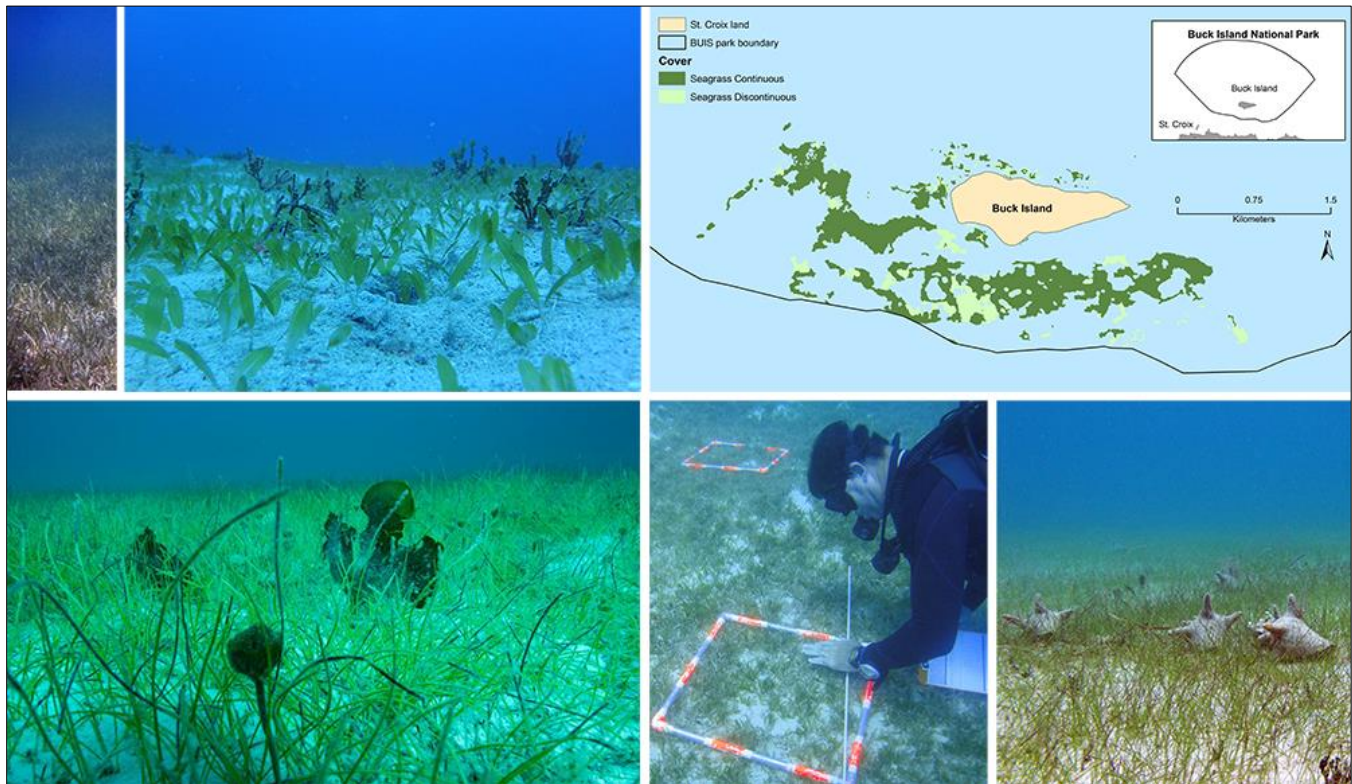




South Florida/Caribbean Network Seagrass Community Monitoring *Protocol Narrative*

Natural Resource NPS/SFCN/NRR—2019/1904



ON THE COVER

Clockwise from top left: *Thalassia testudinum* meadow at Biscayne National Park; photo credit: NPS SFCN staff. *Halophila decipiens* with *Halimeda* sp. at Salt River Bay National Historical Park and Ecological Preserve, canyon floor; photo credit: Jeff Miller, NPS SFCN. Seagrass map for Buck Island Reef National Monument. *Syringodium filiforme* with calcareous green algae at Virgin Islands National Park; photo credit: Susanna Pershern, NPS Submerged Resources Center. NPS scientific diver performing a Braun-Blanquet survey at Virgin Islands National Park; photo credit: NPS SFCN staff. *Lobatus gigas* (Queen Conch) with *Syringodium filiforme* at Virgin Islands National Park; photo credit: Rob Waara, NPS SFCN.

South Florida/Caribbean Network Seagrass Community Monitoring

Protocol Narrative

Natural Resource Report NPS/SFCN/NRR—2019/1904

¹Andy D. Davis, ¹Michael W. Feeley, ¹Mario Londoño, ²Lee Richter, ¹Judd M. Patterson, and
¹Andrea J. Atkinson

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

²National Park Service
South Florida/Caribbean Network
1300 Cruz Bay Creek
St. John, VI 00830

March 2019

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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

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

Please cite this publication as:

Davis, A. D., M. W. Feeley, M. Londoño, L. Richter, J. M. Patterson, and A. J. Atkinson. 2019. South Florida/Caribbean Network seagrass community monitoring: Protocol narrative. Natural Resource Report NPS/SFCN/NRR—2019/1904. National Park Service, Fort Collins, Colorado.

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 Date	Author	Changes Made	Reason for Change	New Version #
–	–	–	–	–
–	–	–	–	–
–	–	–	–	–
–	–	–	–	–
–	–	–	–	–
–	–	–	–	–

Contents

	Page
Change History	iii
Figures.....	vii
Tables.....	ix
Executive Summary	xi
Acknowledgments.....	xiii
List of Acronyms	xv
Background and Objectives	1
Seagrass monitoring in South Florida National Parks.....	3
Everglades National Park	4
Biscayne National Park	5
Dry Tortugas National Park.....	5
Seagrass Monitoring in the Caribbean National Parks.....	6
Virgin Islands National Park	6
Virgin Islands Coral Reef National Monument.....	7
Buck Island Reef National Monument	7
Salt River Bay National Historical Park and Ecological Preserve	7
Seagrass Protocol.....	8
Conceptual Framework for Monitoring.....	9
Measurable Objectives	10
Sampling Design and Monitoring Schedule	13
Sampling Design and Modifications	13
Rationale for Selecting this Sampling Design over Others	16
Benthic Habitat Maps.....	16
Considerations for Monitoring at Virgin Islands Coral Reef National Monument.....	17
Monitoring Schedule	17
Detectable Level of Change	18

Contents (continued)

	Page
Field Methods—What is Being Measured and How	21
Monitoring Methods.....	23
Braun-Blanquet Sampling Methods	24
Permitting and Compliance	24
Data Management, Analysis, and Reporting	25
Data Management.....	25
Protected Data	27
Data Summary	27
Change Detection	28
Additional work and analyses	29
Reporting.....	29
Budget.....	31
Personnel Requirements, Training and Safety	35
Roles and Responsibilities.....	35
Contacts	35
Collaborators (not directly involved with this protocol)	36
Qualifications	36
Training and Safety Procedures.....	36
Standard Operating Procedures and Deviations from Source Protocols.....	39
Literature Cited	41
Appendix A. Park Seagrass Maps.....	51
Appendix B: Seagrass Monitoring Pilot Survey in Virgin Islands National Park, May 2015.....	55

Figures

	Page
Figure 1. National Park Service’s South Florida/Caribbean Network (SFCN)	1
Figure A-1. Virgin Islands National Park seagrass and other soft-bottom habitats.....	51
Figure A-2. Salt River Bay National Historical Park and Ecological Preserve seagrass and other soft-bottom habitats.....	52
Figure A-3. Buck Island Reef National Monument seagrass and other soft-bottom habitats.	53
Figure A-4. Biscayne National Park offshore seagrass and other soft-bottom habitats.....	54
Figure B-1. Sites visited during FY 2015 Seagrass (SAV) Pilot Monitoring Survey at Virgin Islands NP were surveyed with four randomly placed 0.25 m ² (2.7 ft ²) quadrats.....	58
Figure B-2. Field crews on the Seagrass Monitoring Pilot Survey included (left to right) Lee Richter (SFCN), Devon Tyson (VIIS) and Andy Davis (SFCN)	59
Figure B-3. Stratified random survey sites visited during FY 2015 Seagrass (SAV) Pilot Monitoring Survey at Virgin Islands NP	60
Figure B-4. Close-up view of Leinster Bay with a SAV sites visited within selected strata.....	61
Figure B-5. Graphs displaying distribution of BB scores by depth (meters) for all six seagrass species present in the pilot study including <i>Thalassia testudinum</i> , <i>Syringodium</i> <i>filiforme</i> , <i>Halodule wrightii</i> , <i>Halophila stipulacea</i> (exotic), <i>Ruppia maritima</i> , and <i>Halophila decipiens</i>	64

Tables

	Page
Table 1. Factors affecting seagrass ecosystem change within South Florida/Caribbean Network (SFCN) parks and potential measures for vital signs monitoring.	10
Table 2. Comparison between the SFCN seagrass protocol and the Texas protocol.	11
Table 3. Seagrass extent (ha) estimated by initial strata (< 5 m, 5 – 15 m, > 15 m depth) and by park and initial proposed sample size	14
Table 4. The SFCN seagrass protocol proposed sampling schedule.....	18
Table 5. Average Braun-Blanquet (BB) score for pilot data plus detectable differences for sampling at the 5% significance level with 80% power with differing sample sizes.....	19
Table 6. Average frequency of occurrence for pilot data plus detectable differences for sampling at the 5% significance level with 80% power with differing sample sizes.	19
Table 7. General field method modifications of the Texas seagrass protocol for the SFCN seagrass protocol.....	21
Table 8. Specific survey design and field method modifications of Tier 2 of the Texas seagrass protocol for the SFCN seagrass protocol.....	21
Table 9. Supplementary monitoring metrics, field methods and variables measured at South Florida/Caribbean Network parks in Tier 2 of the SFCN seagrass protocol.	22
Table 10. Data processing and certification matrix for the SFCN seagrass protocol.....	26
Table 11. Estimated annual operating cost (based on FY2016 dollars) for the SFCN seagrass protocol.....	32
Table 12. Relevant documents and location on South Florida/Caribbean Network server.....	37
Table 13. Standard operating procedures required for the SFCN seagrass protocol.....	39
Table B-1. Strata, depths (ft.) and locations of sites (n = 54) visited during the 2015 Seagrass Pilot Monitoring Survey.....	56
Table B-2. Stratum averages (Avg) and standard errors (SE) of Braun-blaunquet (BB) scores for seagrass species	63
Table B-3. Calculated averages (Avg) and standard error (SE) of BB scores for seagrass species based upon three depth categories	65
Table B-4. Maximums (Max) and Minimums (Min) of BB scores for seagrass species based upon three depth categories	65

Tables (continued)

	Page
Table B-5. Average percent of quadrats with species present per site and standard error (SE) for seagrass species based upon three depth categories.....	66
Table B-6. Change detectable in BB scores (0–5) and frequency (percent quadrats with species present per site) with varying sample size by strata with 95% confidence and 80% power (β).....	66

Executive Summary

Seagrass communities in nearshore coastal ecosystems provide important habitat for numerous species including recreationally and commercially important juvenile fish and invertebrate species, sea turtles, and wading and diving birds. These ecosystems also increase water clarity by reducing the impact of wave energy and helping to stabilize sediments. However, these communities are sensitive to natural and anthropogenic effects such as eutrophication, pollution, physical damage and changes in hydrological patterns (Lapointe et al. 1994; Fourqurean et al. 2002). Seven native seagrass species occur inside or in close proximity to seven of the South Florida/Caribbean Network (SFCN) parks. Seagrass communities in the SFCN parks have been exposed to significant anthropogenic stress, such as eutrophication and changes in salinity patterns associated with water management in south Florida, among other effects. More recently, an invasive exotic seagrass species has been responsible for seagrass community changes in the U.S. Virgin Islands.

The South Florida/Caribbean Network is developing monitoring programs for natural resource “vital signs” including seagrass communities within the network’s parks. As several partners already monitor seagrass communities in and near network parks, the *South Florida/Caribbean Seagrass Community Monitoring: Protocol Narrative* (SFCN seagrass protocol) is focused on the gaps in existing monitoring programs, including offshore Biscayne National Park, Buck Island Reef National Monument, Salt River National Historical Park and Ecological Preserve, and Virgin Islands National Park. Partners already monitor Biscayne Bay, Florida Bay (in Everglades National Park) and Dry Tortugas National Park.

The primary objective of the SFCN seagrass protocol is to monitor trends in seagrass cover, community composition and the presence of invasive exotic species within mapped seagrass habitat in network parks. Secondary objectives for the SFCN seagrass protocol are:

- Collect ancillary information (i.e., water depth, sediment depth, substrate type, canopy height, *Lobatus gigas* [Queen Conch] counts) that can be used to improve understanding of seagrass species and habitat relationships or provide information to support another vital sign.
- When requested by park management and logistically feasible, compare trends in seagrass cover, species composition, and the presence of invasive exotic species within and outside of parks to evaluate the effectiveness of park management actions.
- When requested by park management and logistically feasible, perform additional “episodic” monitoring in response to unforeseen events or circumstances.

Seagrass is monitored using a stratified random survey where sites are monitored by teams of divers deploying four 0.25 square meter (2.7 square foot [ft²]) quadrats which are assessed using a Braun-Blanquet methodology. Sampling in parks will occur in rotation with parks revisited once every three years after a baseline is established. As extensive seagrass monitoring is already conducted by well-established programs, the network developed the SFCN seagrass monitoring protocol using established methods described in *A Seagrass Monitoring Program for Texas Coastal Waters*:

Multiscale Integration of Landscape Features with Plant and Water Quality Indicators (Dunton et al. 2011; also referred to as ‘The Texas Seagrass Protocol’), *Spatial and Temporal Pattern in Seagrass Community Composition and Productivity in South Florida* (Fourqurean et al. 2001), and *Integrating Scales of Seagrass Monitoring to Meet Conservation Needs* (Neckles et al. 2012). The sample design is a stratified random design using depth as strata and a random selection of points within each stratum. The Texas seagrass protocol is based on the work by Jim Fourqurean of Florida International University (FIU) (Fourqurean et al. 2001) and Neckles et al. (2012), and is currently being used in the Gulf Coast Network (GULN). This SFCN seagrass protocol follows field methods described in the Texas seagrass protocol, while maintaining consistency with the work performed by Florida International University and other regional seagrass monitoring efforts.

The South Florida/Caribbean Network will generate basic data summary reports and publish the data, making them available to park staff and the scientific community through the [Integrated Resource Management Applications \(IRMA\) Portal](#). Results are expected to fill gaps in the knowledge of seagrass systems in network parks, and help expand the collective understanding of seagrass conditions.

Acknowledgments

This SFCN seagrass community monitoring protocol was based on the Dunton et al. (2011) protocol, and the Fourqurean et al. (2001) publication. We acknowledge the significant contributions of the authors of those papers who, through their work, provided the critical background upon which this document is based. We also acknowledge Jim Fourqurean (Florida International University) and his collaborating authors for the significant historical literature of seagrass work that heavily informed the development of this protocol. We thank Dean Tucker (NPS Water Resources Division) for significantly streamlining data management by providing access and training to the NPStoret database; and Pablo Ruiz, who provided invaluable GIS subject matter expertise. Additionally, we acknowledge the individual contributions (in alphabetical order) of Adam Glahn, Kim Jackson, Paul Jensen, Joe Meiman, Jeff Miller, Caroline Rogers, Martha Segura, Devon Tyson and Rob Waara for their role in supporting the development of this seagrass monitoring document at the South Florida/Caribbean Network. Finally, we wish to thank Ken Dunton, Victoria Congdon, Hilary Neckles, Tom Philippi and Clayton Pollock for their insightful comments and expert review of this protocol, associated standard operating procedures, appendices and data quality standards.

List of Acronyms

BB:	Braun-Blanquet
BICY:	Big Cypress National Preserve
BISC:	Biscayne National Park
BUIS:	Buck Island Reef National Monument
CERP:	Comprehensive Ecosystem Research Plan
DEEP:	Dive Emergency Evacuation Plan
DERM:	Miami-Dade County Department of Environmental Resource Management
DPNR:	Department of Planning and Natural Resources
DRTO:	Dry Tortugas National Park
EQulS :	Environmental Quality Information System
EVER:	Everglades National Park
FHAP:	Florida Bay Fisheries Habitat Assessment Program
FIU:	Florida International University
FTE:	Full Time Equivalent
FWC:	Florida Fish and Wildlife Conservation Commission
GIS:	Geographic Information System
GULN:	Gulf Coast Network
I&M:	Inventory and Monitoring Division
IRMA:	Integrated Resource Management Applications
JHA:	Job Hazard Analyses
MOCC:	Motor Boat Operations Certification Course
NOAA:	National Oceanic and Atmospheric Administration
NPS:	National Park Service
NPSTORET:	NPS's Storage and Retrieval Database

PDS:	Protocol Development Summary
QA/QC:	Quality Assurance/Quality Control
QAP:	Quality Assurance Plan
SARI:	Salt River Bay National Historical Park and Ecological Preserve
SAV:	Submerged Aquatic Vegetation
SCUBA:	Self Contained Underwater Breathing Apparatus
SERL:	Seagrass Ecosystem Research Laboratory
SFCN:	South Florida/Caribbean Network
SFNRC:	South Florida Natural Resources Center
SIMM:	Seagrass Integrated Mapping and Monitoring Program
SOP:	Standard Operating Procedure
SAV:	Submerged Aquatic Vegetation
STORET :	Environmental Protection Agency's Storage and Retrieval Database
VICR:	Virgin Islands Coral Reef National Monument
VIIS:	Virgin Islands National Park

Background and Objectives

The South Florida/Caribbean Network (SFCN) is one of 32 networks in the National Park Service (NPS) Inventory and Monitoring Division (I&M) (Figure 1). The network is responsible for inventorying and monitoring natural resources or “vital Signs” in seven national parks in south Florida and the Caribbean. Virgin Islands National Park (NP), Buck Island Reef National Monument (NM) and Salt River Bay National Historical Park and Ecological Preserve (NHP&EP) are located in the U.S. Virgin Islands. Biscayne NP, Everglades NP, Dry Tortugas NP and Big Cypress National Preserve are located in Florida. The Virgin Islands Coral Reef NM contains significant marine resources, but does not currently fall within the auspices of the network for natural resource inventory and monitoring.

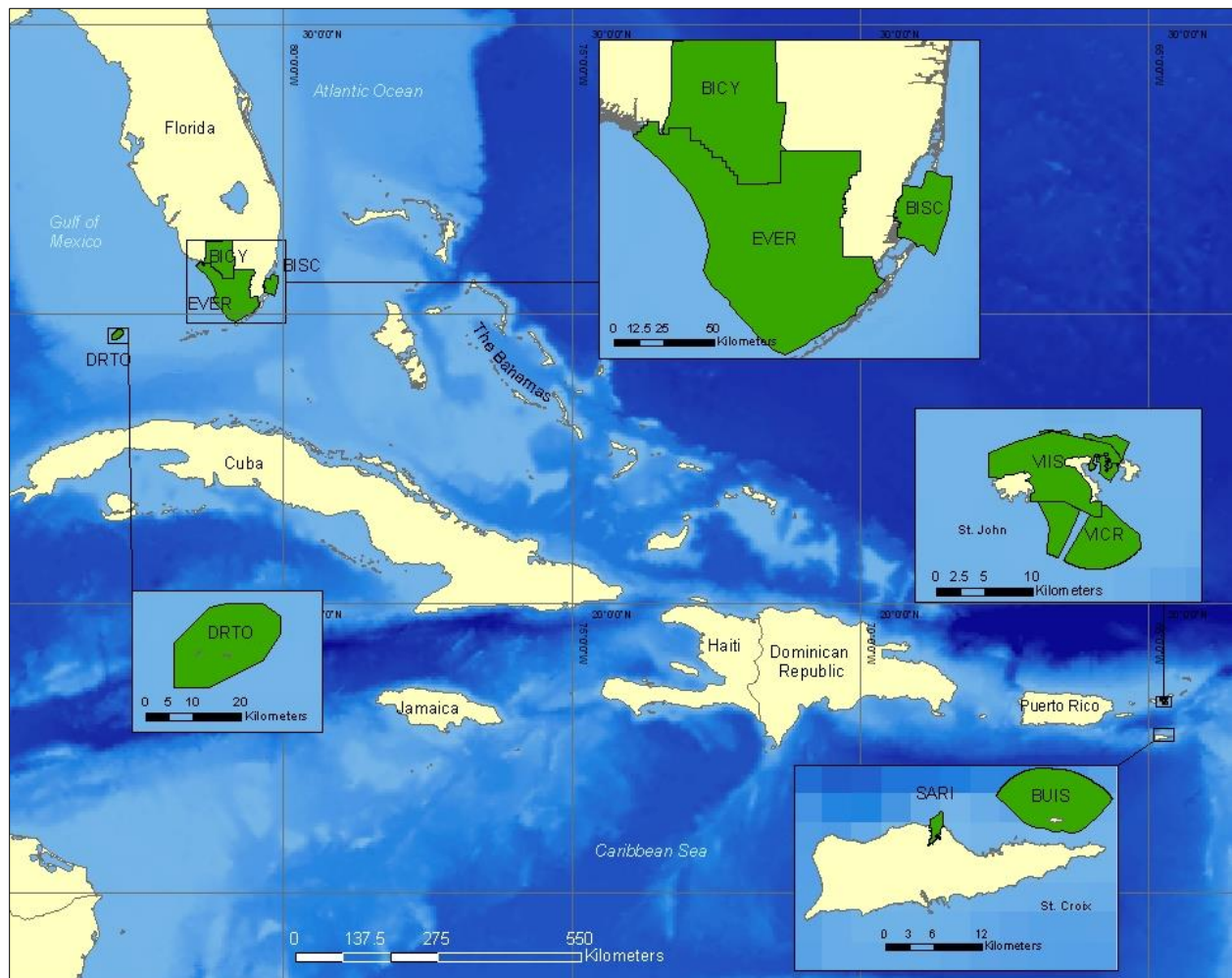


Figure 1. National Park Service’s South Florida/Caribbean Network (SFCN). In south Florida: Big Cypress National Preserve (BICY), Everglades National Park (EVER), Biscayne National Park (BISC), and Dry Tortugas National Park (DRTO). In the Caribbean: Buck Island Reef National Monument (BUIS), Salt River 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.

Seagrass communities in nearshore coastal ecosystems provide habitat for numerous fish and invertebrate species, sea turtles, and are important for wading and diving birds. These ecosystems also increase water clarity by reducing the impact of wave energy and helping to stabilize sediments. However, these communities are sensitive to natural and anthropogenic effects such as eutrophication, pollution, physical damage and changes in hydrological patterns; these effects have been correlated to seagrass community changes (Lapointe et al. 1994; Fourqurean et al. 2002). Monitoring the status and trends of seagrass parameters is an important step to understanding ecosystem health. Results can help inform management decisions and fill in knowledge gaps and assess seagrass condition across large-scales. Introduction of an invasive Mediterranean seagrass species is a current management concern in the U.S. Virgin Islands since it may displace native seagrass species.

