



Long-term Monitoring of Caribbean Spiny Lobster (*Panulirus argus*)

Protocol Narrative—Version 1.1

Natural Resource Report NPS/SFCN/NRR—2020/2177



ON THE COVER

Caribbean Spiny Lobster (*Panulirus argus*) in Dry Tortugas National Park.

Photograph by: NPS / Lee Richter

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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 Log. Shows the revision changes for each version of the protocol. Add new rows as needed.

Revision Date	Author	Changes Made	Reason for Change	New Version #
3/24/2020	Lee Richter	1) Bedrock stratum removed from SARI sample domain. 2) Removed Plot % = Habitat metric. 3) Spotted lobsters added to survey (estimated size only). 4) Rapid queen conch and long-spined sea urchin counts added to survey. 5) Included snare as lobster catching option. 6) Remove calipers as necessary tool. 7) Contacts section was moved out of narrative to SOP 9. 8) Removed Appendix C (printable data sheets). 9) 9) The data management section was simplified to remove specific file paths and details that are covered in SOPs.	1) Safety concerns. 2) Redundant data from abiotic assessment section. 3) Opportunistic and informative addition to survey. 4) Opportunistic and informative addition to survey. 5) Situationally, may be better tool to capture lobster (surveyor preference). 6) Measuring aid on snare/tickle stick is adequate and accurate. 7) Section contents will change occasionally; easier to update as SOP. 8) Printable field forms can be found in SOP 4 9) 9) Detail that is covered in the SOP was removed from the narrative.	1.1

Contents

	Page
Figures.....	ix
Tables.....	xi
Appendices.....	xiii
Executive Summary.....	xv
Acknowledgments.....	xvii
Acronyms.....	xix
Background and Objectives	1
Rationale for Monitoring.....	1
Biology of the Caribbean Spiny Lobster (<i>Panulirus argus</i>).....	3
Habitat and Life Cycle.....	3
Age and Growth	3
Reproduction	3
Disease.....	4
History and Status of the Spiny Lobster Fishery in Florida	4
History and Status of the Spiny Lobster Fishery in the U.S Virgin Islands.....	6
Link to Management Decision-Making.....	8
Study Area.....	9
Biscayne National Park	9
Everglades National Park	12
Dry Tortugas National Park.....	12
Virgin Islands National Park	13
Buck Island Reef National Monument	14
Salt River Bay National Historical Park and Ecological Preserve.....	15
Measurable Objectives of Monitoring.....	15
Sampling Design.....	17
Overview	17

Survey Background	17
Concepts from the Reef Fish Monitoring Protocols.....	17
Concepts from the Torres Strait Rock Lobster Monitoring Program.....	20
Sampling Domain.....	20
Number and Location of Sampling Sites.....	24
Temporal Schedule.....	25
Change Detectable.....	26
Virgin Islands National Park Pilot.....	30
Biscayne National Park Pilot Study.....	31
Future Sampling	32
Combination with other Protocols.....	33
Field Methods	35
Requisites of a Data Collection Program	35
Survey Method Background and Justification.....	35
Field Survey Methods.....	41
Field Season Preparations and Equipment Setup	45
Post-sampling Procedures	45
End-of-season Procedures	46
Data Handling, Analysis, and Reporting	47
Scanning Datasheets, Data Entry and Verification	47
Overview of QA/QC.....	47
Recommendations for Routine Data Summaries and Statistical Analyses	47
Cautions on Interpretation of Data	49
Iterative Approach to Survey Design	50
Protected Data	51
Metadata and Archiving	51
Participant Roles, Requirements, and Training	53
Roles and Responsibilities.....	53

Contents (continued)

	Page
Qualifications	53
Training	54
Operational Requirements.....	55
Annual Workload and Field Schedule.....	55
Facility and Equipment Needs.....	55
Sequence of Events During Field Season.....	56
Frequency and Timing of Sampling	57
Startup Costs and Budget Considerations	57
Safety.....	59
Literature Cited	63

Figures

	Page
Figure 1. National Park Service’s South Florida/Caribbean Network (SFCN).	2
Figure 2. Different habitats used by various life history stages in the life cycle of the Caribbean Spiny Lobster.....	4
Figure 3. Commercial lobster landings in Florida from 1950–2017, in pounds.	5
Figure 4. Lobster landings by fishing method for St. Thomas/St. John and St. Croix from 1974 through 2016 (Olsen et al. 2018).	8
Figure 5. Map of Biscayne Bay-Card Sound Lobster Sanctuary and Biscayne NP (NPS 2015).	10
Figure 6. Commercial catch data for Biscayne NP (FWC 2018).....	11
Figure 7. This n^* curve was generated from Lobster Pilot survey data collected in Virgin Islands NP in 2017.	30
Figure 8. This n^* curve was generated from Lobster Pilot survey data collected in Biscayne NP in 2017.....	32
Figure 9. Example of how the two averaged circular plots may be located at a site.	42
Figure 10. Diagram showing how the circular plot can be partitioned into quadrants.	43
Figure 11. A diagram displaying the iterative approach to data collection.....	51
Figure A-1. Photographic examples of linear reef terrace.	A-2
Figure A-2. Photographic examples of linear reef remnant.....	A-3
Figure A-3. Photographic examples of high-relief spur and groove.....	A-4
Figure A-4. Photographic examples of low-relief spur and groove.....	A-5
Figure A-5. Photographic examples of reef / hard-bottom.	A-6
Figure A-6. Photographic examples of individual patch reef.	A-7
Figure A-7. Photographic examples of aggregated patch reef.	A-8
Figure A-8. Photographic examples of patchy coral and/or rock in unconsolidated hard-bottom.	A-9
Figure A-9. Photographic examples of pavement.....	A-10
Figure B-2. Examples of linear reef.....	B-2
Figure B-3. Example of spur and groove.....	2

Figures (continued)

	Page
Figure B-4. Example of patch reefs.	B-4
Figure B-5. Example of colonized bedrock.	B-5
Figure B-6. Example of aerial view of uncolonized bedrock.	B-6
Figure B-7. Example of uncolonized bedrock.	B-6
Figure B-8. Example of colonized pavement.....	B-7
Figure B-9. Example of aerial view of colonized pavement with sand channels.	B-8
Figure B-10. Example of uncolonized pavement.....	B-8
Figure B-11. Example of uncolonized pavement with sand channels.	B-9
Figure B-12. Example of scattered coral/rock in unconsolidated sediment.....	B-10
Figure D-1. Length-frequency diagram for all lobsters observed in the Virgin Islands NP pilot survey, including those that evaded capture.	D-4
Figure D-2. Length-frequency diagram for all lobsters observed in the Biscayne NP pilot survey, including those that evaded capture.	D-7
Figure D-3. Length-frequency diagram for all lobsters that were successfully captured and sex recorded in the Biscayne NP pilot survey.....	D-7
Figure D-4. Measured versus estimated carapace lengths (mm) of lobster captured in Virgin Islands NP and Biscayne NP during the 2017 pilot study.	D-9

Tables

	Page
Table 1. Key similarities and differences between the SFCN Spiny Lobster Monitoring Protocol and the SFCN Reef Fish Monitoring Protocols.....	18
Table 2. Strata in the Virgin Islands NP sample domain.	21
Table 3. Strata in the Buck Island Reef NM sample domain.	22
Table 4. Strata in the Salt River Bay NHP&EP sample domain.	22
Table 5. Strata in the Dry Tortugas NP sample domain.....	22
Table 6. Strata in the Biscayne NP sample domain. This is a subset of the strata that appear in Brandt et al. (2009) because some of them do not occur within Biscayne NP.	23
Table 7. Estimated number of sites possible per stratum during a full-scale sample event in each park unit, based on an even distribution of samples among strata.	25
Table 8. Target change detectable for exploited phase lobster relative density.....	27
Table 9. Target change detectable for exploited phase lobster relative frequency of occurrence.	27
Table 10. Target change detectable for average carapace length of exploited phase lobster.....	29
Table 11. Selected relevant studies highlighting the use of timed-searches and fixed area plots to monitor lobster populations.....	37
Table 12. Comparison of two visual fishery-independent methods (fixed area plots vs. timed searches) to survey lobster.	38
Table 13. Monitoring objectives, sampling design, sampling methods, and metrics measured at SFCN parks as part of the spiny lobster Monitoring Protocol.....	40
Table 13 (continued). Monitoring objectives, sampling design, sampling methods, and metrics measured at SFCN parks as part of the spiny lobster Monitoring Protocol.	41
Table 14. Projected implementation schedule for spiny lobster monitoring.....	56
Table 15. Sampling schedule by park.	57
Table 16. SFCN monitoring budget protocol implementation.....	58
Table 17. Relevant documents and location on South Florida/Caribbean Network server.....	60
Table C-1. Mean density, variance and allocation.	C-1
Table C-2. Proportion of occurrence.....	C-2

Tables (continued)

	Page
Table C-3. Average size in exploited phase.....	C-2
Table D-1. Summary statistics for strata surveyed in Virgin Islands NP lobster pilot 2017.....	D-2
Table D-2. Habitat classes of in different depth strata were combined in order to allow calculations of the relative indices of frequency of occurrence, density, and abundance.....	D-3
Table D-3. Relative indices of frequency of occurrence, density (lobsters per hectare), abundance, and coefficient of variation (CV) are reported here with $\pm$ standard error..	D-3
Table D-4. Descriptive analyses of captured lobster.....	D-4
Table D-5. Summary statistics for strata surveyed in Biscayne NP lobster pilot 2017.....	D-6
Table D-6. Relative indices for frequency of occurrence, density (lobsters per hectare), abundance, and CV with $\pm$ standard error.....	D-6
Table D-7. Descriptive analyses of captured lobster.....	D-8
Table D-8. A t-test was used to compare visual estimates of carapace length on lobster to the recorded actual size	D-9

Appendices

	Page
Appendix A. Benthic Habitat Classifications in Florida.....	A-1
Appendix B. Benthic Habitat Classifications in the U.S. Virgin Islands.....	B-1
Appendix C. Glossary of Statistical Symbols of Computational Formulas (Adapted from Brandt et al. 2009).....	C-1
Appendix D. 2017 Pilot Studies.....	D-1
Appendix E. Data Quality Standards for Long-term Monitoring of Caribbean Spiny Lobster (<i>Panulirus argus</i>).....	E-1
Appendix F. R code	F-1

Executive Summary

This *Long-term monitoring protocol of Caribbean Spiny Lobster (Panulirus argus): Protocol narrative v. 1.0* provides a technical background and detailed description of monitoring and assessment methods for Caribbean Spiny Lobster populations in Florida and the United States Virgin Islands (USVI). The protocol draws strongly from the SFCN Reef Fish Monitoring Protocols for Florida and the Virgin Islands, and from the findings of a 25-year long lobster (*Panulirus ornatus*) monitoring program in Torres Strait, Australia. The goal of this monitoring protocol is to build a statistically robust and cost-effective monitoring program with methods applicable at the park level. Estimates of population-level metrics such as a relative density index and average length are used to inform park managers of the status of spiny lobster within their park boundaries and evaluate any potential management actions.

The Caribbean spiny lobster is one of the most economically important fisheries in both Florida and the U.S. Virgin Islands. The crustacean is under substantial recreational and commercial fishing pressure in the regions and in some cases within park boundaries. The monitoring methodologies described in this document will allow us to understand the status and trends of spiny lobster populations in the parks. This knowledge is critical for informed sustainable management.

The monitoring program objectives focus on estimating a population level relative density index, frequency of occurrence index, and average size of spiny lobster and using these metrics to assess changes through time. Changes in these metrics can be evaluated after each survey season and with respect to habitat features, physical environment, and management actions.

Survey sites are selected from a gridded sample frame using a stratified random sample design with an even sample allocation across strata initially. Florida parks (Biscayne National Park and Dry Tortugas National Park) use a 100 × 100-meter (328 × 328-feet [ft]) sample grid from *A Cooperative Multi-agency Reef Fish Monitoring Protocol for the Florida Keys Coral Reef Ecosystem* (Brandt et al. 2009). The USVI parks (Buck Island Reef National Monument, Salt River Bay National Historical Park and Ecological Preserve, and Virgin Islands National Park) use a 50 × 50-meter (164 × 164-ft) sample grid from *A Cooperative Multiagency Reef Fish Monitoring Protocol for the U.S. Virgin Islands Coral Reef Ecosystem* (Bryan et al. 2013). Sites are selected using a uniform probability distribution within each stratum.

Field methods for lobster surveys consist of one set of paired 7.5-meter (24.6-ft) radius circular plots per site. All lobsters within the plot are counted and sizes estimated. Lobsters are then captured and biological conditions (e.g., sex, presence of eggs) are recorded. The lobsters are then released. Surveys take place inside park boundaries, unless a park specifically requests that surveys are completed in a limited defined area outside the park for assessment of management zones (no-take reserves).

Methods used to accomplish the monitoring objectives are detailed in eight Standard Operating Procedures. The steps to creating a statistically robust stratified random sample design are explained in SOP SL01 *Sample Frame and Habitat Classification—Version 1.1* (SFCN 2020a), SOP SL02

Stratification—Version 1.1 (SFCN 2020b), and SOP SL03—*Sample Allocation—Version 1.1* (SFCN 2020c). Field methodologies for conducting the circular plot surveys are described in SOP SL04—*Lobster Data Collection and Survey Methods—Version 1.1* (SFCN 2020d). SOP SL05—*Training—Version 1.1* (SFCN 2020e) describes training for survey participants and SOP SL06—*Data Entry, QA/QC, and Management—Version 1.1* (SFCN 2020f) and SOP SL07—*Data Analysis and Reporting—Version 1.1* (SFCN 2020g) describe data entry, management, analysis, and reporting procedures. Revision procedures for the protocol are described in SOP SL08—*Revising the Protocol—Version 1.1* (SFCN 2020h).

Acknowledgments

Many parts of this document draw heavily from the two reef fish monitoring protocols already in use by the South Florida / Caribbean Network: *A Cooperative Multi-agency Reef Fish Monitoring Protocol for the Florida Keys Coral Reef Ecosystem* (Brandt et al. 2009), and *A Cooperative Multiagency Reef Fish Monitoring Protocol for the U.S. Virgin Islands Coral Reef Ecosystem* (Bryan et al. 2013). The contributions of the authors for those protocols are gratefully acknowledged: Alejandro Acosta, Jerald Ault, James Bohnsack, Marilyn Brandt, David Bryan, Douglas Harper, John Hunt, Todd Kellison, David McClellan, Matt Patterson, Ben Ruttenberg, Steve Smith, Brian Witcher, and Natalia Zurcher. Several sections, including the SOPs, are included here in their entirety or with only minor changes.

Tom Matthews and Rod Bertelsen, Florida Fish and Wildlife Conservation Commission, provided helpful information and background to existing lobster survey monitoring practices in Florida that helped refine the survey methods. Leslie Henderson, USVI Department of Planning and Natural Resources, provided similar information and background to existing lobster survey monitoring practices in the Virgin Islands. Darren Dennis, CSIRO Marine Laboratories, provided details regarding the lobster monitoring practices in Torres Strait, Australia. Steve Smith and Jerry Ault, University of Miami, provided insightful comments on statistics, sample design, and updates to the existing reef fish monitoring protocol sample design. Methods testing and pilot surveys would not have been possible without the help of Isabel Cardenas, Adam Glahn, Thomas Kelley, Tanya Ramseyer, Colin Howe, Rob Waara, Elissa Connolly-Randazzo, Vanessa McDonough, Shelby Moneysmith, Kelsy Armstrong, Michael Hoffman and Erin Nassif. We also thank Tom Philippi, Mark Butler and Eva Plaganyi for their insightful comments and expert review of this protocol and associated standard operating procedures.

Acronyms

BICY:	Big Cypress National Preserve
BISC:	Biscayne National Park
BUIS:	Buck Island Reef National Monument
CL:	Carapace Length
CPUE:	Catch-per-unit-effort
CSIRO:	Commonwealth Scientific and Industrial Research Organization
CV:	Coefficient of Variation (Standard deviation / mean)
DPNR:	Department of Planning and Natural Resources
DRTO:	Dry Tortugas National Park
EVER:	Everglades National Park
FL:	Florida
FWC:	Florida Fish and Wildlife Conservation Commission
GIS:	Geographic Information System
GMSAFMC:	Gulf of Mexico and South Atlantic Fishery Management Councils
GPS:	Global Positioning System
JHA:	Job Hazard Analysis
MOCC:	Motorboat Operator Certification Course
NCCOS:	National Center for Coastal Ocean Science
NAUI:	National Association of Underwater Instructors
NOAA:	National Oceanic and Atmospheric Administration
NOAA-BB:	NOAA Center for Coastal Monitoring and Assessment Biogeography Branch
NOAA-SEFSC:	NOAA National Marine Fisheries Service Southeast Fisheries Science Center
NRDS:	Natural Resource Data Series
NP:	National Park
NPS:	National Park Service
PADI:	Professional Association of Diving Instructors
PaV1:	<i>Panulirus argus</i> Virus 1
PDO:	Park Dive Officer
QA/QC:	Quality Assurance / Quality Control
RNA:	Research Natural Area (Dry Tortugas NP)
SE:	Standard error
SARI:	Salt River Bay National Historical Park and Ecological Preserve
SCUBA:	Self-contained Underwater Breathing Apparatus
SEDAR:	Southeast Data Assessment and Review
SFCN:	National Park Service South Florida/Caribbean Network
SOP:	Standard Operating Procedure
USVI:	United States Virgin Islands
VICR:	Virgin Islands Coral Reef National Monument
VIIS:	Virgin Islands National Park

Background and Objectives

Rationale for Monitoring

The South Florida/Caribbean Network (SFCN) is one of 32 networks of parks within the National Park Service (NPS) Inventory and Monitoring Division (IMD). The network consists of seven national park units spanning South Florida and the U.S. Virgin Islands (USVI): Big Cypress National Preserve, Biscayne National Park, Buck Island Reef National Monument, Dry Tortugas National Park, Everglades National Park, Salt River Bay National Historical Park and Ecological Preserve, and Virgin Islands National Park; (Figure 1). The network is tasked with monitoring “Vital Signs,” a subset of the elements or processes in park ecosystems that represent the overall health and condition of the park’s natural resources, or that have important human values. The intent of the Marine Exploited Invertebrates Vital Sign is to assess the status of marine invertebrates that receive heavy fishing or commercial harvest pressure either within or near SFCN park boundaries. This includes the spiny lobster, pink shrimp, queen conch, crabs, sponges, oysters, and whelk (Patterson et al. 2008).

The Caribbean Spiny Lobster, *Panulirus argus*, is a common tropical and sub-tropical panulirid species that can be found throughout the western Atlantic and Caribbean oceans (Williams 1965). The crustacean has been harvested as a food source for many years and is currently one of the region’s most economically important fisheries, second only to penaeid shrimp (Ehrhardt 2005). Since the 1950s, the international market and demand for spiny lobster has continued to grow, fueled by increases in human population and tourism in Florida, the Virgin Islands, and the wider Caribbean region (Ehrhardt 2005).

This protocol provides a general overview and specific methodologies for Caribbean spiny lobster (*P. argus*) monitoring in parks within the network that contain marine habitat suitable for adult spiny lobster: Biscayne NP, Dry Tortugas NP, Virgin Islands NP, Buck Island NM, and Salt River Bay NHP. The protocol uses a stratified random sampling survey design to improve the statistical power of spiny lobster monitoring, drawing heavily upon the previously published reef fish monitoring protocols currently used by the network (Brandt et al. 2009; Bryan et al. 2013). Survey methodology and design were also significantly influenced by a long-term ongoing lobster (*Panulirus ornatus*) monitoring program in Torres Strait, Australia (Pitcher et al. 1992; Ye et al. 2004; Ye et al. 2005; Ye et al. 2007; Plagányi et al. 2010; Plagányi et al. 2015).

Marine exploited invertebrates ranked tenth in priority among the 44 SFCN vital signs (Patterson et al. 2008). Caribbean spiny lobster is the most heavily harvested species within the marine exploited invertebrates’ vital sign and as such, is one of the most important exploited species to park managers and users alike. The spiny lobster is under heavy fishing and commercial harvest pressure near SFCN parks, and in the cases of Biscayne NP (ocean-side) and Virgin Islands NP, within park boundaries. Throughout their life cycle, the spiny lobster uses multiple habitats both inside and outside park boundaries and is highly dependent on regional connectivity and adversely impacted by stressors. Thus, balancing resource extraction and environmental degradation with sustainability is a key management concern.

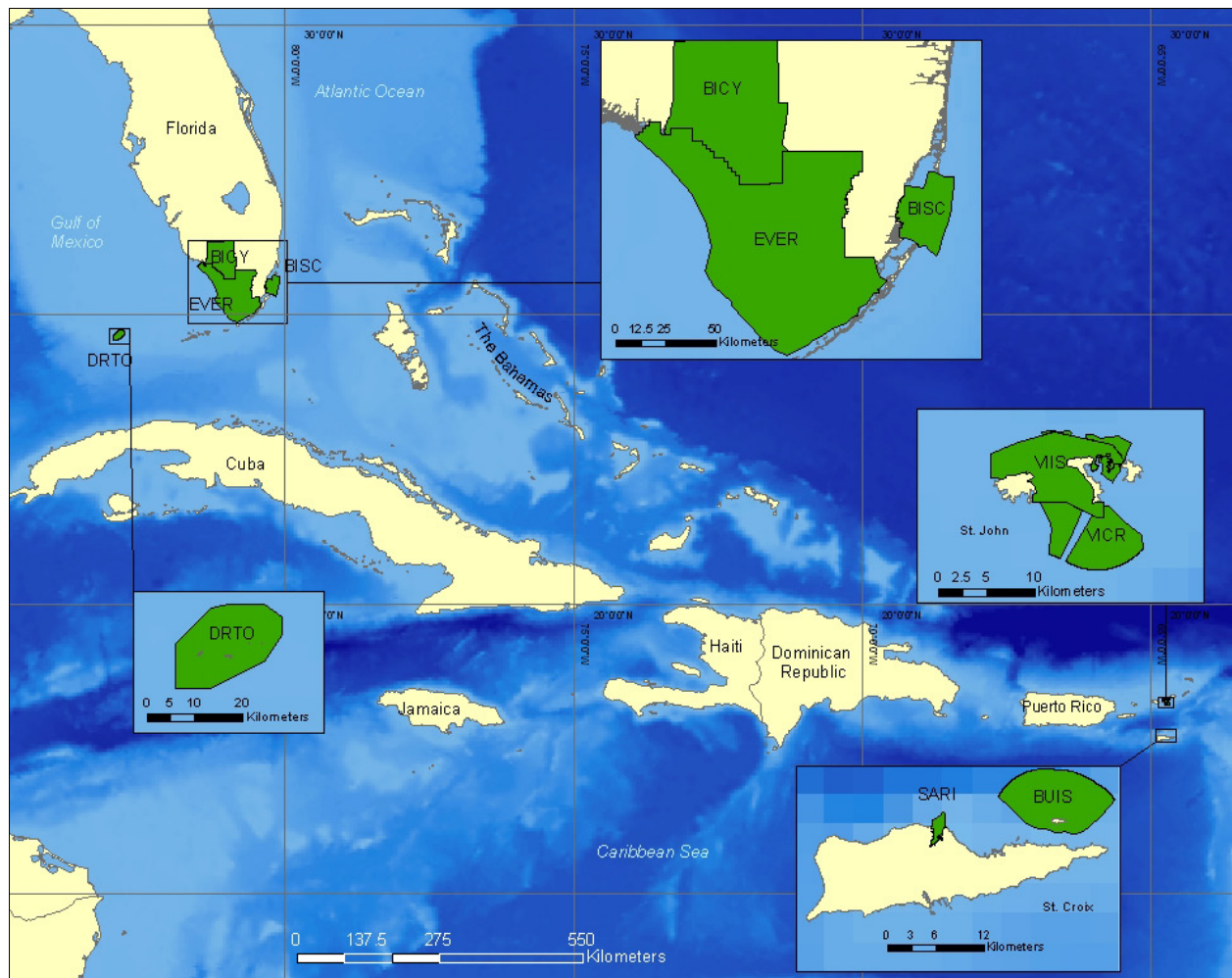


Figure 1. National Park Service's South Florida/Caribbean Network (SFCN). In South Florida: Big Cypress National Preserve (BICY), Everglades National Park (EVER), Biscayne National Park (BICY), and Dry Tortugas National Park (DRTO). In the Caribbean: Buck Island Reef National Monument (BUIS), Salt River Bay National Historical Site and Ecological Preserve (SARI), and Virgin Islands National Park (VIIS). The Virgin Islands Coral Reef National Monument (VICR) is included on the map but is not part of South Florida/Caribbean Network.

This protocol is designed to provide an understanding of current conditions and trends for adult Caribbean spiny lobster in the SFCN parks that contain suitable marine habitat for the species. If resources allow, it is highly recommended to monitor post-larval recruitment and juvenile populations as well, to provide a more comprehensive assessment of lobsters throughout the entirety of their life cycle. This also has the potential to alert managers of any issues prior to the lobster recruiting to the exploited phase. Presently, the South Florida/Caribbean Network does not have the time, budget, or personnel to pursue multiple types of lobster monitoring and, at the request of park resource managers, has chosen to focus on the exploited phase of the species. Information derived from this monitoring will provide critical data to support the sustainable management of spiny lobster within these parks. This protocol will provide information about relative density, relative frequency of occurrence, average size, and biological condition of adult spiny lobster within the SFCN parks.

Biology of the Caribbean Spiny Lobster (*Panulirus argus*)

Habitat and Life Cycle

The Caribbean Spiny Lobster, *P. argus*, has a geographic range spanning from North Carolina to Brazil and utilizes a variety of shallow coastal habitats throughout its life cycle (Figure 2; Williams 1965). Spiny lobsters spend the first five to seven months of their lives as larvae in the open ocean, at the mercy of wind-driven and ocean currents (Goldstein et al. 2008). The larvae then metamorphose into “pueruli,” a post-larval stage with a carapace length (CL) of 5–7 millimeters (0.1–0.2 inches [in]) that can actively swim inshore in search of shallow seagrass or macroalgae-covered hard-bottom habitats to settle in (Marx and Herrnkind 1985; Herrnkind and Butler 1986; Forcucci et al. 1994; Butler and Herrnkind 1997; Kough et al. 2014). After settling, young lobsters (6–17 millimeters [0.2–0.6 in] CL) tend to inhabit clumps of red algae, particularly *Laurencia* spp., where they find shelter and an abundant, diverse source of prey items (Marx and Herrnkind 1985). Post-algal phase juvenile lobsters leave the red algae habitats to seek shelter in small crevices associated with sponges, rocks or other structures, often aggregating with other lobsters (Olsen et al. 1975; Andree 1981; Marx and Herrnkind 1985; Herrnkind et al. 1994; Butler and Herrnkind 1997). Lobsters remain in these shallow nursery habitats for about two years until they approach maturity (70–80 millimeters [2.7–3.1 in] CL), when they begin migrating to reefs in deeper water (Witham et al. 1968; Olsen et al. 1975; Davis 1979; Butler and Herrnkind 1997). Once on the reefs, adult lobsters often aggregate in dens, under coral heads or in crevices that provide shelter from predators. The animals mostly emerge at night to forage for small mollusks and crustaceans (Herrnkind et al. 1975; Andree 1981; Herrnkind et al. 1994).

Age and Growth

Like many crustaceans, lobsters shed their exoskeleton as they grow, molting two to three times per year. The new exoskeleton hardens in about 12 days following the molt (Lipcius and Herrnkind 1982; Williams 1984). After settlement, lobsters can grow between 2–5 millimeters [0.07–0.1 in] CL per month (Witham et al. 1968; Eldred et al. 1972; Little 1972; Davis and Dodrill 1980; Davis 1981). The rate of growth varies, depending largely on prey availability, water temperature, population density, and injuries sustained from predators (Newman and Pollock 1974; Chittleborough 1976; Davis 1979; Aiken 1980; Waugh 1981). The Caribbean spiny lobster can potentially live more than 20 years, though natural predation and fishing practices typically prevent the lobsters from reaching such ages (FAO 2001).

Reproduction

Reproductive lobsters seek each other out via chemical cues released in urine, and during copulation the male deposits a tar-like spermatophore on the female’s underside, which can remain viable for up to one month (Atema and Cobb 1980; Bliss 1982; Marx and Herrnkind 1986). A female can carry several hundred thousand eggs under her tail, which become fertilized when she scratches at a deposited spermatophore with her legs (Williams 1984; Marx and Herrnkind 1986). Gravid females will then migrate offshore to deeper waters, where after three weeks of embryonic development, their newly hatched eggs are released into the water column to be dispersed by ocean currents (Crawford 1921; Butler and Herrnkind 1997). Time and duration of the spawning season is highly dependent on water temperature. For example, in tropical environments (e.g., the U.S. Virgin Islands) reproduction

can occur year-round, though in sub-tropical environments (e.g., Florida Keys) a much shorter reproductive season of March through June exists (Marx and Herrnkind 1986).

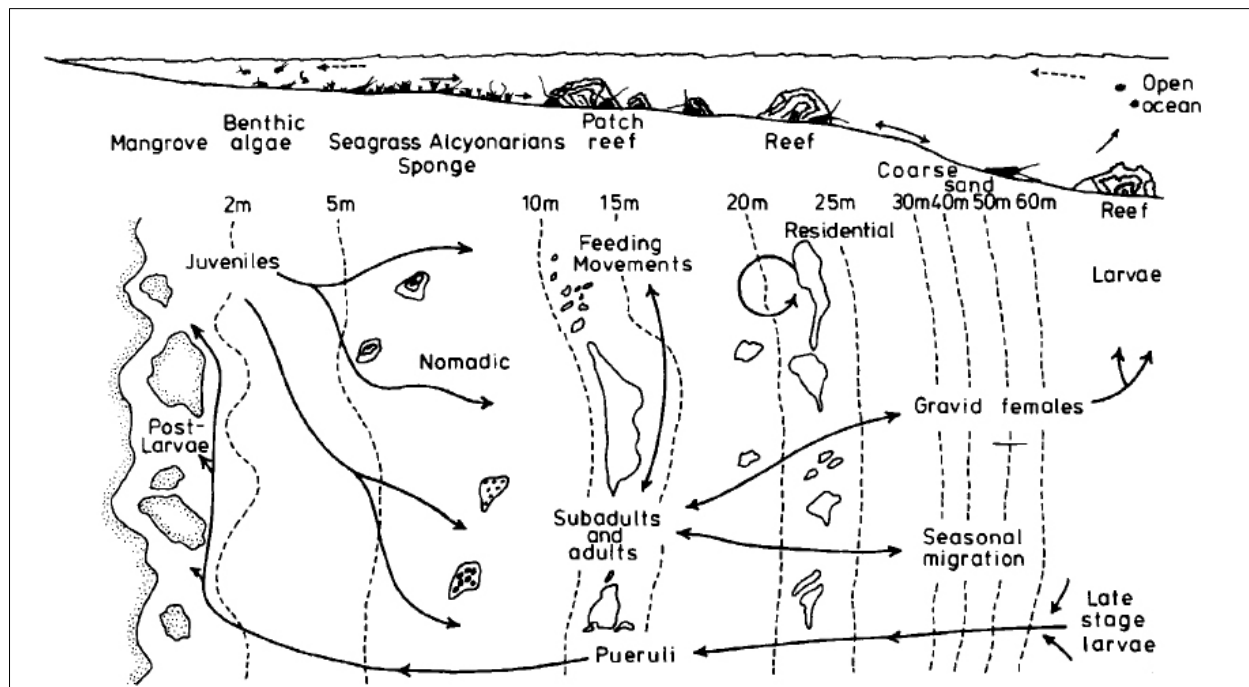


Figure 2. Different habitats used by various life history stages in the life cycle of the Caribbean Spiny Lobster. (Marx and Herrnkind 1986; reprinted from Herrnkind 1980).

Disease

In 1999, a viral disease affecting spiny lobsters was discovered in the Florida Keys and has since been reported throughout the Caribbean (Behringer 2003; Behringer et al. 2011). The lethal virus, *P. argus* Virus 1 (PaV1), causes lobsters to become lethargic and cease feeding, eventually leading to death (Behringer et al. 2011). The disease is most prevalent in juveniles, leading to mortality one to several months after onset (Behringer et al. 2011). Infected juveniles are often sluggish, have discolored or heavily fouled carapaces, and have chalky-white hemolymph, which is usually clear and amber in color (Shields and Behringer 2004). Adult lobsters infected with PaV1 do not typically present obvious visual signs of infection, and detection in adults is more accurate with use of molecular markers and polymerase chain reaction techniques (Behringer et al. 2011; Moss et al. 2013).

History and Status of the Spiny Lobster Fishery in Florida

In Florida, an artisanal and bait-source Caribbean spiny lobster fishery started in the late 19th century, and expanded as a food fishery with the introduction of the railroad from Miami to Key West in 1912 (SEDAR 2005). The fishery continued to grow until 1969, when commercial landings stabilized somewhat, varying between four and six million pounds per year (Figure 3; SEDAR 2005; Ehrhardt and Deleveaux 2009; NOAA 2017). The commercial lobster fishery in Florida primarily relies on traps, while recreational fishers typically either freedive or use SCUBA to harvest lobster.

While the commercial fishery has remained rather stable, the recreational spiny lobster fishery has grown extensively. Since the 1950s, Florida has grown to be the most intensive recreational lobster fishery in the world (Labisky et al. 1980; Sharp et al. 2005). A two-day mini-season (also known as “sport-season”) was introduced in 1975, where recreational fishermen may harvest lobster prior to the opening of the eight-month regular season (August–March), in an attempt to lessen user conflicts between commercial and recreational fishermen (Sharp et al. 2005). In 1982, the annual recreational catch represented only about 10% of the fishery. However, in recent years, an average of 1.7 million pounds is harvested recreationally in the first five weeks of the season, representing roughly 30% of the annual commercial landings (GMSAFMC 1982; Sharp et al. 2005). Overall, the heavy fishing pressure on lobster in Florida is thought to reduce the adult population by 90% each year (Harper 1991; Hunt 1994). Such a drastic reduction in the adult population likely has negative consequences on reproductive output and decreases the number of larvae that self-recruit as well as those that recruit to downstream populations. During the mini-season alone, Eggleston et al. (2003) estimated that up to 90% of legal-sized lobsters are removed at some locations in the Florida Keys, the area of Florida where fishing pressure on lobsters is greatest (SEDAR 2005).

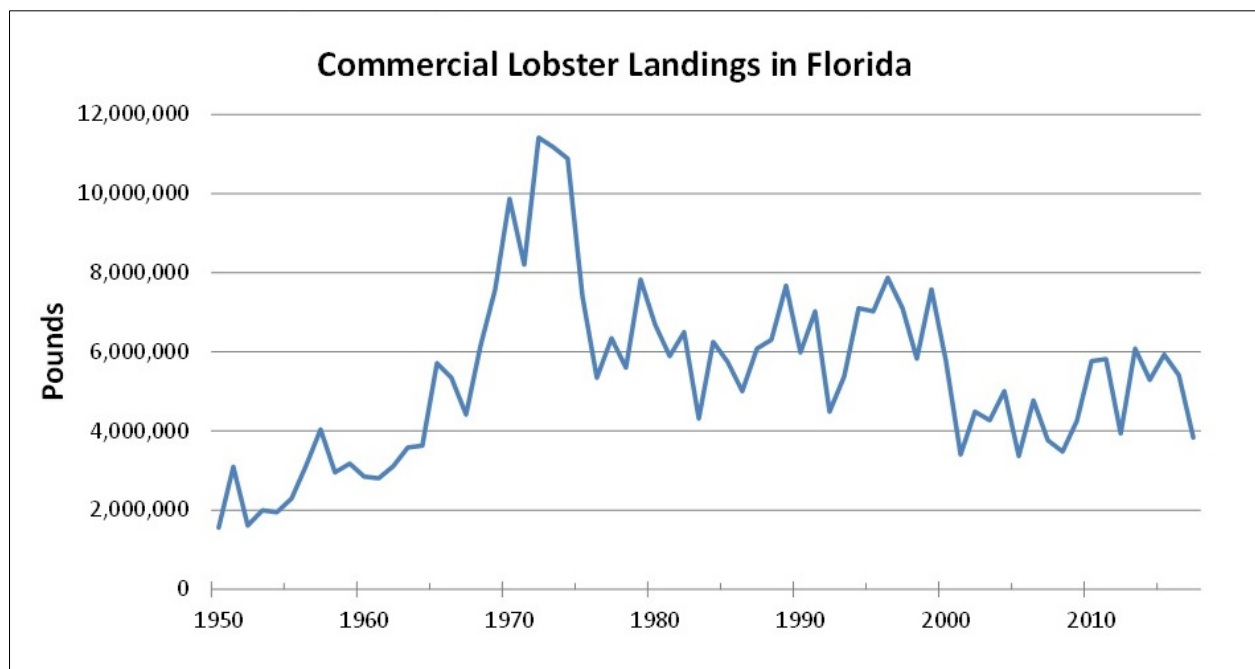


Figure 3. Commercial lobster landings in Florida from 1950–2017, in pounds.

There have been several efforts to help sustain and protect the lobster fishery in Florida. The fishery was first regulated in 1919 with the advent of a closed season of March 1 through June 1 (Labisky et al. 1980). A minimum legal size of one pound was established in 1929, and the closed season lengthened to four months (Prochaska and Baarda 1975). In 1965, the minimum size limit was changed to a carapace length of 3 inches (76.2 millimeters [mm]) and the taking of egg-bearing females was prohibited. These regulations have stayed consistent through today (Labisky et al. 1980). Lobster sanctuaries were established in Dry Tortugas NM (1971), Card Sound and Biscayne

Bay (1979), and the Everglades NP section of Florida Bay (1980), in an effort to protect important nursery areas for juvenile lobsters (Marx and Herrnkind 1986). Additionally, the Tortugas Ecological Reserves, 19 smaller Special Protection Areas, and Western Sambo's Ecological Reserve in the Florida Keys, all no-take reserves, were established in 2001.

