species such as snappers and groupers due to overfishing and habitat loss. Additionally, factors such as coral bleaching, hurricanes, invasive species (e.g., lionfish), and coastal development have altered reef fish communities. By standardizing monitoring efforts, this protocol ensures consistent high-quality data for fishery stock assessments, regulatory changes, and adaptive management strategies. This initiative is a collaborative effort among federal and territorial agencies, academic institutions, and conservation organizations, including the National Oceanic and Atmospheric Administration (NOAA), the University of Miami, the National Park Service (NPS), and the Florida Fish and Wildlife Conservation Commission (FWC). NOAA serves as the data management and survey design lead, ensuring data integrity and accessibility for research and policy applications. As reef ecosystems continue to face ecological challenges, this protocol remains essential for guiding effective conservation and management decisions. Ongoing refinements in methodology, expansion into deeper reef habitats, and integration of new technologies will further enhance monitoring efforts, and ultimately support the long-term sustainability of these ecosystems.

List of Terms or Acronyms

APT: All-Purpose Tool

BB: Center for Coastal Monitoring and Assessment Biogeography Branch

BICY: Big Cypress National Preserve

BISC: Biscayne National Park

BUIS: Buck Island Reef National Monument

CV: Coefficient of Variation (Standard deviation / mean)

DEEP: Dive Emergency Evacuation Plan

DPNR: Department of Planning and Natural Resources

DRTO: Dry Tortugas National Park

EEMP: St. Croix East End Marine Park

EVER: Everglades National Park

FIM: Fisheries Independent Monitoring

FKNMS: Florid Keys National Marine Sanctuary

FTE: Full Time Employee

FWC: Florida Fish and Wildlife Conservation Commission

FWRI: Fish and Wildlife Research Institute

GIS: Geographic Information System

GMSAFMC: Gulf of Mexico and South Atlantic Fishery Management Councils

GPS: Global Positioning System

I&M: Inventory and Monitoring (NPS)

IRMA: Integrated Resource Management Applications

JHA: Job Hazard Analysis

MCD: Marine Conservation District

MOCC: Motorboat Operator Certification Course

NAUI: National Association of Underwater Instructors

NCCOS: National Center for Coastal Ocean Science

NCEI: National Centers for Environmental Information

NCRMP: Coral Reef Conservation Program, National Coral Reef Monitoring Program

NHP&EP: Natural Historical Park and Ecological Preserve (SARI)

NM: National Monument

NOAA: National Oceanic and Atmospheric Administration

NRDS: Natural Resource Data Series

NTMR: No-take Marine Reserve

NP: National Park

NPS: National Park Service

PADI: Professional Association of Dive Instructors

PDO: Park Dive Officer

PSU: Primary Sample Unit

QA/QC: Quality Assurance/Quality Control

RM-4: Diving Management Reference Manual 4

RNA: Research Natural Area

RVC: Reef-fish Visual Census

SARI: Salt River Bay National Historical Park and Ecological Preserve

SCUBA: Self-contained Underwater Breathing Apparatus

SE: Standard Error

SEDAR: Southeast Data Assessment and Review

SEFSC: National Marine Fisheries Service, Southeast Fisheries Science Center

SFCN: National Park Service South Florida/Caribbean Network

SOP: Standard Operating Procedure

SSU: Secondary Sample Unit

STEER: St. Thomas East End Reserve

TCRMP: USVI Territorial Coral Reef Monitoring Program

UM-RSMAS: University of Miami, Rosenstiel School of Marine and Atmospheric Science

USVI: United States Virgin Islands

UTM: Universal Transverse Mercator

VICR: Virgin Islands Coral Reef National Monument

VIIS: Virgin Islands National Park

VRM: Vector Rugosity Measure

Executive Summary

Reef fish populations are of great economic, cultural and ecological significance throughout the Caribbean and are essential components of coral reef ecosystems in U.S. North Atlantic territorial waters including Florida, United States Virgin Islands (USVI), Puerto Rico, and Flower Garden Banks. Recent stressors on these populations include severe quality degradation of essential habitats, such as widespread coral bleaching and disease outbreaks, as well as substantial increases in recreational and commercial fishing efforts. Reef fish populations have historically been difficult to assess due to a lack of traditional fishery-dependent data and limitations on interpreting catch data at a fine spatial scale. The monitoring methodologies described in this document are a culmination of over 40 years of assessing reef fish communities and survey design work by dedicated fisheries scientists at multiple agencies and universities. The data collected according to these procedures are useful for understanding the ecological effect of natural and man-made stressors as well as management actions to promote sustainability of reef fish populations and communities, particularly in tropical reef ecosystems where traditional stock assessments may be challenging due to insufficient historical fishery-dependent databases.

This document, “*A Cooperative Multiagency Reef Fish Monitoring Protocol for the Florida and U.S. Virgin Islands Coral Reef Ecosystems, Protocol Narrative Version—2.0*” is a revised and unified version of two previous published reef fish protocols (Brandt et al. 2009; Bryan et al. 2013). Brandt et al. (2009) was originally developed as a collaborative, multi-agency effort to monitor reef fish populations in the Florida Keys and the Tortugas. The Bryan et al. (2013) protocol was later created to monitor and assess reef fish communities and populations within the U.S. Virgin Islands and specific shelf sub-regions (e.g., islands of St. Croix, St. John and St. Thomas). These earlier versions shared a common survey design but relied on different fish count methods (stationary point count and belt transect count) and site selection protocols. This protocol represents the first-time reef fish fishery-independent monitoring methods have been consolidated across all U.S. territorial interests in the Caribbean and Florida. It focuses on shallow coastal shelf areas within and near U.S. National Park Service (NPS) units and is the product of nearly four decades of independent localized reef fish population monitoring programs. A complementary NOAA Technical Memorandum is planned for the Caribbean and Atlantic waters outside National Park Service unit areas of interest including southeast coastal Florida, Puerto Rico and the Flower Garden Banks in the Gulf of Mexico. The statistical sampling design and survey methods described here are also the basis for a large-scale diver visual survey monitoring program that surveys coral reef fish assemblages and habitats of most of the U.S.-affiliated tropical Pacific Ocean islands. Currently these regions include the main and Northwestern Hawaiian Islands and affiliated geopolitical regions of American Samoa, the Commonwealth of the Northern Mariana Islands, Guam, and the Pacific Remote Islands Areas.

In order to efficiently sample within a heterogeneous environment, the sampling effort is optimized using a single-stage stratified random sampling design. Before sampling occurs, the sampling domains are partitioned into 50 × 50 meter (164 × 164 feet) grid cells, or primary units, which are each assigned a stratum designation based on habitat type, geographic sub-region, management type

(open vs. closed to extraction), depth, and rugosity. The number of primary units to be sampled in each stratum type is based on a Neyman allocation scheme, which accounts for the stratum's size and standard deviations for focal fish species densities in each region. Once the optimal number of primary units per stratum is chosen based on a target precision and the capabilities of the agencies, primary units to be sampled are randomly selected from a list of all primary units for each stratum. Within each selected primary unit, one smaller second-stage unit is selected for survey. The second-stage unit consists of a buddy pair of divers who each perform a Reef Visual Census (RVC) timed point count within a 15-meter (49.2 feet) diameter cylinder. A stationary point count method was chosen as the *in situ* visual sampling method of choice because the complexity and spatial extent of habitats often precludes the use of linear transects and it is a better method for exploited fish species (e.g., snappers and groupers) that may exhibit diver avoidance. The RVC method allows divers to simultaneously collect data on the relative density and size distributions of the entire fish community, as well as information on benthic habitat features. Atlantic and Caribbean sampling occurs every other year in the summer months, generally between May and September. The Florida Keys, Tortugas, and Flower Garden Banks are surveyed during the same year and are alternated every other year with surveys in the U.S. Virgin Islands and Puerto Rico. Qualified and trained personnel participate from all participating agencies.

The protocol narrative gives an overview of the monitoring program's background, sample design, methods, and objectives, which are focused on tracking changes in several metrics including the relative densities, spatial distributions and size structures of exploited reef fish species and the reef fish community. These changes are evaluated every other year with respect to the habitat features, the physical environment and potential management actions that may have affected the dynamics of fish populations. The narrative is published as a separate volume from the Standard Operating Procedures (SOPs) and glossaries of statistical symbols and computational formulae to allow the SOPs and glossaries to be easily updated following annual operational reviews of the protocol as needed. The current narrative, SOPs, and glossaries are available at:

<https://irma.nps.gov/DataStore/Reference/Profile/2311356>.

The specifics of the methods are detailed in six SOPs. The SOPs are stand-alone documents that can be used at different stages of program implementation and published individually. These SOPs are: SOP RF01 *Statistical Sampling Design—Version 2.0*, SOP RF02 *Participant Training—Version 1.1*, SOP RF03 *Field Data Collection—Version 2.0*, SOP RF04 *Data Entry and Proofing—Version 2.0*, SOP RF05 *Data Analyses and Reporting—Version 1.1*, and SOP RF07 *Revising the Protocol—Version 1.0*. The protocol also includes: a glossary of statistical symbols and computational formulae used in the survey calculations ([Glossary A](#)); a glossary of statistical symbols and computational formulae used in historical two-stage surveys ([Glossary B](#)); benthic habitat maps and map variables of the Florida Reef Tract (SOP RF01-A) and United States Virgin Islands (SOP RF01-B); SOP RF03-A, reef fish codes and species names, and SOP RF03-B, a guide to habitat component identification that can be printed and used in the field for reference; R-code for data QA/QC and data verification (SOP RF04-A); data output and verification variables (SOP RF04-B); and data quality standards (SOP 04-C).

Implementation of this protocol is a collaborative effort amongst federal, territorial, academic, and non-governmental organization partners including but not limited to the National Oceanic and Atmospheric Administration (NOAA) National Centers for Coastal Ocean Science (NCCOS), NOAA National Marine Fisheries Service's Southeast Fisheries Science Center (SEFSC), Florida Fish and Wildlife Conservation Commission's Florida Fish and Wildlife Research Institute (FWRI), National Park Service (NPS) South Florida/Caribbean Network (SFCN), Biscayne National Park, Dry Tortugas National Park, Virgin Islands National Park and Virgin Islands Coral Reef National Monument, Buck Island Reef National Monument, Virgin Islands Department of Planning and Natural Resources (DPNR), University of Miami's Rosenstiel School of Marine and Atmospheric Science (UM), University of Virgin Islands (UVI), and The Nature Conservancy (TNC). The regional scale of this effort is beyond the scope of the National Park Service and warrants NOAA SEFSC and NOAA NCCOS to be the lead agency for logistical planning and data management under the Coral Reef Conservation Program's (CRCP) National Coral Reef Monitoring Program (NCRMP). NOAA SEFSC serves as the data manager for all partners, overseeing data assimilation, QA/QC proofing, data management and sharing of analysis ready data sets. The South Florida/Caribbean Network will represent the NPS to ensure data collected within park boundaries are robust enough to evaluate effectiveness of management actions, e.g., no-take reserves or MPAs within the parks.

Acknowledgments

This document is the culmination of over 40 years of work by numerous people from various agencies and universities. We'd like to extend special thanks to Michael Allen, Evan Childress, and Mary Christman for their critical review of this document and providing valuable comments and advice. We also thank all our partners and park resource staff for their contributions and understanding during the transitional and trying years of this collaborative effort. We also want to recognize the more than 600 scientific divers that have contributed to the collection of data and data quality proofing over the years. In addition, we particularly recognize Andrea Atkinson, Chris Caldwell, Douglas Harper, John Hunt, Todd Kellison, Mark Monaco, David McClellan, Matt Patterson and Benjamin Ruttenberg for making significant contributions to previous versions of this protocol. This partnership and protocol would not be possible without their commitment and perseverance. We also thank Irina Ford, Brian Mitchell, Ellen Cheng, Rob Waara, Jeff Miller, Matthew W. Johnson for their guidance and contributions during the peer review process.

Development and application of mapping and assessment methods over the years would not have been possible without the technical assistance of John Brock (USGS) and Chris Taylor (NCCOS) who provided LIDAR and multibeam data for the Florida Keys National Marine Sanctuary, including the Tortugas, and Jingang Luo at the University of Miami who integrated and interpreted multiple mapping data layers for the Florida ecosystem. We are also greatly indebted to Ken Buja, Matt Kendall, Kim Edwards and Laughlin Siceloff for providing and managing the benthic mapping and grid layers for the United States Virgin Islands (USVI). We are indebted to Captain Frank Wasson and Dive Officer Melony Wasson of the M/V Spree and more recently to Captain Joe Bailey and the able crew of the M/V Makai for providing intuition, success and safety for over 25 years. A thematic layer classification scheme modified by the University of Miami was originally created by the Florida Marine Research Institute (FMRI 1998) from photogrammetric interpretation of aerial surveys performed between December 1991 and April 1992 (see Franklin et al. 2004 for more information) and quantified more recently by Smith and Luo (2021). The following funding sources contributed greatly to program development and/or application of these methodologies in previous years (in no particular order): U.S. Man and the Biosphere Program, National Undersea Research Program, Southeast Fisheries Science Center (SEFSC, NMFS), Department of the Interior and the National Park Service, Biscayne National Park, Everglades/Dry Tortugas National Park, Florida Keys National Marine Sanctuary, U.S. Army Corp of Engineers, NOAA Coastal Ocean Program, NOAA National Coral Reef Monitoring Program (NCRMP), U.S. Environmental Protection Agency, National Fish and Wildlife Foundation, Florida Fish and Wildlife Conservation Commission, National Sea Grant College Program, NOAA Biogeography Program, Florida Fish and Wildlife Research Institute, the U.S. Fish and Wildlife Service, Federal Aid for Sportfish Restoration fisheries-independent monitoring (F-43) and reef fish (F-7) projects, proceeds from the sale of Florida recreational fishing licenses, and most notably NOAA's Coral Reef Conservation Program.

In memory of Joseph Contillo (September 2, 1957–August 6, 2024). Rest Easy, “RVC001.”

Change History

Protocol versions are tracked in the revision history log attached to the narrative and to each standard operating procedure (SOP). Major changes result in an update by whole numbers (i.e., version 1.0, version 2.0, etc.), and minor changes by tenths (e.g., version 1.1, version 1.2, etc.).

Revision History Log

Table 1 records revisions to the protocol narrative.

Table 1. Revision history log.

Revision Date	Author	Changes Made	Reason for Change	New Version #
11/09/2020	Mike Feeley	Merger of USVI and Florida Keys Protocols	Unified protocol and methods adopted across both the USVI and Florida regions	2.0
	Mike Feeley	Adoption of 50 × 50 m grid in Florida region	Improved habitat maps	2.0
	Mike Feeley	Fish survey stations per PSU reduced from two secondary sample units to one secondary sample.	Smaller grids (survey area)	2.0
	Mike Feeley	Survey method changed from belt transect to stationary point count in USVI	Stationary point count method better estimates target species and remains consistent with methods used in Florida	2.0
	Mike Feeley	Site selection in USVI: surveys are conducted at first hardbottom encountered in grid cell and no longer use a random compass bearing from the centroid.	Artifact from change from belt transect to stationary point count.	2.0
	Mike Feeley	Florida strata changed to incorporate quantitative rugosity measurements	Including rugosity in the strata allows more efficient sampling of fish populations	2.0

1. Introduction

1.1 Rationale Behind this Document and Underwater Visual Reef Fish Monitoring

This protocol narrative is meant as a reference and describes the background, justification, and objectives for monitoring, as well as an overview of the survey design, training, sampling, data entry, data management, analysis and reporting for the biennial fishery-independent monitoring of reef fish populations within the Florida Keys, Tortugas, and United States Virgin Islands (USVI) reef ecosystems. It is supplemented by six standard operating procedures (SOPs) reviewed annually and updated as needed to ensure they accurately reflect the monitoring effort. This document conforms to formatting guidelines for NPS long-term monitoring protocols (Oakley et al. 2003; Mitchell et al. 2018). A revision history log is required to reflect updates and changes to the protocol narrative (Table 1). The protocol builds upon a previously published guide for reef fish monitoring (Menza et al. 2006) and replaces the published multiagency reef fish protocols for Florida (Brandt et al. 2009) and for the U.S. Virgin Islands (Bryan et al. 2013). Brandt et al. (2009) was a collaborative effort among government and university groups that formally organized the first joint fishery-independent reef fish monitoring program by multiple independent groups in South Florida. This revision represents over 40 years of collaborative monitoring efforts and marks a shared consistency in methodology and expansion of the program to other areas in the Caribbean (USVI and Puerto Rico), the Gulf of Mexico (Flower Gardens Bank) and Southeast coastal Florida (Martin to Palm Beach Counties).

Underwater visual fish surveys (belt transect, stationary point count, roving/towed) are used worldwide to monitor shallow water marine and freshwater environments to estimate fish populations and support fisheries management actions (Caldwell et al. 2016; Pais and Cabral 2017). Long-term research and monitoring programs provide park scientists with ecological insights, which are critical to improve management of ecosystems and park natural resources (Lindenmayer and Likens 2009) and create opportunity for assessing sustainability of data-limited tropical reef fisheries (Ault et al. 2019). However, it is recognized that the nature of fish behavior may introduce an element of bias that may affect the accuracy and precision of these types of surveys (Pais and Cabral 2017).

There is no single standardized visual method or survey area configuration that is a best fit for all species, conditions and habitats encountered in field surveys. In a simulated comparison of methods, point counts exhibit a higher bias and less precision on average than transect counts, but narrow belt transects create more bias for schooling, shy and bold fish (Pais and Cabral 2018). Part of this is attributed to the non-instantaneous nature of underwater surveys since fish can enter a survey area after the start (Pais and Cabral 2018). However, Colvocoresses and Acosta (2007) compared point and transect methods in-situ and concluded that higher densities of fishes observed in point counts was a truer, more accurate representation of fish densities. Since commercially important snappers and groupers, not the cryptic or pelagic species, are focal to this program, minimizing fish avoidance behavior to divers actively swimming during a strip transect survey was an important consideration.

Pais and Cabral (2018) suggest point counts may increase bias and overestimate shy species, but the bias should not be significant if using a large radius and short survey time.

Underwater visual assessments are not expected to be free of bias and report absolute probability detection across the entire reef fish community. The methods for estimating detection probability and understanding observer effects in underwater visual census methods are beginning to be understood (Bacheler et al. 2013; Bernard et al. 2013; Bacheler and Shertzer 2015; Suarez and Grabowski 2021; Ault et al. 2024a). Analysis of historical data may be utilized, and future data would not necessarily need to be collected at every site, but a subset of sites used to establish relationships for standardized estimates using covariates likely to influence detectability. These factors could include physical environmental variables (depth, visibility, habitat) and/or species characteristics such as species-specific size and behavior. These questions will be explored in a long-term iterative process, but concerns about detectability or catch (q) bias are currently offset by utilizing paired non-independent samples collected by two trained and experienced observers using a single standardized visual assessment methodology (Bohnsack and Bonnerot 1986) in an intensive large scale stratified random survey environment. Nonetheless, Ault et al. (2024a) found that rare species disproportionately contribute to bias in the RVC data, thus the influence of species type suggests the need to account for detection probability.

1.2 Fishing Pressure on the Reef

Reef fish communities are a vital component of coral reef ecosystems and have major economic and ecological importance throughout the world. The Florida Reef Tract extends approximately 270 kilometers (167.8 miles) from Miami to the Dry Tortugas and is the third largest coral barrier reef in the world. This reef provides the ecological foundation for vital fisheries and a tourism-based economy that generated an estimated U.S. \$6 billion of economic activity in 2001 (Johns et al. 2001; Lirman et al. 2013) and is currently valued by the Florida Keys National Marine Sanctuary at U.S. \$8.5 billion annually (KeysWeekly 2024). Reef fish communities are ranked second of 69 vital signs considered in seven National Parks within the South Florida/Caribbean Network of the National Park Service's Inventory and Monitoring Division.

“Vital signs” are a “subset of physical, chemical and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources or elements that have important human values” (from Patterson et al. 2008).

Reef fish communities' high ranking is due to their significance in maintaining the ecological balance of coral reef ecosystems and their economic importance. These factors make coral reef fish communities a sensitive indicator of both ecosystem degradation and/or overexploitation.

Despite their significance, the abundance and diversity of reef fish communities throughout the Caribbean have seen unprecedented declines due to a combination of direct and indirect anthropogenic stressors, including overfishing (Hughes 1994; Ault et al. 1998; Ault et al. 2002; Mora 2008; Kadison et al. 2017; Valdivia et al. 2017). Although the dynamics of reef communities have likely been altered for centuries (Jackson 1997; Jackson et al. 2001; McClenachan et al. 2017), recent

increases in recreational and commercial fishing in the Florida Keys region have resulted in an overfished status for several economically important fish species (Ault et al. 1998; Ault et al. 2005a, Ault et al. 2014, Ault et al. 2019, Ault et al. 2022). Loss of spawning aggregations, declines in densities and biomass, and changes in size structures of exploitable fish populations have been documented and are indicators of overexploitation throughout the western Atlantic Ocean and Caribbean (Bohnsack et al. 1994; Ault et al. 1998; Nemeth 2005; Kellison et al. 2012; Valdivia et al. 2017; Chollett et al. 2020). Once historically productive reef fisheries, such as groupers and snappers, have experienced major declines in catch and sustainability in recent years (Allen and Tashiro 1976; Bohnsack et al. 1994; Ault et al. 2005b; Ault et al. 2019; Ault et al. 2022). Large-bodied, apex piscivores are often the first species to be overexploited in small-scale island artisanal fisheries such as the United States Virgin Islands (Kadison et al. 2017). Further, commercial fishing pressure on key species worldwide has led to the alteration and/or shortening of marine food webs, which can result in a loss of ecosystem function and fishery resilience (Pauly et al. 2002; Ainley and Pauly 2014).