The SFCN marine benthic communities vital sign consists of seagrass and other submerged aquatic vegetation (SAV) and coral reef communities. Both habitat communities are part of the network's top-ranked vital sign (Patterson et al. 2008). *The Coral Reef Monitoring: Protocol Narrative—Version 2.0* is principally focused on biotic cover on hard-bottom reef habitats (Miller et al. 2017), while seagrass and submerged aquatic vegetation occupy soft-bottom habitat generally dominated by seagrass associated with populations of algae. For simplicity, in this text the terms “seagrass,” “seagrass habitat,” “seagrass communities” and “seagrass ecosystems” are meant to include all other associated submerged aquatic vegetation.

Seagrass communities occur in all SFCN parks, except Big Cypress National Preserve. These seagrass habitats are influenced by estuarine, nearshore or offshore conditions depending on their geographic location. Distribution of seagrasses is affected by salinity, with changes in salinity affecting seed germination, growth, photosynthesis and biomass (Short and Neckles 1999). Seagrass productivity decreases with water depth and increased turbidity, which decrease light availability and may stimulate the growth of epiphytes (Short and Neckles 1999). Biscayne NP and Everglades NP contain vast shallow estuaries where seagrasses dominate most of the benthic community. In contrast, seagrass meadows east of the island chain in Biscayne NP are more exposed to offshore currents than inside the bay. Salt River Bay NHP&EP contains a smaller estuary-like habitat supporting seagrass that is gradually replaced by coral habitat farther from shore. Nevertheless, the Salt River is ephemeral and salinity data suggest true estuarine conditions do not exist in Salt River (Hubbard 1989; Kendall et al. 2005). Seagrass communities at Virgin Islands NP and the Virgin Islands Coral Reef NM are exposed to occasional freshwater runoff in some locations but there are no permanent rivers or streams on St. John (Yates et al. 2014). There are significant seagrass communities at Buck Island Reef NM (Pittman et al. 2008) and Dry Tortugas NP (Waara et al. 2011), neither of which are appreciably influenced by freshwater runoff.

Seven native seagrass species occur inside or in close proximity to the SFCN parks. Shoal grass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*) represent the Cymodoceae family, while turtle grass (*Thalassia testudinum*), paddle grass (*Halophila decipiens*) and star grass (*H. engelmannii*) represent the Hydrocharitaceae family. Widgeon Grass (*Ruppia maritima*) is a native species of the Ruppiaceae family and occurs in Everglades NP (Odum and Heald 1972; Fourqurean

et al. 2002) and Biscayne NP (Braun et al. 2004). The species was first observed in Virgin Islands NP in 2016 by network and park staff. *Ruppia maritima* is a euryhaline species found in freshwater, estuarine, and marine environments (Odum and Heald, 1972; Acevedo-Rodriguez 1996; Fourqurean et al. 2002; Braun et al. 2004). The federally-listed Johnson's seagrass (*Halophila johnsonii*) occurs off Virginia Key just north of the Biscayne NP boundary. The Northern Biscayne Bay area was designated under the Endangered Species Act as critical habitat for the species (16 U.S.C. 1531 1973; 65 Fed. Reg. 17786 2000). The species is of significant interest to the network, even though no sightings have been reported inside Biscayne NP. The species could eventually be found in park waters, which would mean targeted monitoring efforts to address this endangered species would have to be considered.

An eighth species, Mediterranean seagrass (*Halophila stipulacea*), is an invasive exotic in the Caribbean basin. Originally a native species of the Indian Ocean (den Hartog 1970), this species is thought to have invaded the Mediterranean Sea when the Suez Canal between Egypt and Israel was opened in the late 1800s, and has since reached Albania, Cyprus, Egypt, Greece, Italy, Lebanon, Libya, Malta, Syria, Tunisia and Turkey (Sghaier et al. 2011). Researchers recently reported the species occurring in the Virgin Islands NP and the Virgin Islands Coral Reef NM (Willette et al. 2014). Presence of *H. stipulacea* was also recently confirmed (May 2017) in Buck Island Reef NM (C. Pollock pers. comm.). Willette and Ambrose (2012) suggested and provided evidence that *H. stipulacea* may displace *S. filiforme*. The authors experimentally showed that exotic species can directly compete with and displace the native species. They also suggested that as *H. stipulacea* often colonizes bare sediment, the species may also colonize areas in which *S. filiforme* was removed by disturbance such as a tropical weather system. The researchers showed that viable *H. stipulacea* fragments are removed and transported with fish traps, suggesting a means of dispersal to the next location a trap is deployed.

There are transitions of seagrass habitat over time, but recolonization by species is highly variable and is influenced by the composition of the original seagrass bed (Duffy 2006). The extent of seagrass beds may expand. For example, *Syringodium filiforme* beds in Buck Island Channel, St. Croix, USVI, increased in coverage from 1.33 to 4.34 square kilometers (0.51 to 1.68 square miles [mi^2]) from 1971 to 1999. Ninety-two percent of the area already covered in 1971 was still occupied in 1999 (Kendall et al. 2004). Seagrass beds may also be affected by acute events such as hurricanes that may erode and wash away or bury them by sediment deposition (Fourqurean and Rutten 2003). Seed germination and flowering can significantly increase for certain species when water temperature increases (Short and Neckles 1999). Seagrass meadows in Florida Bay indicated a marked seasonality in abundance and standing crop, with maximum values seen in August (Fourqurean et al. 2001). Mean annual productivity also increased with water depth in Florida Bay, but the amplitude of seasonality was inversely proportional with depth.

Seagrass monitoring in South Florida National Parks

Zieman (1982) published a comprehensive work on the ecology of seagrass communities in south Florida, including a significant review of earlier seagrass work. The author and partners later performed extensive seagrass monitoring work in the region (Zieman et al. 1989). This work

eventually led to sustained seagrass monitoring using Braun-Blanquet (BB) methods in south Florida (Braun-Blanquet 1932; Hall et al. 1999; Fourqurean et al. 2001; Fourqurean et al. 2002; Fourqurean and Rutten 2003; Hall and Carlson Jr., 2015). Land-based freshwater and nutrient input changes nearshore have altered the structure of seagrass communities in south Florida (Fourqurean et al. 2003; Fourqurean and Rutten 2003; Herbert et al. 2011). Considering the effect of anthropogenic changes upon seagrasses, Fourqurean and Rutten (2003) developed a long-term program that provided for inventory and monitoring of seagrass health and distribution throughout 1,700,000 hectares of habitat in south Florida. The researchers collected in situ population measurements and analyzed seagrass tissue for nutrient content. They were also able to co-locate sites with water quality sampling stations performed by other partners. Results of this project continue to provide understanding of the causal relationship between decreased salinity and increased eutrophication, and consequent seagrass displacement by competitive algae. The predictive model developed by Herbert et al. (2011) is based in large part on these data. These tools help managers to develop mitigation strategies aimed at reducing the impact of anthropogenic impact to seagrasses.

The Seagrass Integrated Mapping and Monitoring Program (SIMM) has reported periodic seagrass mapping efforts for Florida Bay since 2004, and Biscayne Bay since 2005. The Seagrass Integrated Mapping and Monitoring Program facilitates coordination of mapping and monitoring activities for more than 2.3 million acres (3,594 mi²) of seagrass in Florida. The Comprehensive Ecosystem Research Plan (CERP) also publishes periodic ecosystem status reports that address seagrass status and trends in Florida Bay and inshore Biscayne Bay (CERP 2014). The Florida Fish and Wildlife Conservation Commission (FWC) produced a comprehensive benthic habitat map of the Florida reef tract that also encompasses seagrass ecosystems throughout the region (FWC 2015).

Everglades National Park

Florida Bay is almost entirely contained within the Everglades NP boundaries and has a long history of seagrass research and monitoring. Tabb et al. (1962) provided an early description of *T. testudinum* in Northern Florida Bay, and characterized some regional population differences the authors attributed to salinity and turbidity. The researchers suggested that salinity may play a role in the species' relationship with *S. filiforme* and *H. engelmannii*. They also observed that salinity seemed to influence the distribution of *R. maritima* and *H. wrightii*. Madden et al. (2009) published a comprehensive ecosystem status report for Florida Bay based on historical monitoring and analyses. Freshwater releases in the bay should increase gradient variability, decrease hypersalinity and allow multiple seagrass species to co-exist and support good environmental conditions for *T. testudinum* (Madden et al. 2009).

The Fish and Wildlife Research Institute of the Florida Fish and Wildlife Conservation Commission implemented a seagrass monitoring program in 1995 and expanded in 2005, known as the Florida Bay Fisheries Habitat Assessment Program (FHAP). Florida Bay is divided into 17 basins, each of which is divided into 30 tessellated hexagonal grid cells. A single station is randomly selected from within each cell. This monitoring is currently performed using BB assessments yearly and continues to this day. Results are reported through the Seagrass Integrated Mapping and Monitoring Program (Hall and Carlson Jr. 2015; CERP 2014).

Besides the work already described, Robblee et al. (1991) characterized an extensive seagrass die-off in Florida Bay that started in 1987. Zieman et al. (1999) reported on the effects of that event a decade later. The NPS South Florida Natural Resources Center (SFNRC) reported the occurrence of a die-off in 2015 (Hall et al. 2016). This die-off was correlated with a delay in seasonal summer precipitation and an associated reduction in freshwater runoff into the bay that resulted in a significant increase in salinity (NPS 2016; Hall et al. 2016). The South Florida Natural Resources Center also published an assessment of propeller scarring damage in seagrass communities of Florida Bay (NPS 2008).

Biscayne National Park

The marine component of the park is divided into two areas with distinct characteristics. The “inshore Biscayne NP” area encompasses a large portion of Biscayne Bay, which is generally dominated by seagrass communities throughout. A chain of islands that forms the northern extension of the Florida Keys separates the bay from the offshore portion of the park, or “offshore Biscayne NP.” This area is dominated by seagrass communities in the shallower, nearshore region east of the island chain and extends to the patch reef system that delineates the eastern park boundary.

The Florida Bay Fisheries Habitat Assessment Program (FHAP) performed seagrass monitoring in Biscayne Bay twice yearly using BB assessments from 2005 through 2009 (Yarbro and Carlson Jr. 2013). In 2003, researchers from the University of Miami and the National Oceanic and Atmospheric Administration (NOAA) developed a seagrass monitoring system in Biscayne Bay using geosynchronized still images taken from a glass-bottom boat (Lirman et al. 2008). This Shallow Water Positioning System technique was calibrated against BB methods described in Fourqurean et al. (2002). Researchers used the study to develop the Nearshore Benthic Habitats Program and monitor nearshore, or less than 500 meters (1,640 feet [ft]) from shore, seagrass sites in Biscayne Bay from 2008 through 2011, in a semi-annual rotation (Lirman et al. 2011). The Miami-Dade County Department of Environmental Resource Management (DERM) has conducted seagrass monitoring surveys throughout Biscayne Bay since 1999 and reported results through the Seagrass Integrated Mapping and Monitoring Program (SIMM; Avila et al. 2008; Yarbro and Carlson Jr. 2013).

The offshore seagrass communities that exist in Biscayne NP have not been studied as extensively as seagrasses inside the bay. Lewis III et al. (2000) used aerial photography to produce a Geographic Information System (GIS) map that characterized the extent and distribution of seagrass and associated benthic habitats in that area. The latest map for the offshore portion of Biscayne NP was produced with imagery and data from 2008 (Estep et al. 2017). Because there is already an existing monitoring effort covering the inshore Biscayne NP, seagrass monitoring by the South Florida/Caribbean Network will be confined to the offshore Biscayne NP (Patterson et al. 2008).

Dry Tortugas National Park

Historical seagrass work at Dry Tortugas NP is somewhat limited. However, Agassiz (1883) produced a comprehensive map of the park, and Taylor (1928) provided early descriptions of seagrass community distribution in the Dry Tortugas as part of a comprehensive work on marine algae. Davis (1982) produced an updated map of the benthic habitats of Dry Tortugas NP. More recently, Fourqurean et al. (2001) used data collected throughout south Florida that included Dry

Tortugas NP, to produce maps of seagrass extent and distribution by species throughout the region. Fourqurean et al. (2002) followed with another publication that expanded the knowledge and understanding of seagrass ecology in south Florida, including Dry Tortugas NP. The Seagrass Ecosystem Research Laboratory (SERL) at Florida International University (FIU) continues to monitor seagrass communities in the park as part of the water-quality protection program administered by the EPA and the state of Florida's Department of Environmental Protection for the Florida Keys National Marine Sanctuary. Data sets and interactive plots are publically available (FIU-SERL 2016; <http://seagrass.fiu.edu/data.htm>). Other mapping efforts covering seagrass habitat in the park include works by the Florida Marine Research Institute (FWC 2000), Franklin et al. (2003), Schmidt et al. (2004), Waara et al. (2011) and FWC (2015). Because there is ongoing monitoring at Dry Tortugas NP, the South Florida/Caribbean network will defer seagrass monitoring in this park.

Seagrass Monitoring in the Caribbean National Parks

Virgin Islands National Park

The earliest documented efforts to characterize seagrass habitats around St. John occurred soon after the Virgin Islands NP was established, when Kumpf and Randall (1961) drafted a benthic map of marine habitats around the island. Another study characterized the distribution of *S. filiforme* and *T. testudinum* in Greater and Little Lameshur Bays (Campbell et al. 1983). Beets et al. (1986) produced a more comprehensive and detailed map of 15 marine habitats around St. John using aerial photography. The investigators further refined the maps by ground truthing mapped areas within the boundaries of the park. Williams (1988a) and Rogers and Teytaud (1988) reported early evidence of seagrass decline from comparisons of aerial photography from different years. These efforts provided valuable information on seagrass and other marine habitat distribution around the island; however, these descriptive studies were qualitative in nature. Zitello et al. (2009) produced a map of the shallow water benthic habitats of St. John, as a continuation of work started by Kendall et al. (2001).

Williams (1988a) produced a report containing maps of seagrass beds in Francis and Maho Bays. The author also reported some of the earliest quantitative measures of seagrass density and community structure from seagrass beds in St. John. In 1989, Lisa Muehlstein led the first comprehensive seagrass monitoring work in Great Lameshur Bay, using a combination of Braun-Blanquet and short-shoot count assessments along fixed transects. Short-shoot count methods differ from Braun-Blanquet in that individual seagrass shoots are counted. Another study in Little Lameshur, Salt Pond and Brown Bays started in 1997; however, both studies ended in 2002. Lisa Muehlstein partnered with Jeff Miller in 2000 and began a separate monitoring effort in Great Lameshur Bay, only recording short-shoot counts. The program expanded in 2001 to include sites in Hurricane Hole and Brown Bay, and continued until 2004 (Beets and Muehlstein 2005). From 2001 to present, the Virgin Islands NP established seagrass monitoring sites using short-shoot counts in locations associated with permanent vessel moorings (Beets and Muehlstein 2005; T. Kelly, personal communication).

Beets and Muehlstein (2005), reporting on previous seagrass monitoring in St. John, recommended using the BB method described in Fourqurean and Rutten (2003) and suggested that this method is more efficient than short-shoot density counts.

The network conducted a seagrass monitoring pilot survey in Virgin Islands NP with support from local park staff in May of 2015. The four-day joint team effort conducted 54 BB surveys (with 4 to 6 quadrats per survey) within seagrass habitat throughout the island of St. John. During the visit, the team observed the presence of extensive beds of *H. stipulacea* around the island and also reported *R. maritima* from a shallow embayment on the south side of St. John. The study showed that it is feasible to conduct approximately 50 surveys within the allocated time frame using the Fourqurean et al. (2001) method.

Virgin Islands Coral Reef National Monument

There is no known history of seagrass monitoring occurring specifically in Virgin Islands Coral Reef NM, and the occurrence of mapped seagrass communities in the monument as characterized in Zitello et al. (2009) is negligible. However, it is possible *H. stipulacea* has expanded into areas of the monument since the most recent mapping effort.

Buck Island Reef National Monument

The seagrass ecosystems of Buck Island Reef NM are relatively small and have not been extensively researched. Nevertheless, park documents mention early concerns for damage to *T. testudinum* beds at the monument (Robinson 1973; Schell 1974). Gladfelter et al. (1977) prepared a study for the National Park Service that characterized the distribution of seagrass beds around the monument. Later, Kendall et al. (2004) produced a study characterizing the change in seagrass cover on the south side of Buck Island from 1971 to 1999, showing a significant increase during that period. Pittman et al. (2008) produced a more comprehensive study that characterized the distribution of seagrass and other benthic communities around the monument. Future mapping efforts may be used as comparison with current benthic habitat maps. There is no long-term seagrass monitoring presently at Buck Island Reef NM, although a sea turtle foraging ecology study characterized shallow and deep seagrass beds in 2017 (C. Pollock pers. comm.).

Salt River Bay National Historical Park and Ecological Preserve

Salt River in St. Croix is a unique geological feature in the network, where a shallow terrestrial drainage system discharges fresh water intermittently into an estuarine-like bay. The bay transitions into a relatively deep submarine canyon that cuts through the shelf farther offshore (Josselyn et al. 1986). The seagrass habitats found in the canyon have provided opportunities for research in deeper water seagrass communities (Josselyn et al. 1986; Williams 1988b; Kenworthy et al. 1989). Kendall et al. (2005) used a series of aerial images to characterize seagrass cover in the preserve from the 1970s through 2000, reporting a decline in seagrass cover during the period. Future mapping work may expand on the work performed by that team; however, seagrass is not currently monitored at Salt River Bay NHP&EP.

Seagrass Protocol

The South Florida/Caribbean Network is responsible for monitoring seagrass communities to detect changes such as community shifts and competition from exotic species, and to better understand the effects of stressors. Several partners monitor seagrass communities in and near network parks, but gaps exist in some parks. The network has developed a program that complements work done by others and monitors the remaining gaps. The network plans to monitor seagrass in four locations where either previous work has been discontinued (Virgin Islands NP), or no seagrass monitoring program is in place (Salt River Bay NHP&EP, Buck Island Reef NM and offshore Biscayne NP). Although resource restrictions are expected to limit the scope of this effort, the data collected shall be similar to and comparable with efforts conducted by regional partners.

This protocol outlines how data will be collected, managed, and reported for the seagrass monitoring component of the Marine Benthic Communities vital sign as described in the approved SFCN monitoring plan (Patterson et al. 2008). The *South Florida/Caribbean Network Seagrass Community Monitoring: Protocol Narrative* (SFCN seagrass protocol; this document) describes how the network will implement established methods published in the Texas seagrass protocol (Dunton et al. 2011), the Virgin Islands fish protocol (Bryan et al. 2013) and Fourqurean et al. (2001).

Fourqurean et al. (2001) established seagrass monitoring methods widely used to survey seagrasses in south Florida, the Gulf of Mexico and the Caribbean region. The SFCN seagrass protocol follows field methods described in the Texas seagrass protocol, while maintaining consistency with the work performed by Florida International University and other regional seagrass monitoring efforts. The Texas seagrass protocol was developed based on the work by Jim Fourqurean of Florida International University (Fourqurean et al. 2001) and work later published in Neckles et al. (2012), and it is currently being used in the NPS Gulf Coast Network. Seagrass monitoring in the Texas seagrass protocol is divided into three tiers. Benthic habitat mapping is performed as the Tier 1 component of their monitoring design (remote sensing and aerial imagery). Benthic mapping for SFCN parks is performed by NPS partners and will not be addressed in this document. Tier 2 consists of a rapid assessment procedure to measure seagrass species composition, cover, and key stressors. The network will adopt this procedure with modifications described later in the *Sample Design* section. Tier 3 consists of a comprehensive assessment procedure that will not be implemented initially by the network due to the existence of ongoing research by other organizations and the need for the network to focus resources on monitoring and early detection of changes at all network parks with seagrass communities.

Results obtained from this monitoring program are expected to fill gaps in the knowledge of seagrass systems in network parks, and also help expand the collective understanding of regional seagrass conditions. Standardized methodology across monitoring programs will insure consistency of data acquisition and allow seagrass ecosystem condition assessment across all parks and on a broader scale across the Gulf of Mexico and Caribbean Sea. Multiple monitoring programs that collect and process samples differently can make large-scale assessments difficult. However, the entire Texas coast (multiple agencies), Florida and the U.S. Virgin Islands will follow similar protocols, which will simplify data management and interpretation of data.

Modifications to the sampling design, field implementation processes, and data management approaches used in the source protocols are presented to describe how they are applied in SFCN parks for seagrass monitoring. All SFCN procedural modifications to standard operating procedures (SOP) are summarized and fully described in new SFCN versions in order to facilitate comparison to the source documents. Additional SOPs related to SFCN operations, safety, and equipment are also identified to ensure successful implementation in SFCN parks.

Objectives were initially established for seagrass monitoring at the South Florida/Caribbean Network by Patterson et al. (2008). Overall goals of this protocol stress in-situ rapid assessment of mapped seagrass habitat (Tier 2) rather than including all the intensive monitoring described by Patterson (2008) that also integrates environmental variables. These include Tier 3 work that is designed to test specific hypotheses in response to environmental change (Dunton et al. 2011). Monitoring will address the recently introduced exotic seagrass species *H. stipulacea* in the U.S. Virgin Islands' parks. However, seagrass cover that is monitored in no-anchor zones or to meet park-specific objectives will only be reported in parks that have established their own monitoring program for that specific purpose. Limited monitoring may be reported from, or take place, outside park boundaries to evaluate management strategies. The intent to perform seagrass monitoring outside the parks is implied in the Patterson et al. (2008) *Seagrass Protocol Development Summary (PDS)*. For example, the high human impact areas in Coral Bay, St. John, specifically mentioned in that document are outside park boundaries.

The network recognizes the importance of properly designing an effective monitoring protocol before engaging in data collection. This protocol structure is consistent with requirements established in Oakley et al. (2003). We were also guided by the work of Reynolds et al. (2016) to ensure all necessary and relevant components of a monitoring program were considered during the development of our SFCN seagrass protocol. The basic goal of this monitoring program is to expand upon the limited knowledge about seagrass in the areas of concern. However, the monitoring process is iterative in nature, and may lead to future management actions. Thus, future monitoring efforts may be modified and adapted in response to results from data analysis.

Conceptual Framework for Monitoring

The purpose for establishing the South Florida/Caribbean Network included the selection and monitoring of a set of biotic and abiotic natural resources. These “Vital Signs” were chosen as indicators of the overall health and condition of natural resources within each network park. The Marine Benthic Communities vital sign specifically includes seagrass as a target resource for monitoring in the network (Patterson et al. 2008).