Expansive nursery habitat, when coupled with high rates of recruitment, may be the reason why the South Florida lobster populations can sustain such prolonged high fishing pressure (Acosta et al. 1997; Butler et al. 2010). The main axis of the Gulf Stream is located 25 kilometers (15.5 miles [mi]) from Miami, running northward (Lee et al. 1992). Several wind-driven currents are associated with the Gulf Stream. These counter currents, gyres, and coastal eddies transport lobster larvae shoreward (Yeung et al. 2001). This, coupled with the long pelagic larval duration (five to seven months) and shoreward orientation and swimming of spiny lobster postlarvae, means that South Florida receives a high number of lobster recruits from both up-current and local populations (Acosta et al. 1997; Goldstein et al. 2008; Butler et al. 2010; Kough et al. 2013; Kough 2014; Truelove et al. 2015; Truelove et al. 2017; Yao and Zhang 2018). Florida Bay, Biscayne Bay, and Card Sound are three major nurseries for these lobster recruits with widespread favorable habitat for the high influx of larvae (Marx 1986). The availability of ideal nursery habitats is one of the most important factors contributing to recruitment success and survival of juvenile lobsters in South Florida (Field and Butler 1994; Herrnkind and Butler 1994; Butler and Herrnkind 1997).

An ample supply of recruits from up-current in the Gulf and Caribbean and the availability of nursery habitat in Florida provide the foundation for the sustainability of Florida's intense lobster fishery. Butler et al. (2010) discovered that nearly 70% of the commercial fishery landings in the Florida Keys could be explained by postlarval recruitment 14 months prior. However, a reported 36% decrease in annual post-larval lobster supply since 1988 is troublesome, as the South Florida lobster fishery relies heavily on recruitment from up-current sources (Ehrhardt and Fitchett 2010). Continued protection of nursery habitats, cooperative management strategies with down-current lobster fisheries, and adequate protection of spawning lobster stocks may be needed to ensure the longevity of the Florida lobster fishery.

History and Status of the Spiny Lobster Fishery in the U.S Virgin Islands

The U.S. Virgin Islands support an important but far less intensive spiny lobster fishery than Florida, where spiny lobster landings account for only 9% of the commercial fishery in the territory (Tobias et al. 2000). Historically, while lobster was occasionally harvested for food, it did not represent a traditional food source for Virgin Islanders and was more commonly used as bait for the fin-fish fishery (Olsen et al. 2014). The first documented commercial landings for spiny lobster in the Virgin Islands began in 1974, recording less than 11,000 pounds (4,989 kilograms [kg]) that year (SEDAR 2005; Olsen et al. 2014). That number increased to about 37,500 pounds (17,900 kg) in 1980–88 (NOAA 1992); to about 79,400 pounds (36,015 kg) between 1996–2001 (Tobias et al. 2000; Kojis et al. 2003); and over 220,500 pounds (100,017 kg) between 2007–2011 (Olsen et al. 2014). The substantial increase in commercial catches of lobsters most likely resulted from an expanding tourism industry in the Virgin Islands, allowing more local marketability of lobster (Olsen et al. 2014). From 2011 to 2016 there has been a consistent decline in recorded commercial landings, with just under

100,000 pounds (45,359 kg) recorded in 2016 (Olsen et al. 2018). However, following a short commercial closure in 2013 by the Caribbean Fishery Management Council, it is suspected that catch data (which is voluntarily provided by fishermen) for lobster was underreported and may not accurately represent the actual landings data since then (Olsen et al. 2018).

The northern Virgin Islands of St. Thomas and St. John are separated from St. Croix by about 65 kilometers (40.3 mi) and the Virgin Islands Trough which reaches depths of over 4,270 meters (14,009 ft). The lobster fishery in St. Thomas/St. John is dominated by trap-fishing whereas the St. Croix fishery is dominated by diving methods (Figure 4; Olsen et al. 2014). The same study estimated a probable population size of 400,000 lobsters in the northern Virgin Islands, where the fishery removes an estimated 10% or less of the population annually. They noted that high landings between 2003 and 2006, which exceeded the overfishing limit by 15,000 pounds (6,803 kg), appeared to have no significant effect on catch per unit effort (CPUE) or average size of landed lobsters, suggesting the lobster fishery in St. Thomas and St. John is sustainable. However, while a population estimate was not completed on St. Croix, the authors noted a substantial decline in average size of landed lobsters since 2011 over the previous 30 years. Other studies have also suggested the lobster fishery on St. Croix was fully exploited or experiencing overfishing (Bolden 2001; Mateo and Tobias 2002).

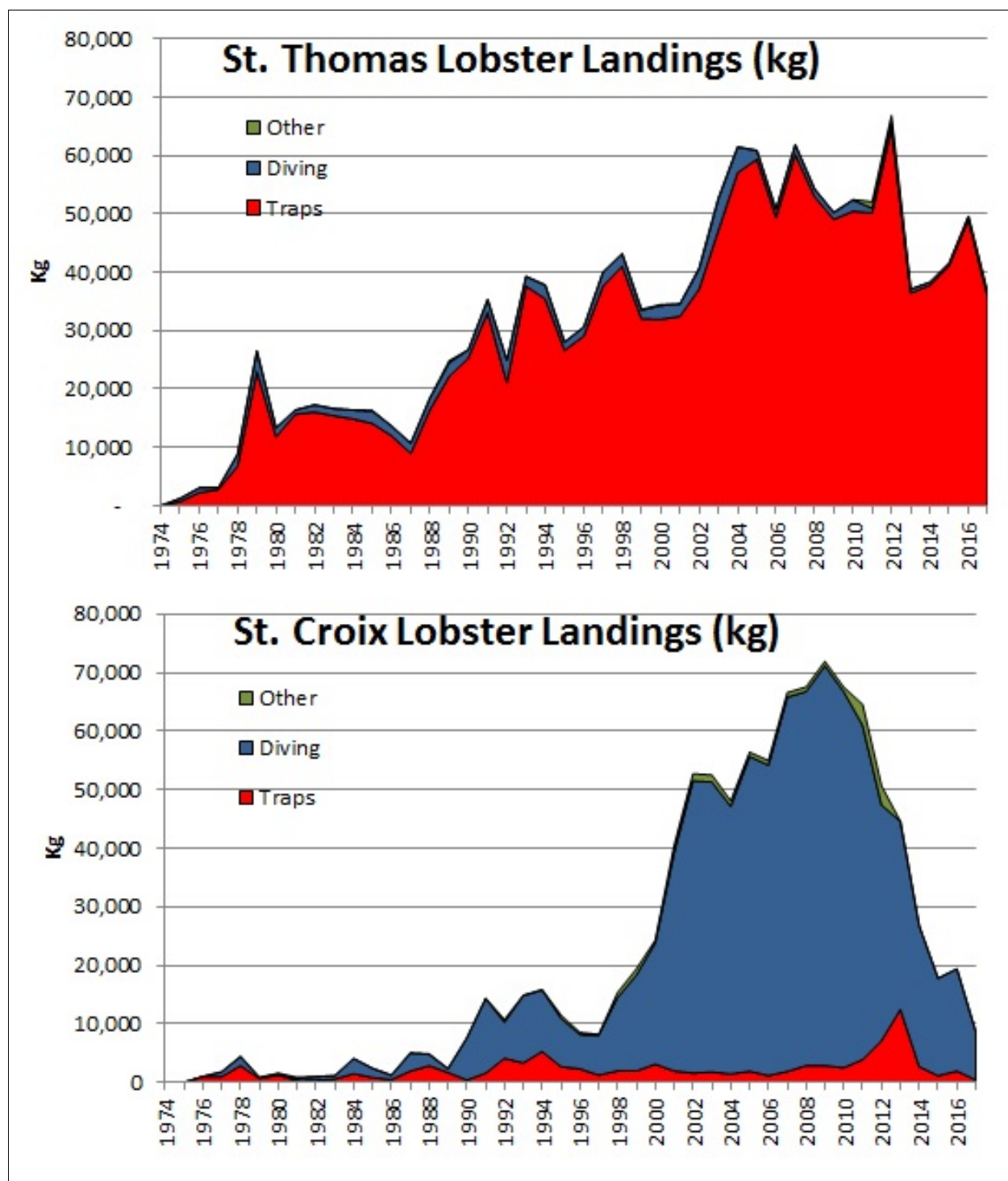


Figure 4. Lobster landings by fishing method for St. Thomas/St. John and St. Croix from 1974 through 2016 (Olsen et al. 2018).

Link to Management Decision-Making

This protocol does not define thresholds or triggers for management decision-making as this is premature at this stage of the program. However, parks, the National Oceanic and Atmospheric

Administration (NOAA), and state and territorial governments can use the data to support changes to outreach, education, enforcement, bag limits, size limits, closures, and gear changes; and evaluate the effectiveness of the size and location of marine protected areas and determine if and where changes are needed.

Overall, there is an expectation that the parks closed to fishing (Buck Island Reef NM and Dry Tortugas NP) should see increases in numbers and size of spiny lobster over time compared with open-use areas outside those parks. Subsequent to increases within these parks, areas adjacent to the parks are expected to see increases as well (i.e. “spillover”). Failure to detect such trends could cause the parks to consider changes in enforcement levels, increases in public education efforts, and targeted studies into the lack of response.

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

Study Area

This protocol is focused on SFCN parks that have sufficient marine habitat suitable for adult spiny lobster within their boundaries. The park units in the Virgin Islands are Virgin Islands NP, Buck Island NM, and Salt River Bay NHP. The park units in south Florida are Biscayne NP and Dry Tortugas NP. While Everglades NP contains substantial habitat for juvenile lobster, it does not support a substantial adult lobster population and is excluded as a study area for SFCN spiny lobster monitoring. An understanding of the lobster population in Everglades NP and its history is important however, as the area is closely connected to the adult lobster populations found in Biscayne NP and Dry Tortugas NP.

Biscayne National Park

Biscayne NP was initially established in 1968 as a national monument and was expanded to a national park in 1980. The park is situated off the Atlantic coast of South Florida and covers over 69,606 hectares (172,000 acres [ac]), 95% of which lies underwater. The northernmost portion of the Florida Keys reef tract and a large portion of Biscayne Bay lie within its boundary. The Eastern boundary is limited by an 18-meter (59 ft) depth contour. In 1979, the State of Florida established a lobster sanctuary in Biscayne Bay (Figure 5) that includes all marine habitat shoreward of the barrier islands within Biscayne NP, primarily in an effort to protect juveniles (Marx and Herrnkind 1986). Offshore of the barrier islands, both commercial and recreational harvest of lobster is permitted inside Biscayne NP boundaries. The commercial fishery primarily uses traps, often with several strung together on submerged lines. Recreational fishers dive or free dive to capture lobsters with nets and “tickle sticks.” While the commercial trap fishery has no bag limit, recreational harvesters are limited to six, per person, per day.

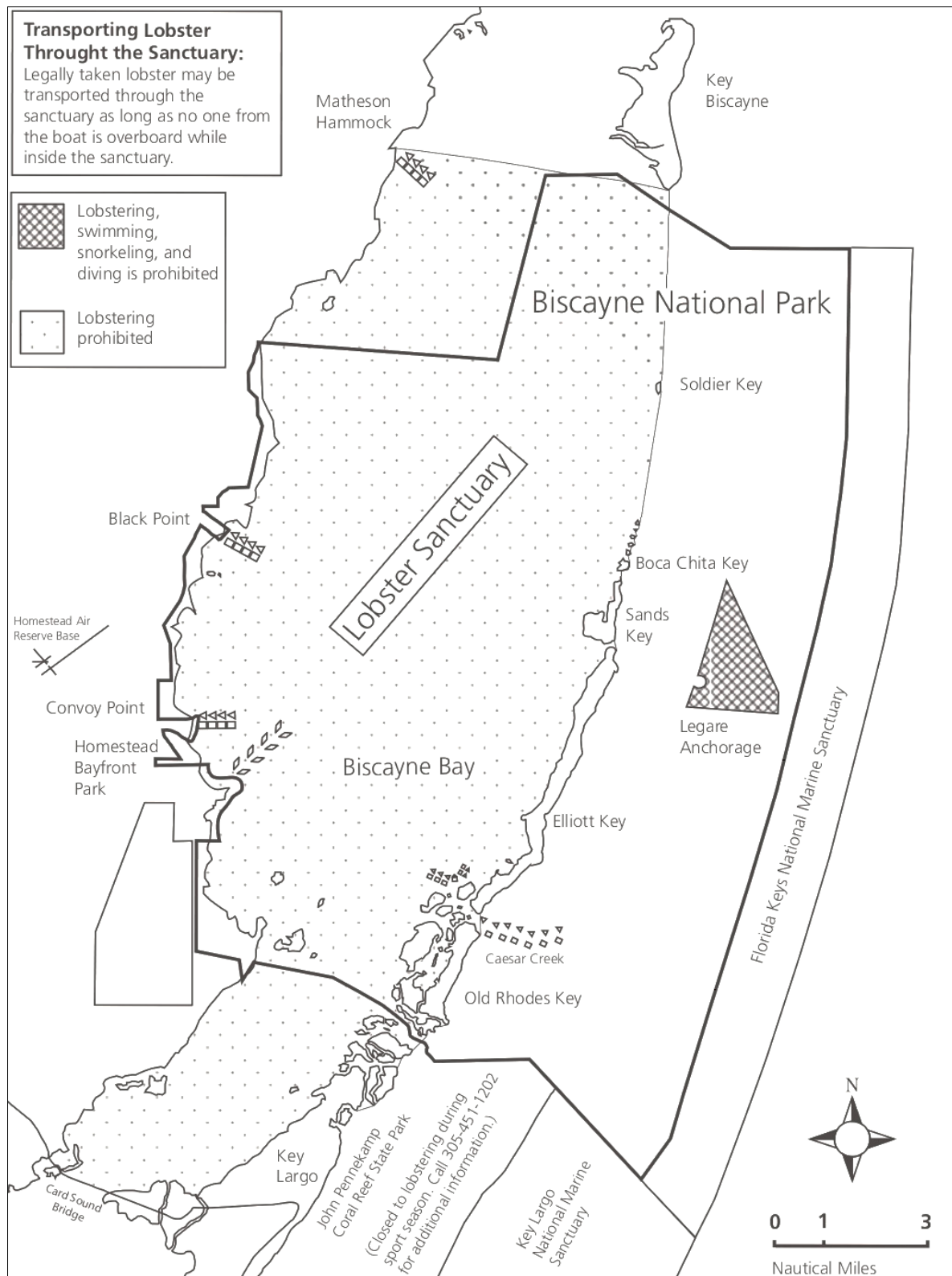


Figure 5. Map of Biscayne Bay-Card Sound Lobster Sanctuary and Biscayne NP (NPS 2015).

The lobster population in Biscayne NP receives substantial harvest pressure, particularly during mini-season, mostly due to the park's proximity to densely populated Miami-Dade County. To monitor the lobster fishery within the park, particularly the effort surrounding mini-season, Biscayne NP has been conducting ongoing creel surveys since 1987 (McDonough 2012). Their data show that CPUE and trip catch (number of lobsters caught per person per trip) during mini season have both decreased gradually since 2002. Data presented by McDonough (2012) suggest that a reduction in bag limit in 2002, from twelve to six lobster per person, was not the limiting factor for declining recreational catch. The mean trip catch prior to 2002 was far less than twelve, suggesting that the observed decline in catch-per-unit-effort and trip catch may be from fluctuation or decline in the lobster population (McDonough 2012). However, the commercial catch inside the park has fluctuated some, but remained fairly stable between 20,000–40,000 pounds (9,072–18,144 kg) over the same time frame (FWC 2018). There was a marked increase in commercial landings between 2013 and 2016, peaking in 2014 with an annual catch of 103,137 pounds (46,782 kg; FWC 2018). The sharp decrease in annual catch which followed this period can be largely attributed to the landfall of Hurricane Irma in September 2017, which displaced and destroyed many of the traps used by the commercial fleet (Figure 6).

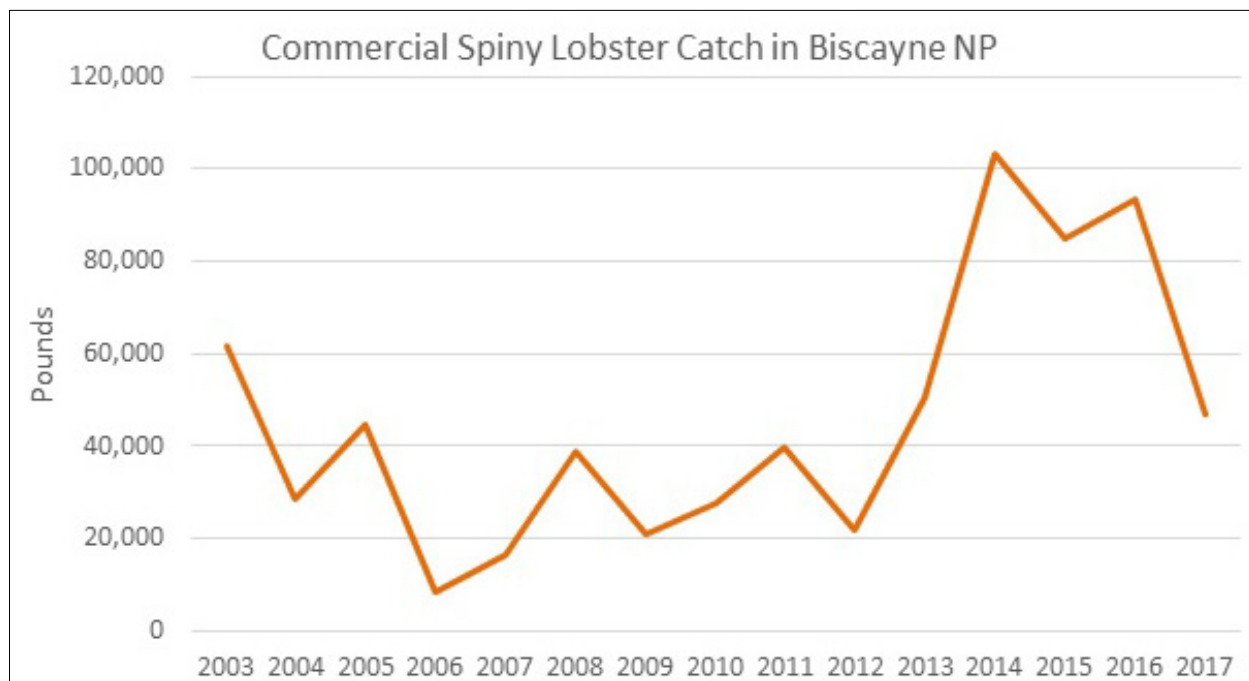


Figure 6. Commercial catch data for Biscayne NP (FWC 2018).

Many studies have focused on lobster in Biscayne NP and the Florida Keys. The Florida Fish and Wildlife Conservation Commission (FWC) has conducted a variety of fishery-dependent and fishery-independent surveys of lobster throughout the Florida Keys. Substantial lobster research has also been conducted by the Mark Butler lab at Old Dominion University and the Bill Herrnkind lab at Florida State University. Their collective efforts include research of larval duration, recruitment, settlement, reproduction, population structure, habitat utilization, growth, movement, survival, and

disease (Lipcius and Herrnkind 1982; Marx and Herrnkind 1985; Marx and Herrnkind 1986; Herrnkind and Butler 1986; Lipcius and Herrnkind 1987; Smith and Herrnkind 1992; Field and Butler 1994; Forcucci et al. 1994; Herrnkind and Butler 1994; Acosta et al. 1997; Butler and Herrnkind 1997; Butler et al. 2005; Butler et al. 2010). Interagency (NOAA, FWC, NPS) reef fish visual census surveys take place biennially in the park. The number of lobsters in the survey is recorded as ancillary data, but the method does not incorporate an active search for lobsters in crevices and holes and likely underestimates the population (Brandt et al. 2009).

Everglades National Park

Everglades NP was created in 1934 and currently protects over 1.5 million acres (607,000 hectares [ha], or 2,343 square miles [mi²]) of ecosystems including pinelands, cypress domes, mangroves, coastal lowlands, estuaries, and the shallow marine environment of Florida Bay. A portion of Florida Bay was added to Everglades NP in 1951, encompassing over 93,078 hectares (230,000 ac) that contains wide expanses of seagrass, algal communities, tidal channels and shallow hard-bottom communities ideal for juvenile lobster settlement (Davis and Dodrill 1989). Historically, Florida Bay supported a substantial spiny lobster fishery, though Everglades NP closed the park waters to all lobstering in 1980 (one year after the establishment of the Biscayne-Card Sound Lobster Sanctuary) in an order to protect juveniles and their associated habitat (Marx and Herrnkind 1986). Prior to the closure, most of the lobstering effort was concentrated in the southern portion of the park, particularly the Twin Key Basin (Davis and Dodrill 1989; Robles et al. 2005). Most lobsters utilize the area for the first two to three years of their life then emigrate offshore to the reefs as far north as Biscayne (109 kilometers [67.7 mi]) and as far southwest as the Dry Tortugas (210 kilometers [130.4 mi]; Davis and Dodrill 1980; Davis and Dodrill 1989). Growth rates of juvenile lobster in Florida Bay were also found to be substantially higher than that of nearby areas, including Biscayne Bay and the Middle and Upper Florida Keys (Davis and Dodrill 1980; Davis and Dodrill 1989). As described above in the section, Rationale for Monitoring, tracking post-larval and juvenile lobsters would be valuable but is outside the scope of this protocol. The South Florida/Caribbean Network has decided not to monitor lobster in this park because Everglades NP does not contain a substantial area of habitat for adult lobsters typically targeted by the fishery.

Dry Tortugas National Park

The Dry Tortugas National Park is located about 112 kilometers (69.5 mi) west of Key West and is 99% marine, with seven small islands, including Garden Key, where Fort Jefferson is located. The park was originally established as Fort Jefferson National Monument in 1935, expanded in 1983, and re-designated as Dry Tortugas National Park in 1992. The park now covers approximately 25,900 hectares (64,000 ac), only 42 (103.7 ac) of which are land. A recreational lobster fishery existed in the park until 1971, but commercial lobster harvest has been prohibited in the park since its inception. The nearby Tortugas Ecological Reserves (split into a northern area and a southern area) are managed by NOAA and also prohibit any extractive activities.

An eight-month experimental sport harvest season took place in 1973–1974, where densities of lobsters in Dry Tortugas NP were estimated to be about 64.8 lobsters per hectare (26.2 per ac; Davis 1977). The temporary re-opening of the fishery was found to be detrimental and significantly reduced

and dispersed the lobster population in Dry Tortugas NP. A more recent assessment by Bertelsen and Maxwell (2005) estimated densities within Dry Tortugas NP to be about 72 lobsters per hectare (29.1 per ac).

The protection of the lobster population in Dry Tortugas NP had several positive effects. The frequency of occurrence of large lobsters is greater inside Dry Tortugas NP than in fished areas of the Florida Keys, where the frequency of larger lobsters declines rapidly after they reach harvestable size (Bertelsen and Matthews 2001; Bertelsen et al. 2004). Lobsters were also more fecund in Dry Tortugas NP than in the surrounding fished waters, exhibiting larger clutch sizes and a shorter, more intense reproductive season (Bertelsen and Matthews 2001). Most of the lobsters in Dry Tortugas NP were also found to be resident, though some lobsters had migrated into the population from Florida Bay after development into adulthood (Davis 1977; Davis and Dodrill 1989). Today, Dry Tortugas NP remains an important sanctuary for lobsters, with documented spillover effects, and serves as a source of larvae for the rest of the Florida Keys (Acosta et al. 1997; Bertelsen and Matthews 2001).

Virgin Islands National Park

The Virgin Islands NP was established in 1956, encompassing approximately 60% of St. John's land and was expanded in 1962 to include over 2,286 hectares (5,648 ac) of shallow marine habitat. Since the park's inception, spiny lobster harvest has been limited to two per person, per day, within the park. The size limit was established at a minimum carapace length of 3.5 inches (8.9 centimeters [cm]). Harvest of females with eggs is prohibited.

There have been few studies to assess both the fishery and ecology of the spiny lobster around Virgin Islands NP. A study by Idyll and Randall (1959) marked one of the first studies to examine spiny lobsters as a resource in the Virgin Islands. The Tektite underwater habitat program fostered several baseline studies of spiny lobster in Lameshur Bay, Virgin Islands NP from 1969–1971, focusing on population dynamics, growth, mortality, ecology, and behavior (Cooper et al. 1975; Herrnkind et al. 1975; Olsen et al. 1975; Olsen and Koblic 1975). Between 1986 and 1988, the Virgin Islands Resource Management Cooperative produced several reports on lobster monitoring and fishery assessments. The studies concluded that spiny lobster populations around St. John were quite low and highly dispersed (Boulon 1986; Boulon 1987). Resource impacts were primarily from subsistence and recreational use, concentrated around Fish and Reef Bays, where the highest lobster abundance was observed (Boulon et al. 1986; Boulon 1987). A study by Wolff (1998) demonstrated that while the observed density (five lobsters per hectare, or two per acre) was similar to the Boulon (1987) study, it had substantially decreased from the baseline observation of 19.4 lobsters per hectare (7.8 per ac) in 1970 (Olsen et al. 1975). The same study also reported that mean carapace length of lobsters found on reefs had decreased from 111 millimeters (4.3 in) in 1970 to 80 millimeters (3.1 in) in 1996. These results are corroborated by Beets et al. (1996). From 1996 onward, there have been few studies that have specifically targeted the status of spiny lobsters within Virgin Islands NP. Since 2003, the NOAA Biogeography Program has conducted continued routine stratified random fish and benthic surveys throughout the Virgin Islands, where any lobsters along a 25 × 4-meter (82.0 × 13.1-ft) transect are recorded, though no size estimates are taken (Friedlander et al. 2013; Bryan et al. 2013). In 2013 and 2015, the transect size was changed to 25 × 2 meters (82.0 × 6.6 ft; Clark et al.

2015). In 2017, the transect size was changed again to 15×2 meters (41.0×6.6 ft; NCCOS and SEFSC 2018). Out of the 319 transects that were completed in Virgin Islands NP between 2004 and 2011, only four lobsters were recorded (NCCOS 2018). In 2013, 54 transects were completed, recording three lobster (NCCOS 2018). In 2015, 46 transects were completed, recording eight lobster (NCCOS 2018). In 2017, three lobster were detected in 55 transects surveyed (NCCOS 2018).

Buck Island Reef National Monument

Buck Island Reef NM, established in 1961 and expanded substantially from 356 hectares (879.6 ac) to 7,695 hectares (19,014 ac) in 2001, is comprised of mostly marine environments except for a 71-hectare (175.4-ac) island. The monument's expansion in 2001 also included legislation that prohibits the harvest of any species, including spiny lobster, where recreational and commercial fishing practices were previously allowed. While Buck Island Reef NM contains over 7,200 hectares (17,791 ac) of marine habitat, less than half of that area is shallow enough for lobsters to inhabit.

Tobias et al. (1988) provided one of the first baseline assessments of the lobster population in Buck Island NM, prior to the monument's expansion. The study focused on patch reefs to the north and west of the island, and the fringing reef along the southern shoreline (all selected non-randomly). Approximate densities of lobster in these areas were 90.9, 19.2, and 8.7 lobsters per hectare (36.8, 7.7, and 3.5 per ac), respectively. The high variability in the lobster densities stems from the relatively small areas that were studied, as the hypothetical discovery of an additional single lobster could nearly double the density estimate. Thus, these values should be interpreted cautiously.

Following the expansion of Buck Island Reef NM in 2001, the FWC was contracted to conduct monitoring of lobsters over five missions from 2004–2007 (Cox et al. 2009). Their objectives were four-fold: (1) compare lobster populations inside and outside Buck Island Reef NM to determine the functionality of its protection, (2) examine breeding metrics, (3) measure postlarval and juvenile abundance, and (4) determine whether the lobster virus PaV1 was present in St. Croix. The researchers discovered that the overall abundance of lobsters (both inside and outside of Buck Island NM) was low, making it difficult to identify temporal trends in the population without a prohibitively large number of samples.

Combining all years of data, they found that lobster abundance and size was greater inside Buck Island Reef NM than outside. Timed searches were used for these surveys, so CPUE was calculated as a proxy for abundance estimates. Two habitat strata were used for pair-wise comparisons for inside and outside Buck Island Reef NM: deep reef and mid-channel patch reef. In these habitats, CPUE was greater inside Buck Island Reef NM than the reference sites outside (4.6 and 2.6 lobsters per hour versus 1.0 and 1.0 lobsters per hour, respectively). Lobsters inside Buck Island Reef NM tended to be larger than those found in the reference sites outside. Lobsters at deep reef sites inside the monument had a mean size of 106 ± 1 (SE) mm (4.17 ± 0.04 in) versus 93 ± 5 (SE) mm (3.66 ± 0.20 in) outside. In the mid-channel patch reefs, lobsters had a mean size of 91 ± 3 (SE) mm (3.58 ± 0.12 in) inside the monument versus 73 ± 4 (SE) mm (2.87 ± 0.16 in) outside. Lobster size also tended to increase with distance from the St. Croix shoreline. They also found that female reproductive activity was greatest in the deep reef habitat regardless of the monument boundary, and in the back reef habitat inside Buck Island Reef NM. The researchers found that there was a high

abundance of postlarvae, but their survival and recruitment may be diminished due to increased predation and the lack of quality habitat. Lastly, they found that the lobster virus PaV1 was present in two of the sampled lobsters, though the significance of the virus to the total population could not be determined.

As in Virgin Islands NP, routine fish and benthic surveys were conducted by the NOAA Biogeography Program between 2004–2011; during these surveys any lobsters sighted along a 25 × 4-meter (82.0 × 13.1-ft) transect were recorded, though no size estimates were taken (Pittman et al. 2008; Bryan et al. 2013). In 2015, the transect size was changed to 25 × 2 meters (82.0 × 6.6 ft; NCCOS 2016). In 2017, the transect size was changed again to 15 × 2 meters (41.0 × 6.6 ft; NCCOS and SEFSC 2018). In 752 transects completed within Buck Island NM from 2004-2012, 54 lobsters were recorded on 29 of those transects (NCCOS 2018). In 2015, a total of five lobsters were recorded over 66 transects (NCCOS 2018). In 2017, three lobster were detected out of 59 transects surveyed (NCCOS 2018).

Salt River Bay National Historical Park and Ecological Preserve

Salt River Bay NHP&EP became part of the National Park System in 1992. The park's 411 hectares (1,015 ac) of terrestrial and marine habitat are jointly managed by the National Park Service and the U.S. Virgin Islands government. In 1995 the territory proposed legislation intended to protect all terrestrial and marine life within the park borders, including the prohibition of harvest or possession of spiny lobster, however that legislation has yet to be enacted. Since its inception, there have been no targeted studies of spiny lobster in Salt River Bay NHP&EP. The only surveys that include lobster in Salt River Bay NHP&EP are those previously mentioned, completed by the NOAA Biogeography program. In 2012, the transect size was 25 × 4 meters (82.0 × 13.1 ft; Pittman et al. 2008; Bryan et al. 2013). In 2015, the transect size was changed to 25 × 2 meters (82.0 × 6.6 ft; NCCOS 2016). In 2017, the transect size was changed again to 15 × 2 meters (41.0 × 6.6 ft; NCCOS and SEFSC 2018). In 2012, Salt River Bay NHP&EP was included as a management stratum in the sample design, where only a single lobster was found in 17 transects (Bryan et al. 2013; NCCOS 2018). In 2015, no lobsters were found in 12 transects completed there (NCCOS 2018). In 2017, one lobster was detected in 12 transects completed (NCCOS 2018).

Measurable Objectives of Monitoring

The primary objectives of this protocol are to determine the status and trends of:

- Relative density index for exploited phase¹ lobsters
- Relative frequency of occurrence index of exploited phase lobsters
- Average size of exploited phase lobsters

These factors are what drive the sample design and allocation for sampling events. Due to current uncertainties in the location and mapped extent of benthic habitats coupled with imperfect detection

¹ Exploited phase lobsters are lobsters that have reached harvestable size, and unexploited phase lobsters are below the harvestable size.

of all lobster present at a site, metrics are considered indices of relative density and relative frequency rather than precise estimates of density of lobster per unit area.

A secondary objective is to record the following descriptive metrics and provide basic park-wide comparisons between sample events:

- Lobster size distribution
- Sex ratios of lobster
- Molt stage ratio
- Prevalence of egg-bearing females
- Prevalence of females with spermatophore

Sampling Design

Overview

This sampling design is modeled after the SFCN Reef Fish Monitoring Protocols (Brandt et al. 2009; Bryan et al. 2013) and is heavily influenced by a 25-plus year lobster (*Panulirus ornatus*) monitoring program in Torres Strait, Australia (Pitcher et al. 1992; Ye et al. 2004; Ye et al. 2005; Ye et al. 2007; Plagányi et al. 2010; Plagányi et al. 2015). This protocol also takes into account existing lobster monitoring practices in both Florida and in the Virgin Islands by other agencies or organizations and seeks to balance scientific integrity, efficiency, and logistical and budgetary constraints (Smith et al. 2011; Bryan et al. 2016).

Survey Background

Concepts from the Reef Fish Monitoring Protocols

The single-stage stratified random design used in this protocol is derived from published reef fish monitoring protocols for Florida and the Virgin Islands (Brandt et al. 2009; Bryan et al. 2013). The FWC Marathon laboratory has monitored the spiny lobster population in the Florida Keys using this sampling design approach based on fisheries (reef fish) independent surveys (Ault et al. 2005; Brandt et al. 2009). The procedures for sample frame and habitat classification (SOP SL01—*Sample Frame and Habitat Classification—Version 1.1* [SFCN 2020a]) and stratification (SOP SL02—*Stratification—Version 1.1* [SFCN 2020b]) are based almost entirely on those developed by Brandt et al. (2009) and Bryan et al. (2013), with minor modifications that allow the surveys to target lobster instead of reef fish.

From Brandt et al. (2009):

There are many ways to select a sample from a population, but if information is known about a population, a selection method can be devised that provides more accurate and precise survey 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. Reef fish are typically heterogeneous with respect to geographic distribution but vary in space with certain environmental covariates, such as habitats with structure that provide shelter. Knowing this, maps of environmental covariates can be used to effectively divide the sampled area into strata. Random samples can then be allocated into these strata based on each stratum's proportional area and variance structure of the population within that stratum. This type of stratified random sampling design is capable of more effectively and efficiently sampling a reef fish population than a simple random sampling design (Cochran 1977).

...

The survey domain ... is partitioned into...grid cells called primary units, and each primary unit is defined by different strata including region, habitat, depth, and management level. The number of samples (primary units) allocated to these strata is based on the variance structure of fish species densities developed from previous sampling... A benefit of this

sample design used here is that there is a clearly defined sample frame, with non-overlapping sample units that have a known chance of selection. This is essential for data analysis under sampling theory (Cochran 1977). These sample units are also updateable if the original designation is inaccurate, or as habitats change or better information becomes available.

The same assumptions made above for reef fish apply for spiny lobster and thus a similar sampling design approach will be used, although strata have been combined in lobster surveys to increase the number of sites per strata. Table 1 highlights key similarities and differences between this sample design and the sample design of the SFCN Reef Fish Monitoring Protocols.

Table 1. Key similarities and differences between the SFCN Spiny Lobster Monitoring Protocol and the SFCN Reef Fish Monitoring Protocols.

Category	SFCN Reef Fish Monitoring Protocols	SFCN Spiny Lobster Monitoring Protocol
Sampling strategy	Stratified-random design based on habitat, depth, and region	Same as SFCN Reef Fish Monitoring Protocol. Some strata have been merged based on habitat similarity or small numbers of cells within strata.
Allocation strategy	Optimal allocation based upon variance calculations from previous sampling event's data. Data from multiple fish species (FL = 8, USVI = 9) used to optimize allocation	Initially, sites are allocated evenly across all strata. The allocation scheme will be revised to a more efficient allocation once more information on lobster density, distribution, and associated variances is available. Sites may be co-located with fish survey sites when statistically valid to do so.
Sample domain	Florida: Florida Keys reef tract (includes Biscayne NP and Dry Tortugas NP) in water depths < 30 m; USVI: All reef habitats on St. John, St. Thomas, and St. Croix (includes Virgin Islands NP, Virgin Islands Coral Reef NM, Buck Island NM, Salt River Bay) in water depths < 30 m	Focuses on park units in FL and USVI (Biscayne NP, Dry Tortugas NP, Virgin Islands NP, Buck Island NM, Salt River Bay) in water depths < 30 m and optionally, unmanaged reef habitat nearby for comparison (outside park)
Sample frame	A grid is overlaid over hard-bottom habitats. Florida uses 100 × 100 m cells and USVI uses 50 × 50 m cells	Same as SFCN Reef Fish Monitoring Protocol
Sampling schedule	Biennial sampling in FL and the USVI from June–September	Sampling is on a four-year rotation, unless park unit decides to decrease monitoring efforts for another resource (e.g. seagrass) for more frequent monitoring; sampling occurs in May
Survey methods	FL = two replicates of two averaged point counts (cylinder with 7.5 m radius) per grid cell; USVI = one replicate of two averaged point counts (cylinder with 7.5 m radius) per grid cell	One replicate of two averaged circular plots (7.5 m radius) per grid cell

Table 1 (continued). Key similarities and differences between the SFCN Spiny Lobster Monitoring Protocol and the SFCN Reef Fish Monitoring Protocols.

Category	SFCN Reef Fish Monitoring Protocols	SFCN Spiny Lobster Monitoring Protocol
Site selection (primary)	Grid cells to be sampled per stratum are randomly selected from complete list of cells within a stratum	Same as SFCN Reef Fish Monitoring Protocol.
Site selection (secondary)	Haphazard selection of survey location within primary unit. Decision rules exist for divers to reduce bias when selecting the point-count location (FL) or laying a transect (USVI)	Same as SFCN Reef Fish Monitoring Protocol (FL)

The sample frame from the reef fish monitoring consists of a construct of grid cells (the primary sample units) which are based on depth and the underlying benthic habitat (Brandt et al. 2009; Bryan et al. 2013). The habitat information is derived from benthic habitat maps which were created through interpretation of aerial imagery and LiDAR (Kendall et al. 2001; Waara et al. 2011; Estep et al. 2017). Map resolution is the primary driver for the size of the grid cells. Currently, the minimum mapping unit of 0.5 hectares (1.2 ac) is used for benthic habitat maps in Florida and 0.4 hectares (1.0 ac) is used for the Virgin Islands LiDAR (Kendall et al. 2001; Waara et al. 2011; Estep et al. 2017). Not all the actual hard-bottom habitats are mapped accurately, meaning that in many cases, unmapped hard-bottom habitat exists within the grid cells. For example, when pavement is covered with a thin veneer of sand, it can be very difficult or impossible to detect through aerial imagery interpretation.