1.3 Other Pressures on the Reef

Changes in habitat structure and quality are also known to have quantifiable repercussions on reef fish abundances and diversity (McClanahan 1994; McClanahan et al. 1999; Wilson et al. 2006; Paddack et al. 2009). At regional levels, events such as mass coral bleaching and disease epizootics have altered the structure and function of reefs by removing reef framework-building live coral (Gardner et al. 2003; Miller and Williams 2007; Precht et al. 2016; Muller et al., 2020) or caused coral community shifts such that topographic complexity is lost (Aronson and Precht 2001; Graham et al. 2007; Fukunaga et al. 2020a). These large shifts in coral structure, function, and community have led to changes in the coral reef fish assemblages (Fukunaga et al. 2020b). The complex life history strategies of many reef fish species can span multiple habitats and can include a large-scale dispersal phase. Fish assemblages can therefore be characteristic of specific habitats and biophysical connectivity among habitats and regions (Kimmel 1985; Chittaro et al. 2005; Claro et al. 2019). While changes in reef fish abundances and structure may indicate direct effects from overfishing, they can also be indicators of the status of the system as a whole and may reflect one or a combination of changes including habitat quality, connectivity, fishing pressure, and long-term ecosystem resilience. A decline in overall fish abundance across trophic levels in fishery targeted and non-targeted populations indicates many Caribbean fishes have responded negatively to habitat degradation (Paddack et al. 2009).

Other impacts that have resulted in the degradation of reef habitats and fish populations include hurricanes, coastal development due to the exponential growth of human population and high volume of tourism, and the introduction of invasive species. Over the past century, activities managing water movement through the Everglades have led to a massive alteration of land drainage patterns in the South Florida region (Light and Dineen 1994). Although intensively managed, the Florida reef ecosystem is also considered one of the most stressed ecosystems in the nation (Porter et al. 1999). Similarly, poor water quality due to sedimentation and pollution from land-based runoff and coastal development represents non-point source concerns to the reef ecosystems throughout the Caribbean as well. Furthermore, the invasive Indo-Pacific lionfish, *Pterois volitans* and *P. miles*, first became

prominent in Florida in 2009 and in the U.S. Virgin Islands in 2011 (Bryan et al. 2018; Sancho et al. 2018). Lionfish quickly expanded throughout South Florida and the Caribbean, with occurrence and abundance increasing dramatically on Florida reefs in a short period of time (Ruttenberg et al. 2012). This expansion raised concern that lionfish could negatively affect commercially important fish species by directly consuming them in their juvenile phase and by consuming large amounts of their prey (Sancho et al. 2018).

1.4 Fisheries Management

1.4.1 Florida Keys and Tortugas

The Florida Fish and Wildlife Conservation Commission (FWC) and the Federal South Atlantic Fishery Management Council are respectively responsible for specific fishery management regulations inside and outside of state waters (0–3 miles [0–4.8 kilometers] Atlantic side). Most commercially and recreationally important fish species are regulated by state and federal minimum size and bag/catch limits. Numerous protected areas have been established within the South Florida region for various purposes and with various levels of protection against resource use and extraction. The largest designated area is the Florida Keys National Marine Sanctuary (FKNMS) which was established in 1990 and covers approximately 9,900 square kilometers (3,800 square miles [mi^2]) extending from Miami to the Tortugas Bank (Figure 1). Biscayne National Park (NP), next to Miami, was established as a National Monument in 1968 and expanded to a National Park (700 square kilometers [270.3 mi^2]) in 1980. The park is open to recreational and commercial fishing in accordance with FWC regulations, but FWC implemented more restrictive size and bag limits and no trawl zones for Biscayne NP in July of 2020 (FWC 2020). Moving from east to west, other protected areas in the “Upper Keys” include Key Largo National Marine Sanctuary, John Pennekamp Coral Reef State Park, Biscayne Bay and Card Sound Aquatic Preserve, and Lignumvitae Aquatic Preserve. In the Middle and Lower Keys, there are the National Key Deer Refuge, Coupon Bight Aquatic Preserve, Looe Key National Marine Sanctuary, the Great White Heron National Refuge, and the Key West Wildlife Refuge. Further to the west is the Dry Tortugas National Park (NP) and the Tortugas South and North Ecological Reserves (Figure 2). Dry Tortugas NP was first established as a National Monument in 1935 (190.7 square kilometers [73.6 mi^2]), expanded (259 square kilometers [100 mi^2]) in 1983 and designated as a National Park in 1992. A network of 23 no-take marine reserves (NTMRs) were also implemented by FKNMS in various areas throughout the Keys in 1997 (Figure 2). These are small reserves, comprising a total area of 46 square kilometers (18 mi^2), and they vary in level of protection, ranging from accessible only by special permit to the allowance of catch-and-release surface trolling. This NTMR network was further expanded in 2001 with the implementation of three large reserves, including the Western Sambos Ecological Reserve (30 square kilometers [12 mi^2]) near Key West, and two more designated areas in the Tortugas: the Tortugas North and South Ecological Reserves, which cover another approximately 566 square kilometers (219 mi^2). In 2007, the National Park Service created the Research Natural Area (RNA), a NTMR within Dry Tortugas NP (120 square kilometers [46 mi^2]), to spatially complement the Tortugas Ecological Reserves. A seasonal 2.6 square kilometers (1 mi^2) no-take closure (April 1 to July 31) to protect fish spawning aggregations at Western Dry Rocks, 16.1 kilometers (10 miles) southwest of Key West, was established in 2021 (Keller et al. 2024).

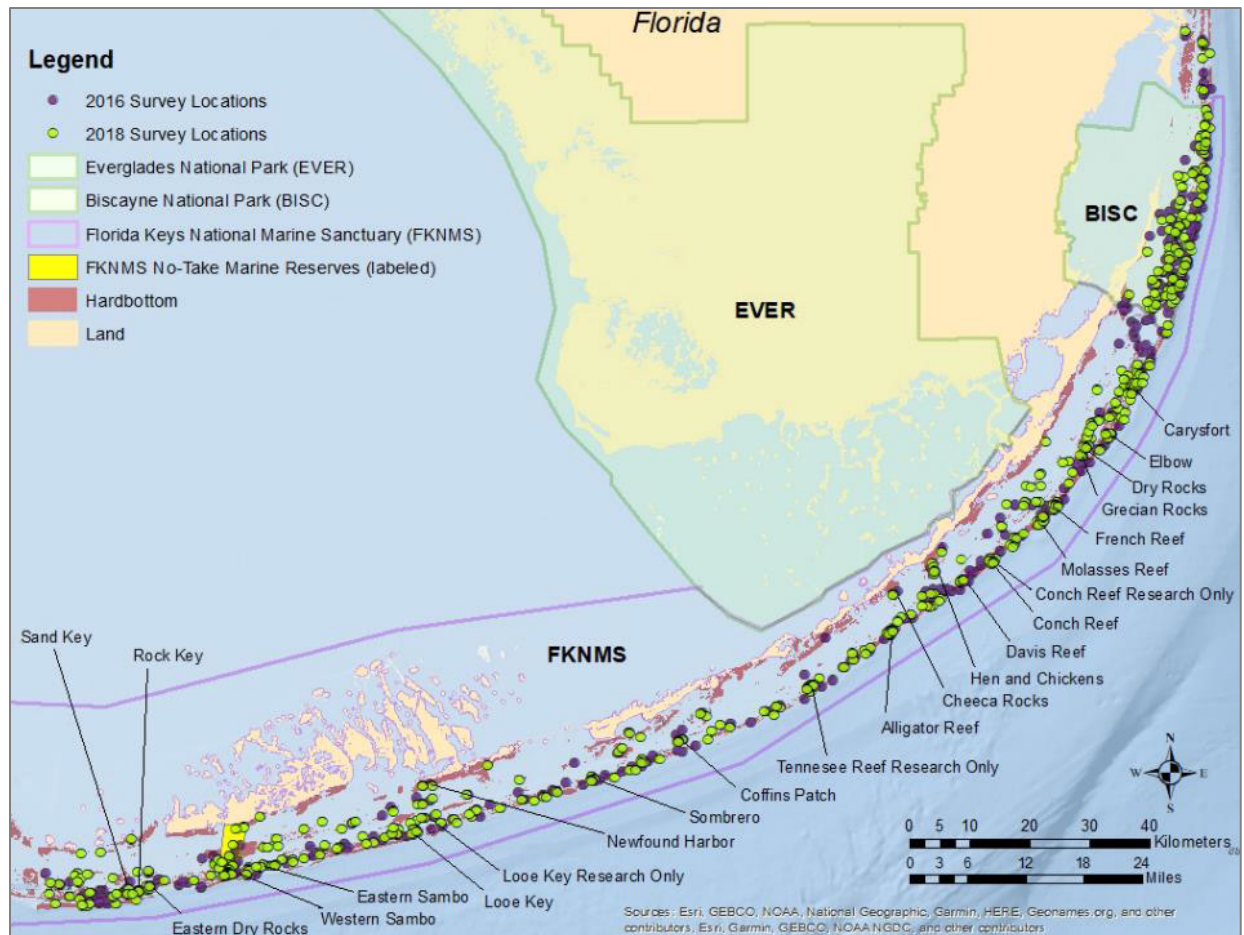


Figure 1. Hardbottom habitat, 2016 and 2018 survey locations, and designated management zones of the Upper, Middle and Lower Keys subregions. Zones include the Florida Keys National Marine Sanctuary (FKNMS), Biscayne National Park (BISC), and 23 no-take marine reserves (NTMRs) including Western Sambo Ecological Reserve. Everglades National Park (EVER) is included for reference and is not part of the survey domain.

NPS / LEE RICHTER

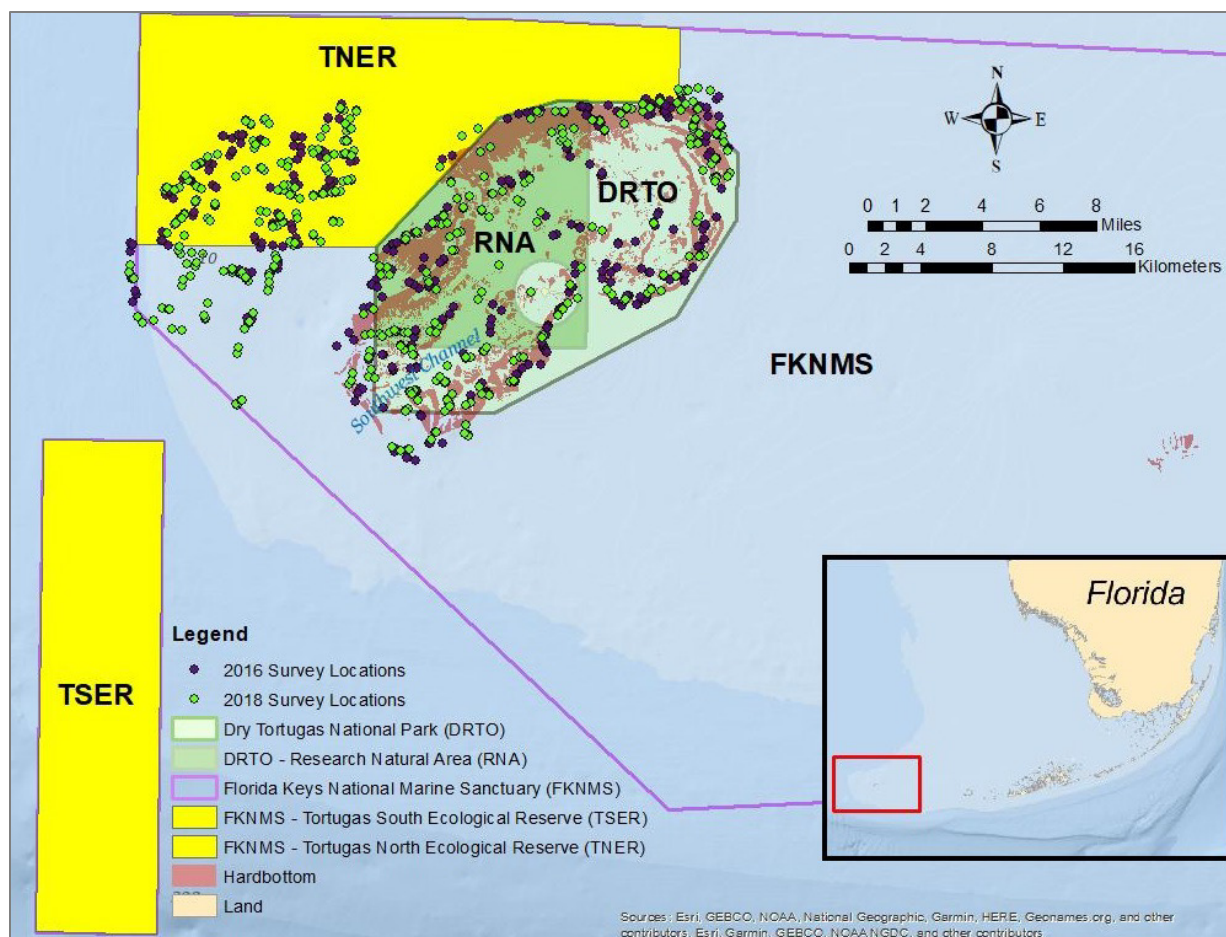


Figure 2. Hard bottom habitat, 2016 and 2018 survey locations, and designated management zones of the Florida Keys reef tract in the Tortugas subregion. Zones include the Florida Keys National Marine Sanctuary (FKNMS), Dry Tortugas National Park (DRTO) and no-take marine reserves including the Research Natural Area (RNA) within Dry Tortugas National Park and the Tortugas North (TNER) and South (TSER) Ecological Reserves.

NPS / LEE RICHTER

1.4.2 United States Virgin Islands

Fishery management regulations in the U.S. Virgin Island territorial waters (0–3 miles [4.8 kilometers]) are administered by the USVI Department of Planning and Natural Resources' Division of Fish and Wildlife and in Federal waters (3–200 miles [4.8–321.9 kilometers]) by the Caribbean Fishery Management Council. Several protected areas and seasonal closures account for the bulk of management tools being used in the U.S. Virgin Islands in conjunction with gear restrictions (minimum opening sizes for traps and banned gillnets). There are no minimum size restrictions for fish except for a 12-inch (30.5 centimeters) total length minimum on Yellowtail Snapper. Twenty-four territorial marine parks and seven federal marine parks have been created, of which several include no-fishing zones (NOAA NOS 2009). Four units of the U.S. National Park Service with significant marine resources fall within this region (Figures 3 and 4). In St. John, Virgin Islands NP was created in 1956 (59.44 square kilometers [22.9 mi²]), and Virgin Islands Coral Reef National

Monument (NM), was established in 2001 (51 square kilometers [19.7 mi²]). Virgin Islands NP allows recreational fishing (except spearfishing) with some restrictions on trap size within the park boundaries. However, the Virgin Islands Coral Reef NM is an NTMR and is also located to the east of three managed areas in St. Thomas: Red Hind Closure (seasonal NTMR), Grammanik Bank (seasonal NTMR) and the St. Thomas East End Reserve. In St. Croix, Buck Island Reef National Monument (NM) was established in 1961 as a no-take marine reserve (3.56 square kilometers [1.4 mi²]), and in 2001 it was expanded to include important offshore deep-water habitat (76.95 square kilometers [29.7 mi²]). Salt River Bay National Historical Park and Ecological Preserve (NHP & EP) located on the north shore of St. Croix was created in 1992 (4.1 square kilometers [1.6 mi²]). Salt River NHP & EP is co-managed by DPNR and NPS and is presently a NTMR, closed to all recreational and commercial fishery activities. Buck Island Reef NM shares boundaries with the territorially managed St. Croix East End Marine Preserve (EEMP), which was established in 2003 (155.4 square kilometers [60.0 mi²]). Both Buck Island Reef NM and the 13 square kilometers (5.0 mi²) of the EEMP are managed as NTMRs. Further to the east, the Red Hind Closure provides seasonal protection on Lang Bank (January and February).

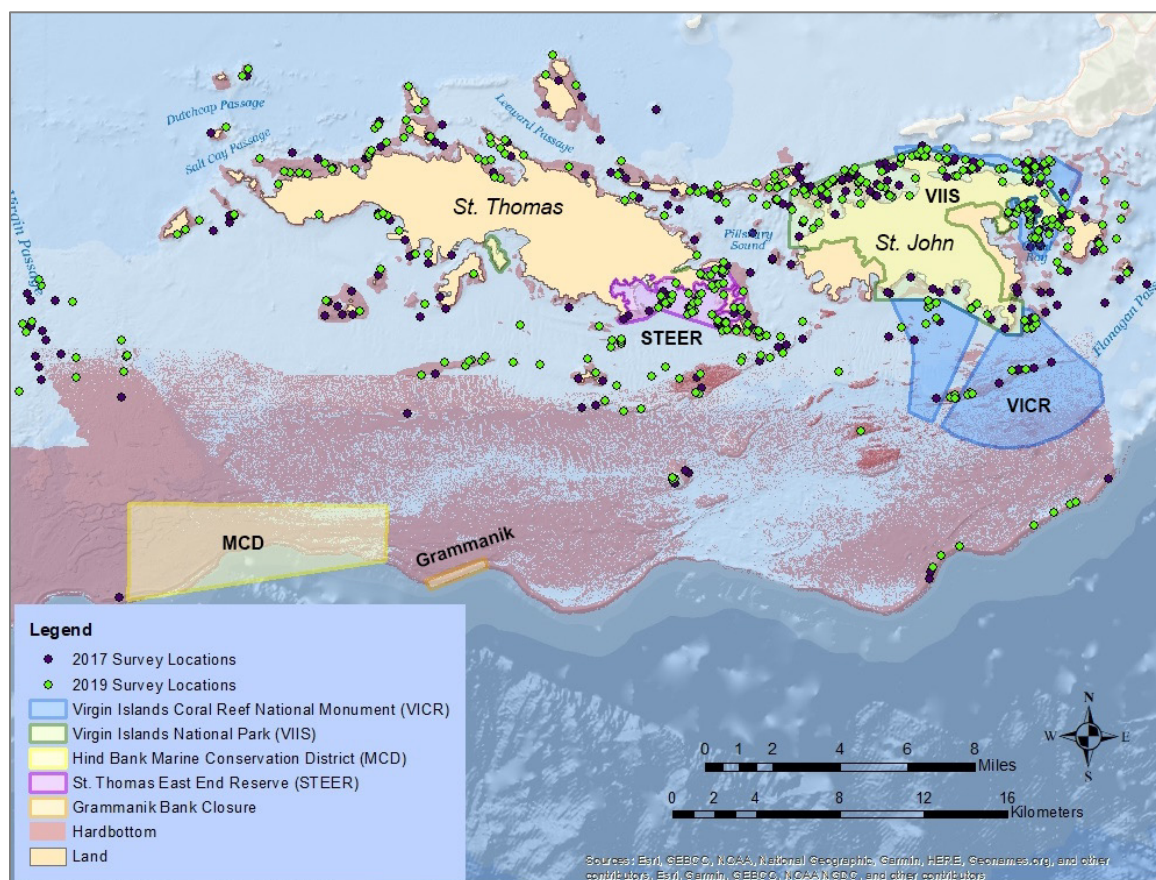


Figure 3. Hard bottom habitat, 2017 and 2019 survey locations, and designated management zoning of the United States Virgin Islands St. Thomas/St. John region. Zones include Virgin Islands Coral Reef National Monument (VICR), Virgin Islands National Park (VIIS), St. Thomas East End Reserve (STEER), Hind Bank Conservation District (MCD) and Grammanik Bank.