Seagrass communities in SFCN parks have been exposed to significant anthropogenic stress, such as eutrophication and changes in salinity patterns associated with water management in south Florida, among other effects. The geographical characteristics associated with watershed drainage from populated areas into an estuarine-like area may be a concern at Salt River Bay NHP&EP, but seagrass communities in Virgin Islands parks are generally well flushed by oceanic currents. Altered salinity and eutrophication tends to occur in shallower embayments associated with rather large watersheds, such as Florida and Biscayne Bays. Anchor damage has also caused impacts to seagrass

communities in the Virgin Islands NP, and more recently, an invasive exotic seagrass species has been responsible for as yet poorly understood community changes in the U.S. Virgin Islands. Natural disturbances such as extreme storm events may affect seagrass communities throughout the network (Table 1).

Table 1. Factors affecting seagrass ecosystem change within South Florida/Caribbean Network (SFCN) parks and potential measures for vital signs monitoring. Measures in *italic*¹ are addressed through other monitoring initiatives by NPS or partners.

Stressor	Perturbation	Metric
Water Quality (changes in nutrients, turbidity, salinity)	Sediment runoff, disturbance from boats, and algal blooms can increase turbidity; nutrient enrichment can be caused by local island, large cruise ships or more distant sewage treatment or agricultural runoff problems; changes in salinity occur in bays and estuaries due to changes in amount and timing of freshwater flows.	Seagrass cover and community composition. ¹ <i>Partners are monitoring seagrass in Florida Bay and Biscayne Bay which are likely to be affected by large changes in salinity and agricultural inputs.</i>
Invasive exotic species	<i>H. stipulacea</i> has invaded seagrass habitat in VIIS and BUIS with unknown consequences. It has also been observed in previously bare soft-bottom areas.	Seagrass cover and community composition.
Storm Events	Vulnerability to extreme weather events such as tropical storms and hurricanes that can damage and/or alter seagrass habitat	Seagrass cover and community composition.
Disturbance / Visitor Use	Boats can damage seagrass in shallow areas with groundings and propeller scars and in deeper areas with anchor damage. Parks are implementing mooring buoy zones and education programs to diminish the effects.	¹ <i>Localized changes in seagrass cover and community composition in areas of known problems. ¹VIIS is conducting monitoring in mooring ball zones. ¹EVER has created maps of seagrass scarring in Florida Bay. ¹BISC does restoration monitoring of boat grounding scars.</i>

Measurable Objectives

The primary objective of this protocol is to monitor trends in seagrass cover, community composition and the presence of invasive exotic species within mapped seagrass habitat in offshore Biscayne NP, Buck Island Reef NM, Salt River Bay NHP&EP, and Virgin Islands NP (Figures A1-1 to A1-4). Secondary objectives for the SFCN seagrass protocol are:

- Collect ancillary information (i.e., water depth, sediment depth, substrate type, canopy height and *Lobatus gigas* [Queen Conch] count) that can be used to improve understanding of seagrass species and habitat relationships or provide information to support another vital sign.

- When requested by park management and logistically feasible, compare trends in seagrass cover, species composition, and the presence of invasive exotic species within and outside of parks to evaluate the effectiveness of park management actions.
- When requested by park management and logistically feasible, perform additional “episodic” monitoring in response to unforeseen events or circumstances.

Note that secondary objectives two and three are not currently part of this protocol and would require a separate study design and analytical plan prior to field work being approved. The design and analyses for such studies are expected to be straightforward extensions of this protocol, and the field methods will be identical to this protocol.

Benthic mapping (Tier 1 of the Texas seagrass program) is performed by remote sensing through NPS partners or contracts and will not be part of this protocol. The South Florida/Caribbean Network will use the most current and accurate benthic maps available. The focus of this protocol is to inventory and monitor the seagrass cover and community composition of seagrass communities within the network where other such efforts do not exist (Patterson et al. 2008). This monitoring focuses on changes happening within seagrass communities which are not detectable via remote sensing. Monitoring results may inform park managers and stakeholders on the effectiveness of seagrass conservation and management within their boundaries. The primary objectives of the SFCN seagrass protocol are consistent with the first objective stated in Dunton et al. (2011); to *“design a monitoring program to detect environmental changes with a focus on the ecological integrity of seagrass habitats.”* The second and third objectives of the Texas seagrass protocol, namely to *“provide insight to the ecological consequences of these changes”* and *“help decision makers ... determine if the observed change necessitated a revision of regulatory or management policy or practices,”* are program specific (Dunton et al. 2011). Likewise, the secondary objectives of the SFCN seagrass protocol address specific network concerns. A comparison between the Texas and SFCN protocol parameters can be seen in Table 2.

Table 2. Comparison between the SFCN seagrass protocol and the Texas protocol.

Feature	SFCN Seagrass	Texas Seagrass
Map products	Available maps	Remote sensing products
Target Population	Mapped soft-bottom with seagrass cover less than 30m depth contained within park boundaries (VIIS, BUIS, SARI and offshore BISC)	Six major estuarine systems in Texas
Sample grid	None	Tessellated hexagons 500 meters on a side
Classification	Mapped seagrass habitat polygons on unconsolidated sediment	Scheme rules not discussed. Defined by macroalgae accumulations, bare patches and gaps of 1-2 m ² , and deep water edge of seagrass beds

Table 2 (continued). Comparison between the SFCN seagrass protocol and the Texas protocol.

Feature	SFCN Seagrass	Texas Seagrass
Stratification	Stratified into three depth classifications; post-stratify testing of seagrass map classes and possible incorporation of them as additional strata at a later date. Stratification can change as described in SOP 2 <i>Stratification</i>	Not discussed
Selection	Stratified random selection of points within sample frame; new random selection with each survey; samples are proportionally allocated within each stratum initially with numbers revised in future sampling to optimize sampling power; GRTS sample allocation also permissible to create spatial balance.	Random selection of fixed points within tessellated hexagons in habitat no deeper than 2 meters, with exceptions. Sample site is 10 meter radius of fixed point.
Schedule	Triennial sampling in mid to late summer	Annual sampling following peak seagrass standing crop (mid to late summer)

The South Florida/Caribbean Network is not monitoring water-quality parameters as part of this protocol. Single measurements in time of turbidity, salinity, dissolved oxygen, and pH are unlikely to be meaningful in interpreting trends at these offshore oceanic monitoring locations. At present, in Biscayne NP and Buck Island Reef NM, park staff and partners are collecting water-quality data which can be associated with seagrass monitoring results. The network may consider adding parameters such as seagrass tissue nutrient content and using continuous water-quality loggers in the future as time and funding permits.

Sampling Design and Monitoring Schedule

The target population for this protocol is all mapped seagrass habitat less than 30 meters (98.4 ft) deep and excluding areas not safely feasible to sample (i.e., high boat traffic areas), areas unreachable by boat, and areas with water-quality concerns (i.e., Salt River Bay). The sample frame is identical to this defined target population. The design is a stratified random survey within the sample frame. Samples are stratified by depth within each park (shallow, mid-depth, deep) but may be modified in the future.

The network will conduct seagrass monitoring at Buck Island Reef NM, Salt River Bay NHP&EP, offshore Biscayne NP, and Virgin Islands NP. The sample size in each domain will be park specific and shall be determined by resource limitations as informed by pilot survey data. The South Florida/Caribbean Network shall initially allocate 10 sampling days per park, but may revise this number as informed by data or limited by available resources. Sampling intensity will also be park specific, informed by power analysis of pilot survey data. Note that some project-specific monitoring is already being conducted by individual park staff. Biscayne NP staff members already monitor seagrass restoration sites, and Virgin Islands National Park monitors seagrass to determine the effectiveness of mooring buoy installation on seagrass recovery.

The poor quality of the water, marina boat traffic, and uncharted sunken wrecks in Salt River Bay NHP where seagrass beds exist are presumed to be hazardous to divers; thus, the South Florida/Caribbean Network will not conduct in situ monitoring inside the bay. Seagrass monitoring at Salt River Bay NHP&EP will be limited to the area mapped in the offshore canyon of the preserve. In Biscayne National Park, areas within the channel markers of Caesar's Creek and the Biscayne Channel as well as east of Lewis Cut are excluded for safety reasons.

Sampling Design and Modifications

The SFCN seagrass survey design is further described in SOP 1 *Sample frame and habitat classification*, SOP 2 *Stratification*, SOP 3 *Creating a Seagrass Layer, Merging with Bathymetry Layer, and Assigning Strata*, and SOP 4 *Sample allocation* (Davis et al. 2019).

The SFCN seagrass protocol targets soft-bottom habitat (unconsolidated habitat) polygons classified as seagrass. The estimated area of seagrass from benthic polygons within each park that is within the target population is listed in Table 3. For all parks, available benthic maps are used to combine all mapped seagrass polygons regardless of density into one "seagrass" stratum. Areas that have become temporarily bare (e.g., blow outs from a storm) are still considered part of the sample frame. U.S. Virgin Islands benthic maps define seagrass as a major biological cover found on unconsolidated sediment which includes sand, mud, and sand with scattered coral and rock (Zitello et al. 2009). Seagrass habitat was described as having 10% or more of the mapping unit dominated by any single species of seagrass (e.g. *Syringodium* sp., *Thalassia* sp., and *Halophila* sp.) or a combination of several species. The south Florida benthic map also defines seagrass as continuous or discontinuous biotic cover of 10% or more on unconsolidated sediment (Estep et al., 2017).

Table 3. Seagrass extent (ha) estimated by initial strata (< 5 m, 5 – 15 m, > 15 m depth) and by park and initial proposed sample size. The allocation of BUIS samples in less than 5 meters depth were increased to 15 sites to ensure sufficient sampling effort. Small strata in SARI and BISC were merged with adjacent strata.

Park	Area (ha)	Area < 5 meters (ha)	Area 5 - 15 meters (ha)	Area > 15 meters (ha)	Sample Points Total	Sample Points < 5 meters	Sample Points 5 - 15 meters	Sample Points > 15 meters
VIIS	383.4	67.1	209.8	105.5	100	18	55	28
BUIS	270.2	20.6	191.1	58.4	80	15	50	15
SARI	2.1	0.0	0.7	1.4	20	–	Merge with > 15 m stratum	20
BISC	22,792.6	5,869.7	16,900.0	15.7	100	26	74	Merge with 5-15 m stratum

Bathymetry layers will be combined with the seagrass layer to create depth strata. Evidence from several studies appears to suggest *S. filiforme* replaces *T. testudinum* in the U.S. Virgin Islands as depth increases (Kumpf and Randall, 1961; Campbell et al. 1983; Beets and Muehlstein 2005). Beets and Muehlstein (2005) showed that at least in one site, this replacement seems to occur at the 4–5 meter (13.1–16.4 ft) depth range. In Florida *T. testudinum* also occurs at shallower depths than *S. filiforme* (Zieman and Zieman 1989; Fourqurean et al. 2001). Fourqurean et al. (2001) characterized the mean depth of *T. testudinum* at 3 meters (9.8 ft) and *S. filiforme* at 5.1 meters (16.7 ft) at their sites. All sampling domains will be stratified by depth in such a way as to allow an opportunity to better understand these differences and better improve estimates; the domains will be initially separated into less than 5-meter (16.4-ft), 5–15-meter (16.4–49.2-ft) and greater than 15-meter (49.2-ft) depth strata and points assigned as a proportional sample allocation. Strata are combined in some parks where there is minimal area of one depth stratum. The stratification may be modified following monitoring data analysis. This protocol shall consider the depth limits reported in Duarte (1991) as guidelines. Observers will take note of any seagrass species observed deeper than expected. Quadrat photos may be used to confirm the observation.

Map classifications for biological cover vary slightly between the U.S. Virgin Islands and south Florida. The biological cover for seagrass is defined as 10 to less than 50% cover, 50 to less than 90% cover and 90 to 100% cover in the US Virgin Islands; in south Florida maps it is defined descriptively as either discontinuous or continuous. In pilot work conducted on 49 seagrass surveys in Virgin Islands National Park, the actual total seagrass Braun-Blanquet cover score for areas classified as less than 50% seagrass cover and greater than 50% seagrass were virtually identical (2.81 vs. 2.87 respectively) with the main apparent difference being in seagrass community composition. However, this was based on limited pilot work in only one park. The South Florida/Caribbean Network will explore post-stratification by map class and may transition to adding seagrass map classes as additional strata if determined to be statistically valid and appropriate after initial sampling, e.g., such map classes are stable through time and reduce variance of estimates. The habitat classification scheme for benthic maps for USVI parks is from Kendall et al. (2001) and for the offshore Biscayne NP from Estep et al. (2017), which is based on the classification scheme in Madley et al. (2002).

Sample sizes are based on previous pilot survey work described in the *Detectable Level of Change* section of this protocol and are provided in Table 3 by park. The SFCN seagrass sampling design is iterative in nature, where sample design changes and improvements are driven by data analysis results. The sample allocation will start out as a proportional allocation (conservative) and then develop a more aggressive approach (adaptive) over time to reduce variance of the estimates in the survey. Most likely densities of two or three focal species for management (*Thalassia testudinum*, *Syringodium filiforme*, *Halophila stipulacea*) will be selected for optimization of the adaptive design (Brandt et al. 2009; Bryan et al. 2013).

Sample selection within each stratum will be a random selection, but a generalized random tessellation stratified (GRTS) sample selection can also be used within each stratum to promote a spatially-balanced sample of points.

Rationale for Selecting this Sampling Design over Others

The South Florida/Caribbean Network has chosen to use a random selection of sampling sites within each stratum. Site selection will be re-randomized each sampling event. While permanent sites tend to have smaller coefficients of variation through time than randomly selected sites that are not revisited, randomly allocating sites each sampling event within strata has the following benefits:

- Provides greater flexibility for a new sampling program as less *a priori* knowledge is needed about the most appropriate strata. Strata and sampling allocations within strata can be changed through time to reduce within-stratum variability, allocate more sites to strata of greater variability, and improve ability to detect change.
- No permanent markers are required if sites are randomized each sampling event. To achieve the full benefit of permanent sites, the actual measurements should be on the exact same quadrats every time, which requires permanent markers. Programs without permanent markers lose some of the benefits of using permanent sites.
- The total number of sites sampled per sampling event can change allowing monitoring to proceed in the face of changing number of staff and financial costs. Permanent site designs are less flexible if there is a need to alter or reallocate sampling effort.
- Randomly selecting sites each sampling event allows a larger total number of sites to be surveyed through time, allowing a greater spatial inventory of the resources in each park.
- Implementing a randomly selected Tier 2 design does not preclude the network from implementing Tier 3 of the Dunton et al. (2011) approach in the future. Tier 3 involves a smaller number of intensive permanent seagrass transects to complement the Tier 2 rapid assessment sampling.

This protocol will target random points within safely accessible areas of mapped seagrass polygons. The target population is thus mapped unconsolidated sediment with seagrass cover, and the sample frame is the portions of those polygons that can be safely accessed. Statistical inference can be made to all areas within the sample frame (safely accessible mapped seagrass polygons), but does not extend to areas that are not safe to sample or to areas that are not within mapped seagrass polygons.

Surveying precisely on a predetermined sampling location is not practical due to factors such as wind, waves, current, depth (either because the water is deep or too shallow), delays in deploying divers, and navigation precision. It is likely that a survey will not occur directly on a point due to these factors, but sampling will occur within 50 meters (164 ft) of a predetermined location. The actual location of the survey is recorded by a GPS carried by the divers. The survey is thus assigned to the in situ stratum (e.g., depth) and location sampled by the divers, not the predetermined sampling location.

Benthic Habitat Maps

The benthic habitats of the shallow-depth marine environment in and around the south Florida and Virgin Islands national parks were mapped using visual interpretation of acoustic and aerial imagery and provide a spatial framework for an improved monitoring sampling design (Kendall et al. 2001; Zitello et al. 2009; Estep et al. 2017). There is a degree of positional and interpretation uncertainty of

imagery however, particularly with increasing depth. The minimum mapping units (MMU) for identifying mapped habitats or features ranged from 1,000–5,000 square meters (10,764–53,820 ft²; Kendall et al. 2001; Zitello et al. 2009; Estep et al. 2017). An independent accuracy assessment for St. John revealed overall map accuracies of over 90% for major structure and cover classes, and 85.7% for detailed structure and cover classes. Similarly, an accuracy assessment of Biscayne NP habitat classes confirmed an exact accuracy of 80.2% and an acceptable accuracy of 94.4% (Estep et al. 2017). Although the polygon map classification has a high degree of accuracy, due to the problems already mentioned, the exact position of line work is less certain and is typically not tested in these maps. All partners involved in the multi-agency, multi-partner reef fish monitoring have a vested interest in updating the benthic maps and improving the accuracy of dependent surveys. As benthic maps are improved, those improvements will carry over into future improvements in seagrass surveys.

The sampling domain will be updated when new habitat maps become available. The National Centers for Coastal Ocean Science (NCCOS) Biogeography group is our federal partner primarily responsible for creating benthic habitat maps in our region. The USVI maps and Biscayne NP benthic habitat map were last updated in 2011 (NOAA 2012; Estep et al. 2017). The SFCN seagrass protocol will not attempt to capture the expansion of seagrass between map updates. The seagrass survey, due to costs and time constraints, will focus on known seagrass cover.

Considerations for Monitoring at Virgin Islands Coral Reef National Monument

The South Florida/Caribbean Network may conduct seagrass monitoring in Virgin Islands Coral Reef NM as network resources become available in the future. An additional consideration for expanded seagrass monitoring at the monument is the possibility that *H. stipulacea*, an invasive exotic species in the U.S. Virgin Islands, may have spread to this location after the latest benthic maps were developed.

Salt River Bay NHP & EP is only monitored in and near the canyon. Because it is a small area, only 20 points are allocated for the initial sample size and the two depth strata are merged.

In Buck Island Reef NM the number of points in the less than 5 meters (16.4 ft) stratum would proportionally have been allocated five points. This number was increased to fifteen samples to more effectively estimate metrics. As this area is primarily in the lagoon area that receives a lot of visitation pressure, the South Florida/Caribbean Network prefers to keep it as a separate stratum during at least the initial sample year.

The deepest depth stratum in Biscayne NP is so small in area, it is merged with the 5–15 meter (16.4–49.2 ft) stratum.

Monitoring Schedule

The South Florida/Caribbean Network shall perform field work according to a three-year rotation, where SFCN staff will visit one park every year; Buck Island Reef NM and Salt River Bay NHP&EP will be surveyed at the same time given the small size of Salt River Bay NHP&EP (Table 4). Current network resources do not permit a more intensive effort; however, the network may intensify initial

efforts to gather essential baseline data and may intensify future efforts with assistance from park staff and park resources. The network may perform episodic monitoring in response to discrete and unusual events such as storms at the request of a park’s natural resource manager. Sampling will take place at peak seagrass productivity periods, during the summer months.

Table 4. The SFCN seagrass protocol proposed sampling schedule.

Park	Season
VIIS	Summer (June–September), every three years beginning in Year 1
BUIS and SARI	Summer (June–September), every three years beginning in Year 2
Offshore BISC	Summer (June–September), every three years beginning in Year 3

Detectable Level of Change

The South Florida/Caribbean Network conducted a pilot test of 49 sites mapped as seagrass in Virgin Islands NP (Appendix B). This pilot test supported the assumption that stratifying by depth would reduce the variance in estimates of average seagrass cover. The pilot test also showed that map polygons having less than 50% seagrass cover compared with those having greater than or equal to 50% cover had virtually identical total seagrass percent cover, although community composition appeared to differ. We will continue using a stratification based on three depth classes, and as more data are collected we will use post-stratified analyses to investigate the utility of stratifying by map classes.

The pilot data were used to estimate the change detectable with varying levels of sample effort (Table 5, Table 6, and Appendix B) at the 5% significance level with 80% power using a 2 sample, 2-tailed t-test. Additional calculations are provided in Appendix B. Average Braun-Blanquet scores were used in the calculations; these are preliminary analyses based on limited pilot data and parametric statistics were used to provide a rough estimate of the sample sizes needed. More appropriate analyses and power analyses using ordinal regression methods will be applied when additional field data have been collected. The design targets a minimum detectable change in percent cover of 0.5 Braun-Blanquet score and in percent of sites occupied (frequency) of 20%. The pilot project data showed the preferred sampling allocation changes depending on the focal seagrass species (Appendix B).

Table 5. Average Braun-Blanquet (BB) score for pilot data plus detectable differences for sampling at the 5% significance level with 80% power with differing sample sizes.

Sample Allocation	# sites	Variable	Target	SFIL	HSTI	TTES	RMAR	HWRI	HDEC
Pilot Data	49	Avg. BB Score	–	1.56	1.38	0.31	0.06	0.02	0.01
Complete Random (no strata)	50	Detectable Difference	0.5	0.39	0.59	0.28	0.10	0.03	0.02
	100	Detectable Difference	0.5	0.27	0.41	0.20	0.07	0.02	0.02
	150	Detectable Difference	0.5	0.22	0.34	0.16	0.06	0.02	0.01

Table 6. Average frequency of occurrence for pilot data plus detectable differences for sampling at the 5% significance level with 80% power with differing sample sizes.

Sample Allocation	# sites	Variable	Target	SFIL	HSTI	TTES	RMAR	HWRI	HDEC
Pilot Data	49	Frequency	–	77%	40%	20%	3%	3%	1%
Complete Random (no strata)	50	Detectable Difference	20%	17%	18%	15%	6%	4%	3%
	100	Detectable Difference	20%	12%	13%	11%	4%	3%	2%
	150	Detectable Difference	20%	10%	10%	9%	3%	2%	2%

Field Methods—What is Being Measured and How

The field methods described in this protocol were adapted from the Texas seagrass protocol, with modifications as described in Tables 8 and 9, and are consistent with prerequisites recommended by Fourqurean and Rutten (2003). The Braun-Blanquet method is an ordinal classification system used to estimate percent seagrass cover, and is further described in SOP 5 *Field Methods*. It is also important to consider the field methods that regional partners use, since seagrass ecosystems in south Florida and in the Caribbean differ from those in the Gulf of Mexico (Zieman 1982; Fourqurean et al. 2001; Onuf 2007). Modifications from the original protocols are separated into two categories. The general field methods modifications describe changes from the original protocols that address ecosystem characteristics and allow for consistency with regional methodology (Table 7). Additionally, Table 8 describes specific field method modifications that characterize deviations from Tier 2 methods in the Texas seagrass protocol based on similar considerations.

Table 7. General field method modifications of the Texas seagrass protocol for the SFCN seagrass protocol.