Many grid cells are mapped with partial coverage of hard-bottom habitat. For stratification and analyses, if we were to use the mapped hard-bottom areas, we would likely underestimate abundance because there are hard-bottom areas that are not mapped. If we treat the entire grid cell area as hard-bottom habitat, then we would likely overestimate abundance. Because of our uncertainty in benthic habitat coverage, we emphasize that any calculated values for abundance are uncertain, inflated, and potentially misleading. Thus, relative density and relative frequency of occurrence are more appropriate and may be estimated for individual strata. However, due to the uncertainty in map weights, when making park-wide calculations we emphasize that relative density and relative frequency of occurrence are unit-less indices. At present in this protocol (and in the reef fish monitoring protocols) the entire grid cell area is treated as hard-bottom habitat when calculating strata weights, and the actual plot cylinders are placed upon true hard-bottom in the grid cell. This creates a known but accepted bias in calculations.

In practice, deploying divers on the intended hard-bottom habitat can be logistically difficult. In part, this is due to map resolution and accuracy. GPS error, currents, wind, and depth of the site can complicate the issue. Furthermore, once deployed, the divers do not know their exact location because GPS does not work underwater. This can lead to the divers conducting a survey on a hard-bottom habitat that is not that of the intended stratum. The divers collect benthic habitat data during

the survey so that their survey may be attributed to the appropriate stratum for analysis. It is important that the survey data collected reflect the actual habitat (i.e., appropriate stratum) on which it was collected. This of course has the potential to affect achieving the required minimum number of samples in rarer habitat types. Keeping track of the post-stratified surveys throughout the sample effort allows for extemporaneous planning to achieve the minimum allocation.

In the event that more accurate benthic habitat data becomes available, the potential exists for the grid cell size to be reduced. In 2014, this happened in Florida for reef fish monitoring and the grid cell size has changed from 200×200 meters (656×656 ft) to 100×100 meters (328×328 ft). With better mapping technology and coverage, the grid cell size for Florida may change to 50×50 meter (164×164 ft) in a few years (S. Smith, pers. comm.). If and when this happens, the total survey domain area remains the same. Individual grid cell classifications may change in order to reflect the more accurate benthic habitat maps. It is imperative that this new grid be applied to historical data and metrics (e.g., relative density) be recomputed. This avoids a false trend being created merely from any changes to the grid itself.

Concepts from the Torres Strait Rock Lobster Monitoring Program

Since the inception of the Torres Strait rock lobster monitoring program there have been several modifications to both the sampling design and sampling method to improve the scientific rigor and address funding limitations and logistical constraints. Over the course of their program, they have surveyed both stratified-random and fixed sites and used either transects or timed swims for their survey method. Ye et al. (2005) reviewed the changes in methodology in the program and concluded that future lobster surveys should aim to maintain design consistency over time, improve coverage of samples across the domain, and ensure that sites were appropriately balanced among strata. Since 2002, the Torres Strait Rock Lobster monitoring program has employed a stratified-random survey design based upon habitat and region, using 4×500 -meter ($13.1 \times 1,640$ -ft) transects. We will also implement a stratified-random design, but using circular plots to monitor spiny lobster (*P. argus*) in SFCN parks.

The decision was made for the SFCN lobster monitoring program to use re-randomized sites instead of fixed sites for two reasons. First, re-randomization of sites for sampling periods can help address changes in lobster distribution over time better than the use of fixed sites. The Torres Strait rock lobster monitoring program used fixed sites for several years until there were concerns that the distribution of lobsters had shifted and the set of sites was no longer representative of the actual population (Ye et al. 2005). Second, the SFCN reef fish monitoring protocol also re-randomizes sites for every sampling event and it is particularly beneficial to maintain consistency with the sampling design of the reef fish protocol. These two reasons outweigh the potential benefits of using fixed sites (e.g. improved trend detection by controlling spatial variability) instead of re-randomized sites.

Sampling Domain

This protocol focuses on survey efforts on adult lobsters that are near, at, or above harvestable size. Adult lobsters tend to inhabit a variety of coral reef habitats that are found within several SFCN parks. During the daytime (when sampling will occur), adult lobsters do not typically use seagrass, mangrove, or other non-reef habitats. Thus, these habitats will be excluded from the sampling

domain. Only the SFCN parks with coral reef habitats (Biscayne NP, Dry Tortugas NP, Virgin Islands NP, Buck Island Reef NM, and Salt River Bay NHP&EP) will be sampled. Although Everglades NP contains habitats suitable for juvenile lobster, there is not enough coral reef habitat to support a population of adult lobsters large enough to sample effectively. There will be a separate sampling domain for each park unit. A park may specifically request to include survey sites outside park boundaries to evaluate management effectiveness (e.g. no-take reserves) if they exist. However, this may require more field survey effort, and will take place when specifically requested by the park and when the park or collaborative partners can offer additional field help and/or resources. Alternatively, data from partner agencies in each region (e.g., FWC, DPNR) may be used to compare different management zones.

A primary consideration of a monitoring program is to define the population and the sampling domain from which samples will be drawn. Adult spiny lobster (*P. argus*) will be surveyed across all mapped hard-bottom habitat found in less than 30-meter (98.4-ft) depths in SFCN park units and optionally, in unmanaged areas for comparison. The Florida reef fish monitoring protocol (Brandt et al, 2009) states all mapped areas of live coral habitat less than 33 meters (108.3 ft) are included in the sample domain. This has since been modified to a 30-meter (98.4-ft) depth limitation.

Benthic habitat maps and the habitat classification scheme are described in SOP SL01—*Sample Frame and Habitat Classification—Version 1.1* (SFCN 2020a; see also Appendices A and B) and were used to create a sample frame constructed with 100 × 100-meter (328 × 328-ft) [Florida] or 50 × 50-meter (164 × 164-ft) [Virgin Islands] grids. If new map products are released in 2020 as anticipated (Steve Smith, Research Scientist, University of Miami, pers. comm. August 14, 2018), the Florida sample frame will be constructed with a 50 × 50-meter (164 × 164-ft) grid. In the Virgin Islands, the strata were defined by habitat type and depth. In Florida, two sets of strata exist: (1) the Dry Tortugas NP strata are based on habitat and management zone and (2) the Biscayne NP strata are based on cross-shelf zone, habitat, and depth. The stratum designations for each of these areas are derived from those described in Brandt et al. (2009) and Bryan et al. (2013). The modifications and the new stratum designations are described below and can be found in Tables 2, 3, 4, 5 and 6.

Table 2. Strata in the Virgin Islands NP sample domain. These strata are not separated by depth and range from 0–30 meters (0–98.4 ft).

Stratum	Map Classification
1	Scattered coral/rock
2	Pavement
3	Bedrock
4	Patch reef
5	Linear reef
6	Unknown hard-bottom

Table 3. Strata in the Buck Island Reef NM sample domain. These strata are not separated by depth and range from 0–30 meters (0–98.4 ft). Bedrock and linear reef have been combined into a single stratum.

Stratum	Map Classification
1	Scattered coral/rock
2	Pavement
3	Patch reef
4	Linear reef & Bedrock

Table 4. Strata in the Salt River Bay NHP&EP sample domain. These strata are not separated by depth and range from 0–30 meters (0–98.4 ft). Pavement and scattered coral/rock have been combined into a single stratum. Linear reef and patch reef have also been combined into a single stratum.

Stratum	Map Classification
1	Pavement & Scattered coral/rock
2	Linear reef & Patch reef

Table 5. Strata in the Dry Tortugas NP sample domain. These strata are not separated by depth and range from 0–30 meters (0–98.4 ft).

Stratum	Map Classification
1	Low-relief continuous reef
2	Mid-relief continuous reef
3	High-relief continuous reef
4	Low-relief isolated reef
5	Mid-relief isolated reef
6	High-relief isolated reef
7	Low-relief spur and groove
8	High-relief spur and groove

Table 6. Strata in the Biscayne NP sample domain. This is a subset of the strata that appear in Brandt et al. (2009) because some of them do not occur within Biscayne NP.

Stratum	Map Classification
1	Inshore Patch Reef (0–6 meters [0–19.7 ft])
2	Mid-Channel Patch Reef (0–6 meters)
3	Offshore Patch Reef (0–6 meters)
4	Forereef, Low-relief, (0–6 meters)
5	Forereef, Low-relief (6–18 meters [19.7–59.1 ft])
6	Forereef, High-relief reef (0–18 meters [0–59.1ft])

In the Virgin Islands NP, the strata designations are derived from the ones presented in Bryan et al. (2013), with two key modifications. In Bryan et al. (2013), depth is used as a modifier for strata designation. Depth has been removed as a modifier for strata in this protocol. This reduces the number of strata for Virgin Islands NP from twelve to six and allows us to increase the number of samples allocated per stratum. While differences in lobster density and distribution may exist as a function of depth, these differences are presumed to be less than those seen between different habitats. Thus, removing the depth modifier was the most logical way to reduce the overall number of strata. The second modification is the addition of an “unknown hard-bottom” stratum. By 2015, several areas that were classified as Unknown habitat were identified to be hard-bottom habitat, though not enough information was present for the areas to be re-classified into an existing habitat class. Two “unknown hard-bottom” strata (shallow and deep) were created and added to the sample design for the Virgin Islands in the reef fish monitoring protocol. Unfortunately at the time of this writing, this change has not been updated in any published protocol or document. Because depth was removed as a modifier, a single “unknown hard-bottom” stratum exists for the lobster monitoring protocol.

In Buck Island Reef NM, the strata designations are derived from the ones presented in Bryan et al. (2013), with two modifications. For the same reasons as in Virgin Islands NP, depth was removed as a modifier for strata designation. The “bedrock” stratum was too small to warrant sampling separately and was combined with the “linear reef” stratum. The nine strata used in the reef fish protocol have been reduced to a total of four strata for this protocol.

In Salt River Bay NHP&EP, the strata designations are derived from the ones presented in Bryan et al. (2013) with four modifications. For the same reasons as in Virgin Islands NP and Buck Island Reef NM, depth was removed as a modifier for strata designation. Second, the “scattered coral/rock” stratum was too small to warrant sampling separately and was combined with the “pavement” stratum. Third, the “patch reef” stratum was also too small to warrant sampling separately and was combined with the “linear reef” stratum. Lastly, the “bedrock” stratum was removed from sampling because all cells within this stratum are located in high wave action environments that are very close

to shore and deemed unduly hazardous for divers and boat operations. The seven strata used in the reef fish protocol have been reduced to a total of two strata for this protocol.

In Dry Tortugas NP, the strata designations are derived from the ones presented in Brandt et al. (2009), with one major modification. Brandt et al. (2009) use the Research Natural Area (RNA) as a modifier for the strata that are otherwise separated by habitat type. This is done because within the RNA, anchoring and extraction of any natural resource is prohibited (NPS 2006). Only recreational harvest of reef fish by hook-and-line is allowed outside of the RNA within Dry Tortugas NP (NPS 2001). This has potential ramifications on the reef fish community and was thus used as a modifier for the strata designations. Within Dry Tortugas NP, both inside and outside the RNA, fishing for lobster is prohibited (NPS 2001). Thus while an effect of the RNA on lobster distribution and density is possible, the management action for lobster is uniform throughout the park. The sixteen strata used in the reef fish protocol have been reduced to a total of eight strata for this protocol. The reduction in the number of strata allows more samples to be allocated to individual strata.

In Biscayne NP, the strata for this protocol represent a subset of the ones presented in Brandt et al. (2009). This is because only some of the habitat classes from the reef fish monitoring protocol exist in Biscayne NP. The inshore patch reef, mid-channel patch reef, and offshore patch reef strata are designated by zone and while they may extend into areas deeper than 6 meters (19.7 ft), they typically range from 0–6 meters (0–19.7 ft). Moving offshore is the forereef zone, which is split into three different strata. The “forereef, high-relief reef” stratum is comprised of all high-relief reef environments, regardless of depth. The remaining two forereef strata are comprised of low-relief environments and then differentiated by the depth ranges of 0–6 meters (0–19.7 ft) and 6–18 meters (19.7–59.1 ft). Biscayne NP is bounded by a 60-foot (18.3-m) depth contour and intersects some grid cells that have depths greater than 18 meters. In the reef fish monitoring protocol these would be part of yet another forereef stratum (18–30 meters [59.1–98.4 ft]). However, in the case of this protocol, these cells are combined with the “forereef, low-relief (6–18 meters)” stratum. At the time of this writing, the management of lobster in the offshore reef environments is consistent throughout Biscayne NP. In this protocol, a total of six strata exist for Biscayne NP.

Number and Location of Sampling Sites

The total allocation and stratification of sites is determined by a stratified-random survey design (details in SOP SL03—*Sample Allocation—Version 1.1* [SFCN 2020c]). Within each park, stratification is based on habitat class and/or depth. Digital layers for each of these components are contained within a geographic information system (GIS) and are used to delineate the survey domain, strata, and sample units. The entire sample domain is parsed into grid cells (Florida—100 × 100 meter [328 × 328 ft]; Virgin Islands—50 × 50 meter [164 × 164 ft]) which serve as the primary sample units. A 200 × 200-meter (656 × 656-ft) grid was used in Florida for reef fish monitoring (as described in Brandt et al. 2009) until 2014, when it was refined to the 100 × 100-meter (328 × 328-ft) grid that is currently in use. Unfortunately, at the time of this writing, there are no publications available that document this change. Initially, sites are evenly allocated across strata. The primary sample units to be selected per stratum are randomly selected from all units within a stratum with a discrete uniform probability distribution, which allows an equal probability for each primary unit to

be selected (Brandt et al., 2009). The first round of sampling will provide needed data about lobster density, distribution, and associated variances for each of the strata in the sample domain. Prior to the second round of sampling and periodically thereafter, the sampling design and allocation scheme will be revised to make sampling more efficient. Specifically, the revised allocation should aim to reduce variance of relative density estimates across all strata, balance areal coverage of the stratum, and keep the number of non-detections within a stratum to a minimum. In some situations, strata may need to be dropped in order to obtain a sufficient sample size in the remaining strata.

During the pilot studies, we found that one boat could survey four to seven sites in a given day (Appendix D). However, transects were used during the pilot and covered a larger area than the circular plots. We expect that we can complete a greater number of sites per day using the circular plots. Over the course of a 10-day mission, with two boats, we can complete an estimated 125 sites during a full-scale sample event (126–128 sites when rounded to whole numbers per stratum, see Table 7). Increased sampling effort would be particularly beneficial for the initial sampling of each park, as it would give an even more precise baseline and also provide variance data that can make the next sampling event more efficient.

Table 7. Estimated number of sites possible per stratum during a full-scale sample event in each park unit, based on an even distribution of samples among strata. These were calculated by dividing the total number of estimated sites to be completed by the number of strata in each park unit and rounded to the nearest whole number.

Park	Estimated total number of samples	Number of strata	Number of samples per stratum
BISC	126	6	21
DRTO	128	8	16
VIIS	126	6	21
BUIS & SARI	126	7	18

Sites are selected using a uniform probability distribution. When statistically valid, the sites may be co-located with sites from the reef fish monitoring protocols.

Temporal Schedule

Parks will be sampled on a four-year rotation, with one park sampled each year (effort in Buck Island Reef NM and Salt River Bay NHP&EP is combined). However, park units may request to decrease SFCN monitoring efforts of one resource (e.g., seagrass) in exchange for increased monitoring of lobster if desired, so that more frequent monitoring can occur. Sampling occurs in May each year. See Operational Requirements for more details on the timing of sampling.

Change Detectable

The relative density of exploited phase lobsters, relative frequency of occurrence of exploited phase lobsters, and average size of exploited phase lobsters are the primary metrics of interest in this protocol. As such, it is important we are able to detect change that is meaningful to management in these metrics from one time frame to the next with confidence, if a change actually exists. Following are the statistical targets for the minimum desired change to detect the true mean at the 5% significance level with 80% power:

- 50% change in relative density of exploited phase lobster;
- 50% change in relative frequency of occurrence of exploited phase lobster;
- absolute change of 10 millimeters (0.4 in) in average carapace length (CL) of exploited phase lobster in Florida parks (Biscayne NP and Dry Tortugas NP); and
- absolute change of 20 millimeters (0.8 in) in average carapace length of exploited phase lobster in Virgin Islands parks (Virgin Islands NP, Buck Island Reef NM, and Salt River Bay NHP&EP).

We want to be able to detect at least a true 50% change in the relative density index of exploited phase lobsters between two sample events (e.g., years 2019 and 2023) at the 5% significance level with 80% power using a two-tailed confidence interval test. South Florida/Caribbean Network conducted two pilot lobster surveys in 2017, one in Biscayne NP and one in Virgin Islands NP. Both pilot studies used two 5 × 100-meter (16 × 328-ft) transects per site, whereas this protocol will use two averaged 7.5-meter (24.6-ft) radius circular plots per site. The transect method covered a total of 1,000 square meters (3,281 square feet [ft²]) per site whereas the circular plot method covers a total of 353 square meters (3,800 ft²) per site. The number of samples required to reach the statistical targets may be higher than suggested by the pilot studies. The preliminary results from these pilot studies were used to estimate the number of samples needed to obtain the target level of precision for the relative density index (exploited phase lobster) estimates. Given the data from the pilot studies, we found that with a sample size of 100, we would be able to detect a 30% change in Biscayne NP and a 47% change in Virgin Islands NP (Table 8).

While the relative mean density index is an important metric for this protocol and the one that is driving the sample design, we also want to be able to detect at least a 50% change in frequency of occurrence of exploited phase lobster between two time periods at the 5% significance level and 80% power. Frequency is the number of sites with a lobster present divided by the total number of sites within each stratum multiplied by each stratum weight and then summed across strata as described in SOP SL07—*Data Analysis and Reporting—Version 1.1* (SFCN 2020g). For example, from the pilot study in Virgin Islands NP, the current frequency of occurrence is 0.17; a 50% change would mean either an increase to at least 0.26 or a decrease to below 0.09 would be detected at the 5% significance with 80% power. From the pilot study in Biscayne NP, if 100 sites were surveyed, we found that a change of 32% in relative frequency of occurrence of exploited phase lobsters could be detected at the 5% significance level and 80% power between two time periods (Table 9).

Table 8. Target change detectable for exploited phase lobster relative density. Number of samples, average relative density (lobsters per site), standard error, and CV are reported for the pilot studies in Biscayne NP and Virgin Islands NP. The target change detectable is 50% for both Florida parks and Virgin Islands parks is 50% with 95% confidence and 80% power. From the pilot data, CV values were calculated for hypothetical sample sizes of 50, 75, 100, and 125 sites. Absolute change and percent change (in parentheses) detectable were calculated for hypothetical sample sizes of 50, 75, 100, and 125 sites. Calculations include strata weights as described in SOP SL07 *Data Analysis and Reporting—Version 1.1 (SFCN 2020g)*.

Park	N	Pilot Study Average (lobsters per site)	Pilot Study Std Error	Pilot Study CV	Target Percent Change to detect	CV for n=50	CV for n=75	CV for n=100	CV for n=125	N=50 Absolute change (% change)	N=75 Absolute change (% change)	N =100 Absolute change (% change)	N=125 Absolute change (% change)
BISC	28	1.22	0.33	27%	50%	14%	12%	10%	9%	0.53 (43%)	0.43 (35%)	0.37 (30%)	0.33 (27%)
VIIS	17	0.19	0.08	41%	50%	21%	17%	14%	13%	0.14 (74%)	0.11 (58%)	0.09 (47%)	0.08 (42%)

Table 9. Target change detectable for exploited phase lobster relative frequency of occurrence. Number of samples, average relative frequency of occurrence (proportion of sites present), standard error, and CV are reported for the pilot studies in Biscayne NP and Virgin Islands NP. The target change detectable is 50% for both Florida parks and Virgin Islands with 95% confidence and 80% power. From the pilot data, CV values were calculated for hypothetical sample sizes of 50, 75, 100, and 125 sites. Absolute change and percent change (in parentheses) detectable were calculated for hypothetical sample sizes of 50, 75, 100, and 125 sites. Calculations include strata weights as described in SOP SL07.

Park	N	Pilot Study proportion of sites present	Pilot Study Std Error	Pilot Study CV	Target Percent Change to detect	CV for N=50	CV for N=75	CV for N=100	CV for N=125	N=50 Absolute change (% change)	N=75 Absolute change (% change)	N=100 Absolute change (% change)	N=125 Absolute change (% change)
BISC	28	0.50	0.11	22%	50%	16%	13%	11%	10%	0.23 (46%)	0.18 (36%)	0.16 (32%)	0.14 (28%)
VIIS	17	0.17	0.07	43%	50%	22%	17%	15%	13%	0.11 (64%)	0.08 (47%)	0.07 (41%)	0.06 (35%)

We also want to be able to detect whether there is a change in average carapace length (CL) of lobsters in the exploited phase at the 5% significance level and 80% power. The absolute change detectable however, is different for Virgin Islands parks than for Florida parks. The disparity between the two locales is because lobsters in Biscayne NP are more abundant, are smaller, and exhibit a comparatively narrow range in size. Conversely, the lobsters in Virgin Islands NP are typically less abundant, are larger, and have a much wider CL size distribution. We want to be able to detect at least an absolute change of 10 millimeters (0.4 in) in CL for exploited phase lobster in Florida parks (Biscayne NP and Dry Tortugas NP). For the Virgin Islands parks (Virgin Islands NP, Buck Island Reef NM, Salt River Bay NHP&EP), we want to be able to at least detect an absolute change of 20 millimeters (0.8 in) in CL for exploited phase lobster. From the pilot study in Virgin Islands NP, if 100 sites were surveyed (with an estimated 35 lobster observed in the exploited phase), an absolute 19-millimeter (0.8 in) change in average size (CL) of exploited phase lobster would be detected at the 5% significance level and 80% power between two time periods. From the pilot study in Biscayne NP, if 100 sites were surveyed (with an estimated 100 lobster observed in the exploited phase), an absolute change of 3 millimeters (0.1 in) in average size of exploited phase lobster would be detected with 95% confidence and 80% power between two time periods (Table 10).

For many of the other secondary metrics, a chi-square test or a confidence interval test can be used to tell whether a significant difference exists between two timeframes, however, estimates of differences detectable are not provided at this time.

Table 10. Target change detectable for average carapace length of exploited phase lobster. Number of measured exploited phase lobsters, legal size (mm), average carapace length (CL) of exploited phase lobsters, standard error, and CV are reported for the pilot studies in Biscayne NP and Virgin Islands NP. Target change detectable is 10 millimeters (mm; 0.4 in) in Florida parks and 20 millimeters (0.8 in) in Virgin Islands parks with 95% confidence and 80% power. From the pilot data, CV values were calculated for hypothetical sample sizes of 50, 75, 100, and 125 sites. Absolute change and percent change (in parentheses) detectable were calculated for hypothetical sample sizes of 50, 75, 100, and 125 sites.

Park	N	Legal size (mm)	Pilot Study Average CL (mm)	Pilot Study Std Error	Pilot Study CV	Target Absolute Change to detect	N= 25 lobsters Absolute change (% change)	N= 35 lobsters Absolute change (% change)	N= 50 lobsters Absolute change (% change)	N=75 lobsters Absolute change (% change)	N= 100 lobsters Absolute change (% change)
BISC	28	76.2	87.9	2.1	13%	10 mm	7 (7%)	5 (6%)	5 (5%)	4 (4%)	3 (4%)
VIIS	6	88.9	137	16.1	29%	20 mm	23 (17%)	19 (14%)	16 (12%)	13 (9%)	11 (8%)

Virgin Islands National Park Pilot

A total of 17 sites (34 transects) were sampled in Virgin Islands NP over the course of four days. Although 12 strata exist in Virgin Islands NP, not enough samples were taken in order to calculate variance in some of the strata. Combining deep and shallow classifications reduced the number of strata to six and made it possible to calculate variance and CV estimates for relative density and relative frequency of occurrence of exploited phase lobsters. Also, there was only one site sampled in the “Unknown hard-bottom” stratum. A fictional survey where zero lobsters were seen was added to the “Unknown hard-bottom” stratum in order to allow for CV estimate calculations. During the pilot, 11 of the 17 sites samples recorded zero lobsters, so the fictional zero value would not have been unusual. The calculations were done using R with code provided by S. Smith and J. Ault of the University of Miami (Appendix F). From the data collected during the pilot in Virgin Islands NP a CV of 43% was achieved for relative density of exploited phase lobster. A total of 53 sites would be necessary to achieve a CV of 20% for relative density of exploited phase lobster, using the data collected (Figure 7). For reference, 91 sites would be necessary to achieve a CV of 15% and 192 sites required to achieve a CV of 10%.

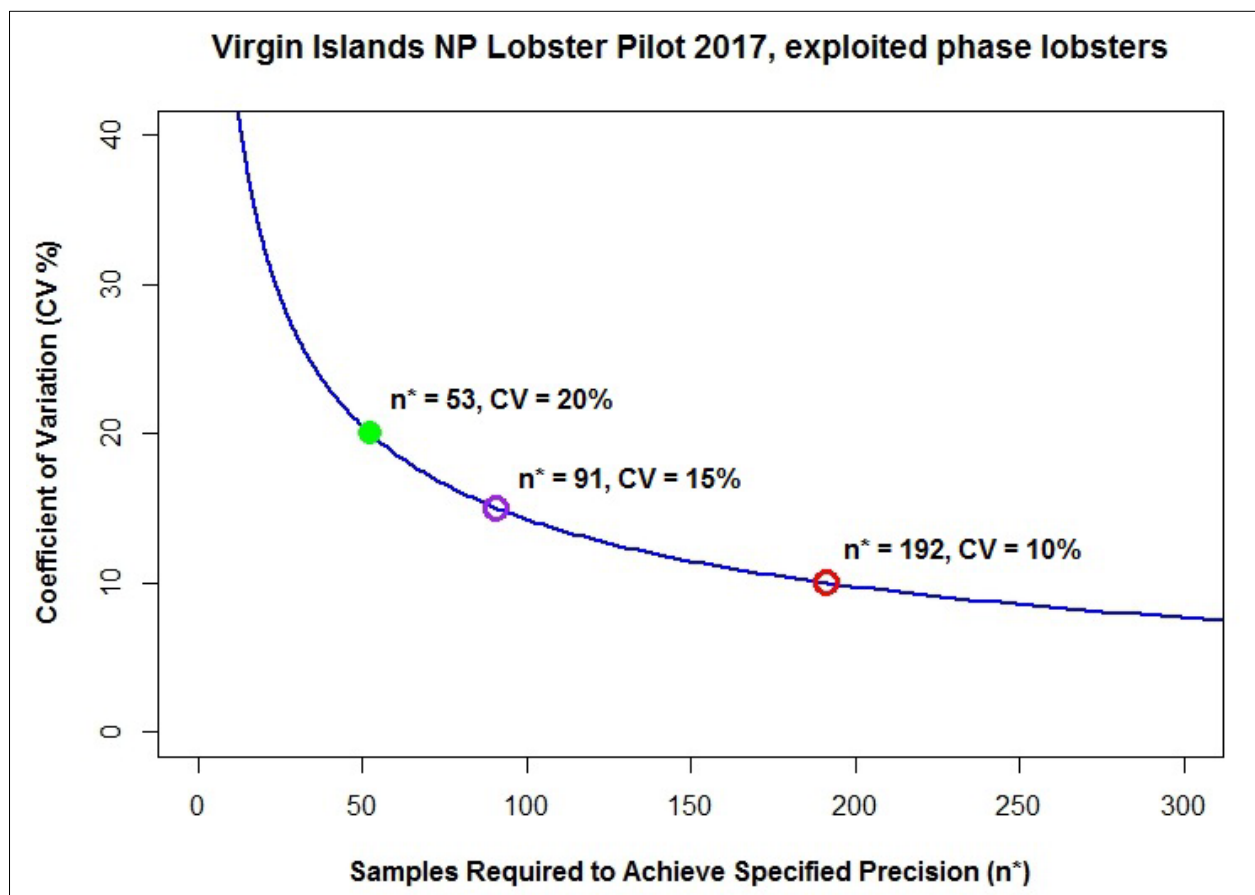


Figure 7. This n^* curve was generated from Lobster Pilot survey data collected in Virgin Islands NP in 2017. The graph plots a curve of the number of sites required to achieve a target CV (precision) for exploited phase lobsters.

We found that the average size of exploited phase lobster was 137 ± 16 millimeters (0.6 in; mean $\pm$ SE) from a total of six exploited phase lobsters observed over 17 samples. Extrapolating using the strata weighting procedures described in SOP SL07, we would expect to observe approximately 35 lobsters if 100 sites were surveyed in the next sample event. From this, we calculated that an absolute change of 19 millimeters (0.8 in) in average size of exploited phase lobster would be detectable at the 5% significance level and 80% power.

We found that the relative frequency of occurrence for exploited phase lobster was 0.17 ± 0.07 (proportion $\pm$ SE) over 17 samples. Extrapolating, we calculated that if 100 samples were conducted at each sample event, we would be able to detect a 0.07 ($100 * 0.07 / 0.17 = 41\%$) change in relative frequency occurrence of exploited phase lobster at the 5% significance level and 80% power.

Biscayne National Park Pilot Study

A total of 28 sites (56 transects) were sampled in Biscayne NP over the course of four days with two boats. Although six strata exist in Biscayne NP, the “inshore patch reef” stratum was omitted and only five strata were sampled during the pilot. Enough samples existed in each stratum to allow for calculation of variance and CV estimates for relative density of exploited phase lobsters. From the data collected during the pilot in Biscayne NP a CV of 27% was achieved. Approximately 46 sites would be necessary to achieve a CV of 15% and 102 sites required to achieve a CV of 10% for relative density of exploited phase lobster (Figure 8).

We found that the average size of exploited phase lobster was 89 ± 2 millimeters (0.08 in; mean $\pm$ SE) from a total of 28 exploited phase lobsters observed over 28 samples. Extrapolating, we would expect to observe approximately 100 lobsters if 100 sites were surveyed in the next sample event. From this, we calculated that an absolute change of 3 millimeters (0.1 in) in average CL size of exploited phase lobster would be detectable with 95% confidence and 80% power.

We found that the relative frequency of occurrence for exploited phase lobster was 0.50 ± 0.11 (mean $\pm$ SE) over 28 samples. Extrapolating, we calculated that if 100 samples were conducted at each sample event, we would be able to detect a 32% change in relative frequency occurrence of exploited phase lobster at the 5% significance level with 80% power.

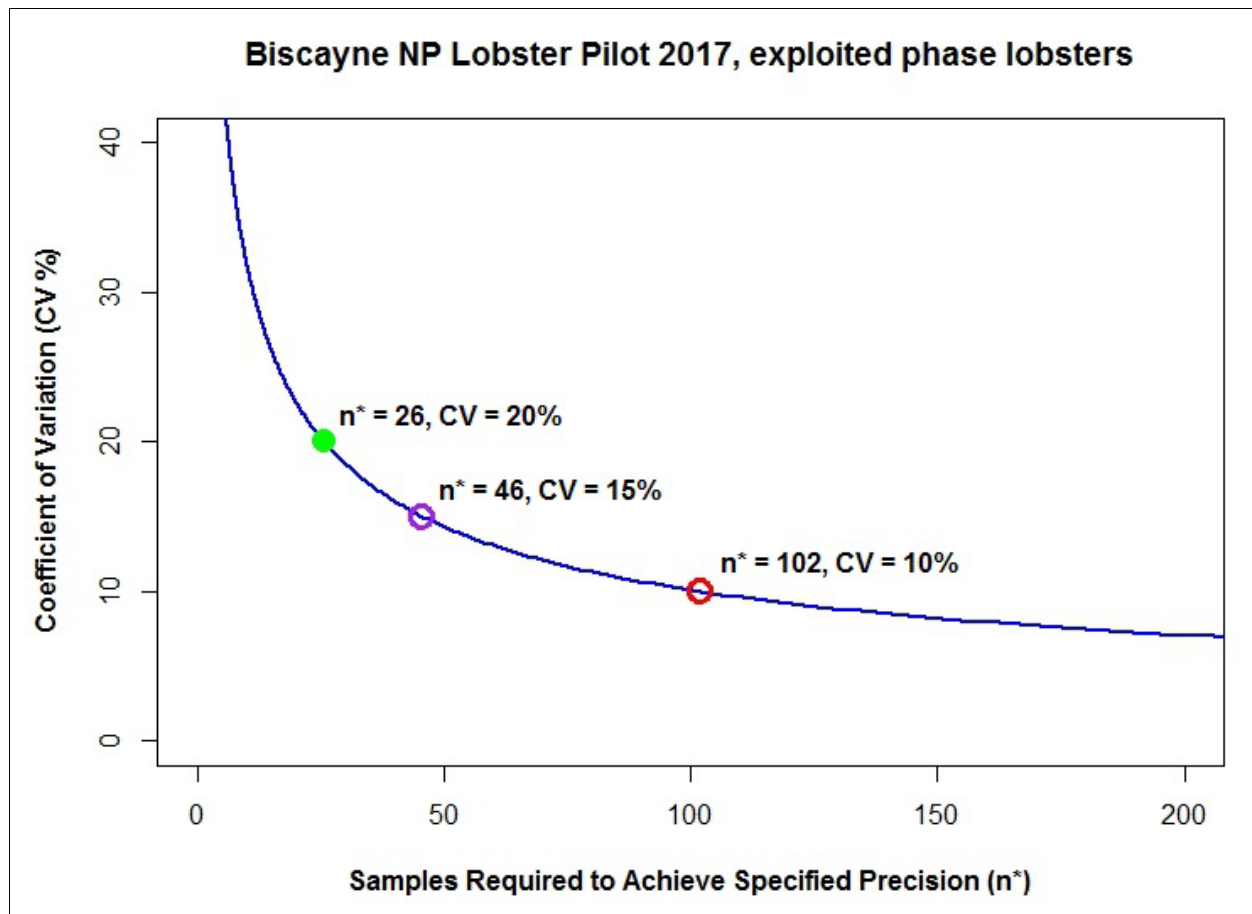


Figure 8. This n^* curve was generated from Lobster Pilot survey data collected in Biscayne NP in 2017. The graph plots a curve of the number of sites required to achieve a target CV (precision) for exploited phase lobsters.

Future Sampling

From the efforts during the pilot surveys in Biscayne NP and Virgin Islands NP, one boat with a team of four divers can realistically complete 5–7 sites a day. Both pilot studies used two 5×100 -meter (16×328 -ft) transects per site, whereas this protocol uses two averaged 7.5-meter (24.6-ft) radius circular plots per site. The transect method covered a total of 1,000 square meters (3,281 ft²) per site whereas the circular plot method covers a total of 353 square meters (3,800 ft²) per site. Thus, the number of samples required to reach the statistical targets will be different than suggested by the pilot studies. Using transects from the pilot studies, two boats could complete approximately 100 sites over the course of a 10-day mission. The circular plots are smaller in size and can be completed much faster. We expect to complete a greater number of sites per day than in the pilot study. The analysis of the pilot survey data shows that 100 sites would allow us to meet and exceed our target for 50% change detectable (with 95% confidence and 80% power) for relative density of exploited phase lobster in both Biscayne NP and Virgin Islands NP. It is important to note that the sample sizes in both of the pilots, but particularly Virgin Islands NP, were small. With a larger sample size (approximately 100 sites) during our first sampling event in each park, we will better understand variance among strata and be able to allocate samples more efficiently for future sampling. A more

appropriately balanced sample allocation may also improve the precision (or reduce sampling effort) compared to what was observed during the pilot surveys. It is important to note that future sampling should improve the efficiency of allocation and fewer sites should be needed to achieve the same target precision.

Combination with other Protocols

The sampling design mirrors the methods used in the previously published SFCN Reef Fish Monitoring Protocols for Florida and the U.S Virgin Islands (Brandt et al. 2009; Bryan et al. 2013). The grid cells and stratification used for the reef fish monitoring will be used for the SFCN spiny lobster design. When statistically valid, sample points for SFCN spiny lobster monitoring may be co-located with the most recent sample locations of the reef fish surveys.

Furthermore, the *Reef Fish Monitoring Protocol for the U.S. Virgin Islands Coral Reef Ecosystem* already collects ancillary lobster data during surveys in coordination with the *National Coral Reef Monitoring Program* (Friedlander et al. 2013; Bryan et al. 2013). The method does not specifically target lobster but can provide some insight to approximate lobster densities. The Reef Fish Monitoring Protocol for the Florida Keys Coral Reef Ecosystem has included lobster observations as part of a survey in the past. At the time of this writing, that practice has been discontinued, though the information could feasibly be reinstated into future surveys. Again, this method does not specifically target lobster, but it too can provide some insight to approximate lobster densities.

Field Methods

Requisites of a Data Collection Program

A successful survey requires a well-designed method for collecting data. Major methodology requisites for a spiny lobster data collection program include:

1. the ability to detect and identify cryptic spiny lobster;
2. a consistent repeatable area component;
3. a type of survey method that limits the number of non-detections per sample; and
4. the ability to collect fundamental information about the species, such as carapace length, sex, presence of eggs or spermatophore, and molting stage.

An effective sampling methodology should also minimize measurement bias. The concept of taking several samples to accurately estimate characteristics of a population requires that each sample is devoid of bias. Since sample area is typically extremely small in comparison to the actual population area, a small bias can have dramatic effects on population estimates. Factors that can influence sample bias in visual surveys include: survey effort, diver behavior, underwater currents, visibility, species detectability, species behavior, observer experience/training, and lobster density.

In addition to data collected on lobster, it is imperative that basic habitat information is collected to aid in analysis. These data include: habitat photos, depth, habitat type (as according to stratification scheme), abiotic footprint, and surface relief coverage. Ultimately, this habitat information is used to ensure that the survey is assigned to the appropriate stratum.

Survey Method Background and Justification

There are a variety of methods employed to assess lobster populations throughout the world. These can be split into two broad categories: fisheries-dependent and fisheries-independent. Fisheries-dependent methods rely on assessing lobster that are caught by various fishing practices. These methods could include analyzing commercial catch data, observer programs aboard fishing vessels, and interviews with recreational fishers, among others. Data from fisheries-dependent data and fisheries-independent studies may complement each other to give a more complete assessment of the species in question. However, many of the parks where we will monitor lobster restrict or prohibit harvest of lobster, necessitating the use of a fisheries-independent method for this protocol.

There are many fisheries-independent approaches used to assess lobster populations throughout the world. Trap-based surveys have been used to assess demographics, obtain a measure of catch-per-unit-effort (CPUE), and to estimate population size and growth rates with mark-recapture techniques (Abramson et al. 2005; Brandão and Butterworth 2009; Hutchings et al. 2009). Other monitoring programs have used pueruli collectors to monitor post-larval recruitment (Gardner et al. 2001; Cohen and Gardner 2007; Butler et al. 2010; Caputi et al. 2010; de Lestang et al. 2015; Yao and Zhang 2018). In situ monitoring methods include timed swims (Ye et al. 2005; Bertelsen et al. 2005; Cox et al. 2009), transects (MacDiarmid 1991; Edgar and Barrett 1997; Haggitt and Kelly 2004; Buxton et al. 2006; Alexander et al. 2014; Haggitt and Freeman 2014; Plagányi et al. 2015; Matthews and Arrone 2015) or extensive searches of specific areas using SCUBA (Wolff 1998). It is important to

note that the list of studies for each method is by no means exhaustive and merely present some of the monitoring efforts that exemplify each method. We feel that an in situ monitoring method is most appropriate to monitor exploited phase lobster and meet the objectives of this protocol. Ideally, if time, budgetary, and personnel constraints were not an issue, pueruli collectors would be beneficial and useful to monitor post-larval recruitment.