NPS / LEE RICHTER

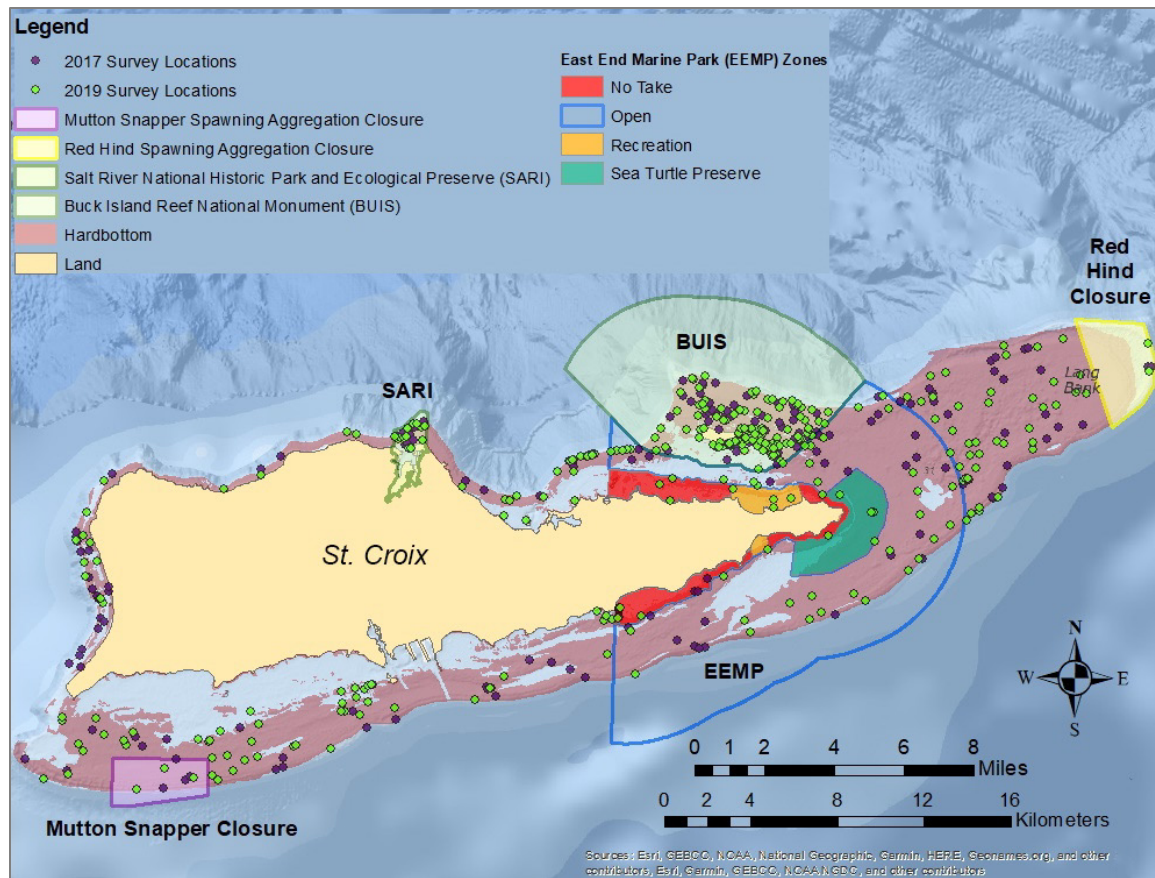


Figure 4. Hard bottom habitat, 2017 and 2019 survey locations, and designated management zoning of the United States Virgin Islands St. Croix region including Buck Island Reef National Monument (BUIS), Salt River National Historical Park and Ecological Preserve (SARI), St. Croix East End Marine Park (EEMP), Red Hind Closure and Mutton Snapper Closure.

NPS / LEE RICHTER

2. Background and Objectives

2.1 Historical Reef Fish Surveys

2.1.1 Florida Keys and Tortugas

The National Oceanic and Atmospheric Administration Southeast Fisheries Science Center (NOAA-SEFSC) began monitoring reef fish populations at fixed sites along the Keys using a fisheries independent scuba-based Reef Fish Visual Census (RVC) approach (Bohnsack and Bannerot 1986) in 1979 (Figure 5). Through time the number and spatial distribution of these sites expanded throughout the Florida Keys. In 1997, the University of Miami's Rosenstiel School of Marine and Atmospheric Science (UM-RSMAS) joined NOAA-SEFSC as a partner and helped to design and implement a habitat-based two-stage stratified random survey design to locate RVC sample locations (Ault et al. 2001; Ault et al. 2002; Smith et al. 2011). The first multi-agency high-intensity survey of the Florida Keys and Tortugas took place in 1999, with 331 sites completed using the habitat-based stratified random sampling design. Sampling continued as a collaborative effort between UM-RSMAS and NOAA-SEFSC on an annual basis in the Florida Keys and every even year in the Tortugas. The schedule shifted to biennial surveys for both the Florida Keys and Tortugas in 2012 to accommodate NOAA NCRMP scheduling additional surveys in other regions (Puerto Rico, SE Florida and the Flower Gardens in the Gulf of Mexico).



Figure 5. RVC diver setting up for an independent scuba-based Reef Fish Visual Census (RVC) survey developed by Bohnsack and Bannerot (1986).

NPS / ROB WAARA

The Florida Fish and Wildlife Conservation Commission's (FWC) Fisheries-Independent Monitoring (FIM) program also began a long-term monitoring effort of key reef fish populations in the Florida Keys National Marine Sanctuary in 1998. This effort was aimed at evaluating the relative abundance, size structure, and habitat utilization of specific reef fish species targeted by commercial and recreational fisheries. In 1999 and 2000, FWC did a formal comparison of the two most-used visual sampling techniques, the 15-meter (49.2 feet) stationary point count method used by the NOAA/UM-RSMAS group (Bohnsack and Bannerot 1986) and the strip transect method (as reviewed in Sale 1997). This comparison determined the stationary point count method was most successful at estimating fish densities and was employed annually within the Florida Keys region (Colvocoresses and Acosta 2007).

In April 2007, FWC's Fish and Wildlife Research Institute (FWRI) and the Florida Wildlife Legacy Initiative conducted a two-day joint workshop to examine Reef Fish Visual Census techniques (RVC) for the assessment of population structure and biodiversity in South Florida waters. The proposed outcome of the workshop was to establish a consensus on the most appropriate methods, and to standardize methodologies across the South Florida region. The workshop goals included examining RVC techniques currently used, exploring alternative techniques and determining the types and magnitude of detectable biotic change. The outcome from this workshop was an agreement between FWC-FWRI, NOAA-SEFSC, and UM-RSMAS to collaborate on a probabilistic sampling design and conduct annual coral reef fish monitoring and assessment efforts in the Florida Keys coral reef ecosystem. Early in 2008, the National Park Service's South Florida/Caribbean Inventory and Monitoring Network (SFCN) also added their cooperative support.

As a result, *A cooperative multi-agency reef fish monitoring protocol for the Florida Keys coral reef ecosystem* (Brandt et al. 2009) was published with the goal of supporting fisheries stock assessments, including determining the effect of various management zones on population metrics of various exploited and non-target reef fish species over time (e.g., annual, biannual) and space (e.g., inside/outside marine reserves). The protocol underwent an NPS external science peer review and had the full support of NOAA-SEFSC, FWC-FWRI, UM-RSMAS, and NPS. This protocol guided cooperative reef fish monitoring in South Florida from 2008 to 2020. Co-located at a subset of fish survey sites, line point intercept (LPI) and coral demographic benthic surveys were added in 2014 as part of NOAA's greater National Coral Reef Monitoring Program (NCRMP). Peer reviewed publications and peer-reviewed scientific journal articles based on RVC surveys are numerous and span multiple decades (Table 2). Additionally, there are many thesis/dissertations, reports, status reports and Southeast Data, Assessment, and Reviews (SEDARs), partnerships and management actions utilizing the RVC database.

Table 2. Peer reviewed reports, protocols and scientific journal articles published based on the multi-agency reef fish visual census (RVC) protocol.

Year	Publication
1986	Bohnsack, J. A. and S. P. Bannerot. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Tech. Report NMFS 41. 15 p.
1998	Ault, J. S., J. A. Bohnsack, and G. A. Meester. A retrospective (1979–1996) multispecies assessment of coral reef fish stocks in the Florida Keys. Fishery Bulletin 96:395–414.
1999	Ault, J. S., G. A. Diaz, S. G. Smith, J. Luo, and J. E. Serafy. An efficient sampling survey design to estimate pink shrimp population abundance in Biscayne Bay, Florida. North American Journal of Fisheries Management 19:696–712.
1999	Bohnsack, J.A., D. B. McClellan, D. E. Harper, G. S. Davenport, G. J. Konoval, A. Eklund, J. P. Contillo, S. K. Bolden, P. C. Fischel, G. S. Sandorf, J. C. Javech, M. W. White, M. H. Pickett, M. W. Hulsbeck, J. L. Tobias, J. S. Ault, G. A. Meester, S. G. Smith, and J. Luo. Baseline data for evaluating reef fish populations in the Florida Keys, 1979–1998. NOAA Technical Memorandum NMFS-SEFSC-427. 61p.
2001	Ault, J. S., S. G. Smith, G. A. Meester, J. Luo, and J. A. Bohnsack. Site characterization for Biscayne National Park: assessment of fisheries resources and habitats. NOAA Technical Memorandum NMFS-SEFSC-468. 185 p.
2002	Ault, J. S., S. G. Smith, J. Luo, G. A. Meester, J. A. Bohnsack, and S. L. Miller. Baseline multispecies coral reef fish stock assessment for the Dry Tortugas. NOAA Technical Memorandum NMFS-SEFSC-487. 117 p.
2002	Bohnsack, J. A., D. E. Harper, D. B. McClellan, D. L. Sutherland and M. White. Resource survey of fishes within Looe Key National Marine Sanctuary, 1983. NOAA Technical Memorandum NOS-NCCOS-CCMA-160 and NMFS-SERSC-478. 327 p.
2003	Ault, J. S., S. G. Smith, E. C. Franklin, J. Luo, and J. A. Bohnsack. Sampling design analysis for coral reef fish stock assessment in Dry Tortugas National Park. Final Report, National Park Service Contract No. H5000000494-0012. 87 p.
2003	Franklin, E. C., J. S. Ault, S. G. Smith, J. Luo, G. A. Meester, G. A. Diaz, M. Chiappone, D. W. Swanson, S. L. Miller, and J. A. Bohnsack. Benthic habitat mapping in the Tortugas region, Florida. Marine Geodesy 26:19–34.
2004	Bohnsack, J. A., J. S. Ault, and B. Causey. Why have no-take marine protected areas? Aquatic Protected Areas as Fisheries Management Tools 42:185–193.
2005	Ault, J. S., J. A. Bohnsack, S. G. Smith, and J. G. Luo. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. Bulletin of Marine Science 76:595–622.
2005	Ault, J. S., S. G. Smith, and J. A. Bohnsack. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. Ices Journal of Marine Science 62:417–423.
2006	Ault, J. S., S. G. Smith, J. A. Bohnsack, J. G. Luo, D. E. Harper, and D. B. McClellan. Building sustainable fisheries in Florida's coral reef ecosystem: Positive signs in the Dry Tortugas. Bulletin of Marine Science 78:633–654.
2007	McClellan, D. B. and D. E. Harper (eds.). Compilation of selected unpublished RVC studies conducted by the Reef Resources Team, 1985–2002. NOAA Technical Memorandum NMFS-SEFSC-561. 104 p.
2008	Ault, J. S., S. G. Smith, J. Luo, M. E. Monaco, and R.S. Appeldoorn. Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. Environmental Conservation 35(3):221–231.
2008	Bartholomew, A., J. A. Bohnsack, S. G. Smith, J. S. Ault, D. E. Harper, and D. B. McClellan. Influence of marine reserve size and boundary length on the initial response of exploited reef fishes in the Florida Keys National Marine Sanctuary, USA. Landscape Ecology 23:55–65.

Table 2 (continued). Peer reviewed reports, protocols and scientific journal articles published based on the multi-agency reef fish visual census (RVC) protocol.

Year	Publication
2009	Ault, J. S., S. G. Smith, and J. T. Tilmant. Are the coral reef finfish fisheries of south Florida sustainable? Proceedings International Coral Reef Symposium 11:989–993
2009	Brandt, M. E., N. Zurcher, A. Acosta, J. S. Ault, J. A. Bohnsack, M. W. Feeley, D. E. Harper, J. H. Hunt, T. Kellison, D. B. McClellan, M. E. Patterson, and S. G. Smith. A cooperative multi-agency reef fish monitoring protocol for the Florida Keys coral reef ecosystem. Natural Resource Report NPS/SFCN/NRR—2009/150. National Park Service, Fort Collins, Colorado.
2010	Jones, D. L., J. F. Walter, E. N. Brooks and J. E. Serafy. Connectivity through ontogeny: fish population linkages among mangrove and coral reef habitats. Marine Ecology Progress Series 401:245–258.
2011	Smith, S. G., J. S. Ault, J. A. Bohnsack, D. E. Harper, J. Luo, and D. B. McClellan. Multispecies survey design for assessing reef-fish stocks, spatially-explicit management performance, and ecosystem condition. Fisheries Research 109(1):25–41.
2012	Ruttenberg, B. I., P. J. Schofield, J. L. Akins, A. Acosta, M. W. Feeley, J. Blondeau, S. G. Smith, and J. S. Ault. Rapid invasion of Indo-Pacific lionfish (<i>Pterois volitans</i> and <i>P. miles</i>) in the Florida Keys, USA: evidence from multiple pre- and post-invasion datasets. Bulletin of Marine Science 88(4):1051–1059.
2013	Ault, J. S., S. G. Smith, J. A. Bohnsack, M. Patterson, M. W. Feeley, D. B. McClellan, B. I. Ruttenberg, D. Hallac, T. Ziegler, J. Hunt, D. Kimball, J. Luo, N. Zurcher, and B. Causey. Assessing coral reef fish changes and marine reserve dynamics in the Dry Tortugas, Florida USA. Fisheries Research 144:28–37.
2013	Bryan, D. R., A. J. Atkinson, J. S. Ault, M. E. Brandt, J. A. Bohnsack, M. W. Feeley, M. E. Patterson, B. I. Ruttenberg, S. G. Smith, and B. D. Witcher. A cooperative multiagency reef fish monitoring protocol for the U.S. Virgin Islands coral reef ecosystem. Natural Resource Report NPS/SFCN/NRR—2013/672. National Park Service, Fort Collins, Colorado.
2014	Ault, J. S., S. G. Smith, J. A. Browder, W. Nuttle, E. C. Franklin, J. Luo, G. T. DiNardo, and J. A. Bohnsack. Indicators for assessing the ecological dynamics and sustainability of southern Florida's coral reef and coastal fisheries. Ecological Indicators 44:164–172
2015	Nadon, M. O., J. S. Ault, I. W. Williams, S. G. Smith, and G. T. DiNardo. Length-based assessment of coral reef fish populations in the Main and Northwestern Hawaiian Islands. PLoS ONE 10(8): e0133960, doi:10.1371/journal.pone.0133960
2016	Bryan, D. R., S. G., Smith, J. S. Ault, M. W. Feeley and C. W. Menza Feasibility of a Regionwide Probability Survey for Coral Reef Fish in Puerto Rico and the U.S. Virgin Islands, Marine and Coastal Fisheries 8(1):135–146.
2016	Harford, W., S. G. Smith, J. S. Ault, and E. A. Babcock. Cross-shelf habitat occupancy probabilities for juvenile groupers in the Florida Keys coral reef ecosystem. Marine and Coastal Fisheries 8(1): 147–159.
2017	Heenan, A. I. D. Williams, T. Acoba, A. DesRochers, R. K. Kosaki, T. Kanemura, M. O. Nadon, and R. Brainard. Long-term monitoring of coral reef fish assemblages in the Western central pacific. Sci. Data 4:170–176 doi:10.1038/sdata.2017.176
2018	Ault, J.S., S. G. Smith, B. L. Richards, A. J. Yau, B. J. Langseth, J. M. O'Malley, C. H. Boggs, M. P. Seki, and G. T. DiNardo. Towards fishery-independent biomass estimation for Hawaiian Islands deepwater snappers. Fisheries Research 208:321–328.
2018	Bryan D. R., J. Blondeau, A. Siana, and J. S. Ault. Regional differences in an established population of invasive Indo-Pacific lionfish (<i>Pterois volitans</i> and <i>P. miles</i>) in south Florida. PeerJ 6:e5700 https://doi.org/10.7717/peerj.5700
2019	Ault, J. S., S. G. Smith, J. A. Bohnsack, J. Luo, M. H. Stevens, G. T. DiNardo, M. W. Johnson, and D. R. Bryan. Length-based risk analysis for assessing sustainability of data-limited tropical reef fisheries ICES Journal of Marine Science 76(1):165–180.

Table 2 (continued). Peer reviewed reports, protocols and scientific journal articles published based on the multi-agency reef fish visual census (RVC) protocol).

Year	Publication
2022	Ault, J. S., S. G. Smith, and Others. Length-based risk analysis of management options for the southern Florida USA multispecies coral reef fish fishery. <i>Fisheries Research</i> (249): 1–19.
2024	Ault, J.S., J. Blondeau, L.J.W. Grove, S.L. Cass-Calay, K.J. McCarthy. Integrating the US Caribbean Reef Fish Visual Census into fishery stock assessments. <i>Bulletin Marine Science</i> .100(2):283–312. https://doi.org/10.5343/bms.2023.0025
2024	Grove, L.J.W., J. Blondeau, D.W. Swanson, and others. Expansion of an established fishery-independent survey into the US Virgin Islands' upper mesophotic zone: feasibility and management implications. <i>Bulletin Marine Science</i> . 100(2):113–131. https://doi.org/10.5343/bms.2023.0013

The survey design and data has been validated by comparing RVC size and abundance data to traditional fishery dependent data sets (recreational and commercial; example SEDAR 64 2020; Ault et al. 2021). The design-based approach of the RVC method (Smith et al 2011) for both juvenile and adult fish was chosen as the preferred fishery independent assessment of Yellowtail Snapper relative abundance by SEDAR 64 (2020). The differences in spatial scales and methodology of the fishery dependent data sets must be considered when comparing indices, nonetheless, the fishery-based metrics are like the RVC derived metrics. For example, over time the population abundance (catch-per-unit-effort [CPUE]) of Yellowtail Snapper from the commercial catch, marine recreation information program catch (MRIP) and RVC data set for juvenile and adult Yellowtail Snapper from Florida match reasonably well with each other and are presented in Figure 6 (SEDAR 64 2020). SEDAR 64 (2020) concluded the RVC surveys spatially operate in core Yellowtail Snapper habitat along the Florida Reef Tract, and adequately target population size ranges vulnerable to the fishery across a sufficient temporal period. Additionally, the effect of exploitation on selected commercial species has shown reasonably good agreement across independent surveys using length-based length analysis for numerous exploited reef fish species (Ault et al 2021). For example, although estimates of average size in the exploited phase have been generally flat for the past 40 years, the adjustments in the minimum size of capture (L_c) for Black Grouper are reflected in the size of capture regulatory changes in the exploited phase across all three survey types (Figure 7 [from Ault et al 2021]). Further, preliminary data comparing creel census data from the recreational catch at Biscayne NP compared to the RVC data indicates medium to strong positive correlation coefficients for several metrics pooled between 2008 and 2018 (V. McDonough pers. comm. Biscayne NP). These variables include average size in the exploited phase (0.95), RVC densities vs. creel landings (0.42) and RVC frequency of occurrence vs. percent of creel surveys (0.53) for 10 Biscayne NP management reef fish species of concern (see Section 2.4).

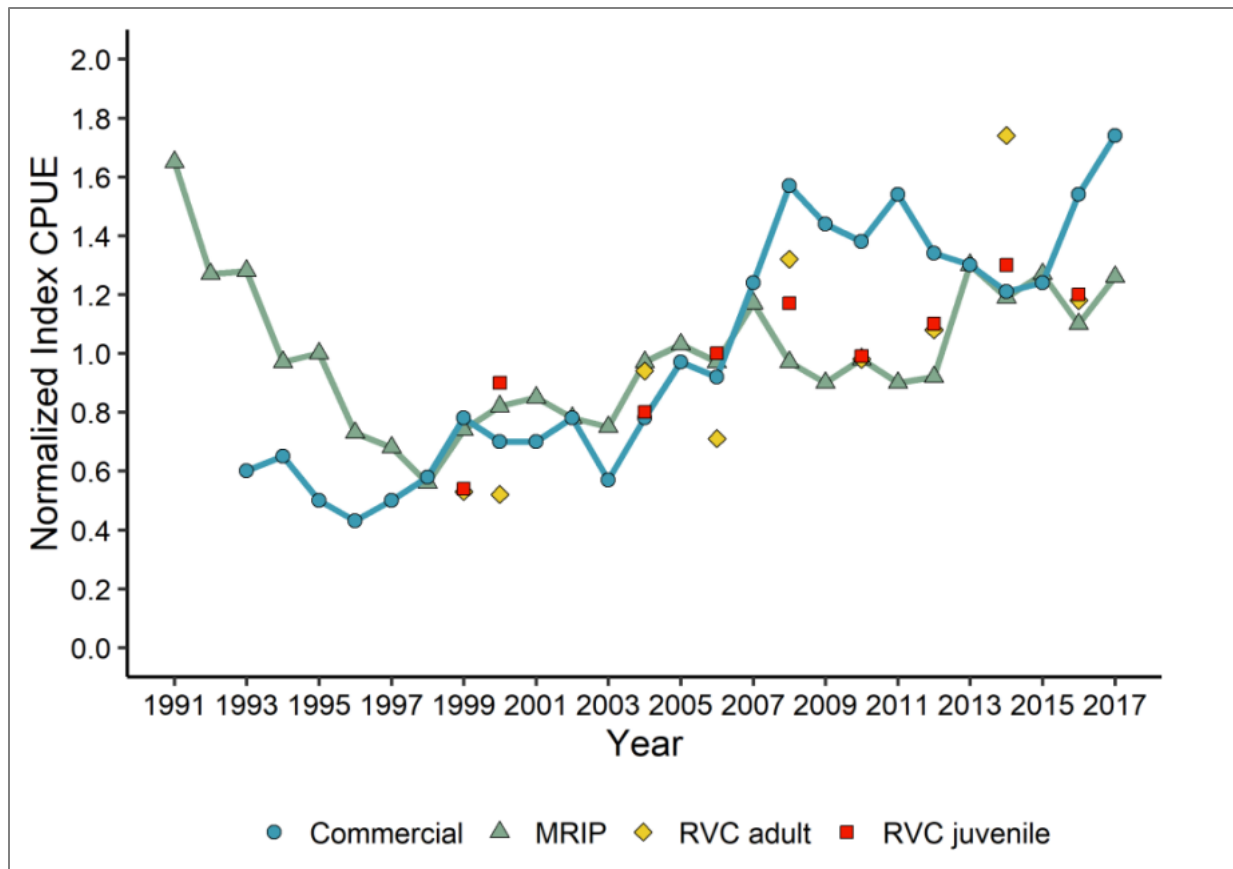


Figure 6. Recommended normalized indices of relative abundance for Yellowtail Snapper from 1991–2017 for stock assessment for the Southeastern United States. MRIP surveys conducted from 1991–2017, the commercial index was from 1993–2017, and RVC surveys from 1999, 2000 and biennially from 2004–2016.