Field methods	SFCN seagrass protocol	Texas seagrass protocol
Tier 2	Implemented as described in SOP 5 <i>Field Methods</i> ; water quality data and most other stressor-related data will not be collected; new random sites selected for each survey within each stratum	Broad-scale, rapid assessment of randomized fixed sample station surveys in designated domain to characterize the system based on specific biotic and abiotic properties of the water column, seagrasses and sediments
Tier 3	Tier 3 will not be performed initially, but may be added in the future	Integrated landscape approach at permanent stations to examine the presumptive factors associated with changes in seagrass maximum depth limits and patchiness

Table 8. Specific survey design and field method modifications of Tier 2 of the Texas seagrass protocol for the SFCN seagrass protocol.

Survey design component or field method	SFCN seagrass protocol	Texas seagrass protocol
Sampling unit	Four haphazard quadrats per random site	Four quadrats per random site, one at each cardinal direction
Sampling site	Surveyors navigate to the sampling coordinates; four quadrats are haphazardly thrown at the site	Surveyors navigate to a 10 meter radius from the GPS station within each tessellated hexagon

Table 8 (continued). Specific survey design and field method modifications of Tier 2 of the Texas seagrass protocol for the SFCN seagrass protocol.

Survey design component or field method	SFCN seagrass protocol	Texas seagrass protocol
Sampling method: seagrass cover	Estimate BB cover categories within 0.25 m ² quadrats. Direct in situ measurement using mask and snorkel or Self-Contained Underwater Breathing Apparatus (SCUBA)	Estimate percent cover within 0.25 m ² quadrats using an underwater digital camera mounted to the quadrat frame, or in shallow water, through direct observation. If water transparency is extremely poor, make direct in situ measurements using a mask and snorkel
Sampling method: habitat assessment and morphometric data	Measure sediment depth, classify sediment type, canopy height, water depth, current and visibility. Habitat assessment is a visual survey to determine if the habitat observed is consistent with the polygon classification. These methods are described in SOP 5 <i>Field Methods</i>	Obtain hydrographic measurements, in vitro water quality testing, morphometric data, biomass, shoot density, classify sediment type
Personnel commitments	Boat crew of at least three (boat operator + two divers); commitment of ten days for each park	Crew of two from a shallow-draft vessel. Commitment of one to three 12-hr days per region

Table 9. Supplementary monitoring metrics, field methods and variables measured at South Florida/Caribbean Network parks in Tier 2 of the SFCN seagrass protocol.

Metric	Area Sampled	Temporal Design	Sampling Method	Data Collected	Purpose
Sediment depth	Inside each BB quadrat	Concurrent with BB surveys	Metric measurement of sediment with probe	Depth of sediment to bedrock, up to 1 meter in depth	Improve descriptive associations with different seagrass species
Substrate type	Inside each BB quadrat	Concurrent with BB surveys	Identification from sediment composition	Sediment characteristics	Improve descriptive associations with different seagrass species
Canopy height	Inside each BB quadrat	Concurrent with BB surveys	Metric measurement of average canopy height	Average height of seagrass canopy per species	Improve descriptive associations with different seagrass species; association with environmental variables
Water depth	Sample site	Concurrent with BB surveys	Recorded from dive computer	Bottom depth at diver's survey location in feet	Characterize site

Table 9 (continued). Supplementary monitoring metrics, field methods and variables measured at South Florida/Caribbean Network parks in Tier 2 of the SFCN seagrass protocol.

Metric	Area Sampled	Temporal Design	Sampling Method	Data Collected	Purpose
Current	Sample site	Concurrent with BB surveys	Diver estimate	Underwater current speed – none, moderate, high	Characterize survey conditions
Visibility	Sample site	Concurrent with BB surveys	Diver estimate	Horizontal visibility limit in feet	Characterize survey conditions
Number of Queen Conch present	Sample site	Concurrent with BB surveys	Visually identify and count number of Queen Conch	Number of Queen Conch present within a 7.5 m radius of site	Detection of Queen Conch aggregations to support Queen Conch protocol

Monitoring Methods

The primary monitoring objective is to determine trends in seagrass cover, composition, and the presence of invasive exotic species within the specified sampling domain of the parks. Visual percent cover estimations are advantageous because they allow for larger sample sizes, reduced sampling error, and more accurate results than more time consuming random-point quadrat counts (Dethier 1993; Furman et al. 2018). Regional partners monitoring seagrass have consistently relied on the BB method described in Fourqurean et al. (2001). The monitoring design and methods adapted for the region are now extensively used and serve as a template for work in other areas of south Florida and the Gulf of Mexico (Lirman et al. 2008; Dunton et al. 2011; Hall and Carlson Jr. 2015). Neckles (2012) determined that four 0.25-square meter (2.7-ft²) quadrats provided 80% probability that the expected value for overall mean percent cover was within 5% of the true mean.

The SFCN protocol is a rapid assessment of seagrass habitat using BB surveys and environmental measurements at stratified random sites. This is compatible with the method described for monitoring Florida Bay seagrasses by Fourqurean et al. (2001), and approximates the mid-scale (Tier-2) monitoring included in the Texas seagrass protocol. Divers will also conduct a general site survey to determine if the observed benthic community at a site is consistent with the mapped habitat classification and search for conch. The Texas protocol also includes mapping (Tier 1) and intensive sampling of a reduced number of sites (Tier 3), but due to resource constraints, monitoring at these scales will not be incorporated in the SFCN protocol. The South Florida/Caribbean Network will work collaboratively with partners to facilitate map updates as well as intensive stressor-response assessments.

The boat driver navigates to the point location identified for the survey, attempting to get within 10 meters (32.8 ft) of the point. The intent is that despite boat and diver drift, the actual quadrat samples are within 50 meters (164 ft) of the pre-established random coordinate and are within the map polygon. Two divers are deployed over soft-bottom habitat and close enough to each other to maintain diver safety. Each diver haphazardly deploys two 0.25 square meter (2.7 ft²) quadrats by

throwing them at random directions away from the body. No attempt is made to place quadrats on any particular type of soft-bottom habitat. If a quadrat lands on hard-bottom habitat however, it will be tossed again. Seagrass species and algae species cover are estimated using Braun-Blanquet (BB) scores. Field methods are further described in SOP 5 *Field methods* (Davis et al. 2019).

Regional partners monitoring seagrass collect additional data beyond what is described here. Some of these data are of general interest to the network, while other data may be useful to expand the general knowledge of seagrass ecology throughout the region. Seagrass monitoring also provides an opportunity to collect supplementary data that can inform other SFCN vital signs. The South Florida/Caribbean Network will record additional parameters that do not appreciably increase monitoring effort at each site (Table 9).

Braun-Blanquet Sampling Methods

Submerged Aquatic Vegetation (SAV) cover in a BB quadrat is defined by Fourqurean et al. (2001) as “the fraction of the total quadrat area that is obscured by a particular species when viewed from directly above.” Scores are estimated in categorical values ranging from 0 to 5 (Fourqurean et al. 2001 and SOP 5 *Field methods*; Davis et al. 2019). Training procedures are described in SOP 6 *Training* (Davis et al. 2019).

Permitting and Compliance

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.

Data Management, Analysis, and Reporting

Data Management

Seagrass data will ultimately become available in the public domain. Appropriate procedures must be followed from the time data are collected in the field until they are certified and exported into databases available to the public. The network will perform data analysis and produce results and reports in formats available to the public.

Steps for seagrass data flow:

- Braun-Blanquet (BB) and associated data are recorded on standard field datasheets printed on waterproof paper for use underwater.
- Recorded BB and associated data are entered into the “seagrass database,” a local NPStoret database on the SFCN server. The data are entered as “Preliminary” in the seagrass database and the data quality at this point is considered “Raw.”
- Once the SFCN project leader has verified that all the data have been entered for a trip, the diver (observer) that collected the data will open the NPStoret database and perform a 100% quality assurance (QA) check to confirm the data on their field form has been accurately entered. Errors will be corrected if they are encountered. Once the quality assurance check has been fully performed the data are changed to “Verified” in the NPStoret seagrass database and the data quality is considered “Provisional.”
- Once all data for a trip are entered and checked, the project leader performs data validation checks to look for outliers, unrealistic values, and other extreme entries. Any problems in the data are documented and records are flagged to allow for inclusion or exclusion during later analysis. If numerous errors are found in this step, the project leader or data manager may request a second 100% QA check. After completion of this review the data quality is changed to “Final” in the NPStoret seagrass database and is considered “Certified” if a Quality Assurance Plan (QAP) is in place; otherwise, the data quality is considered “Accepted.”
- The final tabular data will be sent to the Water Resource Division of the National Park Service in Fort Collins, Colorado annually so it can be incorporated into NPS Environmental Quality Information System (EQuIS) database. From there, the data are exported to the Environmental Protection Agency’s Storage and Retrieval (STORET) database. Data from STORET are publicly available at <https://www.epa.gov/storet>. The STORET data are also exported to the National Water Quality Monitoring Council, where they are publicly available through the Water Quality Portal at <https://www.waterqualitydata.us/>.
- Additional records from this protocol, including scanned datasheets and field photographs, will be archived on the [NPS Data Store](#).
- The data will be analyzed and resulting products will be stored locally. The marine ecologist and project lead are responsible for analyses and reports. Data summary reports and resource briefs will be created annually and shared on NPS Data Store. After each park is revisited (every three years) a separate trend report will be created and shared on NPS Data Store. The

marine ecologist is responsible for updating graphs and completing appropriate analysis for these reports.

The types of data to be collected and requisite processing steps as part of SFCN seagrass protocol are listed in Table 10. Data entry and QA/QC are further described in SOP 7 *Entering, Verifying and Performing a 100% QA/QC Check of Seagrass Data in the NPStoret Seagrass Database* (Davis et al. 2019). Data review, certification and export are further described in SOP 8 *Review, Certification and Export to Microsoft Excel, EQuIS and STORET* (SFCN 2017). Table 10 summarizes the data process and certification procedures.

Table 10. Data processing and certification matrix for the SFCN seagrass protocol.

Data Quality Level	Data Processing Level 0 (Unprocessed)	Data Processing Level 1 (Entered/Validated)	Data Processing Level 2 (Analysis)
Raw	BB data are collected in the field on waterproof paper. Field notes are taken to record general field observations that may be of interest. Paper field forms are archived locally, scanned, and uploaded to NPS Data Store. Field forms are managed as long-term program records.	Data entered from paper field forms into a local NPStoret database	–
Provisional	–	A 100% proofing of the data entered into the database will be checked by the observer (diver) against the field forms.	–
Certified	–	Data in office database are reviewed for problems by the marine ecologist and data manager using data plots and calculations. Problem data are flagged if they should not be used and annotated with documentation to support the decision to exclude from analyses. The marine ecologist or data manager may request a second 100% quality assurance check when too many errors are found. After this review the data are flagged as accepted or certified in the database. The final data are exported to WRD for inclusion in EQuIS and STORET.	Accepted/certified data are exported and processed for analysis. Once analysis is complete scripts, reports, any other products are created locally and archived on NPS Data Store. Seagrass data summary reports and resource briefs will be developed yearly. Trend reports will be developed after a park has been revisited (every 3 years).

Protected Data

There are currently no threatened or endangered species that may be recorded when implementing this protocol. Queen Conch is a commercially prohibited (no-take) species in Florida and a commercially harvested species in USVI waters. 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. Permission must be given and documented by individual park managers prior to the release of any Queen Conch-related data, particularly specific locations of Queen Conch during sampling. If the park manager deems locational data to be protected from public release, specific locations of Queen Conch will be protected by altering each of the locations up to 1 kilometer (0.62 miles) by random direction and distance. Locations of cultural resources accidentally discovered during sampling will be restricted to NPS staff and communicated to the associated park.

Data Summary

Seagrass cover class, species cover class, frequency and richness will be calculated at a site level according to procedures described in Fourqurean et al. (2001; 2002). Summaries in tables and graphs will use means of Braun-Blanquet scores, which is supported by van der Mareel (2007) and Furman et al. (2018) and is consistent with work completed in our region by Manuel et al. (2013), Bourque and Fourqurean (2014), Hall et al. (2016) and Cole et al. (2018). 95% Confidence Intervals will be bootstrapped. This approach provides easily understood displays of the data to resource managers. Statistical analyses for change and trends will use statistical methods designed for ordinal data such as ordinal regression (Guisan and Harrell 2000, Irvine and Rodhouse 2010; Damgaard 2014) or Kruskal-Wallis test (multiple years) or Mann-Whitney U-test (between years).

Cover class (D): $D_i = \frac{\sum_{j=1}^n S_{ij}}{n}$, where D_i = Cover class of species i ; j = quadrat number from 1 to n (the total number of quadrats sampled at a site); and S_{ij} = the Braun-Blanquet score for species i in quadrat j .

Frequency (P): $P_i = \frac{N_i}{n}$; such that $0 \leq P_i \leq 1$, where P_i = Frequency of species i ; N_i = the number of quadrats at a site in which species i was present; and n = the total number of quadrats sampled at a site.

Native Species Richness (S): count of all native seagrass species for which $D > 0$ across all four quadrats at a site.

These variables will be used to calculate measures by stratum and for the sampling domain (combined strata) as described in SOP 9 *Data Summaries, Analysis and Reporting* (Davis et al. 2019).

Cover Class: The following descriptive statistics will be reported by stratum for total seagrass cover, cover by seagrass species, total algal cover and cover by algal species or type: average, maximum,

minimum, 95% Confidence Limits, median, quartiles, and proportion of points using the BB score category.

Frequency: Frequency descriptive statistics will be reported by stratum and for the sampling domain (combined strata) for total seagrass, each seagrass species, total algae, each algal species or type.

Distribution: Kriged maps will be used to display the distribution of different seagrass species. Mapped seagrass extent and shoreline boundaries will be used to bound interpolations of percent cover estimates based on BB classes (Dunton et al. 2011; pers. comm. Ken Dunton).

Native Species Richness: Native seagrass species richness pooled across quadrats per site will be reported. In addition, new seagrass species will be flagged and reported.

Change Detection

Change in cover class and frequency will be calculated within strata and across strata as described in SOP 9 *Data Summaries, Analysis, and Reporting* (Davis et al. 2019). As mentioned above, for seagrass cover metrics based on BB scores, the South Florida/Caribbean Network will use statistical methods designed for ordinal data such as ordinal regression (Guisan and Harrell 2000, Irvine and Rodhouse 2010; Damgaard 2014) or Kruskal-Wallis test (multiple years) or Mann-Whitney U-test (between years). Recently developed ordinal beta models can link category probabilities to continuous variables such as percent cover (Irvine and Rodhouse 2010; Irvine et al. 2016) and use of ordinal regression is appropriate for the interpretation of trends in hierarchical cover classes, such as Braun-Blanquet data (Guisan and Harrell 2000; Irvine and Rodhouse 2010; Damgaard 2014). Cumulative logit models and ordinal beta models are applicable for trend analysis on ordered categorical variables used to visually estimate cover classes using areal plots. Logistic regression models, particularly with unequal cover class intervals, can effectively summarize changes in ranked data and are considered mathematically more appropriate than least squares linear regression modeling using cover class midpoints (Yeo et al. 2009).

For frequency data, means and confidence intervals can be determined by the formulas described in SOP 9. There are two approaches to assessing changes in frequency and species richness 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., binomial for frequency data and Poisson or negative binomial for species richness).

Analyses will be conducted in R. Code will be developed subsequent to publication of this protocol but procedures are available for conducting these analyses in R. R and JAG code for implementation of the ordinal beta hurdle model and POM is available at:

<https://irma.nps.gov/DataStore/Reference/Profile/2231866> (Irvine and Rodhouse 2010; Irvine et al.

2016). R code associated with bootstrapping routines for similar analyses of spiny lobster is found in Appendix G of Richter et al. (2018; <https://irma.nps.gov/DataStore/Reference/Profile/2258540>).

Additional work and analyses

The South Florida/Caribbean Network will explore whether post-stratifying by seagrass map class (e.g., continuous vs. discontinuous) reduces variance in the estimates of cover and frequency. We may transition to adding seagrass map classes as additional strata in a future version of the protocol if determined to be statistically valid and appropriate after initial sampling, (e.g., such map classes are stable through time and reduce variance of estimates). Other factors such as distance from polygon edge will also be explored using post-stratification or other methods.

As mentioned above, ordinal analysis will be used (Irvine and Rodhouse 2010) in the analyses of BB data described in this protocol. However to increase flexibility in analysis tools available in future versions of the protocol, we may follow up on the work of Furman et al. (2018) that found applying parametric analyses to raw BB scores to be a valid approach. This analysis did not explore the effects of some common sources of error in BB data, so further simulations are needed to test for the behavior of BB values or transformed percent cover values collected with four quadrats, zero inflation, and empirical distribution of cover values and estimation variance, with consideration of false positives and unbiasedness of estimates and power. If found valid, this may allow additional methods to be utilized in future trend analyses in a future version of the protocol.

Transformation to percent cover may be useful and more intuitive for data summarization and plot graphics in the future. Consequently, the network will explore methods to convert BB scores to percent cover estimates that are considered valid. For example, a log-linear transformation of the BB data to percent cover can be accomplished following the van der Maarel (2007) conversion to the van der Maarel (1979) ordinal scale, where *OTV* is the ordinal transform value,

$$\ln(C) = \frac{(OTV - 2)}{a}$$

C is percent cover, and *a* is a weighting factor (1.380). This transformation outperformed the midpoint (median) method in simulations representing the multi-story mixed seagrass meadow and macroalgal communities found in Florida (Furman et al. 2018).

Reporting

A Natural Resource Report Series (NRR) will be produced every six years describing the sampling effort and the summary metrics, basic change analyses, graphs, and maps described above and in SOP 9 *Data Summaries, Analysis, and Reporting* (Davis et al. 2019). The South Florida/Caribbean Network will annually produce resource briefs.

Budget

Startup costs, reported in Full Time Equivalent (FTE) hours, include approximately \$200 for BB quadrats and other miscellaneous equipment. For the field sampling effort, there will be a labor cost of \$7,500 for the Marine Ecologist (0.06 FTE), \$7,000 for the Fisheries Ecologist (0.06 FTE), \$7,584 for the Seagrass Project Leader (a Biological Science Technician; 0.10 FTE), and \$9,100 for two additional Biological Science Technicians (0.06 FTE each). For the analysis and reporting effort, there will be a labor cost of \$2,500 for the Marine Ecologist (0.02 FTE), \$1,516 for the Seagrass Project Leader (0.02 FTE), \$2,000 for the Assistant Data Manager (0.05 FTE), \$4,600 for the Data Manager (0.05 FTE), and \$6,400 for the Quantitative Ecologist (0.05 FTE). The estimated annual costs for the SFCN seagrass protocol are presented in Table 11. Field work is dependent on in-kind support from respective parks for boat time and staff.

Table 11. Estimated annual operating cost (based on FY2016 dollars) for the SFCN seagrass protocol. Budget does not include support provided by parks or partners.

Category	Parameter	Costs (FY 2016)	Notes
Personnel SFCN	Marine Ecologist	\$10,000	0.08 FTE GS-12
	Fisheries Ecologist	\$7,000	0.06 FTE GS-11
	Biological Science Technicians ¹	\$18,200	0.24 FTE GS-7
	Data Manager ²	\$4,600	0.05 FTE GS-12
	Assistant Data Manager	\$2,000	0.05 FTE GS-7/9
	Quantitative Ecologist	\$6,400	0.05 FTE GS-12
	Total Personnel Costs³	\$48,200	–
Equipment & Supplies	Marine supplies and Maintenance	\$1,000	0.10 (10%) for 2 SFCN vessels
	Boat Fuel	\$430	0.10 (10%) of annual fuel costs
	Field Supplies	\$1,200	0.10 (10%) of scuba and field supplies
	Total Equipment Costs	\$2,630	–
Travel	Travel: BUIS/SARI	\$8,400	Boat transport (2) and air (2) to STX
	Travel: VIIS	\$4,400	Air (2) to STJ
	Travel: BISC	\$0	Monitored by SFCN Miami & BISC

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

² A portion of all personnel time is devoted to data management and activities including data entry, analysis, Quality Assurance/Quality Control, and reporting. This is in accordance with NPS I&M policies recommending that at least 30% of monitoring resources be allocated to data management, analysis, and reporting.

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

⁴ Average annual travel is 0.33 of the sum of monitoring costs in each park, since each park is surveyed every 3 yrs.

Table 11 (continued). Estimated annual operating cost (based on FY2016 dollars) for the SFCN seagrass protocol. Budget does not include support provided by parks or partners.

Category	Parameter	Costs (FY 2016)	Notes
Travel (continued)	Total Travel Costs⁴	\$4,267	–
Total Annual Protocol Cost		\$55,097	–

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

² A portion of all personnel time is devoted to data management and activities including data entry, analysis, Quality Assurance/Quality Control, and reporting. This is in accordance with NPS I&M policies recommending that at least 30% of monitoring resources be allocated to data management, analysis, and reporting.

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

⁴ Average annual travel is 0.33 of the sum of monitoring costs in each park, since each park is surveyed every 3 yrs.

Personnel Requirements, Training and Safety

Roles and Responsibilities

The field procedures in this protocol for observers can be implemented by any qualified and properly-trained dive team member. The initial data entry is performed by each individual observer, who double checks entered data against the original data sheet as a Quality Assurance/Quality Control (QA/QC) step. The SFCN project leader is responsible for planning and logistics, ensuring all seagrass data are entered timely, and assisting the data manager and marine ecologist with data review, analysis and reporting. The marine ecologist and data manager will review the entered data for accuracy using data plots and calculations. The data manager is responsible for certifying the data, managing the database and archiving annual data sets. The assistant data manager helps with these tasks. The marine ecologist is responsible for assisting with analysis and reports and assisting the data manager to maintain data quality. The SFCN project leader also produces the seagrass reports under the supervision of the marine ecologist.

Rules and regulations applicable to the performance of these tasks shall be observed, with particular note to individual park policies.

