



Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks

Protocol Implementation Plan Narrative—Version 1.1

Natural Resource Report NPS/SFCN/NRR—2021/2269



ON THE COVER

Photograph of Kevin Whelan sampling a Mangrove Soil Surface Elevation Table in Salt River Bay National Historical Park and Ecological Preserve.

Photograph courtesy of the National Park Service

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July 2016	Kevin Whelan	Initial Publication	–	1.0
July 2020	Judd Patterson, Michelle Prats	1.Rewrote Data Management, Analysis, and Reporting section, added sections on Data Processing Levels and Archiving (Patterson). 2.Small updates to safety documents and trainings (Prats).	1.Clarified the data workflow steps and updated them to apply to the multi-network SET online database. 2.Document locations had changed over time.	1.1

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Abstract

The mangrove forest ecosystem is a critical coastal resource in South Florida and the U.S. Virgin Islands. Mangrove wetlands provide flood control, storm protection, shore stabilization, water filtration (capturing soil runoff), carbon sequestration, and habitat for fish and wildlife communities. There is a feedback loop between soil elevation, hydrology, and mangrove forest health. The soil elevation level in mangrove forests affects tidal inundation period, tidal inundation frequency, and overall hydroperiod, all of which affect mangrove seedling species recruitment, composition, and survival.

Due to the importance of soil elevation to mangroves, it is critical to understand the rate of change in soil elevation to better predict the long-term ability of mangrove forests to regenerate. Therefore, the National Park Service (NPS) South Florida/Caribbean (SFCN) Inventory and Monitoring (I&M) Network has established a long-term soil surface elevation monitoring program in Biscayne, Salt River Bay, and Virgin Islands national parks as part of the Coastal Geomorphology Vital Sign.

The program aims to monitor rates of soil accretion and erosion and determine if soil processes are keeping pace with relative sea level. If the rate of change of relative sea level is greater than the rate at which mangrove soil elevation increases then the current mangrove forest will transgress upslope and the current areas occupied by mangrove forest will eventually convert to shallow open-water marine habitats as the trees die off and there is no recruitment to replace them. For resource managers, it will be important to understand how this process is affecting mangrove forest in their park units. Local long-term monitoring is necessary to develop this understanding.

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Section 1. Introduction

The mangrove forest ecosystem is a critical coastal resource in South Florida's Biscayne National Park (BISC); Salt River Bay National Historical Site and Ecological Preserve (SARI) in St. Croix, U.S. Virgin Islands; and the Virgin Islands National Park (VIIS) in St John, U.S. Virgin Islands. Mangrove wetlands provide flood control, storm protection, shore stabilization, water filtration (capturing soil runoff), carbon sequestration, and habitat for fish and wildlife communities. The economic value of the services derived from mangroves has been estimated as high as \$200,000–\$900,000 per hectare (United States Dollar [USD]) (Wells et al. 2006, Gilman et al. 2009).

There is a feedback loop between soil elevation, hydrology, and mangrove forest health. The soil elevation level in mangrove forests affects tidal inundation period, tidal inundation frequency, and overall hydroperiod, all of which affect mangrove seedling species recruitment, composition, and survival (Whelan 2009). Additionally, mangrove forest hydrology affects soil processes such as sedimentation, erosion, and the shrink and swell of soil materials.

Due to the importance of soil elevation to mangroves, it is critical to understand the rate of change in soil elevation to better predict the long-term ability of mangrove forests to regenerate. Therefore, the National Park Service (NPS) South Florida/Caribbean (SFCN) Inventory and Monitoring (I&M) Network is establishing a long-term soil surface elevation monitoring program in Biscayne, Salt River Bay, and Virgin Islands national parks as part of the Coastal Geomorphology Vital Sign. The program aims to monitor rates of soil accretion and erosion and determine if soil processes are keeping pace with relative sea level (RSL) which has been measured at 1.1–1.9 mm per year in South Florida (Maul and Martin 1993). If the RSL rate is greater than the rate at which mangrove soil elevation increases then the current mangrove forest will transgress upslope and the current areas occupied by mangrove forest will eventually convert to shallow open-water marine habitats as the trees die off and there is no recruitment to replace them. For resource managers, it will be important to understand how this process is affecting mangrove forest in their park units. Local long-term monitoring is necessary to develop this understanding.

This plan outlines the means by which monitoring data will be collected, managed, and reported for the monitoring of Mangrove Soil Surface Elevation Tables in SFCN parks and park units, as described in the approved SFCN monitoring plan (Patterson et al. 2008). The South Florida/Caribbean Network is implementing the Southeast Coast Network's (SECN) peer-reviewed and approved *Protocol for Monitoring Coastal Salt Marsh Elevation and Vegetation Communities in Southeast Coast Network Parks* (DeVivo et al. 2015) as it relates to soil elevation monitoring. The South Florida/Caribbean Network did not implement the soil salinity component or the marsh vegetation sampling. The modifications made to the sampling process are minor but reflect necessary changes to implement the SECN protocol in the park units of our network. We deviated from the SECN peer-reviewed protocol for a few of the standard operating procedures (SOPs). For example, we drew from the Northeast Coastal and Barrier Network (NCBN) protocol *Measuring and Understanding Wetland Elevation Change using the Surface Elevation Table (SET) and Marker Horizon Techniques* (Lynch et al. 2015) because we are using a shared database.

The two source protocols listed above are based heavily on work by Don Cahoon, Phillippe Hensel, Jim Lynch, and several others who have developed and refined the Rod-Surface Elevation Table (RSET) methods used to measure elevation changes in salt marshes. The RSET installation procedures in all of the above protocols were borrowed extensively from the Louisiana Department of Natural Resources SOPs (Folse and West 2004, Folse et al. 2008).

The largest difference between the SFCN implementation and SECN monitoring is that SFCN monitoring is in mangrove forest instead of salt marshes. Implementation of the SECN protocol in SFCN parks will occur with the following modifications:

1. Sampling will occur in mangrove forest and not salt marshes.
2. Sampling design differs. Sites are non-random index sites (as opposed to sites from a spatially balanced random selection), which are selected by a combination of judgment and exclusion criteria as follows:
 - a. Sampling locations are restricted to mature mangrove forest locations based on recent vegetation maps of the NPS units, except in Virgin Islands National Park where sampling locations were also restricted to areas that appear to be intact mangrove forest based on the 1940 aerial imagery of St. John.
 - b. The area of mature mangrove forest is limited in Biscayne, Salt River Bay, and Virgin Islands national park units. In Biscayne, the mature mangrove forests are located on the main shoreline of Biscayne Bay. At this park, the site locations were restricted to a band within approximately 30 meters (m) of the main shoreline, to match United States Geological Survey (USGS) Surface Elevation Table (SET) sites established in Everglades National Park. In Salt River Bay, only one forest area is large enough for a site to be established. In Virgin Islands, only four mangrove forest areas present in the 1940 aerial imagery are still mangrove forest today and are large enough for a site to be established.
 - c. All potential sampling locations were evaluated for the following criteria: safe accessibility (required), low visibility, low amount of trash present, low to moderate amount of pneumatophores present, low to moderate extent of leaf litter, excluding the presence of berms/mud banks (if possible), and low potential for vandalism.
3. Sampling occurs twice a year to estimate and incorporate the wet-dry season effect into the soil elevation trend.
4. The database currently being used is a Microsoft SQL Server database with a web application front-end. This database is shared by 5 networks across the Inventory and Monitoring Division (SFCN, SECN, Northeast Temperate Network (NETN), NCBN, and National Capital Region Network (NCRN)).
5. We are initially monitoring within-site benchmark stability using an autolevel. We will reassess in the future if significant resources become available to attempt to relate RSET benchmarks to the National Spatial Reference System (NSRS) maintained by the National Geodetic Survey.

The SOPs have been modified to reflect SFCN-specific changes (see Section 9 Standard Operating Procedures for further details).

Section 2. Conceptual Framework for Monitoring

Understanding the effects of multiple concurrent stressors that affect soil surface elevation in parks and mitigating the impacts of those stressors at multiple spatial and temporal scales, is an ongoing challenge for SFCN park managers. This complex relationship was explained in the SFCN Coastal Wetland ecological zone model that is described in the approved SFCN monitoring plan (Patterson et al. 2008). Further details on the relationships between coastal wetlands, sea-level rise, and climate change are explored in Cahoon and Guntenspergen (2010, Figure 1). There are both positive and negative feedback loops that are believed to affect the elevation capital of these wetlands. Relationships between coastal zone management, sea-level rise, and extreme weather events can be a challenge to manage, but the coastal geomorphology vital sign can supply relevant information to resource managers (Table 1).

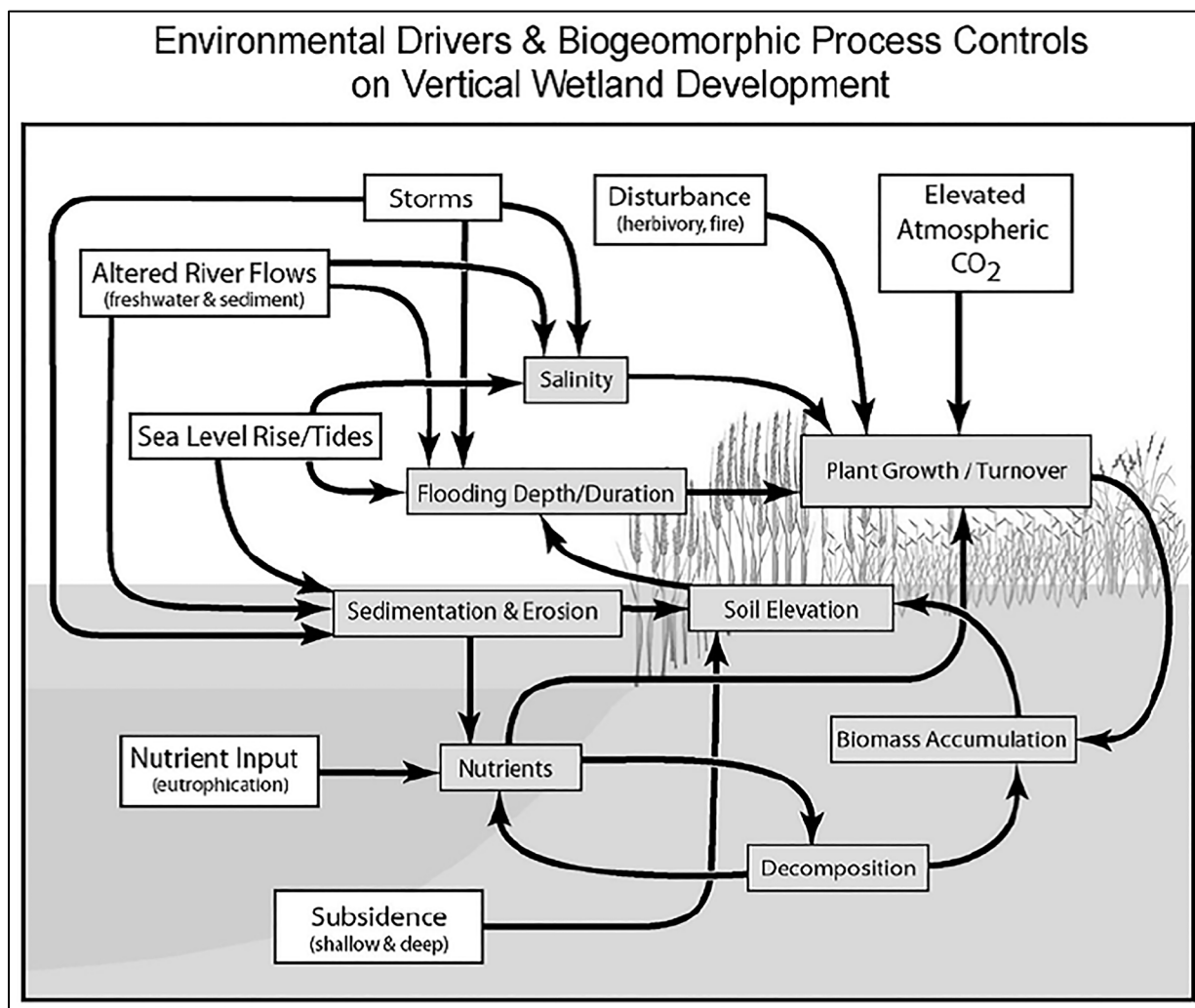


Figure 1. Conceptual model illustrating linkages and feedback relationships among factors controlling habitat stability and nutrient and carbon dynamics in coastal wetlands. External forcing functions that may destabilize the system are indicated in white boxes. Figure reproduced from Cahoon and Guntenspergen (2010).

Table 1. Factors affecting coastal geomorphology within South Florida/Caribbean Network parks and potential measures for vital signs monitoring.

Category	Management Issue(s)	Potential Measures
Wetland Management	Construction of roads and canals, filling and draining of wetlands, and obstructions to the natural fluctuations of sediment transport to the mangrove zone.	<i>Monitoring of soil surface elevation change and accretion at specific sites.</i>
Sea-Level Rise	Projections of 21st-century sea-level rise that may accelerate 2- to 5-fold compared to the global rate during the 1900s, likely increasing vulnerability to coastal erosion.	<i>Monitoring of soil surface elevation change and accretion at specific sites will be related to regional sea-level monitoring rates.</i>
Extreme Weather Events	Vulnerability to shoreline erosion due to changes in the frequency, magnitude, and duration of storm events as well as local variations in tidal ranges.	<i>Monitoring of soil surface elevation change and accretion at specific sites will occur before the hurricane season with follow-up monitoring after major storms pass (e.g., Hurricane Wilma, Superstorm Sandy).</i>

Section 3. Measurable Objectives

The primary goal of the SFCN mangrove soil surface elevation table monitoring is to detect trends in mangrove soil elevation at index sites within three parks. Monitoring data will be useful for understanding the effects of the various forces shaping mangrove soil elevations and for adaptive management planning to sustain mangrove forest persistence. We hope to determine whether or not mangrove soil surface elevation at our index sites can keep pace with relative sea level rise.

Objectives that will be addressed by the measurement of mangrove soil surface elevation include:

1. Determine mangrove forest soil surface elevation trajectories over time (e.g., decades) at specific intertidal mature mangrove forest sites.
2. Determine the current rate of accretion/erosion at specific intertidal mature mangrove forest sites.

The SFCN coastal geomorphology objectives (above) are comparable to the objectives in the *Protocol for Monitoring Coastal Salt Marsh Elevation and Vegetation Communities in Southeast Coast Network Parks* (DeVivo et al. 2015). Our objectives are more specific inquiries of the first two objectives of the SECN protocol: (1) Determine the magnitude, rate, and within-site variability of change in ground surface elevation in SECN salt marshes; and (2) Determine the status, trends, and within-site variability in surface sediment accretion or erosion. Understanding soil surface trajectories over time (SFCN objective 1) is a more detailed question of determining the rate of change (SECN objective 1). Monitoring accretion or erosion is an objective of both protocols (SFCN and SECN objective 2).

In addition to the two monitoring objectives listed above, we have three analysis goals:

1. Determine the relative contributions of accretion, erosion, and compaction to trends in soil surface elevation.
2. Determine the effects of storm events on the soil elevation at specific intertidal mature mangrove forest sites.
3. Determine if mangrove forest soil surface elevations at specific intertidal mature mangrove forest sites are keeping pace with regional relative sea level.

