



South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring

Protocol Narrative

Natural Resource Report NPS/SFCN/NRR—2019/1923



ON THE COVER

Mangrove-marsh ecotone, Everglades National Park

Photography by: South Florida/Caribbean Inventory and Monitoring Network

South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring

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Natural Resource Report NPS/SFCN/NRR—2019/1923

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Abstract

This protocol describes the process used to monitor ecotonal movement of mangroves and upslope freshwater marshes in Everglades National Park and Big Cypress National Preserve. Tracking the position of ecotones can indicate the long-term trajectory of these plant communities. Changes in the ecotone can be indicative of changing environmental drivers. The mangrove to freshwater marsh ecotones are expected to move, for example, in response to changes in water management, sea-level rise, storms, and fire, some of which can be manipulated to alter the rate of change. Ecotonal movement of vegetation communities across the landscape is indicative of large-scale processes affecting the park and preserve.

Remote sensing approaches are used to delineate the physical location of the ecotone (boundaries) between mangroves and freshwater marsh. Fourteen 3 kilometer (1.9 mile [mi]) segments are systematically placed along the ecotone within the two parks. Aerial imagery is used to digitize the mangrove-marsh ecotone in each segment and must be 1 meter (3.3 feet [ft]) or better resolution and have positional accuracy of ± 3 meters (9.8 feet [ft]) or better. Four ground-truth field point locations (marker points) are established approximately 1 kilometer (0.62 miles [mi]) apart along the ecotone of each segment to provide field-based measurements and ground-truthing of the digitized line.

The specific objectives of the Mangrove-Marsh Ecotone Monitoring Protocol are to:

- Determine the spatial and temporal movement of the mangrove-marsh ecotone at systematically selected segments.
- Document the composition of vegetation communities at field verification locations. Collect vegetation data, e.g., composition, percent cover and canopy height of dominant species within herbaceous, shrub, and forest strata, in order to document composition of vegetation communities on both the “mangrove” and “marsh” sides of the ecotone.

Monitoring will be repeated approximately once every ten years as new imagery becomes available. The monitoring duties for the mangrove-marsh ecotone monitoring protocol will be completed by South Florida/Caribbean Network staff and the information collected used to support the management of natural resources in Everglades National Park and Big Cypress National Preserve.

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Acronyms

BICY—Big Cypress National Park
EVER—Everglades National Park
GIS—Geographic Information System
GNSS—Global Navigation Satellite System
GPS—Global Positioning System
IMD—Inventory and Monitoring Division
MOCC—Motorboat Operator Certification Course
NPS—National Park Service
NRDT—Natural Resource Database Template
QA/QC—Quality Assurance / Quality Control
SFCN—South Florida/Caribbean Network
SOP—Standard Operating Procedures
USGS—U.S. Geological Survey

Background and Objectives

The South Florida/Caribbean Inventory and Monitoring Network (SFCN) includes Everglades National Park (EVER), Big Cypress National Preserve (BICY), Biscayne National Park (BISC), Dry Tortugas National Park (DRTO), Buck Island Reef National Monument (BUI), Salt River Bay National Historical Park and Ecological Preserve (SARI), and Virgin Islands National Park (VIIS). Together these parks include more than 2,500,600 acres (1,011,957 hectares [ha]) (Figure 1). The Network systematically monitors vital signs for these seven national park units. The National Park Service (NPS) defines vital signs as a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, or elements that have important human values (Patterson et al. 2008).

The mangrove-marsh ecotone vital sign was ranked 14th among the 44 vital signs identified for the SFCN (Patterson et al. 2008). Plants are important primary producers and are the dominant physical-structure components in terrestrial natural systems (Cox et al. 2014). For these reasons, they are a primary focus of most natural land resource management agencies. Ecotonal movement of vegetation communities across the landscape is indicative of large-scale processes affecting the park. This document describes the process used to monitor ecotonal movement of mangroves into upslope freshwater marshes in Everglades National Park and Big Cypress National Preserve. The monitoring duties for the mangrove-marsh ecotone monitoring protocol will be completed by SFCN staff, and the information collected will be used to support the management of natural resources in Everglades National Park and Big Cypress National Preserve.

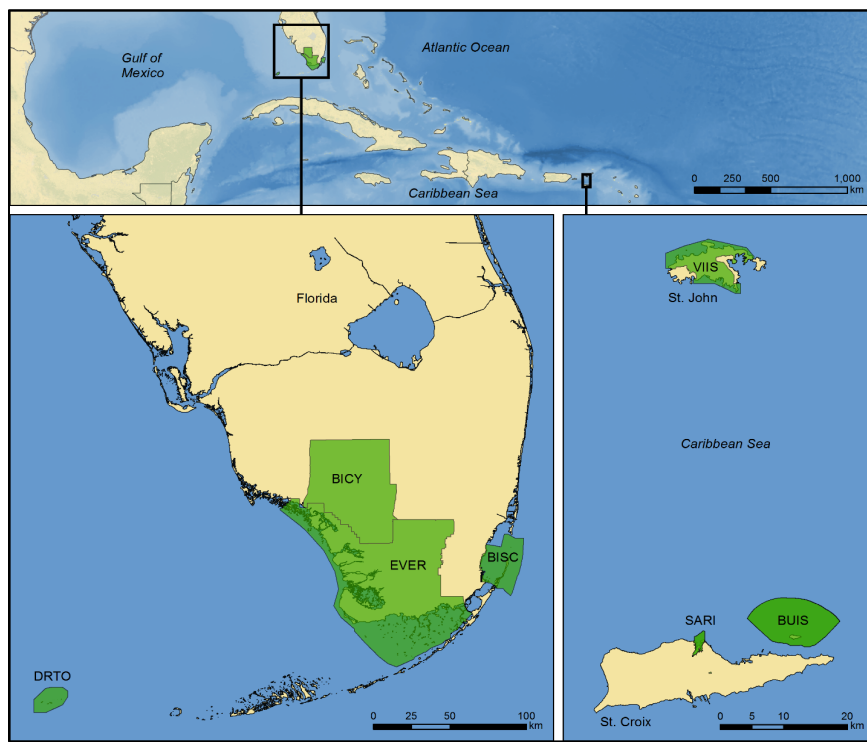


Figure 1. National Park Service units within the South Florida/Caribbean Network.

Rationale for Selecting this Resource

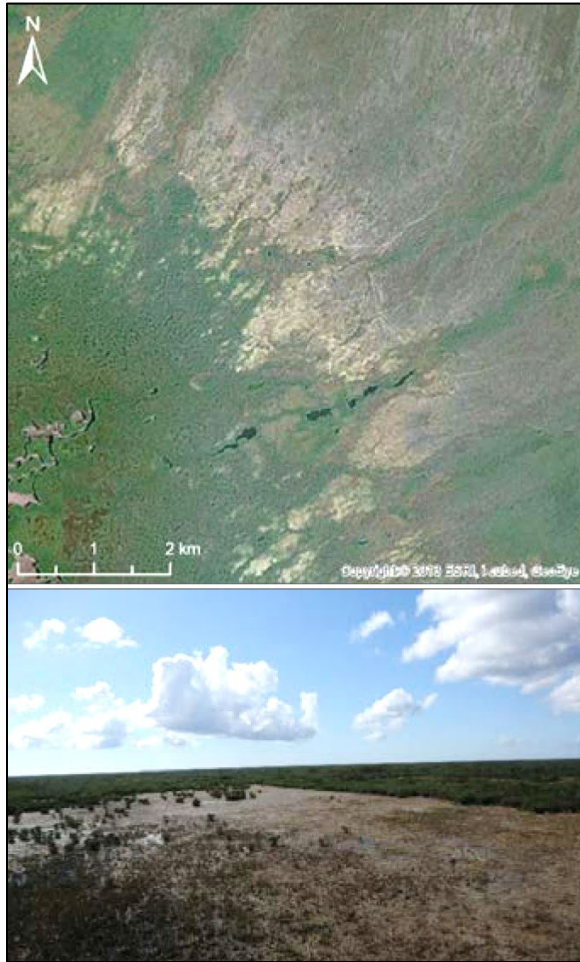


Figure 2. Top: Mangrove-freshwater marsh ecotone in Everglades National Park. Bottom: Regional view of mangrove communities (green areas) and marsh communities (brown areas). Localized view of a marsh community shown as the brown habitat in the foreground of the photo; and a mangrove community shown as the green habitat in the middle of the photo.

Ecotones are transitional zones between habitat types and can be dynamic in their spatial location. As these dynamic transitional zones are typically inhabited by species at the edge of their ecological tolerances, the ecotone may be particularly sensitive to changing environmental conditions (Fortin et al. 2000). This susceptibility to environmental impact can make tracking the ecotone boundary a good indicator of changing conditions (Fortin et al. 2000).

Ecotones as transitional zones can be large, expansive areas or sharp, distinct boundaries. In this protocol, we are interested in monitoring the regional leading upslope mangrove line (typically a distinct boundary) relative to the freshwater marsh (Figure 2). In response to changes in drivers such as freshwater flows and sea-level rise, the ecotonal boundary (referred to subsequently as the “ecotone”) of mangrove movement into freshwater marsh is expected to transgress (move) upslope.

Regression (retreat) of the mangrove ecotone may occur due to storms, increased freshwater flows, and fire (Smith et al. 2013; Wade et al. 1980).

Given the potential for future sea-level rise and changes in freshwater flows, there is significant concern about the upslope movement of mangrove communities in South Florida. Tracking the position of the regional mangrove-marsh ecotone can indicate the long-term trajectory of this wetland ecosystem in the combined context of regional water management changes and sea-level rise. At selected sites in South Florida, ecotonal movement across the landscape has already been an important indicator for water management (Ross et al. 2000; Krauss et al. 2011). The transition from freshwater graminoid marshes and cypress to mangrove communities can be effectively monitored using a combination of aerial photography and on-the-ground data collection.

The National Science Foundation (NSF)-sponsored Florida Coastal Everglades Long Term Ecological Research monitoring program is investigating how specific processes may be forcing physiological changes across the regional ecotone (Rivera-Monroy et al. 2011; Castaneda-Moya et al. 2011). The program is using field-based and remote sensing methods to investigate changes in vegetation (Armentano et al. 2006), periphyton (Gaiser et al. 2011), water nutrients (Naja et al. 2017), freshwater and estuarine fishes (Rehage et al. 2014), and alligators (Platt et al. 2013). Typically these studies are occurring at a few intensively studied sites, whereas the South Florida/Caribbean Network protocol involves less-intensive sampling at the park-wide ecoregion level.

Additional Background

South Florida is characterized by marshlands and wet prairies interspersed with tree islands, cypress swamps, pinelands, hardwood hammocks, and mangrove forests. Slight differences in elevation and landform have important consequences for vegetation and create a number of habitats. Mangrove communities are low-diversity coastal habitats of South Florida that are periodically flooded by high tides and storms. South Florida mangrove communities are primarily composed of black mangroves (*Avicennia germinans*), red mangroves (*Rhizophora mangle*), white mangroves (*Laguncularia racemosa*), and buttonwood (*Conocarpus erectus*) (Tomlinson 1986). Mangroves are salt-tolerant, whereas freshwater marsh vegetation is not (Kuenzler 1974).

Mangrove communities of Florida vary tremendously in their structure and appearance. Mature red and black mangrove trees along Shark River in Everglades National Park can grow to 20 meters (65.6 ft) in height and form dense assemblages (Odom and McIvor 1990). Basin mangrove assemblages (Cintron et al. 1985; Lugo et al. 1989) occur inland and may take a variety of forms including dwarf red mangrove scrub on marl substrates (periphyton-derived substrates rather than peat substrates derived from marsh graminoids such as sawgrass). Dwarf red mangrove scrub is characterized by having scattered shrubs rarely exceeding 1.5 meters (4.9 ft) in height, even though many of the shrubs are more than fifty years old (Odom and McIvor 1990). These dwarf mangrove scrub habitats in many instances occur far inland and are inundated by storm tides or precipitation runoff. It is these dwarf mangrove assemblages that typically form the leading edge of the mangrove-marsh ecotone in the C-111 canal and Mahogany Hammock areas of Everglades National Park (the Taylor Slough region in Figure 3).

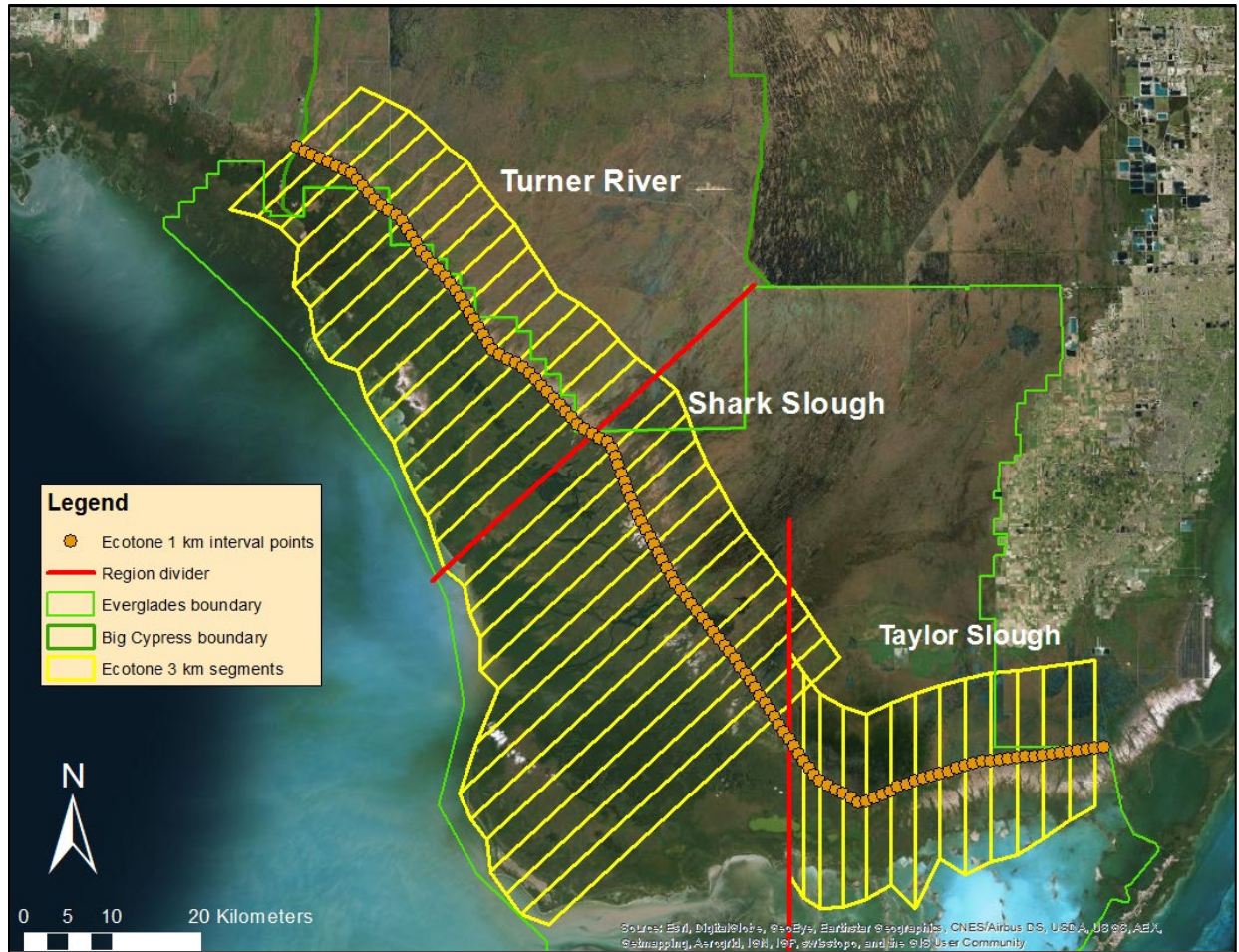


Figure 3. Generalized mangrove marsh ecotone and region dividers. The ecotone is divided into 3 regions and 3 km segments arrayed in the direction of water flow.

Fringing mangrove forests (Cintron et al. 1985; Lugo et al. 1989) form a fringe along waterways and creeks and rarely exceed 10 meters (32.8 ft) in height. These fringing mangrove forests generally form a hard edge ecotone that is common in the Shark Slough (Everglades National Park) and Turner River (Everglades National Park and Big Cypress National Preserve) regions of the ecotonal area (Figure 3).

Marshes are wetlands dominated by herbaceous plants growing in shallow water standing at or above the ground surface. In general, less than one-third of Everglades marsh vegetative cover consists of trees and shrubs (Kushlan 1990). Between the mid-1950s and mid-1970s, marshes in the Everglades have been severely altered by both drainage and unnatural flooding. The seasonality of Florida's rainfall and evaporation is important in the functioning of the marsh ecosystem by creating a seasonal fluctuation in surface water. Water levels rise during the summer rainy season, gradually decline in the winter months, and eventually reach drought conditions as evapotranspiration increases in the spring months (Kushlan 1990).

Sawgrass marshes are the predominant marsh associations in the Everglades and include such species as sawgrass (*Cladium jamaicense*), spikerush (*Eleocharis cellulosa*), arrowhead (*Sagittaria lancifolia*), and maidencane (*Panicum hemitomen*) (Stephens 1984). In some cases, cattail marsh will occur at the ecotone where water levels are deeper and richer in nutrients. This marsh association is characterized by high density stands of cattail (*Typha* spp.) with sparse amounts of spikerush and sawgrass.

Water management and the natural seasonality of rainfall are important drivers influencing vegetation distribution in South Florida parks. Dry season months in South Florida are November through May where rainfall amounts range from 2–4 inches (6–12 cm) per month (Chen and Gerber 1990). Wet season months are June through October where rainfall amounts range from 6–9 inches/month (14–23 cm/month; Chen and Gerber 1990).

More than 1,800 miles (2,896 kilometers [km]) of man-made canals (Figures 4 and 5) have been built in the last 130 years to drain, reroute, and control the annual flooding of the Everglades region in South Florida (SFWMD 2010). These canals have had serious impacts on the vegetation and wildlife of the area. Small alterations in the amount, timing, quality, or location of water result in easily seen changes to vegetation communities. Over the last 30 years, some efforts have been made to restore natural seasonal flow patterns and rehydrate portions of Big Cypress National Preserve and Everglades National Park. The hydrologic effects of projects from the [Everglades Restoration Program](#), such as raising the Tamiami Trail to allow sheet flow into northeast Shark River Slough and restoring flows to Taylor Slough, will continue to have lasting effects on vegetation in these parks.



Figure 4. C-111 canal bordering Everglades National Park. This canal is located in the extreme south of Figure 5.

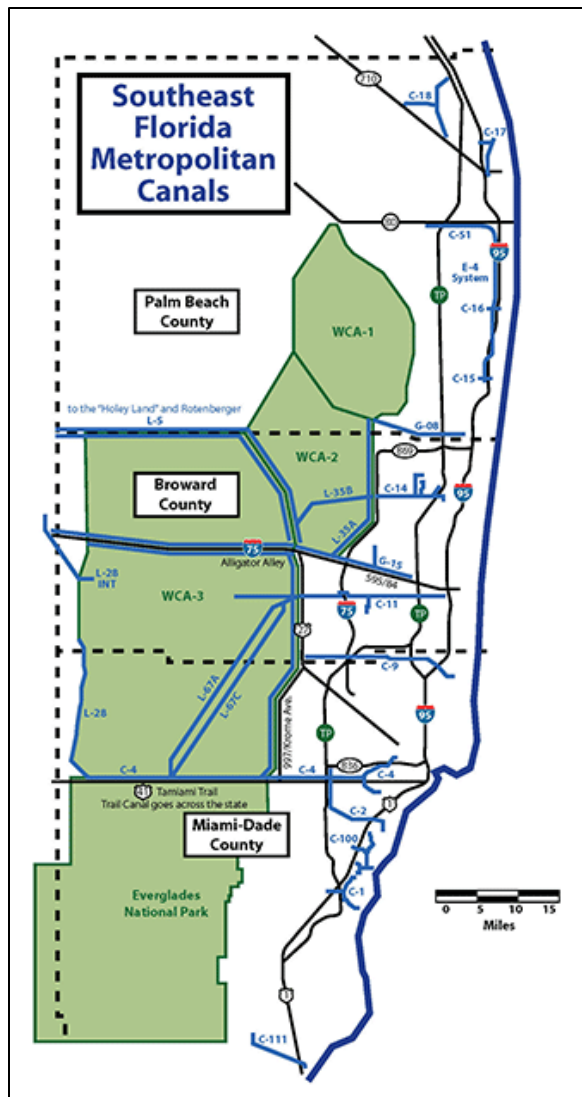


Figure 5. Map of the metropolitan area canal system of southeast Florida. (Source: <https://midcurrent.com/books/alligator-alley-and-tamiami-trail/>; Downloaded 3/15/2019).

Climate change is expected to have an acute impact on South Florida in the form of sea-level rise. The Intergovernmental Panel on Climate Change (IPCC 2013) estimates that global sea level could rise 0.26–0.98 meters (0.85–3.22 ft) by the year 2100. When changing glacial dynamics are added to these conservative estimates, sea-level rise is predicted to be 0.8–2.0 meters (0.3–6.6 ft) by the end of the century (Pfeffer et al. 2008). This has the potential to cause immense changes in the vegetation within SFCN parks because Dry Tortugas National Park, Biscayne National Park, two-thirds of Everglades National Park and portions of Big Cypress National Preserve have elevations lower than 1 meter (3.3 ft). Increases in sea level are associated with mangrove upslope migration. Modeling of Everglades National Park suggests that even a small rise in sea level (15 centimeters [5.9 inches (in)]) could cause upslope migration of mangroves and loss of adjacent marshes and hammocks (Doyle et al. 2003).

Hurricanes are an important driver of the coastal vegetation distribution in South Florida parks (Lodge 2005). Hurricanes can affect vegetation through mortality by wind throw, storm surge, ocean water intrusion, and sediment deposition (Smith et al. 2009). There is also potential for warming ocean temperatures to result in a greater number of strong storms, although this is difficult to predict (Webster et al. 2005). Fire was thought to restrict mangrove expansion into marshes (Taylor 1981); however, a publication by Smith et al. (2013) shows the effects of fire on mangrove expansion is mixed and can sometimes facilitate mangrove expansion.

The composition of the graminoid marshes and the mangrove communities on either side of the ecotone provides supplemental information about the changes that are occurring. The composition of graminoid marshes in Everglades National Park reflects the hydrology (i.e., water depth, duration of flooding, and salinity) and past fire history, as well as the nutrient status at that location. For example, spikerush is associated with deeper water and longer hydroperiods than sawgrass (Myers and Ewell 1990). Presence of cattail is typically indicative of increased phosphorous availability either due to external nutrient enrichment in the water or to local release of phosphorous via the coastal groundwater discharge process that results when seawater intrudes inland, displacing brackish groundwater (Price et. al. 2006). Red mangroves are tolerant of both freshwater and ocean water (Teas 1979) and thus, by themselves, are not indicative of ocean water intrusion; however, other shrubs such as sweetbay (*Magnolia virginiana*) are not tolerant of ocean water intrusion and their presence in the mangrove portion of the ecotone would be indicative of continued freshwater inputs.

Measurable Objectives

The specific objectives of the mangrove-marsh ecotone monitoring protocol are to:

- Determine the spatial and temporal movement of the mangrove-marsh ecotone at systematically selected segments (Figure 6).
- Document the composition of vegetation communities at field verification locations. Collect vegetation data, e.g., composition, percent cover and canopy height of dominant species within herbaceous, shrub, and forest strata, to document composition of vegetation communities on both the mangrove and marsh sides of the ecotone.

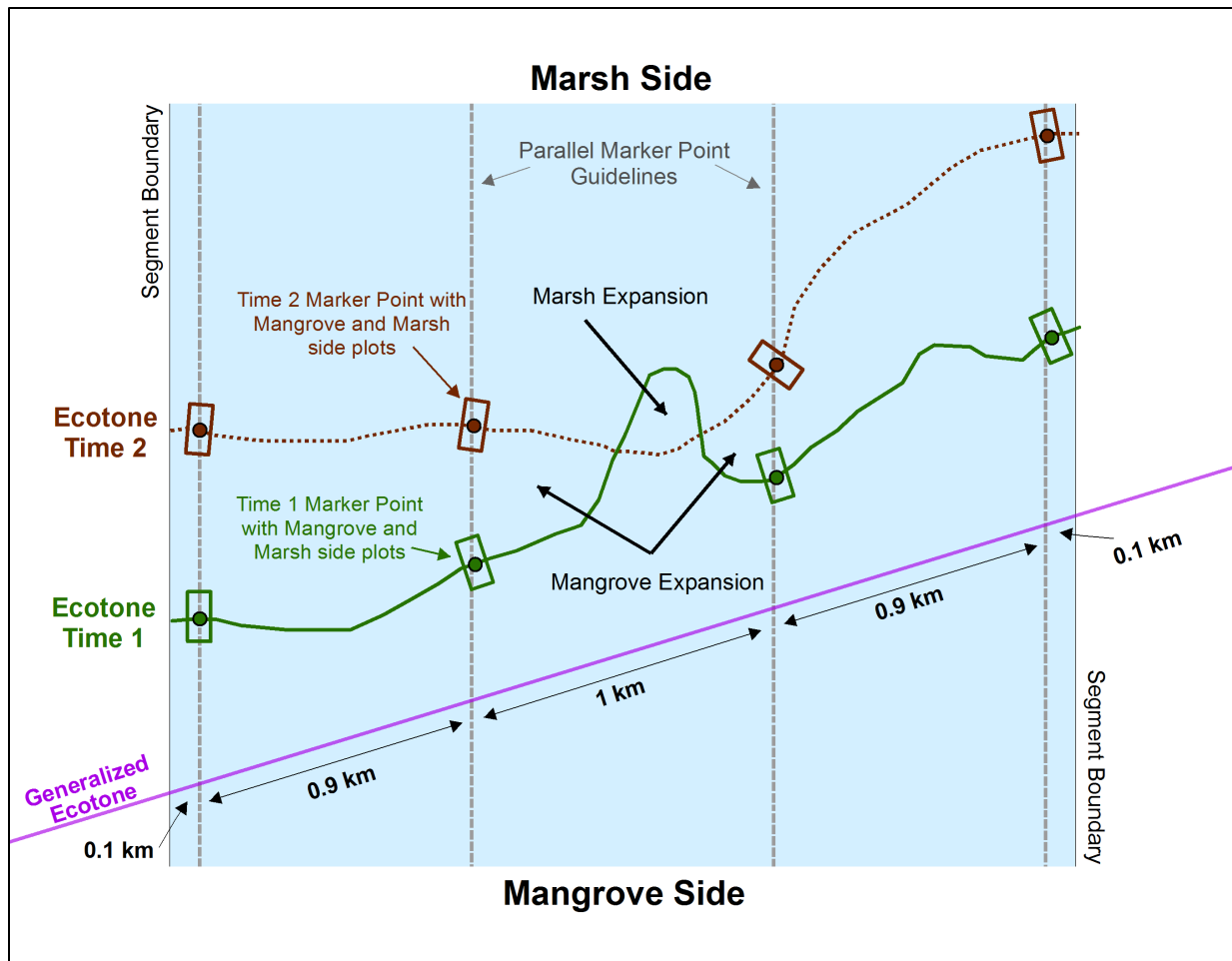


Figure 6. Example of the movement of an ecotone with Time 1 (solid green line), Time 2 (dotted brown line), the marker points (circles), and associated vegetation plots (boxes around circles). Not drawn to scale.

Note that this protocol focuses on intrusion of mangroves into upstream freshwater marshes and does not focus on replacement of saline coastal marshes with mangroves.

Link to Management Decision-Making

The movement or lack of movement of the mangrove-marsh ecotone will help resource managers understand the local impacts of global sea-level rise on the hundreds of miles of ecotone between mangrove and upslope freshwater marsh and associated habitats. The associated habitats include tree islands and low lying pine rocklands—especially pine rockland fragments separated from the larger pine rockland community—within Everglades National Park and Big Cypress National Preserve. Increased freshwater flows from upstream water operations into Everglades National Park and Big Cypress National Preserve, combined with fire management, may slow down the movement of the mangrove-marsh ecotone. Restoration efforts such as the raising of Tamiami Trail, the removal of the C-111 canal, and the addition of the Spreader Canal project in the C-111 area (ACE 2018), will distribute increased freshwater flows to the Taylor Slough region.

This protocol can be linked to other projects in these ecotonal and coastal areas such as compositional effects due to sea-level rise on tree islands in the southeastern coastal everglades (Ross et al. 2014), effects of salinity and inundation on microbial community structure and function in mangrove peat soil (Chambers et al. 2016), effects of sea-level rise and freshwater management on long-term water levels and water quality in the coastal Everglades (Dessu et al. 2018) and, potentially, forest vegetation monitoring done by SFCN (protocol in draft).

Excessively high upslope movement of the mangrove-marsh ecotone may impact long-term park planning, e.g., whether mitigation measures should be developed, whether to replace or move inland old park structures, where restoration efforts should be focused, and whether rare plant species need to be moved inland.