Currently, the two primary fisheries-independent in situ methods that are used to monitor spiny lobster populations are fixed area plots (e.g., circular plots or linear transects) and timed searches (Table 11). There are clear benefits and disadvantages to each method (Table 12). The main benefit of fixed area plots is that they are highly repeatable and cover a known area, which allows for the calculation of a relative density index, an important metric when characterizing a lobster population. However, in places where lobster densities are low, either larger-sized plots or a high number of samples are necessary to obtain statistically meaningful conclusions. Timed searches, because of their open-endedness and flexibility of search area, typically reduce the number of non-observations in a data set in areas with a low density of lobster and thus have the potential to reduce variance between samples. Yet, if the area of a search is not estimated with the timed search (e.g., by towing a GPS), only catch-per-unit-effort (CPUE) may be calculated, which is a less useful metric for characterizing lobster populations. Timed-searches are not easily repeatable in subsequent years, and while limited by time, can be highly variable in the area searched for lobster, and may include unintended habitats.

Table 11. Selected relevant studies highlighting the use of timed-searches and fixed area plots to monitor lobster populations.

Source	Organization	Location	Species	Years	Method	Notes
Pitcher et al 1992	Commonwealth Scientific and Industrial Research Organization (CSIRO)	Torres Strait, Australia	<i>Panulirus ornatus</i>	1989	4 × 500 m transects	Transect size most efficient to survey lobster in Torres Strait; measured with 500 m line
Ye et al. 2005	CSIRO	Torres Strait, Australia	<i>Panulirus ornatus</i>	1990-1997	20-min searches	20-min swim time used to estimate 500 m distance
Plagányi et al 2015	CSIRO	Torres Strait, Australia	<i>Panulirus ornatus</i>	1998-present	4 × 500 m transects	Measured to nearest meter with Chainman ® device
Bertelsen et al. 2004	FWC	Keys Reef Tract / Dry Tortugas, FL	<i>Panulirus argus</i>	1995-2002	60-min searches	–
Ault et al. 2005, Ault et al. 2007, Ault et al. 2008	FWC	Dry Tortugas, FL	<i>Panulirus argus</i>	2004, 2006, 2008	10 × 50 m transects	Co-located with fish surveys
Cox et al. 2009	FWC	Buck Island Reef National Monument, St. Croix	<i>Panulirus argus</i>	2004-2007	60-min searches	–
T. Matthews (pers. Comm., FWC, February 25, 2016)	FWC	South Florida	<i>Panulirus argus</i>	2004-present	10 × 50 m transects	–
L. Henderson (pers. comm., DPNR, November 23, 2015)	DPNR	St. Croix East End Marine Park	<i>Panulirus argus</i>	2008-present	30-min searches	–

Table 11 (continued). Selected relevant studies highlighting the use of timed-searches and fixed area plots to monitor lobster populations.

Source	Organization	Location	Species	Years	Method	Notes
Matthews and Arronne 2015	Gulf and Caribbean Fisheries Institute and Honduras Coral reef Fund	Cayos Cochinos, Honduras	<i>Panulirus argus</i>	1997, 2013, 2014	3 × 100 m transects (1997), 10 × 50 m transects (2013/2014)	Used larger transects to reduce non-detections
Haggit and Kelly 2004; Haggit and Freeman 2014	New Zealand Dept. of Conservation	Cape Rodney to Okakari Point Marine Reserve	<i>Jasus edwardsii</i>	2000 -present	10 × 50-meter (32.8 × 164-ft) transects	–
Buxton et al. 2006; Barrett et al. 2009; Alexander et al. 2014	–	Maria Island Marine Reserve, Tasmania	<i>Jasus edwardsii</i>	1992 - present	1 × 50-meter (3.3 × 164-ft) transect	Four replicates per site

Table 12. Comparison of two visual fishery-independent methods (fixed area plots vs. timed searches) to survey lobster.

Item	Fixed area plots	Timed searches
Area	Known area, highly repeatable	Area component unknown or estimated
Calculated metric	Density	Catch per unit effort (CPUE)
Number of samples	Need high number of samples or large plots where lobster densities are low	Open ended search limits zeros in dataset, fewer samples needed in low density areas
Statistical analyses	Statistically rigorous, far easier when size of plot is kept consistent	Not as statistically rigorous at attempts to calculate density

Currently, in South Florida, the FWC methodology uses transects to survey lobster populations (T. Matthews, pers. comm., FWC, February 25, 2016). Divers conduct 10×50 -meter (32.8×164 -ft) transects, capturing all lobsters within the study area (500 square meters [$5,381 \text{ ft}^2$]) using tickle sticks and nets to measure carapace length (CL), molt condition, sex, reproductive status, and evidence of disease. All measurements are conducted in situ, followed by the return of all lobsters to the appropriate location in which they were captured. Lobsters that evade capture are included in density estimates, whereas all other measurement estimates are marked down as unknown (T. Matthews, pers. comm., FWC, February 25, 2016).

As of this writing, the only ongoing fisheries-independent surveys that target lobster in the Virgin Islands are conducted by the U.S. Virgin Islands Department of Planning and Natural Resources (DPNR). Started in 2008, they use 30-minute timed searches to survey lobsters in the St. Croix East End Marine Park, but their efforts do not extend into SFCN parks. Lobsters are also captured for measurements and documentation of the same life history characteristics as the FWC methodology (L. Henderson, pers. comm., DPNR, November 23, 2015).

To monitor spiny lobster in SFCN parks, 7.5-meter (24.6-ft) radius circular plots will be used. While the use of circular plots is not found in the literature, it is similar to the transect method, as it has a fixed area and is highly repeatable. Thus, circular plots allow for calculations of the preferred metric, lobster density. Circular 7.5-meter (24.6-ft) radius plots also make sampling smaller patch reefs more feasible. These reef features are common in the network parks, particularly Biscayne NP. Furthermore, the size of the circular plots is the same size of the cylinders used by the fish monitoring protocols in the Virgin Islands and in Florida (Brandt et al. 2009, Bryan et al. 2013). If interagency cooperation is possible and desired, similarities between the two methods (fish and lobster) will also make training of surveyors simpler and include a number of scientists across several organizations who are already familiar with the fish monitoring methods.

The pilot studies conducted in Virgin Islands NP and Biscayne NP in 2017 used two 5×100 -meter (16.4×328.1 -ft) transects at each site for the survey method. These transects extended outside the primary sample unit (i.e., grid cell), which complicated analyses and sample design. Determining a transect size that was large enough to adequately sample for lobster but still remained within the primary sample unit proved problematic. However, the use of two 7.5-meter (24.6-ft) radius circular plots can be kept within the bounds of the primary sample unit and remain on the target habitat more effectively. The total area covered by two circular plots is 353 square meters ($3,800 \text{ ft}^2$) versus the 1,000 square meters ($3,281 \text{ ft}^2$) with the two transects.

Ultimately, we want a survey method that is efficient underwater, covers a large enough area that reduces the number of non-detections, covers a small enough area to keep the repeatability and sample size high, can accurately and precisely detect the actual number of lobsters in the plot, is comparable to monitoring by other agencies, avoids crossing habitat types, and remains within the primary sampling unit (i.e. grid cell). We feel the use of two 7.5-meter (24.6-ft) radius circular plots per survey site accomplishes this best and will be most effective.

Lobster relative density, relative frequency of occurrence and average size of exploited phase lobster comprise the focus of this protocol (Table 13). This information can be obtained without actually capturing lobster during a survey, however useful additional information about biological condition of lobster can be obtained with the minimal added effort of capturing the lobster. Prior to any attempt at capture, an estimate of carapace length can be made (see Appendix D). In this manner, even if the observed lobster is not caught, a metric for size-distribution is still available. Furthermore, if an estimate of carapace length is taken before capture, and an actual measurement is taken after a successful capture of the lobster, the observer may then calibrate his or her estimations with an actual measurement. In the event that a lobster is successfully captured, sex, molt condition, presence of eggs or spermatophore, and exact carapace length are recorded.

Table 13. Monitoring objectives, sampling design, sampling methods, and metrics measured at SFCN parks as part of the spiny lobster Monitoring Protocol.

Objective	Area sampled	Temporal design	Sampling method	Data collected	Analysis tool
Exploited phase lobster relative density index	Habitats utilized by adult lobster	Every four years	7.5-meter (24.6-ft) radius circular plots (two per site)	Number of lobsters per pair of plots	Comparison among repeated surveys to detect change
Exploited phase lobster relative frequency of occurrence index	Habitats utilized by adult lobster	Every four years	7.5-meter (24.6-ft) radius circular plots (two per site)	Number of lobsters per pair of plots	Comparison among repeated surveys to detect change
Exploited phase lobster average size	Observed lobsters	Upon 1) first observation and 2) capture of lobster	When first observed, estimate carapace length with visual measurement tool If captured, measure actual carapace length with Vernier calipers	Carapace length	Use measurements to develop a size-frequency distribution Comparison among repeated surveys to detect change
Sex ratio	Captured lobsters	Upon capture of lobster	Observation of sex-specific characteristics	Sex	Comparison among repeated surveys to detect change
Molt condition	Captured lobsters	Upon capture of lobster	Observation of carapace quality	Molt stage	Comparison among repeated surveys to detect change

Table 13 (continued). Monitoring objectives, sampling design, sampling methods, and metrics measured at SFCN parks as part of the spiny lobster Monitoring Protocol.

Objective	Area sampled	Temporal design	Sampling method	Data collected	Analysis tool
Presence of eggs or spermatophore	Captured lobsters	Upon capture of lobster	Observation of lobster underside/tail	Presence of eggs or spermatophore ("tar-patch"); photo taken of eggs or spermatophore	Can use data with size-frequency distribution (i.e. what size lobster are breeding) Comparison among repeated surveys to detect change

Field Survey Methods

The survey establishment at a site mirrors the description found in the reef fish monitoring protocol for Florida (Brandt et al. 2009). Rationale and details for observations in the field is described in SOP SL04 *Lobster Data Collection and Survey Methods—Version 1.1* (SFCN 2020d). One set of paired surveys take place per site, where each survey consists of a 7.5-meter (24.6-ft) circular plot (Figure 9).

At each location, the boat navigates to target habitat within the grid cell. This is done by navigating to the centroid of the grid cell, then using sonar or visual cues to locate hard-bottom habitat within the grid cell. In the Virgin Islands, where 50 × 50-meter (164 × 164-ft) cells are used, this means remaining within 25 meters (82 ft) of the centroid to the north, south, east and west or within 35 meters (115 ft) to the northeast, southeast, northwest, and southwest. In Florida, where 100 × 100-meter (328 × 328-ft) cells are used, this means remaining within 50 meters (164 ft) of the centroid to the north, south, east, and west, or within 71 meters (233 ft) to the northeast, southeast, northwest, and southwest.

It is most efficient to have these surveys completed under live boating conditions instead of anchoring, requiring at least three people in the field (one boat captain, two divers). However, using two rotating teams of two divers (a total of four divers) is preferable. The buddy team will carry a reel with a line attached to a dive flag and GPS unit (in a dry bag) on the surface, which will record the exact location of the sample. Once the divers reach the bottom, one of the divers takes a photo of their datasheet (with site number written on it), and then photos in the four cardinal directions that display the type of habitat present. Decision rules for set up of the sample plots are found in SOP SL04 *Lobster Data Collection and Survey Methods—Version 1.1* (SFCN 2020d). The survey targets hard-bottom habitat within the grid cell but should not be biased with respect to the quality or edge of the hard-bottom habitat. In other words, surveyors should not knowingly set up the plots in hard-bottom areas where they expect more (or less) lobster to be found.

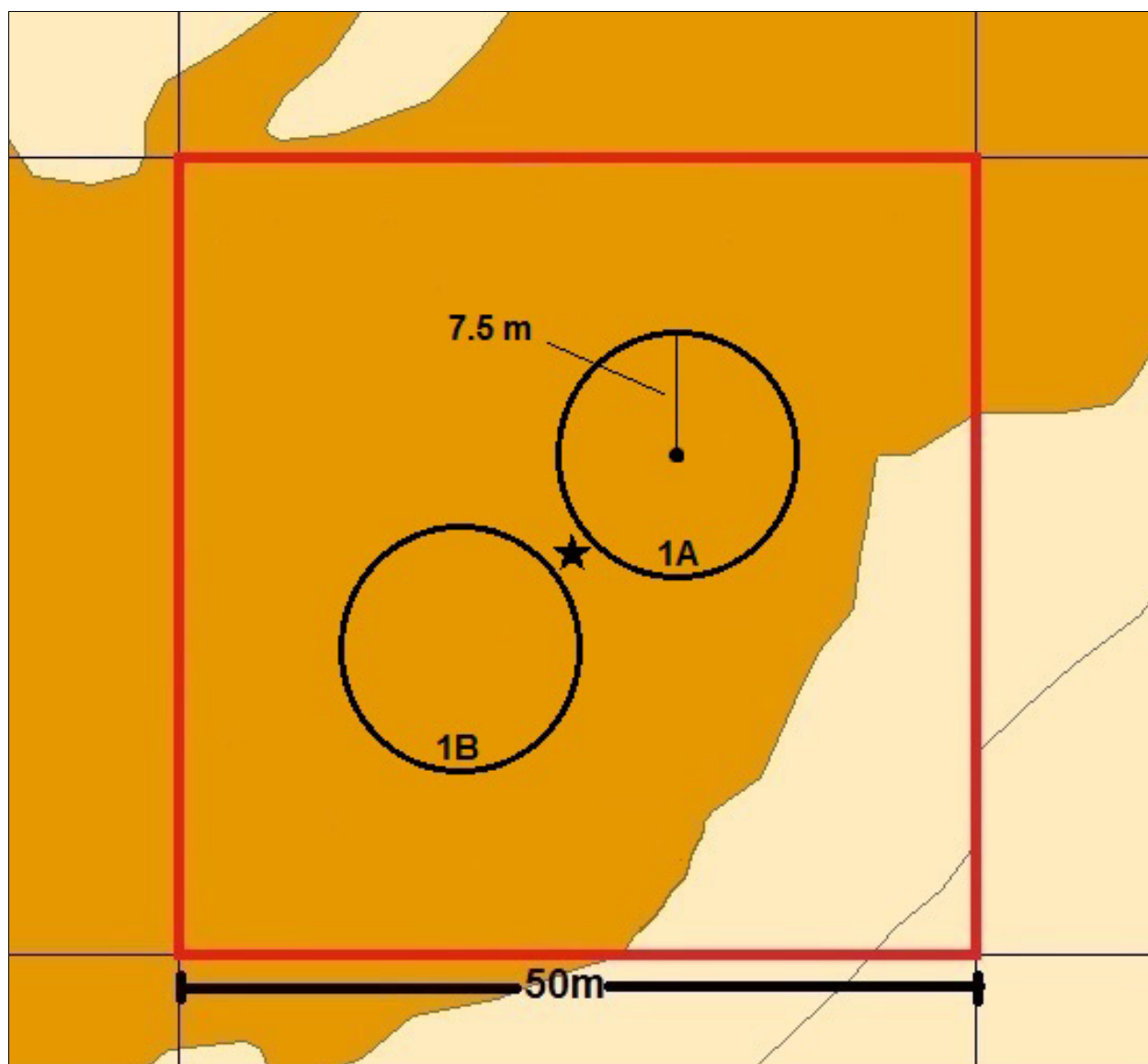


Figure 9. Example of how the two averaged circular plots may be located at a site. Tan is non-target habitat (e.g. sand) and orange is target habitat (e.g. reef). The 50 × 50-meter (164 × 164-ft) grid used in the U.S. Virgin Islands is overlain on the habitat and is outlined in red. Divers descend and attach the dive flag with surface GPS at the star. Two non-overlapping 7.5-meter (24.6-ft) radius circular plots are completed adjacent to one another.

The buddy team will work together to survey the pair of 7.5-meter (24.6-ft) radius plots for all spiny lobster (*Panulirus argus*). Lobster prefer to shelter in cracks, crevices, and under ledges, so it is important that the surveyor take the time to look in these areas. While there are a few approaches to survey a circular plot, the use of a quadrant method is recommended.

After the dive flag is affixed to the bottom, a transect tape is run out to 15 meters (49 ft) which represents the diameter of the plot. One diver runs a second transect tape out 7.5 meters (24.6 ft) perpendicular to the first, beginning at the 7.5-meter (24.6-ft) mark, bisecting one of the halves of the

plot. The second diver repeats the process on the opposite side of the circular plot. This creates four quadrants in the circular plot (Figure 10). Each diver is responsible for searching two quadrants in each circular plot. This method allows for an efficient, but thorough search for lobster within the plot.

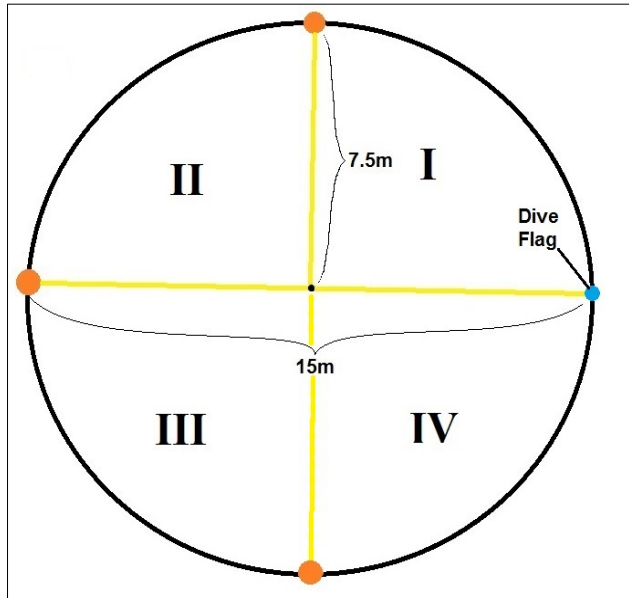


Figure 10. Diagram showing how the circular plot can be partitioned into quadrants.

For each sampled cell, the following information will be recorded (see SOP SL04, Figures 12 and 13 for datasheet):

- Observer
- Buddy
- Date
- Park
- Cell ID/Site location (1A or 1B should be added at the end of the site name to designate the specific circular plot that was surveyed)
- Sample start and stop time (make sure dive computers are synced with GPS on dive flag)
- Station depth (at dive flag)
- Visibility

For each plot, the observer makes a basic habitat assessment. This primarily serves to determine the habitat in which the survey took place. This information is used to ascertain the appropriate stratum to which the survey will be assigned for analysis. The habitat assessment consists of five parts:

1. Photos: After affixing the dive flag to the substrate, one of the divers takes a photo of the datasheet so that the site name is clearly visible. Four photos are then taken in each cardinal direction to provide a representation of the habitat present.

2. Habitat type: The diver circles which habitat type the survey is actually located on. These habitat types align with the region's habitats that the sample design is stratified by. Definitions of the following habitats can be found in SOP SL 01 *Sample Frame and Habitat Classification—Version 1.1* (SFCN 2020a) and in Appendices A and B.
 - a. For parks in Florida, the habitat types are contiguous spur and groove, contiguous reef (other), isolated, rubble, matrix, and sand.
 - b. For parks in the Virgin Islands, the habitat types are bedrock, pavement, aggregate reef, patch reef, and scattered coral/rock in sand.
3. Abiotic footprint: The diver shall estimate the percent of the plot that is covered by sand, rubble, and hard-bottom. The sum of these values will equal 100%.
4. Slope: This is the maximum and minimum depths of the substrate slope within the sample circular plot. These values refer to the maximum and minimum depths on the imaginary plane underlying the sample cylinder. If there is a slope, these depths will be different; if there is no slope minimum depth = maximum depth.
5. Surface relief coverage: The diver shall estimate the percent of the plot that is covered by various bins of surface relief (< 0.2 meters [0.6 ft], 0.2–0.5 meters [0.6–1.6 ft], 0.5–1.0 meters [1.6–3.2 ft], 1.0 – 1.5 meters [3.2–4.9 ft], > 1.5 meters [4.9 ft]). This is defined as the height of hard-structures perpendicular to the plane of the substrate. This includes corals, boulders, rocks, barrel sponges, but does not include soft corals. See SOP SL04—*Lobster Data Collection and Survey Methods—Version 1.1* (SFCN 2020d) for more details.
6. While other species of conch and urchins exist, only the queen conch (*Lobatus gigas*) and the long-spined sea urchin species (*Diadema antillarum*) are quantified. On the datasheet the number of adult queen conch, juvenile queen conch, and *Diadema* urchins are recorded within each plot. These data are considered secondary to the primary survey.

For each lobster encountered inside the plot, a size estimate will be recorded prior to an attempt at capture (1). Spiny lobsters are the target species of this survey, though the presence and estimated sizes of spotted lobsters are also recorded on the datasheet. Spotted lobsters should not be captured nor demographic information recorded. Once a spiny lobster is successfully captured, other biological conditions will be recorded (2–7). Once a lobster assessment is complete, the lobster is released to its original location.

1. An estimate of carapace length (distance between eye sockets to beginning of tail); a measuring aid will be used to help estimate this (stick with mm [millimeter] and/or cm [centimeter] marks that can be held close to the lobster).

Note: This should be done prior to any attempt to capture the lobster, so that an estimate of size exists even if the lobster cannot be caught. If a group of lobster is encountered, size estimates for all individuals in the group should be taken before an attempt at capture is made.

2. Actual carapace length (distance from between the eye sockets to the beginning of the tail).
3. Sex

4. Eggs (orange if new and brown if near hatch). The diver takes a photo of the clutch of eggs, if present.
5. Molt condition (pre/post/intermediate molting stage).
6. Spermatophore (eroded or fresh). The diver takes a photo of the spermatophore, if present.
7. Distance to edge. An edge is defined here as a clear hard-bottom / soft-bottom interface. The observer estimates the distance between the encountered lobster and the edge of the habitat. If the edge is not readily visible, “not visible” is recorded instead.
8. Notes.

Field Season Preparations and Equipment Setup

Sample numbers, locations, and alternate sites will be determined prior to the start of the field season between January and March (see Table 14 in Operational Requirements). Once the site locations are determined, the site list will need to be submitted to the park unit(s) in which the survey will take place so that the site locations may be reviewed and ultimately approved before sampling. This must happen early in the year so that the list of sample points can be approved prior to the training held in April. There are no permitting requirements for any of the field methods described in this protocol except in Salt River Bay NHP&EP which is co-managed by the USVI Department of Planning and Natural Resources (DPNR) and the National Park Service. A research permit is required and issued by DPNR Division of Fish and Wildlife, Frederiksted, St. Croix. The park units will still need to provide approval before sampling in case any of the locations are near and could potentially affect sensitive cultural resources. This is also a good opportunity to ask the park whether any of their staff will be participating in the survey effort. Any staff who will be participating must attend the training prior to sampling.

Prior to each sampling event a training will be held in April for all participants in lobster surveys, including any volunteer or park unit divers (SOP SL05—*Training—Version 1.1* [SFCN 2020e]). Lobster monitoring gear (nets, tickle sticks, gloves, calipers, GPS units, measuring sticks) must be checked and if needed, replaced or repaired before the training occurs. At the training, dates for the actual survey should be discussed with all participants and the time frame established for the survey. The methods must be reviewed verbally and by practicing on land and a size estimation calibration exercise completed (SOP SL05 [SFCN 2020e]). Following the training, any travel arrangements may be made for the survey.

Before sampling begins, the lobster project lead will ensure that all sample points are loaded onto GPS units, dive flags are set up, a site checklist is generated, datasheets are printed, and all monitoring gear is present and functional.

Post-sampling Procedures

Once data collection is completed and all divers are aboard the boat, initial QA/QC will include discussions among dive buddies of the main variables (e.g., habitat characteristics, visibility, carapace length estimates) and review of data sheets to make sure all entries are legible. Data sheets must be maintained securely while on board. After each day of sampling, all gear that came in contact with salt water must be thoroughly rinsed with fresh water and allowed to dry. The data

sheets must be scanned and copies distributed to data collectors for data entry. Electronic copies of all scanned data sheets and boat logs are maintained on the SFCN server (Z:\SFCN\Vital_Signs\Lobster\data\scanned_datasheets or \boat logs). The original datasheets will be archived securely and must not be edited back in the office. Data must be entered according to the procedures detailed in SOP SL06—*Data Entry, QA/QC, and Management—Version 1.1* (SFCN 2020f).

End-of-season Procedures

After sampling is complete, all lobster monitoring specific gear (gloves, net, tickle stick, calipers) will be thoroughly rinsed with fresh water, allowed to dry, and stored together until the next sampling event. All data must be proofed following methods in SOP SL06 (SFCN 2020f) and then submitted for final validation and use in data analysis, reporting, and future sample allocation (as described in SOP SL03 *Sample Allocation—Version 1.1* (SFCN 2020c) and SOP SL07—*Data Analysis and Reporting—Version 1.1* [SFCN 2020g]).

Data Handling, Analysis, and Reporting

Scanning Datasheets, Data Entry and Verification

As soon as possible all datasheets are scanned and stored on the SFCN server. A database that is consistent with NPS Inventory and Monitoring Division guidance is used for long-term storage. It is the responsibility of each participant in the survey to enter and proof their data in the database. Entry and subsequent proofing are expected to occur within one month of each survey. Early entry is recommended while it is still easy to remember dives and to catch mistakes. Subsequent proofing of the data should be done by the same individual as long as the tasks are separated by several days. SOP SL06 *Data Entry, QA/QC, and Management—Version 1.1* (SFCN 2020f) covers data entry steps, verification and database management.

Overview of QA/QC

Quality Assurance/Quality Control (QA/QC) evaluations are done at several levels depending upon the type of data generated.

- Training before each sampling season will be organized to update all participants on the sample design, survey methods, and all relevant information necessary in order to conduct lobster surveys (SOP SL05 *Training—Version 1.1* [SFCN 2020e]). All new participants will undergo more detailed training on the specific methods.
- Immediately after data collection, divers will trade datasheets with their buddy to make sure all fields are completely filled out and readable.
- Immediately after data collection, divers will also compare their data and converse about any discrepancies or consistently different evaluations. Any questions, particularly from inexperienced observers, must be addressed. Any data that appears suspect must be flagged, but not changed.
- 100% verification of all data entered from information recorded on datasheets.
- Some checks are built into the database such as notifications when data are out of range or fields are not filled.
- Verification that data are entered for all sites and sampling periods monitored.
- Graphing of data to check for suspicious data (unusual spikes or changes) in an ecological context that may have made it past the above checks.

Recommendations for Routine Data Summaries and Statistical Analyses

This sampling design allows the following analyses to proceed:

- Calculation of relative lobster density (exploited phase, unexploited phase, total lobsters) per stratum. A unit-less index of relative density is calculated for park-wide estimates.
- Calculation of relative frequency of occurrence (exploited phase, unexploited phase, total lobsters) per stratum. A unit-less index of relative frequency of occurrence is calculated for park-wide estimates.
- Average size of observed exploited phase lobsters

- Average size of all observed lobsters

SOP SL07 *Data Analysis and Reporting—Version 1.1* (SFCN 2020g) describes calculations of the basic metrics. Metrics are calculated by stratum and then combined across strata for relative density indices and relative frequency of occurrence indices. Note that analysis of lobster data deviates from the procedures described in the reef fish protocols (Brandt et al. 2009; Bryan et al. 2013). Because the data are likely to contain a large proportion of zeroes in some strata and to consist of small whole numbers, the data must first be fitted to an appropriate probability distribution function prior to generating estimates. The relative density data will likely adhere to a Poisson or negative binomial distribution, or the zero-inflated equivalents, particularly in Virgin Islands NP where lobster numbers are expected to be low. SOP SL07 (SFCN 2020g) describes the methods to determine the proper distribution for the data and the ensuing analyses to generate estimates. The frequency of occurrence data adheres to a binomial distribution. For both data sets, a non-parametric bootstrap is used to generate confidence intervals for the data when means and confidence intervals are displayed.

There are two approaches to assessing changes to relative density, relative frequency of occurrence, and average size of exploited phase lobsters (computed by averaging lengths of all observed lobsters that are at or above harvestable size) over time. One approach compares two time periods by bootstrapping a 95% confidence interval of the differences between the two time periods. A time period may consist of a single sample event or grouped consecutive sample events. If the confidence interval does not contain zero, the two time intervals are considered significantly different. The second approach uses a generalized linear model (GLM) and is used to compare three or more time periods. It is important to use the appropriate distribution for the data set when using this approach (e.g., Poisson or negative binomial for relative density GLM). Time, strata, and time by strata interactions are included. Time is included as a linear regression variable where possible but if change appears to be non-linear, then time must be included as a categorical variable. A logistic regression is more appropriate for analysis of change in relative frequency of occurrence, especially if numbers in some strata are less than 5%. With sufficient data, additional factors such as distance from edge will be tested.

The following metrics are presented as descriptive statistics following a sample event. They will be compared between two time periods (either two sample events or two sets of sample events that span several years) using either t-tests, ANOVAs, Chi square tests, or Fisher's exact tests.

- Lobster size distribution
- Sex ratios of lobster
- Molt stage ratio
- Prevalence of egg-bearing females
- Prevalence of females with spermatophore

Primarily as a visual aid, GIS maps will be created for each sample event to show the spatial distribution of lobsters in park units.

Basic summary reports will be published in the Natural Resource Data Summary series (NRDS) following each survey season describing the sampling effort and the summary metrics, basic change analyses, graphs, and maps described above and in SOP SL07 (SFCN 2020g). An occasional, more comprehensive in-depth analysis of the data will occur after a few sample events have been conducted.

Cautions on Interpretation of Data

Metrics should be considered relative density and relative frequency of occurrence rather than absolute density and frequency of occurrence. The relative metrics are good for estimating change through time and for comparing with areas monitored in the same manner but do not necessarily provide an accurate estimate of the true density of lobsters in the park. Furthermore, when park-wide calculations are made, relative density and relative frequency of occurrence are reported as unit-less indices to emphasize that any extrapolation from stratum-specific relative density to park-wide relative density must be treated with caution.

Park-wide estimates of lobster density and frequency are based upon strata area which in turn are based upon benthic habitat maps whose accuracy is less than desirable. A map grid cell approach is used to compensate for this inaccuracy in which a grid cell is assigned a strata category as described in the multi-agency reef fish visual census protocols (Brandt et al. 2009; Bryan et al. 2013). However only a portion of each grid cell may be actual lobster habitat. As the entire map grid cell is used to calculate the strata weights to create a park-wide combined density estimate across all the strata, these inaccuracies may overestimate or underestimate the weighting of some strata. As long as the strata weights are consistent across years, the direction of trends should not change.

The grid used is expected to be improved through time as benthic maps become more accurate. The South Florida grid cell size has already been reduced from a 200 × 200-meter (656 × 656-ft) grid to a 100 × 100-meter (328 × 328-ft) grid and is expected to be reduced further in the near future. In order to avoid the appearance of artificial trends as the grid accuracy improves and grid cell sizes decrease, when a new version of the map grid is available for the multi-agency reef fish visual census protocols resulting in reductions in grid cell size, ***the new grid will be used to re-calculate strata weights and will be applied to all data in previous years*** when calculating trends based upon park-wide multi-strata estimates. The justification is that the newer map grid is a truer estimate of the ideal strata weights that should have been used in the past. However, if the strata definitions change in the future, the strata weights for the older years will be calculated with the new grid, but using the original strata definitions, e.g., a newly implemented management stratum such as the Dry Tortugas Research Natural Area will not be applied to older sampling years when calculating the park-wide density estimates as this strata was not part of the planned sampling allocation at the time.

Warnings shall be put into reports that data calculations are dependent on the map grid product used and updates in the map grid cause recalculation of metrics in all previous years. The warning will note that this may result in some shifts in the size of density and frequency estimates, but not in the direction of trends. As the grids for the reef fish sampling are improved and methods are available for improving estimates, the lobster protocol will also be updated as many of the issues are similar.

One reviewer suggested that the protocol may increase the likelihood that edge habitat is sampled compared with habitat further from an edge. This issue is addressed in two ways. The protocol strata design attempts to reduce some of this potential for bias by placing patch reefs, which have the greatest potential for this problem, into a separate stratum from the rest of hard-bottom habitat. In addition, the South Florida/Caribbean Network is estimating the distance lobster are found from the edge of the reef so this potential for bias can be directly factored into the analysis, if it should prove necessary. However, users of the data should be aware of this possibility.

As lobsters may not be 100% detectable, the design will likely underestimate the true number of lobsters present at a sampling location, especially in highly rugose habitat. It is possible that some lobsters in surveyed areas may be hidden too deeply in crevices to be detectable by visual observer methods. This will cause an acknowledged but hopefully small and reasonably constant underestimate of the true density within some rugose strata through time.

Iterative Approach to Survey Design

This monitoring program is comprised of an iterative process of data collection, data set integration, design analysis, and sample allocation along with population and community assessment of managed resources (Figure 11). The initial survey design, including the stratification scheme, is based on previously collected data as well as existing benthic maps. Mapping capabilities and understanding of the linkages between lobster and habitat change over time. As benthic habitat maps are updated and revised, it is important that the lobster sample design reflects those changes, with regard to stratification and allocation. Samples are currently allocated evenly across all strata, though once more information becomes available through sampling, a more efficient allocation scheme will be implemented.

Eventually, the sample allocation will incorporate population-level variance estimates of density per stratum as well as the areal coverage of a stratum with respect to the entire sample domain. In other words, to improve sampling efficiency in the future, more samples will be allocated to larger and more variable strata. The sample effort will also reflect management needs. Data collected during each survey season are incorporated into the sample allocation for subsequent surveys. Since the initial data used to estimate variance among strata were limited or non-existent, it is imperative that future sampling allocation includes the most recent data. Additionally, as the resource changes over time, management needs for data may also change and these requests will be incorporated into the sampling effort.

The existing habitat maps are updated after each survey season based upon field data as appropriate, e.g., linear reef is found to be pavement in a grid cell during a field visit. The current maps are assumed to be the most appropriate for conducting analyses with both current and historical data as these geological formation-based habitats change very slowly through time and the discrepancies are assumed to be errors in the original maps.

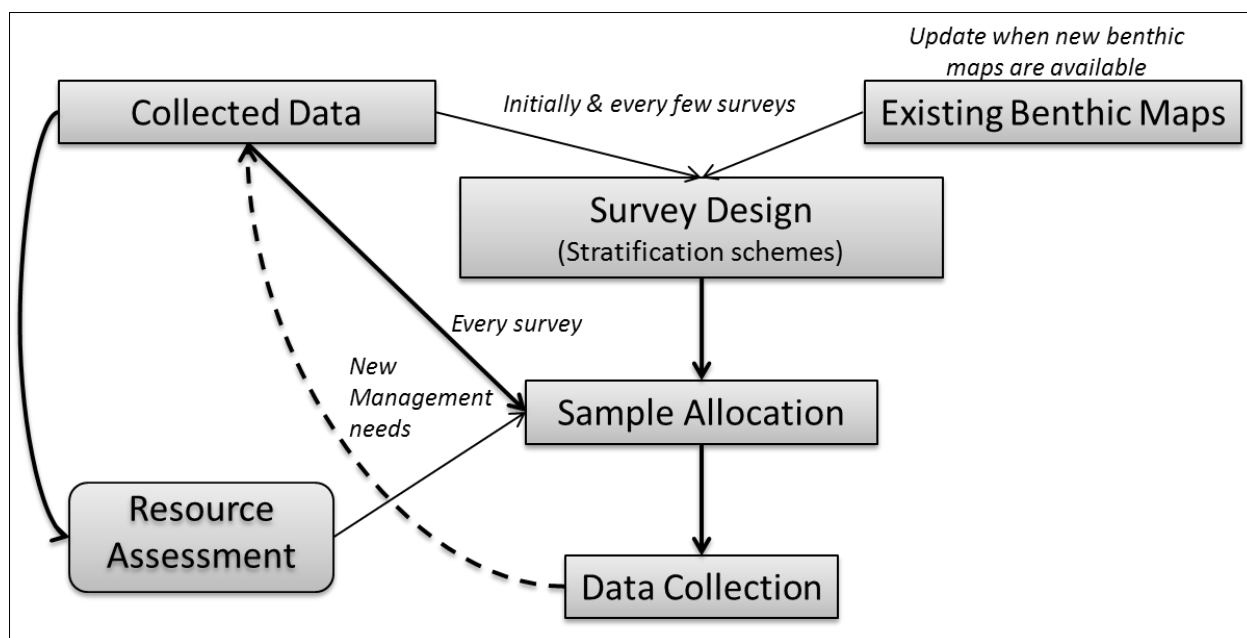


Figure 11. A diagram displaying the iterative approach to data collection. Initial survey design is based on data that has been previously collected and existing benthic maps. Sample allocation is driven by the survey design, estimates of variance structure made from collected data, and needs of resource managers. Sample allocation should be updated each survey with previous survey data and should also be re-evaluated as management needs arise and evolve. The data collected is a function of survey design and sample allocation and is used to guide these parts of the monitoring process. (Bryan et al. 2013).

Protected Data

The spiny lobster is considered a commercially valuable species in both Florida and the USVI. According to the Department of the Interior Freedom of Information Act Handbook (383 DM 15), 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 any lobster-related data, particularly specific locations of lobsters during sampling. If the park manager deems locational data to be protected from public release, this will be incorporated into a park-specific protected data agreement, and coordinates will be fuzzed accordingly.

Metadata and Archiving

Following the guidance of the reef fish protocols, 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 Data Store](#). The target date for archiving all data associated with a survey year will be January of the following year (Bryan et al. 2013).

Participant Roles, Requirements, and Training

Roles and Responsibilities

Prior to each field season, a designated SFCN lobster project lead will update the sample allocation and compile the sample locations for the park unit(s) to be sampled for lobster. This person(s) will also make sure all survey materials, logs, and datasheets are accounted for and prepared prior to beginning field operations. This person will also organize a training for all participants to be updated on sample design, survey methods, and all relevant information necessary in order to conduct lobster surveys (SOP SL05 *Training—Version 1.1* [SFCN 2020e]).