The relative contributions of accretion, erosion, and compaction are derived from the results of elevation and accretion monitoring (SFCN goal 1). The effects of storms (SFCN goal 2) and the correlation of soil surface change rate to sea-level rise (SFCN goal 3) are related to timing of sampling and are also derived from the results of the first two objectives of the SECN protocol. Note that the effects of storm events will be monitored through an additional visit to existing monitoring sites as soon as a visit is practical and safe after a storm event. In some cases, there will not be an additional visit, and the presence of a storm may be used in analysis as a covariate to explain substantial changes in the soil elevation detected during regularly scheduled monitoring.

Section 4. What Is Being Measured and How

The South Florida/Caribbean Network will monitor mangrove soil surface elevation using the same general methods developed and approved for implementation in the *Protocol for Monitoring Coastal Salt Marsh Elevation and Vegetation Communities in Southeast Coast Network Parks* (DeVivo et al. 2015), using the Soil Surface Elevation Table and marker horizons.

Three benchmarks are established at each monitoring location, and each benchmark uses a removable SET measuring device (RSET) to determine surface elevation. The SET instrument is designed to be temporarily attached to a fixed and constant plane in space from which the distance to the sediment surface can be measured via pins lowered to the surface. This allows for the rate of elevation change to be closely and accurately measured across repeated sampling periods and is how the long-term elevation trend is established.

The marker horizons are layers of feldspar placed on the soil surface. These horizons aid in understanding what surface and subsurface processes are affecting soil elevation change, as measured by the SET. These processes can include sediment deposition or erosion, root growth, decomposition, pore water flux, shrink and swell, and compaction. Through the joint use of the SET instrument and the marker horizon methods, we are able to address our monitoring objectives.

The following variables are being calculated from measured variables at each SET site: (1) direct quantitative estimates of surface elevation change, (2) sediment accretion/erosion, and (3) contribution of subsurface processes to surface elevation change (calculated as accretion minus elevation).

The South Florida/Caribbean Network is monitoring the soil surface elevation at specific locations. We currently have two sites in Biscayne, one site in Salt River Bay, and two sites in Virgin Islands. We installed RSETs and marker horizons in these three park units to monitor soil surface elevation, accretion, and erosion with the goal of gaining insight into the soil elevation trends at specific locations within these parks (Table 2). Construction at each site can be labor intensive; however, once a site is established, repeat samplings from a fixed point in space produce highly precise and accurate elevation measurements (± 1.5 millimeter range). Sampling is scheduled to take place twice a year with a three-person field crew to capture the effects of the wet season and the dry season, allowing for a better understanding of the annual change in soil surface elevation. Additionally, we are able to capture the importance of storm events by sampling just prior to hurricane season and minimizing the potential before- and after-event time interval (Table 2).

Table 2. Monitoring objectives, sampling design, sampling methods, and variables measured at SFCN parks as a part of the protocol for monitoring soil surface elevation.

Objective Number	Objective Description	Objective Description	Temporal Design	Sampling Method	Data Collected	Analysis Tool
1	Soil surface elevation trajectories	Specific locations	Twice annually	Autolevel survey	Relative elevation of each benchmark against each other and (if available) external benchmark(s)	Comparison against previous survey data to document shifting of benchmarks
1	Soil surface elevation trajectories	Specific locations	Twice annually	RSET	Relative elevation (mm)	Regression of absolute change
2	Accretion / erosion rates	Specific locations	Twice annually	Feldspar marker horizon	Relative amount (mm)	Regression of change
Derived	Analysis Goal 1: Contributions of accretion, erosion, and compaction	Specific locations	Twice annually	RSET and feldspar marker horizon	Relative elevation and relative amount (mm)	Derived from base measurements
Derived	Analysis Goal 2: Effects of storm events	Specific locations	Episodic (post event)	RSET and feldspar marker horizon	Relative elevation and relative amount (mm)	Derived from base measurements; Regression of interval change
Derived	Analysis Goal 3: Keeping pace with regional relative sea level	Specific locations	Twice annually (RSET) and derived from continuous data (NOAA)	RSET and NOAA sea level data	Relative elevation (mm) and annual sea level change (mm)	Derived from base measurements; Regression or ANCOVA comparing two slopes

Section 5. Sampling Design and Monitoring Schedule

There are several issues to consider when designing a field program for monitoring mangrove soil surface elevation and accretion dynamics. These include the specific monitoring objectives being addressed, and the resultant implications for site selection, sampling frequency, the variables being measured, the sampling unit, and sample sizes. We provide justification and supporting documentation for various aspects of the protocol related to sampling design. The overall design strategy upon which this protocol is based has three components:

1. A clearly defined sampling frame: the area of interest is mature mangrove forest based on analysis of imagery contained within recent vegetation maps of the National Park System units. In all three of these units the area of mature mangrove forest is limited. In Biscayne, the majority of the mature mangrove forests are located on the main shoreline of Biscayne Bay. In this park, the site locations were restricted to a band within approximately 30 meters of the main shoreline to have a similar sampling frame to USGS SET sites established in Everglades National Park. In Salt River Bay, only one mangrove forest area is large enough for a site to be established. In Virgin Islands, only four mangrove forest locations present in the 1940 aerial imagery are still mangrove forest today and are large enough for a site to be established. A number of potential sampling locations were selected within each park's sampling frame.
2. To preserve the mangrove communities from human impact and maintain the public's viewshed within the parks, permanent monitoring stations have been established at locations outside of normal public view and restricted to areas that are regularly flooded or inundated.
3. Potential sampling sites were further evaluated for the following criteria: safe accessibility, visibility, amount of trash present, amount of pneumatophores present, extent of leaf litter, presence of berms/mud banks, and potential for vandalism.

More information is provided in *SOP 01: Mangrove soil surface elevation monitoring: Conducting field site suitability assessments* (Whelan 2016a) and in the Sampling Design (Appendix B. Site Suitability Assessment Reports). The Power analyses (Appendix C. Power Analyses) indicate that there is sufficient power to detect trends in soil surface level of less than 1.0 millimeters per year with greater than 80% power at an alpha level of 0.05.

Sampling Design

1. Site selection occurred following rules (see above and Appendix B. Site Suitability Assessment Reports).
2. Monitoring stations at each site were built following SOPs from DeVivo et al. (2015) with slight modifications (see Section 9. Standard Operating Procedures).
3. Monitoring occurs twice a year. Biannual monitoring allows for a more representative estimate of the annual soil elevation by including seasonal variation, increases the power of the monitoring, and is recommended in the NCBN protocol. Additionally, it allows the South Florida/Caribbean Network to understand the contribution of hurricanes to the wetland soil surface. By sampling just before the hurricane season and maintaining the ability to

episodically monitor sites after a major storm, we are able to minimize the time between the before- and after-storm sampling events.

4. Additional operational implementation notes:

- a. A boat is needed to reach the sample sites in Biscayne and Virgin Islands National Parks. The network has boats available for each of these parks. At Salt River Bay National Historical Park and Ecological Preserve the SET site is accessible by foot.
- b. The parks in the U.S. Virgin Islands require travel, and this can add cost to the sampling. To help mitigate this cost, when possible it is advisable to coordinate sampling with other monitoring activities such as forest sampling. In addition, assistants provided by the parks can also reduce costs.

Monitoring Schedule

Field work for this protocol is conducted twice a year to capture the effects of the dry season and the wet season (Table 3). The park units have distinct dry and wet seasons that strongly affect overland flow, sediment transport, and deposition of allochthonous inputs into the mangrove forest from the nearshore intertidal system. Biannual sampling will allow for a better estimate of annual sediment elevation. In addition, we sample prior to the hurricane season to be better prepared to assess the impact of major storms on the sites' soil elevation trajectories.

Table 3. Proposed sampling schedule for SFCN mangrove soil elevation table monitoring protocol.

Park	Dry Season	Wet Season
Biscayne National Park	Mid-Oct to Mid-May	Mid-May to Mid-Oct
	March—sampling	September—sampling
Salt River Bay National Historical Park and Ecological Preserve	December to August	August to November
	May—sampling	December—sampling
Virgin Islands National Park	December to August	August to November
	April—sampling	November—sampling

Section 6. Data Management, Analysis, and Reporting

An overview of the South Florida/Caribbean Network data workflow for this project is as follows:

Data Workflow

1. Raw pin data are collected on site-specific data forms created for each sampling trip. Field data forms include pin measurements from the previous visit and sample notes to help confirm the newly observed data. The protocol lead or field crew leader checks each datasheet for completeness and realistic entries before leaving the field. In the future we may transition to site-specific digital field data entry forms.
2. Photographs are downloaded from the camera and stored on the network file server. Filenames are renamed to indicate the site and station/benchmark where they were taken.
3. As soon as possible after field collection the original datasheets are scanned, and the original sheets organized in a binder for use during data entry and review.
4. Data entry takes place in the NPS SET web application available through the Integrated Resource Management Application (IRMA) portal.
5. After initial data entry, pin measurements are validated in the database via double entry. During this process, any discrepancies are flagged and corrected. Marker horizon measurements are reviewed manually and then marked as validated. Both of these validations should be done by someone other than the person who did the original entry.
6. If errors are found, they are corrected, and this may lead the protocol lead or data manager to expand the review. At the completion of this activity the data processing level is changed to Provisional.
7. The SET data pin by pin is reviewed to determine which measurements will be excluded from the analysis. These decisions are made by looking for anomalies between pin readings and between sampling visits, and also considering the associated notes (e.g. crab hole or tree root). Any anomalous values are flagged as either “Exclude from Interval Analysis” and/or “Exclude from Cumulative Analysis” in the database. Along with the analysis flags, a reason code, the analyzers name, and a date are recorded. The protocol lead will review the accretion values and survey data.
8. After all quality control checks have been completed, the data processing level is changed to Accepted (or Certified if a Quality Assurance Plan exists). At this point flat files and metadata are generated, and the dataset is uploaded to IRMA Data Store. This process will occur annually.
9. Initial analysis will use a t-test to determine if the observed slope is significantly different from zero. We hope to progress to using a t-test with adjusted degrees of freedom (to account for repeated measures at each SET) or some other appropriate analysis. The analysis plan is currently being developed across multiple networks.

10. Resource briefs will be provided to the parks annually. A more comprehensive report will be produced every five years (this interval is based on power analysis results indicating that five years of data are needed to detect trends; see Appendix C).

Data Processing and Data Quality Levels

The data processing steps, their associated products, and their frequency of completion are listed in Table 4. Table 4 also introduces the three stages of data processing: raw, provisional, and accepted. Raw data are in their original form, either as a field datasheet, photo, or a raw entry into the database. Provisional data have undergone verification steps but are not suitable for general use. Accepted data (or certified data, if the QAP for the protocol is in place) are products from the provisional data step that have been validated and are fit for analysis and publication.

Table 4. Data processing steps for the SFCN SET Protocol. Detailed procedures for processing datasets are outlined in the SOP's mentioned in Tables 7a–7b.

Data Type	Processing Steps	Product Name	Timing
Datasheets	1. Filled-in by hand in the field	Datasheets	At the end of each site sampling event
	2. Reviewed for completeness	Reviewed datasheets	At the end of each site sampling event
	3. Reviewed by the protocol lead or field lead	Reviewed datasheets	At the end of each field sampling day, or within a week
	4. Digitally scanned and originals put in a binder	Scanned datasheets	At the end of each field sampling day, or within a week
	5. Original paper copies are managed as long-term records	Local file storage of reviewed datasheets	Within 2 months of field season's end
	6. Scanned copies are published to NPS Data Store with permissions in alignment with park protected records guidance	Publication of scanned datasheets	Within 6 months of field season's end
Photographs	1. Photos taken in the field	Photos	At the end of each site sampling event
	2. Images reviewed for completeness	Photos	At the end of each site sampling event
	3. Images downloaded and renamed	Renamed and organized photos	At the end of each site sampling event
	4. Images are archived locally	Local archives of photos	Within 6 months of field season's end

Table 4 (continued). Data processing steps for the SFCN SET Protocol. Detailed procedures for processing datasets are outlined in the SOP's mentioned in Tables 7a–7b.

Data Type	Processing Steps	Product Name	Timing
Dataset	1. Data manually entered into online database	Raw data	Within several weeks of the field sampling day
	2. Verification during data entry: self-check	Raw data	Within several weeks of the field sampling day
	3. Data Validation after data entry: For SET pin data, a 100% check (double entry). For Marker Horizons, a 100% review.	Raw data	Within 2 months of the field sampling day
	4. Once 100% double entry is completed and there is not significant errors found then the data status will be changed	Provisional data	Within 3 months of the completion of the annual sampling
	5. Summary statistics generated to look for additional outliers and analysis flagging applied to exclude individual readings from interval and cumulative analysis	Provisional data	Within 6 months of field season's end
	6. Metadata created for the dataset	Accepted or Certified data	Within 6 months of field season's end
	7. Dataset and metadata are published to NPS Data Store with permissions in alignment with park protected records guidance	Publication	Within 6 months of field season's end
	8. Data are analyzed and reports generated	Raw data	Within several weeks of the field sampling day
	9. Once 100% double entry is completed and there is not significant errors found then the data status will be changed	• Event and Status Reports • Status and Trend Reports	• Within 12 months of field season's end • After 10 data collection events for a given park

Data Archiving

Once digital products are created, processed and approved in the steps above, the protocol lead, in coordination with the data manager (data or photos) or managing editor (published reports), prepares them for posting to IRMA Data Store. The types of products that are posted on IRMA Data Store for this project include Resource Briefs (annual) and Status and Trends reports (after five years of data collection per park), digital scans of data sheets, and .csv formatted exports of annual data sets from the NPS SET web application. In their unfinished or provisional forms, these products are generally stored only on the SFCN server. The NPS SET web application and database is used by several networks and will continue to be modified based on group feedback. Reports exist for exporting station information, SET pin measurements and marker horizon measurements.

The timing of posting new products to IRMA Data Store is annually, if not more often. Products on IRMA Data Store can be shared with the public, all of the NPS, or a restricted list of specific individuals based on the park protected records guidance. Public access is given to final, approved reports or to datasets that are accepted or certified and from which protected data have been withheld, where appropriate. Restricted access on IRMA Data Store may be used for provisional products or versions of files that include protected information. All public products will be available through the SFCN SET website (<https://www.nps.gov/im/sfcn/coastal-geo.htm>). Refer to the IRMA Data Store website for upload and product linking instructions, and coordinate with the SFCN data manager or managing editor when undertaking product upload steps.

Section 7. Budget

The estimated annual cost for the SFCN mangrove soil surface elevation tables protocol is presented in Table 5. Startup costs include approximately \$6,600 for equipment used at multiple sites: jack hammer (\$600), generator (\$1,000), auto level (\$3,500), and RSET (\$2,000; the South Florida/Caribbean Network has an RSET for each park). Site-specific startup costs include platform materials (\$1,000), survey rods and receiver (\$1,000), and travel costs for scouting and site establishment (these vary depending on park from \$1,000 to \$8,000). For the five-year analysis and reporting effort, there would be an increased labor cost of \$7,000 for additional time: for the community ecologist (0.04 FTE), data manager (0.01 FTE), and quantitative ecologist (0.01 FTE).

Table 5. Estimated annual operating cost (based on FY2015 dollars) for the SFCN mangrove soil elevation table monitoring protocol. Budget does not include support provided by parks or partners.