The vegetation data collected according to this protocol provide ancillary, descriptive data about the composition of the mangrove and marsh sides of the ecotone, which in turn may inform management about the hydrology and water quality at the interface. Field data documenting vegetation community composition of the mangrove and marsh portions of the ecotone may also increase understanding of which marsh communities are susceptible to rapid mangrove expansion (Smith et al. 2013). For example, the data could document a pattern of association between high density red mangroves adjacent to very low density spikerush in areas that subsequently experience rapid mangrove ecotonal expansion in the next time interval. As another example, if the vegetation community was indicative of freshwater hydrology instead of brackish, this in turn could inform which management actions (such as controlled burns or increased freshwater inputs) are more likely to successfully slow mangrove encroachment.

Some authors have identified a “white zone” in the southeast saline everglades of Everglades National Park (Egler 1952, Ross et al. 2000). Since the mid-1940’s, the interior boundary of a low productivity zone (white zone) moved inland by 1.5 kilometers on average (Ross et al. 2000). Egler described this white zone as a band of mixed vegetation with approximately equal proportions of sawgrass, spikerush, and red mangrove. When Ross re-sampled this area nearly 50 years later in the mid-1990s the vegetative component of the white zone had changed to a monodominant community of red mangrove, indicating that the white zone appearance on aerial imagery results from factors other than species composition (Ross et al. 2000).

Ross suggested that the appearance of the white zone on aerial photography results from the combined effects of a reflective substrate and low plant cover. Ross also observed spatial and temporal variation in the position of the southeast saline everglades white zone that are consistent with the hypothesis that hydrological variables associated with marine and freshwater sources are somehow connected in the presence of this low productivity band of vegetation (Ross et al. 2000). Marsh profiles for Britain and eastern North America showed that the zone of sparsest vegetation occupied a region near the confluence of salt and freshwater bodies (Carter 1988). When comparing the 1940 and 1994 photo series, it appears that the white zone has extended furthest inland in areas most deprived of access to fresh water (Ross et al. 2000).

The network found during a pilot study in the southeast saline everglades (Taylor Slough region segments 13 and 14) that the leading edge of the ecotone in this area is characterized by dwarf red mangrove assemblages interspersed with sawgrass, and located at an average distance of 0.8 kilometers (segment 13) to 2 kilometers (segment 14) inland of the white zone. Future digitization efforts, especially in areas cut off from freshwater flows such as segments 10, 12, 13 and 14 in the Taylor Slough region (Figures 7 and 9), are areas where we believe (based on research done by Egler and Ross) the greatest ecotonal change will take place when compared with changes from other regions and associated segments. These results can inform managers where increased freshwater flows may be warranted throughout the system.

Tentatively, based upon the research and management needs described above, and our expert judgement, park management would benefit from knowing the rate of movement of the mangrove-marsh ecotone in each region and system-wide to assist with park infrastructure, restoration planning, and park management decisions. While a strict trigger point for management actions is premature at this time, a movement of 40–80 meters (131–262 ft) or higher over 10 years (4–8 meters per year or more) would likely be of sufficient concern to trigger discussions about management actions such as hydrologic restoration, fire management, and revisiting management strategies for species ranging from endemic plant species to the Cape Sable seaside sparrow.

Sampling Design

This protocol combines remotely-sensed interpretations of ecotonal boundaries with ground-truthed data collection. Field sample sites are accessed via helicopter, airboat, or by hiking. Fourteen 3-kilometer (1.9 mi) long segments of the ecotone are systematically digitized across the entire ecotone line from southeastern Everglades National Park to southwestern Big Cypress National Preserve. Field ground-truth point locations (marker points) are established approximately 1 kilometer (0.6 mi) apart along each segment. Data collected at each marker point include the field location of the ecotone and vegetation data. The vegetation data include species data for both the marsh and mangrove side of the ecotone point, and percent cover by stratum (tree, shrub, herb) and by species. Sampling frequency is approximately once every ten years.

Rationale for Sampling Design

To determine the actual placement of the mangrove-marsh ecotone, the network has adopted the line digitization method with associated marker points to determine vegetation composition and test accuracy of the digitized ecotone lines. Rather than digitize the entire approximately 129 kilometer (80.2 mi) ecotone, the network has chosen to systematically sample nearly a third of the ecotone in the form of 3-kilometer (1.8 mi) segments. This decision was made for logistical reasons to reduce the workload involved by two-thirds while still providing coverage of the ecotone ranging from Everglades National Park to Big Cypress National Preserve. Others have also digitized linework from aerial imagery (Krauss 2011; Cowart 2010; and Xiaoping et al. 2014).

The systematic sampling method is a type of probability sampling in which members from a larger population are selected according to a random starting point and a fixed periodic interval (Bellhouse 2005). The systematic sampling allows inference of change not only on an individual 3-kilometer (1.8 mi) segment, but also on a regional level. By using a systematic design, no portion along the ecotone will be farther than about 3 kilometers (1.8 mi) from a digitized section. Using a systematic design maximizes the spatial spread among segments and provides the maximum spatial independence possible among segments. Monitoring 14 segments will take approximately the same level of effort as the index sites used during a pilot study, which was a workload the network feels it can reasonably accomplish.

The network explored using five longer, 5 to 16 kilometer (3.1 to 9.9 mi) index sites during a pilot study phase, but switched to the systematic segments to allow inference across the entire ecotone. The benefit of the index sites is that they were located to allow access via hiking or airboats if helicopter use should become restricted. However, the inference of the index sites was only to those site locations and left relatively large unmonitored gaps along the ecotone.

The network chose to use four marker points per segment to provide an ability to estimate accuracy of the linework at the segment, region and ecotone level based upon the pilot study work. A systematic design maximizes the spatial separation among the points in a system where there is some spatial autocorrelation expected and allows field teams to use knowledge gained during previous visits to assist with future visit logistics such as likely accessibility of each point by airboat, hiking, or helicopter. This increases crew efficiency and possibly saves money.

Although using permanent marker points and measuring the distance the ecotone moved in the field would provide even greater accuracy than using GPS devices and visual estimates, the network is not using permanent markers in the field as most of the ecotone exists within wilderness areas.

Additionally, the sub-meter accuracy of current GPS devices is such that the improvement in accuracy was unlikely to be worth the additional field effort required, and the value of the additional precision provided by permanent markers was felt to be minimal after a ten-year resample period.

The ten-year monitoring frequency was selected based on professional best judgement after reviewing a number of other ecotonal movement studies (Carter et al. 1994, Stohlgren and Bachand 1997, Fortin et al 2000, Choesin and Boerner 2002). Egler (1952) contended that over a 100-year period (0.61 mm/year sea-level rise rate), coastal vegetation will transgress at a rate of 4.1 meters/year (13.5 ft/year). Krauss et al. (2011) determined that, on average, mangroves transgressed on average 7.9 meters/year (25.9 ft/year; personal communication, 5/3/2018) into freshwater marsh at the Ten Thousand Islands National Wildlife Refuge. These ecotonal movement estimates suggest that the ecotone may move between 41 meters to 79 meters (134.5–259.2 ft) over a 10-year period (4.1–7.9 meters/year). This time interval would allow us to detect and measure changes greater than the measurement error of our sampling (see Appendix A: *Estimating Detectable Change Based Upon Variance Between Digitized Line and Field Marker Points of Five Index Sites*). Measurement error (or observational error) is the difference between a measured value of a quantity and its true value and is based on the variability that is inherent in the measurement process (Taylor 1999). Primary sources of measurement error associated with this protocol include accuracy of the georectification of the imagery used, resolution of imagery used, clarity of and consistency in application of digitizing rules between digitizers, accuracy of GPS devices used, accuracy of determination of mangrove edge in the field by field crew, and time between imagery acquisition and field data collection.

The frequency of reassessment for the ecotonal monitoring project therefore reflects the time scale that the vegetation communities are expected to show detectable movement based on similar work done by others (Egler 1952; Ross et al. 2000; Ross et al. 2013; Krauss et al. 2011). The sampling interval could be shortened if results are needed earlier by the park in some regions and if time and funding permit. However, the effort to acquire the imagery, setup the digitizing portion of the project, and train personnel are constant regardless of whether only a few segments are analyzed or all segments. Thus, a resample design that would involve increased frequency of sampling at a few select sites was considered to not be cost effective as a permanent part of the monitoring design. The ten-year sample interval is such that the network can reliably fit this protocol in with its other monitoring requirements and likely changes should be detectable with confidence.

The network looked into other techniques to track changes in mangroves including satellite remote sensing to monitor mangrove forest resilience and resistance to sea-level rise (Duncan et al. 2018). This approach relies on unsupervised classification of mangrove habitat to create habitat polygons that can be tracked through time. The most repeatable version of this process utilizes 4-pixel Landsat clusters (60×60 meters or 197 × 197 ft) and is less able to detect fine-scale migration of mangroves (Duncan et al. 2018).

We also considered shoreline change metrics utilizing the USGS Digital Shoreline Analysis System (DSAS) tool (Thieler et al. 2009; Cowart et al. 2010; Psuty et al. 2011). The DSAS tool uses a transect-based approach where shoreline change rates are calculated along these transects. This approach can be problematic when used with highly sinuous lines where transects at varying angles can lead to multiple intersections and distance overestimates (Cowart et al. 2010; Xiaoping et al. 2014).

Sampling Frame

Mangrove-marsh ecotone monitoring will focus on the mangrove-marsh transition in South Florida within Everglades National Park and Big Cypress National Preserve (Figure 7). The majority of field locations are anticipated to be accessible via helicopter, with a handful falling within a feasible walking distance. Should helicopter use be restricted (e.g., unavailable due to fires, increase in helicopter costs, or maintenance requirements), airboat usage will become the primary method of field transportation.

The target population for mangrove-marsh ecotone monitoring includes the entire ecotone area from U.S. Highway 1 in southeast Everglades National Park to the southwestern Big Cypress National Preserve boundary. This ecotone area is divided into three regions based on hydrological flow (from west to east: Turner River, Shark Slough, and Taylor Slough) with each region encompassing approximately 50 kilometers (31 mi) of ecotone (Figure 7). A generalized ecotone line was created at 1:250,000 scale using 2013 USDA NAIP imagery to represent the overall pattern of the ecotone (Figure 7) and is 129 kilometers (80.2 miles) long. That ecotone was then divided into forty-two 3-kilometer (1.8 mi) segments by orienting guide lines at 3-kilometer (1.8 mi) intervals along the generalized ecotone in the approximate direction of water flow (at an azimuth of 0 degrees or north in the Taylor Slough region, 42.5 degrees in the Shark Slough and Turner River Regions). Because the 3-kilometer distance was measured along the generalized ecotone, there is some variation in the apparent width of the segments. Where Shark Slough and Taylor Slough join there is also a small section (3 kilometers [1.8 miles]) of the generalized ecotone that did not become a segment because of the likelihood that the segments will merge. Thus the initial sampling frame of forty-two 3-kilometer segments is slightly smaller than the target population and consists of 126 kilometers (78.3 miles) of the generalized ecotone line.

Site Selection

An R script was used to select the initial starting segment by generating a random number between one and three. The script returned a three, so starting from the northwest and moving east, every third segment was included in the analysis across the park-wide ecotone. This resulted in a total of fourteen 3-kilometer (1.8 mi) ecotone line segments across all three regions (Figure 7). Five segments are associated with both the Turner River and Taylor Slough regions and four segments are associated with the Shark Slough region.

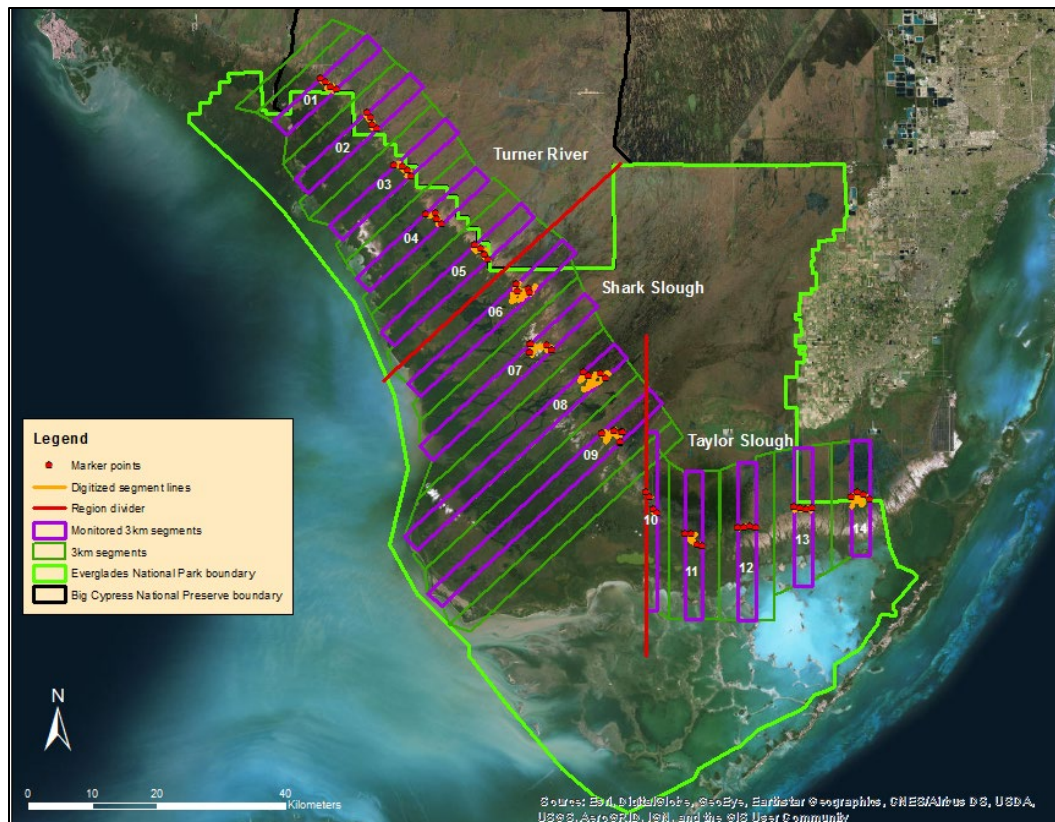


Figure 7. Fourteen ecotone line segments were selected for monitoring in a systematic design with a random start. Starting from the northwest, every third 3-kilometer segment was selected for digitizing and ground-truthing. Each digitized 3-kilometer segment has four ground-truth marker points. Regions are identified by the main water-flow source, and segment guide line dividers are oriented in the main direction of water flow within the region.

For a fuller explanation of mangrove-marsh ecotone monitoring and the pilot work that was done to determine methods and monitoring areas, see Appendix B—*Mangrove-Marsh Ecotone Pilot Project Report* (Moser et al. 2019) and SOP 5—*Mangrove-Marsh Ecotone Field Methods* (SFCN 2019).

Marker Points

Each segment includes four marker points to ground-truth the ecotone line, for a total of fifty-six marker points across the ecotone. The main purpose of the marker points is to calculate positional error of the digitized ecotone line using standard root mean squared error (RMSE) (see Appendix A: *Estimating Detectable Change Based Upon Variance Between Digitized Line and Field Marker Points of Five Index Sites*). The RMSE incorporates the error associated with the digitizing of the line, positional error inherent to the imagery, the error introduced from time since imagery acquisition (1–2 years), the error associated with identifying the ecotone on the ground, and the GPS error associated with the marker point location. In our pilot work this error ranged from 1.7–7.8 meters (5.5–25.5 ft; Appendix A).

In order to place the marker points, marker point guidelines were created within each segment at approximately equal intervals at 0.1, 1.0, 2.0, and 2.9 kilometers along the generalized ecotone. These guidelines are parallel to the segment boundaries and extend both upslope and downslope from the generalized ecotone line. The marker points at the edges of each segment were moved 100 meters in from the edges (0.1 and 2.9 kilometers) to avoid artificially inflating errors if the final field placement of a marker point is beyond the end of the digitized segment.

When each new ecotone line is digitized, a set of GIS-derived marker points is created at the intersection of the marker point guidelines and the newly digitized ecotone (Figure 8). In some extremely sinuous areas there may be more than one location where the marker point can be placed. In this case the marker point is placed at the upslope (most inland) ecotone location (see SOP 2—*Mangrove-Marsh Ecotone Methods for Digitizing and Updating the Ecotone Line*). These are only the preliminary, GIS-derived coordinates for these marker points and they are used to navigate to the marker point in the field.

During field verification a submeter GNSS unit is used to collect more accurate coordinates. In some cases the marker points may require hovering over the point via helicopter rather than a ground GPS point, as access to some points may be blocked by thick impassible stands of vegetation or deep mud where a helicopter or field crew can easily get stuck. It is the GPS coordinates that are used to calculate the RMSE.

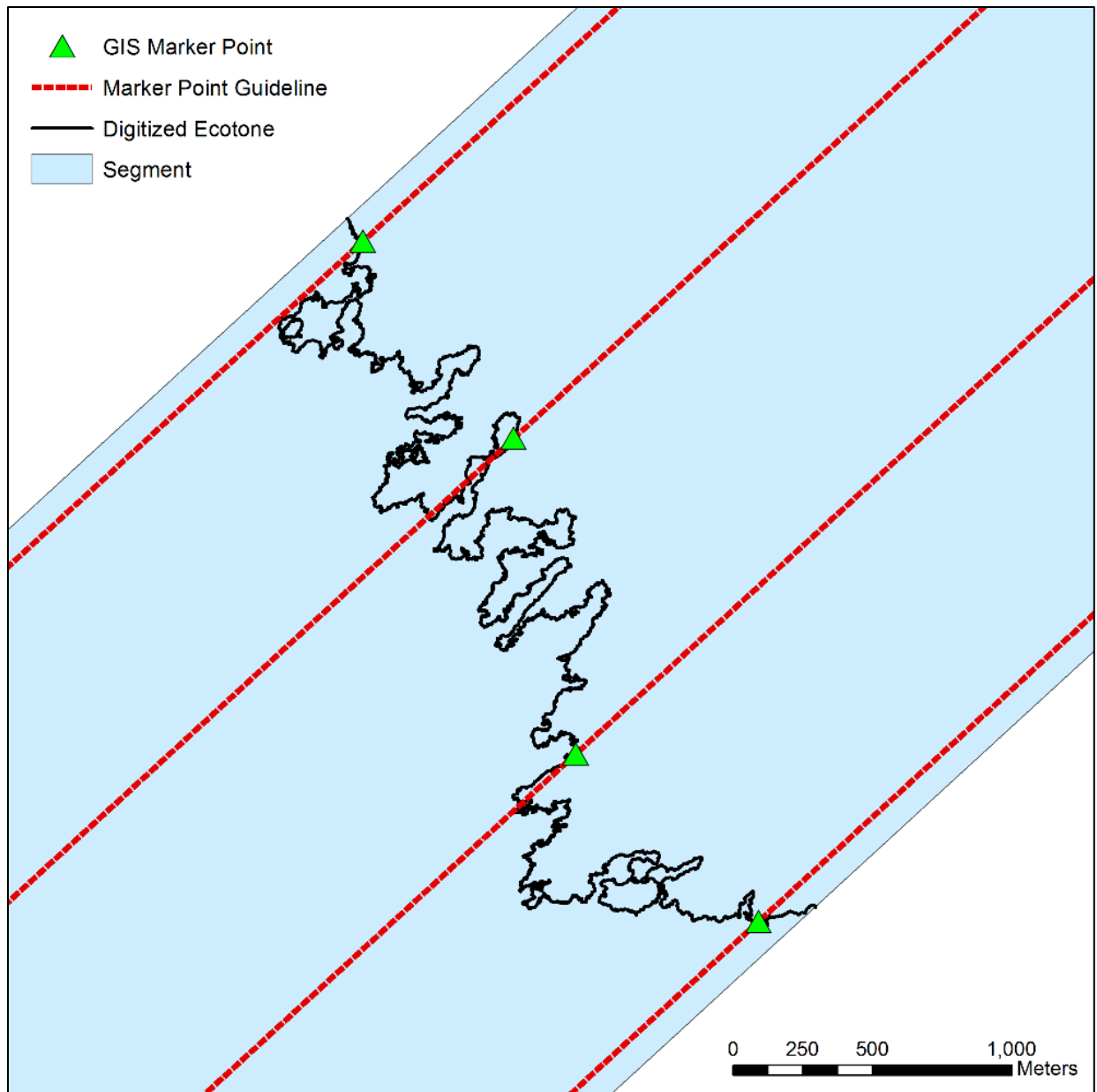


Figure 8. On each segment (blue polygon) four GIS-derived marker points are created. Each marker point (green triangle) is placed at the intersection of the digitized ecotone (black line) and the marker point guidelines (red, dashed lines). The marker points at the edges of each segment are moved 100 meters in from the edges (0.1 and 2.9 kilometers).

Boundary Issues

SFCN found that the digitized ecotone line from the two easternmost segments (segment 13 and segment 14) were either approaching the Everglades National Park park boundary (segment 13) or partially exceeding the park boundary (segment 14; Figure 9). In both cases the network plans to continue to digitize the line beyond the park boundary because of important species and restoration efforts in these areas. When granted access by the South Florida Water Management District the

network plans to continue monitoring marker points in these lands adjacent to Everglades National Park as well.

Segment 13 is of particular interest because six kilometers north of the current ecotone is Population D of the Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis*), a federally endangered bird subspecies. The Spreader Canal hydrologic restoration area (ACOE 2018) is also located to the north of segment 13, which will be a source of incoming freshwater flow into this area.

In the case of segment 14, all four marker points and much of the digitized line are already beyond the park boundary. Two of the marker points have reached their northernmost limit and are situated along the edge of the C-111 canal. The upcoming C-111 canal restoration project seeks to fill the southern portion of the canal and replace it with an east-west spreader canal. This new feature is expected to distribute flood waters in a more natural fashion over a broad expanse of coastal wetlands and into northeast Florida Bay and may impact the ecotone.

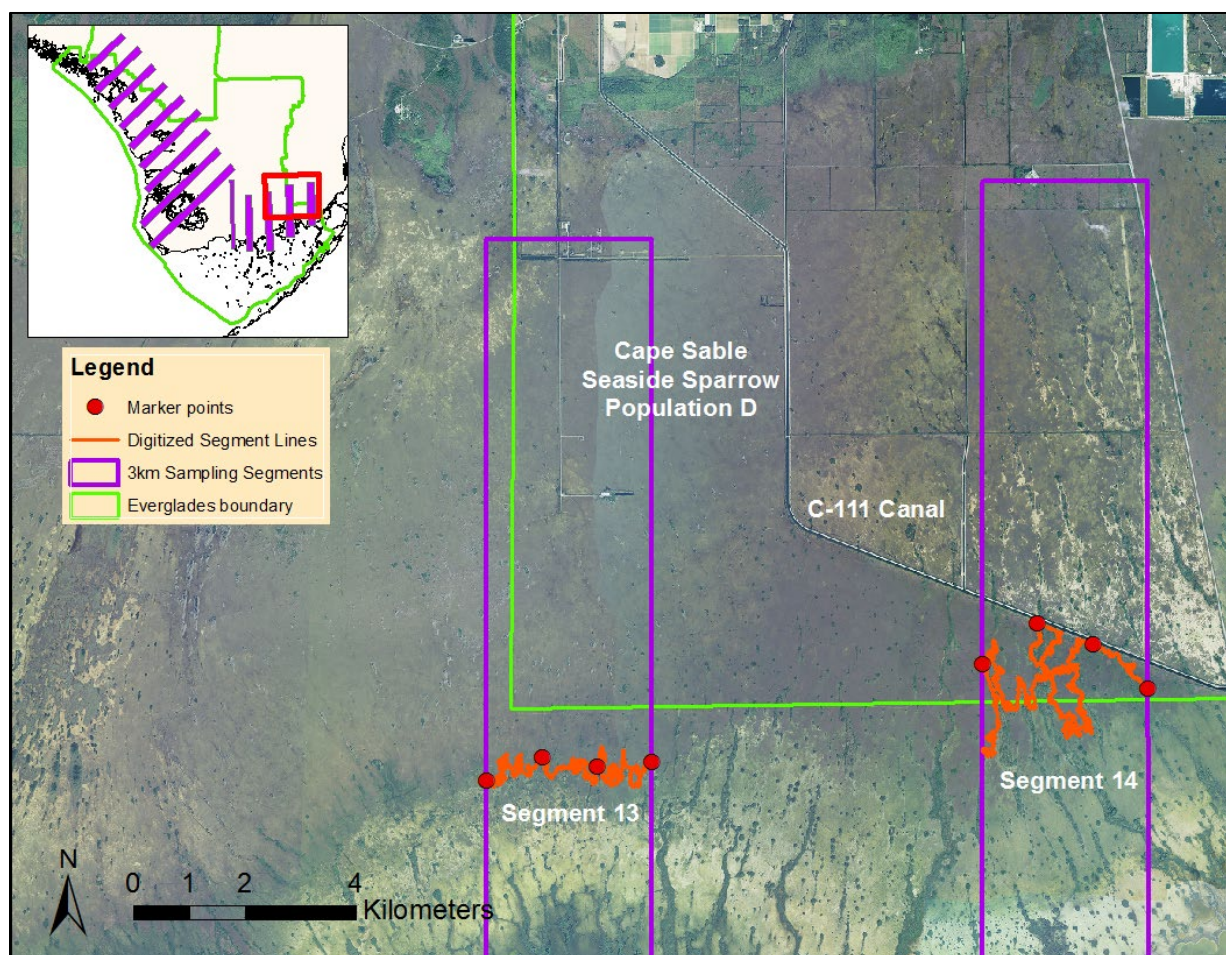


Figure 9. Segments 13 and 14 are either approaching the EVER park boundary (segment 13) or partially exceeding the park boundary (segment 14). Segment 13 will continue to be monitored to capture any future ecotonal changes near the Cape Sable seaside sparrow habitat. Segment 14 will continue to be monitored to capture any changes related to the upcoming C-111 canal restoration project.

Sampling Frequency and Timing

Aerial Imagery Interpretations

The monitoring schedule for ecotonal movement requires aerial imagery of sufficient quality (less than or equal to 1 meter [3.2 ft] spatial resolution). National Agriculture Imagery Program (NAIP) photography is typically available in Florida every two years and meets these requirements. There are also additional sources of imagery related to the Comprehensive Everglades Restoration Plan (CERP) and Florida Department of Revenue (FDOR), and additional sources may arise in the future. Digitizing the mangrove-marsh ecotone using new aerial imagery is the first stage of the monitoring process and cannot begin until imagery is available. Our preferred return period for ecotonal monitoring is approximately every ten years. The frequency of reassessment for this project reflects the time scale over which vegetation communities are expected to move based on our examination of historical imagery and similar work done by others (Egler 1952; Ross et al. 2000; Ross et al. 2013, Krauss et al. 2011). The sampling interval could be shortened if results are needed earlier by the park in some regions and if time and funding permit.

Marker Point Visitation

During a sampling event, each GIS-derived marker point is navigated to over the course of one year, a field determination of the actual ecotone edge is made, and a submeter GPS coordinate is recorded in the field. Marker point visitation can be accomplished at any time during the year; however, the late winter to early spring months (February–May) are the preferred time for monitoring by helicopter, before water levels in the marsh increase. During summer months (June–September) the water levels may be too high to land a helicopter, but are often suitable for monitoring by airboat.

Detectable Amount of Change

Movement of the mangrove-marsh ecotone may be either gradual (due to sea-level rise and changes in freshwater flows) or abrupt (due to storm events or fire). A pilot project (see Appendix B *Mangrove-Marsh Ecotone Pilot Project Report*) was conducted analyzing a 250 meter (820 ft) portion of Coot Bay in Everglades National Park using 1995 Florida Digital Orthophoto Quarter Quad (DOQQ) imagery with a spatial resolution of 1 meter (3.3 ft) and 2009 Comprehensive Everglades Restoration Plan (CERP) imagery with a spatial resolution of 30 centimeter (11.8 in). This analysis identified changes ranging from 3–15 meters (9.8–49.2 ft) over the 14 years between images.

Krauss et al. (2011) documented extensive mangrove transgression into the freshwater marsh in the Ten Thousand Islands region (immediately west of Big Cypress National Preserve) between 1927 and 2005. Krauss (personal communication, 5/3/2018) documented changes in movement of some areas of the ecotone of well over 1,000 meters (3,280 ft) and an average upslope transgression rate of 7.9 meters/year. These results triggered management actions in Ten Thousand Islands National Wildlife Refuge (Ken Krauss, personal communication, 5/3/2018). Smith et al. (2013) found in three study sites in Everglades National Park from 1940–2004 that ecotone movement was not uniform and some areas of the ecotone migrated by more than 100 meters (328 ft; 1.6 meters/year), whereas other areas barely changed. However, even the area that Smith et al. (2013) classified as “hardly any change” migrated upslope around 5–10 meters (16.4–32.8 ft; 0.08–0.16 meters/year). As the different

regions within Everglades National Park differ in their management, the ability to detect movement of the ecotone by 40 meters or more in a 10-year time frame is a reasonable target.

Two different methods were used to estimate the amount of detectable change with this protocol: (1) variance between remotely-sensed and ground-based interpretations of the ecotone location, and (2) variance between two independent remotely-sensed interpretations. During a pilot study (see Appendix A—*Estimating Detectable Change Based Upon Variance Between Digitized Line and Field Marker Points of Five Index Sites*), five index sites (5 to 16 kilometers [3.1 to 9.9 mi] of digitized linework) with 15-20 marker points per site were used to detect differences between marker points and the digitized line. Shortest distances between marker points and digitized ecotone lines were calculated for all five index sites within ArcGIS using the measurement tool. Points that were to the mangrove side of the digitized line (downslope) were recorded as a negative distance, whereas points that were to the marsh side (upslope) were recorded as a positive distance.