REUSED WITH PERMISSION FROM CHRIS SWANSON, UNIVERSITY OF SOUTH FLORIDA / FWC – FISH AND WILDLIFE RESEARCH INSTITUTE

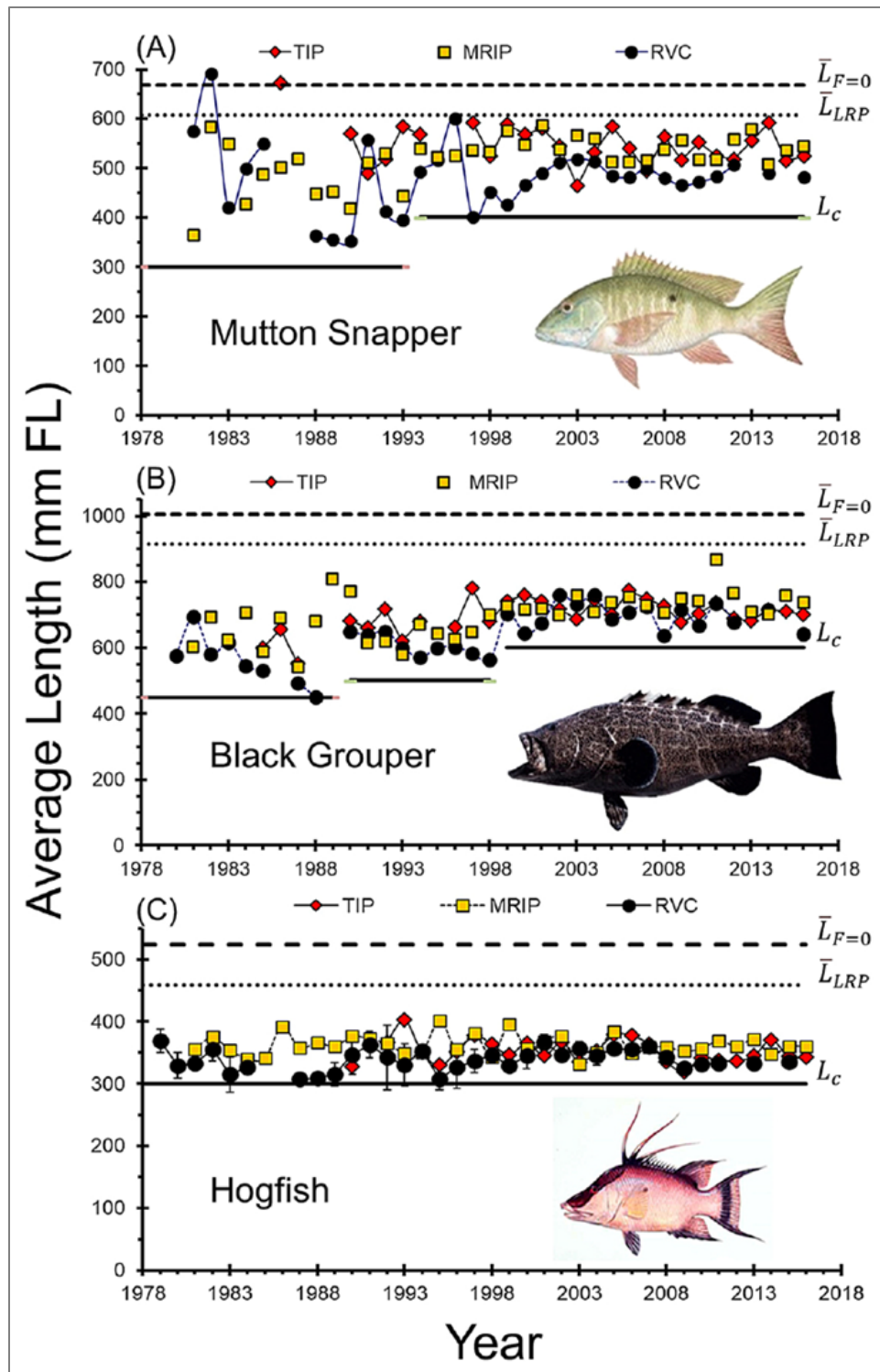


Figure 7. Time series (1978–2016) for average length in the exploited phase (L_{bar}) for three exploited reef fish stocks based on four independent survey types including commercial data (TIP), recreational data (MRIP), and RVC exploited phase data (adults > length of capture (L_c)).

REPRODUCED FROM AULT ET AL. (2022)

2.1.2 United States Virgin Islands

There is a rich history of coral reef and reef fish research in the U.S. Virgin Islands beginning with Dr. Jack Randall in the late 1950s and early 1960s in St. John. Since then, numerous scientists have conducted research in these waters furthering our understanding of coral reef ecosystems and the organisms which inhabit them. Rothenberger et al. (2008) in “*The State of Coral Reef Ecosystems of the US Virgin Islands*” provides a good source for the bulk of this research. Despite extensive studies in the region, long-term efforts directed at understanding trends in reef fish assemblages were limited to monitoring around St. John (Friedlander and Beets 2008). Since 1989, fixed site surveys have continued on an annual basis providing an invaluable historic perspective on the fish assemblages. Currently four sites are annually surveyed: Yawzi Reef, Tektite, Haulover Bay West and Newfound Bay West. Additional reef fish surveys have been conducted more recently on fixed sites in St. Thomas and St. Croix by the University of the Virgin Islands’ USVI Territorial Coral Reef Monitoring Program (TCRMP) since 2003 (Nemeth et al. 2005; Kadison et al. 2017).

Characterization of fish populations using fishery-independent visual fish censuses were also conducted annually in St. John and St. Croix from 2001–2011 by the NOAA-NCCOS formerly known as Center for Coastal Monitoring and Assessment Biogeography Branch (NOAA-BB) in collaboration with NPS (Friedlander et al. 2013). The survey design has changed over time to meet management objectives, but on average 160 and 200 sites were surveyed each year within and adjacent to Buck Island Reef NM, Virgin Islands NP and Virgin Islands Coral Reef NM, including the mid shelf reef habitat south of St. John. The primary method employed was a single visual linear belt transect (25 meters $\times$ 4 meters [82 $\times$ 13.1 feet]) adapted from Brock (1954) to assess fish abundance, composition, and size distributions (Menza et al. 2006). Data collected during these surveys have been used to define habitat influences on fish community metrics (Kendall et al. 2004; Pittman et al. 2007; Friedlander et al. 2013) and on individual species (Kendall et al. 2003; Friedlander et al. 2013). In addition, differences in fish assemblages inside and outside of national park units have been described (Monaco et al. 2007; Monaco et al. 2009; Friedlander et al. 2013; Pittman et al. 2008).

Despite a rich history of reef fish research, the first attempt to monitor ecosystem-wide reef fish populations and community status in the U.S. Virgin Islands occurred in 2012. Population-level estimates are fundamental components of ecosystem management (Levin et al. 2009), and the lack thereof can hinder the implementation and evaluation of proper management actions. *A Cooperative Multiagency Reef Fish Monitoring Protocol for the U.S. Virgin Islands Coral Reef Ecosystem* (Bryan et al. 2013) outlined refinement of the historical efforts described above and expanded spatial coverage to the entire USVI shelf for the islands of St. Thomas, St. John and St. Croix. This program provided population and park-wide estimates of coral reef fish as well as methods to improve the power to detect species-level changes spatially and temporally (Bryan et al. 2016). The protocol represented agreement among NOAA-SEFSC, NOAA-NCCOS, UM-RSMAS and NPS-SFCN, to adopt the stratified survey design from the South Florida protocol (Brandt et al. 2009) across all USVI hardbottom habitats (< 30 meters [98.4 feet] deep) using the belt transect method to quantify reef fishes described by Menza et al. (2006) and Bryan et al. (2013). Shelf-wide single-stage stratified surveys were initiated in St. Croix in 2012 using 50 $\times$ 50 meter (164 $\times$ 164 feet) grids.

Rotation on a USVI biennial schedule started in St. John/St. Thomas in 2013 and resumed in St. Croix in 2015, as part of NOAA's National Coral Reef Monitoring Program (NCRMP) to assess benthic and reef fish populations. Belt-transect fish surveys were concurrent with and along the same transect as Benthic Assessment (Line Point-Intercept) and Coral Demographic surveys. The USVI surveys were scheduled in alternating years with Florida surveys (Figures 2 and 3). Surveys using the belt-transect methodology continued in the U.S. Virgin Islands through 2015. Beginning in 2017, the RVC Bohnsack-Bannerot point count method (Brandt et al., 2009) was adopted by all agencies as the single fish survey method used throughout Florida and the Caribbean. This protocol marks a revision of the Brandt et al. (2009) and Bryan et al. (2013) protocol into a single narrative and set of standard operating procedures for the Florida and USVI coral reef ecosystems.

2.2 Measurable Objectives of Monitoring

The goals of the surveys are to support multispecies stock assessments and determine the effectiveness of different marine management zones in the Florida Keys and USVI regions (Smith et al. 2011). The measurable objectives are to track the following population metrics of target reef fish species over time (e.g., annual, biennial) and space (e.g., inside/outside marine reserves):

- Relative density, abundance, and proportion of occurrence
- Size-structure (size frequency distribution)
- Spatial distribution
- Average size in the exploited phase
- Species richness (target and non-target species)

Importantly, the metrics listed above may also be appropriate for some, but not all non-target species. While the stationary point count method is effective for a wide array of reef fish species, calculated metrics have the potential to be unreliable with species that are rarely seen, cryptic, or highly mobile. The fisheries-independent estimates are considered relative rather than absolute since we do not know the true capture efficiency of the visual survey methodology for individual fish species. In other words, we are not likely counting on average 100% of all fish present within an individual survey; the counts will be higher on average for some species (highly visible, less mobile species) and lower on average for other species (cryptic or highly mobile species). Special attention is paid to specific exploited and/or ecologically important reef fish species for measuring the performance of the survey allocations. While each agency may have their own specific objectives that can vary by sampling year, these primary objectives are agreed upon by all agencies and guide the monitoring effort.

In South Florida, the sampling design is optimized with respect to six focal species which are all important commercial and recreational fisheries in the region: Hogfish (*Lachnolaimus maximus*), Mutton Snapper (*Lutjanus analis*), Gray Snapper (*L. griseus*), Yellowtail Snapper (*Ocyurus chrysurus*), Red Grouper (*Epinephelus morio*), and Black Grouper (*Mycteroperca bonaci*) (Smith et al. 2011). These species are the most prominent examples of overfished high-level predators in the Florida Keys (Ault et al. 1998; Ault et al. 2019; Ault et al. 2021).

The USVI sampling design is optimized with respect to eight ecological and commercially important species, representing seven families (Bryan et al. 2016). Most reef fishes, including parrotfishes, are commercially targeted in the U.S. Virgin Islands. Traditional large-bodied snapper and grouper species were omitted because they occur in very low densities across the region (Kadison et al. 2017). The focal list is: Coney (*Cephalopholis fulva*), Red Hind (*Epinephelus guttatus*), Yellowtail Snapper (*Ocyurus chrysurus*), French Grunt (*Haemulon flavolineatum*), Four-eye Butterflyfish (*Chaetodon capistratus*), Stoplight Parrotfish (*Sparisoma viride*), Blue Tang (*Acanthurus coeruleus*), and Queen Triggerfish (*Balistes vetula*). Large predatory grouper species, including Nassau Grouper (*Epinephelus striatus*), Tiger Grouper (*Mycteroperca tigris*) and Yellowfin Grouper (*M. venenosa*), are uncommon in the U.S. Virgin Islands except on deep water outer shelf reefs; and with the exception of Mutton Snapper, large predatory snappers (Cubera Snapper [*Lutjanus cyanopterus*], Dog Snapper [*L. jocu*]) are rarely encountered in St. Croix (Kadison et al. 2017).

Although the sample design is optimized with respect to those species, all fish species are recorded. Thus, monitoring efforts also obtain important information about many other fishery non-targeted species and the overall trophic structure. These data form the scientific basis for effective management actions. Historically, visual reef fish surveys in Florida and the U.S. Virgin Islands have been limited to approximately 30–33 meter (98.4–108.3 feet) depth but were expanded in 2019 by NOAA’s Coral Reef Conservation Program in partnership with the University of the Virgin Islands to include the 30–50 meter (98.4–164 feet) depth range in the U.S. Virgin Islands through the application of technical diving methods and decompression dive management.

2.3 Overview of Monitoring Program

This protocol describes a probabilistic sampling approach that provides population and community metrics for resource management in South Florida and the U.S. Virgin Islands. The monitoring program is based on an iterative approach which progresses from sample design to analysis and reporting (Figure 8). The survey design was originally developed for the reef fish visual survey program in South Florida (Brandt et al. 2009; Smith et al. 2011) and expanded to the U.S. Virgin Islands in 2012 (Bryan et al. 2013). Data collected will be used towards periodic improvements in the survey design, analysis and annual reports. The overall survey allocation is ultimately limited by resources and time in the form of sampling effort. However, iterative improvement can be achieved through spatial allocation of effort.

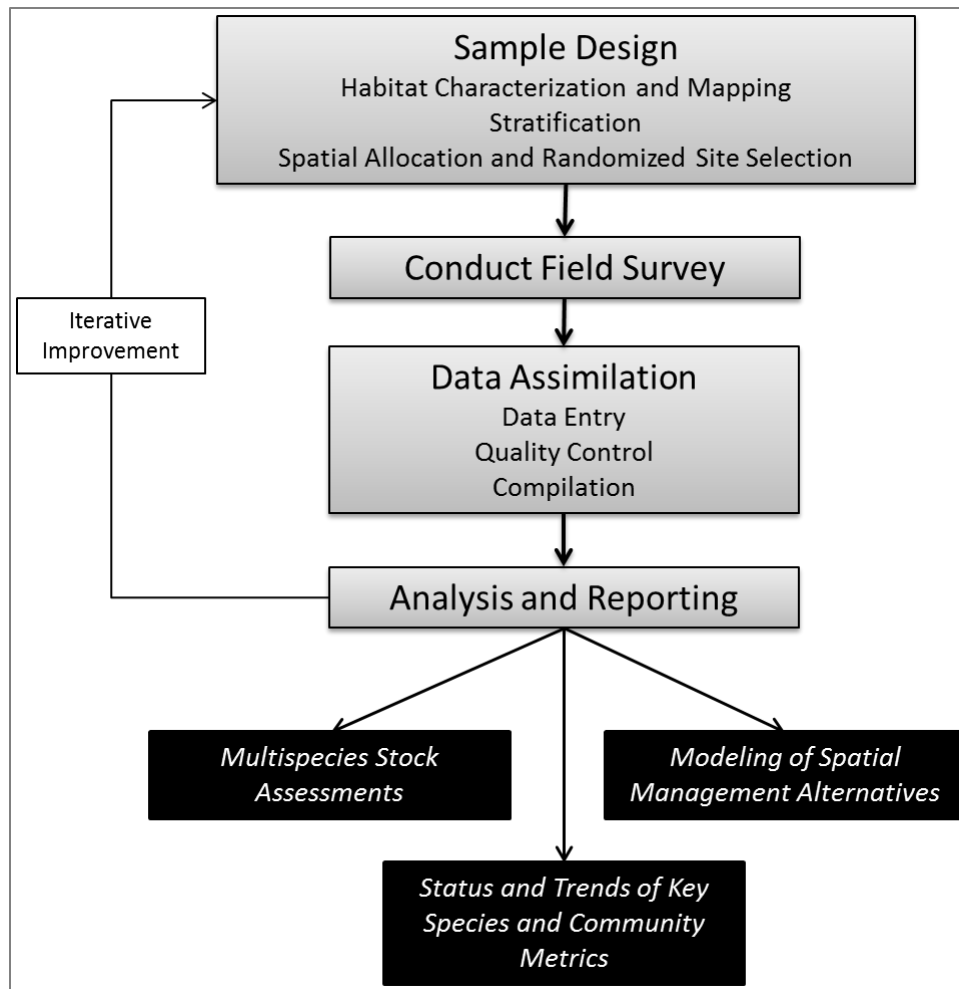


Figure 8. Monitoring program flow chart.
 REDRAWN FROM BRYAN ET AL. (2013)

2.4 Link to Management Decision-Making

Overall, there is an expectation that parks managed as no-take marine reserves (Buck Island Reef NM, Virgin Islands Coral Reef NM, Dry Tortugas NP RNA) will see an increase in the numbers and size of exploited species over time compared with open-use areas outside those reserves, and a return to a sustainable ecological balance with increases seen in the higher trophic levels. After increases within these no-take reserves, adjacent areas “open” to fishing are expected to see increases as well (i.e., “spillover”). Failure to detect such change could cause the parks to consider changes in enforcement levels, increases in public education efforts, and targeted studies into the lack of response, e.g., determining whether critical spawning aggregation sites and/or juvenile habitats are outside reserve boundaries, or investigating the effects of a new invasive species (e.g., lionfish).

This protocol does not define thresholds or triggers for management decision making. However, NOAA, state, and territorial governments can use the data to conduct multi-species stock assessments; support changes to annual total catch limits, bag limits, size limits, closures, and gear changes; and evaluate the effectiveness of the size and location of marine protected areas and

ecosystem-based management (Ault et al. 2024b). The FWC, in collaboration with Biscayne NP, recently approved fishery regulatory changes to help meet the fisheries management goals of the park (FWC 2020). Adjustments included increasing the minimum size limits for a select list of exploited species including Gray Snapper, Lane Snapper (*L. synagris*), Mutton Snapper, Schoolmaster (*L. apodus*), Yellowtail Snapper, Red Grouper, Gray Triggerfish (*Balistes capriscus*), White Grunt (*Haemulon plumierii*) and Bluestriped Grunt (*H. sciurus*); and limiting the aggregate harvest limit for commonly targeted fishes within park boundaries. The performance of these regulatory changes will be evaluated by tracking the population metrics of these species over time and space based on RVC data. These changes and the periodic review of the effectiveness of these changes will ensure the Biscayne NP management goals are met (FWC 2020).

In addition, FWC and Dry Tortugas NP have jointly managed the large (119 square kilometers [46 mi²]) no-take marine reserve (RNA) within the park since 2007 (Hallac et al. 2013). The performance of this area was initially evaluated in five-year intervals, with efficacy evaluated primarily based on data from RVC surveys that established a baseline for the Dry Tortugas fish populations prior to the creation of the RNA and Tortugas Ecological Reserves. The RNA protects shallow water habitat near an offshore multispecies spawning aggregation site, that with the assistance of prevailing currents, distributes fish larvae along the Florida reef tract and southeast Florida coast (Lee and Williams 1999; Domeier 2004; Feeley et al. 2018). Based on the positive improvements in numbers and size of targeted fishes such as Yellowtail Snapper, Mutton Snapper and Black Grouper (Ault et al. 2013), the Florida Fish and Wildlife Conservation Commission voted in 2018 to extend the protected status of the RNA within Dry Tortugas NP for another 20 years.

Finally, the data can be used in public outreach communications to educate the public, elected officials, students and park visitors about the status of reef fish, the rationale for the various fishing restrictions, and whether the combination of management actions are having the desired effect.

3. Sampling Design

3.1 Rationale for Selecting This Sampling Design over Others

There are many ways to select a sample from a population to generate unbiased estimates. A simple random sampling design is appropriate for situations where there is no spatial structure in the variance of the investigated species or when little information is available upon which to logically stratify the sampling effort. If information is known about a population, a selection method that provides more accurate and precise survey estimates than a simple random sample can be devised. Reef fish are typically spatially heterogeneous according to certain environmental covariates, such as depth, habitat and vertical relief (Fukunaga et al. 2020b). Using these covariates to stratify the sampled area can improve sampling efficiency. Random samples can then be allocated within these field strata based on each stratum's proportional area and species-specific (one or more) variance structure within that stratum. This type of stratified-random sampling design was chosen and is capable of more effectively and efficiently sampling a reef fish population than a simple random sampling design (Cochran 1977; Thompson 2002; Smith et al. 2011).

With improvement in high-resolution remote-sensed mapping products, the program has evolved from 200×200 meter (656.2×656.2 feet) to 100×100 meter (328×328 feet) to currently a 50×50 meter (164×164 feet) survey grid design in Florida and in the U.S. Virgin Islands. Ideally, the grid size would match the 15-meter (49.2 feet) diameter circular plot used in the fish visual census survey. However, it became clear that significant positional error (50–100 meter [164–328 feet]) of mapped reef created inefficiency (i.e., aborted survey attempts) and during creation of benthic habitat maps, minimum mapping units led to exclusion of small, isolated reef structures (Smith et al. 2011). The 50×50 meter grid presently used is large enough to implement the survey method while allowing for the positional uncertainty of the global positioning system, underlying benthic habitat maps, and navigation to and dropping divers on survey locations (Stamoulis et al. 2018). The current 50×50 meter grids were nested within the previous UTM grid system.