Category	Costs (FY 2016)	Notes
Personnel SFCN ¹	–	–
Community Ecologist	\$20,600	0.17 FTE GS-12
Intern Assistant	\$13,000	0.50 FTE
Data Manager	\$4,000	0.04 FTE GS-11
Quantitative Ecologist	\$1,400	0.01 FTE GS-12
Total Personnel Costs	\$39,000	–
Equipment and Supplies	–	–
Boat Fuel and Maintenance	\$ 500	–
Field Supplies	\$ 500	–
Total Equipment Costs	\$ 1,000	–
Travel ²	–	–
Travel: SARI	\$2,400	Price for two trips. Park lodging provided
Travel: VIIS	\$3,000	Price for two trips. No park lodging available
Total Travel Costs	\$5,400	–
Total Annual Protocol Cost	\$45,400	–

¹ A portion of all personnel's time is devoted to data management activities including data entry, analysis, and QA/QC. This is in accordance with NPS I&M policies recommending that at least 30% of monitoring resources be allocated to data management.

² Travel assumption is that SARI and VIIS park units will continue to supply NPS assistance and there is a cost reduction by coordinating travel with SFCN forest monitoring protocol.

Section 8. Safety

Implementation of this protocol has multiple complex risks. Staff will continuously evaluate all risks at the programmatic, personnel, and site level. Programmatic-level safety information is presented here and procedures to mitigate risks associated with specific activities related to protocol implementation are addressed in standard operating procedures below.

Job Hazard Analyses (JHAs) were completed for all personnel who implement portions of the protocol in which risks and risk abatement strategies (including training needs) were identified. Risks and abatement strategies for all staff were synthesized to develop a protocol-level JHA.

Specific safety concerns include:

- Slip and fall hazards due to the need to sample the SETs from elevated board walks.
- Crew members will be regularly working in park areas outside of communications range (either by park radio or by cell phone).

Based on the JHA and associated risk abatement measures it was determined that this protocol can be safely implemented provided that the South Florida/Caribbean Network and partner staff implement it in accordance with the referenced SOPs and recommended risk abatement strategies. Personnel must review the relevant documents, SOPs, and JHAs (Table 6). They must also sign the JHA associated with this protocol (see below). All NPS SFCN personnel will follow the Safe Practices Manual and Emergency Operations Plan specific to the respective park within which they are operating.

Table 6. Relevant safety documents and locations on the SFCN server.

Relevant Document, SOP, or JHA	Location of Electronic Version on SFCN Server
Sediment elevation table installation and monitoring JHA	Z:\SAFETY\SFCN_SOPs_with_JHAs\JHAs\Community_Group_JHA's\Job_Hazard_Analysis_SET\JHA_SET_Safety.docx
Safety sign out sheet—Float Plan	Z:\SAFETY\Float_Plans\20181010_SFCN_Float_Plan.pdf
Go-no-go small boat	Z:\SAFETY\SFCN_SOPs_with_JHAs\Community_operations\Tiburon_Go_No_Go_Checklist_Community.docx
Small boat operations SOP	Z:\SAFETY\Section 20 - Watercraft Safety\SFCN Boat Operations Plan.2014.docx
Vehicle go-no-go	Z:\SAFETY\SFCN_SOPs_with_JHAs\Community_operations\Vehicle Go NoGo Checklist CommunityGroup.pdf

Section 9. Standard Operating Procedures and Deviations from Source Protocol(s)

SOPs have been identified or developed (Table 7a–7c). In general, these SOPs are SFCN updates to the SOPs from the approved *Protocol for Monitoring Coastal Salt Marsh Elevation and Vegetation Communities in Southeast Coast Network Parks* (DeVivo et al. 2015). Because we are only implementing the soil elevation part of the protocol, we will not use a number of SECN SOPs. Additionally, since we are using a different database, the database and data management SFCN SOPs are substantially different from the SECN equivalent. We have included crossover tables from the SECN SOPs to the SFCN SOPs (Tables 7a–7c). We have also included a crossover table from the SECN appendices to the SFCN appendices (Table 8).

Table 7a. Monitoring SOPs required for this SFCN mangrove soil surface elevation table monitoring protocol implementation plan. The table includes a brief description of changes from the source document to the SFCN version. Full citations for each source protocol are provided in the literature cited section.

Topic	Source Protocol	Explanation of Differences	SFCN Updated SOP	Link to Published Document / IRMA Record
Site Selection	Protocol for monitoring coastal salt marsh elevation and vegetation communities in Southeast Coast Network parks (DeVivo et al. 2015)	Modified from SECN protocol to document SFCN-specific methods. SFCN uses a judgment sample (index sites) rather than a spatially balanced random sample.	Site suitability assessment report for sample locations of the South Florida/Caribbean Network (Appendix B in this document)	2230638
Site Assessment	Salt marsh community monitoring: conducting field site suitability assessments (Asper and Curtis 2012a)	Modified from SECN SOP to document SFCN assessment method and field form.	SOP 01: Mangrove soil surface elevation monitoring: Conducting field site suitability assessments (Whelan 2016a)	2231913
Monitoring Construction	Salt marsh elevation and vegetation community monitoring site platform construction and installation (Asper and Curtis 2012b)	Modified from SECN SOP to document minor changes in SFCN-specific methods.	SOP 02: Mangrove soil surface elevation Monitoring: Site platform construction and installation (Whelan and Prats 2016c)	2231914
Monitoring Benchmark Installation	Salt marsh community site rod-surface elevation table (RSET) installation (Asper and Curtis 2011)	Modified from SECN SOP to document minor changes in SFCN-specific methods.	SOP 03: Mangrove rod-soil surface elevation table (RSET) benchmark installation (Whelan and Prats 2016b)	2231915

Table 7a (continued). Monitoring SOPs required for this SFCN mangrove soil surface elevation table monitoring protocol implementation plan. The table includes a brief description of changes from the source document to the SFCN version. Full citations for each source protocol are provided in the literature cited section.

Topic	Source Protocol	Explanation of Differences	SFCN Updated SOP	Link to Published Document / IRMA Record
Monitoring Benchmark Stability	Northeast Temperate Network lakes, ponds, and streams monitoring protocol: 2014 revision (Gawley et al. 2014)	The SECN protocol suggests monitoring benchmark stability but does not provide an SOP.	SFCN will follow NETN SOP 19—Leveling water monitoring sites, version 1.02 (Gawley et al. 2014).	2208490
Training	Requirements for SECN salt marsh elevation and vegetation community monitoring field season preparation, equipment, and training (Curtis 2013)	Modified from SECN protocol to focus on methods used by SFCN, with modifications to ensure appropriate use of network- and park-specific equipment.	SOP 04: Requirements for monitoring mangrove soil surface elevation tables in South Florida/Caribbean Network Parks: Field season preparation, equipment and training (Whelan 2016)	2231917
Monitoring—RSET	Salt marsh elevation monitoring (Asper and A. C. Curtis 2013)	Modified from SECN SOP to document minor changes in SFCN-specific methods.	SOP 05: Mangrove elevation monitoring (Whelan and Prats 2021a)	2285044
Monitoring—Accretion	Measuring accretion with a feldspar marker horizon (Asper and T. Curtis 2013)	Modified from SECN SOP to document that the SFCN does not use the liquid nitrogen but cuts plugs/cores manually.	SOP 06: Measuring accretion with a feldspar marker horizon (Whelan and Prats 2021b)	2285045

Table 7b. Data management SOPs required for this protocol implementation plan (SFCN mangrove soil surface elevation table monitoring protocol). The table includes a brief description of changes from the source document to the SFCN version. Full citations for each source protocol are provided in the literature cited section.

Topic	Source Protocol	Explanation of Differences	SFCN Updated SOP	Link to Published Document / IRMA record
Database	Salt marsh elevation and vegetation community monitoring: data management and database technical documentation (Wright and Thompson 2012)	SFCN and NCRN both use an updated, collaboratively developed SET database.	NPS SET Database technical documentation (Patterson et al. 2017)	2277881
Data Input	Southeast Coast Network salt marsh elevation monitoring database user manual (Wright and Thompson 2013)	SFCN does not use the SECN SOP; SFCN developed an SOP for data input into the online database.	SOP 07: Mangrove rod-soil surface elevation table (RSET) database user manual (Montenegro et al. 2021).	2285046
Dataset and Metadata	Dataset and metadata publication (SECN 2013)	SFCN does not use the SECN SOP; SFCN follows the network's data management plan.	SFCN data management plan shared among all approved SFCN protocols	661961
Reporting	Protocol for monitoring coastal salt marsh elevation and vegetation communities in Southeast Coast Network parks (DeVivo et al. 2015)	Documents the SFCN differences and modifications from the SECN protocol. Will work with SECN and others to improve the reporting as progress is made on the National Database and shared analyses.	Protocol implementation plan for monitoring mangrove soil surface elevation tables in South Florida/Caribbean Network parks (this document)	2230638

Table 7c. Safety SOPs required for this protocol implementation plan (PIP; SFCN mangrove soil surface elevation table monitoring protocol). The table includes a brief description of changes from the source document to the SFCN version.

Topic	Source Protocol	Explanation of Differences	SFCN Updated SOP	Link to Published Document / IRMA record
Safety	Sediment elevation table installation job hazard analysis	SFCN does not use the SECN JHA. The SFCN JHA is included in this PIP.	SFCN Safety SOP and JHA Binder	2230638

Table 8. Appendices associated with the SFCN Monitoring Protocol Implementation Plan for Mangrove Soil Surface Elevation Tables. The table includes a brief description of changes from the source (SECN) document to the SFCN version.

Topic	SECN Appendix	Explanation of Differences	SFCN Updated Appendix	Link to Published Document / IRMA record
Field	Appendix A. Field Monitoring Cheat Sheet	Modified to make it specific to the SFCN.	Available in supplemental materials.	Available on request.
Job Hazard	Appendix C. Job Hazards and Risk Assessment	Modified to make it specific to the SFCN.	Appendix A of this document.	2230638
Boat Access	Appendix D. Notes on Site / Boat Access to sampling locations	Modified to make it specific to the SFCN.	Available in supplemental materials.	Available on request.
Assessment Report	Appendix E. Site Suitability Assessment Reports	Modified to document SFCN findings from assessment work.	Appendix B of this document.	2230638
Power	Appendix F. Power Analyses	Modified to reflect SFCN specific findings and analysis.	Appendix C of this document.	2230638
Training	Appendix G. Double reading of Pins	New to reflect SFCN specific findings and analysis.	Appendix C of this document.	2230638

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Appendix A. Job Hazards and Risk Assessment

This appendix describes application of the GREEN-AMBER-RED (GAR) Risk Assessment Model as outlined in the NPS Operational Leadership Student Manual (Version 2; July 2011). This GAR was adopted from the reviewed and approved Appendix C in DeVivo et al. (2015) by the SFCN Ecologist (Kevin Whelan). This GAR was reviewed by the acting SFCN program manager (Karl Brown) on 5 October 2015 and approved by the NPS Southeast Region I&M program manager (Brian Mitchell) on 14 October 2015.

The GAR model allows for a general assessment of a task or operation and generates communication concerning the risks of an activity (in this case, conducting the field-based activities of this protocol implementation plan). The most important part of the process is the team discussions prior to potentially hazardous activities or tasks that will lead to a better understanding of the risks and how they will be managed.

The GAR is a seven-step process. Each step is defined and explained in the context of the sampling that will occur as part of this protocol.

Step 1: Define the Mission or Task

The SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan includes several field-based monitoring activities: construction, installation, and maintenance of monitoring platforms in mangrove forest, collection of data using a variety of equipment, and operation of motorized watercraft to sampling locations (and collection of samples from those locations). Sampling at individual locations typically takes less than a day to complete, but transit times between study sites (located at different parks) takes extended periods of time and may include travel from South Florida to the U.S. Virgin Islands. Shore-based monitoring and boat-based sampling occurs in crews of two to three individuals. The activity is conducted regularly in three coastal parks, with maintenance and monitoring efforts occurring seasonally to annually. Potential safety hazards (along with mitigation measures) have been identified in a protocol job hazard analysis.

Of specific concern is that:

- Crew members will spend many hours traveling between and from sampling locations to carry out the requisite sampling design.
- Crew members will be regularly working by boat in park areas outside of communications range (either by park radio or by cell phone).
- During installation and maintenance phases of protocol implementation, crews will be using power equipment such as jackhammers in remote areas in challenging environments (from platforms).

Injury or loss of life while in transit by vehicle to and from field sites, as well as while in transit to or performance of data collection activities from watercraft, are the most significant risks encountered when conducting this activity.

Step 2: Define the Threats

General field-work threats/hazards as well as those that are specific for implementing this protocol are described within this GAR (Table A-1).

Table A-1. Tasks and mitigations to reduce threats and hazards associated with implementing the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan.

Category	Mitigation Factors
Supervision	(Score 3). The SFCN Protocol Implementation Plan clearly identifies personnel, roles and responsibilities, and a chain of command. In cases where multiple people are present, the field crew lead has many tasks to accomplish in the implementation of the protocol, so is not always focusing solely on supervision. During implementation of this portion of the protocol, a qualified supervisor aware of all portions of the protocol is always present on site. While working on a boat, all personnel are under direct supervision of a trained boat operator. In some cases personnel are accompanied by staff member(s) from the park at which sampling occurs, or with other SFCN staff, depending on the actions being implemented on site (sampling and/or maintenance). During field operations, the field crew lead is responsible for all tasks related to protocol implementation including communications with park staff, logistics getting to and from the site, and implementation of data collection procedures. A portion of this work may be performed by partner staff from parks or other agencies without the direct oversight and supervision of SFCN staff. In such cases the SFCN Ecologist is available for remote support, and partner staff are trained in the operation of equipment required to implement the protocol.
Planning	(Score 3-4). The SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan includes numerous SOPs that explain training, personal safety, and appropriate field activities (See Appendix B). Crew members are required to review these materials during training, and SFCN Staff members are required to have first aid and CPR training. Although much time goes into planning for this type of work, the complexity of operations requires some last-minute changes and adjustments to schedules.
Communication	(Score 5). Routine and emergency communication equipment and procedures are explained in the relevant Safety SOPs. This includes coordination with park natural resource managers, rangers, and dispatch as preferred by each park, as well as procedures for daily crew check-out/check-in with other SFCN staff. Communication can be an issue especially at larger parks where large distances may have to be covered between sites or boat ramps. Cell phone and radio coverage is highly variable among parks where sampling occurs (and areas therein) and in some cases might not work or be reliable.

Table A-1 (continued). Tasks and mitigations to reduce threats and hazards associated with implementing the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan.

Category	Mitigation Factors
Contingency Resources	(Score 4-5). Contingency resources include communication equipment and procedures that explicitly involve park rangers, park dispatch, and 9-1-1. Crew members always have at least one mode of communication, though at some parks radios are not monitored and cell phone coverage is often unreliable. Notification of emergency services should happen within minutes of an incident, but there may be delays depending on where incidents occur. Delays can be substantial in some areas at some parks especially if cell phone and radio services are not available.
Team Selection	(Score 3-5). The monitoring protocol clearly identifies the essential skills and abilities required to execute this protocol in a competent manner. Prior experience is required for most team members. All team members will have basic first aid and CPR skills as well as an ability to swim. Although some of these skills can be worked on during crew training, there is no substitute for experience. The availability of park or SFCN staff with local knowledge of water bodies is variable from park to park (and among sampling events); presence of a dedicated boat captain with local expertise greatly reduces risks related to boating.
Team Fitness	(Score 2-4). Team selection should ensure an overall high level of initial team fitness. Crew members are in the field for approximately eight hours per day (not including transit times to and from sites). Sampling always occurs during daylight hours. A score of 2-4 was assigned because the work is not overly strenuous but can be variable depending on the tasks being conducted on site. Crew members must be diligent about adequate rest and nourishment to ensure that fatigue does not become a safety factor.
Environment	(Score 6-8). Protocol implementation includes inherent environmental dangers associated with field work and transit to field sites. Activities occur during spring and summer months, which exposes crews to a variety of weather conditions, including extreme heat and strong localized storm cells, including exposure to lightning strikes. Additionally, transit times to, from, and between sites can be up to an hour, which (in addition to data collection) can result in workdays exceeding 10 hours and return trips by vehicle at the end of long days in the field. A portion of this work is conducted in open water by boat, where limited cover is available if crews are not aware of dynamic weather conditions. Working on open water is an inherently riskier environment.
Event Complexity	(Score 5). Daily field conditions change due to unpredictable weather. Individual crew members must use judgment and experience to respond appropriately. Work requires operation of multiple vehicles, trailers, and boats including towing, backing, launching, and docking, as well as specialized equipment including RSET measurement devices and a knife for cutting soil accretion plugs.