Contacts

- Mike Feeley (Principal Investigator and NPS Lead), Marine Ecologist, National Park Service, South Florida/Caribbean Network, 18001 Old Cutler Road, Suite 419, Palmetto Bay, FL 33157. 786-249-0036. michael.feeley@nps.gov
- Thomas Kelley (Co-Principal Investigator), Biologist, Virgin Islands National Park, 1300 Cruz Bay Creek, St. John, VI 00830. 340-693-8950. thomas_kelley@nps.gov
- Vanessa McDonough (Co-Principal Investigator), Fishery and Wildlife Biologist, Biscayne National Park, 9700 SW 328 Street, Homestead, Florida 33033. 305-230-1144. vanessa_mcdonough@nps.gov
- Clayton Pollock (Co-Principal Investigator), Biologist, Buck Island Reef National Monument and Salt River Bay National Historical Park and Ecological Preserve, 2100 Church Street #100, Christiansted, VI 00820-4611. 340-773-1460. clayton_pollock@nps.gov
- Jeff Miller, Fisheries Biologist, National Park Service, South Florida/Caribbean Network, 1300 Cruz Bay Creek, St. John, VI 00830. 340-693-8950 x227. william_j_miller@nps.gov
- Lee Richter, Marine Biological Technician, National Park Service, South Florida/Caribbean Network, 1300 Cruz Bay Creek, St. John, VI 00830. 340-693-8950 x228. lee_richter@nps.gov
- Rob Waara, Marine Biological Technician, National Park Service, South Florida/Caribbean Network, 18001 Old Cutler Road, Suite 419, Palmetto Bay, FL 33157. 786-249-0121. rob_waara@nps.gov

- Andrea Atkinson, Quantitative Ecologist, National Park Service, South Florida/Caribbean Network, 18001 Old Cutler Road, Suite 419, Palmetto Bay, FL 33157. 786-249-0176. andrea_atkinson@nps.gov

Collaborators (not directly involved with this protocol)

- Jim Fourqurean, Professor, Florida International University, 11200 SW 8th St, OE 227, Miami, FL 33199. 305-348-4084. Jim.Fourqurean@fiu.edu
- Caroline Rogers, Marine Ecologist, USGS Caribbean Field Station, 1300 Cruz Bay Creek, St. John, VI 00830. 340-693-8950 ext. 221. caroline_rogers@usgs.gov

Qualifications

The following qualifications are accepted minimum standards to perform relevant procedures. 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:

- NPS Blue Card Diver (NPS 2011; 485 DM 27 1999)
- Motor Boat Operations Certification Course (36 CFR part 3 2012; 485 DM 22 2011) (necessary if driving an NPS boat)

Training and Safety Procedures

Personnel should thoroughly review this narrative and the associated SOPs before implementing procedures under the supervision of experienced staff. Personnel assigned to data collection, management and analysis shall be properly trained in the procedures relevant to the assigned tasks. It is the responsibility of the program leads for the South Florida/Caribbean Network and the parks to ensure all personnel possess the necessary training and identification skills necessary to collect field data. Training is a critical component of this protocol and all participants should undergo initial and annual refresher training.

Pre-season out-of-water meetings that consist of overviews of sampling design, logistics, field methods, habitat characteristics and data entry and proofing will be held each year. In-water training will also be conducted each year to ensure accuracy and consistency in how each observer surveys a site (SOP 6 *Training* [Davis et al. 2019]). Estimates of variability in metrics across observers will be made.

In addition, personnel must complete the necessary requirements to maintain NPS Blue Card for divers and minimally, one person on the boat must have passed the Motor Boat Operations Certification Course (MOCC). When a person is required to remain in the boat, at least one topside person must be MOCC certified.

There are no restrictions to training in any procedure that does not entail diving or boating activities by the trainee. Nevertheless, trainees shall not be allowed to perform tasks unless under supervision.

Divers in training and boat operator trainees shall perform under the supervision of qualified personnel, subject to pertinent regulations.

Personnel must review the respective SOP associated with operation of each SFCN vessel, park specific Dive Emergency Evacuation Plan (DEEP), Float Plan Safety Sheet, and any other SOPs associated with this protocol. They must also review and sign all Job Hazard Analyses (JHA) associated with this protocol. These SOPs and JHAs are located in the SFCN Safety SOP & JHA Binder. Electronic versions are available on the SFCN server at Z:\Safety\ with filenames given by protocol in SFCN_Safety_SOP_and_JHA_Binder.pdf.

Nothing in this protocol implies or is meant to imply deviations from established federal, departmental, regional or local safety rules and regulations applicable to the performance of assigned tasks. It is the responsibility of each individual to be familiar with such rules and regulations.

Personnel must follow all rules, regulations, requirements, policies, and procedures from the NPS Dive Program, any park specific requirements, and any other requirements of the NPS not otherwise specified herein. All NPS-SFCN personnel will follow the Safe Practices Manual and Emergency Operations Plan specific to the respective park they are operating within. Dive team roles and responsibilities as predicated in NPS Resource Manual 4 (NPS 2011) will be reviewed in a safety briefing before each dive trip.

Completion of the Department of Interior's MOCC is required for the solo operation of an NPS vessel. Non-certified MOCC personnel may drive a park boat under the supervision of an MOCC certified operator. All SFCN vessels operate using state-of-the-art global positioning system chart plotters to ensure safe and efficient navigation. Training and safety documents associated with the SFCN seagrass protocol are listed in Table 12.

Table 12. 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

Table 12 (continued). Relevant documents and location on South Florida/Caribbean Network server.

Relevant Document, SOP, or JHA	Electronic versions are available on the SFCN server
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

Standard Operating Procedures and Deviations from Source Protocols

The network identified and developed SOPs for the procedures described in this SFCN seagrass protocol (Davis et al. 2019). SOP 1 *Sample Frame and Habitat Classification* and SOP 2 *Stratification* describe the basic characteristics of the sampling design in the SFCN seagrass protocol, as modified from the Virgin Islands fish protocol. SOP 3 *Creating a Seagrass Layer, Merging with Bathymetry Layer, and Assigning Strata* describes the stepwise process to merge the benthic habitat layer with bathymetry data. SOP 4 *Sample Allocation* describes the process of randomly selecting sample sites in the protocol, as modified from the Virgin Islands fish protocol. SOP 5 *Field methods* was based on Dunton et al. (2011) with Braun-Blanquet methods described by Fourqurean et al. (2001). The publications describe the BB sampling procedures to some extent; however, the enclosed SOP details the stepwise process to consistently conduct BB surveys. Supplementary monitoring procedures are also described in SOP 5. SOP 6 *Training* describes training procedures. SOP 7 *Entering, Verifying, and Performing a 100% QA/QC Check of Seagrass Data in the NPStoret Seagrass Database* describes the procedures for entering and verifying data in the NPStoret database. SOP 8 *Review, Certification and Export to EQuIS and STORET* describes the procedures to certify and export data for public availability. SOP 9 *Data Summaries, Analysis, and Reporting* describes how the data will be summarized, analyzed and reported. SOP 10 *Revising the Protocol* describes how changes in the protocol narrative and SOPs will occur and how they will be tracked. SOPs 1–10 are summarized in Table 13.

Table 13. Standard operating procedures required for the SFCN seagrass protocol. The table includes a brief description of changes from the source document to the SFCN version.

SFCN SOP	Source Citation	Explanation of differences	Link to publication
SOP 1 <i>Sample frame and habitat classification</i>	None	Not applicable	2259503
SOP 2 <i>Stratification</i>	None	Not applicable	2259503
SOP 3 <i>Creating a seagrass layer, merging with bathymetry layer, and assigning strata</i>	None	Not applicable	2259503
SOP 4 <i>Sample allocation</i>	None	Not applicable	2259503
SOP 5 <i>Field methods</i>	Dunton et al. (2011); Fourqurean et al. (2001)	SFCN SOP provides finer detail of procedures used as compared to description in source protocol document. In this protocol only BB assessments are performed; however, SFCN performs supplementary monitoring as described in SOP 5. The BB scores are recorded according to the methods described in Fourqurean et al. (2001)	2259503

Table 13 (continued). Standard operating procedures required for the SFCN seagrass protocol. The table includes a brief description of changes from the source document to the SFCN version.

SFCN SOP	Source Citation	Explanation of differences	Link to publication
SOP 6 <i>Training</i>	None	Not applicable	2259503
SOP 7 <i>Entering, verifying, and performing a 100% QA/QC check of seagrass data in the NPStoret seagrass database</i>	None	SFCN-specific SOP describes the procedures for entering and verifying data in the NPStoret database	2259503
SOP 8 <i>Review, certification and export to Microsoft Excel, EQUIS, and STORET</i>	None	SFCN-specific SOP describes the procedures to certify and export data for public availability	2259503
SOP 9 <i>Data summaries, analysis, and reporting</i>	SFCN 2018	SFCN SOP provides data summary, analysis and reporting procedures specific for SFCN seagrass data	2259503
SOP 10 <i>Revising the Protocol</i>	None	SFCN SOP describing procedures to modify the protocol narrative and SOPs	

Literature Cited

- 16 U.S.C. § 1531. 1973. Endangered Species Act. Government Printing Office, Washington. District of Columbia.
- 16 U. S. C. § 5937. 1998. Confidentiality of information. Government Printing Office, Washington. District of Columbia.
- 36 C.F.R. § 3. 2012. Boating and Water Use Activities. Title 36 Code of Federal Regulations, Part 3. Government Printing Office, Washington, DC.
- 485 D.M. § 22. 2011. Watercraft Safety. Department of Interior Departmental Manual, Part 485, Chapter 22. Office of Occupational Safety and Health, Washington, DC.
- 485 D.M. § 27. 1999. Underwater Diving Safety. Department of the Interior Departmental Manual, Part 485, Chapter 27. Office of Managing Risk and Public Safety, Washington, DC.
- 65 Fed. Reg. 17786. 2000. Critical Habitat for Johnson's Seagrass.
- Acevedo-Rodriguez, P. 1996. Flora of St. John, US Virgin Islands: Memoirs of the New York Botanical Garden, Volume 78. The New York Botanical Garden, Bronx, New York.
- Agassiz, A. 1883. Explorations of the surface fauna of the Gulf Stream, under the auspices of the United States Coast Survey. II. The Tortugas and Florida reefs. Memoirs of the American Academy of Arts and Sciences Centennial, Vol II. 107–132.
- Avila, C. L., Blair, S., Kempinski, S., Acevedo, S., and Sidner, J. 2008. Seagrass communities of Biscayne Bay, 1999–2007 Miami-Dade County. Poster session presented at: 2008 Florida Bay and adjacent marine systems conference. 2008 December 8–11; Naples, Florida.
- Beets, J, Lewand, L and Zullo, E. S. 1986. Marine community descriptions and maps of bays within the Virgin Islands National Park/Biosphere Reserve. Biosphere reserve Report No. 2. Virgin Islands National Park, St. Thomas, U.S. Virgin Islands.
- Beets, J and Muehlstein, L. 2005. Marine resource conditions for reef fishes and seagrass around St. John, US Virgin Islands: historical to present, final report. NOAA/NOS grant NA03NOS4260204.
- Bourque, A. S. and Fourqurean, J. W. 2014. Effects of common seagrass restoration methods on ecosystem structure in subtropical seagrass meadows. *Marine Environmental Research* 97:67 – 78.
- Brandt, M. E., N. Zurcher, A. Acosta, J. S. Ault, J. A. Bohnsack, M. W. Feeley, D. E. Harper, J. H. Hunt, T. Kellison, D. B. McClellan, M. E. Patterson, and S. G. Smith. 2009. A cooperative multi-agency reef fish monitoring protocol for the Florida Keys coral reef ecosystem. Natural Resource Report NPS/SFCN/NRR—2009/150. National Park Service, Fort Collins, Colorado.

- Braun, G., Lewis, R. R. and Watson, J. 2004. Fresh water flow and ecological relationships in Biscayne Bay. South Florida Water Management District contract No. C-15967-WO04-06.
- Braun-Blanquet, J. 1932. Plant sociology: the study of plant communities. Authorized English translation of Pflanzensoziologie, 1st edition. Fullard, G. D and Conard, H.S., editors. Hafner Publishing Company, New York.
- Bryan, D. R., Atkinson, A. J., Ault, J. S., Brandt, M. E., Bohnsack, J. A., Feeley, M. J., Patterson, M. E., Ruttenberg, B. I., Smith, S. G. and Witcher, B. D. 2013. A cooperative multiagency reef fish monitoring protocol for the U.S. Virgin Islands coral reef ecosystem, V. 1.00. Natural Resource Report NPS/SFCN/NRR—2013/672. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/DownloadFile/471146> (last accessed March 2019).
- Campbell, D., Brady-Campbell, M. and Levitan, D. 1983. A descriptive study of the sea grass beds of Little and Greater Lameshur Bays, St. John. U.S. Virgin Islands. Report for Virgin Islands National Park Service and The School for Field Studies. The School for Field Studies, Cambridge, Massachusetts.
- Cole, A. M., Durako, M. J. and Hall, M. O. 2018. Multivariate analysis of water quality and benthic macrophyte communities in Florida Bay, USA reveals hurricane effects and susceptibility to seagrass die-off. *Front. Plant Sci.* 9(630): 1 - 16.
- Comprehensive Ecosystem Research Plan (CERP). 2014. 2014 system status report. Office of Everglades Restoration Initiatives, Davie, Florida.
- Damgaard, C., 2014. Estimating mean plant cover from different types of cover data: a coherent statistical framework. *Ecosphere*, 5(2), pp.1-7.
- Davis, A. D., M. W. Feeley, M. Londoño, L. Richter, J. M. Patterson, A. J. Atkinson. 2019. Seagrass Community Monitoring Protocol: Standard Operating Procedures. South Florida/Caribbean Network, Miami, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2259503> (last accessed March 2019).
- Davis, G. E. 1982. A century of natural change in coral distribution at the Dry Tortugas: a comparison of reef maps from 1881 and 1976. *Bulletin of Marine Science* 32(2):608–623.
- den Hartog, C. 1970. The sea-grasses of the world. North-Holland Pub. Co., Amsterdam, Netherlands.
- Department of the Interior (DOI). 2014. Freedom of information Act (FOIA) handbook. 383 DM 15. Department of the Interior, Washington, District of Columbia.
- Dethier, M. N., Graham E. S., Cohen, S. and Tear, L. M. 1993. Visual versus random-point percent cover estimations: ‘objective’ is not always better. *Mar Ecol Prog Ser* 96: 93–100.
- Duarte, C. M. 1991. Seagrass depth limits. *Aquatic Botany* 40:363-377.

- Duffy J.E. (2006) Biodiversity and the functioning of seagrass ecosystems. *Mar. Ecol. Prog. Ser.* 311: 233-250.
- Dunton, K., Pulich, W. and Mutchler, T. 2011. A seagrass monitoring program for Texas coastal waters: multiscale integration of landscape features with plant and water quality indicators. Final Report, Contract No. 0627. Coastal Bend Bays & Estuaries Program, Corpus Christi, Texas.
- Estep, A. J., Waara, R. J., Richter, L. J., Feeley, M. W., Patterson, M. E., Davis, A. D., Miller, J., Witcher, B. D., Patterson, J. M., Vargas, R. M. and Atkinson, A. J. 2017. Biscayne National Park offshore benthic habitat mapping project. Natural Resource Report NPS/SFCN/NRTR—2017/1390. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/DownloadFile/566216> (last accessed March 2019).
- Florida Fish and Wildlife Conservation Commission (FWC). 2000. Benthic habitats of the Florida Keys. FMRI Technical Report TR-4. Florida Marine Research Institute, St. Petersburg, Florida.
- Florida Fish and Wildlife Conservation Commission (FWC). 2015. Unified Florida Coral Reef Tract Map v1.3. Fish and Wildlife Research Institute, Saint Petersburg, FL. Available at: <http://ocean.floridamarine.org/IntegratedReefMap/UnifiedReefTract.htm> (last accessed 12 May 2017).
- Florida International University SERL (FIU-SERL). 2016. Florida Keys National Marine Sanctuary seagrass status and trends monitoring data. Available at: <http://seagrass.fiu.edu/data.htm> (last accessed July 2018).
- Fourqurean, J. W., Boyer, J. N., Durako, M. J., Hefty, L. N. and Peterson, B. J. 2003. Forecasting responses of seagrass distributions to changing water quality using monitoring data. *Ecological Applications* 13(2):474–489.
- Fourqurean, J. W., Durako, M. J., Hall, M. O. and Hefty, L. N. 2002. Seagrass distribution in south Florida a multi-agency coordinated monitoring program. Pages 497–522 in J. W. Porter and K. G. Porter, editors. *The Everglades, Florida Bay, and Coral Reefs of the Florida Keys. An ecosystem sourcebook*. CRC Press, Boca Raton, Florida.
- Fourqurean J. W. and Rutten L. M. 2003 Competing goals of spatial and temporal resolution: monitoring seagrass communities on a regional scale. Pages 257–288 in D. E. Busch and J. C. Trexler. *Monitoring Ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives*. Island Press, Washington, District of Columbia.
- Fourqurean, J. W., Willsie, A., Rose, C. D., and Rutten, L. M. 2001. Spatial and temporal pattern in seagrass community composition and productivity in south Florida. *Marine Biology* 138:341–354.
- Franklin, E. C., Ault, J. S., Smith, S. G., Luo, J., Meester, G. A., Diaz, G. A., Chiappone, M., Swanson, D. W., Miler, S. L. and Bohnsack, J. A. 2003. Benthic habitat mapping in the Tortugas region, Florida. *Marine Geodesy* 26:19–34.

- Furman, B. T., Leone, E. H., Bell, S. S., Durako, M. J. and Hall, M. O. 2018. Braun-Blanquet data in ANOVA designs: comparisons with percent cover and transformations using simulated data. *Mar. Ecol. Prog. Ser.* 597: 13–22.
- Gladfelter, W. B., Gladfelter, E. H., Monahan, R. K., Ogden, J. C. and Dill, R. F. 1977. Environmental studies of Buck Island Reef National Monument, St. Croix, U.S.V.I. West Indies Laboratory, St. Croix, U. S. Virgin Islands.
- Guisan, A. and Harrell, F.E., 2000. Ordinal response regression models in ecology. *Journal of Vegetation Science* 11(5): 617–626.
- Hall, M. O. and Carlson Jr., P. R. 2015. Summary report for Florida Bay. Seagrass integrated mapping and monitoring program—Mapping and Monitoring Report No. 1.1. FWRI Technical Report TR-17. Fish and Wildlife Research Institute, St. Petersburg, Florida.
- Hall, M. O., Durako, M. J., Fourqurean, J. W. and Zieman, J. C. 1999. Decadal changes in seagrass distribution and abundance in Florida Bay. *Coastal and Estuarine Research Federation* 22(2):445–459.
- Hall, M.O., Furman B.T., Merello, M., Durako, M.J. 2016. Recurrence of *Thalassia testudinum* seagrass die-off in Florida Bay, USA: initial observations. *Mar Ecol Prog Ser* 560:243-249. <https://doi.org/10.3354/meps11923>
- Herbert, D. A., Perry, W. B., Cosby, B. J. and Fourqurean J. W. 2011. Projected reorganization of Florida Bay seagrass communities in response to the increased freshwater inflow of Everglades restoration. *Estuaries and Coasts* 34:973–992.
- Hubbard, D.K. 1989. Depositional environments of Salt River estuary and submarine canyon, St. Croix, U.S.V.I. Pages 181-196 in D.K. Hubbard. editor. *Terrestrial and marine geology of St. Croix, U.S. Virgin Islands*. West Indies Laboratory Special Publication No. 8. West Indies Laboratory, St. Croix, U. S. Virgin Islands.
- Irvine, K.M. and Rodhouse, T.J. 2010. Power analysis for trend in ordinal cover classes: implications for long-term vegetation monitoring. *J. Veg. Sci.* 21(6):1152-1161.
- Irvine, K.M. and Rodhouse, T.J. and Keren, I. N. 2016. Extending ordinal regression with a latent zero-augmented beta distribution. *Journal of Agricultural, Biological, and Environmental Statistics* 21(4): 619 – 640.
- Josselyn, M., Fonseca, M., Niessen, T. and Larson, R. 1986. Biomass, production and decomposition of a deep water seagrass, *Halophila decipiens*. *Ostenf. Aquatic Botany* 25:47–61.
- Kendall, M. S., Battista, T. and Hillis-Starr, Z. 2004. Long term expansion of a deep *Syringodium filiforme* meadow in St. Croix, US Virgin Islands: the potential role of hurricanes in the dispersal of seeds. *Aquatic Botany* 78:15–25.

- Kendall, M.S., Kruer, C. R., Buja, K. R., Christensen, J. D. Finkbeiner, M., Warner R. A. and Monaco, M. E. 2001. Methods used to map the benthic habitats of Puerto Rico and the U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS 152. Center for Coastal Monitoring and Assessment, Silver Spring, Maryland.
- Kendall, M. S., Takata, L. T., Jensen, O., Hillis-Starr, Z. and Monaco, M. E. 2005. An ecological characterization of the Salt River Bay National Historic Park and Ecological Preserve. NOAA Technical Memorandum NOS NCCOS 14. Center for Coastal Monitoring and Assessment, Silver Spring, Maryland.
- Kenworthy, W. J., Currin, C. A., Fonseca, M. S. and Smith, G. 1989. Production, decomposition, and heterotrophic utilization of the seagrass *Halophila decipiens* in a submarine canyon. *Marine Ecology Progress Series*, 51:277–290.
- Kumpf, H. E. and Randall, H. A. 1961. Charting the marine environments of St. John, U. S. Virgin Islands. *Bulletin of Marine Science of the Gulf and Caribbean* 11(4):543–551.
- Lapointe, B. E., Tomasko, D. A. and Matzie, W. R. 1994. Eutrophication and trophic state classification of seagrass communities in the Florida Keys. *Bulletin of Marine Sciences*, 54(3):696–717.
- Lewis III, R. R., Hodgson, A. B., Tooze, M., and Kruer, C. D. 2000. The distribution of seagrass and benthic habitats westward of the patch reef system boundary in Biscayne National Park, Florida, USA. Pages 125–132 in Greening, H. S., editor. *Seagrass management: it's not just nutrients!*. Proceedings of a symposium. Technical Publication # 04-02, Final Report. Tampa Bay Estuary Program, St. Petersburg, Florida.
- Lirman, D., Deangelo, D., Serafy, J. E., Hazra, A., Hazra, D. S. and Brown A. 2008. Geospatial video monitoring of nearshore benthic habitats of Western Biscayne Bay (Florida) using the Shallow-Water Positioning System (SWaPS). *Journal of Coastal Research* 24(1A):135–145.
- Lirman, D., Thyberg, T., Collado-Vides, L., Santos R., Deangelo G., Bellmund S., and Serafy J. E. 2011. Biscayne Bay nearshore submerged aquatic vegetation. CERP monitoring and assessment plan component, activity number 3.2.3.3. Annual report, January 2011. University of Miami, Miami, Florida.
- Madden, C. J., Rudnick D. T., McDonald, A. A., Cuniff, K. M. and Fourqurean, J. W. 2009. Ecological indicators for assessing and communicating seagrass status and trends in Florida Bay. *Ecological Indicators* 9S:S68–S82.
- Madley K. A., Sargent, B. and Sargent, F. J. 2002. Development of a system for classification of habitats in estuarine and marine environments (SCHEME) for Florida. Unpublished report to the U.S. Environmental Protection Agency, Gulf of Mexico Program. Grant Assistance Agreement MX-97408100. Florida Marine Research Institute, St. Petersburg, Florida.