Prior to sampling, a designated data manager will ensure that the database is functional and ready for data entry. The data manager will communicate with the lead agency for the Reef Fish Monitoring in Florida (NOAA-SEFSC) and the Virgin Islands (NOAA-BB) and make sure the most recent sample points, benthic habitat map, and sample frame grid are on file and being used.

Each participant is responsible for conducting surveys accurately, entering data into the database in a timely fashion, and providing an initial QA/QC review of the data. The SFCN data manager and SFCN marine ecologist will ensure that all the QA/QC checks have been conducted and the data set is complete and ready for reports and archiving.

The ecologist and project lead should work together and are responsible for conducting the post-stratification analysis and new sampling allocation each year. The sample points from the most recent reef fish monitoring should be used. Additional random samples may need to be generated to make sure an appropriate number of samples are completed for each strata.

The lobster project lead, data manager, and marine ecologist will coordinate to make sure the findings of the lobster survey are reported appropriately.

Qualifications

All participants must be trained in lobster identification and assessment as well as in the ability to make the necessary observations (training requirements are covered in the subsequent section). All participants must also be certified to scuba dive in open water by a recognized and licensed organization (e.g., NAUI, PADI) and must possess a certification to use enriched-oxygen (NITROX) if the mixed gas is to be used. If volunteer surveyors participate, they must be in compliance with their agency/organization's dive safety regulations. It is the responsibility of the lobster lead and SFCN Park Dive Officer (PDO) to confirm prior to operations that participating divers are cleared to dive.

Additional NPS qualifications for operations by NPS staff on NPS boats:

- NPS Blue Card Diver (Ref NPS RM4, 485 DM 27)
- Motorboat Operator Certification Course (ref 36 CFR part 3, 485 DM 22) (necessary if driving an NPS boat)

Tasks may be performed by personnel in training status under the supervision of properly qualified persons. Specific guidelines and applicable regulations shall be strictly adhered to at all times. This list is not meant to be all inclusive and may be supplemented by individual park regulations and qualification requirements.

Training

Training is an important component of the lobster monitoring program. Participants must be capable of accurately identifying and distinguishing Caribbean spiny lobster (*P. argus*) from similar species (e.g., *Panulirus guttatus*). Participants must be capable of using a measuring device to accurately estimate carapace length of lobsters. They must also be able to sex a lobster, determine molt status, and identify status of eggs and spermatophore if present. Participants must be familiar with habitat assessment techniques and benthic categories that are included in the method and detailed in SOP SL05 *Training—Version 1.1* (SFCN 2020e). Furthermore, participants must be able to establish a survey plot and follow the survey methods outlined in SOP SL04—*Lobster Data Collection and Survey Methods—Version 1.1* (SFCN 2020d). An initial training for participants who have not previously participated in SFCN lobster surveys will consist of overviews of sampling design, logistics, survey methods, safe lobster capture techniques, habitat characteristics, and data entry and proofing. The training will also review methods to effectively capture and assess relevant life-history characteristics of individual lobster (SOP SL05 [SFCN 2020e]).

Operational Requirements

Annual Workload and Field Schedule

In a given sample year, sampling occurs in a concerted effort over the course of a few weeks. In subsequent sample years, the monitoring effort takes place around the same time of year. For Florida parks in particular, monitoring must occur in the off-season for the Florida lobster fishery (April–July, before mini-season). However, during this period, females tend to migrate offshore, so minimizing the timeframe of sampling is important. Sampling should take place in a single survey pulse in May and that timing should remain as consistent as possible from year to year. No off-season exists in the Virgin Islands lobster fishery, so the exact time during the year is not critical. However, to remain consistent with the sampling in Florida, sampling will also occur in May. 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.

A captain and two-person dive team is the minimum required for field work, for both boat and diving safety, and data collection. However, a four-person dive team (two rotating teams of two divers) 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 15 to 40 minutes to survey. During the SFCN pilot survey using transects, four to seven sites were completed each day per boat. Using circular plots, based on the similarity to reef fish monitoring, we estimate five to nine sites per day per boat will be typical. When conducting monitoring in SFCN parks, invitations are extended to qualified personnel in the host park to partner or collaborate, either as an observer or data collector (where skills permit). This partnership fosters camaraderie among staff and can increase staff skills.

Facility and Equipment Needs

Field work is conducted out of the Virgin Islands and South Florida offices, with the exception of Dry Tortugas NP, where staging from the Research Vessel Fort Jefferson or NPS quarters within the park are preferable due to the remote location. When field work is conducted, the following equipment is needed:

- Boat.
- Standard dive equipment and accessories (e.g. compass, dive computer).
- Dive and boating safety equipment including first aid kit, oxygen kit, and flares.
- Weighted dive flag with reel.
- GPS and dry bag.
- Tickle stick and flat-bottomed net (for capturing lobster).
- Snare (for capturing lobster)
- Measurement aid in millimeters (mm; this can be attached to the tickle stick to help with carapace length estimates).
- Gloves.

- Several 30 meter (98 ft) transect tapes (at least three per buddy pair)
- Camera housing and accessories (O-rings, O-ring grease, cotton swabs, distance aiming mechanism).
- Miscellaneous underwater equipment (slate, underwater paper, pencils, rubber bands).

Post-data collection, software needed for data storage and analysis includes:

- Microsoft Office—Access, Excel, Word.
- ArcGIS (mapping of sites, site selection, creating field logistic plans).
- DNR GPS (transferring data between GPS devices and GIS software).
- Garmin HomePort (manage field trip data on a Garmin).
- R statistical software (for statistical analyses).
- Adobe Acrobat (for making pdf documents).

Sequence of Events During Field Season

Sampling schedules may vary due to considerations of weather and equipment but a concerted single sampling pulse is recommended. A list of alternate sites is provided that can be used in cases where sites are not accessible, habitat classification is incorrect, or the goal has been met and additional sampling is permitted. As many sites as possible should be surveyed during a day. This goal should determine the assembly of sampling teams and location of sites that are in the same vicinity. Data that are collected are the responsibility of the participants and should be entered and catalogued during or immediately after the end of the sampling event following the methods detailed in SOP SL06 *Data Entry, QA/QC, and Management—Version 1.1* (SFCN 2020f). Preferably, data should be entered as soon as possible upon return from the field (or within one month), as this tends to reduce errors in data entry (Table 14). Once all data are entered, each surveyor will follow proofing steps before submitting the data for final verification (SOP SL06 [SFCN 2020f]).

Table 14. Projected implementation schedule for spiny lobster monitoring. Where “X” indicates sampling was performed that year, and “–” indicates that no sampling was done that year..

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

Frequency and Timing of Sampling

A four-year sampling rotation of surveys is most appropriate (Table 15). Ideally, each SFCN park unit would be monitored annually, but the time and resources to do this are beyond the scope of the South Florida/Caribbean Network at the current time. With a limited sampling effort, we believe it is more important to adequately sample each park during a sampling year with less frequent sampling years, than to under sample each park on a more frequent basis. However, an increase in effort by parks or partners or a change in priorities by park management regarding the frequency of monitoring of other vital signs may allow an increase in frequency.

Table 15. Sampling schedule by park. Where “X” indicates sampling was performed that year, and “–” indicates that no sampling was done that year..

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

* Indicates that sampling may occur in this park on a more frequent basis. This may be possible by replacing other monitoring efforts (e.g., seagrass) with lobster.

Sampling occurs as a single, concerted survey pulse in May for two reasons. The lobster fishing season is closed in Florida during that time (closed from March 31 to August 6, with the exception of mini-season which occurs on the last Wednesday and Thursday in July). Females tend to migrate offshore between March and June, so sampling should occur in as narrow a timeframe as possible and stay consistent throughout sample years. There is no closed season for lobster in the Virgin Islands. However, to remain consistent with the survey effort in Florida, sampling will also occur in May.

Startup Costs and Budget Considerations

Some of the field equipment (e.g., GPS, dive flag, reel, transect tapes, slates, cameras) is shared with other monitoring protocols. Lobster-specific monitoring equipment includes tickle sticks, flat-bottomed nets, and gloves. Lobstering kits (tickle stick, flat bottom net, gloves) can often be purchased for \$20–\$30.

ArcGIS and Microsoft Office products are purchased government-wide with no additional costs to the network. DNR GPS, Garmin HomePort, and R are free.

With a team of two divers, a survey site (one set of paired circular plots) may take 15 to 40 minutes to complete. Sites that are deeper or have more complex habitat will take a longer time to complete. After field collection, the GPS units need to be downloaded, datasheets scanned, and data entered

into the database (SOP SL06 *Data Entry, QA/QC, and Management—Version 1.1* [SFCN 2020f]). The data will then need to be analyzed and communication products (e.g. reports) generated.

The total costs of data entry/proofing, data management, analysis and reporting are approximately 30% of project costs (Table 16). Time and cost allocation from host park staff aiding in data collection are not included. Time and cost allocation (e.g., cooperative agreements) associated with SFCN interns are also not included below but must be a consideration. Costs may be estimated as 0.06 FTE for each individual involved with data collection (includes training, 10 days of data collection, and data entry).

Table 16. SFCN monitoring budget protocol implementation. Note: These costs are approximate based upon 2015 salary, travel cost, and equipment estimates for annual monitoring of sites.

Category	Sub-Category	Costs (FY 2015, in USD)	Notes
Personnel	SFCN Marine Ecologist	13,250	0.10 FTE GS-12
	SFCN Quantitative Ecologist	7,050	0.06 FTE GS-12
	SFCN Fish Biologist	8,250	0.06 FTE GS-11
	SFCN Biological Technician ¹	18,200	0.24 FTE GS-7
	SFCN Data Manager ²	4,950	0.06 FTE GS-11
	Total Personnel Costs³	\$ 51,700	–
Equipment & Supplies	Annual Boat Maintenance	900	0.15 for 2 SFCN vessels
	Annual Boat Fuel	600	0.15 of fuel
	Field Supplies	1,800	0.15 of scuba and field costs
	Total Equipment Costs	\$3,300	–
Travel	Travel: Biscayne NP	0	Monitored by SFCN Miami & Biscayne NP
	Travel: Dry Tortugas NP	4,000	Requires boat transport for staff (4) to Dry Tortugas
	Travel: Virgin Islands NP	4,400	Assisted by Virgin Islands NP staff SFCN Air (2)

¹ Includes time for three biological technicians; the project lead (0.12 FTE) and two assistants (0.06 x 2).

² 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.

³ Includes benefits, hazard pay, overtime for personnel based on two 1-week field missions, data management activities and summary reports.

⁴ Annual travel is 0.25 of the sum of travel costs in each park, since each park is surveyed every four yrs.

Table 16 (continued). SFCN monitoring budget protocol implementation. Note: These costs are approximate based upon 2015 salary, travel cost, and equipment estimates for annual monitoring of sites.

Category	Sub-Category	Costs (FY 2015, in USD)	Notes
Travel (continued)	Travel: Buck Island Reef NM and Salt River Bay NHP	8,400	Requires boat transport (2) and air (2) to STX
	Total Travel Costs⁴	\$ 4,200⁴	–
Total Protocol Implementation Cost	–	\$ 59,200	–

¹ Includes time for three biological technicians; the project lead (0.12 FTE) and two assistants (0.06 x 2).

² 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.

³ Includes benefits, hazard pay, overtime for personnel based on two 1-week field missions, data management activities and summary reports.

⁴ Annual travel is 0.25 of the sum of travel costs in each park, since each park is surveyed every four yrs.

Safety

Miller et al. (2017) states that diving requires 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 must prevail in which problems are considered proactively and each person must feel empowered to think about potential problems and speak up early about safety concerns regardless of their position. All safety concerns must be addressed seriously and respectfully by the rest of the team.

All DOI personnel participating in SFCN dive missions for this monitoring project must be NPS Blue Card Divers (or approved equivalent) with an appropriate depth rating. Tasks may be performed by personnel in training status (NPS Diver in Training) under the supervision of properly qualified persons.

Persons independently driving SFCN boats must complete a Department of Interior Motorboat Operator Certification Course (DOI MOCC) for solo operation of a NPS vessel. Non-MOCC-certified personnel may drive a park boat under the close supervision 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.

South Florida/Caribbean 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 17. These forms may be updated individually and the SFCN Safety Plan updated as a whole, so personnel should 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 fieldwork operations.

Table 17. 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 - Reference Manual - 4	Z:\DiveTech\RM 4
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
SFCN Float Plan	Z:\SAFETY\SFCN_SOPs\Float Plan Document
SFCN Diving from Park Boats JHA	Z:\SAFETY\Section 2Q - Diving Safety
SFCN Safe Diving Operations Plan	Z:\SAFETY\Section 2Q - Diving Safety
Operating SFCN St. John Based Acropora Boat JHA	Z:\SAFETY\Section 2O - Watercraft Safety
Operating SFCN Miami Based Twin Vee Boat JHA	Z:\DiveTech\JHA
Dive Emergency Evacuation Plan (DEEP) Biscayne National Park	Z:\SAFETY\Section 2Q - Diving Safety\Network Parks DEEP's
Dive Emergency Evacuation Plan (DEEP) Buck Island Reef National Monument	Z:\SAFETY\Section 2Q - Diving Safety\Network Parks DEEP's
Dive Emergency Evacuation Plan (DEEP) Dry Tortugas National Park	Z:\SAFETY\Section 2Q - Diving Safety\Network Parks DEEP's
Dive Emergency Evacuation Plan (DEEP) Virgin Islands National Park	Z:\SAFETY\Section 2Q - Diving Safety\Network Parks DEEP's
Dive Emergency Evacuation Plan (DEEP) South Florida/Caribbean Network	Z:\SAFETY\Section 2Q - Diving Safety\Network Parks DEEP's

All SFCN personnel will follow the program-specific Dive Supplement/Diver Emergency Evacuation Plan and Safety Operations Plan specific to the park they are monitoring within. Dive team roles and responsibilities as predicated in NPS Resource Manual 4 (Diving Management Reference Manual) will be reviewed in a safety briefing before each dive trip.

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Appendix A. Benthic Habitat Classifications in Florida

The parks in Florida (Biscayne NP and Dry Tortugas NP) use a different habitat classification scheme than the parks in the U.S. Virgin Islands (Buck Island Reef NM, Salt River Bay NHP&EP, and Virgin Islands NP). The following map class photo-interpretation key and photos are taken from Waara et al. (2011) and provide guidance on identifying hard-bottom habitats in Biscayne NP and Dry Tortugas NP according to the map classes outlined in the System of Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida (Madley et al. 2002).

Reef/Hard-bottom

Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms or exposed bedrock, possibly with various degrees of concealment from attached plant and animal colonization. Unconsolidated bottom and submerged aquatic vegetation may occur within these habitats, although in less abundance than the reef/hard-bottom.

Coral Reef

Hardened substrate formed by reef building corals. May be live coral or relict reefs. Often bedrock is the base for these reefs but the presence of coral or remnant coral on the surface is reason to categorize the dominant habitat as coral reef.

Platform Reef (also bank reef)

Hardened substrate formed by reef building corals that exist in a quasi-continuous structure along a shelf edge or similar dropoff removed from any coastline. These are typically elongate structures and may be referred to as bank reefs. The following Subclass categories may be present in various combinations within a platform reef.

Linear Reef

Linear, contiguous coral formations. Reef crest, fore reef, and back reef zones could be mapped as Linear Reef. Most often has associated spur and groove and reef rubble habitats.

Reef Terrace (high profile)

Contiguous reef with high complexity and high relief (greater than 2 meters [6.6 feet {ft}]) (Figure A-1).

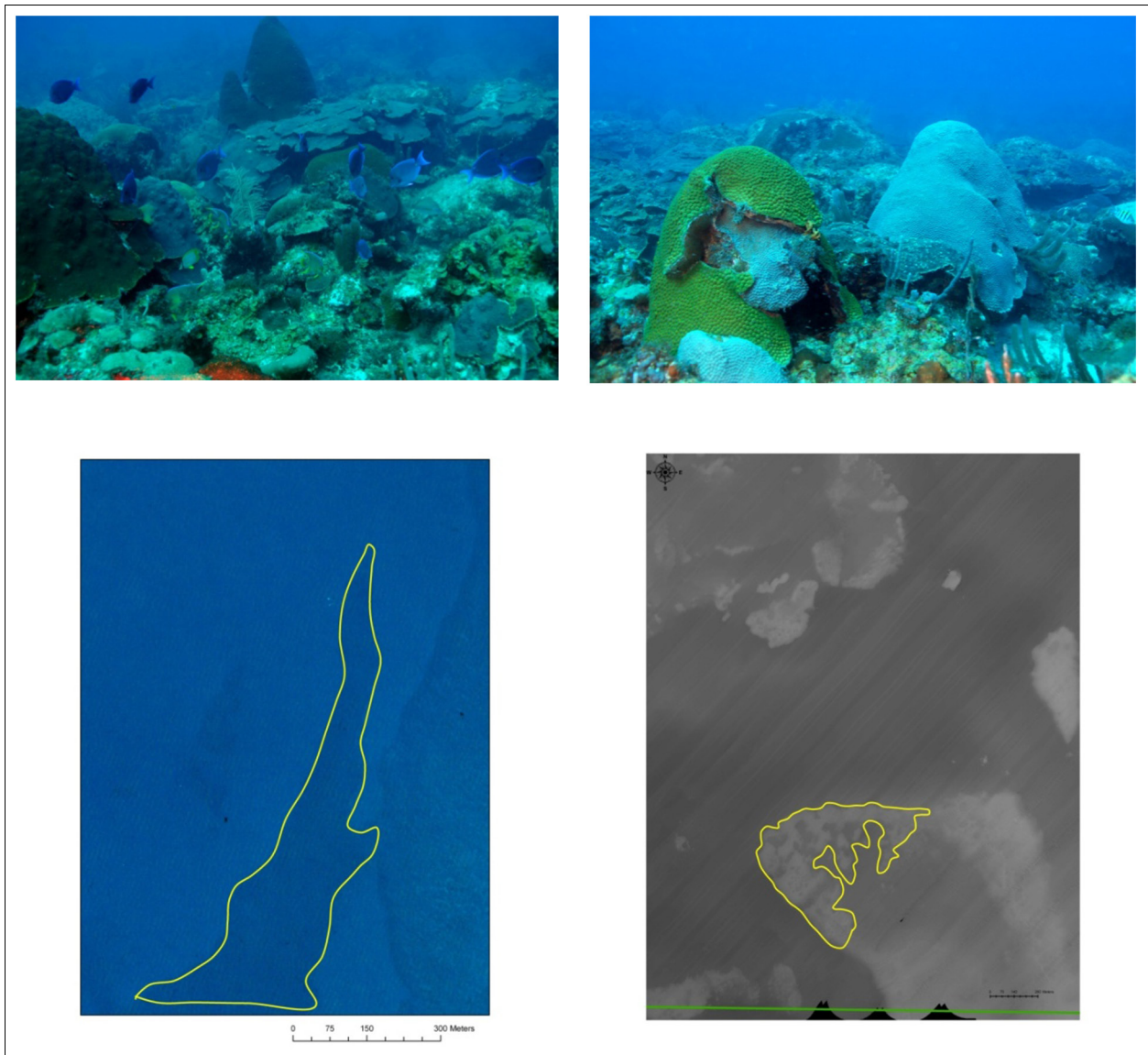


Figure A-1. Photographic examples of linear reef terrace.

Remnant (low profile)

Reefs of relief less than 2 meters (6.6 ft) that lack distinctive spur and groove characteristics (Figure A-2). These reefs consist of coral and hard bottom features; often support soft corals, sponges, seagrass; and are usually found growing parallel to the reef tract, though they may form transverse features that grow perpendicular to the reef tract.

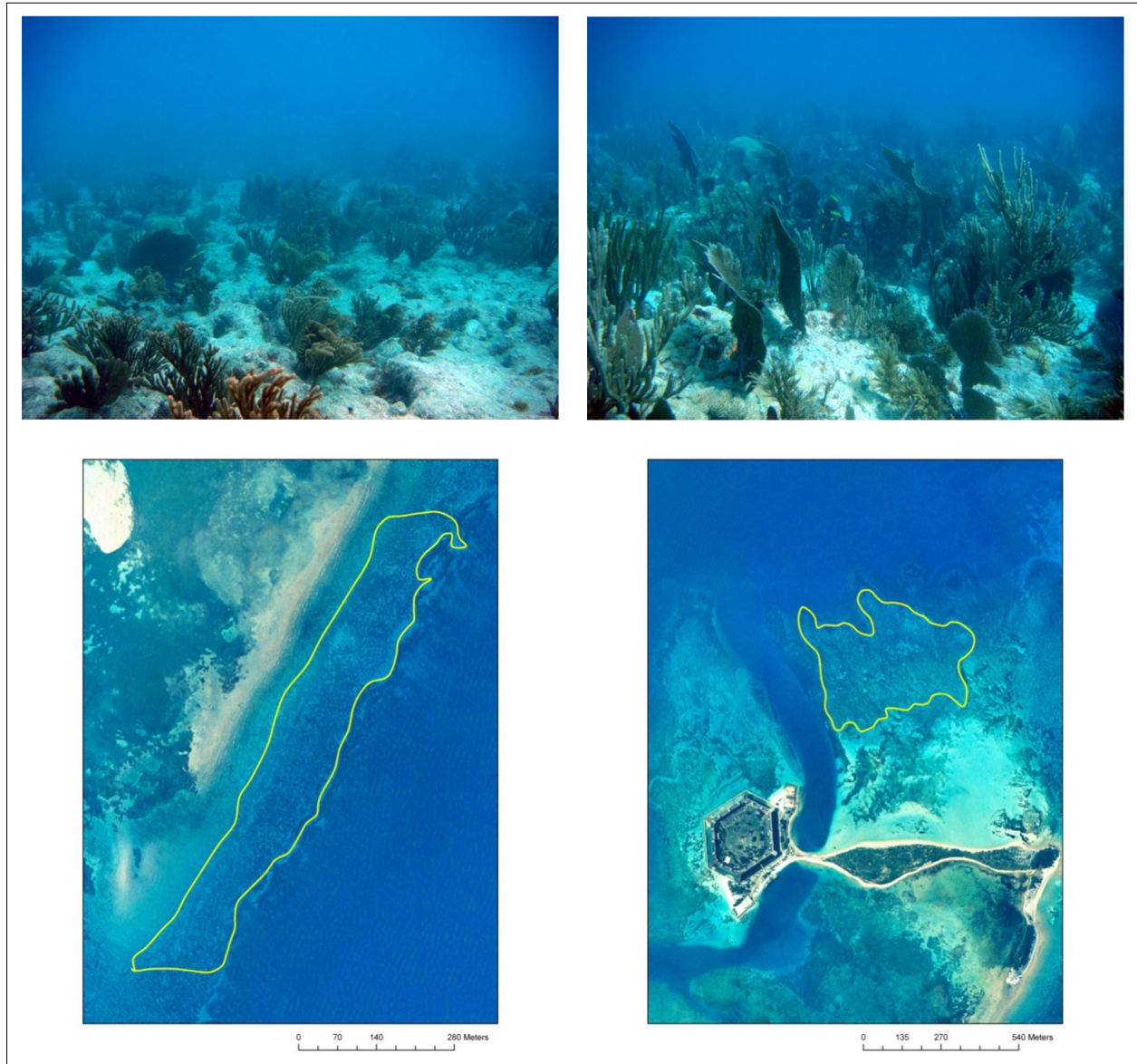


Figure A-2. Photographic examples of linear reef remnant.

Spur and Groove

Distinct coral bands separated by sand or uncolonized hard-bottom grooves (Figure A-3). This habitat type usually occurs in the fore reef zone.

High Relief Spur and Groove

Distinct coral bands separated by sand or uncolonized hard-bottom grooves (Figure A-3). The coral bands have 1.5–4 meters (4.9–13.1 ft) relief.

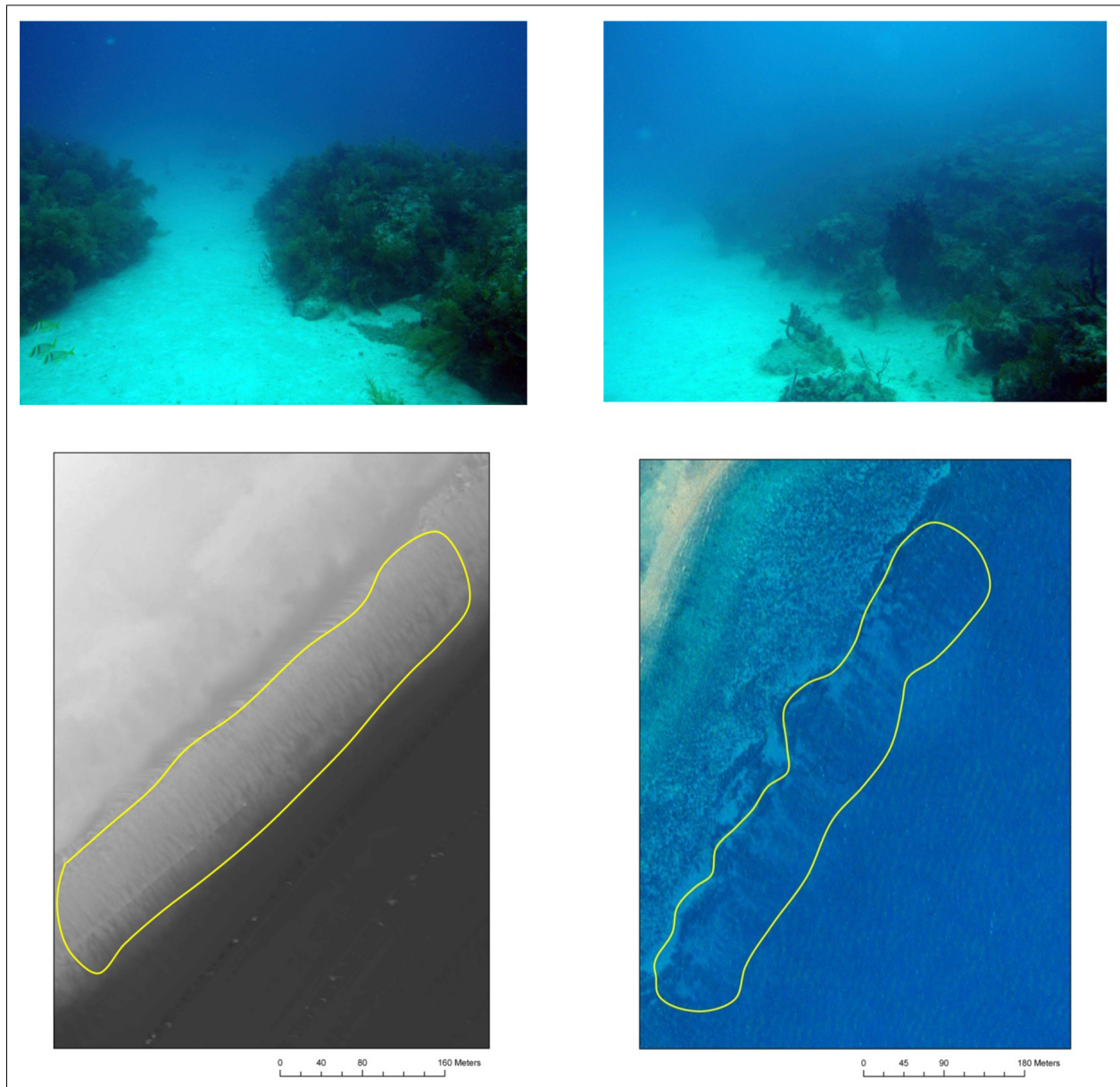


Figure A-3. Photographic examples of high-relief spur and groove.

Low Relief Spur and Groove

Distinct coral bands oriented perpendicular to the shore or bank and separated by sand or uncolonized hard-bottom grooves. The coral bands have less than 1.5 meters (4.9 ft) relief (Figure A-4).

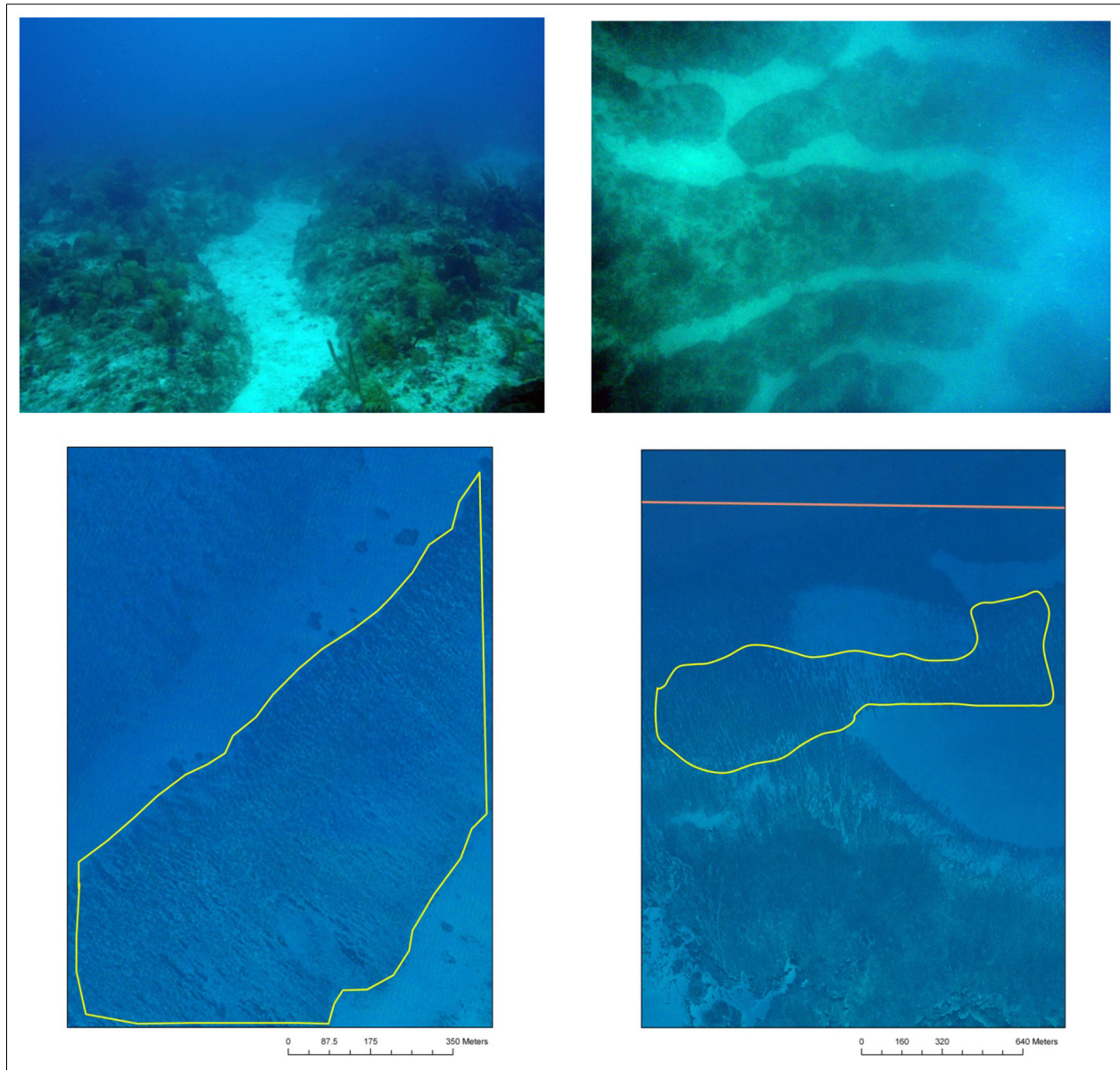


Figure A-4. Photographic examples of low-relief spur and groove.

Reef Rubble

Dead, unstable coral rubble that often occurs landward of platform reefs (Figure A-5).

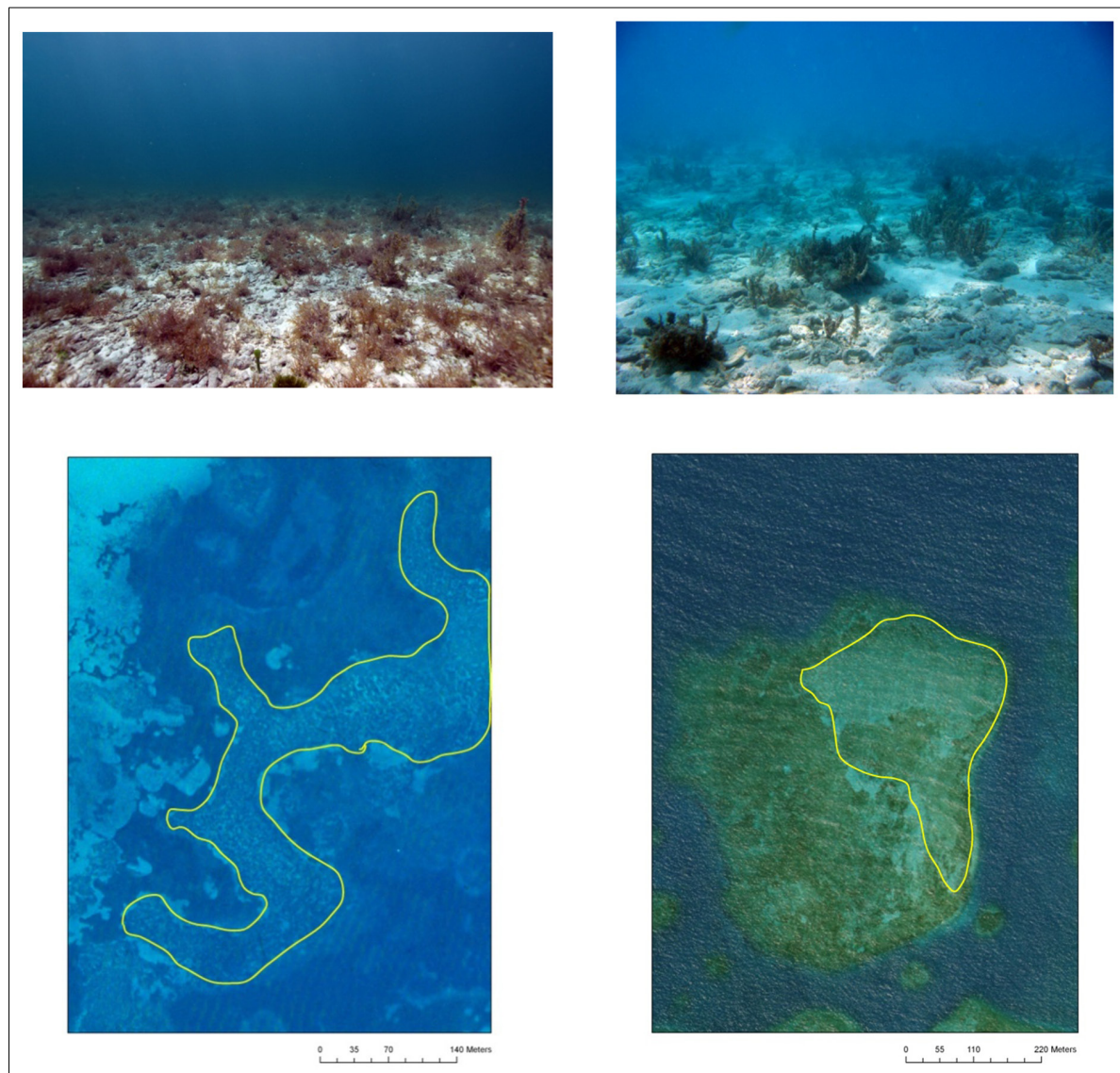


Figure A-5. Photographic examples of reef / hard-bottom.

Patch Reefs

Irregularly shaped reef communities. They may range in size from tens to thousands of square meters. Patches are separated from each other by uncolonized hard-bottom, sand, or colonized substrate with submersed aquatic vegetation (SAV), macroalgae, gorgonians or sponges. Most often the patches are surrounded by a halo of bare substrate created by foraging, obligate reef inhabitants.

Individual Patch Reef

Isolated, single reef (larger than the 0.5 hectare [1.24 acre {ac}] minimum mapping unit of the project) without associated halo area (Figure A-6). These individual reefs may have an associated halo, however if large enough (i.e., greater than the 0.5 hectare [1.24 ac] minimum mapping unit) to be delineated the halo will be mapped as its own subclass.

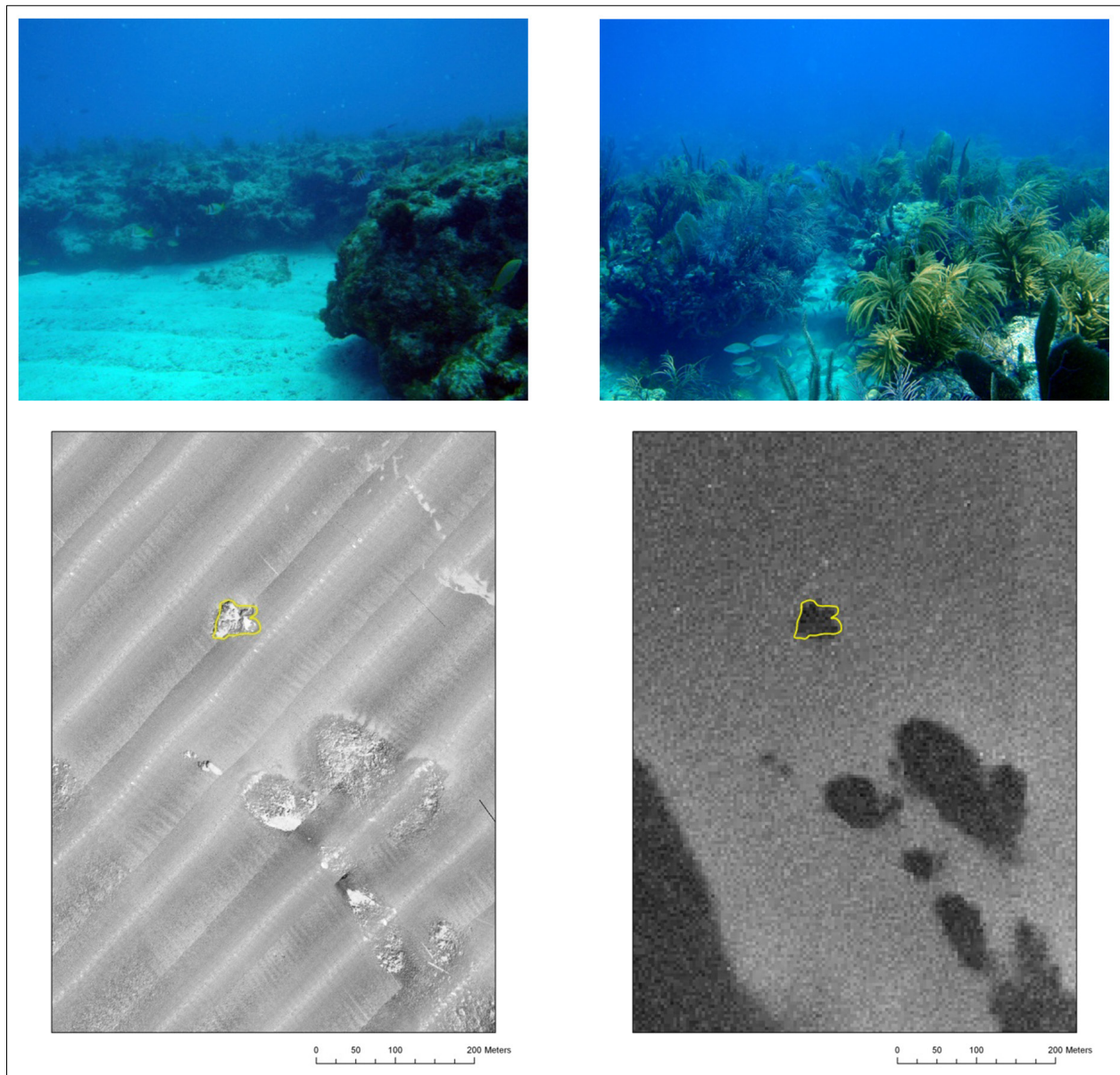


Figure A-6. Photographic examples of individual patch reef.