Step 3: Assess Risk and Assign a Numerical Value

Initial risk-level scores were assigned to all protocol elements following the process as described in the NPS Operational Leadership Student Manual (Table A-1, A-2). Scores were initially assigned by Kevin Whelan, SFCN Community Ecologist and then reviewed by Brian Mitchell, the acting SFCN Program Manager. Final numbers are presented below (Table A-4). It should be noted that at the time final numerical values were assigned (July 13, 2015) the protocol had been in development for several years and considerable time and effort had already gone into evaluating and mitigating risks. Additionally, because of the variability in sites among parks, many element scores are presented as ranges. To compute the total level of risk for the activity, assign a risk code of 0 (For No Risk) through 10 (For Maximum Risk) to each of the eight elements below and then total the risk codes. This is the Total Risk Score and is your personal estimate of the risk. Total Risk Score (Green, Amber, or Red) is based on the GAR Evaluation Scale (Table A-3).

Table A-2. Activity elements and descriptions of major tasks associated with the implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan.

Activity Element	Element Description
Supervision	Supervisory Control considers if supervision is present, how qualified the supervisor is, and whether effective supervision is taking place. Even if a person is qualified to perform a task, supervision acts as a control to minimize risk. This may simply be someone checking what is being done to ensure it is being done correctly. The higher the risk, the more the supervisor needs to be focused on observing and checking. A supervisor who is actively involved in a task (doing something) is easily distracted and should not be considered an effective safety observer in moderate to high-risk conditions.
Planning	Planning and preparation should consider how much information you have, how clear it is, and how much time you have to plan the evolution or evaluate the situation, and the presence of Standard Operating Procedures or pre-plans.
Communication	Communication should include physical (dispatch present, effective repeaters) communication and an assessment of personal communication among team members (assertiveness, climate that values input, high degree of accountability) and the presence of briefs and debriefs.
Contingency Resources	Contingency resources refer to readily available trained assets, and whether there is an established agreement and SOP with the cooperating agency (i.e., local law enforcement agencies, fire departments, ambulance, military units, etc.).
Team Selection	Team selection should consider the qualifications and experience level of the individuals used for the specific event/evolution/incident. Individuals may need to be replaced during the incident. The same concerns apply to the reliefs.
Team Fitness	Team fitness should consider the physical and mental state of the team. This is a function of the amount and quality of rest a team member has had. Quality of rest should consider potential sleep length and any interruptions. Fatigue normally becomes a factor after 18 hours without rest; however, lack of quality sleep builds a deficit and worsens the effects of fatigue.

Table A-2 (continued). Activity elements and descriptions of major tasks associated with the implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan.

Activity Element	Element Description
Environment	Environment should consider factors affecting personnel performance and factors affecting equipment. This includes, but is not limited to, time of day, temperature, humidity, precipitation, wind, terrain, and elevation.
Event or Evolution Complexity	Event/Evolution complexity should consider both the required time and the situation. Generally, the longer one is exposed to a hazard, the greater are the risks. However, each circumstance is unique. For example, more iterations of an evolution can increase the opportunity for a loss to occur but may have the positive effect of improving the proficiency of the team, thus possibly decreasing the chance of error. This would depend upon the experience level of the team. The situation includes considering how long the environmental conditions will remain stable and the complexity of the work.

Table A-3. GAR Evaluation Scale for color coding the level of risk. The activity risk can be visualized using the colors of a traffic light. If the total risk value falls in the GREEN ZONE (1-35), risk is rated as low. If the total risk value falls in the AMBER ZONE (36-60), risk is moderate, and you should consider adopting procedures to minimize the risk. If the total value falls in the RED ZONE (61-80), you should implement measures to reduce the risk prior to starting the event or evolution.

Color Zone	Total Risk Value
GREEN (Low Risk)	1–35
AMBER (Caution)	36–59
RED (High Risk)	61–79

Table A-4. Assigned risk codes of for each of the eight elements of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol. Zero indicates no known risk and 10 indicate maximum level of risk, or a highly dangerous task.

Category	Risk Code Score
Supervision	3
Planning	3–4
Communication	5
Contingency Resources	4–5
Team Selection	3–5
Team Fitness	2–4

Table A-4 (continued). Assigned risk codes of for each of the eight elements of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol. Zero indicates no known risk and 10 indicate maximum level of risk, or a highly dangerous task.

Category	Risk Code Score
Environment	6–8
Event/Evolution Complexity	5
Total Risk Score	31 ^A – 39 ^B

^A. Value is within the range of low risk.

^B. Value is within the range of cautionary risk.

Step 4: Identify Risk Control Options

A protocol JHA was adapted from the SECN approved JHA which was performed by the SECN Collateral Duty Safety Officer (Sarah Corbett) and abatement actions and requisite training needs were identified to mitigate hazards associated with implementation of this protocol (Tables A-4, A-5).

Table A-5. Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Field Work	General Field Safety/ Training	Complete an annual (American Red Cross) or biannual (American Heart Association) First Aid and CPR training course. Always carry standard PPE, which includes a first aid kit, compass, safety whistle, hydration bladder/water bottles.

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Field Work (continued)	Tick Bites (Lyme Disease)	Spray clothing with insect repellent such as Permethrin, as a barrier. Wear light colored clothing that fits tightly at the wrists, ankles, and waist. Each outer garment should overlap the one above it. Cover trouser legs with high socks, boots, or nylon gaiters OR duct tape pant legs to shoes. Tuck in shirt tails. Search the body on a regular basis, especially hair and clothing; ticks generally do not attach for a couple of hours. Run your fingers across your skull feeling for any atypical bumps. If a tick becomes attached, use tweezers to grasp the tick as close as possible to the point of attachment and pull straight out with gentle pressure. If tweezers are not available, use fingernails or pliers. Wash skin with soap and water then cleanse with rubbing alcohol. Place the tick in an empty container for later identification, if the victim should have a reaction. Record dates of exposure and removal. Do not try to remove the tick by burning with a match or covering it with chemical agents. If you cannot remove the tick, or the head detaches, seek prompt medical help. If you are bitten by a tick, the first incident of the season must be documented in the NPS Safety Management Information System (SMIS) or on a calendar or injury log. Additional bites can be documented on a calendar or injury log. Watch for warning signs of illness: a large red spot on the bite area; fever, chills, headache, joint and muscle ache, significant fatigue, and facial paralysis are reactions that may appear within two weeks of the bite. Symptoms specific to Lyme disease include: confusion, short-term memory loss, and disorientation. Review the CDC documents relating to tick-borne diseases at http://www.cdc.gov/ticks/diseases.
	Tetanus	Ensure tetanus booster is up-to-date.

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Field Work (continued)	Allergic reactions, insect stings	If a bite/sting victim develops hives, asthmatic breathing, tissue swelling, or a drop in blood pressure, seek medical help immediately. Be alert to insect hives in brush or in hollow logs. Watch for insects traveling in and out of one location. If you or anyone you are working with is known to have allergic reactions to bee, wasp, hornet, yellow jacket, or other insect stings, tell the rest of the crew and your supervisor. Make sure they carry emergency medication (Epipen, etc.) with them at all times, AND know how to administer that medication. Wear long sleeve shirts and trousers; tuck in shirt. Bright colors and metal objects may attract bees. If you are stung, cold compresses may bring relief. Also, it is advisable to take Benadryl immediately if multiple stings are received. If a stinger is left behind, scrape it off the skin. Do not use tweezers as this squeezes the venom sack, worsening the injury. Minimize exposure to plants that cause contact dermatitis (poison ivy, Brazilian peppertree, poison wood, etc.), EVEN if you do not typically react to them (immunity breaks down with continued exposure). If you are known to have severe reactions, wear ivy block before exposure, and use neutralizing soaps (Technu, etc.) if exposure occurs. Wear long sleeves, long pants, and gloves if working in dense areas with dermatitis-inducing plant species.
	Mosquito Bites - Skin irritation, encephalitis	Wear long sleeves and trousers. Avoid heavy scents, such as strong soap, lotion, or perfume. Use insect repellents. If using Permethrin, do not apply directly to skin, apply to clothing only. Carry after-bite medication to reduce skin irritation.
	Dehydration	Drink at least 1/2 qt. of water every hour. Limit caffeine intake, as caffeine dehydrates you. Carry sufficient amounts of water. Avoid long exposure to sun. Wear hat with wide brim for shade. Use electrolyte supplements or drink sports drinks (e.g., Gatorade).
	Uneven terrain Tripping over rocks	Wear appropriate footwear with nonskid rubber soles. Test and use secure footing. Walk, never run, down slopes. Maintain a safe walking distance between people. In heavy undergrowth, lift knees high to clear obstacles. Know how to fall. Try to land in the least obstructed spot. Protect your head and back. Roll with the fall. Do not stick out your arms to break a fall. Use the entire sole of your foot to increase traction and also reduce the fatigue associated with walking on the toes.
	Solar Ultraviolet Radiation.	Keep exposed skin covered by wearing a hat, a bandanna, and a long-sleeved shirt. Use protective sunscreen lotion.

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Field Work (continued)	Venomous Snakes	Wear high top boots and snake gaiters or chaps. When going through thick underbrush, be alert. Walk slowly and give snakes ample time to move out of the way. Walk on clear paths as much as possible. Be careful where placing feet and hands at all times.
	Working in Isolated Areas	Use the buddy system and carry a cellular phone or NPS park radio. Always be alert. Never work alone or leave partner alone. Exceptions may apply to the coastal ecology program when an individual may be required to work alone, but will always have access to communications (VHF radio, park radio, etc.) However, when possible, it is strongly advised to work in pairs. Carry a satellite Personal Locator Beacon for emergencies.
	Hunting Season	Wear bright colored clothing, hat or orange vests during hunting season. Observe the area for possible hunters.
	Heat Stress	Take appropriate breaks. Maintain proper hydration and electrolyte consumption. Slow pace or reduce field hours if heat index is high (over 95 degrees Fahrenheit).
	Cold Stress/ Hypothermia	Wear layered clothing, gloves, etc. During cold weather—layer clothing and wear wind impervious outerwear; during warm months —wear a long sleeve cotton shirt.
	Fatigue	Know the limits of your own body (e.g., tolerance to heat, cold, allergies, strength, endurance, etc.), pursue physical conditioning prior to the field season if necessary, and do not over-exert yourself. Use proper mechanics when bending over or lifting objects (i.e., lift with your knees, bend knees when bending over). Tighten stomach muscles when standing for long periods of time to support the lower back. When hiking up / down hills, avoid walking on your toes as this cause muscle fatigue rapidly.
	Weather	Know the weather forecast prior to going into the field. Enable weather alerts on GPS units or portable radio. If a tornado approaches and you are caught in the field, take shelter in low area, lie flat on belly and cover head. There is no safe place outdoors in a lightning storm, but if lightning approaches and you are caught in the field, avoid: standing water if possible, isolated trees, picnic tables, pavilions, flagpoles, metal objects, and fences. Seek shelter under a large grove of trees (preferably shorter than those around it), squat close to ground, keep feet together, tuck head down, close eyes and cover ears, stay 50 feet apart from other people, and remove metal objects from your person. When conducting boat operations, seek safe harbor if possible.

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Field Work (continued)	Flash Floods	DO NOT TRY TO WALK, DRIVE, OR OTHERWISE CROSS FLOODWATERS. Keep in mind that floodwaters are swift moving, even if they do not appear to be on the surface. It is possible to drown in just a few inches of water if swept away by floodwaters. Especially important when working in stream and river areas (SARI, VIIS), workers should be aware of the possibility of flash floods. When working in stream and river environments, at least one team member should watch nightly weather reports, or monitor weather band radio, to assess if weather conditions for flash floods may exist. If caught in a flash flood while in a boat, point the boat downstream and continue with the flow until it is safe to pull to the bank. If caught in a flash flood while in an automobile, abandon the vehicle immediately and move to higher ground. If the vehicle is submerged, do not panic, allow the vehicle to fill with water, and open the doors when the vehicle is full (doors will not open until the water pressure is equal outside and in). Opening windows will expedite the process. Hold your breath, and swim for the surface and toward the bank if possible. If caught in a flash flood while on foot, immediately move to higher ground.
	Overwater work sites (docks).	Use elevated caution level when working on docks. Keep workspace neat/organized to reduce possible trip hazards. Wear a personal floatation device when task requires leaning over or reaching over guardrail.
	Usage of coring device for pulling accretion core for Mangrove Soil Elevation Monitoring	The coring tube is plastic but use caution; you are still able to cut yourself. Use caution when using the fillet knife to cut the core plug. Be careful collecting accretion soil core from board walk or nearby vegetation.

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Field Work (continued)	Usage of Powered Equipment for Mangrove Soil Elevation Monitoring (Jackhammer, Generator, Power tools, etc.)	Care will be taken when using power tools in the marsh. Use of power tools must be in accordance with all safety recommendations of the manufacturer. When appropriate, the safety guidelines for tool usage from the user manual will be reviewed prior to tool use. Gloves, safety glasses, and ear hearing protection shall be used at all times. When operating heavy equipment, such as the jackhammer, at least two people must be present. Before operating a tool on the platforms, ensure that each operator has a secure, stable footing, and has the ability to lift 60 pounds over their head. Fueling of the generator shall occur in a well-ventilated area, and not such that overflow will flow into water or wetlands. Electricity and water are a dangerous combination. Use extreme caution when operating power equipment around water. Use Ground Fault Circuit Interrupter (GFCI) extension cord. The GFCI cord should be connected to the generator/electrical source first then connected to another extension cord to reach the piece of power equipment.
Shop/ Warehouse Activities	Power Tool Usage	Care will be taken when using power tools in the shop/warehouse area. Use of power tools must be in accordance with all safety recommendations of the manufacturer. When appropriate, the safety guidelines for tool usage from the user manual will be reviewed prior to tool use. Appropriate protective equipment will be worn at all times, including safety glasses or goggles, air filtration masks (when dealing with materials that produce sawdust or fine particulate matter), ear protection (when dealing with loud tools), work gloves, and closed-toe shoes. Long sleeves and long pants will be worn if any tool emits flames or sparks.
	Hand Tool Use	Always take care to use hand tools for the purpose for which they are intended (use the “right tool for the job”). Wear protective eyewear and clothing while using hand tools if there is any chance of flying debris.