- Manuel, S. A., Coates, K. A., Kenworthy, W. J. and Fourqurean, J. W. 2013. Tropical species at the northern limit of their range: composition and distribution in Bermuda's benthic habitats in relation to depth and light availability. *Marine Environmental Research* 89: 63–75.
- Miller, J., C. S. Rogers, M. W. Feeley, A. J. Atkinson, A. D. Davis, M. E. Patterson, R. J. Waara, B. D. Witcher, J. M. Patterson, and E. M. Muller. 2017. Coral reef monitoring: Protocol narrative—Version 2.0. Natural Resource Report NPS/SFCN/NRR—2017/1464. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2240837> (last accessed March 2019).
- National Park Service (NPS). 2008. Patterns of propeller scarring of seagrass in Florida Bay: associations with physical and visitor use factors and implications for natural resource management. National Park Service, Homestead, Florida. Available at: <https://www.nps.gov/ever/learn/nature/upload/Final%20PropScar%20Report%20Secure%20Low%20Res.pdf> (last accessed March 2019).
- National Park Service (NPS). 2011. Diving Management Reference Manual RM4. National Park Service, Fort Collins, Colorado. Available at: https://www.nps.gov/policy/dorders/rm-4_6-2014.pdf (last accessed March 2019).
- National Park Service (NPS). 2016. 2015 Florida Bay seagrass die-off. National Park Service, Homestead, Florida. Available at: https://www.nps.gov/ever/learn/nature/upload/seagrass-Dieoff_final_web_hi_res.pdf (last accessed March 2019).
- Neckles, H. A., Kopp, B. S., Peterson, B. J. and Pooler, P.S. 2012. Integrating scales of seagrass monitoring to meet conservation needs. *Estuaries and Coasts* 35:23–46.
- NOAA (2012) Buck Island Reef National Monument (BIRNM) Benthic habitats shallow 2011. NOAA/NOS/NCCOS/CCMA Biogeography Branch, Silver Spring, MD.
- Oakley, K. L., Thomas, L. P. and Fancy, S. G. 2003. Guidelines for long-term monitoring protocols. *Wildlife Society Bulletin* 31(4):1000–1003.
- Odum, W. E. and Heald, E. J. 1972. Trophic analyses of an estuarine mangrove community. *Bulletin of Marine Science* 22(3):671–738.
- Onuf, C. P. 2007. Laguna Madre. Pages 29-40 in L. Handley, D. Altsman and R. DeMay, editors. Seagrass status and trends in the Northern Gulf of Mexico: 1940-2002. U.S. Geological Survey Scientific Investigations Report 2006-5287 and U.S. Environmental Protection Agency 855-R-04-003. U.S. Geological Survey, Reston, Virginia.
- Patterson, M. E., A. J. Atkinson, B. D. Witcher, K. R. T. Whelan, W. J. Miller, R. J. Waara, J. M. Patterson, B. I. Ruttenberg, A. D. Davis, R. Urgelles, R. B. Shamblin. 2008. South Florida/Caribbean Network vital signs monitoring plan. Natural Resource Report NPS/SFCN/NRR—2008/063. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/660634> (last accessed March 2019).

- Pittman, S.J., Hile, S. D., Jeffrey, C.F.G., Caldwell, C., Kendall, M.S., Monaco, M.E., and Hillis-Starr, Z. 2008. Fish assemblages and benthic habitats of Buck Island Reef National Monument (St. Croix, U.S. Virgin Islands) and the surrounding seascape: A characterization of spatial and temporal patterns. NOAA Technical Memorandum NOS NCCOS 71. Center for Coastal Monitoring and Assessment, Silver Spring, Maryland.
- Reynolds, J. H., Knutson, M. G., Newman, K. B., Silverman, E. D. and Thompson, W. L. 2016. A road map for designing and implementing a biological monitoring program. *Environmental Monitoring and Assessment* 188:399.
- Richter, L. J., M. W. Feeley, A. J. Atkinson, J. M. Patterson, A. D. Davis, and J. Miller. 2018. Long-term monitoring protocol of Caribbean spiny lobster (*Panulirus argus*): Protocol narrative. Natural Resource Report NPS/SFCN/NRR—2018/1850. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2258540> (last accessed March 2019).
- Robblee, M. B., Barber, T. R., Carlson, P. R., Durako, M. J., Fourqurean, J. W., Muehlstein, L. K., Porter, D., Yarbro, L. A., Zieman, R. T. and Zieman, J. C. 1991. Mass mortality of the tropical seagrass *Thalassia testudinum* in Florida Bay (USA). *Marine Ecology Progress Series* 71:297–299.
- Robinson, A. 1973. Resources management plan, Buck Island Reef National Monument. National Park Service, St. Croix, U. S. Virgin Islands.
- Rogers, C. S. and Teytaud, R. 1988. Marine and terrestrial ecosystems of the Virgin Islands National Park and Biosphere Reserve. Biosphere Reserve report No. 29. Island Resources Foundation, St. Thomas, VI.
- Schell, C. J. 1974. Resources management plan, Buck Island Reef National Monument. National Park Service, St. Croix, U. S. Virgin Islands.
- Schmidt, T. W., Ault, J. S., Bohnsack, J. A., Luo, J., Smith, S. G., Harper, D. E., Meester, G. A. and Zurcher, N. 2004. Site characterization for the Dry Tortugas region: fisheries and essential habitats. NOAA Technical Memorandum NMFS-SEFSC-000. Southeast Fisheries Science Center, Miami, Florida.
- Sghaier, Y. R., Zakhama-Sraieb, R., Benamer, I., and Charfi-Cheikhrouha, F. 2011. Occurrence of the seagrass *Halophila stipulacea* (Hydrocharitaceae) in the southern Mediterranean Sea. *Botanica Marina* 54:575–582.
- Short, F.T. and Neckles H.A. 1999. The effects of global climate change on seagrasses. *Aquatic Botany* 63:169-196.
- Tabb, D. C., Dubrow, D. L., and Manning R. B. 1962. Technical Series No. 39. The ecology of Northern Florida Bay and adjacent estuaries. The Institute of Marine Science of the University of Miami, Miami, Florida.

- Taylor, R. W. M. 1928. Papers from the Tortugas Laboratory of the Carnegie Institution of Washington, Volume XXV. The marine algae of Florida with special reference to the Dry Tortugas. The Carnegie Institute of Washington, Washington, District of Columbia.
- Van der Maarel, E. 1997. Transformation of cover-abundance values in phytosociology and its effect on community similarity. *Vegetation* 39: 97–114.
- van der Maarel, E. 2007. Transformation of cover-abundance values for appropriate numerical treatment - alternatives to the proposals by Podani. *J. Veg. Sci.* 18: 767–770.
- Waara, R. J., Patterson, J. M., Atkinson, A. J. & Estep, A. J. 2011. Development and policy applications of the 2010 benthic habitat map for Dry Tortugas National Park. Natural Resource Technical Report NPS/SFCN/NRTR-2011/474. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2181753> (last accessed March 2019).
- Willette, D. A. & Ambrose, R. F. 2012. Effects of the invasive seagrass *Halophila stipulacea* on the native seagrass, *Syringodium filiforme*, and associated fish and epibiota communities in the Eastern Caribbean. *Aquatic Botany* 103:74–82.
- Willette, D. A., Chalifour, J., Debrot, A. O. D., Engel, M. S., Miller, J., Oxenford, H. A., Short, F. T., Steiner, S. C. C. and Védie, F. 2014. Continued expansion of the trans-Atlantic invasive marine angiosperm *Halophila stipulacea* in the Eastern Caribbean. *Aquatic Botany* 112:98–102.
- Williams S. L. 1988a. Assessment of anchor damage and carrying capacity of seagrass beds in Francis and Maho Bays for green sea turtles. Biosphere Reserve Report No. 25. West Indies Laboratory, St. Croix, U. S. Virgin Islands.
- Williams, S. L. 1988b. Disturbance and recovery of a deep-water Caribbean seagrass bed. *Marine Ecology Progress Series*, 42: 63–71.
- Yarbro, L. A. and Carlson Jr. P. R. 2013. Seagrass Integrated Mapping and Monitoring Program - Mapping and Monitoring Report No. 1. FWRI Technical Report TR-17. Fish and Wildlife Research Institute, St. Petersburg, Florida.
- Yates, K.K., Rogers, C. S., Herlan, J. J., Brooks, G. R., Smiley, N. A. and Larson, R. A. 2014. Diverse coral communities in mangrove habitats suggest a novel refuge from climate change. *Biogeosciences* 11:4321–4337.
- Yeo, J. J., Rodhouse, T. J., Dicus, G. H., Irvine, K. M. and Garrett L. K. 2009. Upper Columbia Basin Network sagebrush steppe vegetation monitoring protocol: Standard operating procedures version 1.0. Natural Resource Report NPS/UCBN/NRR—2009/142. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/DownloadFile/481704> (last accessed March 2019).

- Zieman, J. C. 1982. The ecology of the seagrasses of south Florida: A community profile. FWS/OBS-82/25. U. S. Fish and Wildlife Services, Office of Biological Services, Washington, District of Columbia.
- Zieman, J. C., Fourqurean, J. W., and Frankovich, T. A., 1999. Seagrass die-off in Florida Bay: long-term trends in abundance and growth of turtle grass, *Thalassia testudinum*. Estuaries 22(2B):460–470.
- Zieman, J. C., Fourqurean, J. W. and Iverson, R. L. 1989. Distribution, abundance and productivity of seagrasses and macroalgae in Florida Bay. Bulletin of Marine Science 44(1):292-311.
- Zieman, J. C. and Zieman, R. T. 1989. The ecology of the seagrass meadows of the West Coast of Florida: a community profile. U. S. Fish and Wildlife Service Biological Report 85(7.25). National Wetlands Research Center, Washington, District of Columbia.
- Zitello, A. G., Bauer, L. J., Battista, T. A., Mueller, P. W., Kendall, M. S., and Monaco, M. E. 2009. Shallow-water benthic habitats of St. John, U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS 96, Center for Coastal Monitoring and Assessment, Silver Spring, Maryland.

Appendix A. Park Seagrass Maps

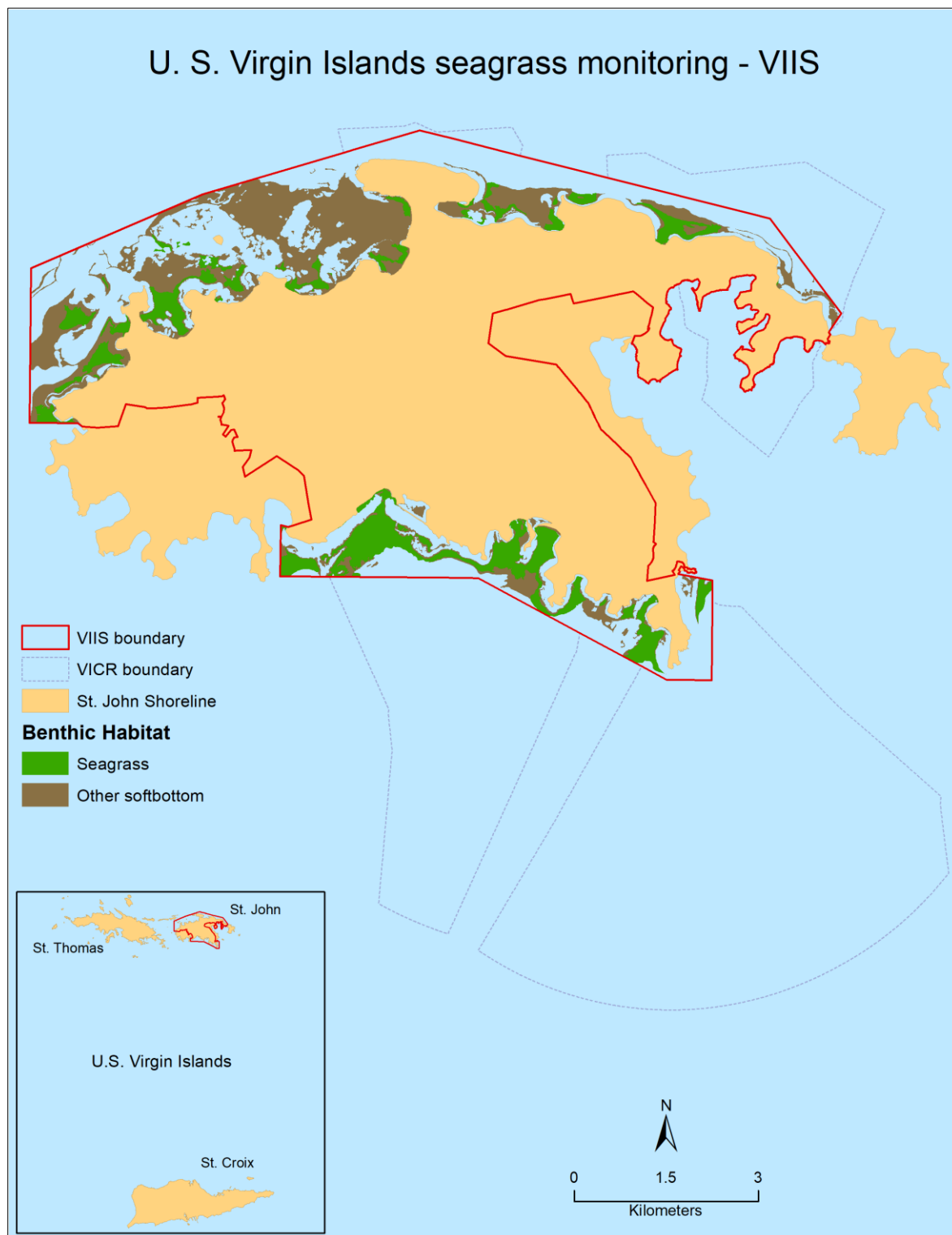


Figure A-1. Virgin Islands National Park seagrass and other soft-bottom habitats.

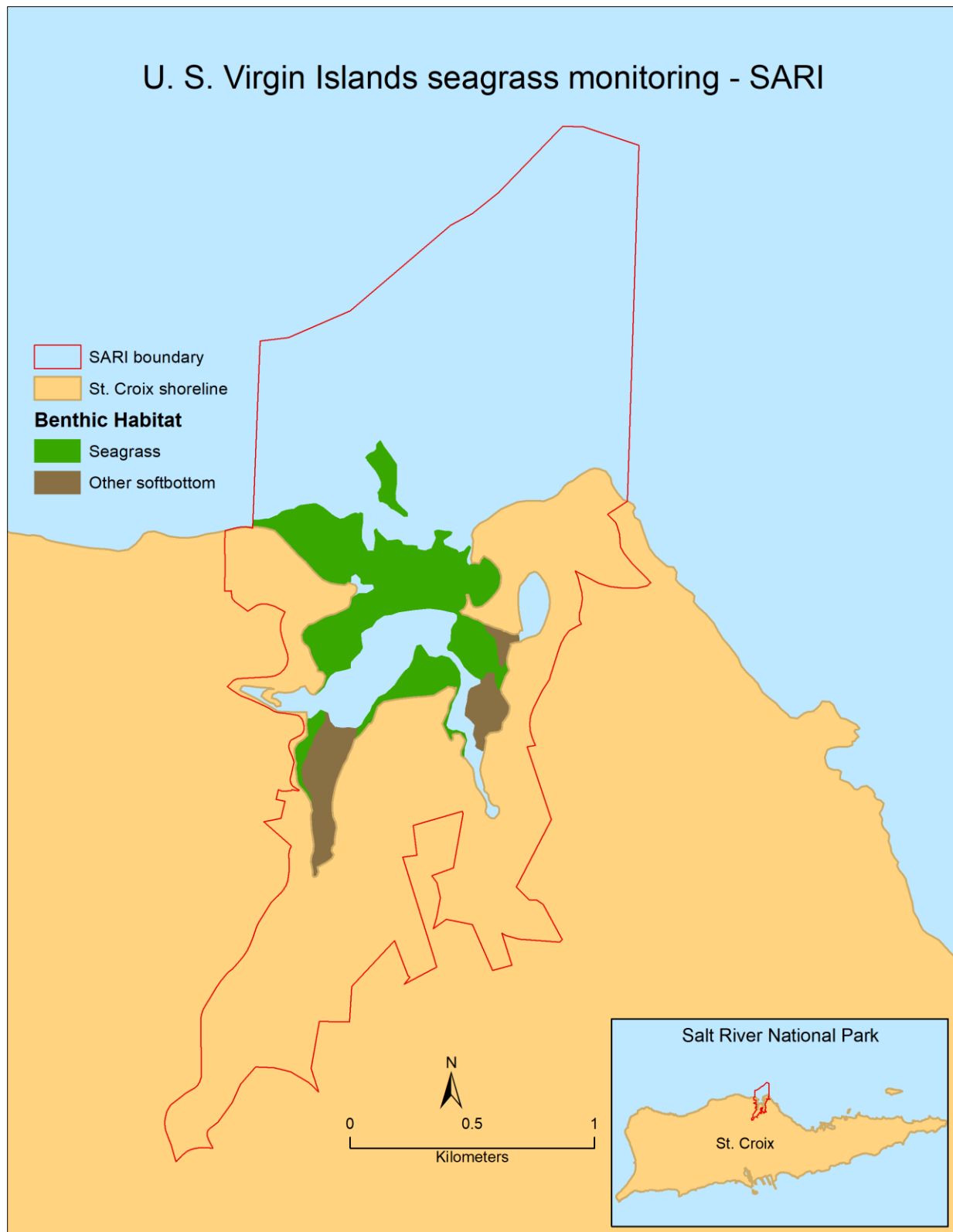


Figure A-2. Salt River Bay National Historical Park and Ecological Preserve seagrass and other soft-bottom habitats. Seagrass surveys are proposed for the offshore canyon area only (isolated small polygon just north of the majority of seagrass and soft-bottom habitat identified within the bay).

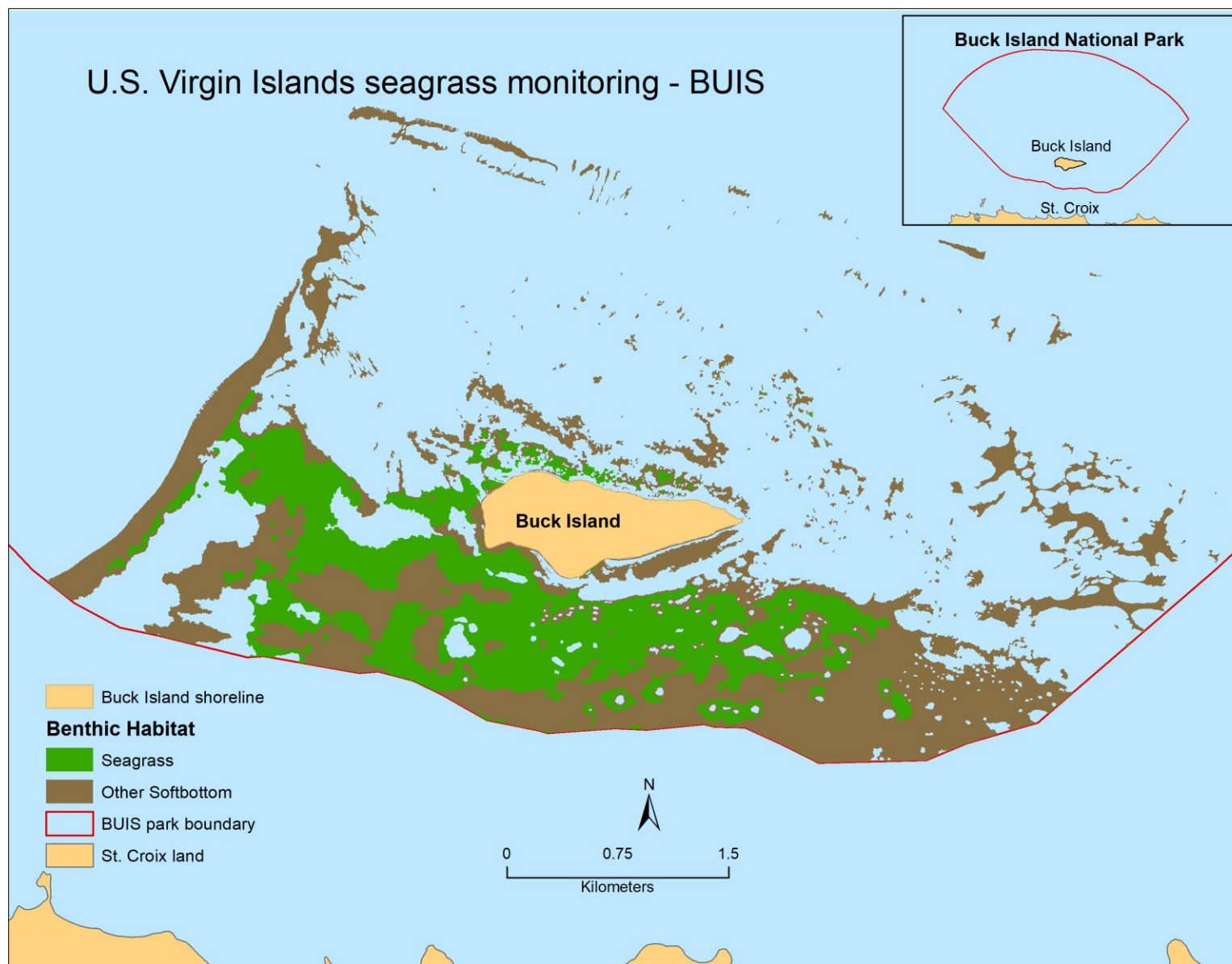


Figure A-3. Buck Island Reef National Monument seagrass and other soft-bottom habitats.