Aggregated Patch Reefs (includes Halo areas if present)

High complexity patch reefs that have high relief (up to 15 meters [49.2 ft]) from the sea floor. These structures may occur in clusters and are typically surrounded by large sand plains (Figure A-7).

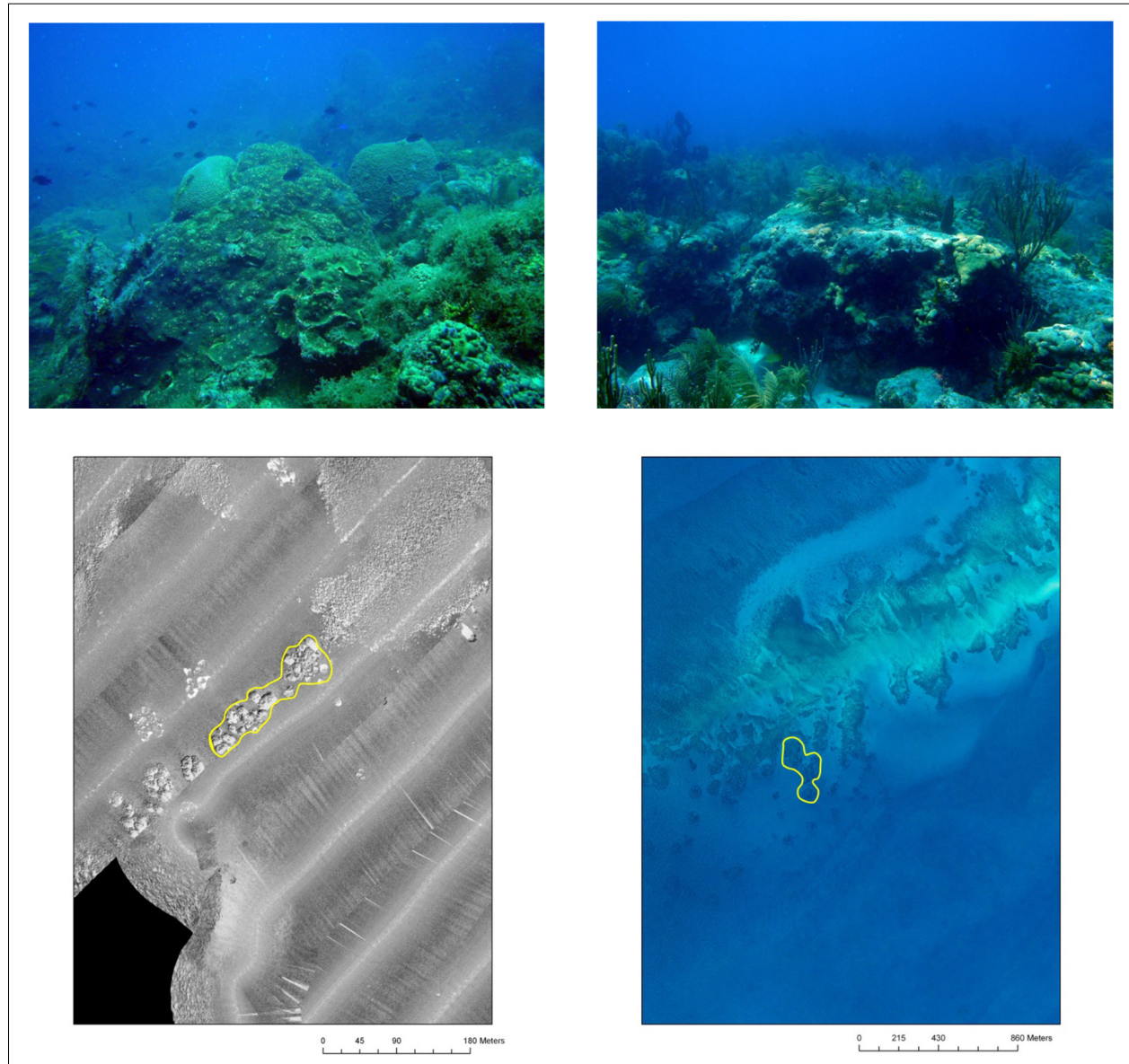


Figure A-7. Photographic examples of aggregated patch reef.

Patchy Coral and/or Rock in Unconsolidated Bottom

Areas of primarily sand, submerged aquatic vegetation, or low relief rock covered with a sand veneer (Figure A-8). Often adjacent to spur and groove habitats, these areas contain small, individual corals or rocks that are distinctive yet a very low percentage of the total cover (and certainly smaller than the 0.5 hectare [1.24 ac] minimum mapping unit).

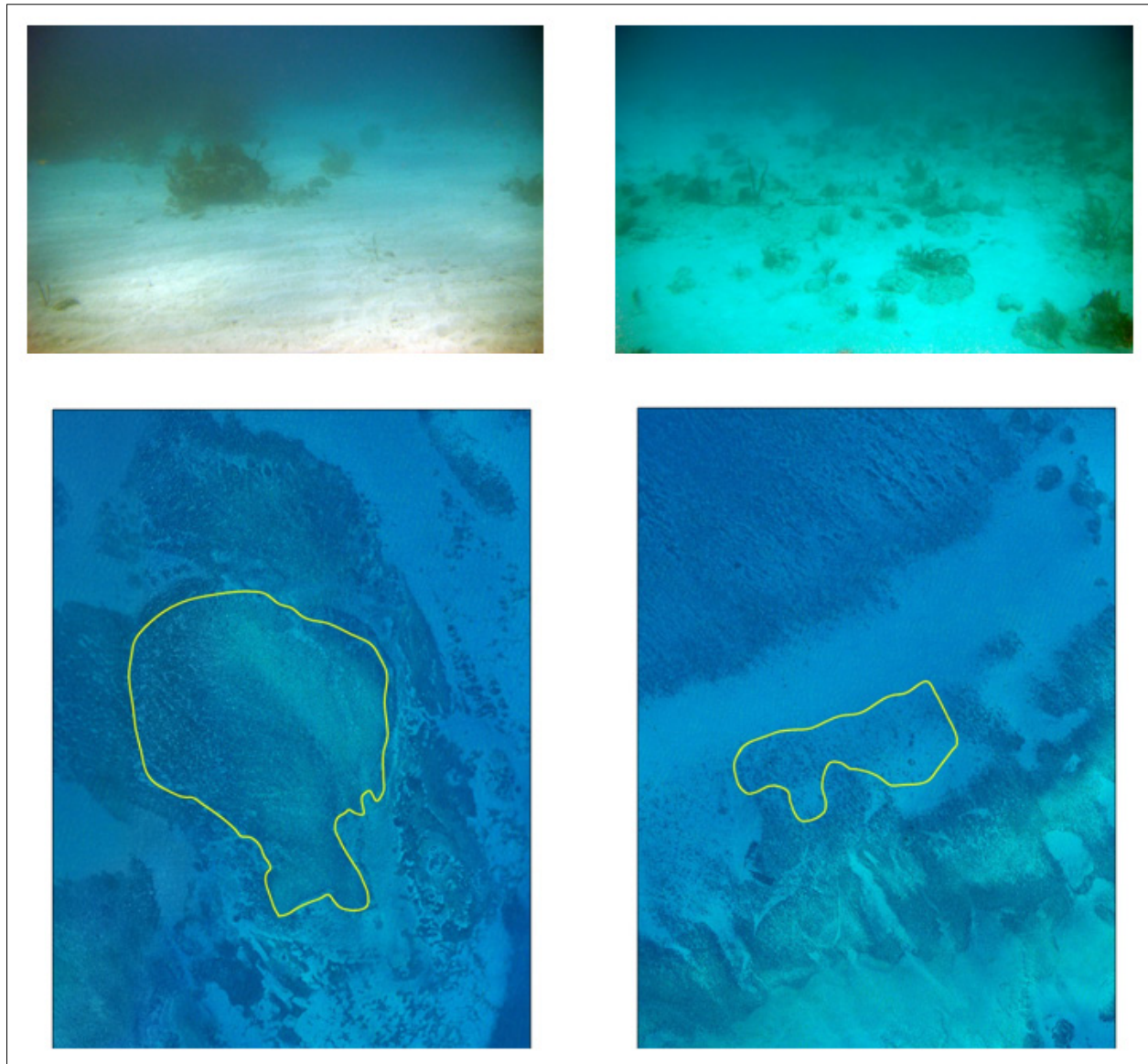


Figure A-8. Photographic examples of patchy coral and/or rock in unconsolidated hard-bottom.

Hard-bottom

Hard substrate composed of exposed bedrock or created through syndepositional cementation of sediment.

Pavement (i.e., low relief hard-bottom)

Flat, low relief, mostly solid rock substrate (Figure A-9).

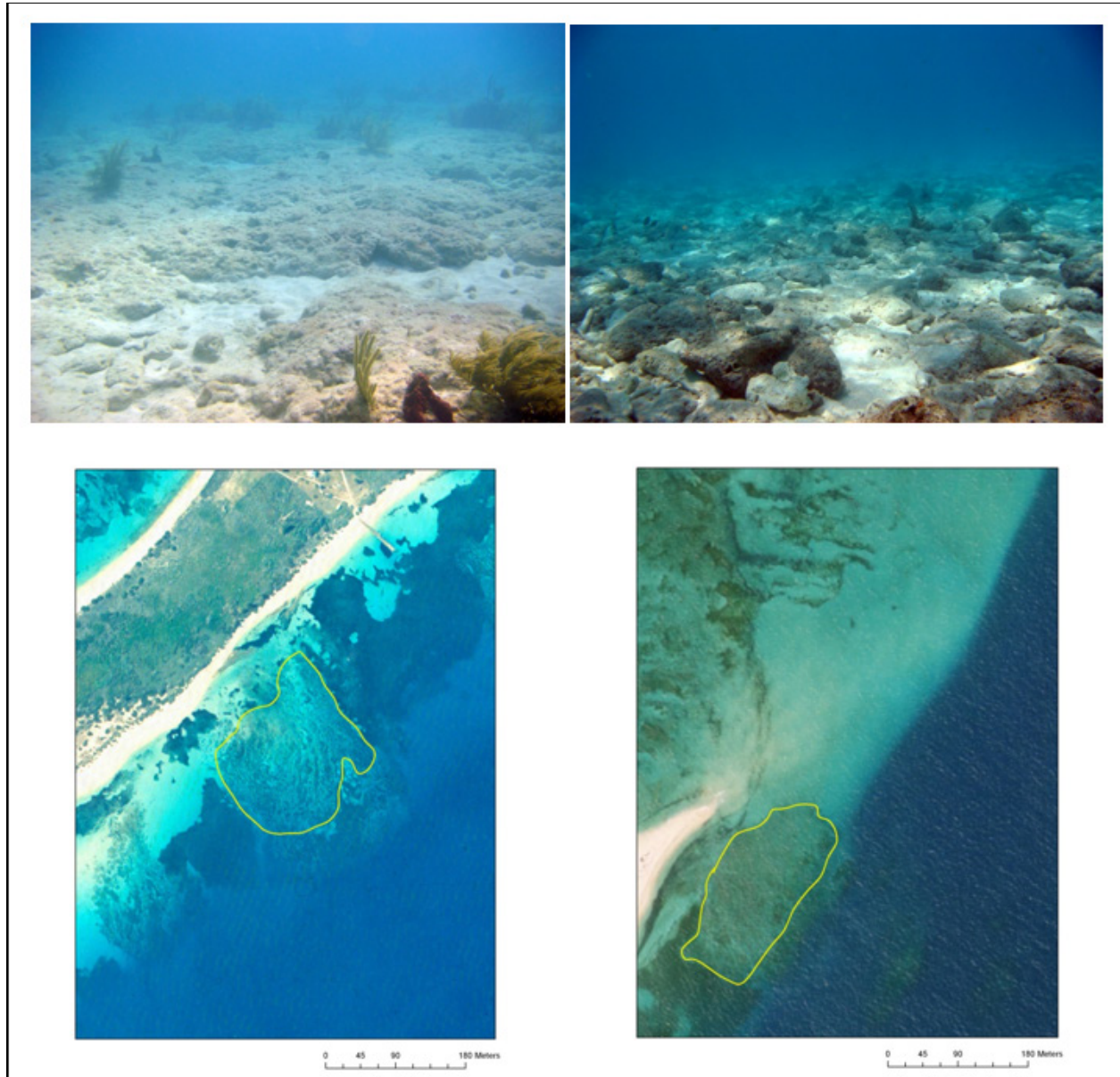


Figure A-9. Photographic examples of pavement.

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Appendix B. Benthic Habitat Classifications in the U.S. Virgin Islands

The parks in the U.S. Virgin Islands (Buck Island Reef National Monument, Salt River Bay National Historical Park and Ecological Preserve, and Virgin Islands National Park) use a different habitat classification scheme than the parks in Florida parks (Biscayne National Park and Dry Tortugas National Park). A detailed description of the five hard-bottom habitats (linear reef, patch reef, bedrock, pavement, and scattered coral/rock) used for this protocol can be found in Kendall et al. (2001). An excerpt from that document is included below in this appendix.

Linear reef: A combination of linear reefs and spur and groove formations (Figure B-1).

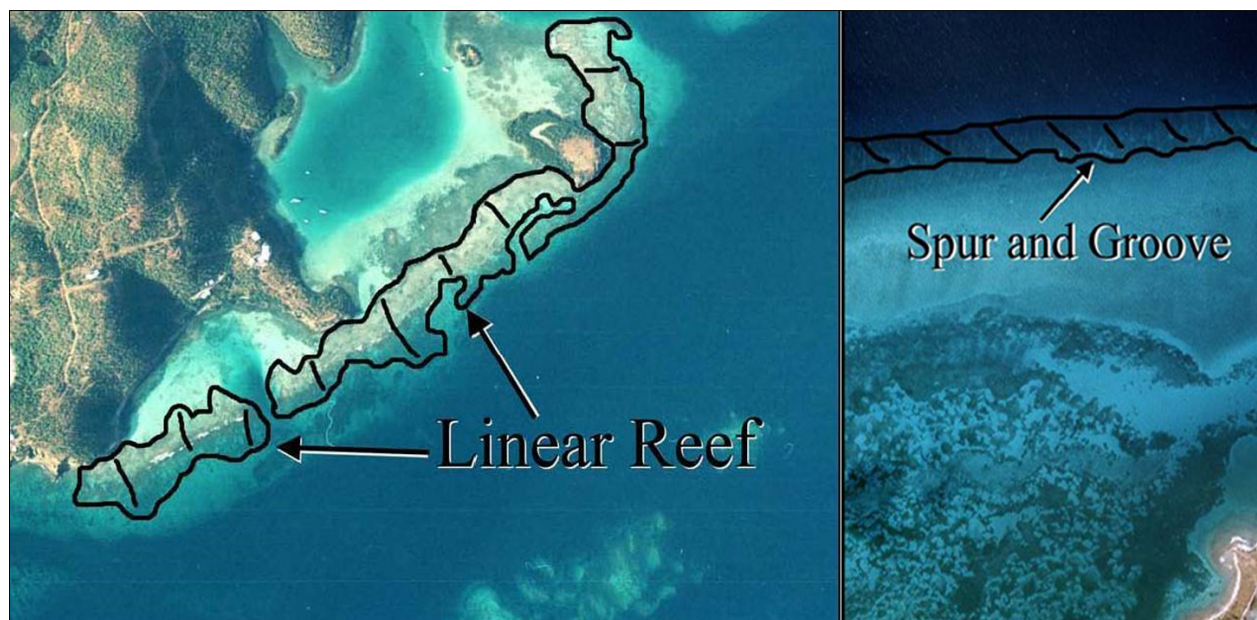


Figure B-1. Examples of linear reef and spur and groove.

Linear reef: Linear coral formations that are oriented parallel to shore or the shelf edge. These features follow the contours of the shore/shelf edge. This category is for commonly used terms such as fore reef, fringing reef, and shelf edge reef (Figure B-2).

Spur and groove: Habitat having alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment (Figure B-3). The coral formations (spurs) of this feature typically have a high vertical relief compared to pavement with sand channels and are separated from each other by 1–5 meters (3.2–16.4 ft) of sand or bare hard-bottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the fore reef or bank/shelf escarpment zone.



Figure B-2. Examples of linear reef.



Figure B-3. Example of spur and groove.

Patch reef(s): Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or

shelf edge. A surrounding halo of sand is often a distinguishing feature of this habitat type when it occurs adjacent to submerged vegetation. Two types of patch reefs were combined.

Individual patch reef: Distinctive single patch reefs that are equal to or larger than the 0.4 hectare (1 acre [ac]) minimum mapping unit. When patch reefs occur in submerged vegetation and a halo is present, the halo is included with the patch reef polygon (Figure B-3).

Aggregate patch reefs: Clustered patch reefs that individually are too small (smaller than the 0.4 hectare [1 ac] minimum mapping unit) or are too close together to map separately. Where aggregate patch reefs share halos, the halo is included in the polygon (Figure B-3).

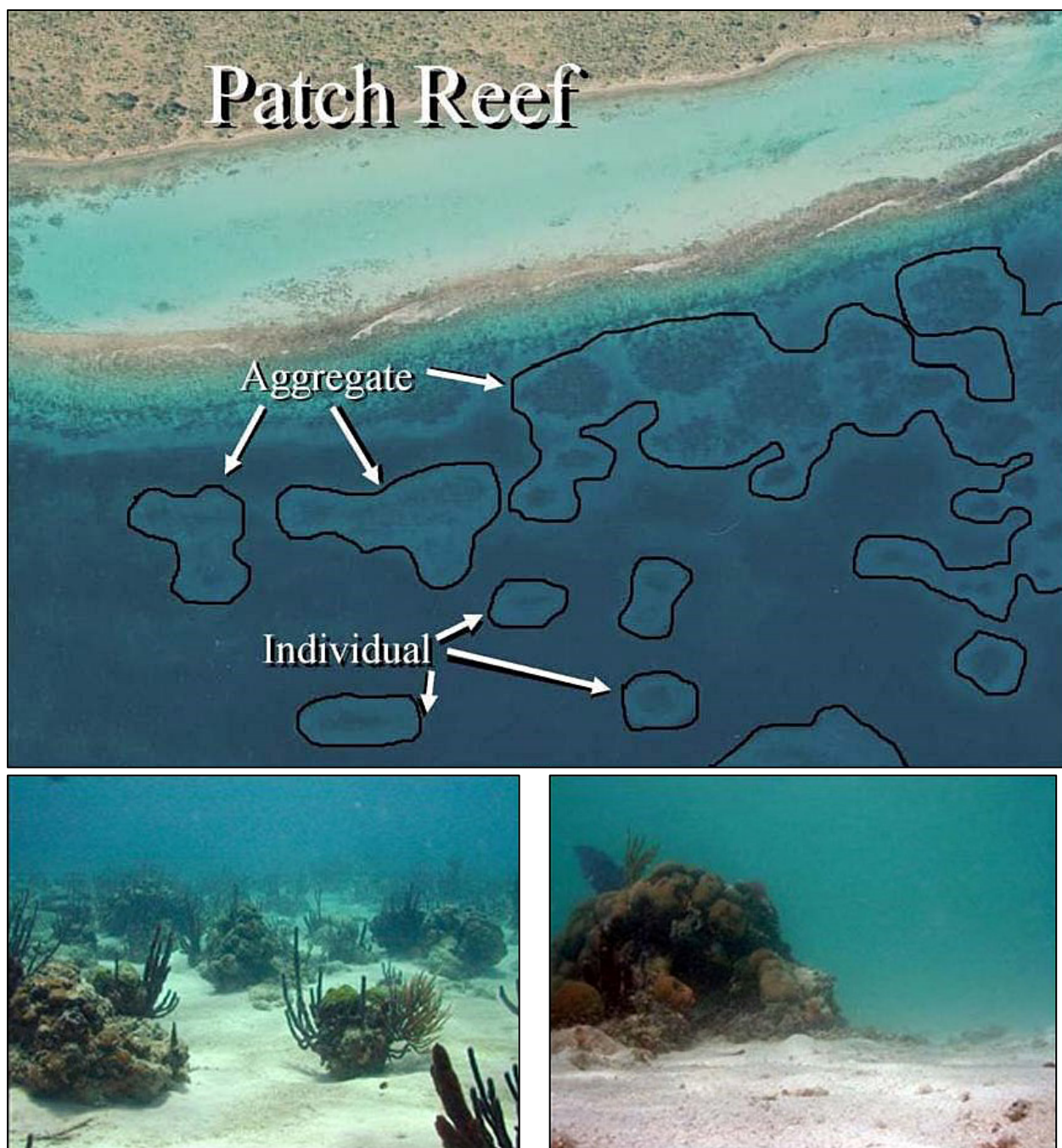


Figure B-4. Example of patch reefs.

Bedrock: The geological formation and subsequent erosion has resulted in the exposure of bedrock in the Virgin Islands. Colonized and uncolonized bedrock were combined into a single bedrock category.

Colonized bedrock: Exposed bedrock contiguous with the shoreline that has coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that partially obscures the underlying rock.

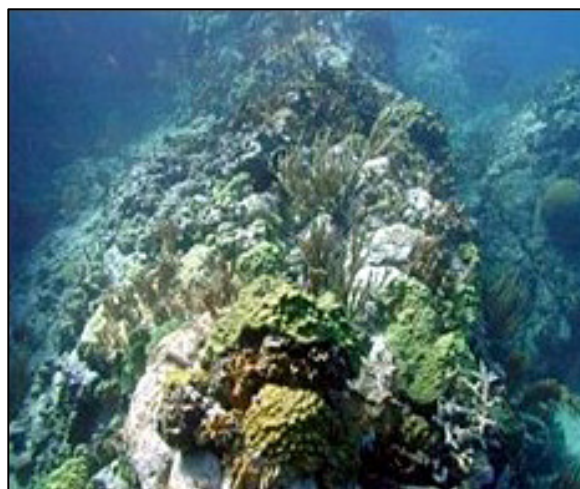
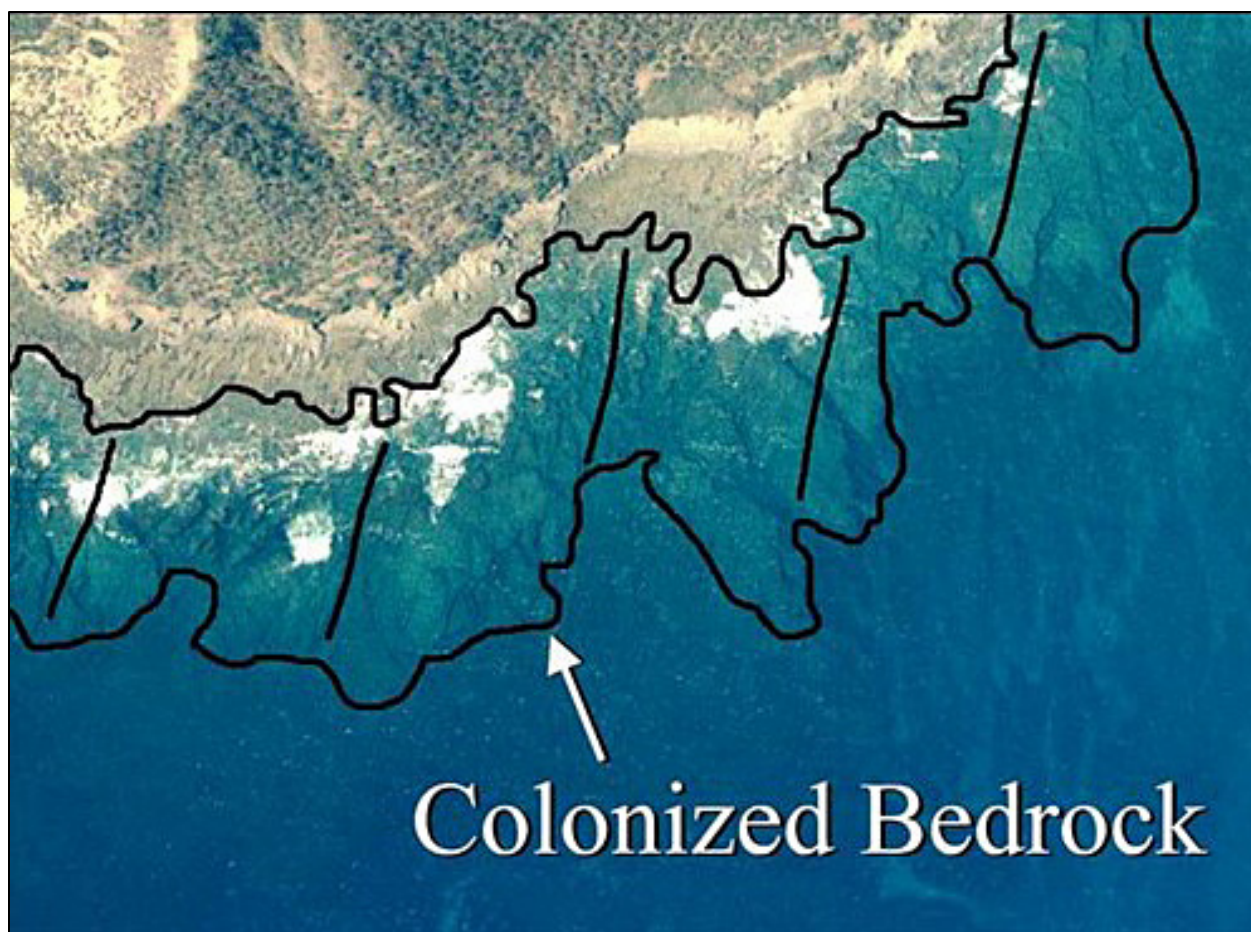


Figure B-5. Example of colonized bedrock.

Uncolonized Bedrock: Exposed bedrock contiguous with the shoreline that has sparse coverage of macroalgae, hard coral, gorgonians and other sessile invertebrates that does not obscure the underlying rock.



Figure B-6. Example of aerial view of uncolonized bedrock.



Figure B-7. Example of uncolonized bedrock.

Pavement: Solid carbonate rock that constitutes the majority of hard-bottom habitat on the Virgin Islands' shelf was classified as a general pavement category. The pavement category is a combination of colonized pavement, colonized pavement with sand channels, uncolonized pavement and uncolonized pavement with sand channels.

Colonized pavement: Flat, low-relief, solid carbonate rock with coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that are dense enough to partially obscure the underlying carbonate rock (Figure B-8).

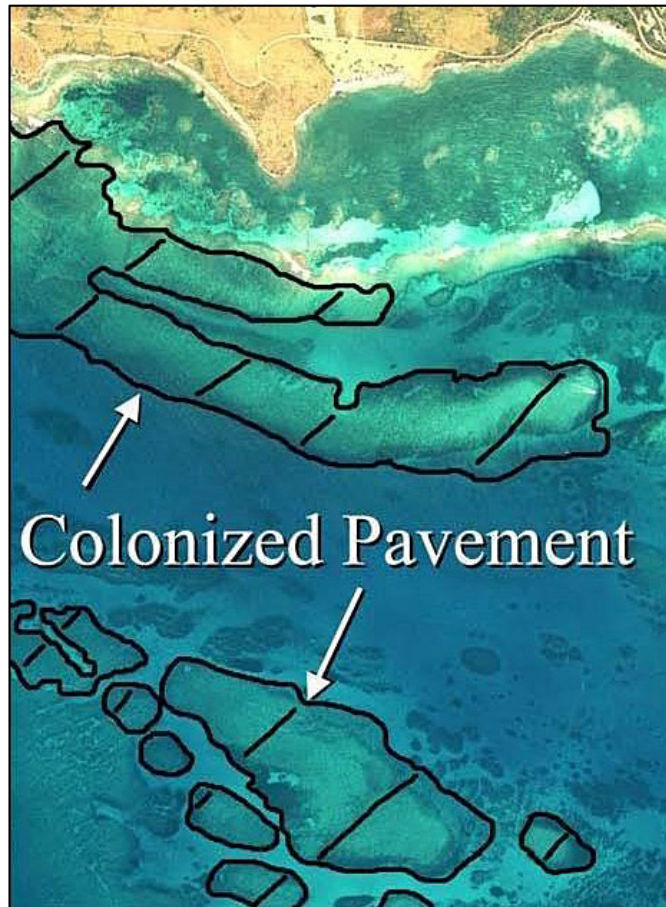


Figure B-8. Example of colonized pavement.

Colonized Pavement with Sand Channels: Habitat having alternating sand and colonized pavement formations that are oriented perpendicular to the shore or bank/shelf escarpment (Figure B-9). The sand channels of this feature have low vertical relief compared to spur and groove formations. This habitat type occurs in areas exposed to moderate wave surge such as that found in the bank/shelf zone.



Figure B-9. Example of aerial view of colonized pavement with sand channels.

Uncolonized pavement: Flat, low relief, solid carbonate rock that is often covered by a thin sand veneer (Figure B-10). The pavement's surface often has sparse coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that does not obscure the underlying carbonate rock.

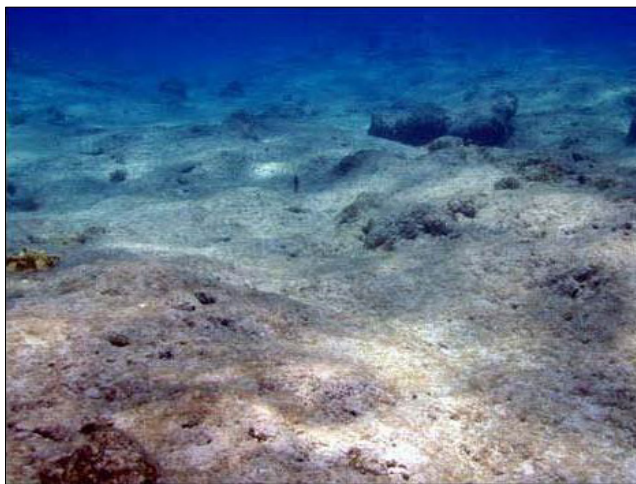


Figure B-10. Example of uncolonized pavement.

Uncolonized pavement with sand channels: Habitat having alternating sand and uncolonized pavement formations that are oriented perpendicular to the shore or bank/shelf escarpment (Figure B11). The sand channels of this feature have low vertical relief compared to spur and groove formations.



Figure B-11. Example of uncolonized pavement with sand channels.

Scattered coral/rock: This category is a combination of scattered coral/rock in unconsolidated sediment and reef rubble.

Scattered coral/rock in unconsolidated sediment: Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e., smaller than individual patch reef).

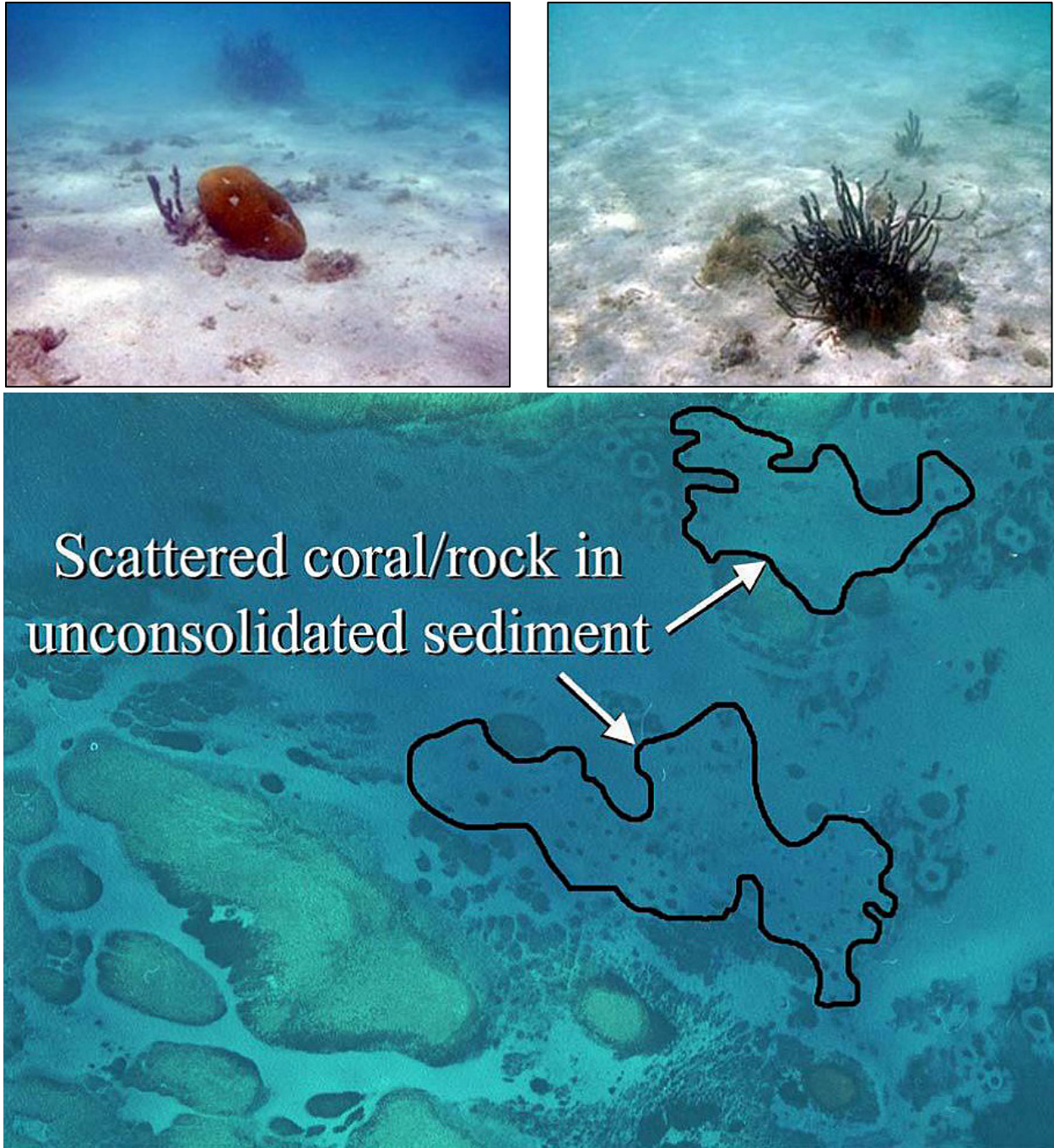


Figure B-12. Example of scattered coral/rock in unconsolidated sediment.

Literature Cited

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Appendix C. Glossary of Statistical Symbols of Computational Formulas (Adapted from Brandt et al. 2009)

Table C-1. Mean density, variance and allocation.

Symbol	Definition	Computational Formula	Equation Number
h	Stratum subscript	–	–
j	Sample unit subscript	–	–
D_j	Density in sample unit j	–	–
A_h	Stratum area	Total primary units in stratum h • 10,000 m ² (FL), Total primary units in stratum h • 2,500 m ² (USVI)	–
n_h	Number of units sampled in stratum h	–	–
N_h	Total possible number of sample units in stratum h	$N_h = \frac{A_h}{10,000 \text{ m}^2}$ (FL) $N_h = \frac{A_h}{2,500 \text{ m}^2}$ (USVI)	SOP 3.1
$\bar{D}_h$	Mean density in stratum h	$\bar{D}_h = \frac{1}{n_h} \sum_j D_{hj}$	SOP 7.1
$P(x : \lambda)$	Poisson distribution	$P(x : \lambda) = \frac{(e^{-\lambda})(\lambda^x)}{x!}$	SOP 7.2
x	Number of theoretical counts in Poisson distribution	–	
λ_h	Mean of Poisson distribution for stratum h	$\lambda_h = \bar{D}_h$	SOP 7.3
w_h	Stratum h weighting factor	$w_h = \frac{N_h}{\sum_1^h N_h}$	SOP 7.5
$\bar{D}_{st}$	Domain-wide mean density for a stratified random survey	$\bar{D}_{st} = \sum_h (w_h \bar{D}_h)$	SOP 7.4

Table C-2. Proportion of occurrence.

Symbol	Definition	Computational Formula	Equation Number
P_j	Occurrence in sample unit j	–	–
$\bar{P}_h$	Proportion of occurrence by stratum	$\bar{P}_h = \frac{1}{n_h} \sum_j P_{hj}$	SOP 7.6
$\bar{P}_{st}$	Domain-wide proportion of occurrence	$\bar{P}_{st} = \sum_h (w_h \bar{P}_h)$	SOP 7.7

Table C-3. Average size in exploited phase. The exploited phase includes lobsters with carapace lengths 3.5 inches (89 mm) or greater in the USVI or 3 inches (76 mm) or greater in FL.

Symbol	Definition	Computational Formula	Equation Number
L_{exp}	Carapace length of lobster in exploited phase	–	–
n_{exp}	Number of lobster in exploited phase	–	–
$\bar{L}_{exp}$	Average size in the exploited phase	$\bar{L}_{exp} = \frac{1}{n_{exp}} \sum L_{exp}$	SOP 7.8
L_{all}	Carapace length of all observed lobster	–	–
n_{all}	Number of all observed lobster	–	–
$\bar{L}_{all}$	Average size of all observed lobster	$\bar{L}_{all} = \frac{1}{n_{all}} \sum L_{all}$	SOP 7.9

Appendix D. 2017 Pilot Studies

Introduction

One lobster pilot study was conducted in Virgin Islands National Park in February and March of 2017, and a second pilot study was conducted in Biscayne National Park in May 2017. The two areas represent two fundamentally different lobster populations, which is why two separate pilot studies were conducted.