The second method (see Appendix C—*Estimating Detectable Change Based Upon Variance Between Two Digitizers*) used eight 3-kilometer ecotone segments that were digitized by two people using the same 1 meter (3.3 ft) 2013 National Agriculture Imagery Program imagery at 1:500 scale. A nearest neighbor technique in ArcGIS used all vertices to calculate distances between the two lines. One line was arbitrarily designated as the baseline and the second line was compared to it. Distances were given a positive value when the comparison line was upslope of the baseline, or a negative value when the comparison line was downslope of the baseline. The standard error was used to estimate the average amount of line movement that is detectable with 95% confidence and 80% power, assuming a paired t-test (Table 1) for a single segment with four marker points, a region with five sampled segments, and the entire ecotone with fourteen sampled segments. Details of the analyses are provided in Appendices B: *Estimating Detectable Change Based Upon Variance Between Digitized Line and Field Marker Points of Five Index Sites* and C: *Estimating Detectable Change Based Upon Variance Between Two Digitizers*.

Table 1. Level of change detectable with 95% confidence and 80% power using two different methods to estimate variance for individual line segments, regions, and entire ecotone. The two methods involve using marker points (Appendix B) and directional distances (Appendix C). Sample unit and sample size (n) vary between methods and between single segment versus region and entire ecotone line. The region and ecotone line results for directional distance are based upon using the segment average differences as replicates. To reduce the impact of autocorrelation on the results in the case of 1 segment, which typically has several thousand directional distance estimates, the sample size used to determine the t values in the test was n=30 and assumes errors in digitization along the line that are 100 meters apart are independent. All units are in meters.

Test	1 segment	Region	Ecotone Line
a. Marker point to line	11.5 (n = 4 marker points)	3.7 (n = 20 marker points)	2.1 (n = 56 marker points)
b. Digitized line to digitized line directional distance	11.1 (n = 30 distances)	7.4 (n = 5 segment averages)	4.3 (n = 14 segment averages)

It should be noted that results specific to the Spreader Canal area, that has a gradual ecotone, had greater variance and larger minimum detectable change in both analyses. The ability to detect an average change of at least 11.5 meters (38 ft) for an individual segment, 7.4 meters (24 ft) for a region and 4.3 meters (14 ft) for the entire multi-park ecotone with 80% power meets the target of 40 meters change after 10 years. These results also suggest that the sampling interval could be shortened if results are needed earlier by the park in some regions and if time and funding permit. However, a ten-year resampling interval should allow acceptable estimation of rates of ecotone movement even in slower moving areas.

The vegetation data collected as part of this protocol are intended to provide a description of the vegetation community on either side of the ecotone and are collected to the accuracy provided in Appendix D—*Data Quality Standards for South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring*. The vegetation data are not intended to assess trends but can be used to summarize communities across the ecotone, e.g., 19 of 20 marker point vegetation plots in the Taylor Slough region exhibited a marsh vegetation community dominated by spikerush (*Eleocharis cellulosa*).

Field Methods and Ecotone Digitization

The standard operating procedures (SOP 1—*Mangrove-Marsh Ecotone Preparation and Equipment Check* [SFCN 2019] and SOP 5—*Mangrove-Marsh Ecotone Field Methods* [SFCN 2019]) provide detailed instructions on field season preparation and equipment, site establishment, and field measurements.

Aerial Imagery Ecotone Interpretation

Imagery no more than 24 months old must be acquired each time the ecotone lines are redigitized (approximately every 10 years). There are several potential sources of high quality aerial imagery covering Everglades National Park and the surrounding areas of South Florida, such as the National Agriculture Imagery Program (NAIP), Florida Department of Revenue (FDOR), and Comprehensive Everglades Restoration Plan (CERP). NAIP at a resolution of 1 meter (3.3 ft) was used to digitize the mangrove-marsh ecotone monitoring lines during the pilot 2010–2014 assessment (Appendix B—*Mangrove-Marsh Ecotone Pilot Project Report*), although later tests have incorporated higher resolution imagery such as the 30 centimeter (1.0 ft) 2009 CERP dataset.

It is likely that imagery sources will change over time, but efforts will be made to maintain consistency as much as possible. New aerial imagery used to digitize the mangrove-marsh ecotone must be 1 meter (3.3 ft) or better resolution and have positional accuracy of ± 3 meters (9.8 ft) or better. When the spatial resolution of the imagery changes, a digitizing test of at least one segment must be completed at both the new resolution and a downsampled 1 meter (3.3 ft) resolution. The primary concern is that higher resolution imagery could reveal mangroves that were present all along, but only visible in the more detailed imagery. This could lead to the detection of a false trend of mangrove expansion. After creating test ecotone lines at both resolutions, the lines will be compared using the procedures in SOP 3—*Analysis of Distance between Two Digitized Lines* (SFCN 2019) and SOP 4—*Analysis of Area between Two Digitized Lines* (SFCN 2019) to investigate for local or systemic differences. Based on these findings a final decision will be made on which resolution to use for digitizing the complete ecotone.

The ecotone (boundary) is defined as the line where a continuous cover (50–100%) of trees and/or shrubs on the mangrove side gives way to a more open marsh environment on the other. In the transition zone a few mangrove shrubs or trees may still be present, but their cover will be less than 50%. In this transition zone the herbaceous vegetation cover will increase substantially. If time and resources permit, a training flight will be scheduled to fly all or part of the 14 ecotone segments. This flight creates a series of flight paths and GPS points used to guide digitizers as to the general location of current ecotone placement.

All ecotone segments are digitized in ArcGIS at a scale of 1:500. This scale is helpful for applying the detailed digitizing rules in SOP 2: *Mangrove-Marsh Ecotone Methods for Digitizing, Updating the Ecotone Line, and Creating Marker Points* (SFCN 2019), especially when paired with periodic reviews of larger landscape patterns at 1:2,000 or beyond. Other projects have digitized natural features at similar scales, including a study of the Neuse River estuary which used 1 m (3.3 ft) 1998 imagery and coarser 1958 imagery to digitize at scales from 1:500 to 1:3,000 (Cowart et al. 2011).

The Arctic Inventory & Monitoring Network's coastal change protocol also uses a range of scales from 1:500-1:800 with imagery with a spatial resolution of "2.5 meter (8.2 ft) or better, preferably 1.0 meter (3.3 ft) or better" (Manley et al. 2012).

The primary digitizer creates each segment using the latest imagery and steps that are detailed in SOP 2—*Mangrove-Marsh Ecotone Methods for Digitizing and Updating the Ecotone Line* (SFCN 2019). While each segment represents only 3 kilometers along the generalized ecotone, the actual linework that is digitized will be substantially longer. Segments created during pilot work varied in length between 11.2 and 59.7 km (7.0 and 37.1 mi).

A secondary digitizer digitizes two randomly chosen segments and then a QA/QC analysis on the difference between the two mangrove-marsh ecotone lines is conducted using SOP 3—*Analysis of Differences Between Two Digitized Lines* (SFCN 2019). The methods used in SOP 3 are also used to analyze the difference between two lines digitized using imagery from different years.

Pre- Field Season Preparation & Equipment Set-up

Field season preparation largely involves: (1) determining that the field crew is up-to-date with the proper field and helicopter training, (2) ensuring helicopter availability, and (3) checking that GPS units (handheld and submeter GPS units) are in good working order. As a back-up mode of transportation, the airboat, its trailer and the towing vehicle are maintained in good working order. A detailed description is found in SOP 1—*Mangrove-Marsh Ecotone Preparation & Equipment Check* (SFCN 2019).

Permitting and Compliance

The network's Board of Directors has previously decided that the network does not need to acquire formal research permits for its work in Network parks. However, the network must seek approval for its proposed method of visiting sites (e.g., helicopter, airboat, hiking) from the Everglades National Park Wilderness Committee. This process can take as much as six months, so it must be started prior to the field season preparation process. The network must also notify both parks' resource management staff of its plans for working in the parks. For 2017–2018 sampling, the Wilderness Committee required submission of a description of the study, marker point sampling locations, a submission of alternatives with levels of impact, an economic analysis, and a formal presentation to the Wilderness Committee.

In Big Cypress National Preserve, there are four marker points (two along the Ochopee pilot study line and two along one of the systematically selected 3-kilometer segments) that fall within eligible wilderness. To receive approval to access these sites by airboat or helicopter, a Request for Off-Trail Administrative Access Form and the Application for Off-Trail Access Form (SOP 15—*Big Cypress Field Forms and Wilderness Area Access Process* [SFCN 2019]) must be filled out and submitted to resource management for approval. This process takes at least two weeks.

The habitat at the mangrove-marsh ecotone is low in species diversity and the plant species dominating this niche are common species of mangrove habitat or freshwater marsh habitat. Therefore, plant specimens are not collected for this protocol.

Field Marker Point Establishment

Best professional judgment will be used to establish the ecotone in the field. The Network staff assessed a number of methodologies including identification from aerial imagery (Beckage et al. 2008), identification in the field by professional best judgment, vegetation analysis using dominance curves (Fortin et al 2000), and vegetation analysis using a moving split window (Choesin 2001; Choesin and Boerner 2002) for determining the ecotone in the field. It was found that best professional judgment was not significantly different from other methods, and that the use of professional judgment saved a substantial amount of time. Refer to Appendix B—*Mangrove-Marsh Ecotone Pilot Project Report*, that provides a complete explanation of assessment methodologies.

For some points not in designated wilderness (e.g., Big Cypress National Preserve), or easily reachable from designated roads and trails by foot, points may be traveled to via airboat. However, visiting via helicopter is preferred.

Field staff navigate to the approximate marker point location derived in GIS using a handheld GPS unit (refer to SOP 9—*Using Garmin Handheld GPS Units* [SFCN 2019] and SOP 10—*Using Trimble Geo7X GPS Unit* [SFCN 2019]). Once in the vicinity of the marker point the field crew uses best professional judgement to determine the nearest mangrove-marsh ecotone edge. At the field-defined ecotonal point, a submeter Global Navigation Satellite System (GNSS) receiver is used to record the coordinates of this marker point.

If the point cannot be safely reached by landing the helicopter and proceeding on foot, the marker point is taken and data collected by hovering the helicopter over the ecotone at the appropriate point. During the pilot study data were collected from a hovering helicopter at three of the fifty-six points (5.4% of the points). The helicopter's passenger side skid is aligned to the point or ecotone edge, and the GPS mark is taken from the hovering helicopter. The distance from the helicopter skid to the GPS antenna within the helicopter is accounted for in the calculations (for more detail see SOP 5—*Mangrove-Marsh Ecotone Field Methods* [SFCN 2019]). South Florida/Caribbean Network staff have tested hovering the helicopter over points at a height of 15.2 meters (50 feet) and generated an accuracy within two meters (6.4 ft; See SOP 13—*Methods for Testing Accuracy of Coordinates Taken from a Hovering Helicopter* [SFCN 2019]).

Field Measurements

Detailed instructions on field data collection methods are provided in SOP 5—*Mangrove-Marsh Ecotone Field Methods* (SFCN 2019). The general types of data to be collected and their purpose are briefly described here.

On ground collection method

Each marker point is considered to be the middle point of a 5 meter stretch of ecotone bisecting a 5 × 10 meter (16.4 × 32.8 ft) rectangle. The marsh side and mangrove side each fill a 5 × 5 meter (16.4 × 16.4 ft) plot. Nine photographs are taken at the marker point with the first picture of the datasheet identifying the marker point number. Then take four photos of the marsh side of the ecotone, followed by four photos of the mangrove side, providing a panoramic view of the ecotone. In each 5 × 5 meter (16.4 × 16.4 ft) plot, overall canopy cover is visually estimated to the nearest 5%, canopy

height is visually estimated to the nearest meter, and all species are identified and cover for each species is visually estimated to the nearest 1%.

Canopy cover is recorded as absolute total canopy cover of all species and then absolute vegetated canopy cover of trees, shrubs and herbs and then absolute species cover for each tree, shrub, and herbaceous species. Vegetation cover is the absolute percent area occupied by vegetation, regardless of species. Tree cover is the absolute percent area occupied by trees, regardless of species. Absolute percent cover of an individual species is evaluated as the total cover of the species, ignoring the presence of other species.

Specific steps:

Step 1. On the mangrove side of the ecotone estimate the absolute total percent vegetated cover to the nearest 5 %.

Step 2. Estimate absolute percent cover for trees, shrubs, and herbs to the nearest 5%. Note that the total of % tree + % shrub + % herbs can be greater than 100%, although this is not common in these communities.

Step 3. Estimate the absolute percent cover of each tree species, shrub species, and herb species to the nearest 1%. The purpose is to provide a rapid assessment of the vegetation community and an exhaustive search and recording of species with less than 5% cover is not expected or assumed. Note that the sum of the absolute percent cover of each individual tree species can be greater than the total absolute cover for trees recorded in Step 2, and similarly for shrub species and herbaceous species, as species canopies can overlap (typically minimal in these communities).

Step 4. Repeat steps 1–3 for the marsh side of the ecotone.

Data collected via helicopter hovering is restricted to a two dimensional view from above and accurately estimating absolute cover in thick, highly overlapping canopies is not possible. However, the communities being investigated in this protocol tend to have limited overlapping structure and the difference in estimates between hovering and ground is expected to be minimal. These estimates will still provide useful information with respect to what vegetation communities are on either side of the ecotone. Thus the researchers estimating via helicopter are instructed to record absolute percent cover to the best of their ability as well as ensure that the method of collection (“hover”) is recorded.

Hovering helicopter collection method

The preference is to collect field data on the ground. However, this may not be possible to safely accomplish at all sites. The detailed methods for collecting data from a hovering helicopter are found in SOP 5—*Mangrove-Marsh Ecotone Field Methods* (SFCN 2019). The submeter GNSS circular, external antenna is mounted on the dashboard of the helicopter. The distance from the middle of the antenna to the outside edge of the helicopter passenger side skid is measured to be later added to the GPS point correction. When arriving at the general vicinity of the marker point in the field, the botanist (positioned in the front passenger side seat) guides the pilot to align the passenger side skid over the nearest ecotone edge.

Depending on wind direction, the helicopter can either be positioned over the mangroves or the marsh, as long as the passenger skid is aligned with the ecotone edge. A compass bearing is taken recording the direction of the front of the helicopter (direction of travel). The pilot is then instructed to hover the helicopter over the ecotone edge for 30 seconds while the botanist takes the GPS mark, averaging the GPS unit for 30 seconds. When the GPS mark has been recorded, vegetation data and pictures (one picture of the datasheet and then four pictures of the marsh habitat and four pictures of the mangrove habitat) are taken. Canopy height is estimated by taking a reading of the helicopter altimeter and subtracting the estimated distance from the helicopter skid to the top of the plot canopy.

Depending on the direction of the helicopter, vegetation data are recorded for either the marsh or mangrove side of the ecotone mark. While the botanist records the vegetation data, a second biologist sitting in the back passenger side seat takes pictures of the habitat. The pilot is then instructed to turn the helicopter 180 degrees so the botanist can record the vegetation data for the other side of the ecotone mark (if marsh vegetation was recorded first, then mangrove data is recorded after repositioning the helicopter). Pictures are taken of the vegetation on this side of the ecotone mark as well.

Re-Digitization and New Field Site Visits

Every 10 years the newest available aerial imagery, no more than 24 months old, with a spatial resolution of 1 meter (3.2 ft) or better and a position accuracy of ± 3 meters (9.8 ft) or better is acquired. The segment ecotones are redigitized by starting at the segment edges (oriented roughly orthogonal to the ecotone) and digitizing across the 3-kilometer segments. Previously digitized ecotone lines are not shown to the digitizer to avoid biasing the final result. After digitization, new marker points are estimated in GIS and Network field staff fly to these by helicopter (or navigate by airboat or hiking), and repeat the field marker point establishment and field measurements described above.

Data Processing, Analysis, & Reporting

Overview of Data Life Cycle

The mangrove-marsh ecotone monitoring data life cycle is described in Figure 10, and Table 2 provides an overview of the file storage locations and naming conventions of mangrove-marsh ecotone monitoring data.

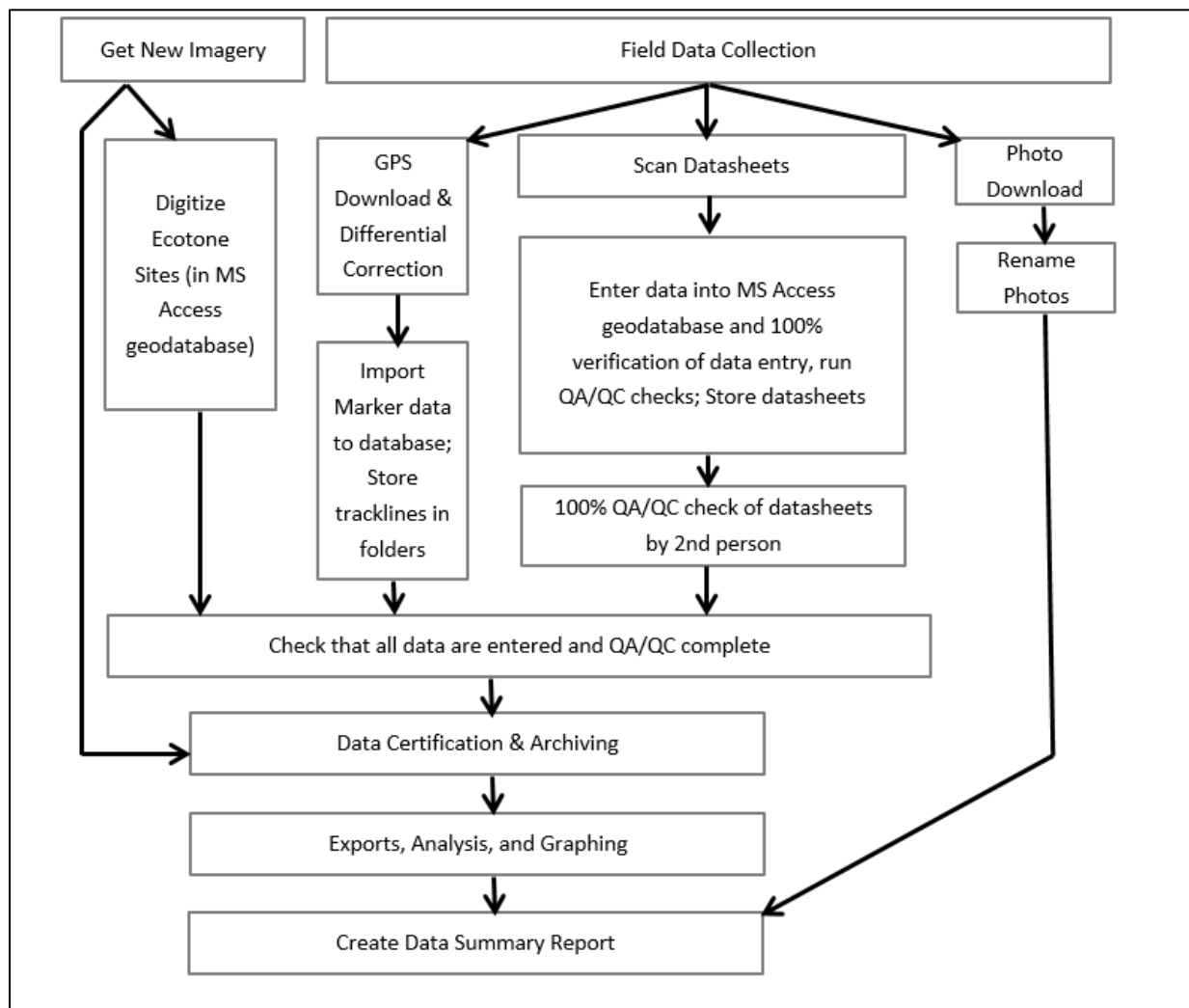


Figure 10. Mangrove-Marsh Ecotone monitoring data life cycle.

Table 2. Mangrove-Marsh Ecotone monitoring storage locations for SFCN datasheets, photos, video, data, analysis scripts, exports, and reports. “...” represents Z:\SFCN\Vital_Signs\Mangrove_Marsh_Ecotone\.

Type	File Type	Folder	Filename
Field Files	Blank Marker Point Datasheet	...\documents\field_documents\datasheets\	Mangrove_Marsh Ecotone_Marker_Datasheet_v16.docx
	Marker Point Datasheet Maps		EcotoneProjectMarkerDatasheet.mxd
	GIS-derived Marker Points	...\spatial_info\marker_points\GIS\	YYYYMMDD_Region_point.shp
	Submeter GNSS Marker Points	...\spatial_info\marker_points\GPS\YYYYMM	YYYYMMDD_Region.ssf
	Handheld GPS Unit Tracklines	...\spatial_info\tracklines\	YYYYMMDD_Region_trackline.shp
Data	Scanned Data Sheets	...\data\scanned_datasheets\YYYY\	YYYYMMDD_TYPE.pdf
	Photos - Datasheet	...\images\YYYY\LocationID_YYYYMMDD\	PARK_YYYYMMDD_Segment Code and Point_datasheet.jpg
	Photos - Plot	...\data\Z:\GIS\PARK\images\	PARK_YYYYMMDD_Segment Code and Point_direction.jpg (direction=marsh, right, mangrove, left)
	Photos - Other	...\data\Z:\GIS\PARK\images\	PARK_YYYYMMDD_Segment Code and Point_description.jpg (description=word or phrase to describe the image)
	Database Aerial Imagery	...\data\Z:\GIS\PARK\images\	SFCN_Mangrove_Marsh_Ecotone.mdb
Reports	Exports	...\data\Exports\csv\	qry_R_Marker_StrataPercentCover.csv qry_R_Marker_SpeciesPercentCover.csv qry_R_SpeciesList.csv
	Analysis Scripts	...\analysis\scripts\	–
	Status and trends Reports	...\documents\summaries_reports\YYYY	Mangrove_Marsh_Ecotone_Report_YYYY.docx
Other	Protocol	...\protocol\	SFCN_Mangrove_Marsh_Ecotone_Protocol.pdf
	Backup Templates, Datasheets, Scripts	...\protocol\backups\	–
	Archives (Database, Protocol, Reports, Export Flat Files)	http://irma.nps.gov	(see above; add _YYYY as needed)

Overview of SFCN Mangrove-Marsh Monitoring Databases

The mangrove-marsh ecotone monitoring database (SFCN_Mangrove_Marsh_Ecotone.mdb) was designed using the Natural Resource Database Template (NRDT) format as a guide in Microsoft Access. Implementation of any future changes to the database will follow published IMD (Inventory and Monitoring Division) database standards. The current design of the database is shown in (Figure 11).

This database contains all GIS and field data including:

- GIS data prior to field work.
 - Digitized ecotone lines.
 - GIS-derived marker point locations.
- GPS field data.
 - Field collected coordinates for each marker point (these will be consolidated from individual field downloads).
 - Tracklines for each marker point visit (these assist future field work logistics; e.g. tracklines can show where the helicopter was able to land and which airboat trails were navigable).
- Field data.
 - Marker point data.

Field Data Processing and Data Entry

Several steps occur as soon after a field assessment as possible to reduce risk of data loss. This pre-data entry processing consists of downloading GPS units, scanning all datasheets, and downloading any photos taken (SOP 6—*Mangrove-Marsh Ecotone Data Processing and Entry* [SFCN 2019]). Mangrove-Marsh Ecotone monitoring storage locations for SFCN datasheets, photos, video, data, analysis scripts, exports, and reports are stored and given specific naming conventions (Table 2).

Data entry will be conducted within two weeks after completing the field assessment while details from the data collection remain vivid in the minds of the researchers. All data from field datasheets will be entered into the Mangrove-Marsh Ecotone Monitoring Access database (SFCN_Mangrove_Marsh_Ecotone.mdb). This Access database has been designed with marker point field datasheet entry forms that resemble field datasheets to ensure more efficient data entry (SOP 6—*Mangrove-Marsh Ecotone Data Processing & Entry* [SFCN 2019]). New GPS marker point locations must be appended into the database first to allow data entry.

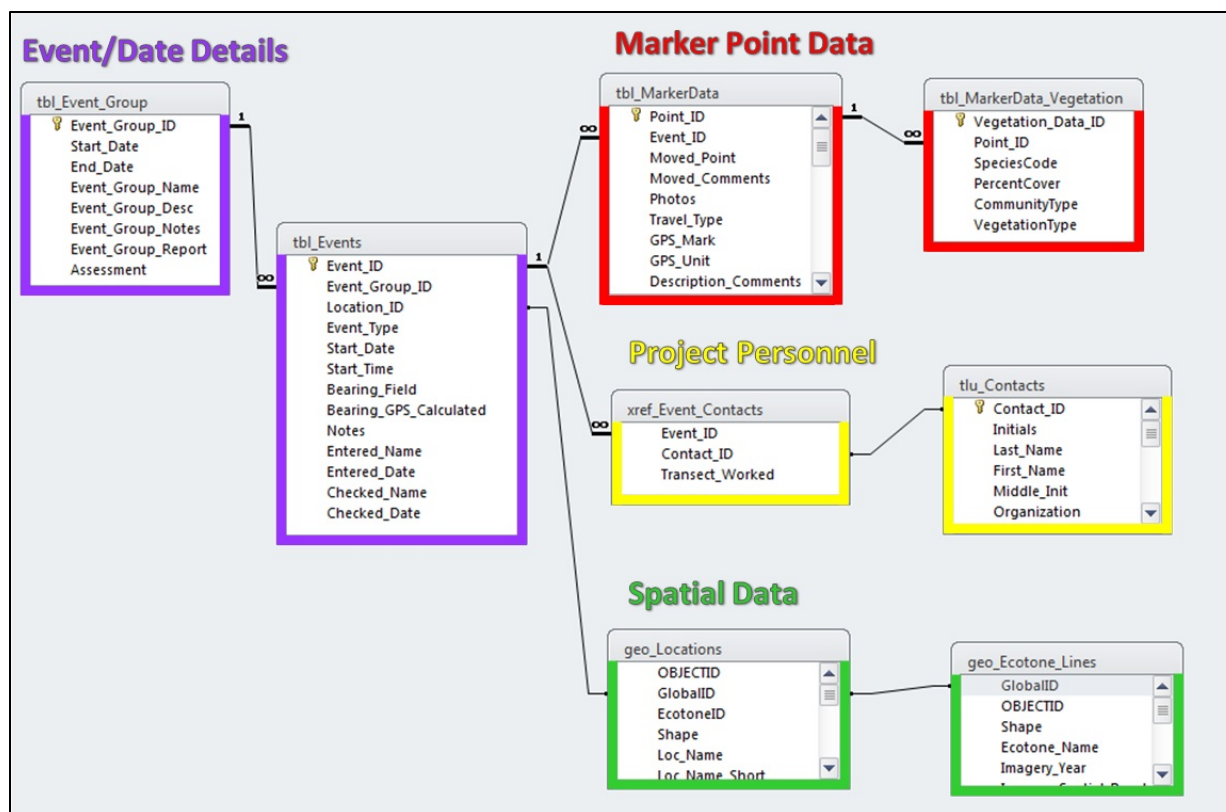


Figure 11. Overview of Mangrove-Marsh Ecotone monitoring database design.

QA/QC Procedures

Quality Assurance/quality Control (QA/QC) evaluations are done at several levels depending upon the type of data generated. The database has automated checks built-in such as a restricted list of species codes that will display a message if the species is not on the list and will take the user to a new form where they can add a new species. Lookup lists for assessments, park unit, site names, and other fields are used where appropriate.

Training

- A subset of lines from the previous sampling event will be re-digitized by the primary digitizer and error calculated to ensure digitizing is done consistently between the two sampling events.

Verification and validation

- When the digitized lines from the current time step are complete, they are reviewed by the Botanist or Community Ecologist as a verification that all segments have been digitized and that decision rules and procedures were followed as described in the protocol. Two randomly selected segments are digitized by a second person using the same imagery and used to check for variance among digitizers and validate that decision rules and procedures were followed. The results of this QA/QC are reviewed by the Community Ecologist. At their discretion partial or complete segments may need to be redigitized.

Field estimation

- One field technician (usually the botanist) estimates the ecotone location and confirms with a second technician.
- One field technician (usually the botanist) estimates percent cover of vegetation, and confirms with a second technician.
- As a QA/QC check, during the course of the sampling season, one segment will be randomly selected and all four marker points will be re-visited (7% of field sampling effort). Ecotone location and vegetation cover are sampled as described above and compared with the results collected by the first field team. If large differences between the teams occur, then that may indicate differences in the application of procedures during field data collection. The choice to only revisit marker points on a single randomly chosen segment was made to keep helicopter costs at a minimum.

Written data from datasheets (such as marker point data) receive the following QA/QC checks:

- 100% verification of entered data by having a second individual compare the records to the original datasheets. If the 100% checks yield errors, these are reviewed by the botanist who determines if there is a systematic problem that must be addressed with training; or whether data entry must be redone for the site.
- Verification that data are entered for all marker points monitored.

Accuracy check of digitized lines using field data points

- Nearest distance between digitized line and each field marker point is measured in ArcGIS and used to estimate accuracy of digitized linework.
- Differences between marker point data and digitized line data are evaluated for patterns (e.g., large differences between the marker points and the digitized line that may indicate changes since the imagery was taken or some difference in application of procedures that was occurring either in field data collection or in line digitization).

