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RECOMMENDATIONS FOR SAMPLING EFFORT OF VEGETATION COMMUNITIES IN THE CRITICAL COASTAL HABITAT ASSESSMENT

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This document relies exclusively on data collected by field crews during the baseline (2015 and 2016) and 2018 Critical Coastal Habitat Assessments. We acknowledge the efforts undertaken in gathering these important data to inform that state of coastal habitats in the Tampa Bay estuary. Specifically, we thank field staff from Atkins North America, Inc. (David Loy, Renee Price), Environmental Science Associates, Inc. (Doug Robison), the Fish and Wildlife Research Institute of the Florida Fish and Wildlife Conservation Commission (Kara Radabaugh, Ryan Moyer), and Gary Raulerson. Preparation of the original Quality Assurance Project Plan and baseline survey design by Lindsay Cross, in addition to several individuals from above, is appreciated. We also thank Pamela Latham for discussions that informed the methods described herein. The conclusions stated in this report were vetted through the Technical Advisory Committee of the Tampa Bay Estuary Program.

Executive Summary

The Critical Coastal Habitat Assessment (CCHA) is a long-term monitoring program to track the potential effects of climate change on emergent tidal wetlands in Tampa Bay at multiple spatial scales of inference. At the finest scale, nine sites are sampled every three to five years along transects that extend landward from the shoreline. The surveys assess characteristics of the vegetation communities, vegetation zones, tree communities, surface elevation, soil characteristics, interstitial porewater salinity, and faunal communities. Basal percent cover of vegetation is recorded in 0.5 x 0.5-m quadrats placed every half meter along the transect and these surveys are the most time-intensive component of the CCHA. The CCHA is expected to continue for several decades and optimizing the sample design for the vegetation communities is critical for long-term sustainability of the monitoring program.

This report evaluates the effect of reduced sampling on key metrics of the vegetation community to identify if reduced sampling effort is possible without compromising quality of the data. Existing data collected at half-meter sampling intervals were systematically down-sampled using a custom software routine. Estimates of species richness at each site, species richness within vegetation zones, elevation estimates of key species, and ability to identify and characterize vegetation zones were obtained for sub-sampled surveys from 1 meter to 10 meter sampling at half-meter intervals.

Conclusions from the analysis are as follows and apply to reductions in effort for sampling vegetation up to 10 meters, or a 95% reduction in relative effort:

- Species richness estimates for vegetation at a site are reduced with lower sampling effort
- The amount of reduction in the species richness estimates was weakly associated with total species richness at a site
- Species richness estimates for a zone are reduced with lower sampling effort
- Species richness estimates will be lower with reduced effort for zones with high richness
- The ranges of elevation occupied by mangroves changes with reduced effort, although patterns varied by site
- All vegetation zones will include at least one quadrat if the sample interval is less than the length of the smallest zone at a site

- Precision of the distance estimates spanned by the quadrats in each vegetation zone decreases with reductions in sampling effort

A reduction in effort by 50%, or sampling every meter, does not significantly affect the key metrics described above. As such, the quantitative assessments included in this report support a recommendation that the 0.5 x 0.5-m quadrats can be placed at 1 meter sampling intervals rather than the previously used 0.5 m (continuous) intervals. This design can be used at all site transects for future surveys without compromising the ability to track long-term changes in vegetation communities in the CCHA.

Additional information supporting this report can be found online at <https://tbep-tech.github.io/ccha-sampling-effort>.

1 Introduction

Native coastal habitats provide multiple ecosystem services that benefit natural communities and human-based uses of the resources. Climate change and sea-level rise are critical threats to the health and resilience of these habitats. Ecosystem changes with projected estimates of sea-level rise and temperature changes are expected to manifest as substantial habitat loss or alteration and landward migration of intertidal species. Mangroves, salt marshes, and salt barrens are collectively referred to as emergent tidal wetlands and are expected to be disproportionately altered by climate change (Sherwood and Greening, 2012; Cavanaugh et al., 2019; Osland et al., 2022). Alteration of these communities may contribute to reduced shoreline stability, increased vulnerability to flooding, changes in water quality, and decreased fisheries production (Kennedy, 1990; Duarte et al., 2013; Gilby et al., 2020). These negative changes may translate to losses of recreational or economic opportunities of those that live in or near coastal environments (Spalding et al., 2014; Toimil et al., 2018).