Both pilots were designed to answer several objectives:

1. Determine whether a transect size of 5×100 meter (16.4×328 ft) is feasible.
2. Determine the efficiency of using two or four divers to complete a survey.
3. Evaluate how many samples could be effectively collected in a day.
4. Evaluate capture of lobsters along a transect and determine whether it is an efficient use of time to capture them to record actual carapace length and relevant biological characteristics.
5. Determine whether snares or tickle sticks and nets were more effective at capturing lobster without injury.
6. See whether visual estimates of carapace length truly represented actual carapace lengths.
7. Evaluate the use of a Chainman[®] device instead of a conventional fiberglass transect tape for surveys.
8. Obtain variance values from a balanced sample allocation to provide a basis for future allocations given the stratified-random design.
9. Evaluate how many samples would potentially be needed to obtain a target coefficient of variation (CV) of 20% for relative density of exploited phase lobster.

The methods and results for each pilot study are described separately below. Then the results from both pilot studies are discussed together with respect to the above objectives.

Virgin Islands NP Pilot Study

Methods

This pilot study took place on February 21–22 and March 23–24, 2017; and used a mixture of divers from the South Florida/Caribbean Network (Lee Richter and Jeff Miller), Virgin Islands NP (Thomas Kelley, Adam Glahn, and Isabel Cardenas), and University of Virgin Islands (Tanya Ramseyer and Colin Howe). A subset of sites was chosen from the list of sites where fish and benthic surveys were completed during the 2015 National Coral Reef Monitoring Program survey in Virgin Islands NP. This subset was chosen to include a balance of sites in the ten strata found in Virgin Islands NP to allow for variance calculations and aid in future sample allocations.

At each site, two 5×100 meter (16.4×328 ft) transects were completed using a conventional fiberglass transect tape. One diver reeled out the transect tape over the target reef habitat and towed a GPS until 100 meters (328 ft) was reached. The second diver followed behind surveying for lobster 2.5 meters (8.2 ft) to the right of the transect. When the second diver completed their survey, they

would then reel up the tape and tow the GPS back to the origin, following the first diver who was surveying the 2.5-meter (8.2-ft) swath on the opposite side of the transect tape while swimming back to the origin. If a lobster was encountered, after visually estimating the carapace length, an attempt at capture using a snare was made. If the lobster was successfully captured, the actual carapace length and relevant biological characteristics were recorded.

At some locations, both transects were completed by a single team of two divers. At the remainder of the sites, each transect was completed by a separate dive team (two teams of two divers).

Results

A total of 17 sites were completed (34 transects) over the course of four days of field work. Sites were fairly balanced among strata, though no samples were collected in the Shallow, Hard-bottom or Deep, Pavement strata (Table D-1). There were not enough surveys in several of the strata to compute variance estimates. Habitat classes of different depths were combined (i.e. depth strata were pooled) in order to estimate occurrence, density, and abundance (Table D-2). Because there was only one survey completed in “Unknown Hard-bottom,” a fictional survey with no lobster seen was added to the stratum to enable calculation of relative indices of occurrence, density, and abundance. Considering that 28 of the 34 transects surveyed had no lobster, a survey with no lobster would have been a feasible outcome.

Table D-1. Summary statistics for strata surveyed in Virgin Islands NP lobster pilot 2017.

Zone	Stratum Classification	Total # Grid Cells	# Grid Cells Surveyed
Virgin Islands NP	Deep, Scattered coral/rock	69	1
Virgin Islands NP	Deep, Pavement	802	0
Virgin Islands NP	Deep, Bedrock	7	0
Virgin Islands NP	Deep, Patch reef	185	2
Virgin Islands NP	Deep, Linear reef	356	2
Virgin Islands NP	Deep, unknown hard-bottom	410	1
Virgin Islands NP	Shallow, Scattered coral/rock	248	2
Virgin Islands NP	Shallow, Pavement	1,186	2
Virgin Islands NP	Shallow, Bedrock	374	3
Virgin Islands NP	Shallow, Patch reef	122	1
Virgin Islands NP	Shallow, Linear reef	392	3
Virgin Islands NP	Shallow, unknown hard-bottom	22	0
Virgin Islands NP	TOTAL	4,173	17

Table D-2. Habitat classes of in different depth strata were combined in order to allow calculations of the relative indices of frequency of occurrence, density, and abundance. A minimum of two samples per stratum was needed to do this.

Zone	Stratum Classification	Total # Grid Cells	# Grid Cells Surveyed
Virgin Islands NP	Scattered coral/rock	317	3
Virgin Islands NP	Pavement	1,988	2
Virgin Islands NP	Bedrock	381	3
Virgin Islands NP	Patch reef	307	3
Virgin Islands NP	Linear reef	748	5
Virgin Islands NP	Unknown hard-bottom	432	2*
Virgin Islands NP	TOTAL	4,173	18*

*Only one sample was collected in the Unknown Hard-bottom stratum, so a fictional survey with zero lobster was included to allow calculations to commence.

Relative indices of frequency of occurrence, density (lobsters per hectare), abundance, and coefficient of variation (CV) were all calculated from the number of lobsters encountered in the surveys, including those that evaded capture (Table D-3). Proportion occurrence refers to the proportion of grid cells where at least one lobster was encountered, weighted by strata. Density refers to the number of lobsters per hectare. Abundance is calculated for the entire park unit, Virgin Islands NP. The CV was calculated using the density metric and is used as a guide for determining future sample allocation. Care should be taken when using the analyses from this dataset as it is based on a small number of lobster recorded ($n = 8$)

Table D-3. Relative indices of frequency of occurrence, density (lobsters per hectare), abundance, and coefficient of variation (CV) are reported here with $\pm$ standard error. The estimates here are based on all lobsters observed during the survey, including lobsters that evaded capture ($n = 8$). CV estimates were generated from density calculations.

Category	Frequency of occurrence	Density	Abundance	CV%
Total lobsters	0.20 ± 0.07	2.5 ± 0.9	$1,054 \pm 384$	36.5
Exploited phase	0.17 ± 0.07	2.0 ± 0.9	824 ± 355	43.1
Unexploited phase	0.06 ± 0.04	0.6 ± 0.4	229 ± 162	70.8

A length-frequency diagram for all lobsters observed on a transect (including those that evaded capture) is presented in Figure D-1. No length-frequency diagram is provided for males and females because of the small sample size ($n = 3$).

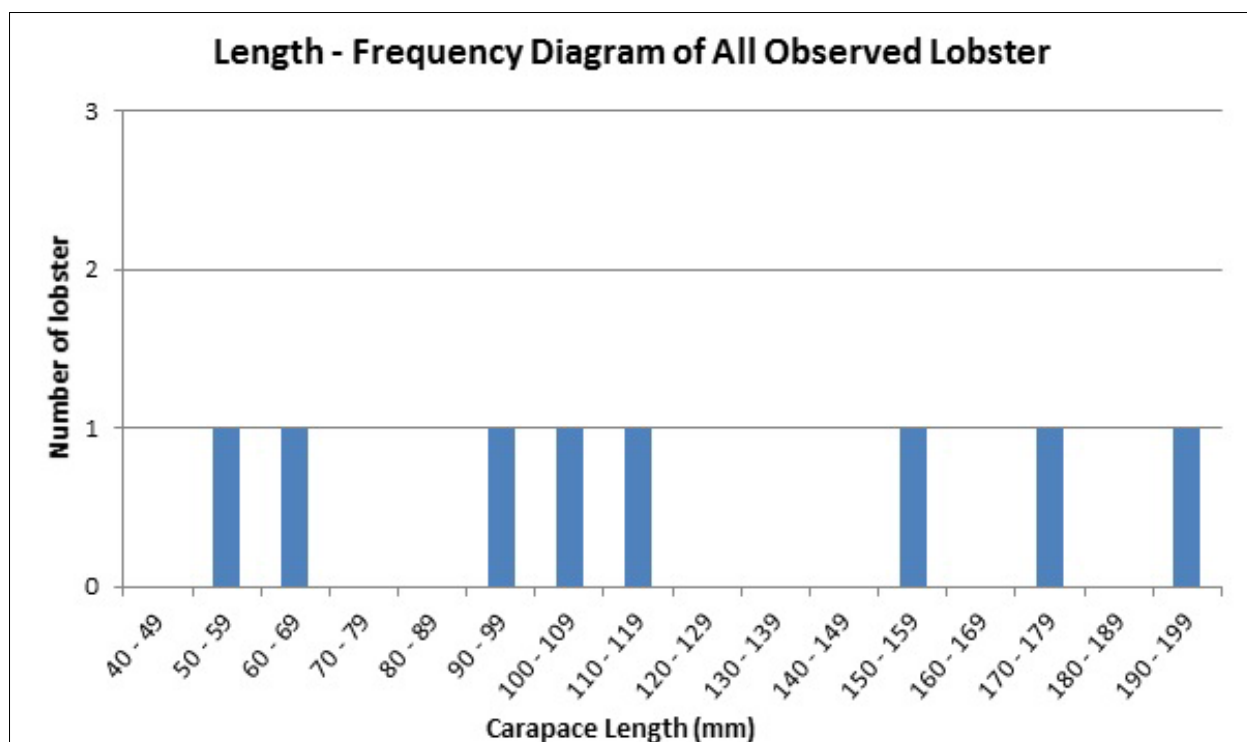


Figure D-1. Length-frequency diagram for all lobsters observed in the Virgin Islands NP pilot survey, including those that evaded capture.

Only lobsters that were caught were included in descriptive analyses for maximum carapace length, average carapace length, sex ratio, molt stage ratio, prevalence of females with eggs, prevalence of females with a spermatophore, and prevalence of PaV1 (Table D-4). While the analyses are included here, they should be interpreted extremely cautiously because of the small sample size ($n = 3$).

Table D-4. Descriptive analyses of captured lobster. Actual carapace lengths, sex, molt stage, presence of eggs and/or spermatophore, and presence of PaV1 were only recorded when lobsters were caught. Only metrics for captured lobster are included below ($n = 3$).

Metric	Result
Total sites completed	17
Total lobster observed	8
Total lobster captured	3
Max carapace length	190 mm
Mean carapace length (exploited phase)	143 mm
Sex Ratio (Males : Females)	1 : 2
Molt Stage Ratio (Pre : Inter : Post)	0 : 1 : 0

Table D-4 (continued). Descriptive analyses of captured lobster. Actual carapace lengths, sex, molt stage, presence of eggs and/or spermatophore, and presence of PaV1 were only recorded when lobsters were caught. Only metrics for captured lobster are included below (n = 3).

Metric	Result
Prevalence of females with eggs	100.00%
Prevalence of females with spermatophore	0.00%
Prevalence of PaV1	0.00%

No *t*-test was performed to compare visual estimates to actual recorded carapace lengths of lobster because the sample size was so small (n = 3). For the lobsters caught, the estimated lengths were 100, 160, and 170 millimeters (3.9, 6.3 and 6.7 inches [in]) and the measured lengths were 110, 190, and 150 millimeters (4.3, 6.3, and 5.9 in) respectively.

Biscayne National Park Pilot Study

Methods

This pilot took place on May 2–4 and May 23, 2017; and used divers from the South Florida/Caribbean Network (Mike Feeley, Andy Davis, Rob Waara, Erin Nassif, and Elissa Connolly-Randazzo) and Biscayne NP (Vanessa McDonough, Mike Hoffman, Kelsy Armstrong, Shelby Moneysmith, Arend Thibodeau, and Brett Lear). Two boats were used to collect data during this pilot, though each boat was only able to conduct field work for three days. A subset of sites was chosen from the list of sites where fish and benthic surveys were completed in Biscayne NP during the multi-agency, Florida Keys-wide survey effort in 2016. This subset was chosen to include a balance of sites in the six strata found in Biscayne NP to allow for variance calculations and aid in future sample allocations.

At each site, two 5 × 100 meter (16.4 × 328 ft) transects were completed using either Chainman® or a conventional fiberglass transect tape. If a lobster was encountered, after visually estimating the carapace length, an attempt at capture using a tickle stick and net was made. If the lobster was successfully captured, the actual carapace length and relevant biological characteristics were recorded.

At some locations, both transects were completed by a single team of two divers. At the remainder of the sites, each transect was completed by a separate dive team (two teams of two divers).

Results

A total of 28 sites were completed (56 transects) over the course of the pilot. Sites were fairly balanced among strata, though no samples were collected in the Inshore Patch Reef stratum (Table D-5). Relative indices of frequency of occurrence, density, and abundance estimates exclude the Inshore Patch Reef stratum (Table D-6).

Table D-5. Summary statistics for strata surveyed in Biscayne NP lobster pilot 2017. No surveys were completed in the Inshore, Mid-relief isolated reef stratum. This stratum was omitted from further analyses.

Zone	Stratum Classification	Total # Grid Cells	# Grid Cells Surveyed
Biscayne NP	Inshore, Mid-relief isolated reef	186	0
Biscayne NP	Mid-channel, Mid-relief isolated reef	4,783	8
Biscayne NP	Offshore, Mid-relief isolated reef	734	5
Biscayne NP	Forereef, Low-relief, (0 - 6 m)	426	3
Biscayne NP	Forereef, Low-relief, (6 - 18 m)	3,180	5
Biscayne NP	Forereef, High-relief spur and groove	191	7
Biscayne NP	TOTAL	9,500	28

Table D-6. Relative indices for frequency of occurrence, density (lobsters per hectare), abundance, and CV with $\pm$ standard error. The estimates here are based on all lobsters observed during the survey, including lobsters that evaded capture ($n = 78$). CV estimates were generated from density calculations.

Category	Frequency of occurrence	Density	Abundance	CV%
Total lobsters	0.64 ± 0.12	30.2 ± 11.3	$28,108 \pm 10,565$	37.6
Exploited phase	0.50 ± 0.11	11.9 ± 3.2	$11,081 \pm 3,002$	27.1
Unexploited phase	0.44 ± 0.13	18.1 ± 8.9	$16,858 \pm 8,301$	49.2

Relative indices for frequency of occurrence, density (lobsters per hectare), abundance, and CV were all calculated from the total number of lobsters encountered in the surveys, including those that evaded capture (Table D-3). Frequency of occurrence refers to the proportion of grid cells where at least one lobster was encountered, weighted by strata. The relative density index refers to the number of lobsters per hectare. The relative abundance index is calculated for the entire park unit, Virgin Islands NP. The CV was calculated using the relative density metric and is used as a guide for determining future sample allocation.

A length-frequency diagram for all lobsters observed on a transect (including those that evaded capture) is presented in Figure D-2. A second length-frequency diagram is included for captured lobsters where sex was recorded (Figure D-3).

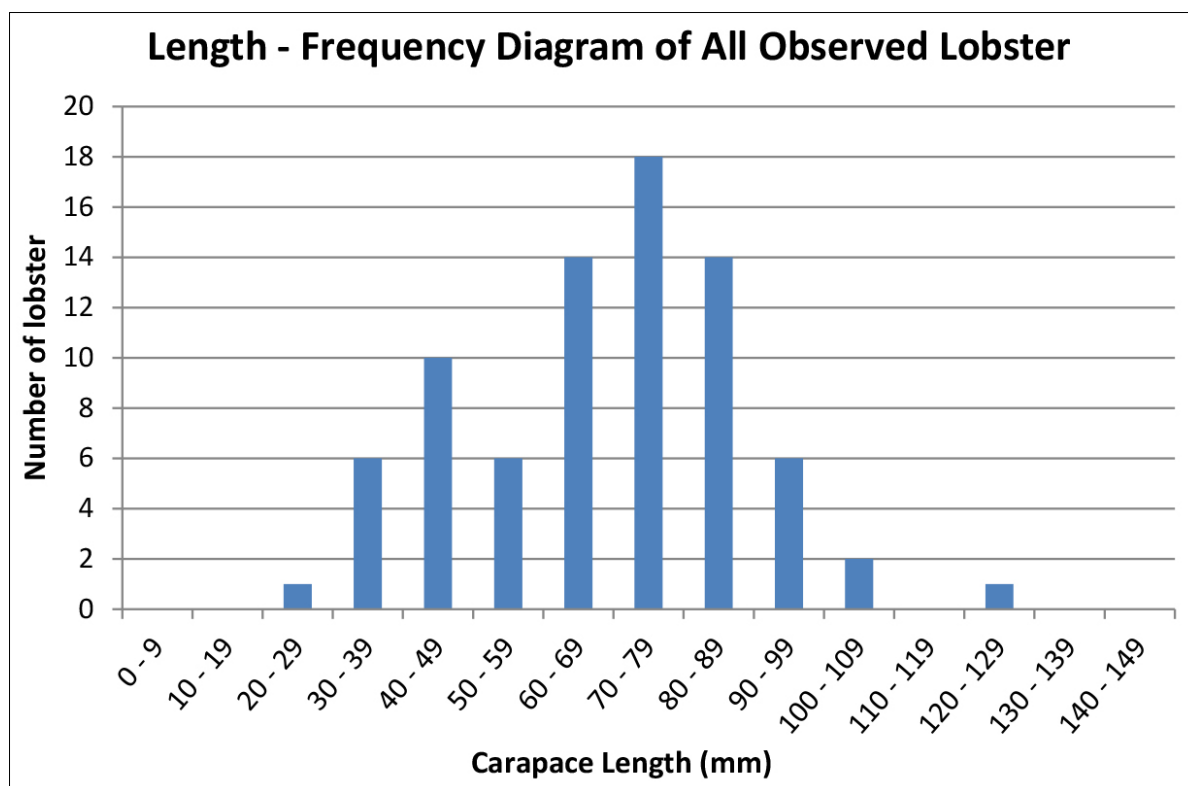


Figure D-2. Length-frequency diagram for all lobsters observed in the Biscayne NP pilot survey, including those that evaded capture.

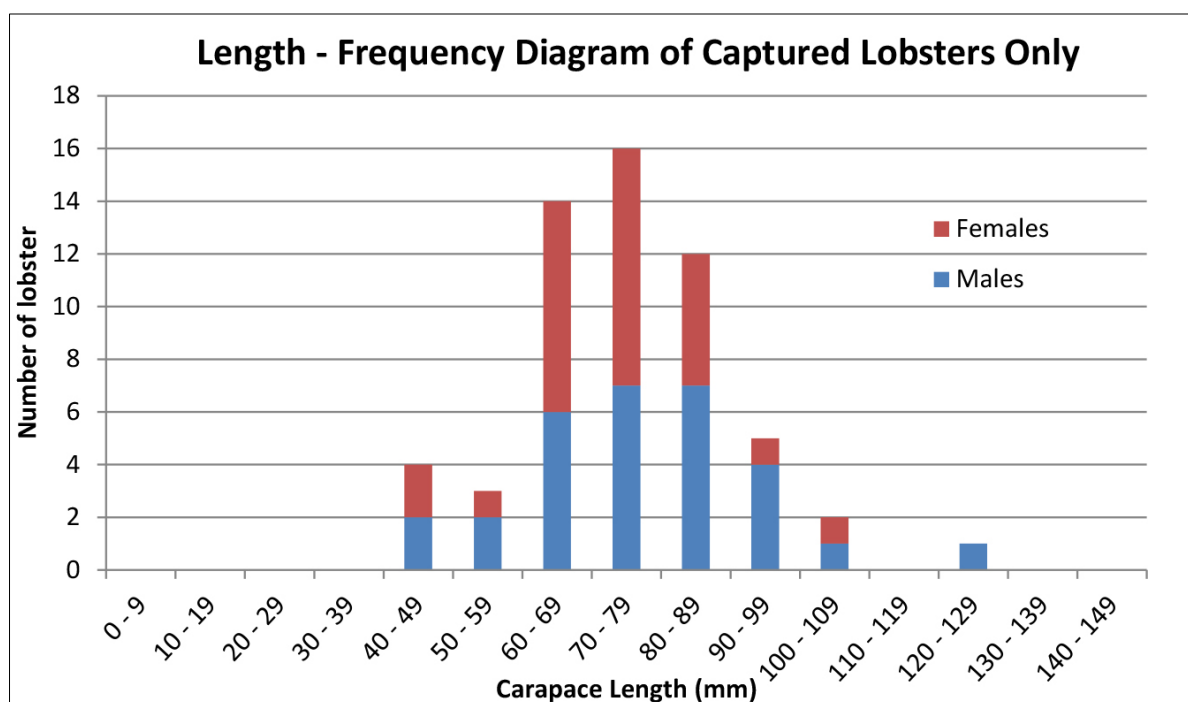


Figure D-3. Length-frequency diagram for all lobsters that were successfully captured and sex recorded in the Biscayne NP pilot survey.

Of the total 78 lobsters observed, only 57 were caught, resulting in a 73% capture success rate by surveyors. Only lobsters that were caught were included in descriptive analyses for maximum carapace length, average carapace length, sex ratio, molt stage ratio, prevalence of females with eggs, prevalence of females with a spermatophore, and prevalence of PaV1 (Table D-7).

Table D-7. Descriptive analyses of captured lobster. Actual carapace lengths, sex, molt stage, presence of eggs and/or spermatophore, and presence of PaV1 were only recorded when lobsters were caught. Only metrics for captured lobster are included below (n = 57).

Metric	Result
Total sites completed	28
Total lobster observed	78
Total lobster captured	57
Max carapace length	127 mm
Mean carapace length (exploited phase)	87 mm
Sex Ratio (Males : Females)	13 : 12
Molt Stage Ratio (Pre : Inter : Post)	*
Prevalence of females with eggs	70.4 %
Prevalence of females with spermatophore	81.5 %
Prevalence of PaV1	13.2 %

*This metric wasn't adequately explained prior to the pilot and the data collected is not representative of the actual sample.

A *t*-test was used to determine whether a significant difference existed between estimated carapace lengths and actual carapace length measurements after a lobster was successfully captured (Table D-8). A total of 51 lobsters had both visual estimates and actual carapace length measurements recorded. The test showed that while not statistically significant ($p = 0.070$), a mean visual estimate of 67.4 millimeters (2.6 in) was recorded when mean actual size was 73.5 millimeters (2.8 in). This *t*-test pooled all observers. Upon closer inspection, the nearly significant difference could be explained by one observer who significantly ($p = 0.02$) under estimated the sizes of lobster, and recorded approximately one-third of the total lobster seen. A linear fit of the pooled lobster carapace data from Virgin Islands NP and Biscayne NP had an $r^2 = 0.44$ (Figure D-4).

Table D-8. A t-test was used to compare visual estimates of carapace length on lobster to the recorded actual size. All observers were pooled. Though not significant ($p = 0.070$), estimates were typically lower than the actual size recorded.

Parameter	Visual estimate	Actual size
Mean	67.4	73.5
Variance	310.0	260.6
Observations	51	51
t Stat	-1.829	—
p-value	0.070	—

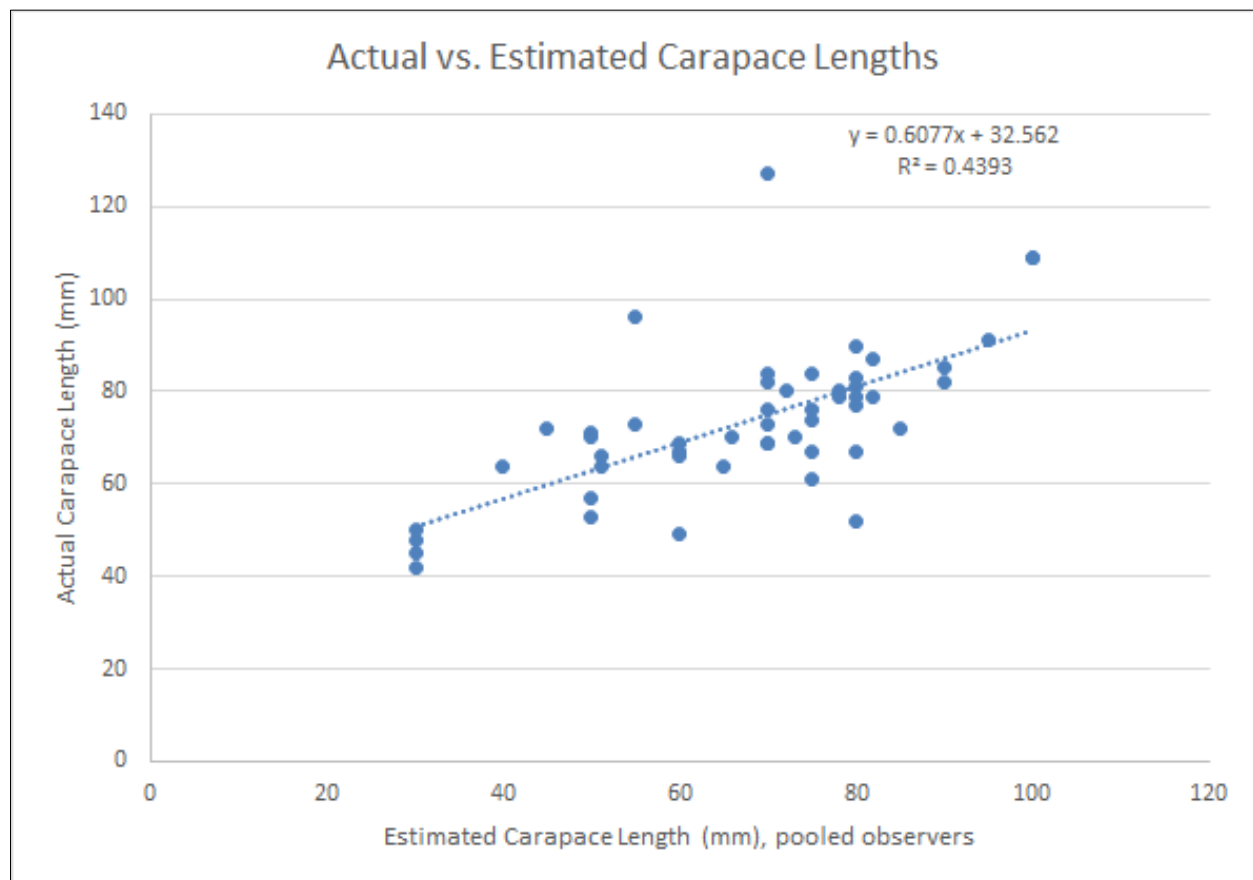


Figure D-4. Measured versus estimated carapace lengths (mm) of lobster captured in Virgin Islands NP and Biscayne NP during the 2017 pilot study.

Discussion

Both pilot studies revealed some important information for guiding further sampling in Florida and the U.S. Virgin Islands. Lobster densities are approximately an order of magnitude larger in Biscayne NP than in the Virgin Islands NP. This may create some challenges for surveys done in the U.S.

Virgin Islands in the future. The small number of captured lobsters in the Virgin Islands NP pilot made it difficult to calculate any meaningful descriptive analyses. The lobsters seen in Virgin Islands NP, though more infrequent, were typically larger than those seen in Biscayne NP. Specific objectives of the pilot survey are discussed below.

Is the Transect Size of 5 × 100 meters (16.4 × 328 ft) Appropriate?

The transect size of 5 × 100 meters (16.4 × 328 ft) worked well. We were able to survey an area of that size at a variety of depths. The transect size was large enough to limit the number of non-detections in the dataset, but small enough to be repeatable to keep the number of samples relatively high. The pilot study in Virgin Islands NP had many non-detections in the data set, but still allowed density calculations to proceed within an acceptable level of variance. A larger transect size would likely be helpful for the Virgin Islands sites, but time and budgetary limitations would probably make the collection of a high enough number of samples difficult. The 2.5-meter (8.2-ft) width of the transect that each diver was responsible for was narrow enough to allow for a thorough search for lobster. Knowing the exact 2.5-meter (8.2-ft) width was not necessary throughout the transect, except for when a lobster was encountered. In these situations, the distance from the transect could be easily measured to determine whether the lobster was in fact inside the transect. It was feasible for one or two teams of divers to complete two replicates of the 5 × 100-meter (16.4 × 328-ft) transects at each site. However, upon reviewing the GPS tracks following the survey, the transects almost always extended outside the primary sampling unit (i.e., grid cell). This has the potential to complicate analyses and allocation. An alternative method, but comparable in size, that remains within the primary sampling unit should be considered.

Is Two or Four Divers be Preferable to Complete a Survey?

Two teams of two divers could complete a site more efficiently than one team of two divers. Completing the transects more quickly helped reduce bottom-time issues at deeper survey sites. When possible, surveys should deploy four divers (two teams of two divers) at a site.

How Many Samples can be Conducted in a Day?

In the Virgin Islands NP pilot, four to five samples were completed in a given day. New divers helped with the sampling on each day, which necessitated time in the beginning of the day to explain the methods. Two of the divers were required to use closed-circuit rebreathers. Rebreathers are great tools for prolonged deeper dives, but are inefficient for multiple, shorter dives.

In the Biscayne NP pilot, between four and seven samples were completed each day. These numbers are likely a more realistic estimate of the number of samples that can be collected in a day. When divers are already accustomed to the survey methods, more samples are generally possible in a day as well.

Is It an Efficient Use of Time to Capture Lobsters to Record Relevant Biological Characteristics?

In both pilot surveys, if a lobster was observed, an attempt at capture was made to record biological characteristics. Originally, the suggested standard survey approach was to only record visual estimates of carapace length and not to capture the lobster to record actual carapace length and

biological condition. Reducing the amount of time spent on a given sample could then increase the possible number of samples, making the key metrics of density and abundance potentially more accurate and precise. However, during the surveys, it was decided that the time spent on a survey to capture a lobster in order to measure actual carapace length and biological condition was more beneficial than increasing the sample size for a more precise density estimate. Furthermore, once a lobster was found on a transect, the time spent to capture it and record the relevant metrics was minimal.

Are Snares or Tickle Sticks more Effective for Capturing Lobster?

Tickle sticks and nets appear to be the more effective tools for these surveys. The capture success rate for tickle sticks and nets (Biscayne NP) was 73% versus a 38% success rate when using a snare (Virgin Islands NP). Using a net provides the added benefit that the lobster can be measured and assessed while still inside the net, reducing the possibility of escape once captured. Using a snare on a female that is carrying eggs could be potentially damaging.

Do Visual Estimates of Carapace Length Accurately Represent Actual Carapace Length?

Only the Biscayne NP pilot had enough lobsters caught to compare visual estimates to actual carapace length. A *t*-test where all observers were pooled showed that the difference seen was not significant ($p = 0.07$), though it was close to significant. Upon closer inspection, this was driven primarily by one observer who recorded nearly one third of the lobster observed and consistently underestimated the sizes. In such cases where an observer is consistent in their visual estimates (either underestimates or overestimates), the use of a correction factor should be considered. The observer should also review their own collected data following sampling to calibrate themselves.

Primarily, the accuracy of visual estimates of carapace length is a variable among surveyors. Proper training and experience can increase the accuracy of visual estimates over time. Some observers may tend to underestimate sizes where some may tend to overestimate. A comparison between visual estimates and actual carapace length measurements should be made periodically for each observer. Actual carapace length measurements should be used first and visual size estimates used only as a backup.

Chainman® vs. Conventional Transect Tape

The Chainman® device is a tool used by the Torres Strait rock lobster monitoring program. It uses a biodegradable thread and a meter counter to measure how far a surveyor travels. Once the surveyor reaches the endpoint of a transect, the thread is then cut and left to decompose. The primary benefit of using a Chainman® device is that the surveyor does not have to swim back over the surveyed area, as a surveyor would if using the conventional transect tape. A Chainman® device was tested during the Biscayne NP pilot and unsurprisingly, surveys were completed more quickly than if a conventional fiberglass transect tape was used. A drawback of using the Chainman® however is that a line of thread is left on the seafloor to decompose. The effect of leaving the thread on the bottom is not well known, though it is believed to degrade within months without noticeable damage (D. Dennis, pers. comm., CSIRO, October 25, 2016). However, the decision to use the Chainman® should be up to the park unit in which lobster surveys are to be completed. If the park unit approves its use, samples may be completed with greater efficiency.

How Many Samples are Necessary to Obtain a Target CV of 20%?

The section, Change Detectable, under Sampling Design, summarizes the sampling effort necessary to achieve a CV of 20% for relative density of exploited phase lobsters based on the pilot surveys. From analyses of the survey data, approximately 26 sites would be needed in Biscayne NP and 53 sites in Virgin Islands NP in order to achieve a CV of 20% (Figure 6 and Figure 7). However, in both Virgin Islands NP and Biscayne NP, samples could have been balanced more appropriately. In Virgin Islands NP, the depth strata were combined in order for analyses to continue and a fictional sample added to the “unknown hard-bottom” stratum in order to achieve a CV estimate. The 53 samples calculated to achieve a CV of 20% in Virgin Islands NP likely underrepresents the number of samples actually needed to achieve the target CV. Similar, in Biscayne NP, no samples were completed in the “inshore patch reef” stratum. Analyses were done without including this stratum. For Biscayne NP, the 26 samples calculated to achieve a CV of 20% also likely underrepresents the number of samples actually needed to achieve the target CV. Regardless, the greater number of samples completed will only improve precision and reduce the CV. It is suggested that when these areas are sampled again, the sample size should be increased substantially. This will not only improve the precision of the data but allow for more optimal sample allocations.

Future Sample Locations

In both pilot studies, there was an attempt to obtain a balanced sample allocation among strata. However, in both cases, the number of samples in each stratum was fairly low, which can lead to a potentially inaccurate optimal sample allocation for the next sample event. It is suggested that the next sampling event in each region still try and attempt an evenly balanced sample allocation among strata but increase the number of samples collected within each stratum substantially. Particularly for the first real sampling event, oversampling would help optimize future sample allocations and also produce a reduced CV for a baseline.

Appendix E. Data Quality Standards for Long-term Monitoring of Caribbean Spiny Lobster (*Panulirus argus*)

Contents

	Page
Tables	E-1
Introduction.....	E-2
Protocol Overview.....	E-2
Protocol Activities and Modules	E-3
Sampling Design	E-4
Data Quality Objectives.....	E-6
Literature Cited	E-9

Tables

	Page
Table E-1. Protocol activity matrix for the <i>Long-term monitoring protocol of Caribbean Spiny Lobster (Panulirus argus)</i> (this document).....	E-3
Table E-2. Activity-level sample design matrix for <i>protocol of Caribbean Spiny Lobster (Panulirus argus)</i> (this document). <i>Long-term monitoring</i>	E-5
Table E-3. Data Quality Values (DQVs) for <i>Long-term monitoring protocol of Caribbean Spiny Lobster (Panulirus argus)</i> (this document).....	E-6
Table E-4. Measurement Quality Objectives for <i>Long-term monitoring protocol of Caribbean Spiny Lobster (Panulirus argus)</i> (this document).....	E-7
Table E-5. Taxonomic standards to be used in <i>Long-term monitoring protocol of Caribbean Spiny Lobster (Panulirus argus)</i> (this document).....	E-8
Table E-6. Data Protection standards for <i>Long-term monitoring protocol of Caribbean Spiny Lobster (Panulirus argus)</i> (this document). With the exceptions noted, all data collected are to be made publicly available in a timely fashion.	E-9

Introduction

The purpose of this report is to document the standards, used by the South Florida/Caribbean Network for activities related to the collection, processing, storage, analysis, and publication of monitoring data as described in the *Long-term Monitoring Protocol of Caribbean Spiny Lobster* (*Panulirus argus*; this document). The policies and procedures documented in this quality-assurance plan for activities complement the quality-assurance plans for other monitoring activities conducted by the South Florida/Caribbean Network and supplement the National Inventory & Monitoring Division Quality Management Plan (in development). The plan also serves as a guide for all South Florida/Caribbean Network personnel who are involved in protocol or program activities and as a resource for identifying memoranda, publications, and other literature that describe associated techniques and requirements in more detail.

Protocol Overview

The *Long-term Monitoring Protocol of Caribbean Spiny Lobster* (*Panulirus argus*): *Protocol Narrative* provides a technical background and detailed description of monitoring and assessment methods for Caribbean spiny lobster populations in Florida and the United States Virgin Islands (USVI). The protocol draws strongly from the SFCN reef fish monitoring protocols for Florida and the Virgin Islands (Brandt et al. 2009; Bryan et al. 2013), and from the findings of a 25-year long lobster (*Panulirus ornatus*) monitoring program in Torres Strait, Australia (Pitcher et al. 1992; Ye et al. 2004; Ye et al. 2005; Ye et al. 2007; Plagányi et al. 2010; Plagányi et al. 2015). The goal of this monitoring protocol is to build a statistically robust and cost-effective monitoring program with methods applicable at the park level. Estimates of population level metrics such as a relative density index and average length are used to inform park managers of the status of spiny lobster within their park boundaries and evaluate any potential management actions.

The Caribbean spiny lobster is one of the most economically important fisheries in both Florida and the USVI. The crustacean is under substantial recreational and commercial fishing pressure in the regions and in some cases within park boundaries. The monitoring methodologies described in this document will allow us to understand the status and trends of spiny lobster populations in the parks. This knowledge is critical for informed sustainable management.

The monitoring program objectives focus on tracking population level changes in a relative density and abundance indices, relative frequency of occurrence, average size, and biological condition of spiny lobster and using these metrics to assess changes through time. Changes in these metrics can be evaluated after each survey season and with respect to habitat features, physical environment, and management actions.

Survey sites are selected from a gridded sample frame using a stratified random sample design with optimal sample allocation. Florida parks (Biscayne National Park and Dry Tortugas National Park) use the 100 × 100-meter (328 × 328-foot [ft]) sample grid from *A Cooperative Multi-Agency Reef Fish Monitoring Protocol for the Florida Keys Coral Reef Ecosystem* (Brandt et al. 2009). The USVI parks (Buck Island Reef National Monument, Salt River Bay National Historical Park and Ecological Preserve, and Virgin Islands National Park) use the 50 × 50-meter (164 × 164-ft) sample grid from *A*

Cooperative Multiagency Reef Fish Monitoring Protocol for the U.S. Virgin Islands Coral Reef Ecosystem (Bryan et al. 2013).

Field methods for lobster surveys consist of one set of paired 7.5-meter (24.6-ft) radius circular plots per site. Lobsters are counted and sizes estimated in each plot. Lobsters are then captured and biological conditions (e.g., sex, presence of eggs) are recorded. The lobsters are then released. Surveys take place entirely inside park boundaries, unless a park specifically requests that surveys are completed in nearby areas outside the park for comparison.

Protocol Activities and Modules

Data are collected or derived as a part of the *Long-term Monitoring Protocol of Caribbean Spiny Lobster* (*Panulirus argus*; this document) in 15 different activities or modules (Table E-1).

Table E-1. Protocol activity matrix for the Long-term Monitoring Protocol of Caribbean Spiny Lobster (*Panulirus argus*; this document).