As documented in detail in SOP RF01 *Statistical Sampling Design—Version 2.0* (SFCN 2025a) existing benthic habitat maps and data collected from previous reef fish sampling are used to optimize sampling. Site selection is based on a single-stage stratified random sampling design which uses the variance structure of previously collected data to efficiently allocate sites. Certain benthic habitat measures are strongly associated with principal reef fish population and community metrics. These measures include depth, the degree of vertical relief (e.g., rugosity, complexity), and the degree of patchiness (e.g., amount of soft bottom substrate interspersed among reef structures) of the hardbottom substrate (Ault et al. 1999; Ault et al. 2002; Franklin et al. 2003; Ault et al. 2005a). The survey regions (Florida Keys, Tortugas, St. Thomas/St. John, and St. Croix) were partitioned into a 50×50 meter Universal Transverse Mercator (UTM) grid framework of primary units, and the benthic map is used to assign each primary unit to a stratum. The strata are defined by region, habitat or habitat zone, depth, rugosity (Florida only), and management level.

The number of samples (primary units) allocated to these strata is based on the variance structure of fish species densities estimated from previous surveys. The grid cells' assigned strata are used as a

guide to sample a particular type of stratum, but the actual “sampled stratum” is based on the environmental information collected by the diver at the location the sample occurred, irrespective of the target grid cell’s assigned stratum, i.e., the survey is not intended to characterize the grid cell. Applying a stratified random method like this instead of a simple random design has been shown to dramatically improve sampling efficiency (Ault et al. 1999; Ault et al. 2005a; Bryan et al. 2013; Bryan et al. 2016). The probabilistic survey requires a clearly defined sample frame, with a finite number of non-overlapping sample units that have a known chance of selection. This is essential for data analysis under sampling theory (Cochran 1977). A grid-based survey that applies adequate effort to each cell surveyed and a scale correction factor is the preferred method for measuring area of occupancy (Kunin et al. 2000; Joseph and Possingham 2008). Population size can be accurately estimated by means of numerical integration over a coarse grid when it is a function of complicated spatial structure (Petrovskaya and Petrovskii 2010).

A stationary point count was chosen as the in situ visual sampling method versus other fishery-independent methods for several logistical reasons. Other methods include image-based methods (Risk and Risk 1997), aerial surveys (Sale and Sharp 1983), and in situ methods such as belt transects (Brock 1954) and roving diver surveys (Pattengill-Semmens and Semmens 2003). For the purposes of this survey, stationary point counts are less costly than image-based analysis (Risk and Risk 1997) and provide more detailed and quantitative information than aerial or roving diver surveys. In comparison with belt transects, stationary point counts allow divers to simultaneously collect data on the relative density and size distributions of the entire fish community, except for rare cryptic species (Bohnsack and Bannerot 1986). Most belt transect methods only target one or a limited number of specific fish groups. These methods were found to be biased in their estimates of fish density and proportion of occurrence, and they require observers to bin size estimates (e.g., 5 centimeter [2 inch] increments) rather than record individual size estimates (Demartini and Roberts 1982; Sale and Sharp 1983). Also, the Florida Keys reef tract encompasses a variety of habitat types, including some that are restricted in size, such as patch reefs, that make the placement of a linear survey unit difficult. In the Florida Keys, Colvocoresses and Acosta (2007) found higher, more accurate density estimates for the targeted fish groups using the point count versus belt transect method. Visual stationary point counts have also been utilized throughout the U.S. Pacific regions of the Hawaiian and Mariana Archipelagos, American Samoa and the Pacific Remote Island Areas since 2009 by NOAA’s NCRMP (McCoy et al. 2018).

3.2 Sampling Domain

3.2.1 Florida and Tortugas

The Florida Keys reef tract consists of a system of reef habitats that extend parallel to the Florida Keys Archipelago of islands approximately 370 kilometers (230 miles) from Key Biscayne near Miami to the Tortugas (Figures 1 and 2). The reef tract lies parallel to the Straits of Florida with the Florida current to the south and southeast and Florida Bay to the north and northwest. The reef tract encompasses a variety of habitats in addition to coral reefs, including mangrove stands, sea grass beds, lagoons, and freshwater marshes and estuaries. These diverse habitats are known to support more than 500 species of fish (Stark 1968), many of which, including important commercial and

recreational fisheries species such as snappers and groupers, utilize a range of habitats throughout their life history (Lindeman et al. 2000). However, 389 of the fish species are primarily associated with coral reef (i.e., hardbottom) habitat (Stark 1968). To increase efficiency and because the RVC methodology is optimized for reef habitat (Bohnsack and Bannerot 1986), the sampling domain for this protocol does not include the seagrass, mangrove, or other, non-hardbottom habitats that lie within the region. Instead, the monitoring program specifically targets reef fish populations and their primary associated hardbottom habitats. Therefore, the sampling domain for reef fish monitoring in the Florida Keys and Tortugas consists of all known mapped hardbottom habitat stretching from Biscayne NP to the lower Florida Keys and extends to the shallow limestone banks of the Tortugas. Presently, surveys target all hardbottom habitats in water less than 33 meters (108.3 feet), but deeper depths (33–50 meters [108.3–164 feet]) and beyond (500 meters [1,640.4 feet]) using multi-gear surveys, could be added to the sampling domain in the future (Grove et al. 2024). Regions are stratified by reef habitat zone (inshore, midchannel, offshore patch reef, forereef, high relief reef), depth (shallow: 0–11.9 meters [0–39 feet], mid: 12–21.9 meters [39.4–71.9 feet], deep: 22–33 meters [72.2–108.3 feet]), rugosity (< 0.15 meters [0.5 feet], 0.15–0.25 meters [0.5–0.8 feet], 0.26–0.39 meters [0.9–1.3 feet] and ≥ 0.4 meters [1.3 feet]) and subregion (Biscayne, Upper, Middle, Lower Keys, Dry Tortugas, Tortugas Bank). There are 11 habitat zone-depth-rugosity strata in the Florida Keys and nine in the Tortugas subregions. Management areas (no-take reserves, ecological reserves) receive an additional level of stratification (inside or outside). Combining all stratum categories with managed reserve areas yields 14 possible field strata across the Florida Keys and 18 strata in the Tortugas (32 total in Florida). This survey design provides flexibility to merge strata for regional and management zone comparisons and address various analyses in an ever-evolving program. SOP RF01 *Statistical Sampling Design—Version 2.0* (SFCN 2025a) provides information on number of cells and particular stratum designations for each subregion or management area.

3.2.2 United States Virgin Islands

The U.S. Virgin Islands are in the northern Caribbean Sea on the western edge of the lesser Antilles, about 62 kilometers (39 miles) east of Puerto Rico. The U.S. territory consists of three main volcanic islands: (1) St. Thomas, (2) St. John and (3) St. Croix. St. Thomas and St. John are located on the Puerto Rico shelf with the British Virgin Islands (Figures 3 and 4). St. Croix, the largest island, sits on a narrow shelf about 60 kilometers (37 miles) south of St. Thomas and St. John and is separated by the 4,000-meter (13,124 feet) deep Virgin Islands Trough. Each of these islands is surrounded by a diverse inter-connected coral reef ecosystem and includes a wide range of habitat types (Kendall et al. 2001). Reef fish use a variety of these habitats (mangroves, seagrasses and unconsolidated vegetated and non-vegetated habits, coral reef) throughout their life history (Christensen et al. 2003; Grober-Dunsmore et al. 2007). However, given limited resources for sampling, effort towards population estimates are more efficient when targeting adult populations, which are typically observed on patch reefs and deeper offshore reefs (Eggleston 1995; Dahlgren and Eggleston 2000; Jones et al. 2010). Total fishable areas on the island shelves vary considerably, with water greater than 25 meters (82 feet) making up 90% of area around St. Thomas/St. John and less than 15% in St. Croix (Kadison et al. 2017). High valued snappers and groupers along with “potfish” (i.e., generic reef fish caught in fish traps) are targeted commercially throughout the U.S. Virgin Islands (Kadison et al. 2017). The sampling domain for reef fish monitoring in the U.S. Virgin Islands is all known

mapped hardbottom habitats in U.S. waters less than 30 meters (98.4 feet) deep, with the exception of an exclusion area south of the approach to the oil refinery on the south shore of St. Croix. Regions (St. Croix, St. Thomas/St. John) are stratified by habitat type, depth (< 12 meters, ≥ 12 meters [39.4 feet]) and management zone (inside, outside). The USVI regions are broken into 12 habitat-depth field strata in both St. Thomas/St. John and in St. Croix. Managed marine reserve areas create 44 total strata in St. Thomas/St. John and 40 in the St. Croix region. SOP RF01 (SFCN 2025a) provides additional information on number of cells and particular stratum designations for each subregion and management area.

3.3 Allocation and Site Selection

Allocation of sampling effort is determined before each sampling season using a stratified random sampling design (rationale and details in SOP RF01 [SFCN 2025a]). Stratification is based on geographic region, habitat class, depth, rugosity, and management zone. Digital layers for each of these components are contained within a geographic information system (ArcGIS) and are used to delineate the survey domain, strata, and sample units. To control for spatial variation in population metrics, a single-stage stratified-random sampling design following Cochran (1977) is utilized with a 50 × 50 meter (2,500 square meters [26,910 ft²]) grid. Individual grid cells serve as the primary sample units (PSU), with one secondary sample selected within each primary unit. The secondary sample unit (SSU) consists of a diver buddy team (typically two divers to meet dive safety standards), with each diver executing a stationary point count. Therefore, two scientific dives are completed within each primary unit and the data are averaged, resulting in one SSU per primary unit.

The number of sites sampled in each stratum follows a Neyman allocation scheme, in which allocation is based on the proportional area of the stratum and the variance structure of the population metric (i.e., fish density) among strata (Cochran 1977). This analysis is performed using previous years' data and with the goal of achieving a maximum 20% coefficient of variation for the focal species in Florida and the U.S. Virgin Islands (listed in Section 2.2). However, the survey targets multiple species and a higher level of precision is possible for several of the target species. Examples of target precisions of focal species are presented in SOP RF01 (SFCN 2025a). Under optimal funding levels, a region-wide sampling effort is encouraged every other year with a proportionally greater amount of effort within the National Parks and NTMRs to allow for inside and outside comparisons (Figures 1 to 4). A proportionally greater amount of effort is required within management zones because although they are smaller in comparison to the area outside of them, reef fish variance is similar and requires an equal amount of effort. Salt River NHP&EP in the U.S Virgin Islands and the 23 small NTMRs in the FKNMS are smaller management zones and would require a dramatic proportional over-allocation to obtain a similar level of precision. Instead, sampling effort should be enough to ensure at least two samples within each stratum inside of Salt River NHP&EP and two samples within the NTMRs to allow for the calculation of variance. Table 3 and Table 4 depict the historical total sampling effort and effort inside NTMRs in Florida and the U.S Virgin Islands since the inception of shelf-wide, stratified-random surveys. The final target number of primary sample units represents a balance between achieving an acceptable precision level in estimating abundances for the focal species as well as the physical and budgetary capacities of the agencies to sample. Although the COVID-19 pandemic led to cancelations, reduced sampling efforts

and disrupted the survey schedule between 2020 and 2023, resulting in domain-wide surveys in the Dry Tortugas taking more than a year to complete.

Table 3. Historical survey effort of primary sampling units (*n*) for reef fish visual census (RVC) stratified random surveys in the Florida Keys, Tortugas and the United States Virgin Islands.

Year	Florida Keys	Tortugas	St. Thomas/ St. John	St. Croix	Total
1999	161	170	–	–	331
2000	228	207	–	–	435
2001	305	–	–	–	305
2002	356	–	–	–	356
2003	237	–	–	–	237
2004	127	310	–	–	437
2005	256	–	–	–	256
2006	328	253	–	–	581
2007	317	–	–	–	317
2008	376	338	–	–	714
2009	516	–	–	–	516
2010	379	364	–	–	743
2011	402	–	–	–	402
2012	416	416	–	–	832
2013	–	–	–	–	0
2014	432	358	–	–	790
2015	–	–	–	–	0
2016	405	286	–	–	691
2017	–	–	236	181	417
2018	434	337	–	–	771
2019	–	–	322	314	636
2020	106	–	–	–	106
2021	115	299	165	148	727
2022	648	118	–	–	766
2023	180	188	287	275	930
2024	622	387	–	–	1009

Table 4. Historical survey effort of primary sampling units (*n*) for reef fish visual census (RVC) stratified random surveys in National Parks and no-take marine reserves (NTMR) in Florida and the United States Virgin Islands.

Year	Biscayne NP	Florida Keys NTMRs	Tortugas NP	Tortugas North ER	Virgin Islands NP	Virgin Islands Coral Reef NM	Buck Island Reef NM & Salt River HP&EP	Total
1999	5	57	78	68	–	–	–	208
2000	25	76	124	61	–	–	–	286
2001	39	98	–	–	–	–	–	137
2002	72	81	–	–	–	–	–	153
2003	57	79	–	–	–	–	–	136
2004	31	37	199	61	–	–	–	328
2005	35	69	–	–	–	–	–	104
2006	47	97	155	63	–	–	–	362
2007	55	75	–	–	–	–	–	130
2008	60	87	213	76	–	–	–	436
2009	69	110	–	–	–	–	–	179
2010	55	100	228	85	–	–	–	468
2011	61	90	–	–	–	–	–	151
2012	55	114	268	91	–	–	–	528
2013	–	–	–	–	–	–	–	0
2014	91	119	238	73	–	–	–	521
2015	–	–	–	–	–	–	–	0
2016	98	105	193	71	–	–	–	467
2017	–	–	–	–	56	36	70	162
2018	88	113	193	95	–	–	–	489
2019	–	–	–	–	56	49	129	234
2020	106	–	–	–	–	–	–	106
2021	115	–	176	91	27	14	48	356
2022	173	184	49	47	–	–	–	280
2023	180	–	134	34	58	42	94	362
2024	184	185	236	92	–	–	–	513

3.4 Level of Change That Can Be Detected

The sampling design is targeted to allow statistically valid comparisons of population metrics through time and in space for selected economically and ecologically important reef fish species and their life stages (listed in Section 2.2). A second major goal is to be able to determine the efficacy of management zones in protecting and enhancing the populations of these species, therefore optimal sampling allocation distributes sites in protected and unprotected areas to allow for direct comparisons between them. Focal species include those targeted heavily by recreational and commercial fisheries. Many of these species have seen significant declines in recent years and are currently considered overfished in South Florida and the U.S. Virgin Islands (Ault et al. 2005a; Kadison et al. 2017). The population metric used for sampling optimization is mean stratum relative fish density (D_{sr}), and the coefficient of variation (CV) of this metric for each focal species is used as a dominant performance measure (SOP RF01 *Statistical Sampling Design—Version 2.0* [SFCN 2025a]). Other metrics used to measure ecosystem health, such as species richness and diversity, typically have low variances. If sample effort is optimized towards individual species, the precision to detect change for these metrics is usually very high (Bryan et al. 2013).

Each year, the sampling effort can change depending on the capacity of the agencies to perform the surveys, but typically a CV of 10–20% is targeted for the focal species investigated. The detectable level of change is directly tied to the CV for individual focal species and with 95% confidence, is approximately twice the CV (see SOP RF05 *Data Analyses and Reporting—Version 1.1* [SFCN 2025b] for details). Thus, with a maximum CV of 20% set for the focal species, we can detect a 40% level of change with 95% confidence. In several cases (and even for some non-focal species) an even smaller level of change can be detected but is dependent on the CV for the period or populations observed. This method is used to compare metrics from different time periods or to compare different management zones.

4. Field Methods

4.1 Field Season Preparations and Equipment Setup

In preparation for each field season, agency groups will meet and determine the abilities and needs of each group for participation in field sampling. At this time, a schedule will be developed for training activities (details in SOP RF02 *Participant Training—Version 1.1* [SFCN 2025c]) and meetings that must take place prior to the start of sampling. Sample numbers, locations, and the agency/group responsible for surveys will be determined prior to the start of the field season (SOP RF01 *Statistical Sampling Design—Version 2.0* [SFCN 2025a]). Live-aboard vessel contracts are the responsibility of the sponsoring agency and will be in place with adequate time to confirm advance scheduling dates before the start of the field season.

Permits are required from the U.S. Virgin Islands Department of Planning and Natural Resources (DPNR) for conducting fish surveys in the Virgin Islands. Permits are also required from the Florida Keys National Marine Sanctuary for surveys in South Florida and the Dry Tortugas, including a special use permit for operating within the Ecological Reserves. Park permits from State parks and from NPS are also required from the individual parks where surveys are planned. The NPS boats driven by NPS staff can work in the national parks without a separate permit, but the overarching NOAA effort still needs the appropriate permits. Anchoring is not permitted within most NPS park boundaries (except Biscayne NP) without special permission from NPS and notification of NPS law enforcement personnel.

All participants are personally responsible for ensuring their compliance with diving authorization requirements. Each agency is responsible for verifying that their participants have received the appropriate level of dive training (Section 7.2 and 7.3) and are equipped with all necessary sampling gear for that season. Equipment details can be found in Section 8.2 and SOP RF03 *Field Data Collection—Version 2.0* (SFCN 2025d).

4.2 Reef Visual Census (RVC) Surveys

The RVC method used in these surveys is based on the timed stationary point count method of Bohnsack and Bannerot (1986), with some modifications and additions. The rationale and details of site selection and making observations in the field are covered in SOP RF03 (SFCN 2025d). In general, one set of paired visual surveys takes place per site in the same stratum, with divers optimally separated by approximately 15 meters (49.2 feet) distance but close enough to respond in case of an emergency, i.e., cylinders may overlap if required for diver safety. Both individual survey cylinders (7.5 meters [24.6 feet] radius) are located within the same primary unit (50 × 50 meter [164 × 164 feet] grid cell). Fish are surveyed within an imaginary cylinder centered on the diver which extends from the reef substrate to the limits of vertical visibility, usually the surface. Divers identify, estimate size, and count all fish species present, followed by a rapid habitat assessment of biotic and abiotic benthic cover and relief.

Divers are deployed either by live boating or by anchoring, but live boating is the preferred method. Teams enter the water within the grid cell on a predetermined general location of hard bottom habitat

(See SOP RF03 [SFCN 2025d]). Each buddy team will carry a reel with a line attached to a surface buoy and surface GPS unit to record the location of the actual sample. The buddy pair descends as a team to the bottom and performs individual timed fish surveys on the first reef habitat encountered and returns together to the surface at the surface buoy for recovery onto the vessel. Consistency in this approach is emphasized, to avoid bias created by preferentially choosing habitat types based on high quality core habitat or edge features. Total dive time for a paired fish survey takes approximately 20–40 minutes depending on the survey depth and site complexity. For each site, two types of data are taken: (1) field/boat log data, which records where, when and by whom sites were sampled, and (2) fish/habitat data, which are the RVC-specific data recorded by each diver.

4.3 Post-mission Equipment Maintenance and Storage

Datasheets are rinsed in freshwater, dried, scanned and transferred to the NOAA Data Manager. All field equipment must be rinsed off in freshwater after the sampling trip, with attention to select decontamination procedures if required. Broken equipment must be repaired or replaced as necessary, and all equipment returned to its assigned location. Care and maintenance procedures for boats are in their boat SOPs (separate from this document).

5. Data Control

5.1 Post-collection Data Handling

Initial discussions among dive buddies will occur immediately after data collection to ensure there is agreement on main variables (e.g., habitat characteristics, visibility, current, species observed).

Underwater data sheets are also reviewed to make sure all entries (e.g., site ID, time) are legible, completed, and accurate. Data sheets are maintained securely while on board the boat, rinsed with fresh water and scanned. Scanned copies of data sheets are organized and stored on the respective agency's server and are re-distributed for subsequent data proofing of the RVC database (Figure 9).

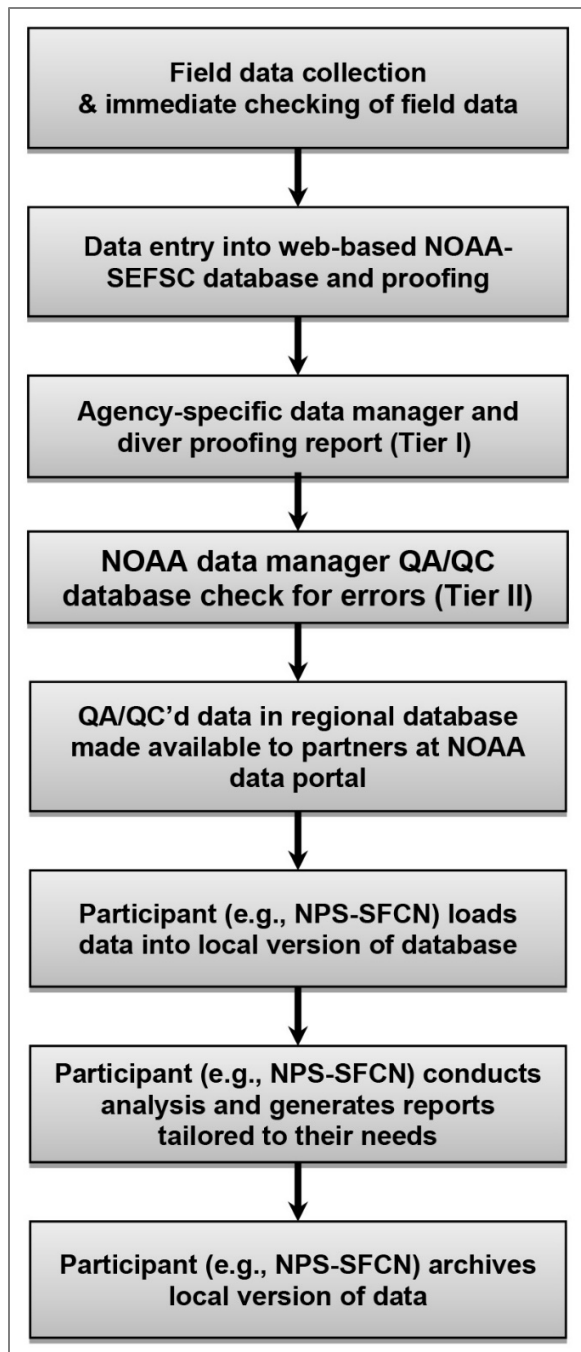


Figure 9. Flow of data and QA/QC process.
ADAPTED FROM BRYAN ET AL. (2013)

5.2 Data Entry, Verification and Editing

The NOAA Data Manager will share the online address of the web-based RVC Data Entry Program with participants prior to the start of the season for Florida (https://grunt.sefsc.noaa.gov/rvc_data_entry/) or Caribbean (https://grunt.sefsc.noaa.gov/caribbean_data_entry/) surveys. Data collected for each stationary point

count are entered via the RVC Data Entry Program following the methods outlined in SOP RF04 *Data Entry and Proofing—Version 2.0* (SFCN 2025e). Divers are responsible for accurately entering their data and checking their entry prior to submitting. Data for the field/boat log will also be entered into the RVC Data Entry Program by the agency-specific data manager or an assigned representative. Initial data entry and proofing is the responsibility of the participants that collected the data in the field. Data are entered the same day as they were collected or as soon as possible, preferably within a week. This minimizes discrepancies with omitted data or interpreting what was recorded by the diver on the datasheet.