More details of QA/QC procedures are listed in SOP 7—*Mangrove-Marsh Ecotone Quality Assurance and Quality Control Procedures* (SFCN 2019) and in Appendix D—*South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring Protocol: Data Quality Standards*.

Estimating Error of the Digitized Lines with Field Data

The GPS locations of the marker points are used to ground truth the digitized segments. The shortest distances between the new digitized segment and the field marker points is measured and is used to estimate the overall accuracy of the segment and all segments in a region.

Basic Metrics Reported

The basic summary metrics reported for the mangrove-marsh ecotone include:

- Single visit metrics
 - Map showing location of the ecotonal lines through time.
 - Accuracy of linework vs. ground marker points and documentation of any segments that required re-digitization based upon field work.
 - Absolute percent cover by tree, shrub, and herb strata (marsh side; mangrove side) at marker points.
 - Compositional data of all segments (mangrove side and marsh side) with absolute percent cover reported for all species identified.
- Additional metrics after two or more visits calculated by segment, region, and entire ecotone:
 - Area and number of polygons of change upslope, area and number of polygons of changes downslope, total area of change (upslope change – downslope change)
 - Nearest Neighbor Directional Distance between the two digitized lines with upslope being positive and downslope being negative (mean, minimum, maximum, standard deviation, and standard error of distance of change).

A transgressing ecotone movement (moving upslope, marsh-wards) is treated as positive distance (+) and regressing ecotonal movement (moving downslope, seaward) is treated as negative distance (-).

Recommended Methods for Analyses

Detailed steps for data analyses are provided in SOP 8—*Mangrove-Marsh Ecotone Data Analysis and Reporting* (SFCN 2019).

The polygons of area change between the digitized lines at Time1 and Time2 and the average nearest neighbor directional distance of change can be analyzed at the regional level and at the multi-park (all segments) level using a t-test to determine if the average change is significantly different from zero.

At the individual segment level, a 95% confidence limit of the nearest neighbor directional distance can be used to determine if the confidence interval contains zero, suggesting there is no movement of the ecotone (i.e., a one-sample t-test for whether the mean is zero). An effective sample size of $n=30$ will be used in the tests as the nearest neighbor method generates greater than 1,000 points and errors from points close in space are likely correlated. The average difference and variance of the differences is calculated based upon the 1,000 plus points but the degrees of freedom used to calculate the confidence interval are based upon 30 sample points ($df = 30 - 1 = 29$). The reduced sample size assumes that errors from points approximately 100 m apart are uncorrelated.

A significant change between the lines detected via the nearest neighbor method must be interpreted in context of the the average distance associated between the digitized line and the field, i.e., if there is a consistent bias in the field versus the digitized line that is greater than or equal to the average

distance between the two lines using the nearest neighbor method, then there is no change even if the directional distance metric is statistically significant.

Detailed steps for mangrove-marsh ecotone monitoring data analyses are provided in SOP 8—*Mangrove-Marsh Ecotone Data Analysis and Reporting* (SFCN 2019).

Status and Trends Report

The status and trends report will summarize results from ecotonal monitoring from a single sampling event, show change from previous sampling events, and synthesize other research and data on important stressors. The status and trends report is completed six months after project fieldwork is completed. Ancillary data and information such as hurricane impacts, sea-level rise, hydrological inputs, restoration activities, fires, and related research are included to assist interpreting the spatial and temporal pattern of ecotone change. Detailed steps for the status and trends report are provided in SOP 8—*Mangrove-Marsh Ecotone Data Analysis and Reporting* (SFCN 2019). A sample status and trends report for the Mangrove-Marsh Ecotone monitoring protocol can be found in SOP 14—*Mangrove-Marsh Ecotone Monitoring Status and Trends Report Template* (SFCN 2019). Status and trends reports will be published in the [NPS Natural Resource Report Series](#) and will require peer review. Once the status and trends report has received its report number, the report will be uploaded to [Integrated Resource Management Applications \(IRMA\) Data Store](#), linked to the SFCN webpage, and copies or links sent to resource management staff in Everglades National Park and Big Cypress National Preserve as appropriate. A resource brief will accompany the data report.

Data Certification and Archiving

Secure data archiving is essential for protecting data files from corruption. Several different types of archiving are involved with this protocol; they are summarized in Table 3.

Table 3. File types and method of archiving.

File Type	SFCN Server Folder	IRMA Data Store
Datasheets	X	X
Photos	X	X
Digitalized Shapefiles	X	X
Database	X	X
Protocol	X	X (upon publication)
Analysis scripts	X	X
Status and trends reports	X	X (upon publication)

Data certification and archiving for these files starts once the community ecologist and the data manager have confirmed that the appropriate QA/QC procedures for the current year's data are complete. This is expected to be in January or February following a sampling event. At this point, the network data manager updates the certification level of the data. if a quality assurance plan (QAP)

exists, then the data can be set to “certified”. If no QAP exists, then the data can be set to “accepted”. The following files are then uploaded to IRMA Data Store and made available to the public: database, shapefiles, scanned datasheets, photos, protocol, and associated analysis scripts. Upon publication of the status and trends reports, PDF versions are stored on the server and loaded to IRMA Data Store and made available to the public. Backup copies of the server data are maintained at the South Florida office and periodic backups are sent to the Inventory and Monitoring Division (IMD) office in Fort Collins, Colorado.

Detailed steps are provided in SOP 11—*Data Archiving Procedures* (SFCN 2019). For further detail of the archiving procedure, please refer to the [SFCN Data Management Plan](#). Physical datasheets are stored in the SFCN conference room in three-ring binders on the mangrove-marsh ecotone shelf.

Protected Data

Park resource managers may require protection of information when releasing that information could result in harm, theft, or destruction of a resource considered endangered, threatened, rare, or commercially valuable. The South Florida/Caribbean Network is not aware of any sensitive data that require special attention in this protocol. The network will consult with Everglades National Park and Big Cypress National Preserve to determine if park management feels any information associated with this protocol requires protection from public release. The South Florida/Caribbean Network will restrict access to such data at the parks’ direction.

Metadata Procedures

Metadata (such as date, location, observers) for each event are stored within the database. Metadata for the spatial location of mangrove-marsh ecotone monitoring marker points are stored with each shapefile. Overall metadata for the database and database field definitions will be maintained.

A Federal Geographic Data Committee (FGDC) compliant metadata file is maintained that requires minimal updates and will accompany exports in response to data requests.

For further discussion concerning metadata requirements please see section 8.3 of the [SFCN Data Management Plan](#).

Analysis and Review of Effectiveness of Sampling Design

The ability of the sample design to detect change will be reassessed after the second assessment of the mangrove-marsh ecotone monitoring project (10 years).

Specimens

Plant specimens (typically an unidentified species or rare species) are not collected in the field, but are photographed with fieldsheet notes describing the location where the plant was found, including coordinates, and descriptions about the plant and the habitat in which it was found. The specimen is identified using plant species keys and by consultation with local experts.

Revising the Protocol

The protocol is a living document and changes will be ongoing, especially with regards to changes in technology. Changes will be made and tracked as described in SOP 12—*Revising the Protocol*

(SFCN 2019). Standard operating procedures and the entire document will be versioned and each will have a revision log to track versions. Upon each protocol revision, the protocol will be uploaded to IRMA and linked to via the SFCN web page.

Personnel Requirements and Training

Roles and Responsibilities

The following personnel are involved in the Mangrove-Marsh Ecotone Monitoring Program: South Florida/Caribbean Network community ecologist, botanist, field crew member (biological technician), data manager, and assistant data manager.

The SFCN community ecologist has final responsibility for implementation of the protocol and products produced but may delegate the day-to-day project lead responsibilities to the SFCN Botanist. The SFCN community ecologist and botanist will work together to ensure the smooth operation of this protocol.

This protocol requires the identification of a variety of native and non-native plant species in South Florida. To accomplish this goal, a trained botanist and a biological technician make up the field crew. Each team member must be properly trained and competent in their respective duties. The data manager, in cooperation with the community ecologist and the botanist, oversees the database design, building in adequate quality assurance/quality control procedures, and maintaining data security and archiving.

Personnel assigned to data collection, analysis, and storage shall be properly trained in the procedures relevant to the assigned tasks. Responsibility of proper adherence to procedure, including quality assurance and quality control, rests with all pertinent personnel. Rules and regulations applicable to the performance of these tasks shall be observed. Nothing in this protocol is implied or meant to imply deviations from established federal, departmental, or local safety rules and regulations applicable to the performance of assigned tasks. It is the responsibility of each individual to be familiar with such rules and regulations.

Botanist

For this protocol, the South Florida/Caribbean Network botanist must have a comprehensive knowledge of South Florida flora. If directed by the community ecologist to be project lead, the botanist is responsible for coordinating all aspects of the project, including field work, data management, and analysis/reporting under the oversight of the community ecologist. Experience should include vegetation-based work with a deep knowledge of the plants of South Florida and/or equivalent college course work with a concentration in botany, plant science, or biological science with an emphasis on South Florida plants. Knowledge of Everglades National Park and Big Cypress National Preserve is imperative in order to facilitate field visits to marker points by helicopter, airboat, or hiking.

Specific responsibilities of the botanist include:

- Obtain and maintain Resource Helicopter Manager Training (S-372) and Water Ditching (A-325).
- MOCC—Motorboat Operator Certification Course for boat operator.
- MOCC—Airboat Safety Module for airboat operator.

- Ensure sites are sampled in a timely fashion according to the ten-year schedule.
- Work with the data manager to acquire imagery.
- Work with the data manager to ensure training of digitizers.
- Digitization of ecotone segments (botanist either digitizes or directs a field crew member or intern).
- Develop field schedule for collecting marker point data.
- Acquire the appropriate permits and/or permission of Everglades National Park's Wilderness Committee. In the case of Big Cypress National Preserve, field forms and Wilderness Area Access forms will need to be filled out and submitted to preserve resource management. See SOP 15—*Big Cypress Field Forms and Wilderness Area Access Process*.
- Prepare, repair, and/or purchase equipment.
- Prepare database for the field season (review species lists, add crew members names, etc.).
- Arrange and/or conduct field crew training.
- Oversee field crew during field season.
- Identify plants accurately and process unknown plant pictures for later identification.
- Ensure work meets the desired standards of quality.
- Ensure effective communication between park staff, field crew, and other SFCN staff.
- Review and revise monitoring protocol and standard operating procedures as needed.
- Ensure proper data QA/QC and data archival procedures are followed.
- Data analysis and report writing.

Community Ecologist

The South Florida/Caribbean Network community ecologist is ultimately responsible for ensuring the successful implementation and reporting of the monitoring protocol. The community ecologist is responsible for big picture oversight of the project, establishing and refining annual and seasonal budgets, reviewing the field plans, assisting in pre-field training, assisting with fieldwork, reviewing QA/QC results, ensuring all checks are complete, certifying or validating the data, and assisting in writing and reviewing the final status and trends report. The Community Ecologist must have extensive training and experience in designing, conducting, and reporting ecological research, preferably with experience in South Florida and with a strong interest or experience in forest or wetland ecology and/or natural resources.

Specific responsibilities of the Community Ecologist include:

- Obtain and maintain Resource Helicopter Manager Training (S-372) and Water Ditching (A-325).
- MOCC—Motorboat Operator Certification Course for boat operator.
- MOCC—Airboat Safety Module for airboat operator.
- Check digitized linework.

- Assist or conduct field crew training with Botanist.
- Assist with fieldwork.
- Ensure work meets the desired standards of quality.
- Work with Data Manager to accept/certify data.
- Ensure effective communication between park staff, field crew, and other SFCN staff.
- Review and revise monitoring protocol and standard operating procedures as needed.
- Ensure proper data QA/QC and data archival procedures are followed.
- Data analysis and status and trends report writing and review.

Field Crew Member

The field crew member will be responsible for ecotone line digitization, data collection in the field, and data entry into the project database and will work closely with the botanist. Field crew members may be employees, interns, or students with a strong interest in forest ecology and/or natural resources. Crew members selected to collect vegetation information must have at least one year of vegetation-based work experience and will be trained in the identification of trees, herbs, and graminoid plants of South Florida. Crew members selected to collect GPS coordinates must have prior experience accurately collecting submeter coordinates, and will be trained in the specifics of using a submeter GNSS receiver.

Specific tasks that the crew members will be responsible for include:

- Digitize ecotone lines using aerial imagery.
- Complete mandatory training. This includes Basic Aviation Safety (A-100) and Water Ditching (A-325).
- Collect accurate coordinates using a submeter GNSS receiver as described in the standard operating procedures.
- Identify plants accurately and collect vegetation data accurately as described in standard operating procedures.
- Ensure field work meets the desired standards of quality.
- Enter data accurately into the project database either in the field or from paper data sheets.
- Ensure all necessary equipment is assembled, clean, and functional prior to and after each sampling trip.

All members of the field crew must have the ability to navigate with map, compass, and GPS. Crewmembers must be physically fit and able to work in adverse environments. This includes working in extreme heat and cold, and in the presence of biting/stinging insects and poisonous plants.

Prior to each field season the field crew member must work with the botanist to ensure that they fully understand the protocol. Field crew training involves careful review and discussion of all standard operating procedures. Specific topics covered during training are detailed in SOP 1—*Mangrove-*

Marsh Ecotone Preparation and Equipment Check (SFCN 2019) and SOP 10—*Using Trimble Geo 7X GPS Unit* (SFCN 2019).

Data Manager and Assistant Data Manager

The data manager will be responsible for providing database training to the Botanist and field crews and will also ensure that all individuals involved in the project are aware of their data management responsibilities. The data manager will be responsible for providing database assistance and GIS support as needed. Some tasks, such as GPS training, may be assigned to the assistant data manager. Specific tasks that the data manager will be responsible for include:

- Create, update, and maintain the structure and functionality of the mangrove-marsh ecotone monitoring database.
- Ensure that the mangrove-marsh ecotone monitoring database is compliant with published IMD (Inventory and Monitoring Division) database standards.
- Provide submeter GNSS receiver training and support.
- Provide database and GIS training and support.
- Coordinate data archival procedures.

Training

Line Digitization

Digitizers are initially trained by repeating the steps to digitize the ecotone line for the previous sampling event. A subset of at least three segments are digitized for training purposes (Figure 12). One segment will be dominated by abrupt ecotone edges (e.g. Segment 11), one will be a mixture of abrupt and gradual transitions (e.g. Segment 04), and one will be comprised of predominately gradual transitions (e.g. Segment 13) (Figure 12). Based on pilot work suggested segments are 11, 13, and 04.

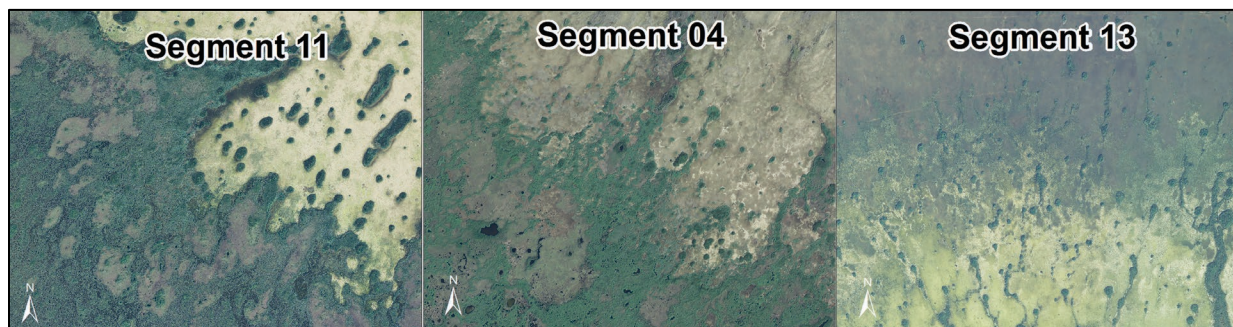


Figure 12. These segments are used for line digitization training. Segment 11 exhibits abrupt ecotone edges (left photo). Segment 04 exhibits a mixture of abrupt and gradual transitions (middle photo). Segment 13 exhibits gradual transitions (right photo).

Another subset of two randomly selected segments are digitized if the first three segments do not meet the minimum requirement of an average of less than 7 meters (23.0 ft) from the previously digitized segments. Training will use the same imagery that was used for the official line. Trainees

will not have access to the official line during the digitizing process. When complete, the distance between the official line and the trainee's line will be measured using the nearest neighbor analysis approach in SOP 4—*Analysis of Area between Two Digitized Lines* (SFCN 2019). The average of these distances must be less than 7 meters (23 ft) before they can begin digitizing current imagery.

Digitizers may have questions as to the actual location of the ecotone (ecotone location may not be clearly detected in the aerial imagery). For these areas a helicopter flight may be scheduled (if time and resources permit) to scout the ecotone and a series of flight paths and GPS points may be used to guide the digitizers in locating the ecotone.

Field Methods

Personnel must thoroughly review this protocol before implementing procedures. An important step to maximize field efficiency is to properly train assistants. Field assistants must be familiar with the plants and the study area, and understand the correct methods for collecting and recording the data. These technicians need not be experts in South Florida flora, but it is crucial that they have the ability to differentiate species in the field, and be experienced in doing so either as a result of academic training or professional experience. For learning the flora, there is no substitute for a strong interest and desire to learn on the part of the trainee and the opportunity to learn by performing ecological fieldwork. They must also have a thorough understanding of the safe and proper use of equipment, and thoroughly understand the rationale of the study so that in the absence of the Botanist or Community Ecologist, they can make an informed decision when an unexpected situation arises.

Prior to the start of the field season, a training session will be conducted on the proper method of identifying the ecotone, filling out the datasheet, estimating species cover, and using the sub-meter GNSS receiver to collect coordinates. A training exercise in a nearby park (Biscayne National Park or Everglades National Park) will be scheduled to conduct this training.

Identifying the ecotone—training will be conducted in the field, preferably in a mangrove-marsh ecotonal setting, where the trainees will start in the marsh habitat and walk toward the ecotone. Personnel will be trained on identifying a gradual ecotone where open marsh gives way to a point where mangrove cover equals 50% cover and an abrupt mangrove ecotone where an open marsh is replaced by sudden mangrove cover of near 100% .

Filling out the datasheet—during field training the trainees will be instructed in filling out datasheets while in a field setting. This also serves as training for estimating vegetation cover by stratum and by species. The trainees will start with the marsh habitat and measure out a 5 × 5 meter plot and first estimate overall vegetation cover for the plot. Next, the tree stratum for the marsh is estimated and then estimated by tree species. This process is repeated for the shrub and then the herb layers within the marsh habitat plot. The process is then duplicated for the mangrove side of the ecotone. Canopy height training includes use of a telescoping height pole to orient trainees on height estimation. A person near 1.8 meters (5.9 ft) in height can be used in the field to estimate heights. An example would be that shrub height is one and a half times taller than the 1.8 meter tall person, arriving at an estimated height of 2.7 meters (8.9 ft). In many cases, when doing actual fieldwork (not training fieldwork), the helicopter has no other option than to land close to where field measurements are

made or, in some cases, the pilot will need to keep the helicopter powered up to keep the helicopter from sinking into a soft substrate, rendering the use of a telescoping height pole too risky. The telescoping height pole can be used when fieldwork is done by airboat or walk-in sites.

Using a submeter GNSS receiver to collect ecotone coordinates—training for use of the GNSS receiver can take place anywhere outside the office building and includes setting up the unit, turning on the unit, creating and then opening a data collection file, averaging point coordinates, filling in required attributes, and placing the GPS in sleep mode while traveling between sites.

Before using the helicopter hover method to collect marker point coordinates, the technique must be practiced with each new pilot and SFCN crewmember. This involves scheduling a short flight, selecting points on the tarmac, collecting GPS coordinates at these points on the ground, collecting GPS coordinates from a hover at a height of 15.2 meters (50 feet), and comparing these two coordinates back in the office. Agreement between the ground and hover points must be 2 meters (6.6 ft) or less, or adjustments must be made until this threshold is reached. See SOP 13—*Methods for Testing Accuracy of Coordinates Taken From a Hovering Helicopter* (SFCN 2019).

Operational Requirements

Field Schedule and Work Load (Every 10 years)

Digitizing imagery typically occurs in fall months (September to December); however, this depends on imagery acquisition, and could take as much as a year from the time the imagery is initially flown. When the digitizing process is nearing completion, this is the time to prepare the project for review by the Everglades National Park Wilderness Committee and to fill out and submit wilderness documents to Big Cypress National Preserve (SOP 15—*Big Cypress National Preserve Field Forms and Wilderness Area Access Process* [SFCN 2019]). This Wilderness Committee review process may take three to six months for completion.

Preparation for field sampling begins when the digitizing process has been completed and after a meeting with the Everglades National Park Wilderness Committee has been scheduled (Table 4). This time is spent reviewing results from the last monitoring event, doing training exercises, and reviewing the protocol and Job Hazard Analyses. A review of the results from the last monitoring event is conducted for the researchers to familiarize themselves with access issues involved with the previous sampling event's data collection sites. If airboat or hiking are used for access, tracklines from the previous sampling event are loaded onto the GPS unit to act as survey guides for the upcoming sampling event. The botanist makes sure that all items are prepared for the field, including data sheets, cameras, GPS units loaded with the previous sampling event's tracklines and the new sampling event's marker points and digitized lines, and that appropriate vehicles are available and ready to go.

When accessing sites by helicopter, spring months (February to May) are preferable because water levels in the marsh are low. When accessing sites by airboat, the summer months (June through October), when water levels in the marsh are high, are preferable. A two person field crew is needed for monitoring ecotone marker points; the crew is usually the botanist and a field crew member. Mode of transportation for marker point assessments is mostly by helicopter; however, the airboat can be used when the helicopter is not available, if approved by the Everglades National Park Wilderness Committee. There are a few marker points that can be accessed by walking to the site.

Field work begins after all lines have been digitized and approval has been granted from the Wilderness Committee. In optimal cases, field work begins sometime in February or March and finishes around the end of September or October. These field work estimates may vary based upon helicopter availability and weather, and field work may proceed beyond October.

In October to November, data collected in the field are entered into the database and checked for accuracy (Table 4). The botanist makes sure that the data are properly entered and checked, and the community ecologist makes sure the entered data are accepted/certified before initiation of report writing. The community ecologist looks for ancillary data sets for other sources that can be included in the trend report. The data management team acquires ancillary data especially spatial data sets.

The trends report is drafted by the botanist and community ecologist with help from the data management team. Data analysis and report writing takes place from October to March (of the next

year) or within six months after completion of fieldwork if fieldwork is delayed. Upon completion, the trends report is uploaded to IRMA and the South Florida/Caribbean Network website by the data management team. The report is then distributed to personnel at Everglades National Park and Big Cypress National Preserve.

Table 4. Mangrove-Marsh Ecotone monitoring sampling event timeline and personnel tasks. *Although months are provided to give the reader an approximate estimate of the project workflow, this timeline may require adjustment for issues outside the Network's control such as time required for imagery acquisition, getting approval by Wilderness Committee, safe time of year for field work given method of access approved by Wilderness Committee, and difficulties with scheduling helicopter time if equipment becomes needed for fire-fighting.

Position	Sep-Dec task*: Acquire new imagery, digitize lines	Jan-Feb task*: Present project to Wilderness Committee, Prep for fieldwork	Feb-Oct task*: Field Sampling	Oct-Dec task*: Data Processing	Oct-Mar task*: Writing status and trends report and resource briefs
Botanist	Digitize ecotone lines; prepare project for review by the EVER Wilderness Committee; schedule meeting with the EVER Wilderness Committee; schedule training helicopter flight if necessary.	Present project to Wilderness Committee; lead crewmember field training; read JHA's; prepare datasheets and maps, load GPS units with waypoints and tracklines from last sampling event; schedule flights and prep airboat for fieldwork; invite park staff to participate in field work.	Conduct mangrove-marsh ecotone monitoring; make sure all sites are monitored; record data; take pictures as needed.	Data entry; QA/QC; Re-train or re-digitize lines if they fail QA/QC checks.	Write trends report ; write resource briefs.
Community Ecologist	Check digitized linework; plan overall strategy.	Review findings from last sampling event; assist with crewmember field training. Look for relevant ancillary data sets.	Assist with fieldwork. Look for relevant ancillary data sets.	Data verification and certification. Look for relevant ancillary data sets.	Write and review trends report; assist with writing and then reviewing resource briefs
Field Crew Member	Re-digitize ecotone lines for training; digitize ecotone lines	Assist with field preparation as needed; read JHA's; complete field training	Conduct mangrove-marsh ecotone monitoring; make sure all sites are monitored; record data; take pictures as needed	Assist with data entry & QA/QC as needed; re-digitize lines if they fail QA/QC checks	–

Table 4 (continued). Mangrove-Marsh Ecotone monitoring sampling event timeline and personnel tasks. *Although months are provided to give the reader an approximate estimate of the project workflow, this timeline may require adjustment for issues outside the Network's control such as time required for imagery acquisition, getting approval by Wilderness Committee, safe time of year for field work given method of access approved by Wilderness Committee, and difficulties with scheduling helicopter time if equipment becomes needed for fire-fighting.

Position	Sep-Dec task*: Acquire new imagery, digitize lines	Jan-Feb task*: Present project to Wilderness Committee, Prep for fieldwork	Feb-Oct task*: Field Sampling	Oct-Dec task*: Data Processing	Oct-Mar task*: Writing status and trends report and resource briefs
Assistant Data Manager	Acquire new aerial imagery	Assist with field preparation if needed; train field crews on how to use submeter GNSS receiver.	Assist with data preservation as datasheets, photos, and GPS coordinates are created during the field sampling. Assist with data collection as needed.	Complete GIS work to calculate point and line movement; assist in data analysis. Incorporate ancillary datasets.	Assist in report writing; assist with updating resource briefs and web page.
Data Manager	Assist with aerial imagery acquisition	Assist with field preparation as needed.	Assist with data preservation as datasheets, photos, and GPS coordinates are created during the field sampling. Assist with data collection as needed.	Assist with database exports, data verification and certification. Incorporate ancillary datasets.	Review finished report; publish report and update project metadata; assist with updating resource briefs and web page.

There are 56 marker points that will need to be sampled each time the protocol is implemented, plus 4 additional QA/QC points. With the helicopter, approximately 6-9 marker points per flight can be sampled; however, this number may change based on weather conditions and helicopter availability (e.g., the helicopter may only be available for half a day). With optimal conditions, 60 marker points can be monitored with eight flights. This amounts to at least eight days of field work every ten years for marker point re-surveying. If only completing 6 marker points per flight, then 10 flights will be necessary to complete the sampling (Table 5).

Table 5. Mangrove-Marsh Ecotone monitoring time estimates per sampling event. Time estimates are based on sampling 56 marker points plus 4 QA/QC points once in a 10-year sampling rotation.

Area	Duty	Time (person-days)
Field	Marker Point sampling and QA/QC (2 person crew X 10 field days)	20
	Subtotal	20
Office	Digitizing Preparation and Training	7
	Line Digitizing (1 digitizer X 28 days and 2 nd digitizer X 4 days)	32
	Field Prep and Training	20
	Field Data Entry and Data Check	10
	Data Management, Data Analysis, and Reporting	57
	Project Management (Wilderness Committee, Meetings, Communication, etc)	14
	Subtotal	140
Total Time –		160

Ecotone line digitization takes approximately twenty-eight days (two days for digitizing each segment) for one person to digitize all segments. Although each segment is 3 kilometers (1.9 mi) along the generalized ecotone, the pilot work showed that the detailed 1:500 scale linework is 3-20 times longer. Another four days are required for a second digitizer to complete two segments (Table 5). Preparation for fieldwork and field training will take ten work days per person to complete. Field training requires a trainer (Botanist and/or Community Ecologist) and a number of trainees depending on number of field helpers for a given sampling season, so this number of person days may be slightly higher or doubled (Table 5). Another 57 days is required for the two-person team to input data, check data, analyze data, and write the summary report, and for data management to assist with databases and make corrections as needed. Overall approximately 150 days are needed, over a fourteen month period, every ten years to complete this project (Table 5).

Facility & Equipment Needs

The following is a general list of equipment needed for this project:

- A vehicle from the South Florida/Caribbean Network's fleet. In some cases, one of the towing vehicles is needed to trailer the airboat. Network fleet vehicles are maintained on a regular schedule with each vehicle assigned to a specific staff member in charge of that vehicle's maintenance.
- Airboat, including boating safety equipment. Safety equipment includes personal floatation devices (PFD's), first aid kit, whistles and flares, and ear protection (such as earmuffs). The Network airboat is maintained on a regular schedule with the boat assigned to a specific staff member in charge of the airboat's maintenance.
- Field gear including datasheets, pencils, a park radio, camera, handheld GPS unit, submeter GNSS receiver and external antennae. A telescoping height pole is utilized when accessing marker points by airboat or on foot.
- Software: Microsoft Access, Microsoft Word, Microsoft Excel, Adobe Acrobat, ArcGIS 10 or higher.
- See SOP 1—*Mangrove-Marsh Ecotone Preparation & Equipment Check* (SFCN 2019) for a more detailed description of equipment.