The Tampa Bay region (Florida, USA) has been identified as one of the most vulnerable areas worldwide to the effects of climate change due to its shallow topography and dense urban population living near the coast (Sherwood and Greening, 2014; Fu et al., 2016). Projections of sea-level rise for Tampa Bay suggest an increase of two to 8.5 feet by the year 2100 (Burke et al., 2019), potentially inundating low-lying coastal areas with emergent tidal wetlands and impacting critical infrastructure. Numerous efforts to track and plan for the projected effects of sea-level rise have been the focus of regional managers in recent decades. The Tampa Bay Estuary Program (TBEP) works to develop science-based solutions for managing the estuary by creating consensus among regional managers on approaches for maintaining a healthy bay and watershed. The TBEP Habitat Master Plan (HMP, Robison et al., 2020) provides coverage targets and goals for all native habitats in the bay, with specific focus on intertidal habitats that are especially vulnerable to climate change and coastal development. These targets and goals are based on coverages that are likely to be achieved following past restoration efforts, available remaining areas for acquisition, and trajectories of land use change for the prior decades.

The Critical Coastal Habitat Assessment (CCHA) complements the HMP by tracking coastal habitat change over time using a long-term monitoring program with multiple spatial scales of inference. The three scales of inference are defined as the “Bay Wide”, “Bay Segment”, and

“Habitat Ecotone” scale (Flaherty-Walia, K. E. and Radabaugh, K. R., 2022). The habitat ecotone scale evaluated herein is designed to complement the coarser scales by providing high-resolution surveys of emergent tidal wetlands (Moyer and Radabaugh, 2017; Price et al., 2017). This is accomplished with field-based estimates of coastal habitats at fixed sites for selected locations around Tampa Bay ([Figure 1](#)). Each of nine sites are sampled every 3-5 years using a transect extending landward from the water to survey herbaceous and woody vegetation, surface elevation, soil characteristics, interstitial porewater salinity, and faunal communities. The surveys also track discrete vegetation zones (e.g., mangrove fringe, salt marsh, coastal uplands, etc.) to assess potential landward shifts or reductions in habitats based on anticipated changes from sea-level rise, increased temperatures, and acute events such as fires and hurricanes. To date, two rounds of sampling have been completed. The first baseline surveys were conducted in 2015 and 2016 (Moyer and Radabaugh, 2017; Price et al., 2017) and a second set of surveys was conducted in 2018.