5.3 Data Management

5.3.1 Data Assimilation

At the end of the field season, designated agency-specific data managers will be responsible for ensuring that all data collected have been entered and proofed again by the diver against a diver proofing report (as described in SOP RF04 [SFCN 2025e]). The data managers also ensure all data products (scanned data sheets, site photos, GPS files) are collated and sent to the NOAA data manager (Figure 9). All habitat site photos are stored in a manner that retains sample date and site number. Each diver must maintain a minimum level of accuracy as described and defined in SOP RF04. The NOAA data manager is responsible for data verification, storage, and distribution following steps in SOP RF04.

5.3.2 Regional NOAA data sets

The RVC sample data, stratum data, taxonomic data and benthic data sets for Florida and the U.S. Virgin Islands are stored and managed by NOAA-SEFSC. Analysis-ready datasets and data attributes for the Florida Keys, Tortugas, St. Thomas/St. John and St. Croix regions are shared on-line at the South Florida National Coral Reef Monitoring Program data portal [RVC | Data Portal](https://grunt.sefsc.noaa.gov/rvc_analysis20/) (https://grunt.sefsc.noaa.gov/rvc_analysis20/). Data collected the previous year will generally be made available for download by August of the following year. All data collected in South Florida since 1999 and since 2017 in the U.S. Virgin Islands are available as comma-separated value (csv) spreadsheet files in uncompressed or compressed zip files for general use. Prior to 2017, the belt-transect method was used to conduct fish surveys in the USVI. These data are archived at [NOAA's Coral Reef Information System](#) website. Variable metadata are also available for each data set as described in SOP RF04 (SFCN 2025e).

5.3.3 Metadata and Archiving

Each agency is responsible for archiving a complete set of the updated data each year. The South Florida/Caribbean Network will archive the data set it uses for its survey year reports by updating metadata associated with the database and storing a copy of the database, associated metadata, associated data summary reports, and exported *.csv flat files, and then uploading copies of the same to the [Integrated Resource Management Applications \(IRMA\) Data Portal](https://irma.nps.gov/Portal/) (<https://irma.nps.gov/Portal/>). The target date for archiving all data and associated metadata for a survey year will be September of the following year.

5.4 Overview of QA/QC

Data quality procedures will have a two-tiered approach with proof checks planned at the diver data entry level (Tier I) and at the NOAA data manager level (Tier II; Figure 9). Quality Assurance/Quality Control (QA/QC) evaluations are done at several levels depending upon the type of data generated.

- A training meeting scheduled prior to each sampling season is organized to update all participants on the sample design, survey methods, and all relevant information necessary in order to conduct reef fish visual surveys. All new participants will undergo more detailed training on the specific methods (SOP RF02 *Participant Training—Version 1.1* [SFCN 2025c]).
- Immediately after data collection, divers review datasheets with their buddy to make sure all fields are completed, legible and consistent. Any questions, particularly from inexperienced observers, must be addressed.
- Some checks are built into the database entry program such as notifications when data are out of range (e.g., quantity, size, time), totals, and when fields are not filled.
- Diver proofs 100% of data entered from the original data sheet to the data proofing report (Tier I).
- Verification that data are entered for all sites and sampling periods monitored by the agency is made by the agency-specific data manager.
- Numerous functions and graphical interpretation of metrics in the database are used to check for completeness, duplication and suspicious data (unusual spike, missing data, unusual species, outliers including number observed [i.e., schooling in a typically solitary species] and reported size [outside accepted species size range]) (Tier II; SOP RF04 [SFCN 2025e]). If the data are real but outlying, they are not removed.

5.5 Protected Data

Many reef fish species are considered commercially valuable in both Florida and the U.S Virgin Islands. According to the Department of the Interior Freedom of Information Act Handbook (383 DM §15 2014), coordination with the NPS in accordance with 16 U.S.C. § 5937 (an Exemption 3 statute) is necessary before records are released that concern the nature and specific location of a National Park System resource that is endangered, threatened, rare, or commercially valuable. It is necessary that permission is given and documented by individual park managers prior to the release of locations of fishes during sampling, particularly the location of transient reef fish spawning aggregations and rare species. Two reef fish species of concern are the Nassau Grouper (*Epinephelus striatus*) and the Goliath Grouper (*Epinephelus itajara*). If the park manager deems locational data to be protected from public release, specific locations of these species will be redacted at Biscayne National Park (SFCN 2021a), Buck Island Reef National Monument (SFCN 2021b), Salt River Bay National Historical Park and Ecological Preserve (SFCN 2021c), and Virgin Islands National Park (SFCN 2021d). The South Florida/Caribbean Network will work with the parks to document whether any data from this protocol requires protection before public release.

6.0 Data Analysis and Reporting

6.1 Recommendations for Routine Data Summaries and Statistical Analyses

The range and types of statistical analyses that can be performed to assess the status and dynamics of reef fish populations and communities depends on the specific research and management questions and resource goals. These questions and goals may change through time or vary by agency, but there are several fundamental metrics generated after each sampling season that are outlined in SOP RF05 *Data Analyses and Reporting—Version 1.1* (SFCN 2025b). Analyses will typically focus on “analysis” strata by region or subregion or across management zones. Analyses below the sub-region level may require enhanced sampling effort to be effective. All fish metrics are relative and not considered an estimate of absolute value. A glossary of statistical symbols and computational formulae is provided in Glossary A (SFCN 2025f; glossaries available at <https://irma.nps.gov/DataStore/Reference/Profile/2311259>). Historical two-stage computational formulae are also presented in Glossary B (SFCN 2025f). Technically these metrics could be reported as “unitless indexes” due to the unknown capture efficiency of fish species and unknown habitat utilization patterns and/or known area of habitats. However, for practical purposes, we acknowledge these unknowns but prefer to interpret metrics as being “relative” and the very best estimate available for these values. Therefore, species richness and relative density data are reported per secondary sampling unit (SSU). Further, statistical totals of relative abundance are considered relative population totals and are not interpreted as absolute values. Table 5 provides a list of metrics whose calculations and R-code are described further in Glossary A and SOP RF05 (SFCN 2025b).

Table 5. Example metrics for summary reports that can be calculated from data. An “X” indicates the metric can be grouped to the indicated taxonomic level.

Metric	Example	Individual Species	Trophic Guilds ^A	Taxa Groups ^B
Species Richness	Average # species/site	X	—	—
	New species detected	X	—	—
Relative Occupancy and Spatial Distribution	Population, Adult, Juvenile, Exploited	X	X	X
Relative Density	Total Population, Adult, Juvenile, Exploited	X	X	X
Relative Abundance	Total Population, Adult, Juvenile, Exploited	X	X	X
Coefficient of Variation (CV)	Exploited, Adult or Total Density	X	—	—
Size Structure	Max Length, Average Length, Average Adult Length, Average Exploited Length	X	—	—
	Length Frequency Distribution (Number of fish in desired length bins)	—	—	—
Biomass ^C	Total Biomass	X	X	X

^A Trophic guilds = piscivores, herbivores, invertivores, planktivores, etc.

^B Taxa groups = groupers, snappers, grunts, parrotfishes, etc.

^C Biomass is calculated from length - weight relationships.

These analyses utilize a range of survey data types to allow for the assessment of reef fish population metrics over time and space. SOP RF05 (SFCN 2025b) focuses on the specific reporting needs of the South Florida/Caribbean Network but can be adapted to meet the needs of other groups. The network provides data summary reports for the parks (Resource Briefs) on an annual basis, with updates reported biennially in each region (Florida and U.S. Virgin Islands). To use the data analysis and graphing tools described in this document requires Microsoft Excel, ArcGIS, and the freeware statistical program R.

6.2 Iterative Approach to Survey Design

This monitoring program incorporates an iterative improvement process that includes sample design and allocation, data collection, data assimilation, and analysis that can be used to improve the design efficacy for future surveys (Figure 5). The survey design described here, including the stratification scheme, is based on previously collected reef fish data as well as existing benthic habitat maps. As the program evolves, data from previous years can be used to refine the stratification scheme with the objective of further reducing sample variance and improving the ability to detect change. Therefore, it is important that the survey design is revisited and updated every few surveys or when significant improvements have been made to benthic maps (SOP RF01 *Statistical Sampling Design—Version 2.0* [SFCN 2025a]). Optimal sample allocation is determined by calculating variance estimates of relative density and proportion area per stratum, but the amount of annual sampling effort reflects a balance between survey effort, management needs and funding/time availability. Data collected during each survey season are incorporated into the sample allocation for subsequent surveys.

The current grid is assumed to be the most appropriate for conducting analyses based on historical data and the best benthic maps available. Coral reef geological formations are not expected to shift in the short term, so discrepancies are assumed to be errors in the original map work. If more accurate and comprehensive benthic habitat data become available, the potential exists for the grid cells to be updated. Individual grid cell classifications may change to reflect the more accurate benthic habitat maps. And if grid cell classification changes, then strata numbers (weighting) will likely change. It is imperative that new strata weighting be applied to historical data and metrics (e.g., relative density) be recomputed. This avoids a false conclusion being reached merely due to changes to strata weighting.

7. Personnel Roles, Requirements and Training

7.1 Roles and Responsibilities

At the start of each field season, responsibilities for sampling will be delegated among the participating agencies. Each agency will provide participants, equipment, and resources to the best of their ability depending on their budgeting constraints and responsibilities to other projects for that year. All agencies will designate a data manager, a chain of command, and points of contact for dealing with scheduling and logistical considerations, as well as for questions regarding procedures and policies. Points of contact will be clarified so that all participants, regardless of agency, are aware of who to contact in the event of a question or issue (SOP RF02 *Participant Training—Version 1.1* [SFCN 2025c]).

7.2 Qualifications

All participants must be trained in reef fish identification and have the ability to make the necessary supporting observations (training requirements covered in the next section). Tasks may be performed by personnel in training status under the supervision of properly qualified persons. All participants must be certified to SCUBA dive in open water by a recognized and licensed organization (e.g., NAUI, PADI), possess a certification to use enriched-air nitrox and be approved to lead a dive to 60-foot (18.3 meters) depth minimum by their organization. Participants must follow their agency's dive safety policies and requirements. NPS personnel must be qualified as current Blue Card Diver (NPS 2019; 485 DM 27). It is also beneficial that personnel have completed a Motorboat Operations Certification Course (MOCC; 36 CFR part 3; 485 DM 22). A current MOCC certification must be held by at least one person topside during NPS operations. Non-certified MOCC personnel may drive a park boat under the supervision of an MOCC certified operator. Depending on the agency in charge of the diving operations, dive reciprocity forms may need to be exchanged. It is the responsibility of the agency in charge to confirm prior to operations that participating divers meet minimum mission dive requirements and are cleared to dive.

7.3 Training

Training is a critical component of the RVC monitoring program and incorporates both initial and annual refresher training components. Personnel must first thoroughly review this narrative and the associated SOPs before implementing procedures under the supervision of experienced staff. Pre-season participant refresher meetings are mandatory and held either jointly or independently depending on the needs of each agency. These meetings consist of overviews of sampling design, logistics, RVC methods, habitat characteristics, and data entry and proofing to ensure methodological consistency and consistency in how each observer collects and processes data. Annual in-water training is organized and executed by each agency independently, although exchange of personnel among agencies is encouraged (SOP RF02 [SFCN 2025c]). Participants must be capable of accurately identifying reef fishes to species and estimating sizes that are encountered in Florida and the USVI ecosystems, be able to establish a survey cylinder, and be familiar with the RVC protocol (SOP RF03 *Field Data Collection—Version 2.0* [SFCN 2025d]). Furthermore, participants must be

familiar with the habitat assessment techniques and benthic categories that are included in the method and detailed in SOP RF03.

8. Operational Requirements

8.1 Annual Workload and Field Schedule

In the U.S. Virgin Islands sampling occurs in a concerted effort over the course of two weeks in St. Croix and another two weeks in St. Thomas/St. John, but the total effort may span several months (May to August). For South Florida, the surveys may begin as early as May, but it could take until October for the agencies to finish all surveys. Surveys in the Tortugas region are best targeted for the months of June and July. This is because wind and storm patterns are most favorable during those months and the odds of successfully completing a full 10-day mission are the greatest. Weather, sea conditions, and in-water visibility are major factors in scheduling sampling and can have a major impact on sampling efficiency and accuracy of the data. Reef fish surveys are difficult to complete safely in South Florida with wind greater than 15 mph. Due to the remote location of the Tortugas, making up sites later from land-based small boat operations is typically not an option.

A captain and two-person dive team are the minimum crew required for field work, for boat and diving safety, and data collection. However, a four-person dive team (or two rotating teams of two divers) for small boat operations is recommended and can greatly increase sampling efficiency. Depending on the depth, complexity of the habitat, and the number of divers, a typical site may take anywhere from 25 to 40 minutes to complete. Five to eight sites can be completed each day per small boat or 20 to 25 sites per day from a live-aboard boat with five 2-person dive teams. The anticipated annual workload per subregion (St. Croix, St. Thomas/St. John, Florida Keys, Dry Tortugas) is approximately 400 primary site surveys in each Florida subregion and 250 primary site surveys in each USVI region. This equates to about 42 boat days per region in the U.S. Virgin Islands and 66 boat days for small boat operations in the Florida Keys. In the Tortugas, 20 live-aboard boat days are required to meet the targeted survey goals. For the concerted effort in the U.S. Virgin Islands, five to six boats and crews are organized and work together to complete the surveys over a two-week period per region (St. Croix or St. Thomas/St. John).

8.2 Facility and Equipment Needs

The logistics of field work in the U.S. Virgin Islands are organized out of the parks and the University of the Virgin Islands. In South Florida, operations are staged from agency offices (Biscayne NP, SFCN, NOAA-SEFSC, FWRI, FKNMS) except for the Tortugas, where operations are typically based from a live-aboard dive boat due to the remote location of the area.

Field work requires the following list of equipment:

- Small boat (3–6 divers) or live-aboard ship (10–12 divers).
- Standard dive equipment and accessories (e.g., compass, dive computer).
- Dive and boating safety equipment including first aid kit, AED, oxygen kit, fire extinguisher and flares.
- Weighted dive flag with reel.
- Handheld GPS and dry bag.

- All-Purpose Tool (APT).
- Timing device.
- Camera housing and accessories (O-rings, O-ring grease, cotton swabs, distance aiming mechanism).
- Miscellaneous underwater equipment (slate, underwater paper, pencils, rubber bands).
- Reef fish field guide.
- Post-data collection, software needed for data storage and analysis includes:
 - Microsoft Office—Excel, Word,
 - ArcGIS (mapping of sites, site selection, creating field logistic plans),
 - Garmin Basecamp (transferring data between GPS devices and a computer),
 - R statistical software (for statistical analyses),
 - Adobe Acrobat (for making pdf documents).

8.3 Sequence of Events During Field Season

Sampling schedules may vary due to considerations for weather, ship, and personnel availability (Table 6). In the Florida Keys sites can be completed by localized small boat operations run independently by the different agencies and may be complemented by additional live-aboard dive boat operations. As many sites that can be safely surveyed in a reasonable amount of time (8–10 hour day) should be completed per day. Consideration for diver safety determines the composition of dive teams and the location and depths of sites that are attempted daily. Data collected are the responsibility of the participants and entered and catalogued during or immediately after the sampling event following the methods detailed in SOP RF04 *Data Entry and Proofing—Version 2.0* (SFCN 2025e). Preferably, data are entered as soon as possible upon return from the field (preferably within a week), as this tends to reduce errors in data entry. Once all data are entered, each surveyor will follow proofing steps detailed in SOP RF04 before submitting the data for final verification.

Table 6. Projected implementation schedule for reef fish visual census monitoring in Florida and US Virgin Islands. An “X” indicates the months that planning, data collection, data proofing and data analysis and reporting occur.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sample point selection and allocation	–	–	X	X	X	–	–	–	–	–	–	–
Training	–	–	–	X	X	–	–	–	–	–	–	–
Data collection	–	–	–	–	X	X	X	X	X	X	–	–
Data entry	–	–	–	–	X	X	X	X	X	X	X	–
QA/QC	X	X	X	X	–	–	–	–	–	X	X	X
Analysis and reporting	–	–	–	–	X	X	X	–	–	–	–	–

8.4 Frequency and Timing of Sampling

A two-year sampling rotation is currently followed in the Florida and Caribbean parks (Table 7). Ideally, the surveys would be conducted annually, but the intensive time and resources required for these surveys are often beyond the scope of individual agencies and parks. Historically, surveys were performed annually in the U.S. Virgin Islands and the Florida Keys, and every other year in the Tortugas. With the expansion of NOAA’s interagency regional monitoring interests in 2014, the region was partitioned by effort to include Florida, Tortugas and the Flower Gardens in year 1 and the U.S. Virgin Islands and Puerto Rico in year 2. Over time, available resources from each agency may vary extensively and in response, the targeted number of sample sites can be adjusted. This sampling methodology does not require a fixed sample size, although more survey sites increase our ability to detect statistical changes in fish populations (see SOP RF01 *Statistical Sampling Design—Version 2.0* [SFCN 2025a]). Changes in effort due to increased resources or a change in priorities by park management regarding the frequency of monitoring of other vital signs may allow an increase in sites sampled or more frequent sampling (i.e., annual). Likewise, the target sample size may decrease based on resources, goals, and participation, with the understanding that this will affect the precision of the sampling results.

Table 7. Sampling schedule by park. An “X” indicates which year a park unit is surveyed.

Park Unit	Year 1	Year 2	Year 3	Year 4
Biscayne NP	X	–	X	–
Dry Tortugas NP	X	–	X	–
Virgin Islands NP	–	X	–	X
Virgin Islands Coral Reef NM	–	X	–	X
Buck Island Reef NM	–	X	–	X
Salt River Bay NHP&EP	–	X	–	X

Sampling occurs between May and October, either by small boats in Florida and the U.S. Virgin Islands or a larger live-aboard vessel in the Tortugas. In South Florida, after the list of sample sites is generated each year, representatives from the participating agencies will meet and assign responsibility for specific sampling sites to an agency. Thereafter, it is the responsibility of the agency to determine when each site will be surveyed. In the U.S. Virgin Islands, the approach has been to work together in a coordinated multi-agency effort over a two-week period in each sub-region (“Fish Blitz”). Resources, personnel, vessels and site assignments are shared. A list of alternate sites is also generated and distributed in case sites are not accessible (e.g., outside safe diving limits) or difficulty is encountered locating hardbottom habitat within an assigned grid cell. All sites are surveyed during these months when favorable winds and hurricanes are less likely to interfere with diving logistics and so possible seasonal effects do not impact assessments of the status of the fish populations through time.

8.5 Startup Costs and Budget Considerations

Some of the field equipment (e.g., GPS, dive flag, reels, cameras) is shared with other monitoring protocols and other agencies. Reef fish survey-specific monitoring equipment is simple and relatively low cost. Fish-specific monitoring equipment includes the APT (1.3 meters [4.3 feet] of three-quarter-inch or one-inch PVC), clipboard, pencils, and a timing device. Total cost of these items per individual diver is approximately \$15, excluding the cost of the timer which is typically personal property of the diver or included as a function of the dive computer. ArcGIS and Microsoft Office products are purchased government-wide with no additional costs to the network. Both Garmin BaseCamp and the R programming language are free software programs.

Personnel costs, small boat maintenance costs, fuel and travel are associated with the field surveys (Table 8). With a team of two divers, a survey site (one set of paired circular plots) may take 25 to 40 minutes to complete depending on depth and complexity of habitat. An average of 5 to 8 sites can be completed per small boat crew per day. On a live-aboard vessel, 20–25 sites per day can be completed when operating with five fish teams. After field collection, the GPS units need to be downloaded, datasheets scanned, and data entered (SOP RF04 *Data Entry and Proofing—Version 2.0* [SFCN 2025e]).

Table 8. SFCN monitoring budget protocol implementation. **Note:** These costs are approximate based upon 2025 salary, travel cost, and equipment estimates for annual monitoring.