Startup Costs and Budget Considerations

Because most of the equipment used (see above) has already been purchased for other vital signs monitoring and projects, no substantial startup costs are included here. Budget considerations include fuel and maintenance for the vehicles and airboat plus salary considerations for the Botanist, Field Crew Member, Community Ecologist, Data Manager and the Assistant Data Manager (Table 6). Helicopter flights will be the largest expense for this project and the cost in Table 6 is based on ten flights to complete the field component, with a flight being approximately two hours of flight time at \$950 a flight hour. These costs are approximate based upon initial surveys and 2017 salary estimates. Travel costs within the parks will vary depending on type of transportation used and distance. Cost of aerial imagery is not included, because it is assumed that it will likely be available within a reasonable time frame from other partners, given the large amount of monitoring and research being conducted in South Florida.

Table 6. One year cost of mangrove-marsh ecotone monitoring (based on 56 marker points plus 4 QA/QC points once in a 10-year cycle). *Note: costs are based upon 2017 salary estimates and helicopter costs.*

Expense	Expense detail	Cost
Salary	Botanist (82 days, GS-7 Step-6)	\$15,826
	Biological Technician (25 days, GS-7 Step-6)	\$4,825
	Assistant Data Manager (19 days, GS-9 Step-2)	\$3,974
	Community Ecologist (24 days, GS-12, Step 7)	\$8,458
	Data Manager (10 days, GS-12, Step 7)	\$3,530
	Subtotal	\$36,613
Transportation	Airboat (maintenance with towing vehicle cost)	\$620
	Helicopter (based on 10 flights and 2 hrs helicopter time/flight)	\$19,000
	Vehicle (when hiking)	\$120
	Vehicle Maintenance	\$500
	Subtotal	\$20,240
Equipment	Trimble Geo 7X GPS Unit (software maintenance)	\$105
	Subtotal	\$105
Total Cost		\$56,958

Safety

Before the field season, all personnel must read through the respective SOPs, Go/No Go checklists, and safety sign-out sheet associated with this protocol. They must also review and sign all Job Hazard Analyses (JHAs) associated with this protocol. These SOPs, JHAs, and the South Florida/Caribbean Network Safety Plan are located in the SFCN Safety folder on the SFCN server at Z:\Safety\.

The SOPs, Go/No Go checklists, and safety sign-out sheet associated with this protocol are located in Z:\SAFETY\SFCN_SOPs_with_JHAs\Community_operations\ and include:

- Safety_Checkout_in sheet_community_latest3.doc
- SFCN_Airboat_Go_No_Go.doc
- SFCN_Helicopter_Go_No_Go_Checklist_Mod.docx
- Vehicle Go NoGo Checklist CommunityGroup.pdf
- Community_Safety_Procedures.docx

The associated JHAs are located in Z:\SAFETY\SFCN_SOPs_with_JHAs\JHAs\Community Group JHA's\:

- JHA_Airboat.docx
- JHA_Helicopter.docx

- JHA_Hiking.docx
- JHA_Truck.docx

Users should check for updated versions in Z:\Safety\. Although every attempt will be made to keep this protocol current, it's possible for a delay to occur between updates of a Safety SOP in Z:\Safety\ and updates of this protocol.

All NPS-SFCN personnel will follow the Safe Practices Manual and Emergency Operations Plan specific to the respective park where they are operating.

In many cases, the sampling sites can only be arrived at by helicopter or airboat. Staff participating in field operations must have the following training:

- MOCC—Motorboat Operator Certification Course for boat operator
- MOCC—Airboat Safety Module for airboat operator
- Botanist and Community Ecologist will need to take A-325 Water Ditching, S-372 Resource Helicopter Manager Training and complete the task sheet for this position.
- Crew members will need to take A-325 Water Ditching, A-100 Basic Aviation Safety training and, preferably, S-271 Interagency Helicopter Crewmember Training.
- CPR/First Aid training
- Operational Leadership

The South Florida/Caribbean Network operates within a culture of safety where operational leadership principles prevail. Problems are considered proactively and each person must feel empowered to think about potential problems, speak up early, and act upon safety concerns regardless of their position. Any concerns must be addressed seriously and respectfully by management.

Nothing in this protocol is meant to imply deviations from established federal, departmental or local safety rules and regulations applicable to the performance of assigned tasks. It is the responsibility of each individual to be familiar with such rules and regulations. Personnel must follow any park-specific requirements, and any other requirements of the National Park Service not otherwise specified herein.

Literature Cited

- Armentano, T. V., J. P. Sah, M. S. Ross, D. T. Jones, H. C. Cooley and C. S. Smith. 2006. Rapid responses of vegetation to hydrological changes in Taylor Slough, Everglades National Park, Florida, USA. *Hydrobiologia* 569(1): 293–309. DOI: 10.1007/s10750-006-0138-8.
- Army Corps of Engineers (ACE). 2018. Comprehensive Everglades Restoration Plan: C-111 Spreader Canal Fact Sheet.
- Beckage, B., B. Osborn, D.G. Gavin, C. Pucko, T. Siccama, and T. Perkins. 2008. A Rapid Upward Shift of a Forest Ecotone during 40 Years of Global Warming in the Green Mountains of Vermont. *Proceedings of the National Academy of Sciences* 105 (11).
- Bellhouse, D.R. 2005. Systematic Sampling Methods. *Encyclopedia of Biostatistics*. John Wiley and Sons, Ltd.
- Carter, R.W.G. 1988. *Coastal Environments*. Academic, London.
- Carter, V., P.T. Gammon, and M.K. Garrett. 1994. Ecotone Dynamics and Boundary Determination in the Great Dismal Swamp. *Ecological Applications*, 4(1), 189–203.
- Castañeda-Moya, E., R.R. Twilley, V.H. Rivera-Monroy, B.D. Marx, C. Coronado-Molina and S.M.L. Ewe. 2011. Patterns of root dynamics in mangrove forests along environmental gradients in the Florida Coastal Everglades, USA. *Ecosystems* 14(7): 1178–1195. DOI: 10.1007/s10021-011-9473-3.
- Chambers, L.G., R. Guevara, J.N. Boyer, S.E. Davis and T. Troxler. 2016. Effects of salinity and inundation on microbial community structure and function in a mangrove peat soil. *Wetlands* 36(2): 361-371. DOI: 10.1007/s13157-016-0745-8.
- Chen, E. and J.F. Gerber. 1990. Climate. *In Ecosystems of Florida* (R.L. Myers and J.J. Ewell eds). University of Central Florida Press, Orlando, Florida.
- Choesin, D.N. 2001. Use of Landscape Ecological Analysis to Determine Ecotone Locations: An Evaluation Based on Field Data. *Journal of Management Sciences*. Vol. 6 (2).
- Choesin, D.N. and R.E.J. Boerner. 2002. Vegetation Boundary Detection: A Comparison of Two Approaches Applied to Field Data. *Plant Ecology* 158: 85–96.
- Cintron, G., Lugo, A.E., and Martinez, R. (1985). Structural and functional properties of mangrove forests. *In The Botany and Natural History of Panama* (W.G. Darcy and M.D. Correa, eds.), *Monogr. Syst. Bot.*, Vol. 10, pp. 53–66. Missouri Bot. Gard., St. Louis.
- Cowart, L., J.P. Walsh, and D.R. Corbett. 2010. Analyzing Estuarine Shoreline Change: A Case Study of Cedar Island, North Carolina. *Journal of Coastal Research*, 26(5), 817-830. West Palm Beach (Florida), ISSN 0749-0208.

- Cowart, L., D. R. Corbett, and J.P. Walsh. 2011. Shoreline Change along Sheltered Coastlines: Insights from the Neuse River Estuary, NC, USA. *Remote Sensing*. 3: 1516–1534.
- Cox, C.J., B. Li, P.G. Foster, T.M. Embley, and P. Civan. 2014. Conflicting Phylogenies for Early Land Plants are Caused by Composition Biases among Synonymous Substitutions. *Systematic Biology*. 63 (2). 10.1093.
- Dessu, S.B., R.M. Price, T. Troxler and J. Kominoski. 2018. Effects of sea-level rise and freshwater management on long-term water levels and water quality in the Florida Coastal Everglades. *Journal of Environmental Management* 211: 164–176.
- Doyle, T. W., G. F. Girod, and M. A. Books. 2003. Modeling mangrove forest migration along the southwest coast of Florida under climate change. *In* Z. H. Ning, R. E. Turner, T. W. Doyle, and K. Abdollahi, editors. Integrated assessment of the climate change impacts on the Gulf Coast Region. LSU Publishing, Baton Rouge, Louisiana.
- Duncan, C., H.J.F. Owen, J.R. Thompson, H.J. Koldewey, J.H. Primavera, N. Pettorelli. 2018. Satellite remote sensing to monitor mangrove forest resilience and resistance to sea level rise. *Methods Ecol Evol*. 2018; 9:1837–1852.
- Egler, F.E. 1952. Southeast saline Everglades vegetation, Florida, and its management. *Vegetation* 3:213–265.
- Fortin, M.J., R.J. Olson, S. Ferson, L. Iverson, C. Hunsaker, G. Edwards, D. Levine, K. Butera, and V. Klemas. 2000. Issues Related to the Detection of Boundaries. *Landscape Ecology* 15: 453–466.
- Gaiser, E.E., P. McCormick, S.E. Hagerthey and A.D. Gottlieb. 2011. Landscape patterns of periphyton in the Florida Everglades. *Critical Reviews in Environmental Science and Technology* 41(S1): 92–120. DOI: 10.1080/10643389.2010.531192.
- IPCC (Intergovernmental Panel on Climate Change). 2013. Climate Change 2013: The physical science basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, United Kingdom.
- Krauss, K. W. 2018. Personal communication in email sent 5/3/2018.
- Krauss, K. W., A. S. From, T. W. Doyle, T. J. Doyle, and M. J. Barry. 2011. Sea-level rise and landscape change influence mangrove encroachment onto marsh in the Ten Thousand Islands region of Florida, USA. *Journal of Coastal Conservation* 15(4):629–638.
- Kuenzler, E.J. 1974. Mangrove swamp systems. *In* Coastal Ecological Systems (H.T. Odom, B.J. Copeland, and E.A. McMahon, eds.), Vol. 1, pp. 346–371. Conservation Found., Washington, D.C.

- Kushlan, J.A. 1990. Freshwater Marshes. *In* “Ecosystems of Florida” (R.L. Myers and J.J. Ewell eds). University of Central Florida Press, Orlando, Florida.
- Lodge, T. E. 2005. The Everglades Handbook: Understanding the ecosystem, Second edition. CRC Press: Boca Raton, Florida.
- Lugo, A.E., M. M. Brinson, and S. Brown. 1989. Forested Wetlands. Ecosyst. World Ser. Elsevier, Amsterdam.
- Manley, W. F., and L. R. Lestak. 2012. Protocol for high-resolution geospatial analysis of coastal change in the Arctic Network of Parks. Natural Resource Report NPS/ARC/NRR—2012/537. National Park Service, Fort Collins, Colorado.
- Myers, R. and J. Ewell. 1990. Ecosystems of Florida. University of Central Florida Press, Orlando, Florida.
- South Florida/Caribbean Network. 2019. Mangrove-Marsh Ecotone Monitoring: Standard Operating Procedures. NPS/SFCN/SOP. South Florida/Caribbean Network, Palmetto Bay, Florida.
- Naja, M., D.L. Childers and E.E. Gaiser. 2017. Water quality implications of hydrologic restoration alternatives in the Florida Everglades, United States. Restoration Ecology 25(S1): S48–S58. DOI: 10.1111/rec.12513.
- Odom, W. E., and C. C. McIvor. 1990. Mangroves. *In* Ecosystems of Florida (R. L. Myers and J. J. Ewell eds). University of Central Florida Press, Orlando, Florida.
- Patterson, M. E., A. J. Atkinson, B. D. Witcher, K. R. T. Whelan, W. J. Miller, R. J. Waara, J.M. Patterson, B.I. Ruttenberg, A. D. Davis, R. Urgelles, R.B. Shamblin. 2008. South Florida/Caribbean Network vital sign monitoring plan. Natural Resource Report NPS/SFCN/NRR—2008/063. National Park Service, Fort Collins, Colorado.
- Pfeffer, W. T., J. T. Harper, and S. O’Neel. 2008. Kinematic constraints on glacier contributions to 21st century sea-level rise. Science 321:1340–1343.
- Platt, S.G., R.M. Elsey, H. Liu, T.R. Rainwater, J. Nifong, A.E. Rosenblatt, M.R. Heithaus and F.J. Mazzotti. 2013. Frugivory and seed dispersal by crocodilians: an overlooked form of saurochory? Journal of Zoology 291(2): 87–99. DOI: 10.1111/jzo.12052.
- Price, R.M., P.K. Swart, J.W. Fourqurean. 2006. Coastal groundwater discharge - an additional source of phosphorus for the oligotrophic wetlands of the Everglades. Hydrobiologia 569(1): 23–36.
- Psuty, N.P., and T. Silveira. 2011. Monitoring Shoreline Change along Assateague Barrier Island: The First Trend Report. Journal of Coastal Research 1: pp.800–804.
- Rehage, J.S., S.E. Liston, K.J. Dunker and W.F. Loftus. 2014. Fish Community Responses to the Combined Effects of Decreased Hydroperiod and Nonnative Fish Invasions in a Karst Wetland:

- Are Everglades Solution Holes Sinks for Native Fishes? *Wetlands* 34(Suppl 1): 159–173. DOI: 10.1007/s13157-012-0361-1.
- Rivera-Monroy, V. H., R. R. Twilley, S. E. Davis III, D. L. Childers, M. Simard, R. Chambers, R. Jaffe, J. N. Boyer, D. T. Rudnick, K. Zhang, E. Castañeda-Moya, S. M. L. Ewe, R. M. Price, C. Coronado-Molina, M. Ross, T. J. Smith III, B. Michot, E. Meselhe, W. Nuttle, T. G. Troxler & G. B. Noe. 2011 The role of the everglades mangrove ecotone region (EMER) in regulating nutrient cycling and wetland productivity in South Florida, *Critical Reviews in Environmental Science and Technology*, 41:sup1, 633-669, DOI: 10.1080/10643389.2010.530907
- Ross, M. S., J. F. Meeder, J. P. Sah, P. L. Ruiz, and G. J. Telesnicki. 2000. The southeast saline everglades revisited: 50 years of coastal vegetation change. *Journal of Vegetation Science* 11:101–112.
- Ross, M. S., J. P. Sah, J. F. Meeder, P. L. Ruiz, and G. Telesnicki. 2013. Compositional effects of sea-level rise in a patchy landscape: the dynamics of tree islands in the southeastern coastal Everglades. *Wetlands* 34: 91–100.
- Ross, M.S., J.P. Sah, J.F. Meeder, P.L. Ruiz and G.J. Telesnicki. 2014. Compositional Effects of Sea-Level Rise in a Patchy Landscape: The Dynamics of Tree Islands in the Southeastern Coastal Everglades. *Wetlands* 34(Suppl 1): 91–100. DOI: 10.1007/s13157-013-0376-2.
- South Florida Water Management District (SFWMD). 2010. Canals in South Florida: a technical support document. West Palm Beach, Florida.
- Smith, T. J., III, G. H. Anderson, K. Balentine, G. Tiling, G. A. Ward, and K. R. T. Whelan. 2009. Cumulative impacts of hurricanes on Florida mangrove ecosystems: sediment deposition, storm surges and vegetation. *Wetlands* 29(1): 24–34.
- Smith, T. J., III, A. M. Foster, G. Tiling-Range, J. W. Jones. 2013. Dynamics of mangrove-marsh ecotones in subtropical coastal wetlands: fire, sea-level rise, and water levels. *Fire Ecology* 9(1): 66–77.
- South Florida/Caribbean Network. 2019. South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring: Standard operating procedures. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2260146> (last accessed May 2019).
- Stephens, J.C. 1984. Subsidence of organic soils in the Florida Everglades-a review and update. In “Environments of South Florida: Present and Past II” (P.J. Gleason, ed.), pp. 375–384. Miami Geol. Soc., Coral Gables, Florida.
- Stohlgren, T.J., and R.R. Bachard. 1997. Lodgepole Pine (*Pinus contorta*) Ecotones in Rocky Mountain National Park, Colorado, USA. *Ecology*, 78(2): 632–641.

- Taylor, D.L. 1981. Fire history and fire records for Everglades National Park: 1948-1979. Report T-619, South Florida Research Center, Everglades National Park, Homestead, Florida, USA.
- Taylor, R.T. 1999. An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements. University Science Books. ISBN 0-935702-75-X.
- Teas, H. 1979. Siviculture with saline water. *In* The Biosaline Concept (A. Hollaender, ed.), pp. 117–161. Plenum, New York.
- Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, Ayhan. 2009. Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278.
- Tomlinson, P.B. 1986. The botany of mangroves. Cambridge Univ. Press, London.
- Wade, D., Ewel, J. and Hofstetter, R., 1980. Fire in south Florida ecosystems. Gen. Tech. Rep. SE-17. Asheville, NC: US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 125 p., 17.
- Webster, P. J., G. J. Holland, J. A. Curry, and H. R. Chang. 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science* 309: 1844–1846.
- Xiaoping, Zhang., D. Pan, J. Chen, J. Zhao, Q. Zhu, and H. Huang. 2014. Evaluation of coastline changes under human intervention using multi-temporal high-resolution images: a case study of the Zhoushan Islands, China. *Remote Sensing*. 6(10): 9930-9950.

Appendix A: Estimating Detectable Change Based Upon Variance Between Digitized Line and Field Marker Points of Five Index Sites

The mangrove-marsh ecotone protocol delineates the ecotone in two ways: digitized, using ArcGIS via imagery and field-marker point estimates of the ecotone edge. Digitizing lines can have variability due to the imagery used (imagery spatial error and resolution), time since imagery was acquired, and observer error. The purpose of the field marker points is to provide a ground-truthing of the digitized line. The field marker points also have error associated with the GPS accuracy and observer error. Below, we estimate the differences between the marker point locations and the digitized ecotone and use the results to estimate how much change in the digitized line will be reasonably detectable with the protocol. Digitized lines and associated marker points used during this analysis are derived from the five index sites of the pilot study (Figure A-1).

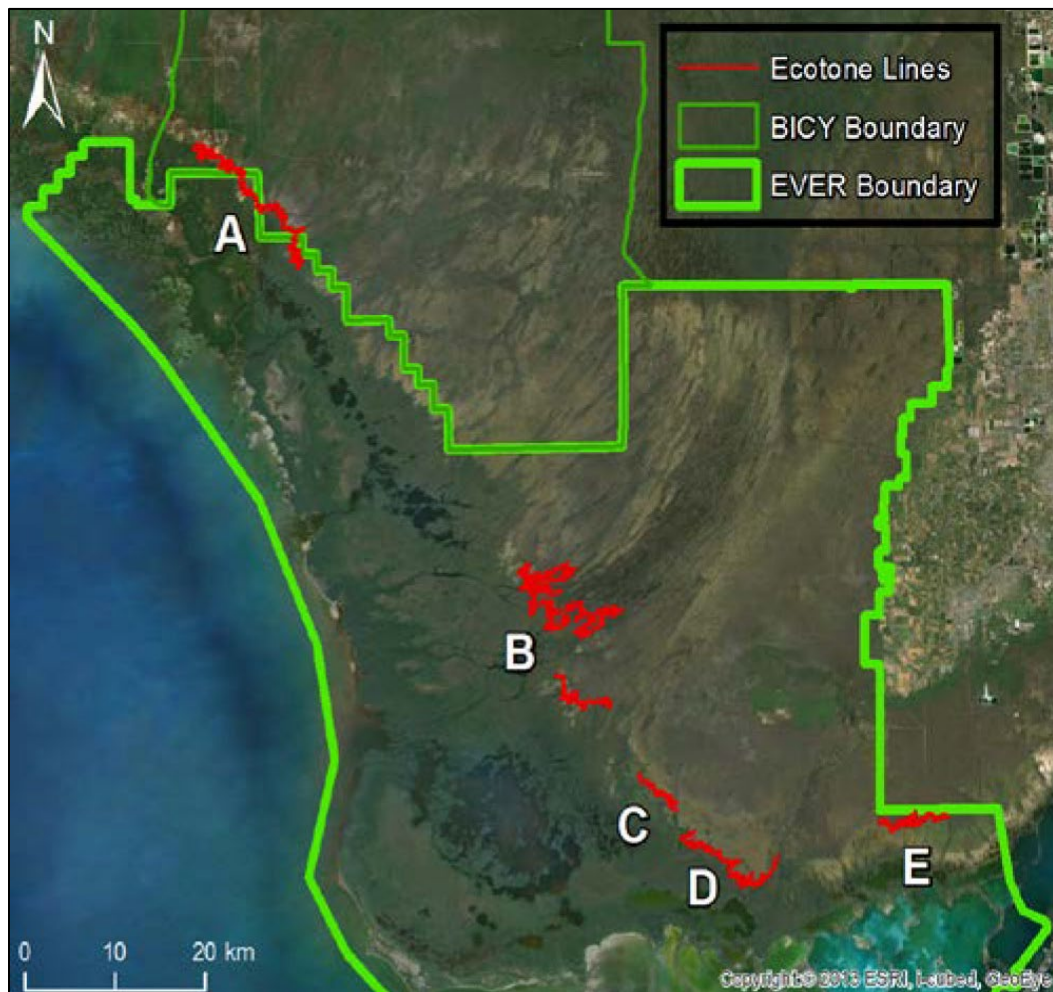


Figure A-1. Map of ecotone lines of the index sites collected during pilot study. A: Ochoppee, B: Shark Slough, C: Mahogany Hammock, D: Taylor Slough, E: Spreader Canal. Green lines represent BICY and EVER park boundaries.

Methods

Establishment of Five Index Sites

Five subjectively selected index sites were established to represent ecotonal zones of main drainage areas, or areas where restoration efforts may have an effect on future water delivery. These sites were used to test digitizing and field methods, and to perform a power analysis. The five index sites are listed below, including the justification for selecting each site.

Ochopee (Figure A-1 Area A, and Figure A-2)

This ecotone line was chosen to provide spatial balance by including a line in the northwest portion of Everglades National Park and because there is adequate access to the area. This area also serves as a main drainage area to the Ten Thousand Islands by way of the Turner River basin.

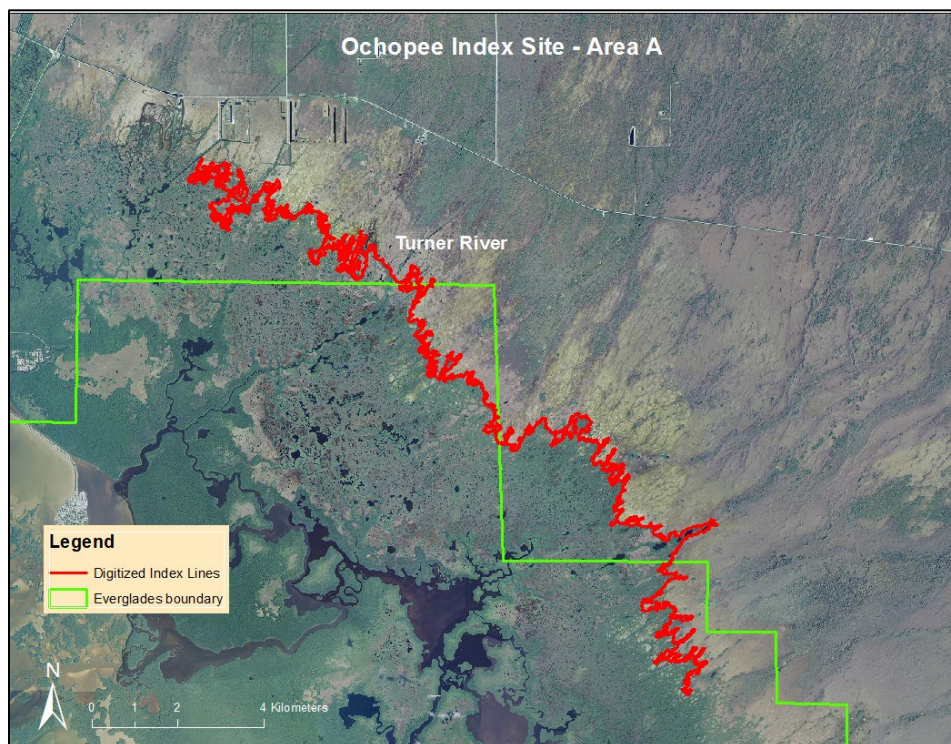


Figure A-2. The Ochopee ecotone line was chosen to provide spatial balance by including a line in the northwest portion of Everglades National Park. This area also serves as a main drainage area to the Ten Thousand Islands by way of the Turner River basin. Scale 1:80,000. 2013 NAIP imagery.

Shark Slough (Figure A-1 Area B, and Figure A-3)

This area was chosen to capture any changes in the main Shark Slough drainage area. The Shark Slough drainage area is important because it could see effects from upstream restoration projects, such as the Tamiami Trail bridge. Two segments were digitized in this area. The area north of Rookery Branch features a sharp mangrove-marsh ecotone, at many times following tidal creeks that run into the upstream marsh. The second segment is located south of Rookery Branch and also features a sharp ecotone edge between mostly dwarf mangroves and the adjacent freshwater marsh. The middle portion, located within Rookery Branch was not digitized because it was composed of

freshwater swamp tree species rather than mangroves, was an area of deeper freshwater flow, and had no clear mangrove to marsh ecotone.

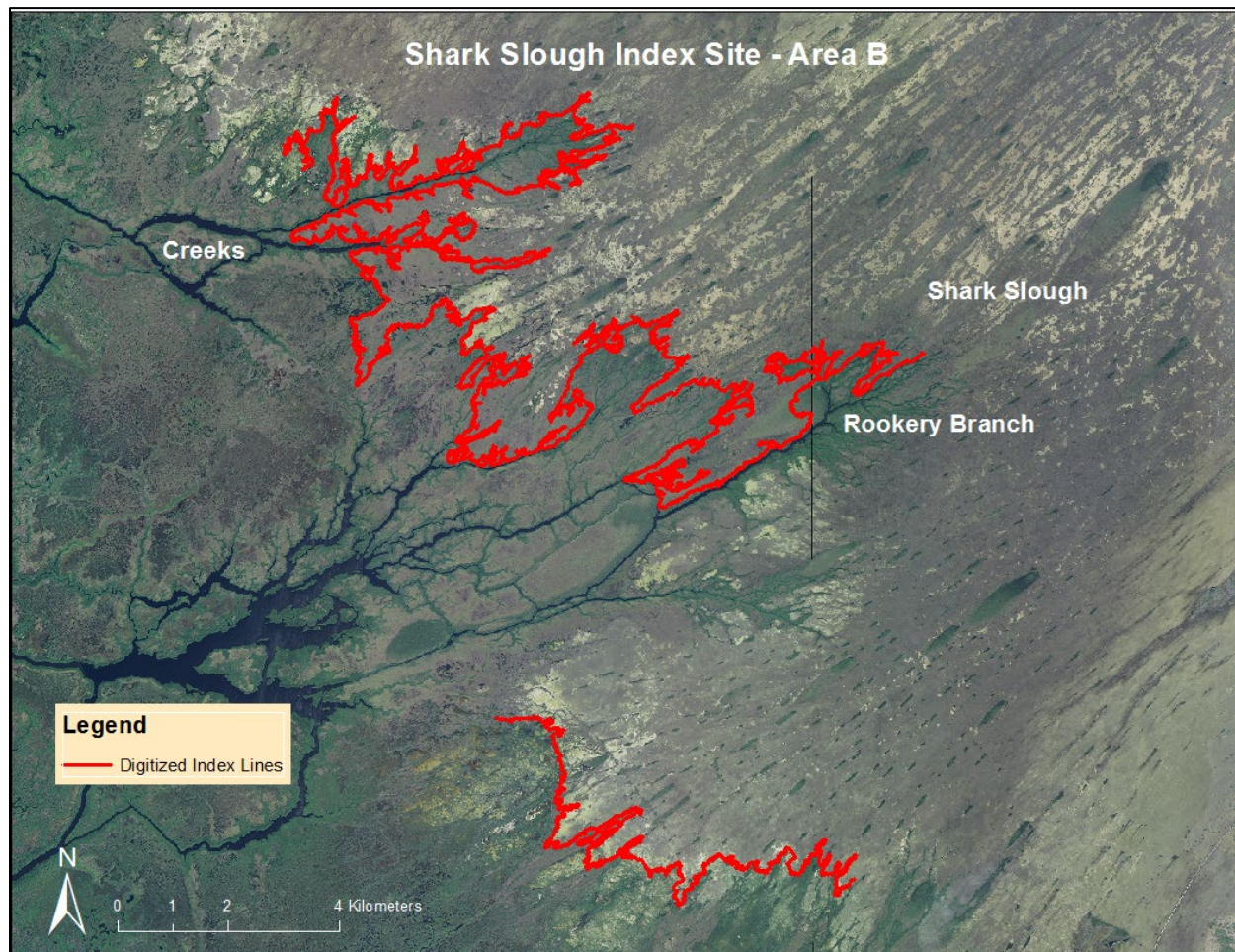


Figure A-3. The Shark Slough ecotone line was chosen to capture any changes in the main Shark Slough drainage area. Two segments were digitized in this area. The area north of Rookery Branch features a sharp mangrove-marsh ecotone, at many times following tidal creeks that run into the upstream marsh. The second segment is located south of Rookery Branch and also features a sharp ecotone edge between mostly dwarf mangroves and the adjacent freshwater marsh. Scale 1:80,000. 2013 NAIP imagery.