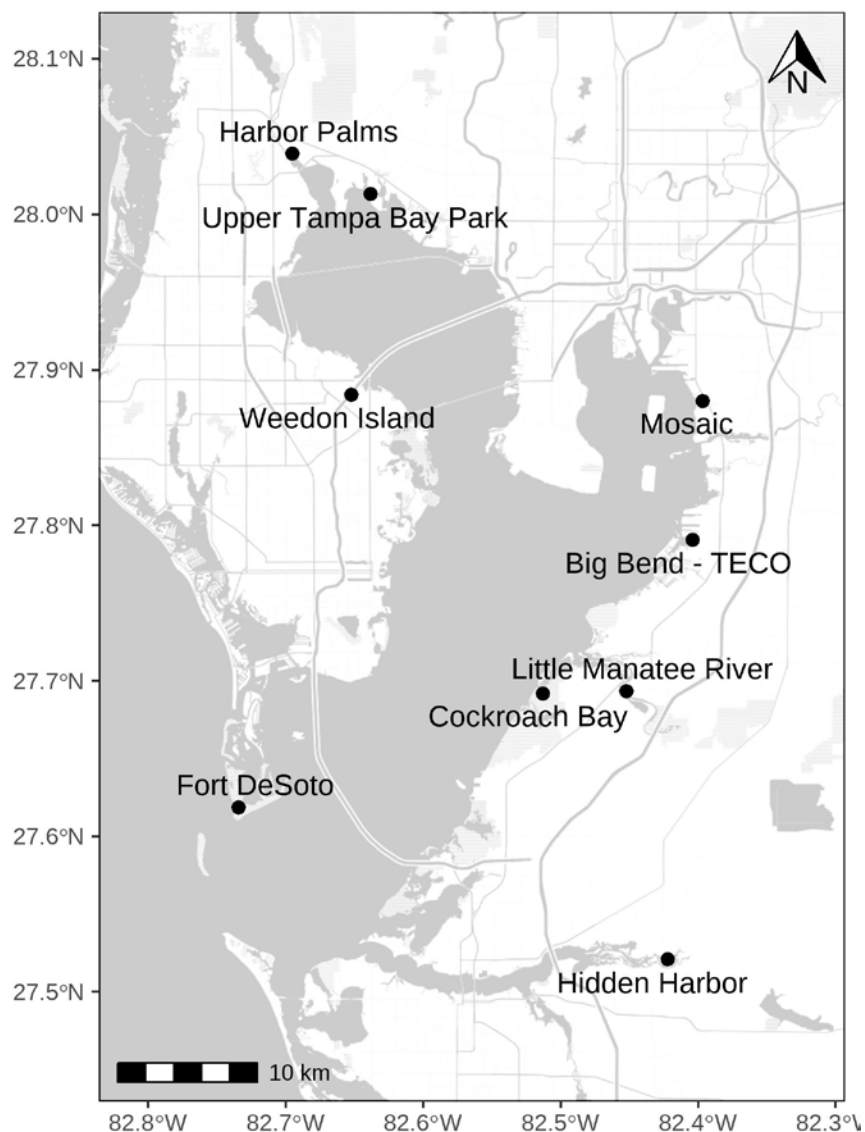


Figure 1: Locations of long-term monitoring sites in Tampa Bay surveyed for the Critical Coastal Habitat Assessment. Each site has been sampled twice as of this report.

The CCHA vegetation surveys are expected to be conducted over the next several decades based on the timeline of likely changes to coastal habitats from climate change (Sherwood and Greening, 2012; Burke et al., 2019). The feasibility of continued surveys depends on the relative effort of collecting useful information that informs understanding of regional effects of sea-level rise and temperature change. The vegetation surveys are a core component of the field efforts that collect information on species richness and cover at each site and within each vegetation zone. Current effort is time-intensive and requires recording basal percent cover of vegetation in a 0.5 x 0.5-m (0.25 m²) quadrat every half meter (continuous sampling) along a transect, where

the mean length of transects is approximately 150 meters. Understanding the quality of data provided by the vegetation surveys at reduced sampling effort will inform the level of effort required for future sampling.

This report evaluates the effect of reduced sampling effort on key metrics for vegetation transects at all CCHA monitoring sites in Tampa Bay. A central hypothesis is that the current sampling effort using quadrats every half meter is not necessary to provide a robust assessment of the vegetation communities and a reduction of effort will not sacrifice the quality of information in the survey. A recommendation of reduced effort is expected to increase the likelihood that surveys will be completed in the future if less time and resources are required for field sampling. A desktop analysis was conducted to sub-sample the existing surveys from 1 meter (50% reduction in effort) to 10 meter (95% reduction in effort) sampling at half meter intervals. Scenarios evaluating more than 50% (1 meter sampling) or 66% (1.5 meter sampling) reduction in effort are unrealistic, but still useful to understand the effects on quantitative measures of habitat. Key metrics describing the vegetation communities were evaluated for each sub-sampled survey and compared to the original estimates calculated from half-meter sampling. Key metrics were evaluated based on information that was considered relevant to evaluate the long-term effects of climate change. These metrics included:

1. Total species richness at a site
2. Total species richness by vegetation zone across sites
3. Elevation at which 95% of key species (e.g., mangroves) occur
4. Vegetation zone identification and lengths by site

Recommendations are provided for the appropriate sampling interval of future surveys.