Category	Sub-Category	Costs (FY 2025, in USD)	Notes
Personnel	SFCN Marine Ecologist	15,400	0.10 FTE GS-12
	SFCN Fish Biologist	12,300	0.08 FTE GS-11
	SFCN Biological Technicians ^A	19,800	0.20 FTE GS-7
	SFCN Data Manager ^B	10,400	0.08 FTE GS-12
	SFCN Interns ^A	9,700	0.20 Intern
	Total Personnel Costs ^C	\$67,600	—
Equipment & Supplies	Annual Boat Maintenance	2,200	0.30 for 2 SFCN vessels
	Annual Boat Fuel	1,000	0.15 of fuel
	Field Supplies	2,200	0.15 of scuba and field costs
	Total Equipment Costs	\$5,400	—

^A Includes time for two biological technicians or interns (0.10 × 2).

^B A portion of all personnel's time is devoted to data management activities including data entry, analysis, and QA/QC. This is in accordance with NPS I&M policies recommending that at least 30% of monitoring resources be allocated to data management.

^C Includes benefits, hazard pay, overtime for personnel based on 1.5 10-day field missions, data management activities and summary reports.

^D Cost of live aboard is supported by DRTO or NOAA agency funded contract.

^E Annual travel is 0.5 of the sum of travel costs in each park, since Florida and USVI parks are alternated and surveyed every other year.

Table 8 (continued). SFCN monitoring budget protocol implementation. **Note:** These costs are approximate based upon 2025 salary, travel cost, and equipment estimates for annual monitoring.

Category	Sub-Category	Costs (FY 2025, in USD)	Notes
Travel	Travel: Biscayne NP	0	Monitored by SFCN-Miami & Biscayne NP staff
	Travel: Dry Tortugas NP ^D	800	Live aboard for staff (4) Dry Tortugas
	Travel: Virgin Islands NP	10,000	SFCN-Miami staff and interns air (4) to STJ
	Travel: Buck Island Reef NM and Salt River Bay NHP	13,700	Requires boat transport (2) and air (4) to STX
	Total Travel Costs ^E	\$12,250	–
Total Protocol Implementation Cost	–	\$85,250	–

^A Includes time for two biological technicians or interns (0.10 × 2).

^B A portion of all personnel's time is devoted to data management activities including data entry, analysis, and QA/QC. This is in accordance with NPS I&M policies recommending that at least 30% of monitoring resources be allocated to data management.

^C Includes benefits, hazard pay, overtime for personnel based on 1.5 10-day field missions, data management activities and summary reports.

^D Cost of live aboard is supported by DRTO or NOAA agency funded contract.

^E Annual travel is 0.5 of the sum of travel costs in each park, since Florida and USVI parks are alternated and surveyed every other year.

The total costs of data entry/proofing, data management, analysis and reporting are specific to the South Florida/Caribbean Network and approximately 30% of project costs (Table 8). Time and cost allocation from host park staff and other agencies aiding in data collection are not included. Time and cost allocation (e.g., cooperative agreements) associated with SFCN interns are included below but are not part of fixed costs. Costs for everyone involved with data collection includes training, 15 days for data collection, travel and time for data entry and proofing.

8.6 Safety

Scuba diving operations require considerable safety training and mission-specific caution and care. Network personnel must follow all rules, regulations, requirements, and policies, as well as procedures from the NPS Dive Program; any park, network, and I&M Division-specific requirements; and any other requirements of the National Park Service not otherwise specified herein. A culture of safety and operational leadership prevails where problems are considered proactively, and each person is empowered to think about potential problems and speak up early about health and safety concerns regardless of their position on the team. All concerns must be addressed seriously and respectfully by the rest of the team members.

All NPS personnel participating in SFCN dive missions for this monitoring project must be NPS Blue Card Divers with a minimum current depth rating (≥ 60 feet [18.3 meters]). Personnel in training status (NPS Diver in Training) may dive under the supervision of properly qualified persons to a maximum depth of 60 feet. Other agency/university divers in training may also dive with NPS divers under an agreement of reciprocity with NOAA or other AAUS recognized organizations (ex. FWC, EPA, universities, and colleges).

Persons independently driving NPS boats must complete a Department of Interior Motorboat Operator Certification Course (DOI MOCC) and maintain a current certificate (renewed every five years) for non-supervised operation of a NPS vessel. Non-MOCC-certified individuals may drive a park boat under the close guidance of someone who is MOCC certified. All SFCN vessels will be operated using state-of-the-art GPS chart plotters to ensure safe and efficient navigation.

Network personnel must also review and implement the respective SOPs associated with operation of each SFCN vessel, Float Plan Safety Sheet, and any other SOPs associated with this protocol and must review and sign all Job Hazard Analyses (JHAs) associated with this protocol. These SOPs and JHAs are located in the SFCN Safety folder Z:\Safety\ with guidance to their location in the Final_SFCN_Safety_Plan.doc. A summary of these SOPs and JHAs are provided in Table 9. These forms may be updated individually and the SFCN Safety Plan updated as a whole, so personnel must check the Z:\Safety\ folder for the most recent versions of these files and any additional requirements. These documents will be made available to non-SFCN personnel without server access prior to field work operations.

Table 9. Relevant documents and location on South Florida/Caribbean Network server.

Relevant Document, SOP, or JHA	Electronic versions are available on the SFCN server
NPS Diving Safety and Operations Manual – Field Manual – 4	Z:\SAFETY\Section 2Q - Diving Safety
NPS Diving Safety and Operations Manual - Reference Manual - 4	Z:\SAFETY\Section 2Q - Diving Safety
NPS Official Travel Driving Policy	Z:\SAFETY\Section 2N - Motor Vehicle Safety
NPS Director Memorandum Motor Vehicle Driving while on Official Travel	Z:\SAFETY\Section 2N - Motor Vehicle Safety
South Florida/Caribbean Network Motor Vehicle Safety Plan	Z:\SAFETY\Section 2N - Motor Vehicle Safety
South Florida/Caribbean Network Safety Plan	Z:\SAFETY\SFCN Safety Plan
South Florida/Caribbean Network Emergency Action and Fire Prevention Plan	Z:\SAFETY\Section 2E - Emergency Response Plans
Hurricane Preparedness Plan – Florida and Caribbean Office	Z:\SAFETY\SFCN_SOPs with JHAs\ FLACO Hurricane Plan & Emergency Contact List
SFCN Float Plan and SFCN Marine GAR	Z:\SAFETY\Float Plans
SFCN Diving Safety Plan	Z:\SAFETY\Section 2Q - Diving Safety
SFCN Safe Diving Operations Plan	Z:\SAFETY\Section 2Q - Diving Safety

Table 9 (continued). Relevant documents and location on South Florida/Caribbean Network server.

Relevant Document, SOP, or JHA	Electronic versions are available on the SFCN server
Eddy Boy JHA	Z:\SAFETY\Section 2O - Watercraft Safety
Twin Vee JHA	Z:\SAFETY\Section 2O - Watercraft Safety
Dive Emergency Evacuation Plan (DEEP) Biscayne National Park (BISC)	Z:\SAFETY\Section 2Q - Diving Safety\Network Parks DEEP's\20XX
Dive Emergency Evacuation Plan (DEEP) Buck Island Reef National Monument (BUIS) / Salt River (SARI)	Z:\SAFETY\Section 2Q - Diving Safety\Network Parks DEEP's\20XX
Dive Emergency Evacuation Plan (DEEP) Dry Tortugas National Park (DRTO)	Z:\SAFETY\Section 2Q - Diving Safety\Network Parks DEEP's\20XX
Dive Emergency Evacuation Plan (DEEP) Virgin Islands National Park (VIIS)	Z:\SAFETY\Section 2Q - Diving Safety\Network Parks DEEP's\20XX

A float plan and dive plan are submitted by SFCN personnel and approved by the supervisor and dive safety officer prior to all SFCN dive operations. Additionally, a Green-Amber-Red (GAR) risk assessment is completed prior to daily operations to review environmental conditions, crew status and task complexity. All SFCN personnel follow the program-specific Dive Supplement/Diver Emergency Evacuation Plan and Safety Operations Plan specific to the park they are monitoring within. The Diving Safety and Operations Manual (FM-4) contains all required elements of the NPS Diving Management Reference Manual 4 (RM-4), a standalone NPS document, as well as information specific to FM-4. Dive team roles and responsibilities will be reviewed in a safety briefing before each dive trip.

Literature Cited

- 36 C.F.R. § 3. 2012. Boating and Water Use Activities. Title 36 Code of Federal Regulations, Part 3. Government Printing Office, Washington, D.C.
- 383 DM § 15. 2014. Freedom of Information Act (FOIA) Handbook. Department of Interior.
- 485 D.M. § 22. 2011. Watercraft Safety. Department of Interior Departmental Manual, Part 485, Chapter 22. Office of Occupational Safety and Health, Washington, D.C.
- 485 D.M. § 27. 1999. Underwater Diving Safety. Department of the Interior Departmental Manual, Part 485, Chapter 27. Office of Managing Risk and Public Safety, Washington, D.C.
- Ainley, D. and D. Pauly. 2014. Fishing down the food web of the Antarctic continental shelf and slope. *Polar Record* **50**(1):92–107. doi:10.1017/S0032247412000757
- Allen, D. M. and J. E. Tashiro. 1976. Status of the U.S. commercial snapper-grouper fishery.
- Aronson, R. B. and W. F. Precht. 2001. White-band disease and the changing face of Caribbean coral reefs. *Hydrobiologia* **460**:25–38.
- Ault, J. S., J. Blondeau, and M. W. Feeley. 2024a. Detection probabilities of coral reef fish assemblages from visual census in Florida and the USVI. Final Report on NPS CESU Contract No. P22AC02392-02.
- Ault, J. S., J. Blondeau, L. J. W. Grove, S. L. Cass-Calay, K. J. McCarthy. 2024b. Integrating the US Caribbean Reef Fish Visual Census into fishery stock assessments. *Bulletin Marine Science*. 100(2):283–312. <https://doi.org/10.5343/bms.2023.0025>
- Ault, J. S., J. A. Bohnsack, and G. A. Meester. 1998. A retrospective (1979–1996) multispecies assessment of coral reef fish stocks in the Florida Keys. *Fishery Bulletin* **96**:395–414.
- Ault, J. S., J. A. Bohnsack, S. G. Smith, and J. G. Luo. 2005b. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. *Bulletin of Marine Science* **76**:595–622.
- Ault, J. S., G. A. Diaz, S. G. Smith, J. Luo, and J. E. Serafy. 1999. An efficient sampling survey design to estimate pink shrimp population abundance in Biscayne Bay, Florida. *North American Journal of Fisheries Management* **19**:696–712.
- Ault, J. S., S. G. Smith, and J. A. Bohnsack. 2005a. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. *Ices Journal of Marine Science* **62**:417–423.

- Ault, J. S., S. G. Smith, J. A. Bohnsack, J. G. Luo, D. E. Harper, and D. B. McClellan. 2006. Building sustainable fisheries in Florida's coral reef ecosystem: Positive signs in the Dry Tortugas. *Bulletin of Marine Science* **78**:633–654.
- Ault, J. S., S. G. Smith, and J. T. Tilmant. 2009. Are the coral reef finfish fisheries of south Florida sustainable? *Proceedings International Coral Reef Symposium* 11:989–993.
- Ault, J. S., S. G. Smith, J. A. Browder, W. Nuttle, E. C. Franklin, J. Luo, G. T. DiNardo, and J. A. Bohnsack. 2014. Indicators for assessing the ecological dynamics and sustainability of southern Florida's coral reef and coastal fisheries. *Ecological Indicators* 44:164–172.
- Ault, J. S., S. G. Smith, B. L. Richards, A. J. Yau, B. J. Langseth, J. M. O'Malley, C. H. Boggs, M. P. Seki, and G. T. DiNardo. 2018. Towards fishery-independent biomass estimation for Hawaiian Islands deepwater snappers. *Fisheries Research* 208:321–328.
- Ault, J. S., S. G. Smith, J. A. Bohnsack, J. Luo, M. H. Stevens, M. W. Johnson, D. R. Bryan, and G. T. DiNardo. 2019. Length-based risk analysis for assessing sustainability of data-limited tropical reef fisheries. *ICES Journal of Marine Science* **76**(1):165–180. doi: 10.1093/icesjms/fsy12
- Ault, J. S., D. B. Smith, E. C. Franklin, J. Luo, and J. A. Bohnsack. 2003. Sampling design analysis for coral reef fish stock assessment in Dry Tortugas National Park. Final Report, National Park Service Contract No. H5000000494-0012. 87 p.
- Ault, J. S., S. G. Smith, J. Luo, G. A. Meester, J. A. Bohnsack, and S. L. Miller. 2002. Baseline multispecies coral reef fish stock assessment for the Dry Tortugas. NOAA Technical Memorandum NMFS-SEFSC-487. 117 p.
- Ault, J. S., S. G. Smith, G. A. Meester, J. Luo, and J. A. Bohnsack. 2001. Site characterization for Biscayne National Park: assessment of fisheries resources and habitats. NOAA Technical Memorandum NMFS-SEFSC-468. 185 p.
- Ault, J. S., S. G. Smith, J. Luo, M. E. Monaco, and R. S. Appeldoorn. 2008. Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. *Environmental Conservation* **35**(3):221–231.
- Ault, J. S., S. G. Smith, J. A. Bohnsack, M. Patterson, M. W. Feeley, D. B. McClellan, B. I. Ruttenberg, D. Hallac, T. Ziegler, J. Hunt, D. Kimball, J. Luo, N. Zurcher, and B. Causey. 2013. Assessing coral reef fish changes and marine reserve dynamics in the Dry Tortugas, Florida USA. *Fisheries Research* **144**:28–37.
- Ault, J. S., S. G. Smith, and Others. 2022. Length-based risk analysis of management options for the southern Florida USA multispecies coral reef fish fishery. *Fisheries Research* **249**:1–19.

- Bacheler, N. M., C. Schobernd, Z. Schobernd, W. A. Mitchell, D. Berrane, G. T. Kellison, and M. J. M. Reichert. 2013. Comparison of trap and underwater video gears for indexing reef fish presence and abundance in the southeast United States. *Fish. Res.* **143**:81–88. doi: 10.1016/j.fishres.2013.01.013.
- Bacheler, N. M. and K.W. Shertzer, 2015. Estimating relative abundance and species richness from video surveys of reef fishes. *Fishery Bulletin.* **113**:15–26.
- Bartholomew, A., J. A. Bohnsack, S. G. Smith, J. S. Ault, D. E. Harper, and D. B. McClellan. 2008. Influence of marine reserve size and boundary length on the initial response of exploited reef fishes in the Florida Keys National Marine Sanctuary, USA. *Landscape Ecology* **23**:55–65.
- Bernard, A. T. F., A. Götz, S. E. Kerwath, C. G. Wilk. 2013. Observer bias and detection probability in underwater visual census of fish assemblages measured with independent double-observers. *Journal of Experimental Marine Biology and Ecology.* **443**:75–8.
- Bohnsack, J. A., J. S. Ault, and B. Causey. 2004. Why have no-take marine protected areas? *Aquatic Protected Areas as Fisheries Management Tools* **42**:185–193.
- Bohnsack, J. A. and S. P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Tech. Report NMFS 41. 15 p.
- Bohnsack, J. A., D. E. Harper, and D. B. McClellan. 1994. Fisheries trends from Monroe County, Florida. *Bulletin of Marine Science* **54**:982–1018.
- Bohnsack, J. A., D. E. Harper, D. B. McClellan, D. L. Sutherland, and M. White. 2002. Resource survey of fishes within Looe Key National Marine Sanctuary, 1983. NOAA Technical Memorandum NOS-NCCOS-CCMA-160 and NMFS-SEFSC-478. 327 p.
- Bohnsack, J. A., D. B. McClellan, D. E. Harper, G. S. Davenport, G. J. Konoval, A. Eklund, J. P. Contillo, S. K. Bolden, P. C. Fischel, G. S. Sandorf, J. C. Javech, M. W. White, M. H. Pickett, M. W. Hulsbeck, J. L. Tobias, J. S. Ault, G. A. Meester, S. G. Smith, and J. Luo. 1999. Baseline data for evaluating reef fish populations in the Florida Keys, 1979–1998. NOAA Technical Memorandum NMFS-SERSC-427. 61p.
- Brandt, M. E., N. Zurcher, A. Acosta, J. S. Ault, J. A. Bohnsack, M. W. Feeley, D. E. Harper, J. H. Hunt, T. Kellison, D. B. McClellan, M. E. Patterson, and S. G. Smith. 2009. A cooperative multi-agency reef fish monitoring protocol for the Florida Keys coral reef ecosystem. Natural Resource Report NPS/SFCN/NRR—2009/150. National Park Service, Fort Collins, Colorado. Available at: [DataStore - A Cooperative Multi-Agency Reef Fish Monitoring Protocol for the Florida Keys Coral Reef Ecosystem](#) (last accessed March 2025).
- Brock, V. E. 1954. A preliminary report on a method of estimating reef fish populations. *Journal of Wildlife Management* **18**:297–308.

- Bryan, D. R., A. J. Atkinson, J. S. Ault, M. E. Brandt, J. A. Bohnsack, M. W. Feeley, M. E. Patterson, B. I. Ruttenberg, S. G. Smith, and B. D. Witcher. 2013. A cooperative multiagency reef fish monitoring protocol for the U.S. Virgin Islands coral reef ecosystem. Natural Resource Report NPS/SFCN/NRR—2013/672. National Park Service, Fort Collins, Colorado. Available at: [DataStore - A cooperative multiagency reef fish monitoring protocol for the U.S. Virgin Islands coral reef ecosystem](#) (last accessed March 2025).
- Bryan, D. R., S. G. Smith, J. S. Ault, M. W. Feeley, and C. W. Menza. 2016. Feasibility of a Regionwide Probability Survey for Coral Reef Fish in Puerto Rico and the U.S. Virgin Islands, Marine and Coastal Fisheries **8**(1):135–146.
- Bryan, D. R., J. Blondeau, A. Siana, and J. S. Ault. 2018. Regional differences in an established population of invasive Indo-Pacific lionfish (*Pterois volitans* and *P. miles*) in south Florida. PeerJ 6:e5700 <https://doi.org/10.7717/peerj.5700>
- Caldwell, Z. R., B. J. Zgliczynski, G. J. Williams, and S. A. Sandin. 2016. Reef fish survey techniques: Assessing the potential for standardizing methodologies. PLoS ONE **11**(4):e0153066. <https://doi.org/10.1371/journal.pone.0153066>
- Chittaro, P. M., P. Usseglio, and P. Sale. 2005. Variation in fish density, assemblage composition and relative rates of predation among mangrove, seagrass and coral reef habitats. Environmental Biology of Fishes **72**:175–187.
- Chollett, I., M. Priest, S. Fulton, and W. D. Heyman. 2020. Should we protect extirpated fish spawning aggregation sites? Biological Conservation **241**:108395.
- Christensen, J., C. Jeffrey, C. Christopher, M. Monaco, M. Kendall, and R. Appeldoorn, Richard. 2003. Cross-Shelf Habitat Utilization Patterns of Reef Fishes in Southwestern Puerto Rico. Gulf and Caribbean Research **14**:9–27.
- Claro, R., K. C. Lindeman, A. S. Kough, and C. B. Paris. 2019. Biophysical connectivity of snapper spawning aggregations and marine protected area management alternatives in Cuba. Fisheries Oceanography **28**(1):33–42.
- Cochran, W. G. 1977. Sampling techniques, 3rd Ed. Wiley, New York.
- Colvocoresses, J. and A. Acosta. 2007. A large-scale field comparison of strip transect and stationary point count methods for conducting length-based underwater visual surveys of reef fish populations. Fisheries Research **85**:130–141.
- Dahlgren, C. P. and D. B. Eggleston. 2000. Ecological processes underlying ontogenetic habitat shifts in coral reef fish. Ecology **81**(8):2227–2240.
- Demartini, E. E. and D. Roberts. 1982. An empirical test of biases in the rapid visual technique for species-time censuses of reef fish assemblages. Marine Biology **70**:129–134.