Mahogany Hammock (Figure A-1, Area C and Figure A-4)

This site was chosen to detect change in the mangrove-marsh ecotone in the area just west of the main park road and to the east of the main drainage area of Shark Slough. This ecotone line is composed of two portions. The northern portion of the line segment captures a sharp ecotone delineation of thick, almost impenetrable mangrove habitat that gives way to an open marsh. Approaching the southern part of the line, this sharp ecotone becomes gradual as the thick mangroves give way to a mangrove habitat that is approximately 50% mangrove cover with a more open graminoid marsh understory.

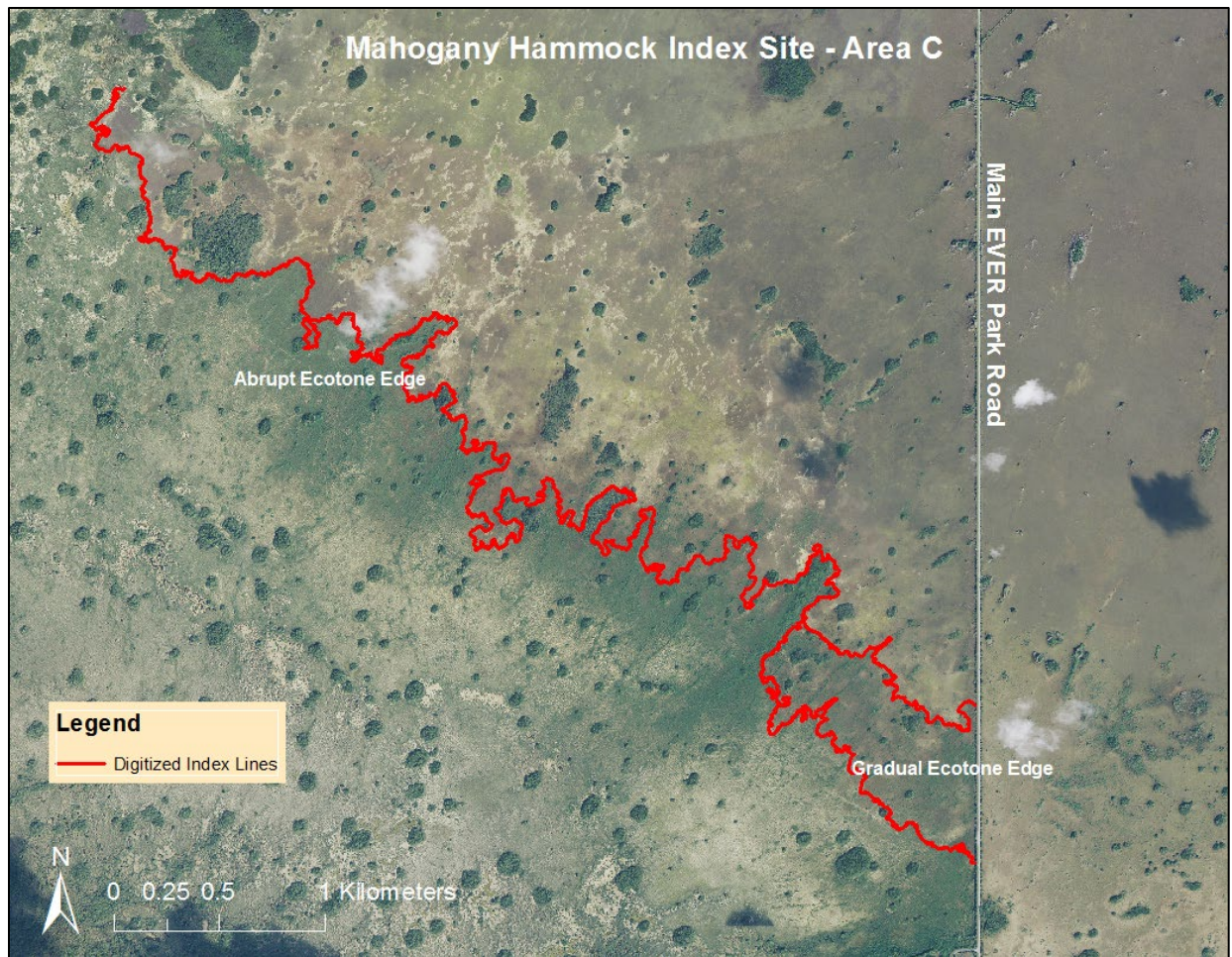


Figure A-4. The Mahogany Hammock ecotone line was chosen to detect change in the mangrove-marsh ecotone in the area just west of the main park road and to the east of the main drainage area of Shark Slough. The northern portion of the line segment captures an abrupt ecotone edge. The southern part of the line is a gradual ecotone that is approximately 50% mangrove cover with a more open graminoid marsh understory. Scale 1:21,000. 2013 NAIP imagery.

Taylor Slough (Figure A-1, Area D and Figure A-5)

This area was chosen because it is a main drainage area of southeastern EVER. Having a monitoring site allows detection of any changes from upstream restoration efforts, that may include increased water flow or even a decrease in water delivery to this area. This area also displays an abrupt delineation between the mangroves and the upstream marsh community.

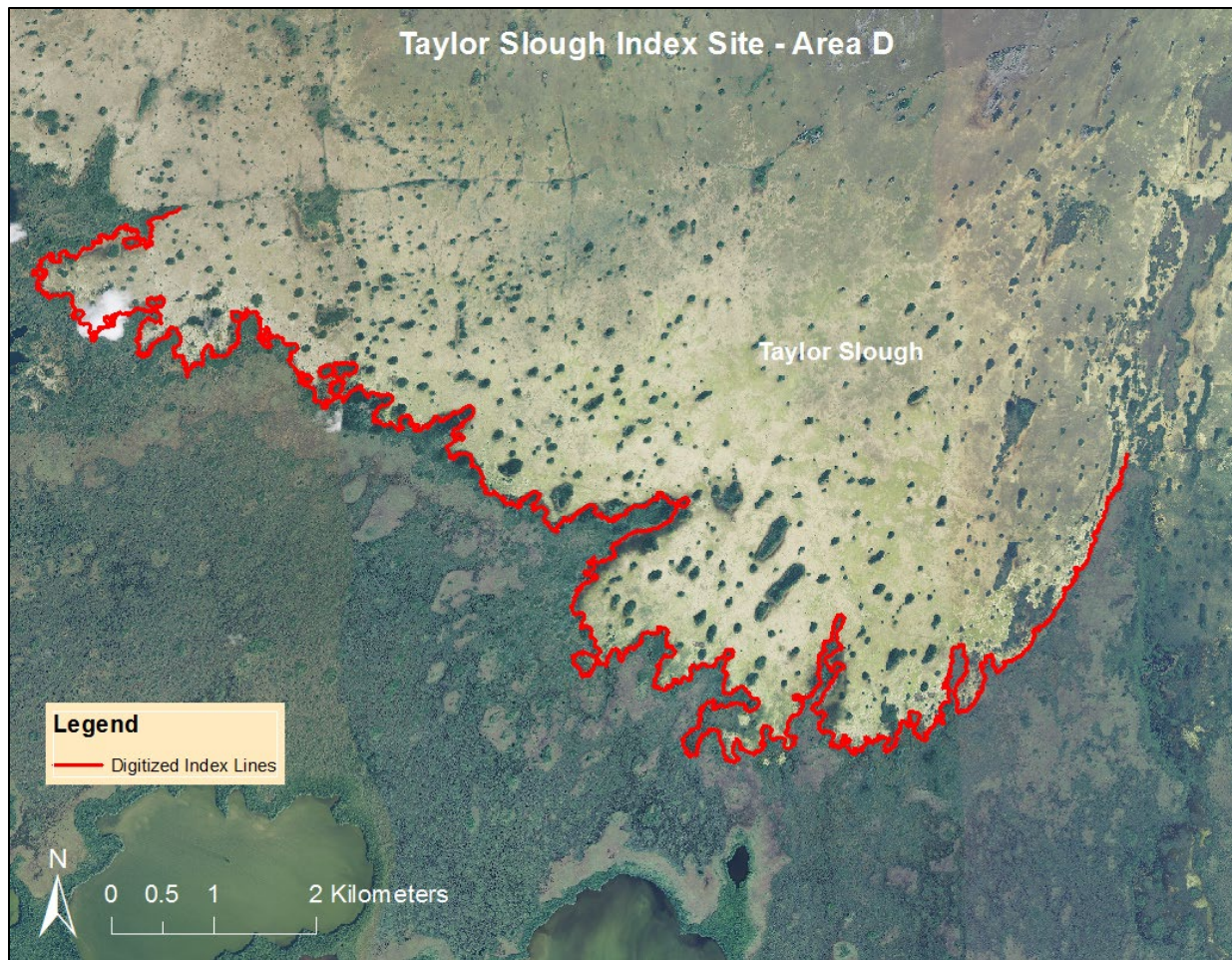


Figure A-5. The Taylor Slough ecotone line was chosen because it is a main drainage area of southeastern EVER. Having a monitoring site allows detection of any changes from upstream restoration efforts, which may include increased water flow or even a decrease in water delivery to this area. Scale 1:45,000. 2013 NAIP imagery.

Spreader Canal (Figure A-1, Area E and Figure A-6)

The C-111 Spreader Canal ecotone line is located approximately 10 kilometers (6.2 mi) south of the C-111 Spreader Canal restoration project. This site was chosen to capture effects from the C-111 restoration effort and because there have been numerous projects (Ross et al. 2013, Doyle et al. 2003, Ross et al. 2000) regarding sea-level rise and mangrove migration in this area.

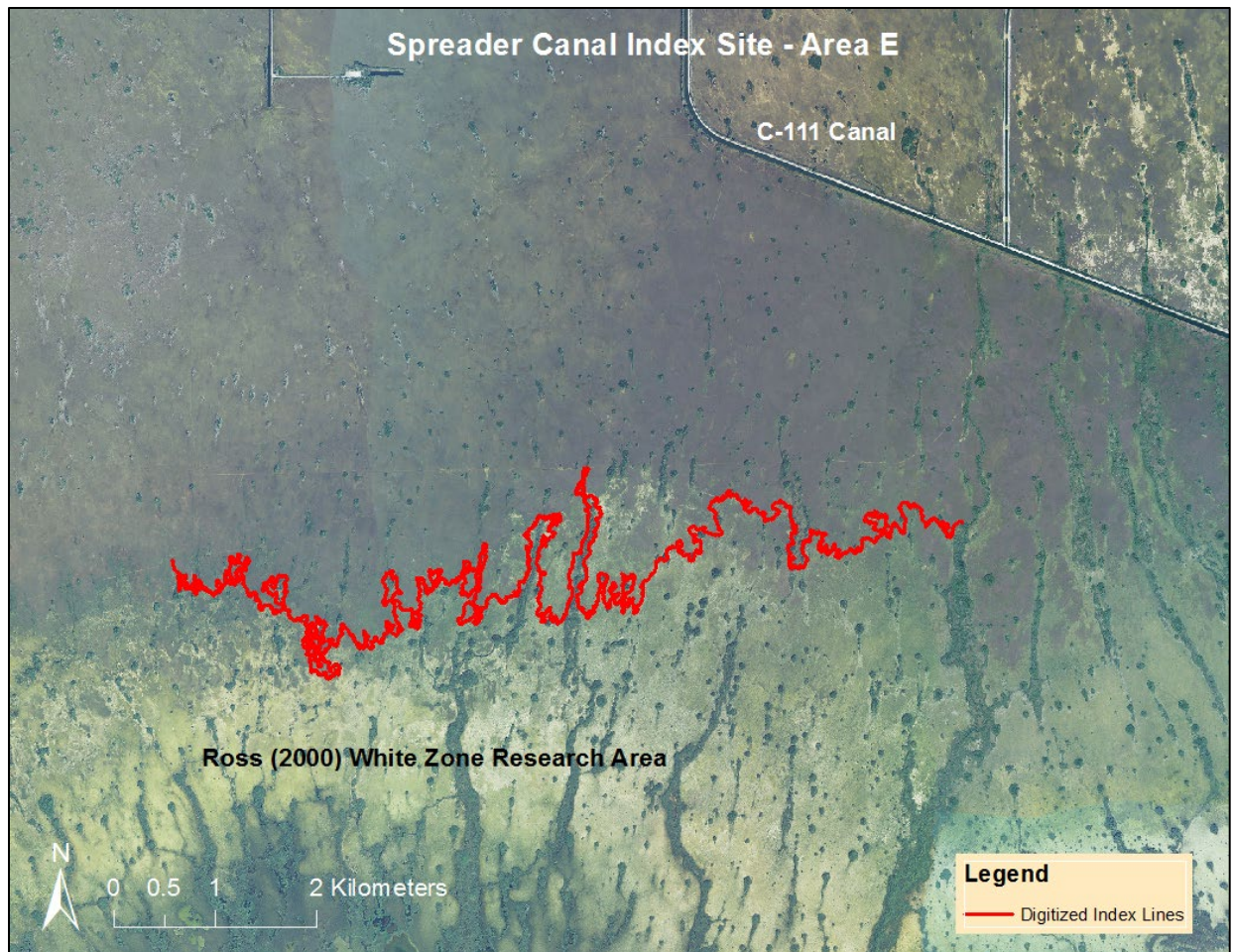


Figure A-6. The Spreader Canal ecotone line is located approximately 10 kilometers (6.2 mi) south of the Spreader Canal restoration project. This site was also chosen to capture effects from the C-111 restoration effort and because there have been projects (Ross et al. 2013, Doyle et al. 2003, Ross et al. 2000) regarding sea-level rise and mangrove migration in this area. Scale 1:45,000. 2013 NAIP imagery.

Marker points

Fifteen to twenty marker points were established per index site at even spacing along the ecotone. We took the length of each ecotone index site line and divided the length by 16 to arrive at 16 marker points per line regardless of the line's length. The first and last marker point locations were located at the beginning and end of the line, respectively. Each marker point was set using best judgement at the mangrove-marsh ecotone interface. Locations of marker points were recorded with a Trimble GPS unit and initially permanently marked with rebar and a PVC pipe (rebar and pipe were subsequently removed).

For Mahogany Hammock, an ecotone of near 100% mangrove cover was initially digitized (Figure A-7). Following marker point collection, the resulting large differences between the field data and the digitized line resulted in digitizing a second line. This second line branched from the hard edge line of near 100% mangrove cover and followed the leading mangrove edge of 50% mangrove cover (Figure A-7) with an additional four marker points added to this new branch.



Figure A-7. The initial Mahogany Hammock area ecotone line followed an ecotonal edge of 80-100% mangrove cover (left line). When field data differed from the ecotone line placement, a second ecotone line was drawn to catch the ecotone characterized by 50% mangrove cover (right line). Marker points do not appear in this area of the map. Scale 1:2,500. 2013 NAIP imagery.

The accuracy of the digitized linework was estimated by measuring the distances between the marker points and the digitized ecotone line. The measurement tool was used within ArcGIS 10.2 to measure the shortest distance between each marker point and the digitized line (Figure A-8).

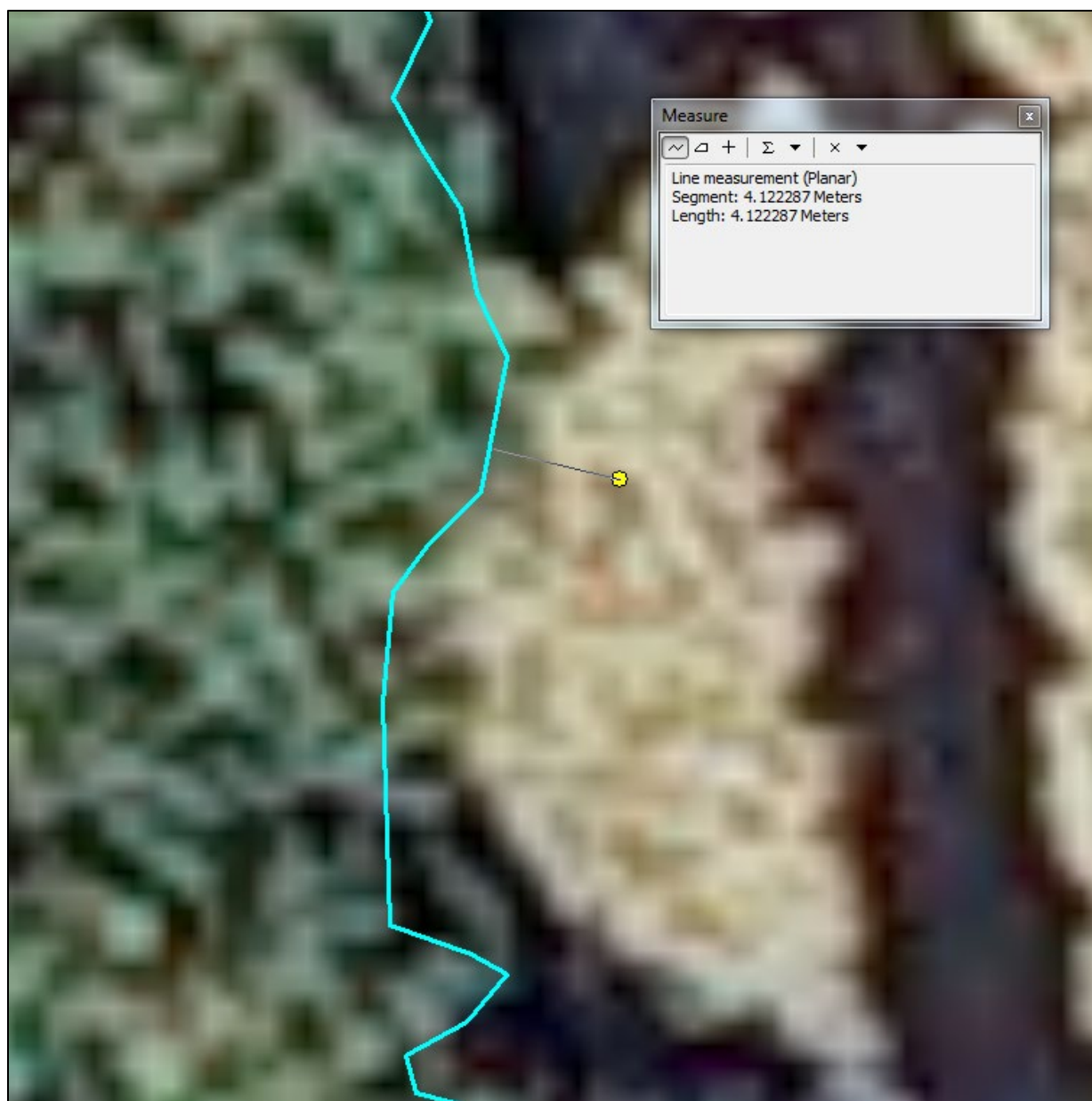


Figure A-8. The Measure tool is used to determine the distance from the center of the marker point (yellow dot) to the nearest location on the digitized line (cyan line). Scale 1:125. 2012 FDOR imagery.

Points that were to the mangrove side of the digitized line (downslope) were recorded as having a negative distance, whereas points that were to the marsh side (upslope) were recorded as having a positive distance (Table B-1). In two cases, marker points in Shark Slough were established beyond the end of the initial digitized line and were dropped from the analysis. A distribution of the differences is provided in Table A-2. The average distance, median, standard deviation, minimum, and maximum distances were calculated. The Root Mean Square Error (RMSE) of the differences was calculated. A t-test was used to determine if the average distance between the digitized line and the marker points at each of the five sites was different from zero (see Table A-3.). The RMSE was

used to estimate the average line movement detectable with 95% confidence and 80% power, assuming a paired *t*-test. As a future digitized line would be measured back to the same marker points, a paired *t*-test is appropriate. Upper and lower 95% confidence limits for change at an individual point along the line were also calculated.

Results and Discussion

Four of the five sites did not have a distance between the line and the marker point significantly different from zero. Taylor Slough (the first site digitized and visited) had the marker point placed toward the mangrove side of the line 16 out of 17 times. This means that the digitized line was placed farther into the marsh than the actual field data would suggest; upon examination, the digitizing appeared to have been placed upon the shadow of the mangroves rather than on the actual edge between the mangroves and the marsh. On average, the difference between the marker points and ecotone lines of the other mapped sites were not significantly different from zero. However, there were some extreme values that will be investigated during the QA/QC process, as it appears there were some interpretation differences in cases where there was a gradual transition zone rather than an abrupt demarcation line. The Spreader Canal site in particular had both extreme negative and positive values (> 10 meters [32.8 ft]). The Spreader Canal site is an area of low-density mangroves with a gradual “gradient” change in the ecotone. The line in some areas appeared to be digitized primarily on the basis of “white zone” graminoid/herbaceous color change rather than on mangrove boundary, whereas the field point placement was based on the nearest mangroves; this led to larger differences between the line and the marker point.

The detectable change was evaluated at the 95% significance level and the 80% power level. This difference ranged from 1.7–7.8 meters (5.5–25.5 ft) with the Spreader Canal site having the largest minimum detectable change. Wide areas of gradually changing ecotones such as the Spreader Canal site will be more difficult to detect differences, but should be easily identifiable on the imagery as challenging areas due to the gradual (diffused) nature of this ecotonal area.

These results underscored that (a) areas of gradual ecotonal change will have wider variance in placement of the ecotone line and marker points, (b) ground-truthing of the lines with marker points is valuable for detecting digitizing bias as well as to detect areas that may need to be re-digitized, and (c) even at the most complex site (Spreader Canal), an average movement of the line of 7.8 meters (25.5 ft) should be detectable with 80% power, which is acceptable for the purposes of this protocol. It should be noted that this analysis of movement in the Spreader Canal area was done based on GPS points collected at index sites initially installed from September 2011 to August 2012. These GPS points were then compared to the placement of the digitized line.

Ability to detect change across the entire Everglades mangrove-marsh ecotone

The five sites monitored were not randomly selected from the entirety of the Everglades mangrove-marsh ecotone. Thus, the results at each site from a statistical viewpoint relate only to those five sites. However, roughly measured using a straight line calculation, the five sites cover approximately 40–50% of the ecotone ranging from southwestern Big Cypress National Preserve to southeastern Everglades National Park. The only large gap occurs in the “stairsteps” region of the boundary between the park and the preserve where accessibility issues limited establishing a site. Thus, these

sites cover a large proportion of the logistically accessible ecotone areas. With the exception of the stairsteps area (straight line distance between sites is approximately 40 kilometers [24.8 mi]), the remaining un-monitored areas are within a 7-kilometer (4.3-mi) distance of a measured ecotone and are presumed to be affected by the same drivers and stressors. Extrapolating results to the entire ecotone must be done with caution and is statistically inappropriate. However, the results at these five sites provide a reasonable indication of ecotone change throughout Everglades National Park. Recommendations for QA/QC cleanup of the sites evaluated:

1. If the Taylor Slough site is retained in the design, it should be re-digitized using the original imagery to try and correct the consistent bias that put the line too far into the marsh rather than right on the marsh/mangrove line.
2. Extreme differences between the marker point location and the ecotone line, e.g., greater than five meters (16.4 ft) should be investigated to determine if the line must be re-digitized (or if the marker point was incorrectly placed), and/or notes added to assist interpretations of change in the future. This typically occurs in large areas of sparse shrubs near the 50% cutoff. Some notes were already included in Table A-1.
3. If the Spreader Canal site is retained in the sampling design, the line needs to be re-digitized to conform to the mangrove line, as the line currently appears to be delineated based upon the “White Zone” (Ross et al. 2000).

Estimates of detectable change based upon revised sampling design

The network changed the sampling design in the final protocol from the one used in the pilot project to one using fourteen 3-kilometer segments systematically placed across the ecotone (consisting of 42 segments). Instead of 16-20 marker points per pilot study site, there are now 4 marker points per segment. Detectable change was estimated using marker point data combined across all sites (86 points) to calculate change detectable with 1 segment (4 points), 5 segments (20 points), and the entire ecoregion (56 points). A basic confidence interval was calculated using the standard error and a t-test. Differences detectable with 95% confidence and 80% power were estimated at 11.51 meters, 3.71 meters, and 2.12 meters, respectively. Results are in Table B-4. Alternatively, the change detectable was also calculated for the region and the entire ecotone by treating the average difference of each segment as the sample points and again a basic confidence interval of the average of the site differences and the standard error of the site differences was calculated. This resulted in 1.82 meters difference for a region and 0.89 meters for the ecotone.

Table A-1. Distances between marker points and digitized line by index site. Negative distances mean the marker point is on the mangrove side of the digitized line. Positive distances mean the marker point is on the marsh side of the digitized line.

Site	Marker	Distance (m)	Comment
Mahogany Hammock	MH_1	0.14	–
Mahogany Hammock	MH_2	-0.5	–
Mahogany Hammock	MH_3	0.02	–
Mahogany Hammock	MH_4	-0.25	–
Mahogany Hammock	MH_5	-2.35	–
Mahogany Hammock	MH_6	0.15	–
Mahogany Hammock	MH_7	0.03	–
Mahogany Hammock	MH_8	-0.67	–
Mahogany Hammock	MH_9	-0.59	–
Mahogany Hammock	MH_10	0.9	–
Mahogany Hammock	MH_11	2.92	–
Mahogany Hammock	MH_12	-0.24	–
Mahogany Hammock	MH_13	-1.51	–
Mahogany Hammock	MH_14	-0.7	–
Mahogany Hammock	MH_15	0.2	–
Mahogany Hammock	MH_16	4.5	–
Mahogany Hammock	MH_17	0	–
Mahogany Hammock	MH_18	-0.41	–
Mahogany Hammock	MH_19	-2.97	–
Mahogany Hammock	MH_20	-1.94	–
Ochopee	OC_01	-2.76	–
Ochopee	OC_02	0	–
Ochopee	OC_03	3.23	–
Ochopee	OC_04	-1.6	–
Ochopee	OC_05	-0.3	–
Ochopee	OC_06	-1.5	–
Ochopee	OC_07	0.98	–
Ochopee	OC_08	20.54	Mangrove line thin. Point on small finger that was cut off on mapped line.
Ochopee	OC_09	2.51	–

Site	Marker	Distance (m)	Comment
Ochopee	OC_10	-0.53	–
Ochopee	OC_11	0.94	–
Ochopee	OC_12	0.08	–
Ochopee	OC_13	-1.32	–
Ochopee	OC_14	0.92	–
Ochopee	OC_15	-0.11	–
Spreader Canal	SC_01	-1.31	–
Spreader Canal	SC_02	-6.78	–
Spreader Canal	SC_03	1.44	–
Spreader Canal	SC_04	22.79	Multiple ecotone lines in close proximity. Appears field chose to place ecotone on small side loop not digitized.
Spreader Canal	SC_05	2	–
Spreader Canal	SC_06	-0.29	–
Spreader Canal	SC_07	26.58	Ecotone line drawn at soil change but mangroves change in different place.
Spreader Canal	SC_08	-10.97	Ecotone line drawn at soil change but mangroves change in different place.
Spreader Canal	SC_09	-5.92	Ecotone line drawn at soil change but mangroves change in different place.
Spreader Canal	SC_10	-3.67	Ecotone line drawn at soil change but mangroves change in different place.
Spreader Canal	SC_11	-0.94	–
Spreader Canal	SC_12	0.36	–
Spreader Canal	SC_13	-12.72	Ecotone line drawn at soil change but mangroves change in different place
Spreader Canal	SC_14	-8.85	Ecotone line drawn at soil change but mangroves change in different place
Spreader Canal	SC_15	-3	–
Spreader Canal	SC_16	-6.13	Ecotone not distinct. Gradual thinning of mangroves.
Shark Slough	SS_01	0.7	–
Shark Slough	SS_02	12.22	Mangroves thin out. Difficult to determine where to place point.
Shark Slough	SS_03	-3.17	–

Site	Marker	Distance (m)	Comment
Shark Slough	SS_04	-1.57	–
Shark Slough	SS_05	-0.98	–
Shark Slough	SS_06	-1	–
Shark Slough	SS_07	-1.96	–
Shark Slough	SS_08	-0.96	–
Shark Slough	SS_09	1.34	–
Shark Slough	SS_10	6.73	Just a difference in where field line and digitized line placed.
Shark Slough	SS_11	-1.13	–
Shark Slough	SS_12	-0.17	–
Shark Slough	SS_13	2.09	–
Shark Slough	SS_14	0.1	–
Shark Slough	SS_15	0.36	–
Shark Slough	SS_16	202.83	Dropped - Placement is beyond end of initial digitized line
Shark Slough	SS_17	-5.88	Thinning mangroves. Just difference in digitized line versus field point.
Shark Slough	SS_18	2.24	–
Shark Slough	SS_19	-0.02	–
Shark Slough	SS_20	9.06	Dropped - Placement is beyond end of initial digitized line
Taylor Slough	TS_1	-3.45	–
Taylor Slough	TS_2	-3.4	–
Taylor Slough	TS_3	-0.77	–
Taylor Slough	TS_4	-0.88	–
Taylor Slough	TS_5	-4.33	–
Taylor Slough	TS_6	-5.5	–
Taylor Slough	TS_7	-0.82	–
Taylor Slough	TS_8	-1.34	–
Taylor Slough	TS_9	-1.79	–
Taylor Slough	TS_10	0.43	–
Taylor Slough	TS_11	-1.1	–
Taylor Slough	TS_12	-0.4	–

Site	Marker	Distance (m)	Comment
Taylor Slough	TS_13	-2.19	–
Taylor Slough	TS_14	-1.8	–
Taylor Slough	TS_15	-2.36	–
Taylor Slough	TS_16	-1.38	–
Taylor Slough	TS_17	-1.32	–

Table A-2. Frequency distribution of distances between marker point and digitized line. Negative distances indicate the marker point is to the mangrove side of the digitized line. Positive distances indicate the marker point is to the marsh side of the digitized line. Table shows number of marker points per distance category from the line for each site. All units are in meters.