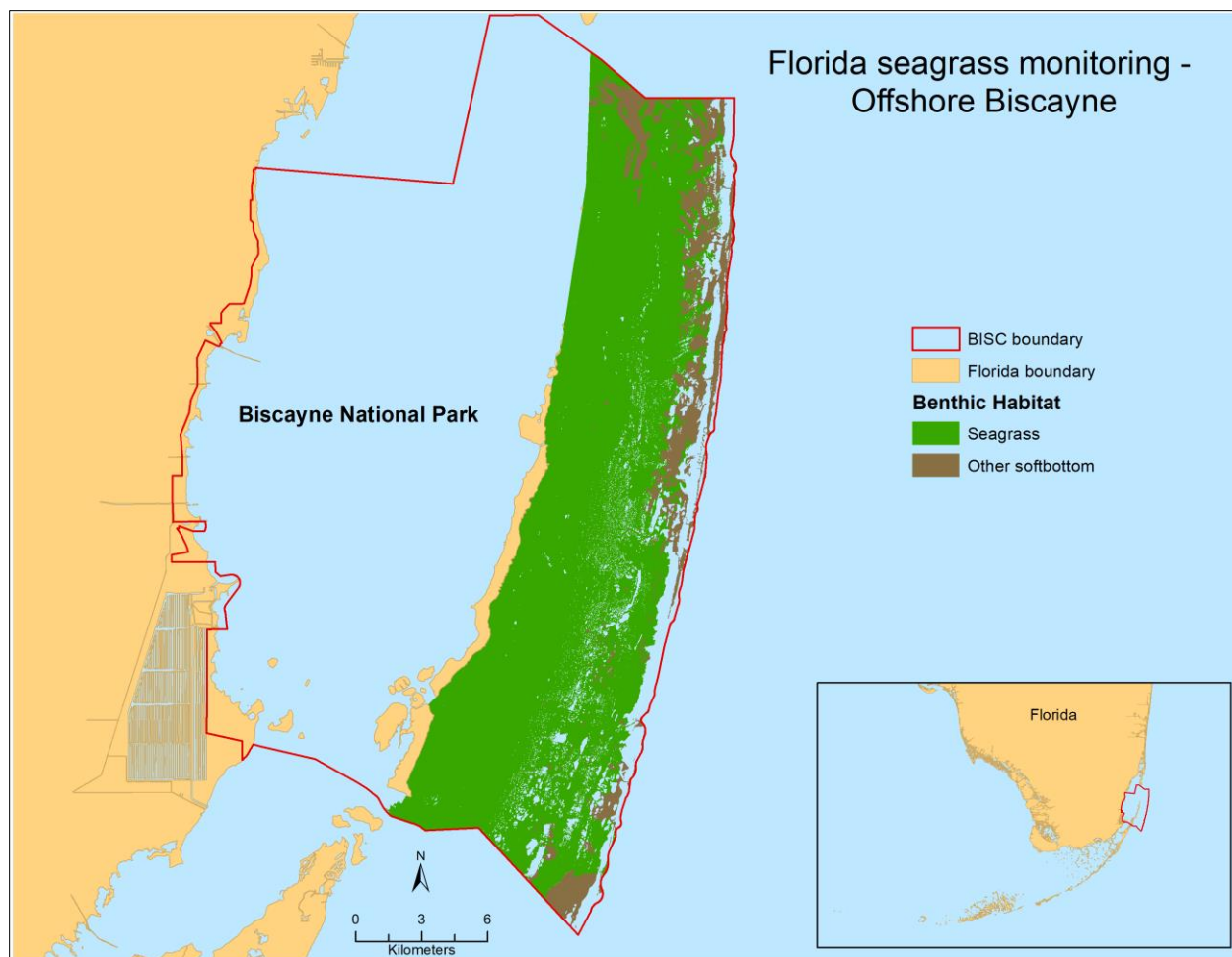


Figure A-4. Biscayne National Park offshore seagrass and other soft-bottom habitats.

Appendix B: Seagrass Monitoring Pilot Survey in Virgin Islands National Park, May 2015

Introduction

The South Florida/Caribbean Network conducted a seagrass monitoring pilot survey in Virgin Islands National Park in May 2015. The pilot monitoring survey was designed to test methods for providing a rapid assessment of Submerged Aquatic Vegetation (SAV) spatial distribution in and near the park.

Overall pilot monitoring survey objectives included:

- Test and finalize field methods, data collection format and database structure.
- Evaluate whether using less than 50% and greater than 50% seagrass percent cover map class as strata and depth strata are useful at decreasing variance and improving change detectable with lower levels of sample effort.
- Determine how many daily average sample sites can be surveyed at Virgin Islands NP.
- Evaluate the category accuracy of randomly chosen other soft-bottom sites.
- Determine subsample number and statistical power to monitor Submerged Aquatic Vegetation using Braun-Blanquet (BB) surveys.

Methods

Submerged Aquatic Vegetation survey sites in and around the park were randomly chosen based on the seagrass distribution mapped by the National Oceanographic and Atmospheric Administration (NOAA) Biogeography Branch team (Zitello et al. 2009). Sites were selected within eight strata based on depth (shallow vs. deep), seagrass cover (< 50% and > 50%) and inside versus outside the park classifications. Due to time constraints, only bare unconsolidated and four seagrass strata within the park were actually surveyed (Table B-1).

The survey was based on established SAV monitoring programs in South Florida and Texas using a BB quadrat method (Dunton et al. 2010; Fourqurean et al. 2001; Fourqurean and Rutten 2003; Figure B-1). At each point, two sets of paired 0.25 square meter (2.7 ft²) quadrats (four total) were haphazardly thrown in different directions and two divers followed them down. At sites where a third diver was available, an additional two quadrats were thrown. Braun-Blanquet data were collected on all seagrass species and algae located within each quadrat. All seagrass was identified to species. Algae were identified to genus or a general taxa division (e.g., Green alga other). Supplementary data as described in SOP 5 *Field methods* (Davis et al. 2019) were also collected.

Table B-1. Strata, depths (ft.) and locations of sites (n = 54) visited during the 2015 Seagrass Pilot Monitoring Survey.

Site id	Strata*	Depth	Bay
2	DL**	13.4	Leinster Point
4	DL	15.2	Leinster
5	SL	12.5	Leinster
6	SM	12.2	Lameshur
7	DM	18.3	Brown
8	DM	18.0	Trunk
9	DM	15.8	Hawksnest
10	DM	23.5	Salt Pond
12	DM	18.3	Lameshur
14	DM	17.7	Hawksnest
17	DM	21.3	Lameshur
19	SM	14.0	Reef Bay
21	SM	14.0	Brown
23	DM	21.6	Lameshur
24	DM	17.4	Fish
28	DM	17.7	Reef Bay
30	DM	18.9	Trunk
32	DM	18.3	Lameshur
33	DM	17.1	Trunk
34	DM	15.2	White Point
35	DM	19.2	Trunk
56	SL	3.0	Cinnamon
58	SL	11.9	Leinster
59	SL	4.6	Reef Bay
60	SL	2.7	Maho

*Strata: Deep Inside Less (DL), Deep Inside More (DM), Shallow Inside Less (SL), Shallow Inside More (SM);
Depth: Deep = > 15 m, Shallow = < 15 m; Cover: Less = < 50% seagrass density map class; More = > 50%
seagrass density map class; Inside = VIIS; UCO = bare unconsolidated

** SiteID 2 set to DL although depth only 13.4 meters to place minimum of two points in DL category

Table B-1 (continued). Strata, depths (ft.) and locations of sites (n = 54) visited during the 2015 Seagrass Pilot Monitoring Survey.

Site id	Strata*	Depth	Bay
64	SM	11.6	Reef Bay
66	SM	7.3	Salt Pond
67	SM	11.3	Brown
69	SM	10.4	Salt Pond
70	SM	11.6	Reef Bay
71	SM	11.0	Reef Bay
74	SM	4.0	Brown
75	SM	4.0	Salt Pond
80	SM	6.4	Brown
81	SM	4.3	Leinster
84	SM	0.3	Reef Bay
85	SM	7.9	Lameshur
86	SM	7.6	Leinster
87	SM	12.2	Brown
90	DM	16.8	Hawksnest
92	SM	7.3	Kiddel
94	SM	5.2	Salt Pond
96	SM	3.4	Lameshur
97	SM	0.6	Lameshur
98	SM	0.6	Leinster
135	UCO	6.1	Fish
136	UCO	1.8	Leinster
140	UCO	11.9	Brown
144	UCO	4.0	Salt Pond
148	UCO	4.3	Lameshur

*Strata: Deep Inside Less (DL), Deep Inside More (DM), Shallow Inside Less (SL), Shallow Inside More (SM);
Depth: Deep = > 15 m, Shallow = < 15 m; Cover: Less = < 50% seagrass density map class; More = > 50%
seagrass density map class; Inside = VIIS; UCO = bare unconsolidated

** SiteID 2 set to DL although depth only 13.4 meters to place minimum of two points in DL category

Table B-1 (continued). Strata, depths (ft.) and locations of sites (n = 54) visited during the 2015 Seagrass Pilot Monitoring Survey.

Site id	Strata*	Depth	Bay
155	DM	15.8	White Point
164	DM	19.2	Lameshur
189	SM	1.5	Leinster
191	SM	12.2	Trunk

*Strata: Deep Inside Less (DL), Deep Inside More (DM), Shallow Inside Less (SL), Shallow Inside More (SM); Depth: Deep = > 15 m, Shallow = < 15 m; Cover: Less = < 50% seagrass density map class; More = > 50% seagrass density map class; Inside = VIIS; UCO = bare unconsolidated

** SiteID 2 set to DL although depth only 13.4 meters to place minimum of two points in DL category

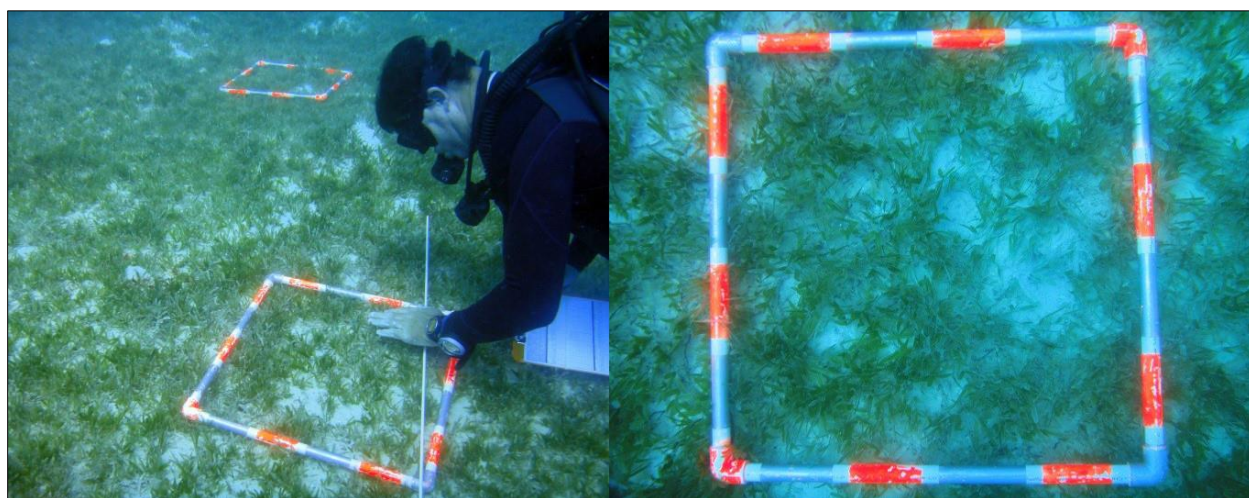


Figure B-1. Sites visited during FY 2015 Seagrass (SAV) Pilot Monitoring Survey at Virgin Islands NP were surveyed with four randomly placed 0.25 m² (2.7 ft²) quadrats. Pictured are BB quadrats in a seagrass bed at Hawksnest Bay, composed of 50–75% *Halophila stipulacea*, an invasive seagrass species native to the western Indian Ocean. Photo credit: NPS SFCN staff.

The South Florida/Caribbean Network conducted a four-day pilot-scale SAV survey within Virgin Islands National Park May 12–15, 2015. Andy Davis performed field training of Braun-Blanquet and other survey methods with all divers. A team of four network divers assisted by two park biologists surveyed 49 seagrass sites and explored five randomly-selected unconsolidated sediment (other soft-bottom) sites to check for presence or absence of seagrass (Figures B-1 and B-2). Site locations visited included the following bays: Hawksnest, Trunk, Cinnamon, Maho, Leinster, and Brown on the north side; and Fish, Reef, Lameshur, Kiddel, and Salt Pond on the south side (Figures B-3 and B-4; Table B-1). However, time limitations for this survey did not allow for visiting planned random sites outside park boundaries. Divers observed an unidentified seagrass species at several sites on the south side of the island. Some characteristics of the species were consistent with *R. maritima*, known to occur in the U.S. Virgin Islands; however, the habitat characteristics in which the species was

found did not seem consistent with literature descriptions. Samples were collected, pressed or frozen, and stored at the SFCN office located at Virgin Islands NP, for identification.



Figure B-2. Field crews on the Seagrass Monitoring Pilot Survey included (left to right) Lee Richter (SFCN), Devon Tyson (VIIS) and Andy Davis (SFCN). Not pictured, Adam Glahn (VIIS), Jeff Miller (SFCN) and Mike Feeley (SFCN). Photo credit: Mike Feeley, NPS SFCN.

These samples are now in the custody of Dr. Sandy Wyllie-Echeverria of the University of Washington. The samples were tentatively identified as *Ruppia maritima*, but further sampling and analysis may be needed for a definite identification. The SFCN marine ecologist, Mike Feeley, and SFCN fishery biologist, Jeff Miller, met with Virgin Islands NP Resource Chief Dave Worthington and lead biologist Thomas Kelley to discuss progress, park involvement and future seagrass work.

St. John Seagrass (SAV) Pilot Monitoring

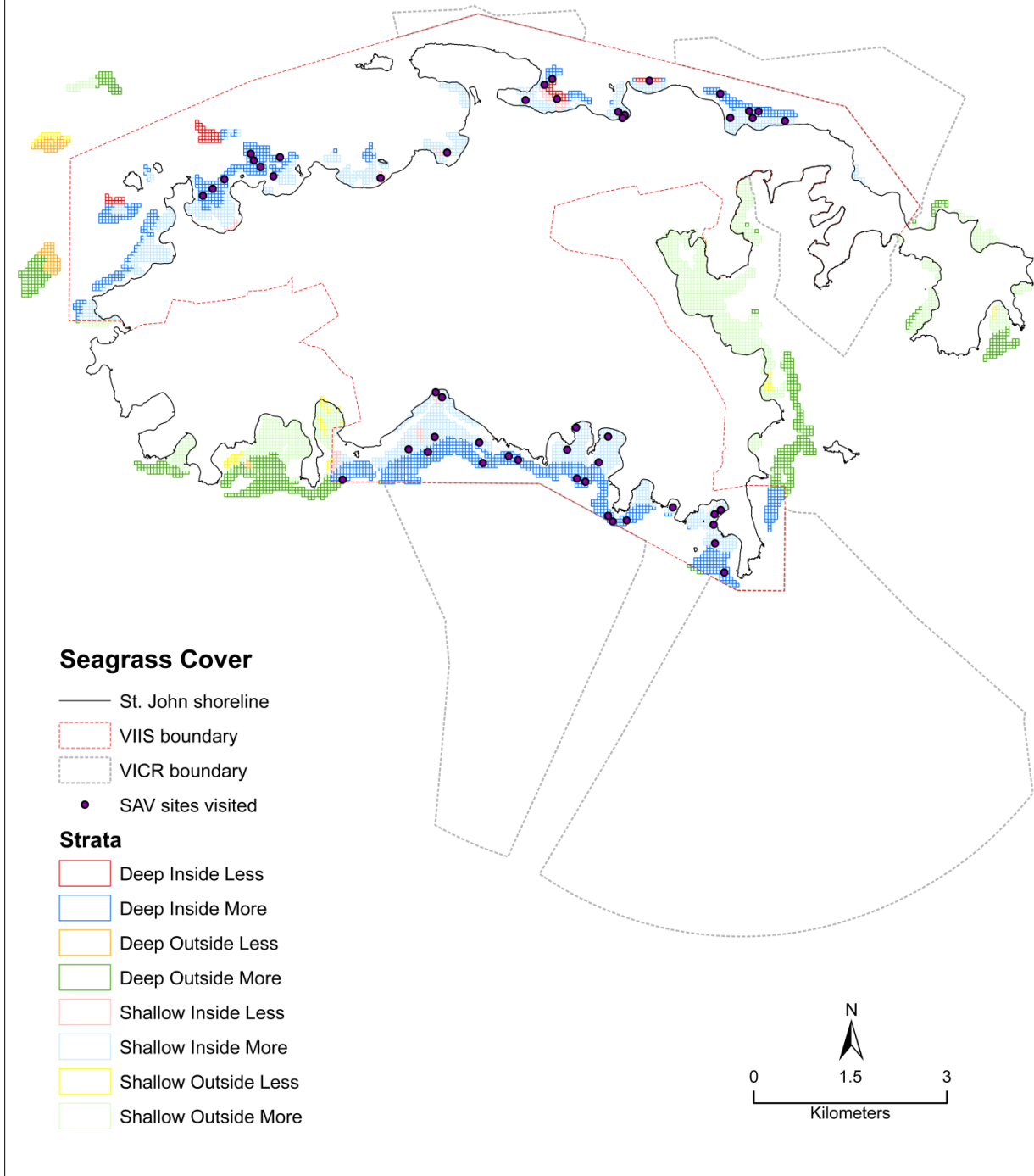


Figure B-3. Stratified random survey sites visited during FY 2015 Seagrass (SAV) Pilot Monitoring Survey at Virgin Islands NP. Note: Seagrass habitat within Virgin Islands Coral Reef National Monument (VICR), including Coral Bay, was excluded from the survey design.

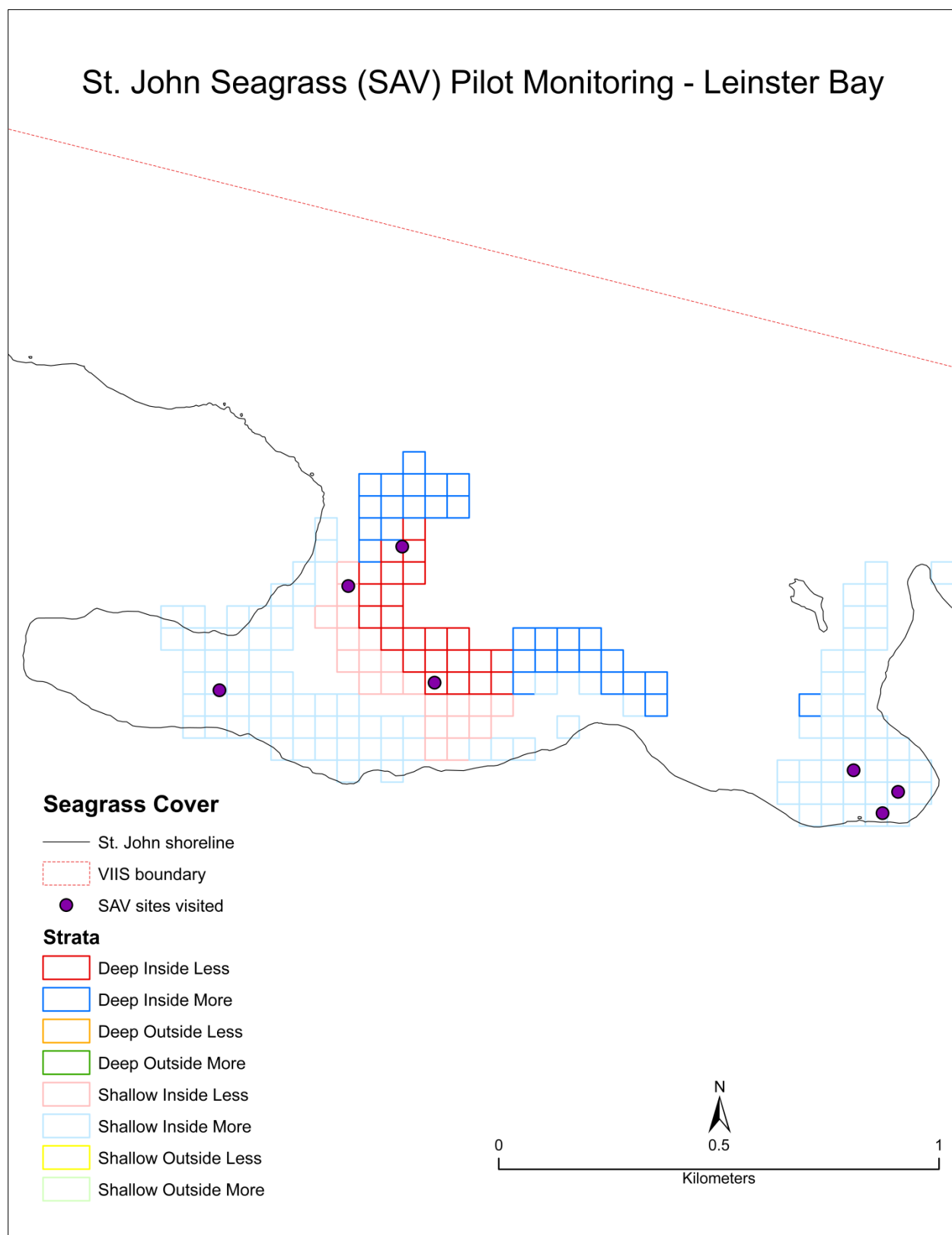


Figure B-4. Close-up view of Leinster Bay with a SAV sites visited within selected strata.

Results

Table B-2 provides average BB scores and standard errors for initial strata combinations. Deep Inside Less (DL) is greater than 13 meters (42.7 feet [ft]) deep and less than 50% cover. Deep Inside More (DM) is greater than 15 meters (49.2 ft) deep and greater than 50% cover. Shallow Inside Less (SL) is less than 13 meters (42.7 ft) deep and less than 50% cover. Shallow Inside More (SM) is less than 15 meters (49.2 ft) deep and greater than 50% cover. The depth cutoff for less than 50% map class cover was set to 13 meters instead of 15 meters to ensure there were two samples in the DL category. Averages for different depth (S: < 15 m vs D: > 15 m) and different seagrass cover (L vs. M) strata as well as overall average BB scores are also provided. Summarizing ordinal data by means and standard error is considered less than ideal; however, we feel such an approach is sufficient for a rough characterization of the sample sizes needed to detect change. In the future, for density comparisons between samples a Kruskal-Wallis test (multiple years) or Mann-Whitney U-test (between two years) is a recommended alternative approach. When additional data are available ordinal regression analysis will be used to determine resource trends (Irvine and Rodhouse 2010) and sample sizes and power can be re-calculated based upon those approaches. Figure B-5 graphically shows the distribution of BB scores by depth (meters) for all six seagrass species present in the pilot study including: *Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, *Halophila stipulacea* (exotic), *Ruppia maritima*, and *Halophila decipiens*.

Table B-3 contains recalculated BB score averages based upon three different proposed depth strata for Virgin Islands NP (0–5 meters [0–16.4 ft], 5–15 meters [16.4–49.2 ft] and > 15 meters [49.2 ft]). Table B-4 also provides the range of the data (maximum and minimums) for the three proposed depth strata. Table B-5 provides the average percent of quadrats with species present and the associated variance.

Change detectable at 80% power and 95% confidence was calculated for each stratum and seagrass species with sample sizes varying from 10–100 sites. The calculations were conducted assuming a basic t-test comparing only that stratum between survey events. Results are presented in Table B-6 for percent cover and for the percent of quadrats with species present.

Table B-2. Stratum averages (Avg) and standard errors (SE) of Braun-blaunquet (BB) scores for seagrass species. Depth: Deep (D) = > 15m, Shallow (S) = < 15 m; Cover: Less (L) = < 50% seagrass; More (M) = > 50% seagrass. Note: One DL site only 13.4 m deep quadrat [TTES—*Thalassia testudinum*; SFIL—*Syringodium filiforme*; HWRI—*Halodule wrightii*; HSTI—*Halophila stipulacea*; RMAR—*Ruppia maritima*; and HDEC—*Halophila decipiens*].