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Vehicle Operation	Type of Vehicle, Training	Select appropriate vehicle for work needs and location. Familiarize yourself with the vehicle and know where the controls are located. Make the "circle of safety" check of vehicle condition. Review maps and plan route prior to beginning your trip. Report any accident (gov, leased or pov), regardless of extent. Complete forms SF-91 and SF-94 immediately if involved in an accident. Copies of these forms should ALWAYS be present in the vehicle. If you are using a POV for government travel, obtain copies of the forms before departure. Obey speed limit, drive defensively. Obtain general safety training from a qualified operator before hauling trailers behind any vehicle. Be conscientious of other drivers (e.g., the left lane is the passing lane and not a cruising lane, pass then get over; do not park too closely to other vehicles). Always keep your eyes on the road, do not eat and drive, do not talk on phone and drive. When possible, take a defensive driving course.
	Vehicle Fires	All vehicles must be equipped with a working fire extinguisher (the extinguisher should be appropriate for the use, class type, in date and fully charged). Never park a warm engine vehicle in tall grass. Avoid engine fuel spills. Be alert of fire conditions. Do not enter uncontrolled burning areas with a vehicle. Minimize flammables in and near vehicle and work area. If a vehicle is on fire and the fire cannot be suppressed with an extinguisher, MOVE AWAY FROM THE VEHICLE. Under no circumstances should you re-enter the vehicle to remove belongings or equipment when a vehicle is burning.
	Vehicle Security/ Visibility	Always lock vehicle, do not leave valuables in vehicle, and cover or otherwise keep from view any equipment left in vehicle. Conduct a full walk-around of vehicle and place orange marker cones behind and/or in front of the vehicle to increase visibility if leaving the vehicle in a generally unsecure area (on a roadside or narrow road shoulder, in a road median, or in an otherwise high-traffic area).
	Vehicle Maintenance	Check oil and all fluids during every refueling. Document. Perform vehicle inspection for obvious items such as tire inflation, windshield wipers, and sufficient fuel to get to destination. Observe federal guidelines for use of a federal vehicle: make certain procedures regarding accidents, injuries, vehicular break downs or roadside emergencies are available in vehicle (Forms SF-91 and SF-94). Replace windshield wipers annually and replace tires when they exceed wear.
	Weather Conditions	Changes in climatic conditions require adjusting to different weather situations. When using windshield wipers during rain, turn on headlights. Do not drive in adverse weather conditions if the trip can be delayed. Avoid being rushed; you will need more time to prepare the vehicle and get to your destination.

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Vehicle Operation (continued)	Off Highway Driving/ Driving in Mud and Soft Sand	Check with local unit as necessary prior to driving on back roads, for items such as construction, washouts, blowdowns and closures. Obey all posted travel signs. Proceed slowly around corners and drive on the correct side for the road (on the right in South Florida and on the left in the US Virgin Islands). Use four-wheel drive in appropriate situations. Always put vehicle in 4WD long before you think you might need it. Do not cause extensive damage to unpaved roads by driving on them when too saturated. Avoid driving in ruts because the vehicle is susceptible to bottoming out. Get out of the vehicle to investigate all puddles to determine depth and if the bottom of the puddle is hard enough to support a vehicle. Walk through the puddle if necessary. Drive SLOWLY through puddles, as driving fast can flood the engine, and/or cause the vehicle to slide laterally. It may also cause more erosion and damage in the road. Turn around in areas only where enough space on solid ground is available, have passengers get out to help direct, take your time.
	Towing	Do not exceed recommended towing weight of tow or tow vehicle. Be aware that states may have speed limits when towing that are not published on speed limit signage. Insure tow vehicle has proper mirrors installed to view trailer appropriately. Load trailer per manufacturer's guidance. Use a hitch lock or safety pin at all times when towing. Organize load logically so trailer can be hitched and unhitched easily (i.e., not too much weight in the front of the trailer). Insure all trailer lights and brakes are operational before driving. Insure safety chains are installed correctly, crossed under the trailer and connected to the tow vehicle. Check tire pressure, spare tire, and jack. Maintain bearing grease, checking regularly. Practice driving vehicle with trailer attached in safe area until comfort level is obtained. Be careful when towing in strong cross winds. All SFCN Employees who will tow a boat or cargo trailer must read and understand the brochure "Towing a Trailer: Being Equipped for Safety" available from the U.S. Department of Transportation website at: www.nhtsa.gov/cars/problems/equipment/towing/index.htm

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Watercraft Operation	Watercraft Safety and Training	All SFCN employees operating or riding in a watercraft MUST read and understand the SFCN Boat Operation Plan Z:\SAFETY\Section 2O - Watercraft Safety\SFCN Boat Operations Plan.2014.docx. This document provides more comprehensive guidance than that provided here. All SFCN employees who operate a motorized vessel must complete the USDI Motorboat Operators Certification Course and maintain their certification (refresher courses as required). All DOI employees must wear approved life vests while underway. Carry cell phone and vhf radio. File a float plan and work in pairs when possible. Do not exceed the rated capacity of the vessel (includes personnel and cargo). It is advisable that all personnel know how to swim OR know what to do if thrown overboard. Life vests MUST be worn. All new employees will complete a safety orientation with the boat operator or the SFCN safety officer prior to getting underway.
	Vessel Maintenance	Perform vessel inspection for obvious items such seaworthiness of craft, assure oil levels are good, and assure motor is in working order. Maintain vessel and proper safety equipment. Look for any damage to the hull. For non-motorized vessels, ensure craft is in good condition.
	Onboard Safety Equipment	All motorized vessels shall carry U.S. Coast Guard (USCG) and state required safety equipment, including USCG approved life jackets, throwable device, fire extinguisher, working marine radio, sufficient chain/rope and proper anchor, oar/paddle, flares and signaling device, approved navigation lights, and tool kit.
	Weather Conditions	Changes in climatic conditions require adjusting to different weather situations. Do not operate vessels in adverse weather conditions if the trip can be delayed. Avoid traveling in high winds or rough water. Avoid being rushed; you will need more time to prepare the vehicle and get to your destination.

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Watercraft Operation (continued)	Overturned/ Capsized Vessels	To avoid the likelihood of capsizing, keep a lookout facing the direction of movement of the vessel (motorized vessels), and take extreme care when navigating in areas with shallowly submerged objects or sandbars by moving slowly and avoiding sudden port or starboard movements (motorized and non-motorized vessels). In the event that a motorized or non-motorized vessel overturns or is capsized, first account for the location of all passengers and ensure that they are wearing life vests. If not wearing a vest, get one to them as soon as possible. If a vessel does capsize, assess whether or not you can safely upright it. If so, upright the craft and bail all water out of it before reentering the craft. If a vessel is unable to be righted, for non-motorized vessels including rowboats, canoes, and kayaks, drag the vessel to the shore if you can and upright it there. This is not advisable with motorized craft, generally due to their size and weight and the additional danger and effort of recovering a beached craft. For motorized vessels, it is advised to remain with the vessel and signal for help (flare, whistle, cell phone, radio if operable).
Office Work	Computer Use Fatigue	Take appropriate breaks. Perform other job duties. Trade appropriate and assigned duties with coworker. Apply work/rest ratio guidelines.
	Computer Use Eye Strain	Take appropriate breaks. Perform other job duties for a time. Use a non-glare screen or an anti-glare device on screens. Trade appropriate and assigned duties with coworker. Individuals requiring prescription eye wear should ensure proper focal distance is achieved without having to tilt the head. Adjust screen refresh rate as needed to eliminate screen flicker.
	Carpal Tunnel Syndrome	Take appropriate breaks. Use wrist exercises. Stretch hands. Ensure proper keyboard position. Adjust chair height so that forearms are parallel to the work surface.
	Physical Stress	Take appropriate breaks. Ensure proper keyboard, chair, and computer monitor positions.
	Electrical Cords and Electrical Hazards	Do not overload outlets. Use surge protection for computer equipment. Keep cords organized and out of walkways. Never use personal space heaters in government buildings unless approved by facility maintenance supervisor.

Table A-5 (continued). Job Hazard Analysis (JHA) for safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan, including potential hazards and recommended abatement actions.

Task/ Procedure	Hazards	Abatement Action
Office Work (continued)	Indoor Supplies and Activities	Keep area clean and organized. Use step ladder for out-of-reach supplies. NEVER use a chair as a step ladder. Use proper containers and storage for supplies. Follow MSDS rules and recommendations if applicable. If using volatile chemicals (including paints), supply appropriate ventilation or conduct activities outdoors. For all stored chemicals, keep a Materials Data Safety Sheet nearby (includes volatile glues, insect repellants, and cleaners). Walk in the office, do not run. Watch out for tripping hazards. Follow good housekeeping practices, including closing drawers, properly disposing of waste, and properly storage of materials and equipment not in use. Report maintenance issues that pose a fall/trip hazard to maintenance staff immediately (e.g. wet floor from leaky toilet, torn carpet).
	Inadequate Lighting and Poor Air Circulation	Take appropriate breaks. Alternate indoor and outdoor activities. Adjust thermostat and open windows as needed. Turn lights on or off.
	Lacerations and Punctures	Do not use paper cutters if the guard is removed or blade is dull. Keep fingers and hands away from point of operation.
Qualified Personnel	Untrained/ Unqualified Personnel	Personnel will have the correct qualifications for the job assigned. Trainees will work under the supervision of an appropriately qualified individual. Trainees will be trained locally or attend appropriate safety courses. Non-DOI or other government agency personnel (interns and contractors working for SFCN) or park personnel will follow SFCN safety rules.
Contact with visitors, adjacent landowners, and concessioners	Aggressive or Inappropriate Behavior	Act professionally (do not yell or antagonize) but ALWAYS protect yourself. Do not confront an angry landowner/visitor when alone. Leave quickly if the situation is unsafe. Call 911 if situation is or becomes dangerous. If the opportunity exists, listen to grievances, use a calm voice. Immediately report incident to supervisor.
General Worker Safety and Reporting	Emergency and Hazard Reporting	Know where fire or emergency alarm pull stations are located in the building. Know the emergency evacuation routes for the building and the rally point once outside. Perform periodic workplace assessments for potential hazards. Know your building Maintenance Supervisor and report hazards to them for correction. Know procedures for reporting work related injuries.

Training and proficiencies

Training and proficiencies required or recommended for the safe implementation of the SFCN Monitoring Mangrove Soil Surface Elevation Tables in Network Parks Protocol.

Required Training and Proficiencies

- First Aid and CPR training for field workers; renewed annually or biannually (depending on length of certification).
- USDI Motorboat Operators Safety Training for positions that require operation of a motorized vessel.
- Read and understand the “SFCN Boat Operation Plan” for positions that require operation or riding in a motorized vessel.
- All employees riding or operating a motorized or non-motorized vessel will undergo a safety briefing by a certified operator or the SFCN Safety Officer.

Optional / Recommended Training and Proficiencies (DOI LEARN Online Courses)

- Cool Ideas on a Hot Topic
- Authorities, Roles, and Responsibilities
- Blood borne Pathogens
- Fall Protection
- Fire Protection
- Office Safety
- Flammable and Combustible Liquids
- Hand and Portable Powered Tools
- Walking and Working Surfaces
- Resources, References, and Standards
- Personal Safety Through Awareness
- Laboratory Safety
- Hazard Communication
- First Responder Awareness Level
- NSC Defensive Driving II
- Personal Protective Equipment
- Stress Management

Step 5: Evaluate Risk vs. Gain

The acting SFCN Program Manager has determined that the activity has an acceptable level of risk, if carried out in accordance with all SOPs and risk abatement measures as outlined in Step 4.

Step 6: Execute Decision

The decision made by the acting SFCN Program Manager is to conduct the activity in accordance with the SOPs and risk abatement measures for the SFCN Monitoring Mangrove Soil Surface Elevation Tables in South Florida/Caribbean Network Parks Protocol Implementation Plan as outlined in Step 4.

Step 7: Supervise—Watch for Change

The SFCN Program Manager and Protocol Lead will continually solicit feedback from the NPS and cooperator staff on safe execution of this protocol including risk control options not considered thus far.

Appendix B. Site Suitability Assessment Reports

South Florida/Caribbean Network staff, in consultation with NPS staff, determined potential mangrove community sites within each park study area (Table B-1). Sites were evaluated for their ability to support a mangrove soil surface elevation monitoring site as well as whether they met site-selection criteria as per the sampling design.

Table B-1. Site suitability assessments conducted at each park to select permanent sampling locations for SFCN mangrove soil surface elevation monitoring.

Park	SFCN Staff	Park Staff	Dates	# Sites Evaluated	# Suitable Sites	Installed by 6/25/2014
BISC	Kevin Whelan	–	January to March 2008	21	2	2
SARI	Kevin Whelan	Zandy Hillis-Starr	January 2012	5	1	1
VIIS	Kevin Whelan	Rafe Boulon Thomas Kelley	March 2011	3	2	2

The overall design strategy, upon which this protocol is based, has three components:

1. The sampling frame is restricted to mature mangrove forest locations based on recent imagery analysis and vegetation maps of the NPS parks. In all three NPS park units, the amount of mature mangrove forest is limited. A number of sampling locations were selected within each study sampling frame. The number varied by park depending on the amount of mangrove area present.
2. To preserve the mangrove communities from human impact and maintain the public's viewshed within the park, permanent monitoring stations were established at locations outside of public view.
3. Potential sample sites were evaluated based on whether they met the following criteria: regularly-flooded, safe accessibility, low visibility, low amount of trash present at the site, low to moderate high quantity of pneumatophores present, moderate low extent of leaf litter, low presence of berms/mud banks, and low potential for vandalism.

Sample Frame

The sampling frame is restricted to mature mangrove forest locations. In BISC, the majority of the mature mangrove forests are located on the main shoreline of Biscayne Bay. The potential site locations were restricted by the need to be established within approximately 30 m from the main shoreline, thus maintaining continuity with the USGS SET sites in Everglades National Park (EVER). In SARI, there was only one mangrove forest that was large enough for a site. In VIIS, there were only three forest locations that were present in the 1940 aerial imagery that were still mangrove forests and were large enough for a site to be established.

Sample Locations

The monitoring objectives and the environmental settings influenced the selection of appropriate sample locations. Mangrove forests are affected by multiple variables including elevation, hydrologic and salinity gradients, inundation periodicity, soil composition, geomorphology, and current velocities—all of which affect the soil processes differently.

The number of sampling locations for each park was determined after consideration of park size and hydrologic characteristics, safety concerns, logistical issues regarding travel time and conducting monitoring activities, monitoring objectives of interest at each park, and how much mature mangrove forest was available to select from.

At each of the three parks, a maximum of two sampling locations was selected to address the monitoring objectives. At least one sampling location was selected with three replicate SET stations where sediment elevation, accretion, and other characteristics are measured.

Sample Location Selection

The sampling frame for each park was in mature mangrove forest areas. A two-level selection process was applied to all potential sampling locations: inspection of aerial imagery either by itself or in concert with an NPS vegetation map, and then field assessment of the site for evaluating additional criteria.

In BISC in 2008, we used aerial imagery and identified the large patches of mature mixed mangrove forest along the main shoreline that were not adjacent to canals. We generated 21 possible locations for field assessment.

In SARI, Hurricane Hugo (1989) caused extensive damage to approximately 100% of the mature mangrove forest of Sugar Bay in SARI (Rothenberger 1999). Because of this past disturbance there was only one area that had relatively intact mixed mangrove forest, allowing the establishment of a single SET sampling location. We assessed six locations in that area for field suitability.

In VIIS, mangrove forest locations were selected from the recent NPS vegetation map of the park (Thanawastien unpublished). These forest locations were overlaid upon a georectified 1947 aerial image of VIIS. There were only three locations that were historically and recently forested, and all three locations were assessed.

Once general location selection occurred for each park unit, the individual site selection criteria were then applied. Field evaluation was necessary because there are a number of factors that affect the soil elevation and these cannot be assessed remotely.