Category	Difference (m)	Mahogany Hammock	Ochopee	Spreader Canal	Shark Slough	Taylor Slough
Marker Point is mangrove side of digitized line	<-5	–	–	6	1	1
	-4 to -5	–	–	–	–	1
	-3 to -4	–	–	2	1	2
	-2 to -3	2	1	–	–	2
	-1 to -2	2	3	1	3	6
	-.001 to -1	7	3	2	5	4
Marker Point is marsh side of digitized line	0 to 1	7	5	1	3	1
	1 to 2	–	–	1	1	–
	2 to 3	1	1	1	2	–
	3 to 4	–	1	–	–	–
	4 to 5	1	–	–	–	–
	>5	–	1	2	2	–

Table A-3. Summary metrics for differences between the Marker point and the Digitized Line for all five sites including movement in line detectable. All units are in meters.

Site	# Marker points used	Mean	Median	Min.	Max.	RMSE	Different from zero?	Line movement ¹	Comments
Ochopee	15	1.41	0.00	-2.76	20.54	5.51	No	4.3	Sharp Ecotone
Spreader Canal	16	-0.46	-2.16	-12.72	26.58	10.72	No	7.8	Gradient Ecotone
Shark Slough	18	0.50	-0.10	-5.88	12.22	3.81	No	2.7	Sharp Ecotone
Taylor Slough	17	-1.91	-1.38	-5.50	0.43	2.40	Yes	1.7	Sharp Ecotone; Digitized line biased towards marsh
Mahogany Hammock	20	-0.16	-0.25	-2.97	4.50	1.61	No	Line corrected prior to analysis & 2 nd branch added	Sharp & Gradient Ecotone

¹ Detectable with 95% confidence and 80% power

Table A-4. Summary metrics for differences between the Marker point and the Digitized Line for all five sites including movement in line detectable. All units are in meters.

Site	N	Average Distance	Standard Deviation	Standard Error	Maximum Distance	Minimum Distance	1 Segment	Region (5 Segments)	Ecotone (14 Segments)
Mahogany Hammock	20	-0.16	1.64	0.82	4.50	-2.97	3.42	1.10	0.63
Ochopee	15	1.41	5.52	2.76	20.54	-2.76	11.48	3.70	2.11
Spreader Canal	16	-0.46	10.75	5.37	26.58	-12.72	22.36	7.20	4.12
Shark Slough	18	0.50	3.89	1.94	12.22	-5.88	8.09	2.61	1.49
Taylor Slough	17	-1.91	1.51	0.76	0.43	-5.50	3.14	1.01	0.58
All marker data combined	86	-0.15	5.53	2.77	26.58	-12.72	11.51	3.71	2.12
Site Results as Data	5	-0.13	1.10	0.22	—	—	—	1.82	0.89

Literature Cited

- Doyle, T. W., G. F. Girod, and M. A. Books. 2003. Modeling mangrove forest migration along the southwest coast of Florida under climate change. *In* Z. H. Ning, R. E. Turner, T. W. Doyle, and K. Abdollahi, editors. Integrated assessment of the climate change impacts on the Gulf Coast Region. LSU Publishing, Baton Rouge, Louisiana.
- Ross, M. S., J. F. Meeder, J. P. Sah, P. L. Ruiz, and G. J. Telesnicki. 2000. The southeast saline everglades revisited: 50 years of coastal vegetation change. *Journal of Vegetation Science* 11:101–112.
- Ross, M. S., J. P. Sah, J. F. Meeder, P. L. Ruiz, and G. Telesnicki. 2013. Compositional effects of sea-level rise in a patchy landscape: the dynamics of tree islands in the southeastern coastal Everglades. *Wetlands* 34: 91–100.
- Zar, J. H. 1999. *Biostatistical Analysis*. Prentice Hall. New Jersey.

Appendix B: Mangrove-Marsh Ecotone Pilot Project Report

Introduction



Figure B-1. Example of an ecotone edge (red line) between mangrove and marsh as seen from the ground during pilot monitoring.

This appendix explains in detail the pilot work that was conducted in 2010–2011 to help determine field methods used to monitor mangrove-marsh ecotonal movement. Many lessons were learned during this early work, and as a result the methods described in this appendix are sometimes different from those that were used in more recent pilot work and those written into this protocol for long-term monitoring.

The potential impacts of possible future sea-level rise are great, particularly in a flat, low-lying region such as Everglades National Park (EVER). It is expected that many South Florida plant communities will be impacted by sea-level rise as a result of climate change. Increased salinity will affect the spatial distribution of coastal plant communities. Mangroves in particular are expected to transgress upslope, and that migration will affect the adjacent freshwater marsh communities immediately higher in elevation from the mangroves. The USGS computer model SELVA-MANGRO (Doyle et al. 2003) predicts a 450-square kilometers (173 square miles [mi^2]) increase in mangrove habitat (using the lowest estimates of sea-level rise) during the next 100 years (15 centimeters [5.9 in]). The high estimates of sea-level rise (110 centimeters [43.3 in]) predict a 3,300-square kilometer (1,274- mi^2) increase to mangrove habitat. Saltwater intrusion, coupled with the effects of fire, managed freshwater flows, and hurricanes, all affect the mangrove-marsh ecotone and suggest the need for monitoring movement of the ecotone. As a tier-one vital sign for the South Florida/Caribbean Inventory and Monitoring Network (SFCN), our vegetation monitoring vital sign includes a protocol for tracking the movement of mangrove communities at the local and landscape scale.

Movement of an ecotone, or the transition zone between two distinct plant communities (Figure B-1), can provide insight about possible environmental changes occurring within an ecosystem. Ecotones

can range from a hard edge that delineates the boundary shared by two communities, to a wider area where the vegetation composition is a mixture of both communities (Figure B-2). The mangrove-marsh ecotone in Everglades National Park varies from a very sharp transition resembling a hedge to a gradual transition with a mixture of graminoids and shrubby mangrove trees.

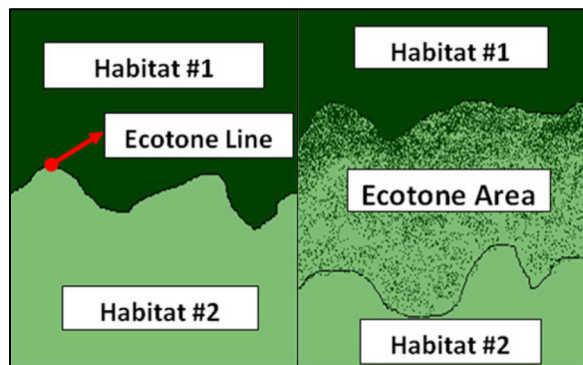


Figure B-2. Sharp Ecotone (left) vs. Gradual Ecotone (right).

The purpose of this project was to test four methods of determining the transition point between communities (the ecotone line) and refine the associated field methods for these techniques. Mangrove-marsh ecotones were used to test these methods. Ground truth points were tested along the mangrove-marsh ecotone. A subset of these points included a transect that extended from mangrove to open marsh. At these intensive sampling points, plant community structure was monitored in order to understand changes occurring at the local level. The remaining ground truth points were used to improve landscape scale monitoring using aerial imagery.

Methods

Site Selection

Four sites in Everglades National Park were chosen to test methods for determining the transition point between mangrove and marsh communities (Taylor Slough, Coot Bay, Harney River, and Rookery Branch in Shark Slough). These sites were chosen to represent the range of natural variability in mangrove-marsh ecotonal structure. An additional site at Long Pine Key was assessed to test the methods in pineland/hardwood hammock ecotones as part of the Forest Vegetation Monitoring protocol (Moser 2019 in draft).



Figure B-3. Location of a point using the Trimble GeoXT.

A qualified individual made a visual estimate of the transition point within the ecotone at each site using ArcGIS with National Agriculture Imagery Program (NAIP) 2007 imagery (1-meter [3.2 ft] resolution) at 1:600 scale. At a scale of 1:300, three to six estimates (spaced at least 30 meters [98.4 ft] apart) were made for each site, so additional data could be collected or points rejected in the field. Transition points for each site were uploaded to the Garmin 60CSx and Trimble GeoXT GPS devices.

Field Methods

The field team utilized the Garmin 60CSx GPS device to navigate to the GIS-estimated transition points at each site. Once an accessible point was reached, the Trimble GeoXT 2005 was used to record the estimated point to within 1 meter (3.3 feet; Figure B-3).

A tape was then pulled out across this point ten meters (32.8 ft) in each direction approximately perpendicular to the ecotone. The Trimble GeoXT was then removed from its location and the SFCN botanist, who was out of view during the location process and unfamiliar with the exact location of the estimated point, visually estimated the transition point along the tape using professional best judgment. This field-estimated point was marked using the Trimble GeoXT, which was allowed to average for at least 100 seconds.

A 10×100 meter (32.8×328 ft) belt transect was laid out along the same bearing as the tape used for the field estimate transition point (perpendicular to the ecotonal edge). The belt transect was centered on the point from the original estimate using imagery and extended for 50 meters (164 ft) into both community types. The belt transect was typically laid out 50 meters (164 ft) at a time from the center line for convenience purposes. A compass was used to maintain our bearing. The belt transect was divided into 5×5 meter (16.4×16.4 ft) plots, that were labeled with a number and a letter (Figure B-4). PVC poles connected with pink string were used to visually delineate the plots as they were surveyed (Figure B-5).

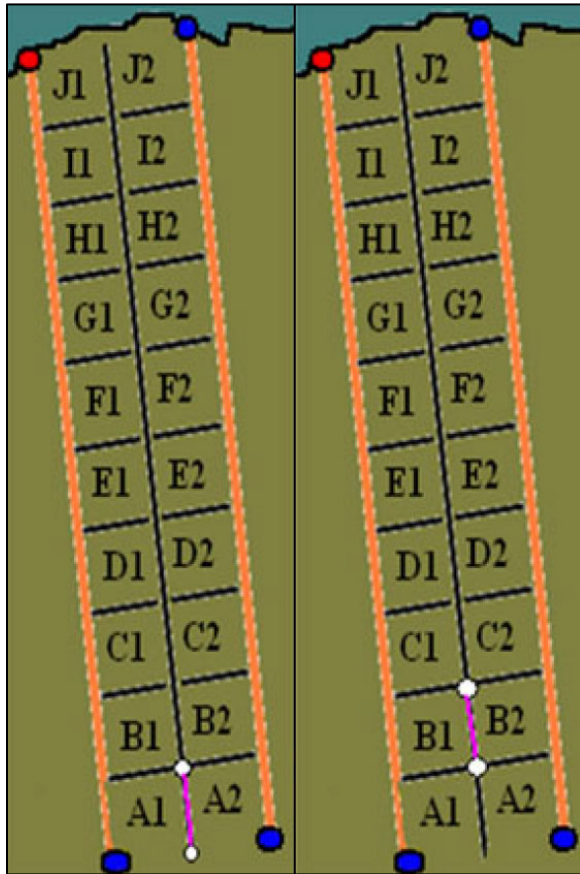


Figure B-4. Shows the collection of vegetation data was done first on plot “A”, then moving “up” to plot “B”, and so on until reaching “J”.

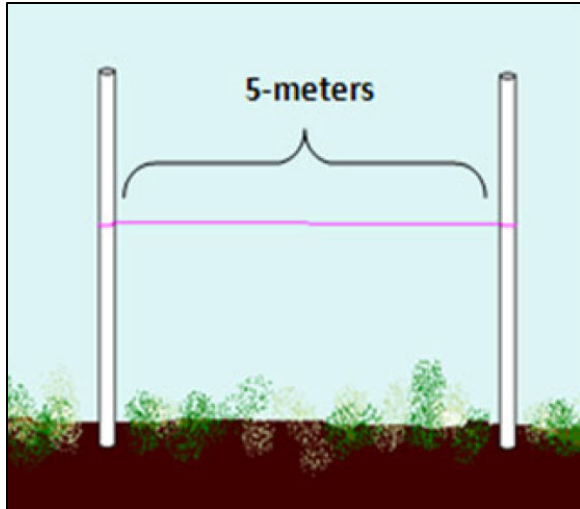


Figure B-5. Two PVC pipes attached to a 5-meter (16.4 ft.) string and inserted in the ground to visually mark plot boundaries.

Vegetation data were collected along the entire belt transect in 5×5 meter (16.4×16.4 ft) subplots. Data collected included species identity, stem count, and percent cover. Percent cover was estimated for all plant species within each 5×5 meter (16.4×16.4 ft) plot that covered at least 5% of the plot. Stems were counted for each tree and shrub species within each plot. In order to count stems for herbs, each of the plots were visually divided into 1×1 meter (3.3×3.3 ft) quadrats that were referred to by X,Y coordinates with the origin in the bottom-left corner (Figure B-6). Five X,Y coordinates were selected for each plot using a random number generator, and a 20×20 centimeter (7.9×7.9 in) PVC frame was placed in the center of the quadrat where herbaceous stems were counted (Figure B-7). These counts were used to estimate the herbaceous species stem counts for the entire 5×5 meter (16.4×16.4 ft) plot.

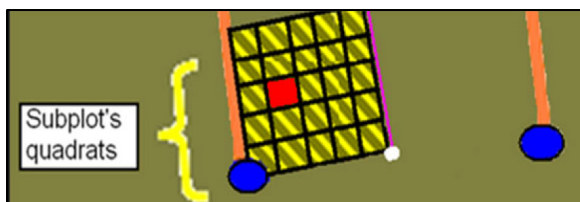


Figure B-6. Shows 1×1 meter (3.3×3.3 ft) quadrats inside of a 5×5 meter (16.4×16.4 ft) plot. As an example, the red square would be quadrat 3-2.



Figure B-7. Model of 20 × 20 centimeters (7.9 × 7.9 in) PVC frame placed on the ground centered inside of the desired quadrant.

Lastly, two points (averaged for 100 points) were taken with the Trimble Geo7X device at the middle of the two ends of the belt transect (Figure B-8). These points were used as reference points to calculate the spatial location of the transition point based on analysis of the vegetation data.

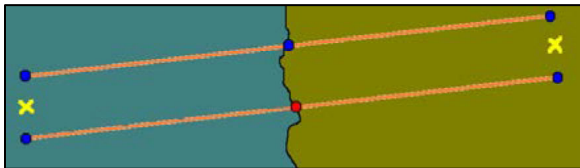


Figure B-8. The yellow crosses indicate where the Trimble GPS waypoints were taken to measure the ends of the transect belt area.

Data Management

Data collected using the Trimble GeoXT were downloaded, differentially corrected, and exported as ArcGIS shapefiles. Vegetation data sheets must be scanned and a PDF copy saved on the server. Also, vegetation data from the belt transect was entered into a Microsoft Excel spreadsheet and checked for accuracy according to standard SFCN data quality procedures.

Vegetation Data Analysis

Two methods of analyzing the vegetation data were used to identify the transition point within the ecotone. One of these was a simple graphical method using dominance curves. Stem count and percent cover of the most abundant and characteristic species in each of the two adjacent plant communities were plotted against distance from the transition point to create a dominance curve. The distance for each plot was the midpoint distance along the transect for that plot. The transition point is the place on the graph where the two lines cross and the dominance shifts from one characteristic species to the other. This is the place on the transect that is the ecotone transition point.

The other method was the moving split window (MSW) technique (Figure B-9). Species composition and abundance were used to calculate the dissimilarity between two adjacent “windows” on the belt transect.

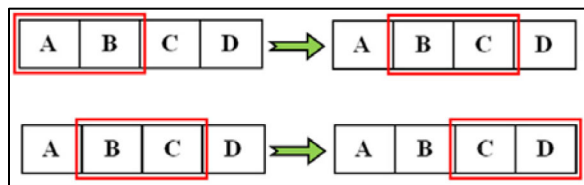


Figure B-9. Squares labeled with letters represent four plots in the transect belt. The Moving Split Window consists of choosing any desired plot(s) (two in the picture) and comparing the vegetation content in the chosen “window” (red square) with the next adjacent “window” of the same size.

We chose the squared Euclidean distance (SED) as our index because it is commonly used as part of this method. The “windows” then slide down the belt transect one sample unit (5 meters [16.4 ft]) and the calculation is repeated until reaching the end of the transect. The SED value is then plotted against distance, with the dividing line between the two “windows” as the distance value. A strong peak in the index value indicates a transition point. That is, the point along the transect where the maximum SED occurred was considered to be the ecotone transition point (See Figure A-13 for clarification).

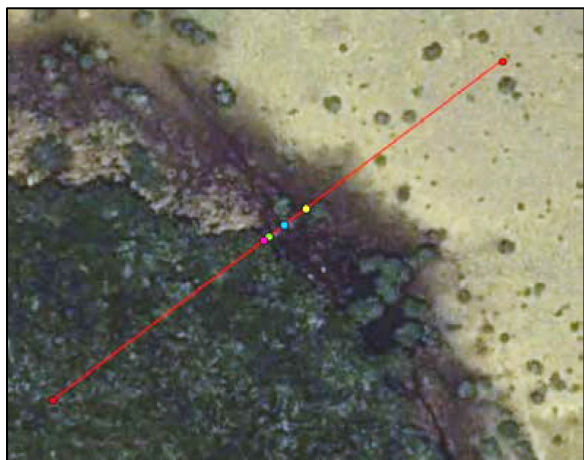


Figure B-10. Pilot site at Taylor Slough showing ecotone transition points from all four methods. Red line is the center line of the 100 meter (328 ft) vegetation transect with red endpoints. Pink = professional best judgment, Green = estimate from aerial imagery, Yellow = dominance curve, Blue = MSW.

Graphical examples of the results of vegetation data analysis from Coot Bay, Everglades National Park are illustrated by Figures B-11 through B-13. Dominance curves were created using stem counts and percent cover for the most abundant and characteristic species for each community. The point along the transect where dominance shifts is considered to be the ecotone transition point (Figures B-11 and B-12). The MSW method was used to calculate the squared Euclidian distance (SED)

between the vegetation on the two halves of the window. The point along the transect where the maximum SED occurred was considered to be the ecotone transition point (Figure B-13).

The location of the professional best judgment estimate of the ecotone was similar to the vegetation analysis methods (Table A-1). The visual field estimate generally fell within the error range determined by the 5-meter (16.4-ft) resolution of the vegetation methods and the positional error inherent to the imagery (2007 NAIP $\pm$ 6 meters [19.6 ft]) when digitizing the ecotone with the exception of sites with wider, more complex ecotonal transition zones (e.g., Harney River and Taylor Slough). The only significant deviation between these methods occurred at Harney River where the on-the-ground method placed the ecotone 8.1 meters (26.5 ft) from all other identified locations. The moving split window (MSW) method placed the ecotone closest to the location identified using aerial imagery with the lowest mean difference overall using a 5-meter (16.4-ft.) window size. However, the 5-meter (16.4-ft.) MSW frequently had significant noise and was un-interpretable for Harney River. The Harney River site had been affected by a freeze event the preceding winter and the ecotone transition zone was complicated by mangrove mortality. The Taylor Slough ecotone location was affected by a patch of cattail near the mangrove edge.

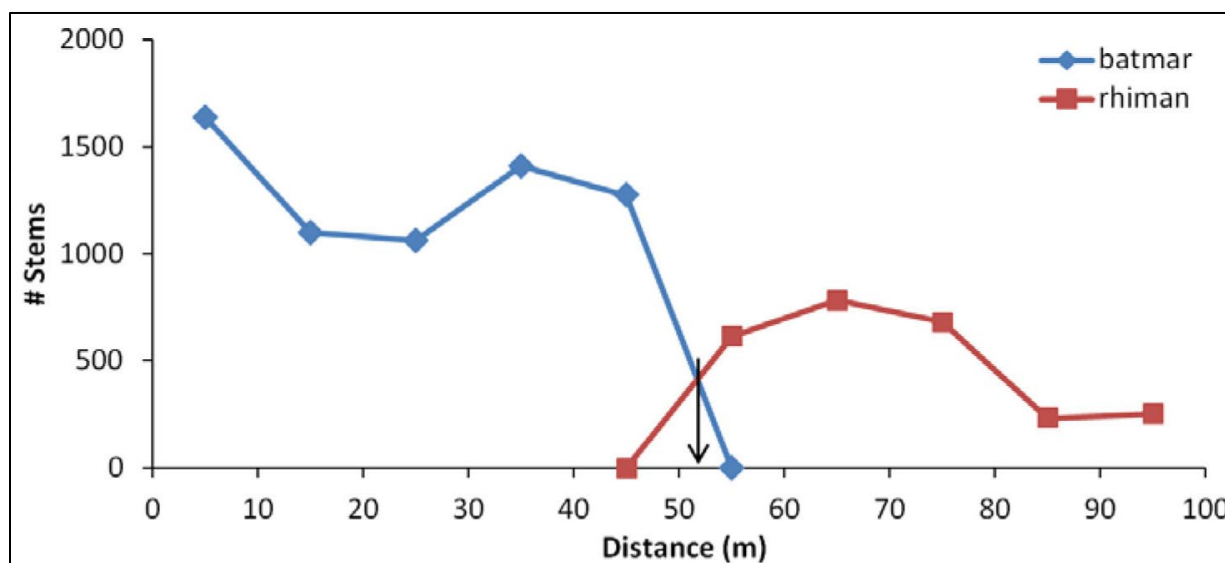


Figure B-11. Results of vegetation data analysis from Coot Bay, EVER. This graph was created with the dominance curve method, using stem count data. Stem counts of dominant species were calculated using a 10 × 10-square meters (107.6 × 107.6-ft²) window. The ecotone, or transition point, is identified by the arrow. (batmar = *Batis maritima*, rhiman = *Rhizophora mangle*).

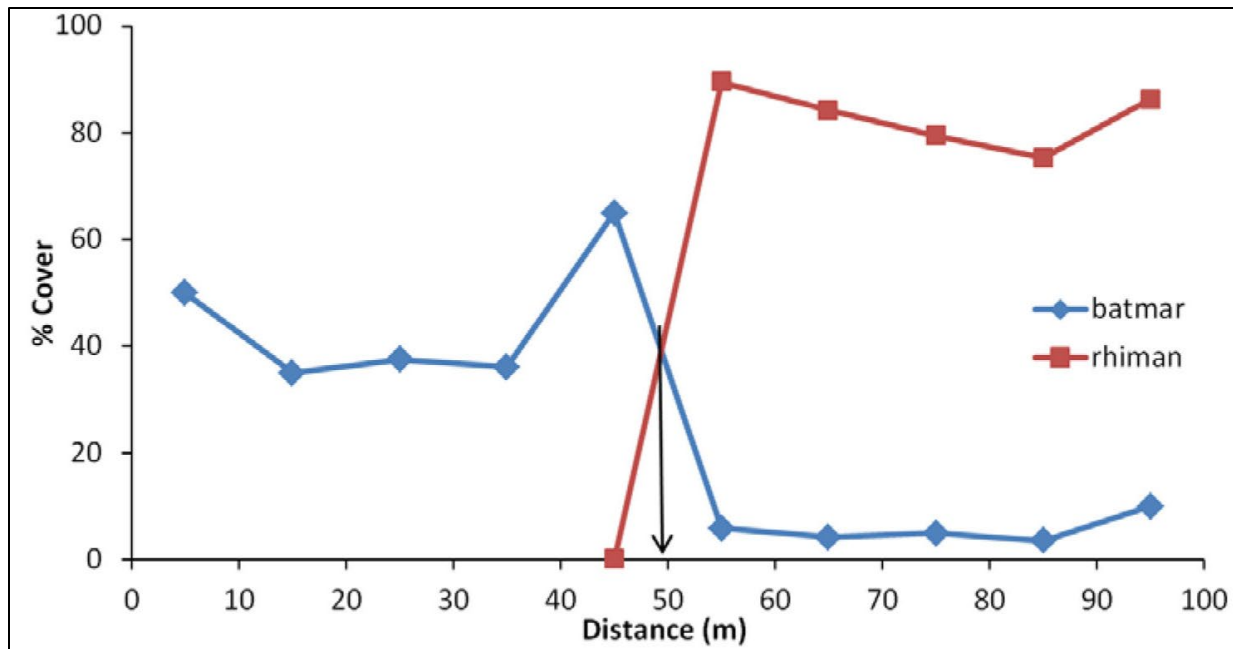


Figure B-12. Results of vegetation data analysis from Coot Bay, EVER. This graph was created with the dominance curve method, using percent cover. Percent cover of dominant species estimated within a 10 × 10-square meters (107.6 × 107.6-ft²) window. The ecotone, or transition point, is identified by the arrow. (batmar = *Batis maritima*, rhiman = *Rhizophora mangle*).

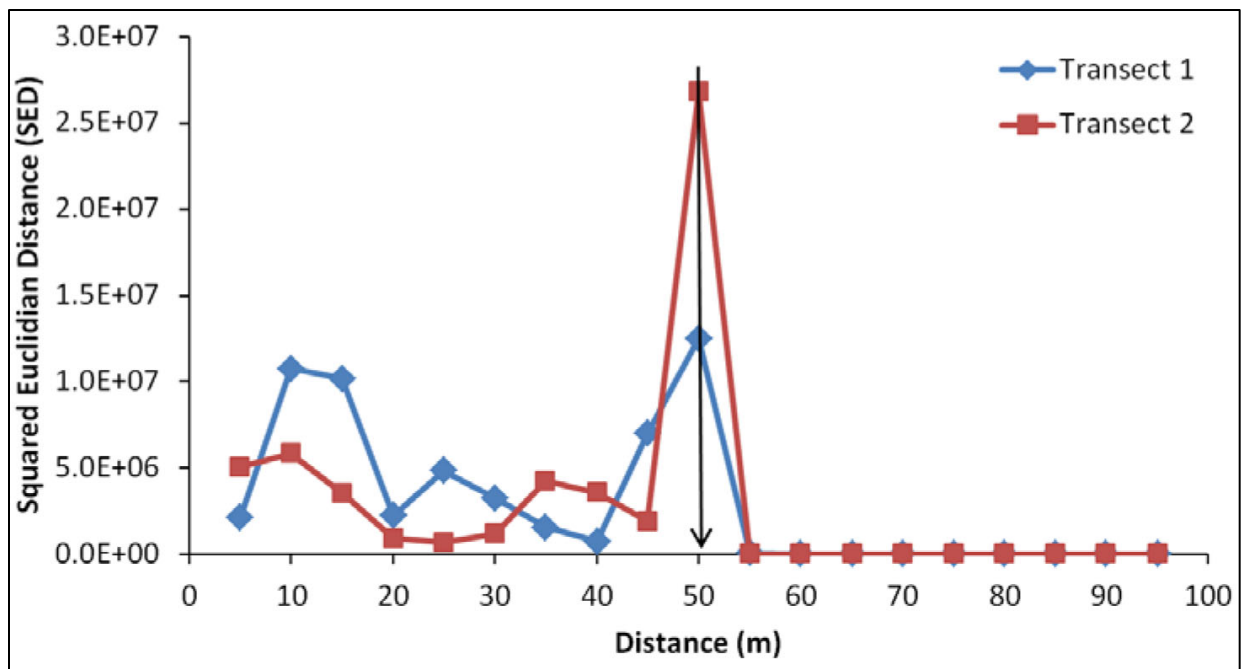


Figure B-13. Results of vegetation data analysis from Coot Bay, EVER. This graph was created with the moving split window (MSW) method using squared Euclidian distance (SED). Stem counts of all species were measured within a 5 × 5-square meters (53.8 × 53.8-ft²) window. The ecotone, or transition point, is identified by the pronounced peak in the SED value.

Table B-1. Linear distance between ecotone as identified by professional best judgment and ecotone identified by vegetation data methods. The subplots of the 10 × 100-square meters (107.6 × 1076-ft²) belt transect were grouped in three ways to determine how subplot size affected analysis results. Distance is measured in meters. SC=Dominance curve based on stem count, PC=Dominance curve based on percent cover, MSW=Moving Split Window method.

Site	SC	SC	SC	SC	PC	PC	PC	PC	MSW	MSW
	5×5 (1)	5×5 (2)	5×10	10×10	5×5 (1)	5×5 (2)	5×10	10×10	5m	10m
Coot Bay	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	5.3
Long Pine Key	2.8	2.8	2.8	2.8	— ^B	— ^B	2.2	2.2	7.2 ^A	2.2
Harney River	18.9 ^A	13.9 ^A	18.9 ^A	18.9 ^A	13.9 ^A	13.9 ^A	13.9 ^A	13.9 ^A	— ^C	13.9 ^A
Taylor Slough	9.9 ^A	9.9 ^A	9.9 ^A	9.9 ^A	0.1	0.1	4.9	4.9	15.1 ^A	5.1
Rookery Branch	1.6	1.6	1.6	1.6	3.4	1.6	1.6	3.4	3.4	3.4

^A Differences greater than 5 meters, also highlighted in yellow

^B = insufficient data

^C = excessive data noise

Discussion

The difference in time cost between professional best judgment in the field and the vegetation data methods is significant. A visual estimate and GPS location can be determined by a single individual in a matter of minutes once at the selected site. The vegetation methods require six hours of belt transect setup and data collection by a four person team, then an additional four hours of data entry and analysis by one person. The reduction in person hours for the visual estimate would allow SFCN to increase the number of ground truth points and the size of the areas of interest being monitored. The increase in understanding about ecotone fluctuations because of a greater number and spatial extent of monitoring sites likely outweighs the possible increase in accuracy gained by using the MSW method.