Category	Activity number	Activity	Description
Site Recon, Establishment, and Maintenance	1	Sampling frame, strata, and site selection	Shapefiles of sampling frame and strata, number of total cells available within each strata, and number of cells sampled each year are documented. Sites are re-randomized during each sampling event and selected according to Richter et al. (2018). Sites visited once. No physical markers left in field.
Field Observations	2	Event data / boat log	Dive-of-day, Site ID, Estimated Time, Dive team, location, target habitat type, GPS/Flag #, and surface-data-collector comments.
	3	Lobster plot measurements	In submerged 7.5-meter (24.6-ft) radius circular plots divers record habitat type, substrate, surface relief, and visibility.
	4	Lobster individual measurements	In submerged 7.5-meter (24.6-ft) radius circular plots divers count and capture (and release) lobsters, estimate carapace length, measured carapace length, and record sex, molt stage, presence of eggs, and presence of spermatophore.
Sensor Data	5	GPS location	A GPS attached to a towed dive flag is used to record the position of the paired circular plots. Logging interval (tracks) set to one point every 10 seconds.
	6	Habitat photos (4)	Four photos taken at each site to help characterize habitat type
	7	Egg clutch photo	Only taken for captured individuals with eggs present
	8	Spermatophore photo	Only taken for captured individuals with spermatophore present

Table E-1 (continued). Protocol activity matrix for the Long-term Monitoring Protocol of Caribbean Spiny Lobster (*Panulirus argus*; this document).

Category	Activity number	Activity	Description
Derived Data	9	Relative Density and Abundance Indices	Average relative density of spiny lobster per hectare and estimated relative abundance within and across strata (based on raw counts unadjusted for detection probability)
	10	Relative Frequency Index	Relative proportion of sites with spiny lobster present within and across strata (based on raw counts unadjusted for detection probability)
	11	Average size	Average size of exploited phase lobsters captured and of total lobsters captured
	12	Sex ratio	Ratio of captured male / captured female lobster
	13	Molt stage ratio	Ratio of pre-molt captured lobster / inter-molt captured lobster / post-molt captured lobster
	14	Proportion females with eggs	Proportion adult captured females with eggs
	15	Proportion females with spermatophores	Proportion adult captured females with spermatophores

Sampling Design

Information regarding the sampling design is provided in Table E-2.

Table E-2. Activity-level sample design matrix for *Long-term monitoring Protocol of Caribbean Spiny Lobster* (*Panulirus argus*; this document).

Category	Activity Number	Activity	Sampling Design	Revisit Design
Site Recon, Establishment, and Maintenance	1	Sampling frame, strata, and site selection	Probability: stratified random selection across mapped hard-bottom habitat. Sites are randomized each sampling period and may be co-located with fish monitoring sites following the same sampling design when statistically valid.	Re-randomized sample every fourth year
Field Observations	2	Event data / Boat Log	Same as Activity 1	Same as Activity 1
	3	Lobster plot measurements	Paired 7.5-meter (24.6-ft) radius circular plots on target habitat first encountered in grid cell. This is used to determine habitat type (and appropriate stratum) in which the survey took place.	Same as Activity 1.
	4	Lobster individual measurements	Targeted: Attempted capture of all lobsters detected within plots.	None; individual lobsters captured as encountered
Sensor Data	5	GPS location	Same as Activity 1	Same as Activity 1
	6	Habitat photos (4)	Same as Activity 3	Same as Activity 3
	7	Egg clutch photo	Targeted: Photos taken when individual lobsters with egg clutches are encountered.	Same as Activity 4
	8	Spermatophore photo	Targeted: Photos taken when individual lobsters with egg clutches are encountered.	Same as Activity 4

Data Quality Objectives

Data quality values and standards for implementation are provided in Table E-3 through Table E-6.

Table E-3. Data Quality Values (DQVs) for *Long-term monitoring protocol of Caribbean Spiny Lobster (Panulirus argus)* (this document).

Category	Data Quality Value	Definition	Protocol Considerations
Intrinsic Data Quality	Accuracy	Measurements reflect the true value of the parameter being observed. This applies to measures (length, width, position) or classes (species, types, or categories). Includes components of precision and bias.	Before each sampling season, lobster project leader will conduct a training session for surveyors in office followed by in-field training for species identification, size estimation calibration, and assessment of biological condition.
	Representativeness	Measurements represent conditions at the time of sampling. Combined with accuracy, leads to repeatable data collection.	Sample sites are randomly selected within each strata within the sampling domain.
Contextual Data Quality	Comparability	The degree to which data can be compared among sample locations, data sources, or periods of time.	All sample locations are monitored following the schedule and methods outlined within this document and associated SOPs.
	Timeliness / Currency	How recent the data need to be to be considered valid for their intended use. Data represents conditions and/or is available and in a format for use at the appropriate time in the decision-making process.	Data entry occurs within a month after field sampling. Reporting target is to complete data summary report by the end of the calendar year as described in this document.
	Completeness	All data/ measures required to evaluate accuracy representativeness are present; incomplete data sets (either at a location, across sampling locations, or over time) lose utility or relevance. Data records contain values as planned across the period of record.	Sample sites are re-selected and re-randomized each sample year. All sampling locations are monitored following the methods described in this document. Some lobsters are not detected in plots, but it is assumed that non-detection is a random occurrence (potentially varying by habitat type) that will not affect the comparability of data over time. Some lobsters will be seen but not caught, and it is assumed that this is a rare and random event that does not affect derived metrics.

Table E-3 (continued). Data Quality Values (DQVs) for *Long-term monitoring protocol of Caribbean Spiny Lobster (Panulirus argus)* (this document).

Category	Data Quality Value	Definition	Protocol Considerations
Representational Data Quality	Consistent Representation	Use of standard definitions when describing data quality or resource quality based on data	Data quality is defined as “fit for analysis” or “not fit for analysis.” Data collection should occur during similar time of year to reduce effect of seasonal variation on data collection.
Data Accessibility	Secure	Access to data, products, and systems limited to appropriate audiences.	Certified (QA/QCed) data and products generated from this monitoring effort will be available to the public via IRMA with the exception that monitoring locations will be obscured.

Table E-4. Measurement Quality Objectives for *Long-term Monitoring Protocol of Caribbean Spiny Lobster (Panulirus argus)*; this document).

Category	Measure / Quality Indicator	Quality Objective
Sampling Frame, strata, and site selection	Location Accuracy	± 5 meters (16.4 feet [ft])
Lobster plot measurements	Habitat type	100% agreement between the two surveyors
	Abiotic footprint	± 10% for each value (sand, rubble, hard-bottom)
	Surface relief coverage	± 10% for each bin
	Visibility	± 3 meters (9.8 ft)
	% Plot = Habitat	± 10%
	Slope	± 1 meter (3.3 ft)
Lobster individual measurements	Taxonomic Resolution	Identifications made to the species level
	Identification Accuracy	100% accuracy for visual observations
	Identification Completeness	100% of observations made to species level
	Carapace length estimate	± 20 millimeters (0.8 inches [in])
	Carapace length measurement	± 5 millimeters (0.2 in)
	Sex designation	90% accuracy for visual assessment
	Molt designation	90% accuracy for visual assessment

Table E-4 (continued). Measurement Quality Objectives for *Long-term Monitoring Protocol of Caribbean Spiny Lobster (Panulirus argus; this document)*.

Category	Measure / Quality Indicator	Quality Objective
Lobster individual measurements (continued)	Egg presence and condition	100% accuracy for visual assessment
	Spermatophore presence and condition	90% accuracy for visual assessment
	Distance to edge	± 3 meters (9.8 ft)
GPS Location	Location Accuracy	Plots occur within target grid cell GPS path within ±4 meters (13.1 ft).

Table E-5. Taxonomic standards to be used in *Long-term Monitoring Protocol of Caribbean Spiny Lobster (Panulirus argus; this document)*.

Activity #	Options	Activity	Standard to be Used	Reference / Authority
3	Collection of Observational Data	Lobster plot measurement (habitat classification)	Scientific Publication	System of Classification of Habitats in Estuarine and Marine Environments (Madley et al. 2002); Methods Used to Map the Benthic Habitats of Puerto Rico on the U.S. Virgin Islands (Kendall et al. 2001)
4	Collection of Observational Data	Lobster individual measurements (lobster identification)	Scientific Publication	Reef Creature Identification (Humann et al. 2013)
3	Reporting of Observational Data	Lobster plot measurement (habitat classification)	Scientific Publication	System of Classification of Habitats in Estuarine and Marine Environments (Madley et al. 2002); Methods Used to Map the Benthic Habitats of Puerto Rico on the U.S. Virgin Islands (Kendall et al. 2001)
4	Reporting of Observational Data	Lobster individual measurements (lobster identification)	Scientific Publication	Reef Creature Identification (Humann et al. 2013)

Table E-6. Data Protection standards for *Long-term Monitoring Protocol of Caribbean Spiny Lobster* (*Panulirus argus*; this document). With the exceptions noted, all data collected are to be made publicly available in a timely fashion.

Category	Type of Data	Level of Protection	Rules for Dissemination
Resource Data and Information	Spiny lobster locations	Legally Protected	Locations of observations obscured up to one kilometer in a random direction
Personally Identifiable Information	Non-NPS Staff Information	Legally Protected	All but first name and last initial redacted from public release

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Appendix F. R code

R code used to determine whether the sample data fits a Poisson, negative binomial, or zero-inflated equivalent is found here. There is also R code that uses a non-parametric bootstrap process to determine 95% confidence intervals for relative density index estimates, as well as relative density per stratum. Some of the code has been adapted from code provided by Steve Smith and Jerald Ault from the University of Miami Rosenstiel School of Marine and Atmospheric Science used to calculate density and frequency of occurrence and for sample allocation analysis in the reef fish protocols. Their original code can also be found in this appendix

Determining appropriate probability distribution for sample data

```
## This code is used to determine whether sample data fits a Poisson,
Negative Binomial (NB), Zero-inflated Poisson (ZIP), or Zero inflated
Negative Binomial (ZINB) distribution

## This code is derived from https://stats.idre.ucla.edu/r/dae/poisson-
regression/
## There are 5 main steps in this code, which should be executed
sequentially

# 1. Load packages and data
# 2. Test Poisson distribution for good fit
# 3. Test Negative Binomial distribution for good fit
# 4. Test Zero-inflated Poisson distribution for good fit
# 5. Test Zero-inflated Negative Binomial distribution for good fit

## 1. Load required packages and sample data
require(pscl)
require(MASS)

# Read in *.csv with sample data
# *.csv file should have the site id in column 1, number of lobster in
column 2, and the stratum in column 3.

lob<-
read.csv("X:\\SFCN\\Vital_Signs\\Lobster\\analysis\\r_code\\Poisson\\2017_
bisc_exp_poisson.csv")

# View first 6 rows of data and summarize the data
head(lob)

# Summarize the data
summary(lob)

# View data on histogram to get a visual idea of how data are distributed
```

```

hist(lob$no_lobster)

## 2. Test for Poisson Distribution

# Create a Poisson model from the sample data
model.pois <- glm(no_lobster ~ strat, data = lob, family = poisson)
summary(model.pois)

# Divide the residual deviance by the degrees of freedom
# A value < 2 (closer to 1 is better) indicates the selected model is
acceptable. Values 2-5 may be acceptable, but other regressions may
perform better. Values >5 indicate the regression is a poor representation
of the data.

# Test for goodness-of-fit of the Poisson model with a chi-square test
based on the residual deviance and degrees of freedom
1 - pchisq(summary(model.pois)$deviance,
summary(model.pois)$df.residual)

# If the above value is greater than 0.05, then the Poisson model is a
good fit for the data and you can stop here. No need to proceed further.
# If the value is <0.05, proceed to test if a NB model is a good fit.
Proceed to Step 3.

## 3. Test for Negative Binomial (NB) distribution

#Load the MASS package
require(MASS)

# Create a NB model from the sample data
model.nb <- glm.nb(no_lobster ~ strat, data = lob)
summary(model.nb)

# Divide the residual deviance by the degrees of freedom
# A value < 2 (closer to 1 is better) indicates the selected model is
acceptable. Values 2-5 may be acceptable, but other regressions may
perform better. Values >5 indicate the regression is a poor representation
of the data.

# Test for goodness-of-fit of the NB model with a chi-square test based on
the residual deviance and degrees of freedom
1 - pchisq(summary(model.nb)$deviance,
summary(model.nb)$df.residual)

```

```
# If the above value is greater than 0.05, then the NB model is a good fit
for the data and you can stop here. No need to proceed further.
# If the value is <0.05, proceed to test if a ZIP model is a good fit.
Proceed to Step 4.
```

```
## 4. Test for Zero-Inflated Poisson (ZIP) distribution
```

```
# Load pscl package
require(pscl)
```

```
# Create a ZIP model from the sample data
model.zip <- zeroinfl(no_lobster ~ strat | strat, data = lob)
summary(model.zip)
```

```
# Divide the residual deviance by the degrees of freedom
```

```
# A value < 2 (closer to 1 is better) indicates the selected model is
acceptable. Values 2-5 may be acceptable, but other regressions may
perform better. Values >5 indicate the regression is a poor representation
of the data.
```

```
# If the count and zero-inflation portions of the model are statistically
significant, then the model fits the data significantly better than the
null model (i.e. intercept-only model)
# A chi-squared test can compare this model to a null model
zip.null <- update(model.zip, . ~ 1)
```

```
pchisq(2 * (logLik(model.zip) - logLik(zip.null)), df = 3, lower.tail =
FALSE)
```

```
# If the p-value of this function is significant, then the ZIP model is a
good fit
# HOWEVER, it does not indicate whether the zero-inflated model is an
improvement over a standard Poisson regression.
# This can be determined by running the corresponding standard Poisson
model and performing a Vuong test of the two models
```

```
vuong(model.pois, model.zip)
```

```
# If the ZIP performs better than an ordinary Poisson, the Raw, AIC-
corrected, and BIC-corrected p-values should all be <0.05
# If the p-values are not similar and one or more of them is >0.05, then
an ordinary Poisson is a better fit for the data
# If the Poisson, NB, or ZIP models tested are not a good fit for the
data, a ZINB model can be tested. Proceed to Step 5.
```

```
## 5. Test for Zero-Inflated Negative Binomial (ZINB) distribution

# Load pscl package
require(pscl)

# Create a ZINB model from the sample data
model.zinb <- zeroinfl(no_lobster ~ strat | strat, data = lob,
dist="negbin", EM=TRUE)
summary(model.zinb)

# Divide the residual deviance by the degrees of freedom
# A value < 2 (closer to 1 is better) indicates the selected model is
acceptable. Values 2-5 may be acceptable, but other regressions may
perform better. Values >5 indicate the regression is a poor representation
of the data.

# If the count and zero-inflation portions of the model are statistically
significant, then the model fits the data significantly better than the
null model (i.e. intercept-only model)
# A chi-squared test can compare this model to a null model
zinb.null <- update(model.zinb, . ~ 1)

pchisq(2 * (logLik(model.zinb) - logLik(zinb.null)), df = 3, lower.tail =
FALSE)

# If the p-value of this function is significant, then the ZINB model is a
good fit
# HOWEVER, it does not indicate whether the zero-inflated model is an
improvement over an ordinary NB regression.
# This can be determined by running the corresponding ordinary NB model
and performing a Vuong test of the two models

vuong(model.nb, model.zinb)

# If the ZINB performs better than an ordinary NB, the Raw, AIC-corrected,
and BIC-corrected p-values should all be <0.05
# If the p-values are not similar and one or more of them is >0.05, then
an ordinary NB is a better fit for the data
# If neither the Poisson, NB, ZIP, or ZINB is a good fit, then you're SOL.
Pull your hair out, then get more samples.
```

Relative Frequency of Occurrence: Non-Parametric Bootstrap and Confidence Interval Estimation

```
# Calculating lobster frequency of occurrence and 95% confidence intervals
from non-parametric bootstrapping
```

```

# Lee Richter
# Last edited: 10/25/2018

# The following code is used for three separate processes:

# 1. Read in data frames
#This requires two .csv files
#-> lob: Lobster survey data. This should include at a minimum three
columns: "site number", "number of lobster at site", "stratum"
#-> ntot: Two columns, "stratum" and "number of total possible cells in
stratum"
#-> the count data is transformed into presence/absence data
#
# 2. Determine Relative Frequency of Occurrence Index and 95% confidence
intervals for the sample domain
# Function (pres) calculates a sum of the weighted mean frequency of
occurrences in domain
# This function is used in the bootstrap
# This value and associated CI's are for the whole park unit
#
# 3. Determine Frequency of Occurrence and 95% confidence intervals for
each individual stratum
# A new function (s.pres) reports frequency of occurrence for each stratum
# Examining strat.out (e.g. cleaned up output of s.boot) gives
approximation of 95% CI's
# Roughly 2 * SE approximates 95% CI
#The object s.ci can be used to determine true 95% CI for each stratum,
but the "index" needs to be changed for each stratum

#####

#### 1. Read in dataframes ####

# Read in Case Study dataframe #

lob<-
read.csv("X:\\SFCN\\Vital_Signs\\Lobster\\analysis\\r_code\\Poisson\\test\\
\\test_lob_data_bisc.csv")
head(lob)

# Add a column "pres" to the dataset which converts number of lobster to
presence/absence
lob$pres <- ifelse(lob$num>0,1,0)

# Read in ntot, i.e., total possible sampling units by stratum

```

```

ntot<-
read.csv("X:\\SFCN\\Vital_Signs\\Lobster\\analysis\\r_code\\Poisson\\test\\
\\test_ntot_bisc.csv")
ntot

# Compute sample weights per stratum
ntot$ngrtot<-with(ntot, rep(sum(ntot), length(ntot)))
ntot$wh<-with(ntot, ntot/ngrtot)
ntot

#### 2. Determine Relative Frequency of Occurrence Index and 95%
Confidence Interval for the park unit ####

# Create function to calculate average frequency of occurrence in sample
domain (from lob), using stratum weights (from ntot)
# x = lob$num
# indices = allows boot() to select from the sample

presence <- function(x, indices) {
  p <- x[indices] # allows boot to select sample
  strat.pres <- (aggregate(p, by = list(lob$strat), FUN = mean)) # this
step calculates the frequency of occurrence per stratum
  names(strat.pres) <- c("strat", "pres") # Assigns the column headers
"strat" and "pres" to strat.pres
  #return(strat.pres) # The "#" may be deleted at the beginning of this
line of code to see the actual occurrence calculations per stratum. This
returns "strat.pres" and the rest of the function does not run.
  ntot2<- merge(ntot, strat.pres, by="strat") # This merges ntot with
strat.pres so that the weight vectors and individual stratum frequencies
of occurrence are in one place
  avp <- sum(ntot2$wh * ntot2$pres) # Multiply wh and pres to get the
weighted stratum frequencies of occurrence. Sum these for the total
frequency of occurrence across the domain.
  return(avp) # Returns a value for frequency of occurrence across the
domain.
}

# Calculate the index of frequency of occurrence for the sample domain.
Notice how "1:length(lob$pres)" serves as the "indices" argument.

Index.freq.occur <- presence(lob$pres, 1:length(lob$pres))
Index.freq.occur

## Conduct a bootstrap using a) the data "lob", b) the "pres" function,
and c) a vector of stratum memberships ##

```

```

# Load boot() package
library(boot)

# Bootstrap process with 10,000 re-samples, where lob$strat is used to
define stratum memberships
lob.boot <- boot(lob$pres, presence, 10000, strata = lob$strat)
lob.boot

# Load broom to get a tidy dataframe as output
library(broom)
tidy(lob.boot)

plot(lob.boot) # Plots the output of the bootstrap

# boot.ci() can return 5 different types of confidence intervals (normal
approximation, basic, studentized, percentile, and bias-corrected,
accelerated).
lob.CI<-boot.ci(lob.boot, conf = 0.95, type = "all")

# View all.ci.lob to see the different confidence intervals that were
generated
lob.CI
#### 3. To examine the frequencies of occurrence of each stratum more
closely, use the following function. ####
# Note that no stratum weights are used here
# x = lob$num
# indices = allows bootstrap to occur

s.pres <- function(x, indices) {
  p <- x[indices] # allows boot to select sample
  strat.pres <- (aggregate(p, by = list(lob$strat), FUN = mean)) # this
step calculates the prop occurrence per stratum
  names(strat.pres) <- c("strat", "pres") # Assigns the column headers
"strat" and "pres" to strat.pres
  return(strat.pres[,2])
}

# Note: the strata.pres values that are produced are ordered
alphabetically by the names of the strata

# Uses the s.pres function to produce a table of stratum prop occurrences
strata.pres <- s.pres(lob$pres, 1:length(lob$pres))
strata.pres

# Completes a bootstrap for each of the strata, separately
s.boot <- boot(lob$pres, s.pres, 10000)

```

```

s.boot

# the tidy() function converts the bootstrapp output to a tibble, and the
as.data.frame converts the tibble to a dataframe
strat.out <- as.data.frame(tidy(s.boot))

# This adds back in the names of the individual strata. The sort()
function makes sure the strata labels are alphabetical and match the
s.boot output
row.names(strat.out) <- sort(ntot$strat)

# View the bootstrapped means for each stratum
# original = the original mean from the actual data
# bias = the difference between the mean of the bootstrapped samples
(n=10,000) and the original mean
# std. error = the standard deviation of the bootstrapped samples
(n=10,000)

strat.out

# The 95% CI's can be roughly estimated by 2 * "standard error" in
strat.out
# A qualitative assessment of strat.out can give an idea of which strata
should receive more sampling in the future
# Strata with a large SE in comparison to the mean are quite variable.
More samples in those strata should reduce variance

# Output for 95% CI's for individual strata. Need to change index value
for each stratum.
# Changing the index value will determine which value the 95% CI's are
returned.
# Example: index = 3 returns CI's for s.boot$t3, which is in this case
HRRF

s.ci <- boot.ci(s.boot, index = 2)
s.ci
Relative density: non-parametric bootstrap and confidence interval
estimation

# Calculating lobster density and 95% confidence intervals from non-
parametric bootstrapping
# Lee Richter
# Last edited: 10/25/2018

# The following code is used for three separate processes:

```

```

# 1. Read in data frames
# This requires two .csv files
# -> lob: Lobster survey data. This should include at a minimum three
columns: "site number", "number of lobster at site", "stratum"
# -> ntot: Two columns, "stratum" and "number of total possible cells in
stratum"
#
# 2. Determine Relative Density Index and 95% confidence intervals for the
sample domain
# Function (den) calculates a sum of the weighted mean densities in domain
# This function is used in the bootstrap
# This value and associated CI's are for the whole park unit
#
# 3. Determine Relative Density and 95% confidence intervals for each
individual stratum
# A new function (s.den) reports relative densities for each stratum
# Examining strat.out (e.g. cleaned up output of s.boot) gives
approximation of 95% CI's
# Roughly 2 * SE approximates 95% CI
# The object s.ci can be used to determine true 95% CI for each strata,
but the "index" needs to be changed for each stratum

#####

#### 1. Read in dataframes ####

# Read in Case Study dataframe #
lob<-
read.csv("X:\\SFCN\\Vital_Signs\\Lobster\\analysis\\r_code\\Poisson\\test\\
\\test_lob_data_bisc.csv")
head(lob)

# Read in ntot, i.e., total possible sampling units by stratum
ntot<-
read.csv("X:\\SFCN\\Vital_Signs\\Lobster\\analysis\\r_code\\Poisson\\test\\
\\test_ntot_bisc.csv")
ntot

# Compute sample weights per stratum
ntot$ngrtot<-with(ntot, rep(sum(ntot), length(ntot)))
ntot$wh<-with(ntot, ntot/ngrtot)
ntot

#### 2. Determine Relative Density Index and 95% Confidence Interval for
the park unit ####

```

```

# Create function to calculate average density in sample domain (from
lob), using stratum weights (from ntot)
# x = lob$num
# indices = allows boot() to select from the sample

den <- function(x, indices) {
  d <- x[indices] # allows boot to select sample
  strat.den <- (aggregate(d, by = list(lob$strat), FUN = mean)) # this
step calculates the densities per stratum
  names(strat.den) <- c("strat", "dens") # Assigns the column headers
"strat" and "dens" to strat.den
  #return(strat.den) # The "#" may be deleted at the beginning of this
line of code to see the actual density calculations per stratum. This
returns "strat.den" and the rest of the function does not run.
  ntot2<- merge(ntot, strat.den, by="strat") # This merges ntot with
strat.den so that the weight vectors and individual stratum densities are
in one place
  avd <- sum(ntot2$wh * ntot2$dens) # Multiply wh and dens to get the
weighted stratum densities. Sum these for the total density across the
domain.
  return(avd) # Returns a value for average density across the domain.
}

# Calculate the relative density index for the sample domain. Notice how
"1:length(lob$num)" serves as the "indices" argument.

RDI <- den(lob$num, 1:length(lob$num))
RDI

## Conduct a bootstrap using a) the data "lob", b) the "den" function, and
c) a vector of stratum memberships ##

# Load boot() package
library(boot)

# Bootstrap process with 10,000 re-samples, where lob$strat is used to
define stratum memberships
lob.boot <- boot(lob$num, den, 10000, strata = lob$strat)
lob.boot

# Load broom to get a tidy dataframe as output
library(broom)
tidy(lob.boot)

plot(lob.boot) # Plots the output of the bootstrap

```

```

# boot.ci() can return 5 different types of confidence intervals (normal
approximation, basic, studentized, percentile, and bias-corrected,
accelerated).
lob.CI<-boot.ci(lob.boot, conf = 0.95, type = "all")

# View all.ci.lob to see the different confidence intervals that were
generated
lob.CI

#### 3. To examine the densities of each stratum more closely, use the
following function. ####
# Note that no stratum weights are used here
# x = lob$num
# indices = allows bootstrap to occur

s.den <- function(x, indices) {
  d <- x[indices] # allows boot to select sample
  strat.den <- (aggregate(d, by = list(lob$strat), FUN = mean)) # this
step calculates the densities per stratum
  names(strat.den) <- c("strat", "dens") # Assigns the column headers
"strat" and "dens" to strat.den
  return(strat.den[,2])
}

# Note: the strata.den values that are produced are ordered alphabetically
by the names of the strata

# Uses the s.den function to produce a table of stratum densities
strata.den <- s.den(lob$num, 1:length(lob$num))
strata.den

# Completes a bootstrap for each of the strata, separately
s.boot <- boot(lob$num, s.den, 10000)
s.boot

# the tidy() function converts the bootstrap output to a tibble, and the
as.data.frame converts the tibble to a dataframe
strat.out <- as.data.frame(tidy(s.boot))

# This adds back in the names of the individual strata. The sort()
function makes sure the strata labels are alphabetical and match the
s.boot output
row.names(strat.out) <- sort(lob$num)

# View the bootstrapped means for each stratum
# original = the original mean from the actual data

```

```

# bias = the difference between the mean of the bootstrapped samples
# (n=10,000) and the original mean
# std. error = the standard deviation of the bootstrapped samples
# (n=10,000)

strat.out

# The 95% CI's can be roughly estimated by 2 * "standard error" in
strat.out
# A qualitative assessment of strat.out can give an idea of which strata
should receive more sampling in the future
# Strata with a large SE in comparison to the mean are quite variable.
More samples in those strata should reduce variance

# Output for 95% CI's for individual strata. Need to change index value
for each stratum.
# Changing the index value will determine which value the 95% CI's are
returned.
# Example: index = 3 returns CI's for s.boot$t3, which is in this case
HRRF

s.ci <- boot.ci(s.boot, index = 2)
s.ci

```

Reef Fish: R code for Calculating Density

```

# Read in dataframe #
fish<-
read.csv("X:\\SFCN\\Vital_Signs\\Marine_exploited_invertebrates\\data\\Lob
ster\\rcode\\2017_bisc_lobster_pilot.csv")
# fish
attach(fish)
head(fish)
tail(fish)

# Calculate mean Density (avdns), Variance of Density (svar), Sample Size
(n) and Standard Deviation of Density (std)
fish.est<-with(fish, aggregate(num, by = list(species_cd2,year,strat), FUN
= mean))
header<- c("species_cd2","year","strat","avdns")
names(fish.est) <- header
# attach(fish.est)

fish.est$svar<-with(fish, aggregate(num, by =
list(species_cd2,year,strat), FUN = var))[,4]
fish.est$n<-with(fish, aggregate(num, by = list(species_cd2,year,strat),
FUN = length))[,4]

```

```

fish.est$std<-sqrt(fish.est$svar)

fish.est

# Read in ntot, i.e., total possible sampling units by stratum
ntot<-
read.csv("X:\\SFCN\\Vital_Signs\\Marine_exploited_invertebrates\\data\\Lob
ster\\rcode\\2017_BISC_StRS_ntot.csv")
ntot

# Compute sampling weight factor by stratum
ntot$ngrtot<-with(ntot,rep(sum(ntot),length(ntot)))
ntot$wh<-with(ntot,ntot/ngrtot)
ntot

# Merge ntot with fish.est
fish.est<-merge(fish.est,ntot, by="strat")
fish.est

# Stratum-specific Estimates
fish.est$f<-with(fish.est, n/ntot)
fish.est$vbar_dns<- with(fish.est,(1-f)*(svar/n))
fish.est$wavdns<-with(fish.est,wh*avdns)
fish.est$wvbar<-with(fish.est,wh^2*vbar_dns)
fish.est$yt<-with(fish.est,ntot*avdns)
fish.est$vbar_yt<- with(fish.est,(ntot^2)*vbar_dns)
fish.est

# Domain-wide Population Estimates
n<-sum(fish.est$n)
avD<-sum(fish.est$wavdns)
vbar_D<-sum(fish.est$wvbar)
ytot<-sum(fish.est$yt)
vbar_ytot<-sum(fish.est$vbar_yt)
nstrat<-length(fish.est$ntot)
se_D<-sqrt(vbar_D)
cv_D<-(se_D/avD)*100
se_ytot<-sqrt(vbar_ytot)

# Population Estimates from StRS Sampling Design
# Number of Survey Strata and Total Sample Size
# Lobster are greedy. Why? They're shellfish #
nstrat
n
# Average Population Density and SE
round(avD,4)
round(se_D,4)

```

```

# CV for the mean Density estimate
round(cv_D,4)
# mean Population Size (number of fish) and SE
ytot
se_ytot

```

Reef Fish: R code for Calculating Frequency of Occurrence

```

## Calculation of Proportions (i.e., Percent Occurrence)

# Read in Dataframe #
# Lobsters don't do drugs...they say no to pot #
fish<-
read.csv("X:\\SFCN\\Vital_Signs\\Marine_exploited_invertebrates\\data\\Lob
ster\\rcode\\2017_bisc_lobster_pilot_numbers.csv")
pres<-ifelse(fish$num>=1,1,0)
fish<-cbind(fish,pres)
fish

# Calculate sample presence (smpres), n, avprp and svar
fish.est <- with(fish, aggregate(pres, by = list(species_cd2,year,strat),
FUN = sum))
header <- c("species_cd2","year","strat","smpres")
names(fish.est) <- header
head(fish.est)

fish.est$n<-with(fish, aggregate(num, by = list(species_cd2,year,strat),
FUN = length)) [,4]
fish.est$avprp<-with(fish.est,smpres/n)
fish.est$svar<-with(fish.est, (n/(n-1)) *avprp*(1-avprp))

# Bring in ntot file
ntot<-
read.csv("X:\\SFCN\\Vital_Signs\\Marine_exploited_invertebrates\\data\\Lob
ster\\rcode\\2017_BISC_StRS_ntot.csv")

ntot$ngrtot<-with(ntot,rep(sum(ntot),length(ntot)))
ntot$wh<-with(ntot,ntot/ngrtot)
ntot

# Merge Files "ntot" with "fish.est"
fish.est<-merge(fish.est,ntot, by="strat")
fish.est

# Compute Stratum estimates
fish.est$f<-with(fish.est, n/ntot)
fish.est$vbar_prp<- with(fish.est, (1-f)*(svar/n))

```

```

fish.est$wavprp<-with(fish.est,wh*avprp)
fish.est$wvbar<-with(fish.est,wh^2*vbar_prp)
fish.est

# Compute Domain estimates
n<-sum(fish.est$n)
nstrat<-length(fish.est$ntot)
avP<-sum(fish.est$wavprp)
vbar_P<-sum(fish.est$wvbar)
se_P<-sqrt(vbar_P)

# Proportions: STRS Design Domain-wide outputs
# Number of Survey Strata and Total Sample Size
nstrat
n
# Average Population proportion (Frequency of Occurrence) and SE
round(avP,4)
round(se_P,4)

# Clear workspace
rm(list=ls())

```

Reef Fish: R code for Sample Allocation Analysis

```

library(ggplot2)
library(gcookbook)
library(plyr)

## Compute strata means and variance
## Compute metrics for sample allocation analysis

# Read in Dataframe #
fish<-
read.csv("X:\\SFCN\\Vital_Signs\\Marine_exploited_invertebrates\\data\\Lob
ster\\rcode\\2017_bisc_lobster_pilot.csv")
head(fish)
# fish

##### StRS Computations #####
# Calculate avdns, svar, n and std
fish.est <- with(fish, aggregate(num, by = list(species_cd2,year,strat),
FUN = mean))
header <- c("species_cd2","year","strat","avdns")
names(fish.est) <- header
fish.est$svar<-with(fish, aggregate(num, by =
list(species_cd2,year,strat), FUN = var))[,4]
fish.est$n<-with(fish, aggregate(num, by = list(species_cd2,year,strat),
FUN = length))[,4]

```

```

fish.est$std<-sqrt(fish.est$svar)
fish.est

##### Create a barplot for Species density by Stratum. Add SDs #####
bp<-barplot(fish.est$avdns, names.arg=fish.est$strat, ylab="Mean Density",
xlab="Stratum", ylim=c(0,30),
col="green",main="STX Blue Tang 2012", font.lab=2,cex.axis=1)
arrows(bp,fish.est$avdns, bp,fish.est$avdns + fish.est$std, lwd=2.0,
angle=90, length=0.25)
box(bty="l")

# gcookbook routine to create barplot
fish.est.od<-arrange(fish.est,avdns,strat)
fish.est.od
ggplot(fish.est.od, aes(x=strat, y=avdns)) +
geom_bar(stat="identity", fill="red", colour="black", width=0.75,
position="dodge") +
theme(axis.text.x = element_text(angle=90, hjust=1, vjust=0.5)) +
labs(x = "Strata", y = "Average
Density",family="Helvetica",fontface="bold",size=4) +
theme(axis.line = element_line(colour="black"))

# ggplot to create a Cleveland Dot Plot
ggplot(fish.est.od, aes(x=svar, y=reorder(strat,svar))) +
  geom_point(size=3) +
  theme(axis.text.x = element_text(angle=90, hjust=1, vjust=0.5)) +
  theme(axis.line = element_line(colour="black"))

# Create a scatter plot for Stratum Variances
plot(fish.est$avdns,fish.est$std,xlab="Mean Density", ylab="Standard
Deviation of Density", pch=16, cex=1.7,
col="blue",ylim=c(0,75),xlim=c(0,25), main="STX Blue Tang 2012",
font.lab=2 )
text(fish.est$avdns, fish.est$std, labels=fish.est$strat ,pos=3)

# Same situation using ggplot
fish.est[,c("avdns","std")]
ggplot(fish.est, aes(x=avdns, y=std)) +
  geom_point(stat="identity", shape=16, size=3) +
  geom_text(aes(label=strat),size=3,hjust=0) +
  labs(x = "Average Density", y = "Standard
Deviation",family="Helvetica",fontface="bold",size=4) +
  theme(axis.line = element_line(colour="black")) +
  scale_y_continuous(breaks=c(0,10,20,30,40,50,60)) +
  scale_x_continuous(breaks=c(0,1,2,3,4,5,10,15,20,25,30))

#####

```

Design Metrics for Sample Allocation Analysis

```
# Read in ntot
ntot<-
read.csv("X:\\SFCN\\Vital_Signs\\Marine_exploited_invertebrates\\data\\Lobster\\rcode\\2017_BISC_StRS_ntot.csv")
ntot$ngrtot<-with(ntot,rep(sum(ntot),length(ntot)))
ntot$wh<-with(ntot,ntot/ngrtot)
# Merge ntot with fish.est
fish.est<-merge(fish.est,ntot, by="strat")
head(fish.est)

# Stratum estimates
fish.est$wavgdns<-with(fish.est,wh*avdns)
fish.est$whsvar<-with(fish.est,wh*svar)
fish.est$whstd<-with(fish.est,wh*std)

fish.est

# Domain Estimates
avD<-sum(fish.est$wavgdns)
wsvar<-sum(fish.est$whsvar)
vc1<-sum(fish.est$whstd)^2
ngrtot<-sum(fish.est$ntot)
tab<-cbind(avD,wsvar,vc1,ngrtot)
round(tab,4)

# Computation & Plotting of n* curve
y<-seq(1,100,0.1)
mod<- (vc1/(((y/100)*avD)^2)+(wsvar/ngrtot)))

plot(mod,y,type="l",lty=1,lwd=2, xlim=c(0,600), ylim=c(0,40), ylab=
"Coefficient of Variation (CV %)",
      xlab="Samples Required to Achieve Specified Precision (n*)", main="BISC
Lobster Pilot 2017", col="blue",
      font.lab=2)

# nstars Required for 5% CV, 10% CV, 15% CV and 20% CV Survey Precision #
V_20=(0.20*avD)^2
nstar_20=vc1/(V_20+(wsvar/ngrtot))
round(nstar_20,0)

V_15=(0.15*avD)^2
nstar_15=vc1/(V_15+(wsvar/ngrtot))
round(nstar_15,0)
```

```

V_10=(0.10*avD) ^2
nstar_10=vc1/(V_10+(wsvar/ngrtot))
round(nstar_10,0)

V_5=(0.05*avD) ^2
nstar_5=vc1/(V_5+(wsvar/ngrtot))
round(nstar_5,0)

plot(mod,y,type="l",lty=1,lwd=2, xlim=c(0,1800), ylim=c(0,40), ylab=
"Coefficient of Variation (CV %)",
xlab="Samples Required to Achieve Specified Precision (n*)", main="BISC
Lobster Pilot 2017", col="blue",
font.lab=2)
lines(nstar_20,20,type="p",cex=2,pch=16,col="green",lwd=2)
lines(nstar_15,15,type="p",cex=2,pch=1,col="purple",lwd=3)
lines(nstar_10,10,type="p",cex=2,pch=1,col="red",lwd=3)
lines(nstar_5,5,type="p",cex=2,pch=16,col="black",lwd=2)

```

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.

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National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science

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