- Domeier, M. L. 2004. A potential larval recruitment pathway originating from a Florida marine protected area. *Fisheries Oceanography* **13**:287–294.
- Eggleston, D. B. 1995. Recruitment in Nassau grouper *Epinephelus striatus*: post-settlement abundance, microhabitat features, and ontogenetic habitat shifts. *Marine Ecology Progress Series* **124**:9–22.
- Feeley, M. W., D. Morley, A. Acosta, P. Barbera, J. Hunt, T. Switzer, and M. Burton. 2018. Spawning migration movements of Mutton Snapper in Tortugas, Florida: Spatial dynamics within a marine reserve network. *Fisheries Research*: **204**:209–223.
- Florida Marine Research Institute (FMRI). 1998. Benthic habitats of the Florida Keys. St. Petersburg, Florida.
- Franklin, E. C., J. S. Ault, S. G. Smith, J. Luo, G. A. Meester, G. A. Diaz, M. Chiappone, D. W. Swanson, S. L. Miller, and J. A. Bohnsack. 2003. Benthic habitat mapping in the Tortugas region, Florida. *Marine Geodesy* **26**:19–34.
- Friedlander, A. and J. Beets. 2008. Temporal trends in reef fish assemblages inside Virgin Islands National Park and around St. John, U.S. Virgin Islands 1988–2006. Biogeography Branch, Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 70. 60 pp.
- Friedlander, A. M., L. Wedding, and S. J. Pittman and C. F. G. Jeffrey. 2013. Chapter 4: Fish Communities around St. John. pp. 61–130. In: A.M. Friedlander, C.F.G. Jeffrey, S.D. Hile, S.J. Pittman, M.E. Monaco and C. Caldwell (eds.). *Coral reef ecosystems of St. John, U.S. Virgin Islands: Spatial and temporal patterns in fish and benthic communities (2001–2009)*. NOAA Technical Memorandum 152. Silver Spring, MD. 150 pp.
- Fukunaga, A., J. H. R. Burns, K. H. Pascoe, R. K. Kosaki. 2020a. Associations between Benthic Cover and Habitat Complexity Metrics Obtained from 3D Reconstruction of Coral Reefs at Different Resolutions. *Remote Sensing* **12**(6):1011.
- Fukunaga, A., R. K. Kosaki, K. H. Pascoe, J. H. R. Burns. 2020b. Fish assemblage structure in the Northwestern Hawaiian Islands is associated with the architectural complexity of coral-reef habitats. *Diversity* **12**:430. <https://doi.org/10.3390/d12110430>
- Florida Fish and Wildlife Conservation Commission (FWC). 2020. Website. Accessed 03/18/2021. [Biscayne National Park | FWC](#) (last accessed March 2025).
- Gardner, T. A., I. M. Cote, J. A. Gill, A. Grant, and A. R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. *Science* **301**:958–960.
- Graham, N. A. J., S. K. Wilson, S. Jennings, N. V. C. Polunin, J. Robinson, J. P. Bijoux, and T. M. Daw. 2007. Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. *Conservation Biology* **21**:1291–1300.

- Grober-Dunsmore, R., T. K. Frazer, W. J. Lindberg, J. Beets. 2007. Reef fish and habitat relationships in a Caribbean seascape: the importance of reef context. *Coral Reefs* **26**(1): 201–216.
- Grove, L. J. W., J. Blondeau, D. W. Swanson, and others. 2024. Expansion of an established fishery-independent survey into the US Virgin Islands’ upper mesophotic zone: feasibility and management implications. *Bulletin Marine Science*. **100**(2):113–131.
<https://doi.org/10.5343/bms.2023.0013>
- Hallac, D. E., J. H. Hunt, D. Morrison, A. Clarke, T. A. Ziegler, W. C. Sharp, and R. Johnson. 2013. Development of a collaborative science plan to evaluate the conservation efficacy of a no-fishing, no-anchor marine reserve in Dry Tortugas National Park, Florida, USA. *Fisheries Research* **144**:15–22.
- Harford, W., S. G. Smith, J. S. Ault, and E. A. Babcock. 2016. Cross-shelf habitat occupancy probabilities for juvenile groupers in the Florida Keys coral reef ecosystem. *Marine and Coastal Fisheries* **8**(1): 147–159.
- Heenan, A. I. D. Williams, T. Acoba, A. DesRochers, R. K. Kosaki, T. Kanemura, M. O. Nadon, and R. Brainard. 2017. Long-term monitoring of coral reef fish assemblages in the Western central pacific. *Scientific Data* **4**:170176. doi:10.1038/sdata.2017.176
- Hughes, T. P. 1994. Catastrophes, Phase-Shifts, and Large-Scale Degradation of a Caribbean Coral-Reef. *Science* **265**:1547–1551.
- Jackson, J. B. (1997). Reefs since Columbus. *Coral reefs* **16**(1): S23-S32.
- Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kidwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. J. Tegner, and R. R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**:629–638.
- Johns, G. M., V. R. Leeworthy, F. W. Bell, and M. A. Bonn. 2001. Socioeconomic study of reefs in southeast Florida. NOAA and Florida Fish and Wildlife Conservation Commission. 235 p.
- Jones, D. L., J. F. Walter, E. N. Brooks and J. E. Serafy. 2010. Connectivity through ontogeny: fish population linkages among mangrove and coral reef habitats. *Marine Ecology Progress Series* **401**:245–258.
- Joseph, L. N. and H. P. Possingham. 2008. Grid-based monitoring methods for detecting population declines: Sensitivity to spatial scale and consequences of scale correction. *Biological Conservation* **141**:1868–1875.

- Kadison, E., M. Brandt, R. Nemeth, J. Martens, J. Blondeau, and T. Smith. 2017. Abundance of commercially important reef fish indicates different levels of over-exploitation across shelves of the U.S. Virgin Islands. *PLoS ONE* **12**(7): e0180063.
- Keller, J. A., J. Renchen, J. Herbig, J. Hunt, and A. Acosta. 2024. Reef Visual Census: a review of an essential long-term data source for reef-fish management in Florida. *Bulletin Marine Science*. **100**(2):313–331. <https://doi.org/10.5343/bms.2023.0028> (last accessed March 2025).
- Kellison, G. T., V. McDonough, D. E. Harper, and J. T. Tilmant. 2012. Coral reef fish assemblage shifts and declines in Biscayne National Park, Florida, USA. *Bulletin of Marine Science* **88**(1): 147–182.
- Kendall, M. S., J. D. Christensen, and Z. Hillis-Starr. 2003. Multi-scale data used to analyze the spatial distribution of French grunts, *Haemulon flavolineatum*, relative to hard and soft bottom in a benthic landscape. *Environmental Biology of Fishes* **66**: 19–26.
- Kendall, M. S., J. D. Christensen, C. Caldow, M. Coyne, C. F. G. Jeffrey, M. E. Monaco, W. Morrison, and Z. Hillis-Starr . 2004. The influence of bottom type and shelf position on biodiversity of tropical fish inside a recently enlarged marine reserve. *Aquatic Conservation: Marine and Freshwater Ecosystems* **14**: 113–132.
- Kendall, M. S., C. R. Kruer, K. R. Buja, J.D. Christensen, M. Finkbeiner, R. A. Warner, and M. E. Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico and the U.S. Virgin Islands. NOAA Technical Memorandum, Vol. 152, Silver Spring, Maryland.
- KeysWeekly. 2024. Coral Bleaching Hinders Environment & Economy. Website. Accessed 3/21/2025. [Coral Bleaching Hinders Environment & Economy](#) (last accessed March 2025).
- Kimmel, J. J. 1985. A characterization of Puerto Rican fish assemblages. Ph.D. Dissertation. University of Puerto Rico, Mayaguez, P. R. 106 p.
- Kunin, W. E., S. Hartley, J. J. Lennon, and J. J. 2000. Scaling down: on the challenge of estimating abundance from occurrence patterns. *American Naturalist* **156**(5):560–566.
- Lee, T. N. and E. Williams. 1999. Mean distribution and seasonal variability of coastal currents and temperature in the Florida Keys with implications for larval recruitment. *Bulletin of Marine Science* **64**(1):35–56.
- Levin, P. S., M. J. Fogarty, S. A. Murawski, D. Fluharty. 2009. Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean. *PLoS Biology* **7**(1): 23–28.
- Light, S. S. and W. Dineen. 1994. Water control in the Everglades: A perspective. In: *Everglades: The Ecosystem and Its Restoration*. Steven Davis and John Ogden (eds). St. Lucie Press, Boca Raton, Florida.

- Lindeman, K. C., R. Pugliese, G. T. Waugh, and J. S. Ault. 2000. Developmental patterns within a multispecies reef fishery: Management applications for essential fish habitats and protected areas. *Bulletin of Marine Science* **66**:929–956.
- Lindenmayer, D. B. and G. E. Likens. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. *Trends in Ecology and Evolution*, **24**(9):482–486. [Adaptive monitoring: a new paradigm for long-term research and monitoring - ScienceDirect](#) (last accessed March 2025).
- Lirman, D., N. Formel, S. Schopmeyer, J. S. Ault, S. G. Smith, D. Gilliam, and B. Riegl. 2013. Percent recent mortality (PRM) of stony corals as an ecological indicator of coral reef condition. *Ecol. Indic.* [Percent recent mortality \(PRM\) of stony corals as an ecological indicator of coral reef condition - ScienceDirect](#) (last accessed March 2025).
- McClanahan, T. R. 1994. Kenyan Coral-Reef Lagoon Fish - Effects of Fishing, Substrate Complexity, and Sea-Urchins. *Coral Reefs* **13**:231–241.
- McClanahan, T. R., V. Hendrick, M. J. Rodrigues, and N. V. C. Polunin. 1999. Varying responses of herbivorous and invertebrate-feeding fishes to macroalgal reduction on a coral reef. *Coral Reefs* **18**:195–203.
- McClellan, D. B. and D. E. Harper (eds.). 2007. Compilation of selected unpublished RVC studies conducted by the Reef Resources Team, 1985–2002. NOAA Technical Memorandum NMFS-SEFSC-561. 104 p.
- McClenachan, L., G. O'Connor, B. P. Neal, J. M. Pandolfi, J. B. C. Jackson. 2017. Ghost reefs: Nautical charts document large spatial scale of coral reef loss over 240 years. *Science Advances* **3**:e1603155.
- McCoy, K., A. Heenan, J. Asher, P. Ayotte, K. Gorospe, A. Gray, K. Lino, J. Samzow, and I. Williams. 2018. Pacific reef assessment and monitoring program data report. PIFSC Data Report DR-18-008.
- Menza, C. W., J. S. Ault, J. Beets, J. A. Bohnsack, C. Caldow, J. D. Christensen, A. M. Friedlander, C. Jeffrey, M. Kendall, J. Luo, M. E. Monaco, S. G. Smith, and K. Woody. 2006. A guide to monitoring reef fish in the National Park Service's South Florida / Caribbean Network.
- Miller, M.W. and D.E. Williams. 2007. Coral disease outbreak Navassa, a remote Caribbean island. *Coral Reefs* **26**(1): 97–101.

- Mitchell, B., A. Chung-MacCoubrey, J. Comiskey, L. Garrett, M. MacCluskie, B. Moore, T. Philippi, G. Sanders, and J. P. Schmit. 2018. Inventory and Monitoring Division protocol review guidance. Natural Resource Report. NPS/NRSS/IMD/NRR—2018/1644. National Park Service. Fort Collins, Colorado. Available at: [DataStore - Inventory and Monitoring Division protocol review guidance](#) (last accessed March 2025).
- Monaco, M., A. M. Friedlander, C. Caldow, J. D. Christensen, C. Rogers, J. Beets, J. Miller, and R. Boulon. 2007. Characterizing reef fish populations and habitats within and outside of the US Virgin Islands Coral Reef National Monument: a lesson in marine protected area design. *Fisheries Management and Ecology* **14**(1):33–40.
- Monaco, M., A. M. Friedlander, C. Caldow, S. D. Hile, C. Menza, and R. H. Boulon. 2009. Long-term monitoring of habitats and reef fish found inside and outside the U.S. Virgin Islands Coral Reef National Monument: A comparative assessment. *Caribbean Journal of Science* **14**(2–3): 338–347.
- Mora, C. 2008. A clear human footprint in the coral reefs of the Caribbean. *Proceedings of the Royal Society B-Biological Sciences* **275**:767–773.
- Muller, E. M., C. Sartor, N. I. Alcaraz, and R. van Woesik. 2020. Spatial epidemiology of the stony-coral-tissue-loss disease in Florida. *Frontiers Marine Science* **7**:163. doi: 10.3389/fmars.2020.00163. Available at: [Frontiers | Spatial Epidemiology of the Stony-Coral-Tissue-Loss Disease in Florida](#) (last accessed March 2025).
- Nadon, M. O., J. S. Ault, I. W. Williams, S. G. Smith, and G. T. DiNardo. 2015. Length-based assessment of coral reef fish populations in the Main and Northwestern Hawaiian Islands. *PLoS ONE* **10**(8): e0133960. Available at: [Length-Based Assessment of Coral Reef Fish Populations in the Main and Northwestern Hawaiian Islands | PLOS One](#) (last accessed March 2025).
- National Oceanic and Atmospheric Administration’s National Ocean Service Management & Budget Office (NOAA NOS). 2009. Coral Reef Habitat Assessment for U.S. Marine Protected Areas: U.S. Virgin Islands. Siler Spring, Maryland.
- National Park Service (NPS). 2019. Diving safety and operations manual: Reference manual 4. Available at [Reference Manual - 4 - DocsLib](#) (last accessed March 2025).
- Nemeth, R. S. 2005. Population characteristics of a recovering US Virgin Islands red hind spawning aggregation following protection. *Marine Ecology Progress Series*. **286**:81–97.
- Oakley, K. L., L. P. Thomas, and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. *Wildlife Society Bulletin* **31**:1000–1003.
- Paddack, M. et al. 2009. Recent region-wide declines in Caribbean reef fish abundance. *Current Biology* **19**: 590–595.

- Pais, M. P. and H. N. Cabral. 2017. Fish behaviour effects on the accuracy and precision of underwater visual census surveys. A virtual ecologist approach using an individual-based model. *Ecological Modelling* **346**: 58–69.
- Pais, M. P. and H. N. Cabral. 2018. Effect of underwater visual survey methodology on bias and precision of fish counts: a simulation approach. *PeerJ* **6**:e5378. Available at: [Effect of underwater visual survey methodology on bias and precision of fish counts: a simulation approach \[PeerJ\]](#) (last accessed March 2025).
- Pattengill-Semmens, C. V. and B. X. Semmens. 2003. Conservation and management applications of the reef volunteer fish monitoring program. *Environmental Monitoring and Assessment* **81**:43–50.
- Patterson, M. E., A. J. Atkinson, B. D. Witcher, K. R. Whelan, W. J. Miller, R. J. Waara, J. M. Patterson, B. I. Ruttenberg, A. D. Davis, R. Urgelles, R. B. Shamblin. 2008. South Florida/Caribbean Network: Vital Signs Monitoring Plan. Natural Resource Report. NPS/SFCN/NRR—2008/063. National Park Service. Fort Collins, Colorado. Available at: [DataStore - South Florida / Caribbean Network: Vital Signs Monitoring Plan](#) (last accessed March 2025).
- Pauly, D., V. Christensen, S. Guenette, T. J. Pitcher, U. R. Sumaila, C. J. Walters, R. Watson, and D. Zeller. 2002. Towards sustainability in world fisheries. *Nature* **418**:689–695.
- Petrovskaya, N. B. and S. V. Petrovskii. 2010. The coarse-grid problem in ecological monitoring. *Proceedings of the Royal Society A* **466**:2933–2953.
- Pittman, S. J., C. Caldow, S. D. Hile, and M. E. Monaco. 2007. Using seascape types to explain the spatial patterns of fish in the mangroves of SW Puerto Rico. *Marine Ecology Progress Series* **348**: 273–284.
- Pittman, S. J., S. D. Hile, C. F. G. Jeffrey, C. Caldow, M. S. Kendall, M. E. Monaco, and Z. Hillis-Starr. 2008. Fish assemblages and benthic habitats of Buck Island Reef National Monument (St. Croix, U.S. Virgin Islands) and the surrounding seascape: A characterization of spatial and temporal patterns. NOAA Technical Memorandum NOS NCCOS 71. Silver Spring, Maryland. 96 pp.
- Porter, J. W., S. K. Lewis, and K. G. Porter. 1999. The effect of multiple stressors on the Florida Keys coral reef ecosystem: A landscape hypothesis and a physiological test. *Limnology and Oceanography* **44**:941–949.
- Precht, W. F., B. E. Gintert, M. L. Robbart, R. Fura, and R. van Woesik. 2016. Unprecedented Disease-related coral mortality in southeastern Florida. *Scientific Reports* **6**:31374. Available at: [Unprecedented Disease-Related Coral Mortality in Southeastern Florida | Scientific Reports](#) (last accessed March 2025).

- Risk, M. J., and A. C. Risk. 1997. Reef surveys as an aid in management. Proceedings of the 8th International Coral Reef Symposium **2**:1471–1474.
- Rothenberger, P., J. Blondeau, C. Cox, S. Curtis, W. S. Fisher, V. Garrison, Z. Hillis-Starr, C. Jeffrey, E. Kadison, I. Lundgren, W. J. Miller, E. Muller, R. Nemeth, S. Paterson, C. Rogers, T. Smith, A. Spitzack, M. Taylor, W. Toller, and J. Waddell. 2008. The state of coral reef ecosystems of the U.S. Virgin Islands. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. 73. 29–73.
- Ruttenberg, B. I., P. J. Schofield, J. L. Akins, A. Acosta, M. W. Feeley, J. Blondeau, S. G. Smith, J. S. Ault. 2012. Rapid invasion of Indo-Pacific lionfishes (*Pterois volitans* and *Pterois miles*) in the Florida Keys, USA: evidence from multiple pre- and post-invasion data sets. Bulletin of Marine Science **88**(4):1051–1059. Available at: <https://doi.org/10.5343/bms.2011.1108> (last accessed March 2025).
- Sale, P. 1997. Visual census of fishes. How well do we see what is there? Pages 1435–1440 Proc. 8th Int. Coral Reef Sym.
- Sale, P. and B. J. Sharp. 1983. Correction for bias in visual transect censuses of coral reef fishes. Coral Reefs **2**:37–42.
- Sancho, G., P. R. Kingsley-Smith, J. A. Morris, Jr., C. A. Toline, V. McDonough, and S.M. Doty. 2018. Invasion Lionfish (*Pterois volitans*/miles) feeding ecology in Biscayne National Park, Florida, USA. Biological Invasions **20**:2343–2361. Available at: [Invasive Lionfish \(Pterois volitans/miles\) feeding ecology in Biscayne National Park, Florida, USA | Biological Invasions](#) (last accessed March 2025).
- SEDAR 64. 2020. Southeast Data, Assessment, and Review. Stock Assessment Report. Southeastern US Yellowtail Snapper. March 2020. North Charleston, South Carolina. Available at: [SEDAR 64 Southeastern US Yellowtail Snapper – SEDAR – SouthEast Data, Assessment, and Review](#) (last accessed March 2025).
- South Florida/Caribbean Network (SFCN). 2025a. Statistical Sampling Design—Version 2.0. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—RF01. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2309696> (last accessed March 2025).
- South Florida/Caribbean Network (SFCN). 2025b. Data Analyses and Reporting—Version 1.1. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—RF05. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2309701> (last accessed March 2025).

- South Florida/Caribbean Network (SFCN). 2025c. Participant Training—Version 1.1. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—RF02. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2309697> (last accessed March 2025).
- South Florida/Caribbean Network (SFCN). 2025d. Field Data Collection—Version 2.0. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—RF03. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2309698> (last accessed March 2025).
- South Florida/Caribbean Network (SFCN). 2025e. Data Entry and Proofing—Version 2.0. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—RF04. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2309699> (last accessed March 2025).
- South Florida/Caribbean Network (SFCN). 2025f. Glossary A. Statistical Symbols and One-Stage Computational Formulae Used in the Coral Reef Fish Sampling Surveys and Glossary B. Statistical Symbols and Two-Stage Computational Formulae Used in Historical (1998–2018) Coral Reef Fish Sampling Surveys. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2311259> (last accessed May 2025).
- South Florida/Caribbean Network (SFCN). 2021a. Re: Handling of Protected Natural Resource Data, Biscayne National Park. Available at: [DataStore - Handling of Protected Natural Resource Data, Biscayne National Park](#). (last accessed March 2025).
- South Florida/Caribbean Network (SFCN). 2021b. Re: Handling of Protected Natural Resource Data, Buck Island Reef National Monument. Available at: [DataStore - Handling of Protected Natural Resource Data, Buck Island Reef National Monument](#). (last accessed March 2025).
- South Florida/Caribbean Network (SFCN). 2021c. Re: Handling of Protected Natural Resource Data, Salt River Bay National Historical Park. Available at: [DataStore - Handling of Protected Natural Resource Data, Salt River Bay National Historical Park and Ecological Preserve](#). (last accessed March 2025).
- South Florida/Caribbean Network (SFCN). 2021d. Re: Handling of Protected Natural Resource Data, Virgin Islands National Park. Available at: [DataStore - Handling of Protected Natural Resource Data, Virgin Islands National Park](#). (last accessed March 2025).
- Smith, S. G., J. S. Ault, J. A. Bohnsack, D. E. Harper, J. Luo, and D. B. McClellan. 2011. Multispecies survey design for assessing reef-fish stocks, spatially explicit management performance, and ecosystem condition. *Fisheries Research* **109**: 25–41.

Stamoulis, K. A. et al. 2018. Seascape models reveal places to focus coastal fisheries management. *Ecological Applications*. **28**(4):910–925.

Stark, W. A. 1968. A list of fish of Alligator Reef, Florida, with comments on the nature of the Florida reef fish fauna. *Undersea Biology* **1**:4–40.

Suarez, B. and T. B. Grabowski. 2021. Estimating detection and occupancy coefficients for the Pacific Islands coral reef fish species. Hawai'i Cooperative Fishery Research Unit Technical Report Series HCFRU-001. University of Hawai'i at Hilo.

Thompson, S. K. 2002. *Sampling*, second ed. Wiley-Interscience, New York.

Valdivia, A., C. E. Cox, and J. F. Bruno. 2017. Predatory fish depletion and recovery potential on Caribbean reefs. *Science Advances* **3**:e1601303.

Wilson, S. K., N. A. J. Graham, M. S. Pratchett, G. P. Jones, and N. V. C. Polunin. 2006. Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient? *Global Change Biology* **12**:2220–2234.



Sargassum Triggerfish or Redtail (*Xanthichthys ringens*) on Riley's Hump, Tortugas.

FWC / DON DEMARIA

National Park Service
U.S. Department of the Interior



Science Report NPS/SR—2025/327
<https://doi.org/10.36967/2310167>

Natural Resource Stewardship and Science

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525