Strata	No. Sites	TTES Avg	SFIL Avg	HWRI Avg	HDEC Avg	HSTI Avg	RMAR Avg	TTES SE	SFIL SE	HWRI SE	HDEC SE	HSTI SE	RMAR SE
DL	2	–	1.26	–	–	2.17	–	–	1.24	–	–	1.83	–
DM	18	–	1.62	–	0.03	1.88	–	–	0.36	–	0.028	0.44	–
SL	5	–	0.94	–	–	1.40	0.40	–	0.44	–	–	0.86	0.40
SM	24	0.64	1.68	0.04	–	0.93	0.05	0.22	0.16	0.03	–	0.31	0.03
D	19	–	1.54	–	0.03	1.99	–	–	0.35	–	0.03	0.43	–
S	30	0.51	1.58	0.03	–	0.98	0.10	0.18	0.16	0.02	–	0.28	0.07
L	7	–	1.03	–	–	1.62	0.29	–	0.41	–	–	0.73	0.29
M	42	0.36	1.65	0.02	0.01	1.34	0.03	0.14	0.18	0.02	0.01	0.27	0.02
All	49	0.31	1.56	0.02	0.01	1.38	0.06	0.12	0.16	0.01	0.01	0.25	0.04

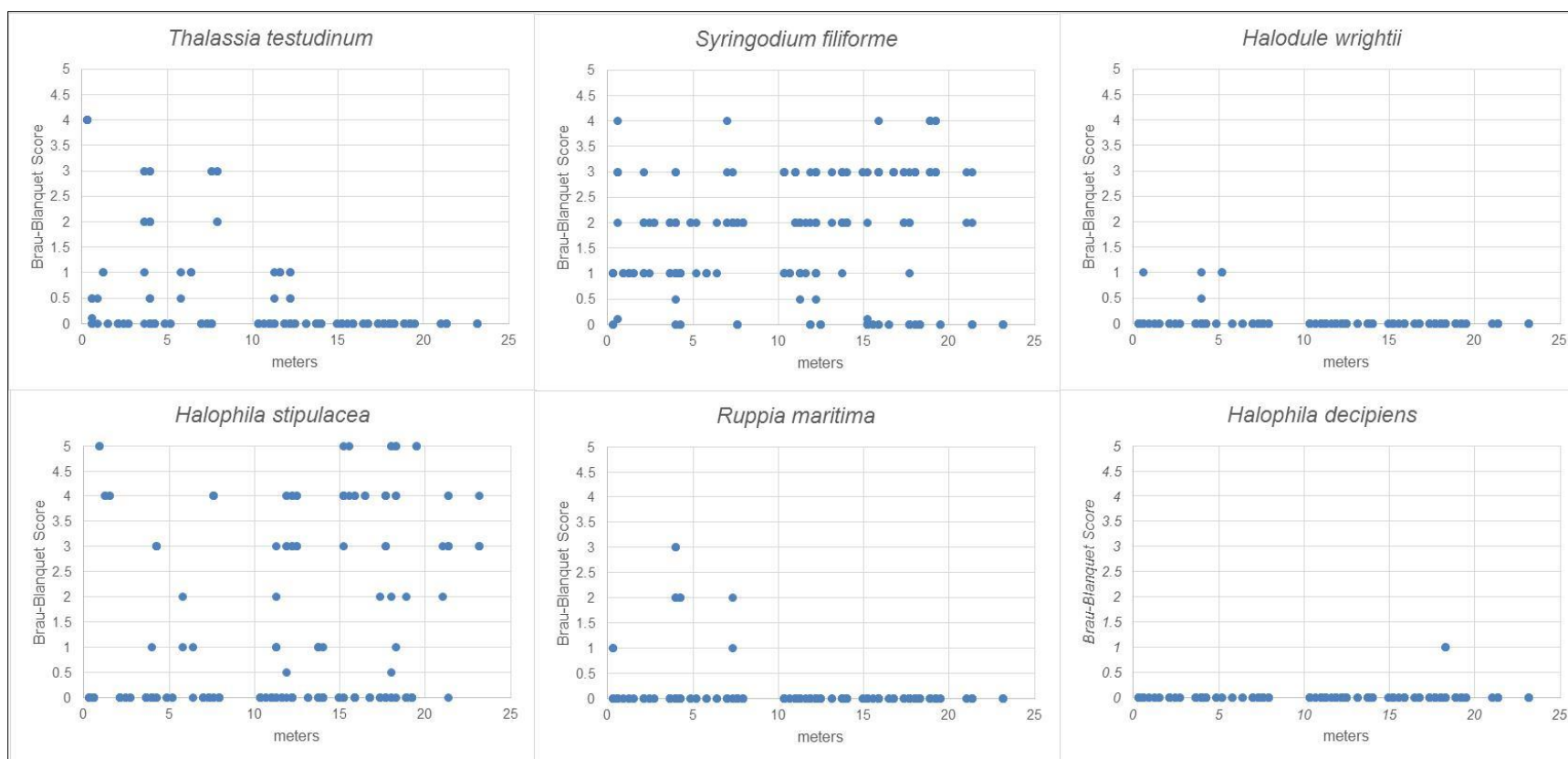


Figure B-5. Graphs displaying distribution of BB scores by depth (meters) for all six seagrass species present in the pilot study including *Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, *Halophila stipulacea* (exotic), *Ruppia maritima*, and *Halophila decipiens*.

Table B-3. Calculated averages (Avg) and standard error (SE) of BB scores for seagrass species based upon three depth categories: > 15 m, 5 – 15 m, and < 5 m. quadrat [TTES— *Thalassia testudinum*; SFIL—*Syringodium filiforme*; HWRI—*Halodule wrightii*; HSTI—*Halophila stipulacea*; RMAR—*Ruppia maritima*; and HDEC—*Halophila decipiens*].

Strata	No. Sites	TTES Avg	SFIL Avg	HWRI Avg	HDEC Avg	HSTI Avg	RMAR Avg	TTES SE	SFIL SE	HWRI SE	HDEC SE	HSTI SE	RMAR SE
> 15 m	19	--	1.54	--	0.03	1.99	--	--	0.35	--	0.03	0.43	--
5 – 15 m	19	0.27	1.66	0.03	--	0.96	0.04	0.15	0.23	0.03	--	0.34	0.04
< 5 m	11	0.92	1.45	0.05	--	1.02	0.21	0.42	0.18	0.04	--	0.52	0.18

Table B-4. Maximums (Max) and Minimums (Min) of BB scores for seagrass species based upon three depth categories: > 15 m, 5 – 15 m, and < 15 m. “All Seagrass” is the maximum BB score of any seagrass species per quadrat quadrat [TTES—*Thalassia testudinum*; SFIL—*Syringodium filiforme*; HWRI—*Halodule wrightii*; HSTI—*Halophila stipulacea*; RMAR—*Ruppia maritima*; and HDEC—*Halophila decipiens*].

Strata	No. Sites	TTES Max	SFIL Max	HWRI Max	HDEC Max	HSTI Max	RMAR Max	TTES Min	SFIL Min	HWRI Min	HDEC Min	HSTI Min	RMAR Min
> 15 m	19	–	3.75	–	0.50	5.00	–	–	0.00	–	0.00	0.00	–
5 – 15 m	19	2.67	3.00	0.50	–	4.00	0.75	0.00	0.00	0.00	–	0.00	0.00
< 5 m	11	4.00	2.52	0.38	–	4.50	2.00	0.00	0.67	0.00	–	0.00	0.00

Table B-5. Average percent of quadrats with species present per site and standard error (SE) for seagrass species based upon three depth categories: > 15 m, 5 – 15 m, and < 5 m. “All Seagrass” is the maximum percent cover of any seagrass species per quadrat quadrat [TTES—*Thalassia testudinum*; SFIL—*Syringodium filiforme*; HWRI—*Halodule wrightii*; HSTI—*Halophila stipulacea*; RMAR—*Ruppia maritima*; and HDEC—*Halophila decipiens*].

Strata	No. Sites	TTES Avg	SFIL Avg	HWRI Avg	HDEC Avg	HSTI Avg	RMAR Avg	All Seagrass Avg	TTES SE	SFIL SE	HWRI SE	HDEC SE	HSTI SE	RMAR SE	All Seagrass SE
> 15 m	19	0%	54%	0%	3%	55%	0%	99%	0%	12%	0%	3%	10%	0%	1%
5 – 15 m	19	21%	84%	3%	0%	35%	3%	100%	10%	9%	3%	0%	10%	3%	0%
< 5 m	11	45%	92%	6%	0%	30%	11%	100%	14%	6%	5%	0%	14%	8%	0%

Table B-6. Change detectable in BB scores (0–5) and frequency (percent quadrats with species present per site) with varying sample size by strata with 95% confidence and 80% power (β). “All Seagrass” is the maximum percent cover of any seagrass species per quadrat [TTES—*Thalassia testudinum*; SFIL—*Syringodium filiforme*; HWRI—*Halodule wrightii*; HSTI—*Halophila stipulacea*; RMAR—*Ruppia maritima*; and HDEC—*Halophila decipiens*].

Strata	n	TTES BB Score	SFIL BB Score	HWRI BB Score	HDEC BB Score	HSTI BB Score	RMAR BB Score	TTES% Quadrats	SFIL% Quadrats	HWRI% Quadrats	HDEC% Quadrats	HSTI% Quadrats	RMAR% Quadrats	All Seagrass % Quadrats
All Depth Combined	10	0.64	0.89	0.07	0.05	1.34	0.24	35%	40%	10%	7%	43%	14%	3%
	20	0.44	0.62	0.05	0.04	0.94	0.16	24%	27%	7%	5%	29%	9%	2%
	30	0.36	0.50	0.04	0.03	0.76	0.13	19%	22%	5%	4%	24%	8%	2%
	40	0.31	0.43	0.03	0.03	0.66	0.12	17%	19%	5%	3%	20%	7%	2%
	50	0.28	0.39	0.03	0.02	0.59	0.10	15%	17%	4%	3%	18%	6%	1%
	60	0.25	0.35	0.03	0.02	0.54	0.09	14%	16%	4%	3%	17%	5%	1%
	70	0.23	0.33	0.03	0.02	0.50	0.09	13%	14%	3%	2%	15%	5%	1%

Table B-6 (continued). Change detectable in BB scores (0–5) and frequency (percent quadrats with species present per site) with varying sample size by strata with 95% confidence and 80% power (β). “All Seagrass” is the maximum percent cover of any seagrass species per quadrat [TTES— *Thalassia testudinum*; SFIL—*Syringodium filiforme*; HWRI—*Halodule wrightii*; HSTI—*Halophila stipulacea*; RMAR—*Ruppia maritima*; and HDEC—*Halophila decipiens*].

Strata	n	TTES BB Score	SFIL BB Score	HWRI BB Score	HDEC BB Score	HSTI BB Score	RMAR BB Score	TTES% Quadrats	SFIL% Quadrats	HWRI% Quadrats	HDEC% Quadrats	HSTI% Quadrats	RMAR% Quadrats	All Seagrass % Quadrats
All Depth Combined (continued)	80	0.22	0.31	0.02	0.02	0.46	0.08	12%	13%	3%	2%	14%	5%	1%
	90	0.21	0.29	0.02	0.02	0.44	0.08	11%	13%	3%	2%	13%	4%	1%
	100	0.20	0.27	0.02	0.02	0.41	0.07	11%	12%	3%	2%	13%	4%	1%
	110	0.19	0.26	0.02	0.02	0.39	0.07	10%	11%	3%	2%	12%	4%	1%
	120	0.18	0.25	0.02	0.02	0.38	0.07	10%	11%	3%	2%	12%	4%	1%
	130	0.17	0.24	0.02	0.01	0.36	0.06	9%	11%	3%	2%	11%	4%	1%
	140	0.17	0.23	0.02	0.01	0.35	0.06	9%	10%	2%	2%	11%	3%	1%
	150	0.16	0.22	0.02	0.01	0.34	0.06	9%	10%	2%	2%	10%	3%	1%
> 15 m	10	–	1.18	–	0.09	1.45	–	–	47%	–	11%	42%	–	5%
	20	–	0.82	–	0.06	1.01	–	–	32%	–	7%	29%	–	4%
	30	–	0.67	–	0.05	0.82	–	–	26%	–	6%	24%	–	3%
	40	–	0.58	–	0.04	0.71	–	–	23%	–	5%	20%	–	3%
	50	–	0.52	–	0.04	0.63	–	–	20%	–	5%	18%	–	2%
	60	–	0.47	–	0.04	0.58	–	–	18%	–	4%	17%	–	2%
	70	–	0.44	–	0.03	0.53	–	–	17%	–	4%	15%	–	2%
	80	–	0.41	–	0.03	0.50	–	–	16%	–	4%	14%	–	2%

Table B-6 (continued). Change detectable in BB scores (0–5) and frequency (percent quadrats with species present per site) with varying sample size by strata with 95% confidence and 80% power (β). “All Seagrass” is the maximum percent cover of any seagrass species per quadrat [TTES— *Thalassia testudinum*; SFIL—*Syringodium filiforme*; HWRI—*Halodule wrightii*; HSTI—*Halophila stipulacea*; RMAR—*Ruppia maritima*; and HDEC—*Halophila decipiens*].

Strata	n	TTES BB Score	SFIL BB Score	HWRI BB Score	HDEC BB Score	HSTI BB Score	RMAR BB Score	TTES% Quadrats	SFIL% Quadrats	HWRI% Quadrats	HDEC% Quadrats	HSTI% Quadrats	RMAR% Quadrats	All Seagrass % Quadrats
> 15 m (continued)	90	–	0.38	–	0.03	0.47	–	–	15%	–	3%	13%	–	2%
	100	–	0.36	–	0.03	0.45	–	–	14%	–	3%	13%	–	2%
0–15 m	10	0.78	0.66	0.09	0.00	1.20	0.30	41%	30%	12%	–	41%	17%	–
	20	0.54	0.46	0.06	0.00	0.84	0.21	28%	20%	8%	–	28%	12%	–
	30	0.44	0.37	0.05	0.00	0.68	0.17	23%	17%	7%	–	23%	10%	–
	40	0.38	0.32	0.04	0.00	0.59	0.15	20%	14%	6%	–	20%	8%	–
	50	0.34	0.29	0.04	0.00	0.52	0.13	18%	13%	5%	–	18%	7%	–
	60	0.31	0.26	0.04	0.00	0.48	0.12	16%	12%	5%	–	16%	7%	–
	70	0.29	0.24	0.03	0.00	0.44	0.11	15%	11%	4%	–	15%	6%	–
	80	0.27	0.23	0.03	0.00	0.41	0.10	14%	10%	4%	–	14%	6%	–
	90	0.25	0.21	0.03	0.00	0.39	0.10	13%	9%	4%	–	13%	6%	–
	100	0.24	0.20	0.03	0.00	0.37	0.09	12%	9%	4%	–	12%	5%	–
5–5 m	10	0.51	0.76	0.09	--	1.15	0.13	39%	35%	11%	–	41%	11%	–
	20	0.35	0.53	0.06	--	0.80	0.09	27%	24%	7%	–	28%	7%	–
	30	0.29	0.43	0.05	–	0.65	0.07	22%	19%	6%	–	23%	6%	–
	40	0.25	0.37	0.04	–	0.56	0.06	19%	17%	5%	–	20%	5%	–

Table B-6 (continued). Change detectable in BB scores (0–5) and frequency (percent quadrats with species present per site) with varying sample size by strata with 95% confidence and 80% power (β). “All Seagrass” is the maximum percent cover of any seagrass species per quadrat [TTES— *Thalassia testudinum*; SFIL—*Syringodium filiforme*; HWRI—*Halodule wrightii*; HSTI—*Halophila stipulacea*; RMAR—*Ruppia maritima*; and HDEC—*Halophila decipiens*].

Strata	n	TTES BB Score	SFIL BB Score	HWRI BB Score	HDEC BB Score	HSTI BB Score	RMAR BB Score	TTES% Quadrats	SFIL% Quadrats	HWRI% Quadrats	HDEC% Quadrats	HSTI% Quadrats	RMAR% Quadrats	All Seagrass % Quadrats
5–5 m (continued)	50	0.22	0.33	0.04	–	0.50	0.06	17%	15%	5%	–	18%	5%	–
	60	0.20	0.30	0.04	–	0.46	0.05	15%	14%	4%	–	16%	4%	–
	70	0.19	0.28	0.03	–	0.43	0.05	14%	13%	4%	–	15%	4%	–
	80	0.17	0.26	0.03	–	0.40	0.05	13%	12%	4%	–	14%	4%	–
	90	0.16	0.25	0.03	–	0.37	0.04	12%	11%	3%	–	13%	3%	–
	100	0.16	0.23	0.03	–	0.36	0.04	12%	11%	3%	–	12%	3%	–
< 5 m	10	1.06	0.46	0.09	–	1.33	0.46	43%	18%	14%	–	43%	25%	–
	20	0.74	0.32	0.06	–	0.93	0.32	29%	12%	10%	–	29%	17%	–
	30	0.60	0.26	0.05	–	0.76	0.26	24%	10%	8%	–	24%	14%	–
	40	0.52	0.22	0.04	–	0.65	0.23	21%	9%	7%	–	21%	12%	–
	50	0.46	0.20	0.04	–	0.58	0.20	18%	8%	6%	–	18%	11%	–
	60	0.42	0.18	0.04	–	0.53	0.18	17%	7%	6%	–	17%	10%	–
	70	0.39	0.17	0.03	–	0.49	0.17	15%	6%	5%	–	15%	9%	–
	80	0.37	0.16	0.03	–	0.46	0.16	14%	6%	5%	–	14%	8%	–
	90	0.35	0.15	0.03	–	0.43	0.15	14%	6%	5%	–	14%	8%	–

Discussion

Determine how many daily average sample sites can be surveyed at Virgin Islands NP

Fifty-four sites were surveyed across four days, so approximately 12–14 sites can be sampled per day with a team of five.

Evaluate utility of depth and mapped seagrass cover strata

In Virgin Islands NP, average overall seagrass cover was the same in both mapped greater than 50% and less than 50% seagrass strata, although community composition differed. The species with a significant difference was *Thalassia testudinum* and may be indicative that when dense seagrass was mapped, what was frequently being mapped was the visible signature of *T. testudinum* as the map was created before the widespread expansion of *H. stipulacea*. With the rapid colonization of *H. stipulacea*, and the potential for the boundaries and composition of these strata to change through time, using the mapped percent cover is likely to cause problems for monitoring unless remapping regularly occurs.

The greater than 15 meter (49.2 ft) and less than 15 meter (49.2 ft) depth strata do show significant differences and this makes sense in light of Figure B-5, which shows that *Thalassia testudinum*, *Halodule wrightii*, and *Ruppia maritima* were only recorded at shallower sites.

Evaluate the category accuracy of randomly chosen other soft-bottom sites

Four out of the five sites visited that were classified as “other soft-bottom” were actually hard-bottom. The one soft-bottom site had dense *H. stipulacea* present.

Visiting other mapped soft-bottom sites in the future for a presence or absence survey is recommended to determine if such areas are continuing as other soft-bottom or whether species such as *H. stipulacea* are moving in and areas should be reclassified. However since four of the five sites mapped as other soft-bottom were actually hard-bottom, what is generally being classified as bare unconsolidated may actually not be unconsolidated and at present should not be included as a regular stratum.

Determine change detectable with varying levels of sample effort

Increasing sample size has the biggest ability to reduce the level of change detectable. Stratification by depth can provide some limited additional improvement depending on the seagrass species. The initial recommendation for each park is to implement a proportional allocation across all strata being tested, i.e. if a proposed strata is 10% of the habitat, it gets 10% of the sites. This will provide the initial data to determine if allocations should be changed in future sampling.

For Virgin Islands NP, a proportional allocation of 100 sites will result in 20 sites less than 5 meters (16.4 ft) deep, 51 sites from 5–15 meters (16.4–49.2 ft) deep, and 29 sites greater than 15 meters (49.2 ft) deep. This will allow a good ability to detect change in the deeper strata, where *H. stipulacea* is expanding in occurrence and cover. However a proportional allocation will result in less ability to detect change in shallower depths where *T. testudinum* is more prevalent.

Tested and established field methods, data collection format and database structure

Sampling at a site with two divers and two quadrats per diver is logistically feasible and seems appropriate for this protocol. Minor modifications were made to the logistics of field methods and field data sheet but overall the procedures worked. The NPStoret database structure was adapted based upon testing the data entry, QA/QC, and export processes with real data.

Literature Cited

- Bryan, D. R., Atkinson, A. J., Ault, J. S., Brandt, M. E., Bohnsack, J. A., Feeley, M. J., Patterson, M. E., Ruttenberg, B. I., Smith, S. G. and Witcher, B. D. 2013. A cooperative multiagency reef fish monitoring protocol for the U.S. Virgin Islands coral reef ecosystem, V. 1.00. Natural Resource Report NPS/SFCN/NRR—2013/672. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/DownloadFile/471146> (last accessed March 2019).
- Dunton, K., Pulich, W., and Mutchler, T. 2010. A seagrass monitoring program for Texas coastal waters: multiscale integration of landscape features with plant and water quality indicators. Final Report contract No. 0627. Coastal Bend Bays & Estuaries Program, Corpus Christi, Texas.
- Fourqurean, J. W. and Rutten, L. M. 2003 Competing goals of spatial and temporal resolution: monitoring seagrass communities on a regional scale. Pages 257-288 in D. E. Busch and J. C. Trexler. Monitoring Ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, District of Columbia.
- Fourqurean, J. W., Willsie, A., Rose, C. D., and Rutten, L. M. 2001. Spatial and temporal pattern in seagrass community composition and productivity in south Florida. *Marine Biology* 138:341–354.
- Patterson, M. E., Atkinson, A. J., Witcher, B. D., Whelan, K. R. T., Miller, J. W., Waara, R. J., Patterson, J. M., Ruttenberg, B. I., Davis, A. D., Urgelles, R. and Shamblin, R. B. 2008. South Florida/Caribbean Network vital signs monitoring plan. Natural Resource Report NPS/SFCN/NRR–2008/063. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/660634> (last accessed March 2019).
- South Florida/Caribbean Network (SFCN) 2019. South Florida/Caribbean Network seagrass community monitoring: Standard operating procedures. South Florida/Caribbean Network, Miami, Florida.
- Zitello, A. G., Bauer, L. J., Battista, T. A., Mueller, P. W., Kendall, M. S., and Monaco, M. E. 2009. Shallow-water benthic habitats of St. John, U.S. Virgin Islands. National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

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.

NPS 910/151177, March 2019

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525