Sampling locations were excluded from sampling if:

- The site was not accessible.
- The site could not be safely accessed.
- The sampling location occurred on private in-holdings where access was not permitted.

- The characteristics of the sampling location did not allow for the installation of three monitoring sites, including platforms 30 feet in length.
- The sites were not regularly inundated by water.
- The sites were visible to normal public view within park lands.
- The sites were not vegetated with typical mixed mangrove species (e.g., *Rhizophora mangle*, *Avicennia germinans*, and *Laguncularia racemosa*).
- The sampling location was potentially unsafe.
- Signs of recent impacts or stressors such as wildlife disturbance or trampling were present.
- The site was within 50 m of creeks and rivers (except SARI, where the whole mangrove forest was part of the Salt River drainage).
- There was insufficient depth of soil/peat to adequately establish a SET. We have determined that at least 120 cm of sediment on soft base rock (limestone) is needed for sufficient penetration by the jack-hammered survey rods. Over hard base rock (granite) a greater depth of soil substrate may be needed.

Potential sample sites were further evaluated for the following criteria: amount of trash present at the site, quantity of pneumatophores present, extent of leaf litter, presence of berms/mud banks, and potential for vandalism.

Field crews visited designated sites by boat and, at the accessible sites, conducted a baseline survey. This included taking vegetation data and photos and collecting GPS data. All sites deemed inappropriate (i.e., did not meet the aforementioned criteria) were recorded as such and this information, and the corresponding location, will be maintained by SFCN.

Biscayne National Park SET Site Assessment Report

In FY 2008, 21 sites were selected for field assessment in BISC (Figure B-1). Five sites were eliminated after further assessment determined that these sites were too close to public access or too close to a canal or creek. The remaining 16 sites were visited in the field. Field assessment data are reported in Table B-2.

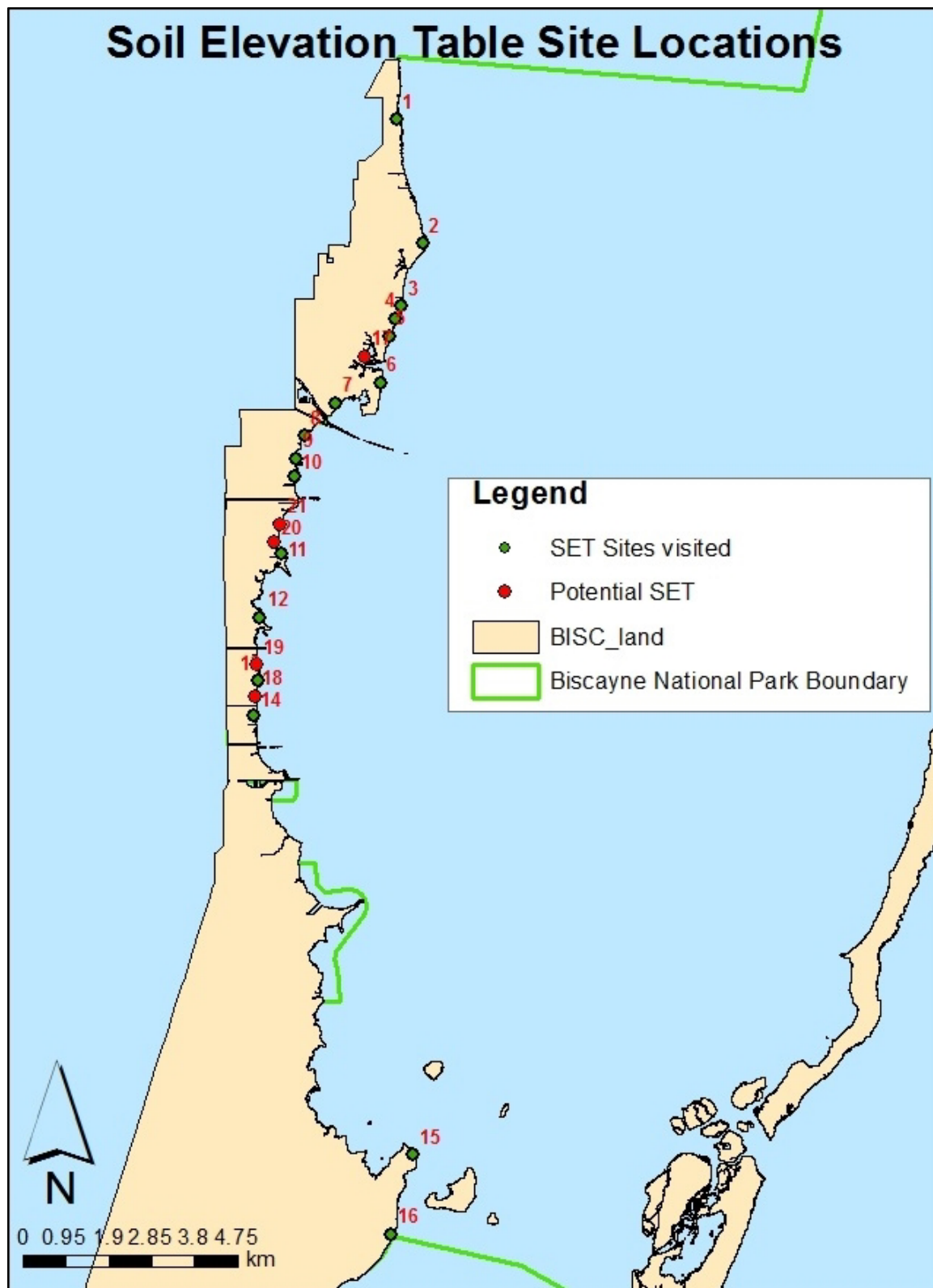


Figure B-1. Twenty-one potential SET sites in Biscayne National Park. Sites too close to public access or too close to a canal or creek were removed, shown in red. The remaining sixteen sites were visited, shown in green.

Table B-2. Field assessment data for 16 potential SET sites located in Biscayne National Park. Restoration column refers to if the site is within the Biscayne Bay Coastal Wetlands restoration footprint and if the site would be potentially affected by restoration (based on professional judgment).

Site	Easting	Northing	Field date	Berm	Trash	Restoration	Comment	Access information	Saplings
1	569417	2831026	1-18-2008	N	Low	Unlikely	Mangroves may continue 550m to the west, but they appear disturbed by former irrigation canal.	Mark 466. At 9:50am it is going on low tide, long walk at low tide, 150ft 30 mi.	From the shoreline to 15m in there are a lot of <i>Rhizophora mangle</i> with small dbh, From 15 to 25 m there are <i>Laguncularia racemosa</i> .
2	569995	2828283	1-18-2008	Y	Moderate	Unlikely	Mangroves continue 300m to the west where there appears to be a small canal; tidal creek 550m to the east.	Mark 467 is the shoreline (570097,2828259). Mark 468 is the max distance traveled into the site (569995,2828283).	<i>Laguncularia racemosa</i> on a berm. <i>Avicennia germinans</i> , <i>Laguncularia racemosa</i> , and <i>Rhizophora mangle</i> , all show signs of Hurricane Andrew damage.
3	569525	2826890	1-18-2008	Y	Low	Likely	Mangroves run 275m to the west with apparent agricultural land beyond that. There is a canal 200m to the east.	Mark 474-creek, Mark 475-creek (nearby). Mark 476 (569549,282688) shoreline location	Lots of small <i>Rhizophora mangle</i> dying at the site.
4	569369	2826604	1-18-2008	Y	Low	Likely	Mangroves run 250m to the west with apparent agricultural land beyond that. Site is full of mangroves.	Mark 469, easy to access walked 40 ft in 5 min. Mark 470 is a creek.	<i>Avicennia germinans</i> and <i>Laguncularia racemosa</i> are 10-15m tall. Site has a berm behind which there are mostly <i>Laguncularia racemosa</i> , then a few <i>Rhizophora mangle</i> .
5	569256	2826219	1-18-2008	Y	Low	Likely	Mangroves run 275m to the west with apparent agricultural land beyond that.	Mark 471 the shoreline entrance (569267, 2826197). Mark 473 is the site.	<i>Avicennia germinans</i> and <i>Laguncularia racemosa</i> on the berm.
6	569053	2825194	2-29-2008	N	Low	Likely	Mangroves run at least 300m to the west. There are bays 300m to the north and 400m to the southwest.	Mark 493, Can get boat close to shore even at low tide. Good water depth from the site.	<i>Avicennia germinans</i> and <i>Rhizophora mangle</i> mostly with a few <i>Laguncularia racemosa</i> . <i>Avicennia germinans</i> are bigger than the others.
7	568065	2824738	2-29-2008	N	Low	Likely	Mangroves run at least 325m to the west where they end in a parking lot. There is a small canal 250m to the north.	Mark 495, Left boat at black point, canoed in, water deep further back in bay.	High density of many small mixed mangrove species.
8	567376	2824013	2-29-2008	N	Low	Unlikely	Mangroves run 500m to the east. There is a large canal 525m north and a smaller canal 300m southwest of the site.	Mark 497 Sand and shells at edge, shallow hardbottom out 50m from shoreline.	High density of mangroves.

Table B-2 (continued). Field assessment data for 16 potential SET sites located in Biscayne National Park. Restoration column refers to if the site is within the Biscayne Bay Coastal Wetlands restoration foot print and if the site would be potentially affected by restoration (based on professional judgment).

Site	Easting	Northing	Field date	Berm	Trash	Restoration	Comment	Access information	Saplings
9	567199	2823515	2-29-2008	N	Low	Unlikely	Mangroves run 400m to the west. Small canal 250m to the north and 200m to the south.	Mark 498 Shallow water starts 30m from the shoreline.	Medium density saplings. Larger <i>Laguncularia racemosa</i> and <i>Rhizophora mangle</i> .
10	567158	2823131	2-29-2008	N	Low	Unlikely	Mangroves run 550m to the west. There are small canals approximately 200m to the north and the south.	Mark 499, Shallow water starts 40m from the shoreline.	Medium density saplings. <i>Rhizophora mangle</i> dominate.
11	566874	2821410	2-29-2008	N	Moderate-Low	Potential	Mangroves run 150 m to the west. There is a canal 75 m to the south and 350 m to the north.	Mark at 500	Medium size <i>Rhizophora mangle</i> and <i>Laguncularia racemosa</i> .
12	566392	2819986	3-28-2008	N	Moderate-Low	Potential	Mangroves run 400 m to the west. Small canals are located 150m to the northwest and 325m to the southeast.	Not flooded, able to boat to shoreline at high tide. Lightning gap nearby.	Medium to low density of mixed mangrove species.
13	566350	2818581	3-28-2008	N	Moderate-Low	Potential	Appears that mangroves go back about 700m to a canal. Mangroves up to the north for 675m.	Boat able to get to shoreline on most tides. Some trees have tipped up in the past.	Low density mixed mangrove saplings. Forest is relatively open.
14	566253	2817807	3-28-2008	N	Moderate-Low	Potential	Mangroves run 200 m to the west. Tidal creek is 150 m to the north.	Not flooded at high tide.	Medium sapling density, mostly <i>Rhizophora mangle</i> , regrowth from Hurricane Andrew.
15	569760	2808087	3-28-2008	N	Low	Unlikely	Mangroves in all directions for at least 300m. There is a lagoon approximately 350m to the southwest.	Took 40 min run time from Convoy point.	Lots of small <i>Rhizophora mangle</i> , with few <i>Laguncularia racemosa</i> , <i>Avicennia germinans</i> .
16	569291	2806316	3-28-2008	N	Low	Unlikely	Mangroves appear to be at least 500m in all non-ocean directions. Dwarf mangroves >100.	Beach site. Deeper water if come in from south of Arsenicker Key.	Lots of small mangrove mixed at shoreline <i>Avicennia germinans</i> dominates.

After visiting all of the sites above, site 13 was selected to become BISC 1 and site 6 was selected to become BISC 2 site. These two sites were selected to minimize confounding effects. These sites had lower trash content, no berm present, low potential for discovery by public, ease of access, moderate sapling presence, and enough distance from tidal creeks to minimize hydrologic impacts. Both soil elevation sites within BISC are on the main shoreline and within the Biscayne Bay Coastal Wetlands restoration footprint. The sites were selected to maximize the distance between the sample locations in order to have index sites in different portions of the park. When selecting the sites, it was found that the average peat depth above the limestone bedrock was 193 cm at BISC1 and 155 cm at BISC2, which are acceptable levels for establishing monitoring sites.

Salt River Bay National Historical Park and Ecological Preserve (SARI) SET Site Assessment Report

In 1989, Hurricane Hugo caused extensive damage (approximately 100%) to the mature mangrove forest of Sugar Bay in SARI (Rothenberger 1999). Because of this past disturbance there is only one forest location that has relatively intact mixed mangrove forest. Using the NPS vegetation map (Moser et al. 2011) the network identified the single mixed mangrove forest polygon large enough to support a SET sampling platform. A scouting trip in January 2012 assessed five potential sites within this area (Figure B-2). Scouting sites were confined to the eastern region of the drainage due to extreme vandalism and trash dumping that routinely occurs on the western side of the drainage.

Field-collected assessment data are reported in Table B-3. After visiting all five sites, site 1 was selected for establishment of SARI 1. This site was found to have the lowest number of confounding effects. It had low trash content, no berm present, lower potential for discovery by the public, ease of access (defined here as being able to build the platform from an old road bed), and moderate sapling presence. Access via the road bed was critical because soil disturbance is an issue at this site. At the SARI site, final soil depth was estimated at over 12.19 m (40 ft) based on the depth of the SET survey rods during the installation.

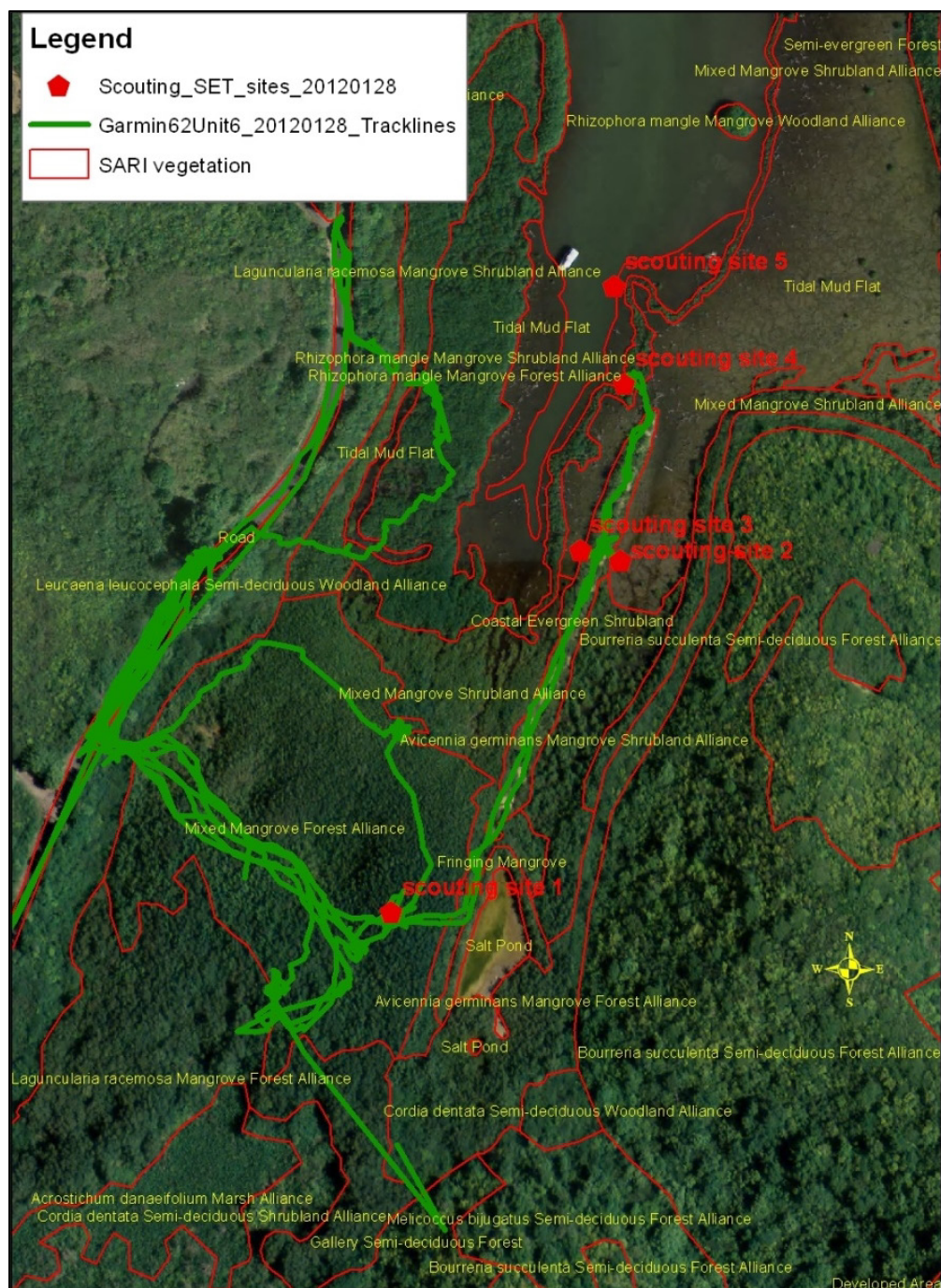


Figure B-2. Salt River Bay National Historical Park and Ecological Preserve (SARI) scouting sites assessed in January 2012.