Given predefined criteria for the ecotone based on easily identifiable vegetation characteristics, professional best judgment in the field could likely be improved and made more consistent than presented here in this pilot study. If this is true, then the on-the-ground visual estimate is the most cost effective method of locating the ecotone. This method is also directly relatable to ecotonal movement monitoring using aerial imagery. The visual estimate sites would serve as ground-truthing locations for more continuous ecotone fluctuation monitoring using imagery time series.

A combination of GIS and field methods that mitigates time cost will yield the greatest information benefit to park management. Representative sections of ecotone should be selected based on accessibility. The location of the ecotone within these areas will be periodically monitored using aerial imagery and ground-truthing using reference sites where an on-the-ground visual estimate point will be collected with survey grade GPS. Within each monitoring section, a very limited number of permanent transects will be established where intensive vegetation structure data will be

collected for the purpose of understanding the structural changes associated with ecotonal fluctuations.

Proposed Monitoring Methods

In order to monitor mangrove-marsh ecotonal movement, a number of representative areas of interest will be selected within Everglades National Park based on accessibility and history of ecotonal flux (e.g., Figure B-14). The number and length of the areas of interest will be a function of cost and representation of the ecotone. It should be feasible to monitor 15–20% of the approximately 150 kilometers (93.2 mi) of mangrove-marsh ecotone in Everglades National Park. The location of the ecotone will be periodically monitored using aerial imagery and thoroughly ground-truthed. Within each area of interest, vegetation structure data will be collected. Monitoring will occur at approximately 10-year intervals, and exact timing of the resurveys is dependent on the availability of new aerial imagery of sufficient quality (≤ 1 meter [3.2 ft] resolution).

At each “sampling” interval, the mangrove-marsh ecotone of the areas of interest will be digitized as a line using GIS. Equally spaced ground-truth points will be selected for assessment by qualified personnel to confirm the mangrove-marsh ecotone and collect a survey-grade GPS point (Figure B-15). These points will then be used to estimate the positional accuracy of the digitized ecotone line following standard root mean square error (RMSE) methodology. The digitized lines from an area of interest can then be compared across time steps to estimate distance and direction of mangrove-marsh ecotonal movement. The data from these areas of interest could be scaled up to suggest regional patterns about mangrove-marsh ecotonal flux.

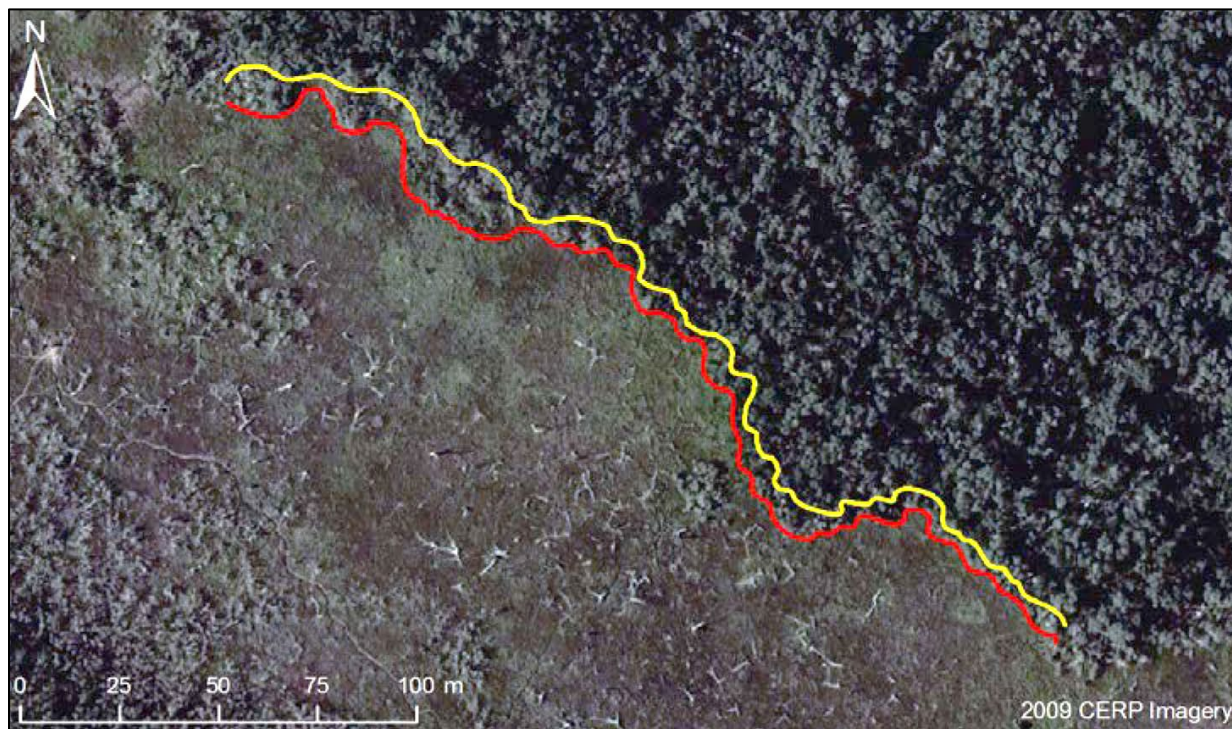


Figure B-14. Map showing mangrove-marsh ecotonal movement near Coot Bay, EVER. The yellow line is the digitized ecotone from 1995 DOQQ imagery and the red line is the ecotone from 2009 CERP

imagery (pictured). Mangrove forest appears to have advanced 3–15 meters (9.8–49.2 ft) into the salt marsh.

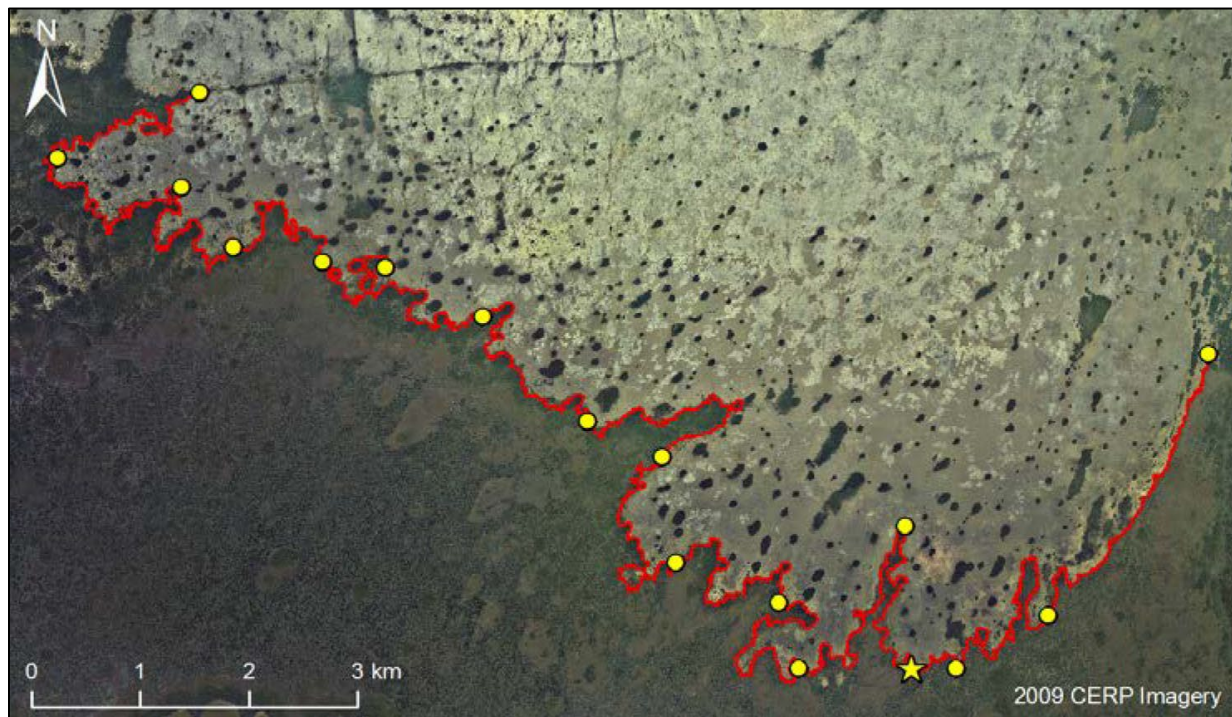


Figure B-15. Example of the Taylor Slough mangrove-marsh ecotone area of interest showing the entire area of interest with 17 ground truth points (yellow dots) and one vegetation transect (yellow star).

References

- Doyle, T.W., Girod, G.F. and Books, M.A., 2003. Modeling mangrove forest migration along the southwest coast of Florida under climate change. *Preparing for a changing climate: the potential consequence of climate variability and change: Gulf Coast Region*, pp.211–222.
- Moser, J., R. B. Shamblin, A. J. Atkinson, J. M. Patterson, K. R. T. Whelan, and T.A. Fotinos. 2019. South Florida/Caribbean Network Forest Vegetation Monitoring: Protocol Narrative–Version 1.0. (In Review). Natural Resource Report. Natural Resource Report NPS/SFCN/NRR—2019/XXX. National Park Service, Fort Collins, Colorado.

Appendix C: Estimating Detectable Change Based Upon Variance Between Two Digitizers

Introduction

The SFCN Mangrove-Marsh Ecotone Protocol delineates the ecotone by interpreting the boundary line between mangrove and marsh habitat in ArcGIS using aerial imagery. Digitizing lines can have variability due to the imagery used, time since imagery acquired, and observer (i.e., digitizer) error. Standard Operating Procedures (e.g., SOP 2—*Mangrove-Marsh Ecotone Methods for Digitizing and Updating the Ecotone Line* [SFCN 2019]) can reduce digitizer error, but the amount of error introduced by different digitizers interpreting the ecotone has not previously been quantified. Below we report the differences between ecotone lines by two different digitizers using the same imagery and standard operating procedure in order to inform future estimates of how much change in the mangrove-marsh ecotone will be reasonably detectable with the SFCN Mangrove-Marsh Ecotone Monitoring Protocol (Moser et al. 2019).

Methods

The 2013 mangrove-marsh ecotone was digitized by two different digitizers using 2013 USDA NAIP imagery and many of the procedures described in SOP 2—*Mangrove-Marsh Ecotone Methods for Digitizing and Updating the Ecotone Line* (SFCN 2019). Since the time these lines were digitized SOP 2 has been strengthened with additional rules that should help digitizers make even more similar decisions. The differences between the two lines were evaluated using the methods described in SOP 3—*Analysis of Distance Between Two Digitized Lines* (SFCN 2019). The two separate digitizers at SFCN digitized the same nine segments (three per region) using the same imagery to provide an estimate of inter-observer variability in digitizing of mangrove-marsh ecotone segments. Both digitizers were interns in the office. They attempted to use the SOPs in this protocol and made recommendations based upon the results to improve the clarity of the SOPs. They provided examples in the SOPs for resolving digitizing questions in order to reduce future variability in digitizing. One of the Taylor Slough segments (segment 10) was not corrected using the field data collected to ground truth the segments, so that segment was dropped from further analysis. Analysis was conducted in two ways.

Absolute difference between the segments drawn by two digitizers

The nearest distance tool as described in SOP 3—*Analysis of Distance Between Two Digitized Lines* (SFCN 2019) was used for each segment to estimate the nearest distance from Digitizer A's segment to Digitizer B's segment without regard to direction. Points were evenly spaced every 10 meters.

All numbers are positive regardless of the direction to the other digitizer's segment. One-tailed confidence intervals were calculated for each region using the average differences for each segment as replicates. Similar calculations were made for the entire ecoregion.

Directional difference between the segments drawn by the two digitizers

SOP 3—*Analysis of Distance between Two Digitized Lines* was further used to calculate the directional distance between the segments drawn by the two digitizers. One digitizer was assigned as

Time 1 and the other as Time 2. A positive (+) or negative (-) sign is then assigned based on whether the distance is measured within a mangrove increase or marsh increase polygon respectively.

Two-tailed confidence intervals were calculated for each region using the average differences for each segment as replicates and for the entire ecoregion.

Results and Discussion

Tables C-1 and C-2 provide a summary of the raw data. Table C-3 provides a summary of the differences detectable using the absolute difference between two digitizers at the individual segment, region, and overall ecotone level. However the directional distance estimate provides the better estimate of the change detectable by this protocol as the digitizers' lines would frequently intersect and were not consistently upslope or downslope. The average distance between the two digitizers across all eight segments was 1.5 meters. All digitizer differences (n=8) were included to estimate the change detectable on a single segment with 95% confidence (2-tailed) and 80% power; this detectable change is estimated to be 15.4 meters. When using digitizer differences as replicates in a t-test and assuming a finite population of 42 segments, the distance detectable in Shark Slough, Taylor Slough, and Turner River with 95% confidence and 80% power are 8.2, 3.7, and 10.1 meters, respectively, whereas the difference detectable across the entire region is 4.3 meters (see Table C-4).

The average directional distance for all 14 segments is 1.2 meters with a standard deviation of 18.8 meters. Assuming an effective sample size of $n = 30$, the change detectable for an individual segment should be 11.1 meters with 95% confidence and 80% alpha.

Future digitizers should attempt to re-digitize the same segments using the same imagery. Acceptable average directional change differences is less than 5 meters on an individual segment. Areas with points showing large differences (> 10 meters) between the digitized lines should each be investigated as usually these are indicative of differences in understanding of how the digitizing decision rules should be applied.

Table C-1. Summary of results of using the Near Distance tool in ArcGIS 10.5 to estimate the difference between lines of the same mangrove-marsh ecotone drawn by two different digitizers. Results for 8 segments are presented. The average absolute distance, RMSE, and percentage of points found within different distances of the other line are presented. Distances are in meters (m).

Region	Segment	Number of measurements	Absolute Distance Average (m)	Absolute Distance Root Mean Square Error (RMSE)											Absolute Distance Maximum (m)
					<1 m	<2m	<3m	<4m	<5m	<10 m	<15m	<20m	<25m	<50m	
Shark Slough	06	5,121	1.74	4.93	58%	80%	88%	92%	94%	98%	99%	99%	100%	100%	100
–	09	5,075	10.80	31.06	47%	62%	67%	71%	74%	83%	87%	89%	90%	94%	235
–	07	5,582	3.50	13.66	63%	80%	85%	88%	90%	94%	96%	97%	97%	99%	162
Taylor Slough	13	3,017	6.14	19.25	46%	65%	73%	78%	82%	89%	92%	94%	95%	97%	185
–	11	2,771	5.82	14.98	49%	65%	71%	75%	78%	87%	90%	92%	94%	98%	113
Turner River	02	2,357	9.31	29.88	55%	73%	79%	82%	84%	88%	90%	91%	92%	94%	179
–	03	3,494	4.84	13.76	47%	64%	72%	78%	81%	91%	93%	95%	96%	98%	132
–	01	4,192	3.83	12.58	57%	78%	84%	87%	89%	93%	95%	95%	96%	98%	112
Shark Slough	Average	5,259	5.35	16.55	56%	74%	80%	84%	86%	92%	94%	95%	96%	97%	235
Taylor Slough	Average	2,894	5.98	17.11	47%	65%	72%	77%	80%	88%	91%	93%	94%	97%	185
Turner River	Average	3,348	5.99	18.74	53%	72%	78%	82%	85%	91%	93%	94%	94%	97%	179
All	Average	3,951	5.75	17.51	53%	71%	77%	81%	84%	90%	93%	94%	95%	97%	235

Table C-2. Segment directional change differences averaged by segment for differences between two digitizers of the same imagery. The average and standard deviation of the segment differences were calculated based upon the individual segment averages. Distances are in meters (m).

Region	Segment	Number of measurements	Average of segment directional change differences	Standard Deviation of Segment Directional Change Differences
Shark Slough	06	5,121	-0.68	4.88
	09	5,075	5.85	30.51
	07	5,582	1.02	13.62
Taylor Slough	13	3,017	3.10	19.00
	11	2,771	1.80	14.87
Turner River	02	2,357	8.19	28.74
	03	3,494	-4.19	13.11
	01	4,192	-3.35	12.13
Shark Slough	Average and SD of Averages	–	2.06	3.39
Taylor Slough	Average and SD of Averages	–	2.45	0.92
Turner River	Average and SD of Averages	–	0.22	6.92
All	Average and SD of Averages	–	1.47	4.26

Table C-3. Change detectable based upon absolute differences between two digitizers. n= number of segments. Distances are in meters (m).

Region	Pilot Sample n	Final Design n	Total Ecotone n	Segment Absolute Differences Average	Segment Absolute Differences Standard Deviation	Segment Absolute Differences Standard Error	Individual Segment 1-tailed 95% Confidence Level + 80% power	Region 1-tailed 95% Confidence Level + 80% power
Shark Slough	3	4	13	5.35	4.81	2.08	31.14	14.01
Taylor Slough	2	5	13	5.98	0.22	0.08	9.10	6.28
Turner River	3	5	16	5.99	2.92	1.12	21.63	10.14
Entire Ecotone	8	14	42	5.75	3.03	0.67	15.61	7.77
Region	8	5	14	5.75	3.03	1.13	15.61	9.93

Table C-4. Change detectable based upon directional differences between two digitizers. n= number of segments. Distances are in meters (m).

Region	Pilot Sample n	Final Design n	Total Ecotone n	Segment Directional Change Differences Average	Segment Directional Change Differences Standard Deviation	Segment Directional Change Differences Standard Error	Individual Segment 2 tailed 95% Confidence Level + 80% power	Region 2 tailed 95% Confidence Level + 80% power
Shark Slough	3	4	13	2.06	3.39	1.47	20.23	8.16
Taylor Slough	2	5	13	2.45	0.92	0.33	15.37	3.69
Turner River	3	5	16	0.22	6.92	2.65	37.32	10.07
Entire Ecotone	8	14	42	1.47	4.26	0.94	15.37	4.32
Region	8	5	14	1.47	4.26	1.59	15.37	7.36

Appendix D. South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring: Data Quality Standards

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Introduction

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

Protocol Overview

This protocol describes the process used to monitor ecotonal movement between mangroves and upslope freshwater marshes in Everglades National Park and Big Cypress National Preserve. Tracking the position of ecotones can indicate the long-term trajectory of these plant communities. Changes in the ecotone can be indicative of changes in the levels or effects of environmental drivers. The mangrove to freshwater marsh ecotones are expected to move, for example, in response to changes in water management, sea-level rise, storms, and fire, some of which can be manipulated to alter the rate of change. Ecotonal movement of vegetation communities across the landscape is indicative of large-scale processes affecting the parks.

Remote sensing approaches are used to delineate the physical location of the ecotone between mangroves and freshwater marsh. Fourteen 3-kilometer segments are systematically placed across the ecotone within the two parks. New aerial imagery is used to digitize the mangrove-marsh ecotone in each segment and must be 1 meter or better resolution and have positional accuracy of ± 3 meters (9.8 feet [ft.]) or better. Four ground-truth field point locations (marker points) are established systematically along the ecotone boundary of each segment to provide field-based measurements and ground-truthing of the digitized line.

The specific objectives of the mangrove-marsh ecotone monitoring protocol are:

- Determine the spatial and temporal movement of the mangrove-marsh ecotone at systematically selected segments.
- Document the composition of vegetation communities at field verification locations. Collect vegetation data, e.g., composition, percent cover and canopy height of dominant species within herbaceous, shrub, and forest strata, to document composition of vegetation communities on both the “mangrove” and “marsh” sides of the ecotone.

Monitoring will be repeated approximately once every ten years as new imagery becomes available. The monitoring duties for the South Florida/Caribbean Network mangrove-marsh ecotone monitoring protocol will be completed by network staff and the information collected used to support the management of natural resources in Everglades National Park and Big Cypress National Preserve.

Protocol Activities and Modules

Data are collected or derived as a part of the South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring protocol in 11 different activities or modules (Table D-1).

Table D-1. Protocol activity matrix for *South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring: Protocol Narrative* (Moser et al. 2019).

Activity type	Activity #	Activity type	Description
Site Establishment	1	Segment Establishment	Fourteen 3-kilometer segments are selected in a systematic design across the mangrove-marsh ecotone from the western Everglades/Big Cypress interface to eastern Everglades National Park south of the C-111 Spreader Canal project. SFCN has visited the segments that will be monitored as part of this protocol. The sites are known to be accessible by at least one of the following: helicopter, airboat, or hiking. GPS track files for reaching field ground truth ("marker") points are retained to show accessible paths and landing points for future sampling.
Field Observations	2	Vegetation plots on both sides of ecotone	Four ground truth points ("marker points") are placed in each segment. A segment represents a 3 kilometer (1.86 mi) section of the generalized ecotone line. Within each segment, and along the generalized line, marker points are placed at 0.1, 1.0, 2.0, and 2.9 kilometer (0.06, 0.62, 1.24, and 1.80 mi). No permanent markers are placed in field. A 10 × 5 meter rectangle is located with its center at the marker point indicating the mangrove-marsh ecotone and oriented perpendicular to the ecotone. Canopy height of tree, shrub, and herbaceous strata, and percent cover of tree, shrub, and herb species are recorded in each 5 × 5 meter portion of the plot.
Sensor Data	3	GPS location of marker points	Submeter GPS locations taken of field measured mangrove-marsh ecotone at marker points.
	4	Photopoint data	Photos are taken of the data sheet and then down the left side ecotone moving clockwise at 45° intervals take photos of the marsh. Take photo down right side of ecotone and then clockwise at 45° intervals take photos of the mangroves.
External data	5	Aerial Imagery	New aerial imagery must be acquired so the ecotone lines can be re-digitized with each revisit (approximately every 10 years). There are several sources of high quality aerial imagery covering Everglades National Park and the surrounding areas of south Florida, such as the Comprehensive Everglades Restoration Plan (CERP), Florida Department of Revenue (FDOR), and National Agriculture Imagery Program (NAIP). It is likely that imagery sources will change over time but effort should be made to maintain consistency. New aerial imagery used to digitize the mangrove-marsh ecotone must be 1 meter (3.3 ft) or better resolution and have positional accuracy of ± 3 meters (9.8 ft) or better.

Activity type	Activity #	Activity type	Description
Derived Data	6	Continuous Mangrove-Marsh Ecotone segments	The mangrove to marsh ecotone is digitized along fourteen 3-km segments.
	7	Ecotone movement distance	Average movement of digitized lines as mangrove expansion (+) or marsh expansion (-).
	8	Ecotone movement area	Average area of change between digitized lines.
Quality Control Data	9	Distance between marker points and digitized line	The calculated minimum distance between each marker point and the digitized line is used to evaluate accuracy of digitized line (ground truthing remotely sensed feature) and determine when segments generated in activity 6 must be re-digitized.
	10	Duplicate digitization of two segments	Duplicate two digitized segments by a second digitizer for purpose of providing an estimate of digitizing variance on current sampling event and highlight any problems with consistent digitization. This creates the features that are used to estimate the variance in activity 11.
	11	Average distance between digitized lines of two digitizers on two QC segments	Average of nearest neighbor distances between digitized lines of two different digitizers. Used to indicate a value of precision for the primary digitizer.

Sampling Design

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

Table D-2. Activity-level sample design matrix for *South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring: Protocol Narrative* (Moser et al. 2019).

Activity type	Activity #	Activity	Sampling design	Revisit design
Field Observations	2	Vegetation plots on both sides of ecotone	Marker point sample locations along the ecotone, which are a hierarchical systematic sample of 14 segments and 4 points per segment. 5 x 10 m plot oriented perpendicular to ecotone and centered on marker point, with 5 x 5 meter plot on each side of the ecotone.	No revisit of exact plot. New plots along current ecotone sampled approximately every 10 years.
Sensor Data	3	GPS location of marker points	As in activity 2	As in activity 2
	4	Photopoint data	As in activity 2. Four standardized photos are taken at each point.	As in activity 2

Data Quality Objectives

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

Table D-3. Data Quality Values (DQVs) for *South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring: Protocol Narrative* (Moser et al. 2019).

Data quality type	Data quality value	Definition	Protocol considerations
Intrinsic Data Quality	Accuracy	Measurements reflect the true value of the parameter being observed. This applies to measures (length, width, position) or classes (species, types, or categories). Includes components of precision and bias.	RMSE of differences between digitized line and marker points was 3.1 m during pilot work. This positional uncertainty is related to the following potential sources of error: GPS/GNSS accuracy, aerial imagery accuracy, interpretation of line by digitizers, and interpretation of field ecotone position by field personnel.
	Representativeness	Measurements represent conditions at the time of sampling. Combined with accuracy, leads to repeatable data collection.	By digitizing 14 of 42 possible segments along the mangrove-marsh ecotone in a systematic design, any non-digitized section is no greater than 3 km from a digitized section and the sampling should provide a good representative sample of the entire multi-park ecotone. Field work is conducted within 3 years of the imagery date.
Contextual Data Quality	Comparability	The degree to which data can be compared among sample locations, data sources, or periods of time.	Digitizers are trained and then tested by digitizing at least three previously digitized segments to ensure their digitizing is consistent with previous efforts and average difference between the digitizers is 3 m or less. Two segments during a current sampling event are also digitized by a second digitizer to estimate variance in digitization across observers using the current imagery. All sample locations are monitored following the schedule and methods outlined within Moser et al (Draft).

Data quality type	Data quality value	Definition	Protocol considerations
	Timeliness / Currency	How recent the data need to be to be considered valid for their intended use. Data represents conditions and/or is available and in a format for use at the appropriate time in the decision-making process.	Data entry occurs immediately after field sampling. Reporting target is to complete status and trends report by February of following year as described in Moser et al. (Draft). Field data collection should occur within 3 years of imagery collection (closer in time is better).
Contextual Data Quality (continued)	Completeness	All data/ measures required to evaluate accuracy representativeness are present; incomplete data sets (either at a location, across sampling locations, or over time) lose utility or relevance. Data records contain values as planned across the period of record.	Field data for all segments should be collected within 2 years of digitizing of segments. Field marker points which are impossible to navigate to by foot may be collected via helicopter from the air. Marker points collected from the air will be flagged in the database and noted in reports.
Representational Data Quality	Consistent Representation	Use of standard definitions when describing data quality or resource quality based on data	Digitizers are trained and data are collected in accordance with protocol described in Moser et al (Draft).
Data Accessibility	Secure	Access to data, products, and systems limited to appropriate audiences.	All accepted (QA/QC'd) data and products generated from this monitoring effort will be available to the public via IRMA. Raw and provisional data will also be published on IRMA, but their distribution will be limited to network staff and will be made available upon request.

Table D-4. Measurement Quality Objectives for *South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring: Protocol Narrative* (Moser et al. 2019).

Measure	Quality Indicator	Quality Objective
Vegetation Plots on Both Sides of Ecotone	Percent vegetated and non-vegetated cover	± 10%
	Percent vegetation cover by species	± 1%
	Canopy Height	From ground: ± 1 meters for trees, ± 0.5 meter for shrubs, ± 0.5 m for herbs. From helicopter: ± 2 meters for trees, ± 1 meter for shrubs, ± 1 m for herbs.
	Taxonomic Resolution	Identifications made to the species level
	Identification Accuracy	95% accuracy for visual observations
	Identification Completeness	95% of observations made to species level
GPS location of marker points	Location Accuracy	± 1 meter (GPS/GNSS accuracy)
Photopoints	Image resolution	≥ 5 megapixel (≥ 5 million pixels)
	Image format	JPG
Aerial Imagery	Imagery resolution	One meter or better resolution with positional accuracy of ± 3 meters (9.8 ft) or better
	Imagery color	Full color
Continuous Mangrove-Marsh Ecotone segments	Segment Ecotone Location Accuracy	RMSE of differences between digitized line and marker points is ≤ 3.1 m
	Segment Ecotone Digitization Variability	Average distance between two digitizers on two segments is less than 3 meters.

Table D-5. Taxonomic standards to be used in *South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring: Protocol Narrative* (Moser et al. 2019).

Data	Activity	Standard to be Used	Reference/Authority
Collection of Observational Data	3. Vegetation Plots on Both Sides of Ecotone	Scientific Publication	Wunderlin and Hansen (2011)
Reporting of Observational Data	3. Vegetation Plots on Both Sides of Ecotone	Scientific Publication	Wunderlin and Hansen (2011)

Table D-6. Data Protection standards for *South Florida/Caribbean Network Mangrove-Marsh Ecotone Monitoring: Protocol Narrative* (Moser et al. 2019). With the exceptions noted, all data collected are to be made publicly available in a timely fashion.

Type of Information	Type of Data	Level of Protection	Rules for Dissemination
Personally Identifiable Information	Non-NPS Staff Information	Legally Protected	All but initials redacted from public release

Literature Cited

Wunderlin, R. P. and B. F. Hansen. 2011. Guide to the Vascular Plants of Florida, 3rd edition. University Press of Florida, Gainesville, Florida.

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

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