Table B-3. Field-collected assessment data for five potential SET sites located in Salt River Bay National Historical Park and Ecological Preserve (Zone 20 Q, Soil depth (m)).

Site	Easting	Northing	Soil (m)	Trash	Trees	Comments
1	313389	1965172	4.57	low	Mature mostly	<i>Laguncularia racemosa</i> are 18 to 20 m tall.
2	313498	1965339	5.18	low	Stunted	<i>Avicennia germinans</i> 2 m tall. Area is an open pond. In the top 2.44 m of soil column hit 3 marine deposits.
3	313479	1965344	6.10	low	Dense thicket. Young trees.	<i>Rhizophora mangle</i> 4 m tall. Near Narrow Creek Marine deposit 1.5 m down core
4	313500	1965423	6.10	low	Dense thicket. Young trees.	<i>Rhizophora mangle</i> 4 m tall edge of sugar bay— marine deposit 1.5 m down core
5	313495	1965469	7.01	low	Dense thicket. Young trees.	<i>Rhizophora mangle</i> 4 m tall. Site is on edge of sugar bay.

Literature Cited

- Moser, J. G., K. R. T. Whelan, R. B. Shamblin, A. J. Atkinson, and J. M. Patterson. 2011. Salt River Bay National Historical Park & Ecological Preserve, U.S. Virgin Islands, Vegetation Mapping Project, 2009. Natural Resource Technical Report. NPS/SFCN/NRTR—2011/448. National Park Service. Fort Collins, Colorado.
- Rothenberger, P. 1999. Utilization of encasement technology in restoration of mangrove forest on St. Croix, US Virgin Islands. Reef Research 9(3), 4.

Virgin Islands National Park (VIIS) SET site assessment report

Because of past disturbance, there were only eight forest locations that had relatively intact mixed mangrove forest and were potentially suitable for the establishment of a SET sampling location (Figure B-3 and B-4). These forest locations were overlaid upon georectified 1947 aerial imagery of VIIS. There were only four forest locations that were forested in 1947 and in the more recent vegetation map, and these four locations were assessed on 11 April 2013. Sites were scouted to determine if SET platforms could be established at the site and assessed for other site factors.

Field assessment data is reported in Table B-4. After visiting all four sites, one site (Princess Bay) was removed due to high likelihood of vandalism. It is a location that sail-boating visitors cut through to gain access to a nearby road. Another site (Borch Bay) was removed because of high visibility from the nearby road. It was determined that the other two forest locations could support the establishment of SET monitoring platforms. Mary's Creek site has a storm shell berm and grades into salt pond habitat. The site has the typical mangrove forest association in the U.S. Virgin Islands. The Water Creek site has low potential for human activity due to the high cliff behind the mangroves. These sites have relatively lower trash content, low potential for discovery by public,

ease of access (ability to build platform from the upland side of the mangroves), and low sapling presence. At the VIIS site, soil depth was estimated at 5.4 m for Mary's Creek and 1.10 m for Water Creek; these estimates were based on probing the soil depth.



Figure B-3. Virgin Islands National Park (VIIS) Mary's Point area; sites assessed in April 2013.



Figure B-4. Virgin Islands National Park (VIIS) Hurricane Hole area; sites assessed in April 2013.

Table B-4. Assessment data for eight potential SET sites located in the Virgin Islands National Park (Zone 20 Q, Soil depth (m)). [y—yes; n—no].

Site	Eastings	Northing	Safe	Visible	Trash	Pneumat- ophore	Leaf litter	Mud bank/ berm	Site good	Site description	Canopy	Soil depth
Mary's Creek	2031612	316598	y	n	low	medium	low	y	y	Behind shell mound. Between shell mound and salt pond. It is a basin mangrove forest.	Trees are 4–5 m tall mixed mangroves (Avicennia germinans, Rhizophora mangle, Laguncularia racemosa) with 85% canopy cover.	Probed soil depth to 6.10 m.
Water Creek	2029809	321538	y	y	low	medium	low	n	y	Mangroves wide enough for a site in the SW part of the forest; fringing mangrove forest.	Trees are 8 m tall with 75% canopy cover. Composition is 70% Rhizophora mangle and 30% Laguncularia racemosa.	Probed soil depth with T post to 1.1m.
Princess Bay	2030436	321364	y	y	low	high	low	n	n	Between salt pond and ocean; too much human activity; short cut from moored sail boats to road.	Trees are 8 m tall with 60% canopy cover comprised entirely of Rhizophora mangle.	Probed soil depth to 6.10 m.
Borch Bay	2030352	320445	y	y	low	high	low	n	n	Between salt pond and ocean; too much human activity; road runs behind site.	Trees are 6 m tall with 60% canopy cover comprised entirely of Rhizophora mangle.	Soil not probed for depth.
Otter Creek	2029951	321297	–	–	–	–	–	–	n	On 1940's imagery mangroves are very small fringing mangroves.	–	–
Turner Point	2028761	321229	–	–	–	–	–	–	n	On 1940's imagery mangroves are very small fringing mangroves not connected to ocean.	–	–
Annaberg Ruins	2031295	317408	–	–	–	–	–	–	n	Had mangroves in the 1940's but is basin forest not connected to ocean, separated by a beach.	–	–
Annaberg school Ruins	2031271	316786	–	–	–	–	–	–	n	Had mangroves in the 1940's but it is basin forest not connected to ocean, separated by a road.	–	–

Literature Cited

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- Thanawastien, T., K. R. T. Whelan, H. C. Giannini, R. B. Shamblin, and J. M. Patterson. (Unpublished). The National Park Service Vegetation Map of the Virgin Islands National Park, St. John, USVI. Natural Resource Report NPS/SFCN/NRR. National Park Service, Fort Collins, Colorado.

Appendix C. Power Analyses

Whelan K.R.T., A. J. Atkinson, and B. R. Mitchell

We report power calculations investigating whether a change in soil elevation can be detected using three RSETs within 4 or 5 years (based on two different analysis approaches) when there is a true change in elevation of 1 mm per year. Before we present the power analyses we begin with an investigation into the appropriate unit of replication for the SET. Is the appropriate unit the SET benchmark or each arm on the SET? The traditional approach has been a very conservative interpretation that each SET is the unit of replication—so most sites would have a sample size of 3 for the three benchmarks installed at the site. Here we present evidence that arms are the appropriate unit of replication. We investigated the average arm values relative to the SET average and graphed the residuals through time. We also investigated the spatial autocorrelation of the pin measures using a Morgan's I statistic. Both analyses suggest that arms can be considered independent. However, to be conservative we present power for both the more traditional interpretation at the SET benchmark level and at the arm level. Assuming the arms are independent increases the sample size in each time step to $N=12$, which increases the degrees of freedom and hence the power to detect difference over time.

Power analyses were conducted using the online power analysis calculator from Decision Support Systems

(<https://www.dssresearch.com/KnowledgeCenter/toolkitcalculators/statisticalpowercalculators.aspx>).

The description of each analysis contains notes on the types of tests performed and parameters included in the analyses. Finally, an additional power analysis was performed on arm-level SET data using a modification of the R statistical analysis code developed by Miller and Mitchell (2014). The analyses indicate that changes of less than 1 mm per year in soil elevation can be detected with 80% power and an alpha of 0.05 within five years using three SET benchmarks per site.

Elevation Measurements from RSET Devices

We used SET data from the Biscayne National Park Site 1 (BISC 1), which had three benchmark RSETs established. This site was first sampled on 11 February 2011 and had a total of nine sample events with the last sampling occurring on 13 February 2015. For all analyses, we assumed pin data had normal distribution. We reported paired pin interval data and absolute change for the period of record. We used the BISC 1 data record for our pilot sample data because it was the longest period of record for the SFCN RSETs and it had the greatest variance. It is important to note that the BISC 1 site was affected by episodic seagrass deposition and erosional events from the near-shore environment. Additionally, this site was affected by superstorm Sandy which removed significant seagrass material that had been deposited at the site. These events added variation to the surface elevation dataset.

Investigating Independence at the Arm Level

There are typically three SETs (benchmarks) installed at a site. Each SET has four arms (directions) with each arm having nine pins for a total of 36 sample pins per SET. We report the interval data averaged at the arm level for each SET and the SET average (Table C-1). We plotted the residuals for

each arm as the difference between the arm and that particular SET average for each sample interval (Figure C-1). We find no pattern to the arms' residuals with respect to the SET average for all three SETs, which suggests the arms are acting as independent sampling units.

Table C-1. Interval change in elevation for the three SETs (1, 2, 3) and four arms (A, B, C, D) for each SET at BISC 1 during the pilot sample period. [Base—baseline; I—interval].

Category	Parameter	Base	I-1	I-2	I-3	I-4	I-5	I-6	I-7	I-8
Interval Description	Date	11Feb 2011	6 Jul 2011	5 Jan 2012	11 Sep 2012	20 Feb 2013	13 Sep 2013	13 Feb 2014	3 Sep 2014	13 Feb 2015
	Days since establishment	0	145	328	578	740	945	1,098	1,300	1,463
	Days in interval	0	145	183	250	162	205	153	202	163
SET average change per sample interval	SET 1	0.00	-7.02	31.73	23.29	-14.34	-5.99	11.11	-11.25	0.65
	Ste Dev	0.00	9.84	7.67	19.57	14.98	4.50	2.22	1.04	1.71
	SET 2	0.00	-8.06	2.01	39.72	-30.97	2.29	18.14	-10.17	6.42
	Ste Dev	0.00	6.28	6.05	16.11	15.23	1.23	2.87	0.82	1.76
	SET 3	0.00	-1.57	33.37	3.80	-18.20	-2.80	8.69	-11.88	6.15
	Ste Dev	0.00	2.03	7.77	19.61	17.77	5.01	3.77	1.42	2.18
Arm change per sample interval	1A	0.00	-2.33	26.11	27.44	-15.00	-11.22	11.00	-11.33	3.11
	1B	0.00	-21.67	41.67	-4.56	6.56	-7.13	13.75	-10.75	-0.22
	1C	0.00	-0.57	33.88	29.00	-28.43	-0.38	11.38	-12.67	0.44
	1D	0.00	-3.50	25.29	41.29	-20.50	-5.22	8.33	-10.25	-0.75
	2A	0.00	-17.13	9.00	59.00	-47.43	1.56	16.89	-9.00	6.67
	2B	0.00	-3.88	-1.50	32.56	-27.78	4.11	19.78	-10.22	5.44
	2C	0.00	-7.44	-4.33	45.56	-37.11	1.50	21.13	-10.56	8.78
	2D	0.00	-3.78	4.89	21.78	-11.56	2.00	14.75	-10.89	4.78
	3A	0.00	0.00	43.14	-14.11	-13.56	-5.00	13.00	-12.00	9.38
	3B	0.00	0.11	29.11	-6.88	1.75	-6.11	7.89	-10.44	5.44
	3C	0.00	-4.13	25.50	30.56	-41.11	-4.75	9.86	-11.29	5.22
	3D	0.00	-2.29	35.71	5.63	-19.88	4.67	4.00	-13.78	4.56

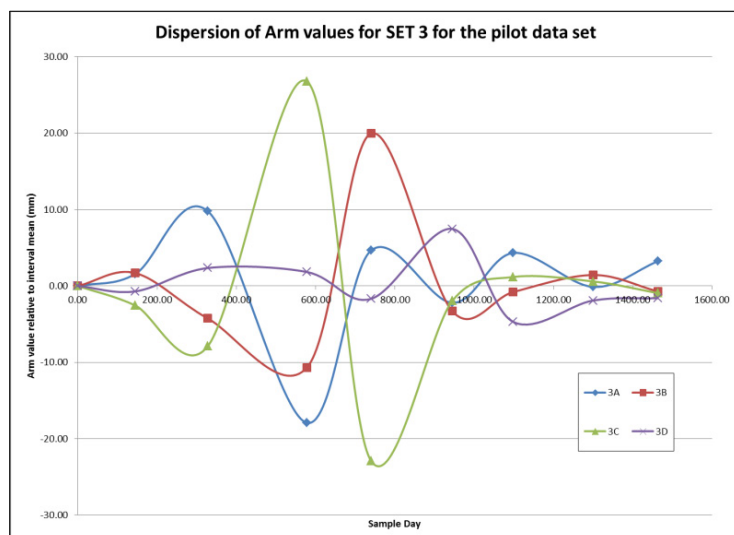
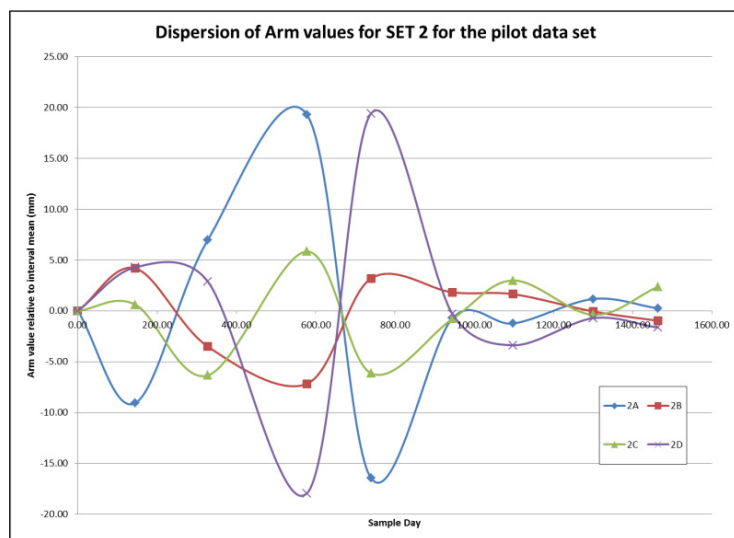
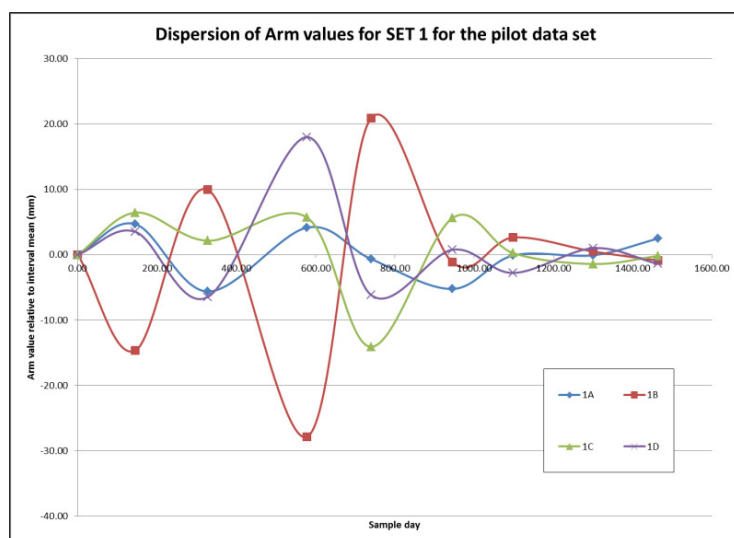


Figure C-1. Plot of arm residuals (mm) compared to SET average per sample interval over the sample day for SET 1 (top), SET 2 (middle), and SET 3 (bottom) at BISC 1.

Investigating Spatial Independence

A second investigation into whether the arms were acting independently was conducted to determine the spatial independence of the individual pins on a particular SET for one interval data set. Each pin is 6.35 mm (¼ in) in width and pins are separated by 38 mm (1 ½ in) with the first pin being 330.2 mm (13 in) from the center of the bench mark. The total distance from the first pin (pin 1) to the last pin (pin 9) is 305 mm on a single arm. We created a spatial representation of SET 1 for BISC1 in ArcGIS® ARCMAP 10.3® for all four arms on SET 1 for one interval data set. We used the Incremental Spatial Autocorrelation function in ARCMAP 10.3® to determine the spatial autocorrelation in a series of distances between pins and calculate the Morgan's I value. The first peak in the Z-score for the 36 pins of SET 1 was at 267 mm, suggesting spatial independence beyond this distance (Table C-2, Figure C-2). Applying this distance to the measured distance between the pins of the RSET, we find that up to eight pins on an arm (bearing) may be autocorrelated. The arms are at a greater distance apart than this and should be spatially independent.

Table C-2. Incremental Spatial Autocorrelation on 36 pins of BISC 1. First peak Z-score (maximum) was at 267 mm.

Distance	Moran's Index	Expected Index	Variance	Z-score	p-Value
39.00	0.384965	-0.028571	0.034223	2.235390	0.025392
77.00	0.326690	-0.028571	0.017774	2.664726	0.007705
115.00	0.317195	-0.028571	0.012515	3.090740	0.001997
153.00	0.314307	-0.028571	0.008904	3.633752	0.000279
191.00	0.307748	-0.028571	0.007316	3.932003	0.000084
229.00	0.337115	-0.028571	0.006427	4.561506	0.000005
267.00	0.347062	-0.028571	0.005749	4.954260	0.000001
305.00	0.324670	-0.028571	0.005144	4.925251	0.000001
343.00	0.309567	-0.028571	0.004820	4.870527	0.000001
381.00	0.318776	-0.028571	0.004384	5.246193	0.000000

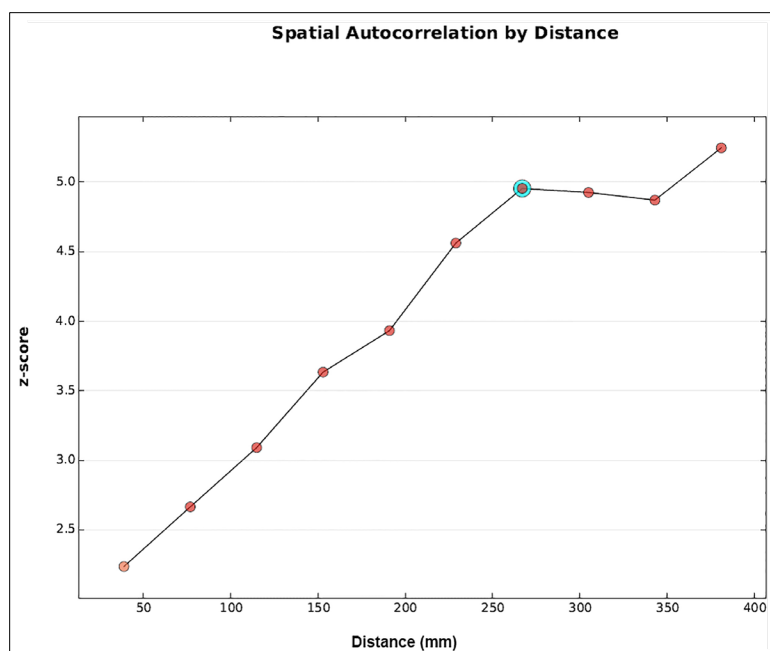


Figure C-2. Morgan's I value to determine spatial independence by determining the first peak in the Z-score (circled).

Results for t-Test

We used a t-test to determine if the slope (in mm of change per year) from the three benchmarks over a four-year period of time was different from zero. The site consisted of three fixed benchmarks, each with four arms and nine pins per arm. The pins are lowered at the exact same location during each sampling event so measurements are considered paired or repeated.

Null Hypothesis: Slope of linear regression = 0;

Alternative Hypothesis: Slope of linear regression $\neq$ 0;

We conducted the test using first the SET benchmarks as replicates ($N=3$) and then individual arms as replicates ($N=12$). We first calculated the slope of the linear regression of each pin through time (absolute change in pin elevation) and then averaged them at the appropriate level (arm or SET). The results of the t-test indicate that the slope is not significantly different from zero at the SET level (p-value = 0.07, Table C-3). This was the most conservative interpretation of the data and was due to the high variability along with the low sample size ($N = 3$ benchmarks). However, if we analyze the data at the arm level ($N = 3$ sets $\times$ 4 arms = 12), the slope was significantly different from zero (p-value < 0.001, Table C-3). The arm level analysis assumes independence of arms and benchmarks. This assumption is violated if data from arms within a benchmark are more similar than data from arms at different benchmarks; however, the tests described in the previous sections support each arm being considered independent.

Table C-3. T-test was used to determine if the slope (mm/year) of the change in soil elevation for the BISC 1 RSET was different from zero. Results are reported using an average for three RSET benchmarks for the site (N=3) and also using the four individual arms for the three benchmarks (N=12).

Type	Slope Mean (mm yr ⁻¹)	Std Dev (mm yr ⁻¹)	N	Std Error (mm yr ⁻¹)	Reference Constant	t-Value	df	p
SET	4.903	2.35	3	1.36	0	3.61	2	0.06892
Arm	4.904	2.25	12	0.65	0	7.52	11	0.00001

Based on this pilot data we are interested in knowing if we have sufficient power (80% power is desired) at an alpha of 0.05 to detect that a 1.0 mm yr⁻¹ change differs from the null hypothesis (0 mm yr⁻¹ change). The slope of 1 mm yr⁻¹ is biologically significant in that a change at this level can become important to mangrove ecosystems on a decadal scale, and it is sufficiently small relative to sea level rise estimates (2.3 ± 0.1 mm yr⁻¹ for the period from 1925–1992; Maul and Martin 1993) that the network will be able to evaluate whether soil elevation is keeping pace with sea level. We based our power calculation on our pilot data's standard deviation for a paired t-test for both slope and absolute change over four years (Table C-4a and C-4b). Minimum detectable difference and minimum absolute change were calculated using the minimum detectable difference equation (7.9) from Zar (1999). We desired to be able to detect a slope of 1 mm yr⁻¹ which is an absolute change of 4 mm after four years at an alpha of 0.05 and 80% power (Table C-4a and C-4b). We found that we have sufficient power (100%) for detecting the slope of 1 mm yr⁻¹ when analyzing the data at the arm level (N=12) and only 18% power at the SET level. We determined that we would be able to detect a minimum change of 1.55 mm in absolute elevation after four years at the arm level and 15.58 mm for absolute elevation at the SET level, which is less than the 21.27 mm observed in the pilot study.

Table C-4a. Pilot data descriptive statistics.

Type	Slope	Std dev slope	Coefficient of variation	N	Slope minimum detectable difference	Absolute change	Std dev absolute change
SETs	4.9	2.35	0.480	3	7.28	21.27	4.97
Arms	4.9	2.26	0.461	12	2.13	21.27	1.75

Table C-4b. Power.

Type	Desired absolute change	Desired slope	Minimum detectable difference for absolute change	% Power Slope not equal to zero	Absolute change	Slope ^A
SETs	4.0	1.0	15.38	18	3.05	1.45
Arms	4.0	1.0	1.55	100	0.95	0.19

^A Approximation of a Hierarchical ANCOVA minimum detectable difference using a t-test with modified degrees of freedom.

When we used a t-test with an adjusted degrees of freedom (to account for repeated measures at each SET), we increased our ability to detect a smaller minimum detectable difference for absolute elevation change at both the arm level (0.95 mm) and at the SET level (3.05 mm) after four years. In this analysis, the degrees of freedom were the number of SETs (or arms, depending on the analysis) minus one, times the number of sampling occasions minus one (following the minimum detectable difference equation (7.9) from Zar (1999)). Additionally, we increase our ability to detect a smaller minimum detectable difference for slope to 0.19 mm yr⁻¹ at the arms level and 1.45 mm yr⁻¹ at the SET level after four years. Using this type of analysis we gain degrees of freedom with each repeated sampling event. In the next section, we present an alternative power analysis using a hierarchical linear model approach, but it should be noted that our estimate of 0.40 mm yr⁻¹ uses adjusted degrees of freedom (to account for repeated measures at each SET).

Descriptive statistics for the pilot data

Descriptive statistics for the pilot data set reported for SETs (N = 3) and Arms (N = 12), including slope and absolute change over the four years sampled. Power analysis of SET data for two scenarios: 1) SET slope calculated at the benchmark level (3 SETs; N = 3), 2) SET slope calculated at the arm level (3 SETs x 4 arms; N = 12). Power is reported for a 2-tailed test of the hypothesis (H₀) that the overall slope is not equal to zero for 1 mm yr⁻¹ or 4 mm absolute change after four years. Power for the entire table is always 80% at an alpha of 0.05. All minimum detectable differences are calculated at 80% power at an alpha of 0.05 for a 2 tailed t-test. All slope values are reported as mm yr⁻¹. Absolute change is reported in mm after four years.

Power Analysis Simulation

We used a hierarchical linear modeling approach developed by Miller and Mitchell (2014) to investigate the power for detecting a linear trend between -1 and 1 mm yr⁻¹ in pin height (summarized to the arm level) over a five-year period assuming two sample events per year. The data used in the simulation were the pin heights from two sample events (9/03/2014 and 2/13/2015) for the three benchmarks located at the BISC 1 site. Miller and Mitchell (2014) developed R code for simulating power for a set of random sites nested within a network of parks; we applied the approach to simulate power for a set of independent arms nested within a network of SETs at a site. The code was modified to simulate a fixed trend effect (-1 to 1 mm yr⁻¹) rather than a proportional effect (e.g., 25% change per year).

Full details of the simulation can be found in Miller and Mitchell (2014). Briefly, the sample data were used to estimate year-to-year variation for each benchmark, and a bootstrap simulation generated a data set with the appropriate amount of variation and imposed a trend on the data set. Then a hierarchical linear model was used to estimate the annual trend, and the percentage of simulations where the trend was detectable is the estimated power. As observed by Pescott et al. (2015), this approach is only as good as the source data, which in this case is a very small pilot data set, so true power will vary depending on how closely the variance in the pilot data matches the actual variance encountered during monitoring. However, we used our site with the greatest variance due to storms and sea grass deposition and thus assume the less variable sites will have even greater power to detect the desired change.

We used 250 bootstrap simulations to determine the power to detect a trend after five years with 80% power and an alpha of 0.05. Simulations were conducted for trends ranging from -1.0 mm yr^{-1} to 1.0 mm yr^{-1} . The simulation tested the power to detect a trend when all three SETs experience the same trend, as well as the power when the trend only occurred at one SET. We found that we should be able to detect changes of $\pm 0.6 \text{ mm yr}^{-1}$ or greater in five years with 80% power and an alpha of 0.05 (Figure C-3). When the trend only occurred at one SET, power to detect a $\pm 1.0 \text{ mm yr}^{-1}$ change in five years was less than 50% for two benchmarks, and approximately 80% for the third.

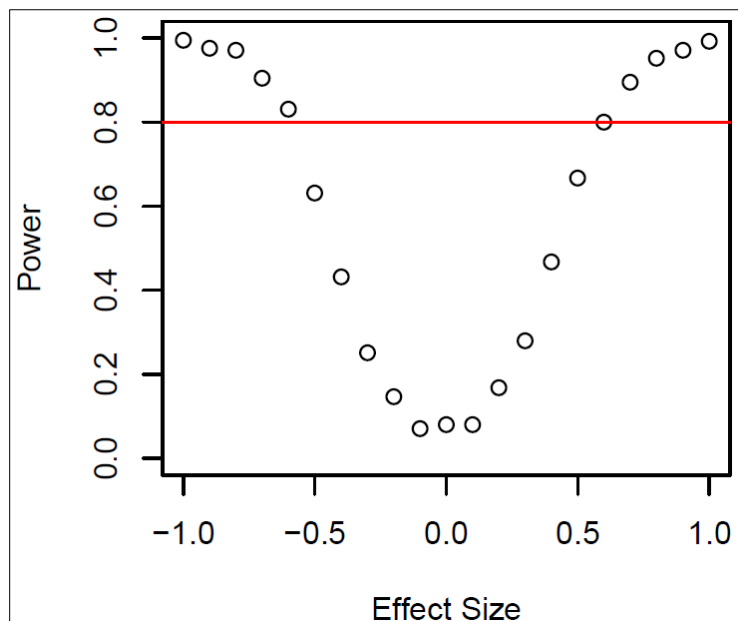


Figure C-3. Power to detect different effect sizes (change in elevation in mm/year) at three benchmarks within a site with four arms each and 10 sample events with alpha = 0.05. The red line indicates a power of 80%.

Summary Statement

An investigation of residuals and a Morgan's Index of spatial autocorrelation both suggest that arms are an appropriate level of summarization instead of SET benchmarks. Using arm-level summarization we have approximately 100% power at an alpha of 0.05 for detecting that a 1 mm yr^{-1}

slope in elevation change over a four-year period differs from 0 regardless of analysis method used. We determined that with 80% power and an alpha of 0.05 for a t-test design we would be able to detect a minimum change of 1.55 mm for absolute elevation after four years, which is much lower than the minimum of 4 mm desired. Additionally, a t-test design with adjusted degrees of freedom and a minimum detectable difference calculation indicated that even if summarized at the SET level we were able to detect a 1.45 mm yr⁻¹ slope after four years (eight sampling events). This suggests that with a longer-term data set we will be able to detect the 1 mm yr⁻¹ trend desired even if we are conservative about our unit of replication. Finally, the alternative power analysis based on a hierarchical linear modeling approach indicates that we should be able to detect a slope of ± 0.6 mm yr⁻¹ or greater in five years with 80% power and an alpha of 0.05.

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