2 Methods

The current sampling design used at each CCHA site is shown in [Figure 2](#). The transects are perpendicular to the coastline and extend from the water to upland habitats using bench-marked beginning and end locations that are fixed at each site. The vegetation community is surveyed at half-meter marks using a 0.5 x 0.5-m quadrat, where species and basal percent cover of each species are recorded. Additional information collected at each transect includes tree surveys around randomly placed 1 x 1-m quadrats (red boxes, [Figure 2](#)) using the Point-Center-Quarter

method (Cottam and Curtis, 1956), elevation surveys along the length of the transect using Real Time Kinematic (RTK) Global Positioning System, porewater interstitial salinity within each vegetation zone, feldspar horizons and soil samples analyzed for total percent organic content and sediment grain size, and faunal surveys at random plots evaluating species composition and density of crabs (*Uca* spp.) and snails (*Littorina* spp.). Locations of the vegetation zones and the transitions between them are visually assessed and the meter marks are recorded where the transitions occur.

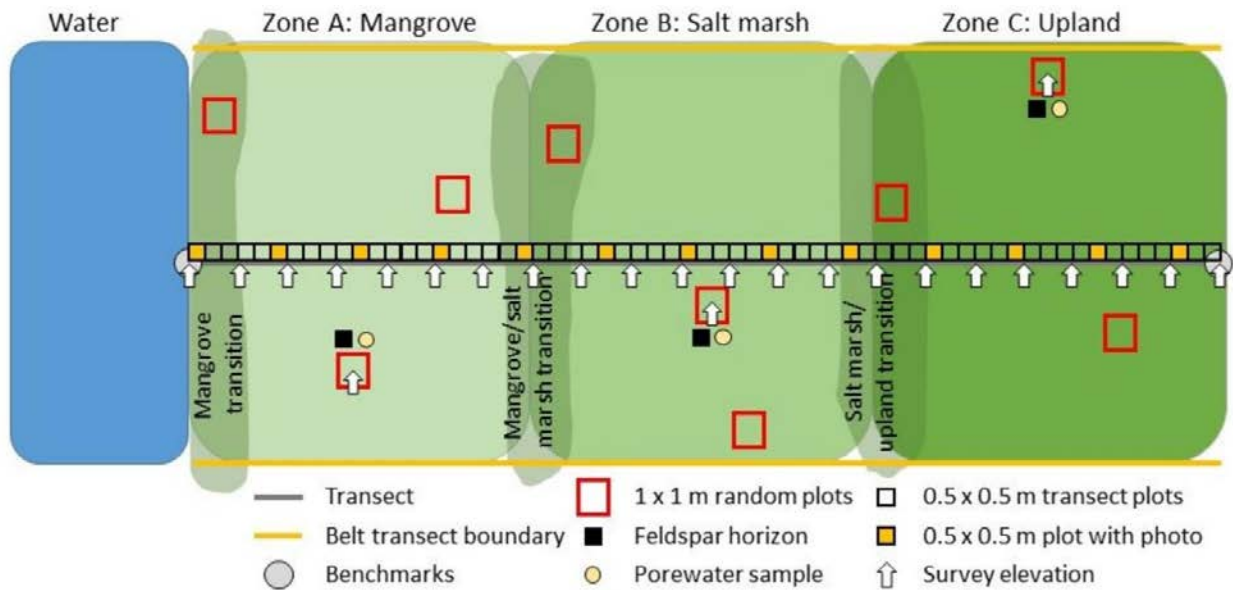


Figure 2: Schematic of the sampling design at all CCHA sites (from Moyer and Radabaugh, 2017). Vegetation quadrats (hollow black boxes) are placed every half meter (continuous) along the main transect from the water to the landward end.

All existing CCHA vegetation surveys at each site and for baseline (2015 - 2016) and 2018 data were sub-sampled from the existing effort of sample plots every half meter. Figure 3 shows an example of the sub-sampling scheme, where effort was reduced in half-meter increments, starting from the complete survey to an upper limit of sampling every 10 meters. For simplicity, Figure 3 shows sub-sampling up to every three meters for a hypothetical 30 meter transect (mean transect length across all sites is approximately 150 meters). The top row represents the complete existing survey as the basis of comparison for the metrics estimated from the sub-sampled datasets in the rows below. The existing surveys were sub-sampled at the specified meter interval for every unique subset (or replicate) that was possible. For example, two unique replicates can be created with sub-sampling every meter, three every 1.5 meters, etc. The large red points in

Figure 3 show which of the existing survey points were sampled for each replicate at the specified sub-sample distance.

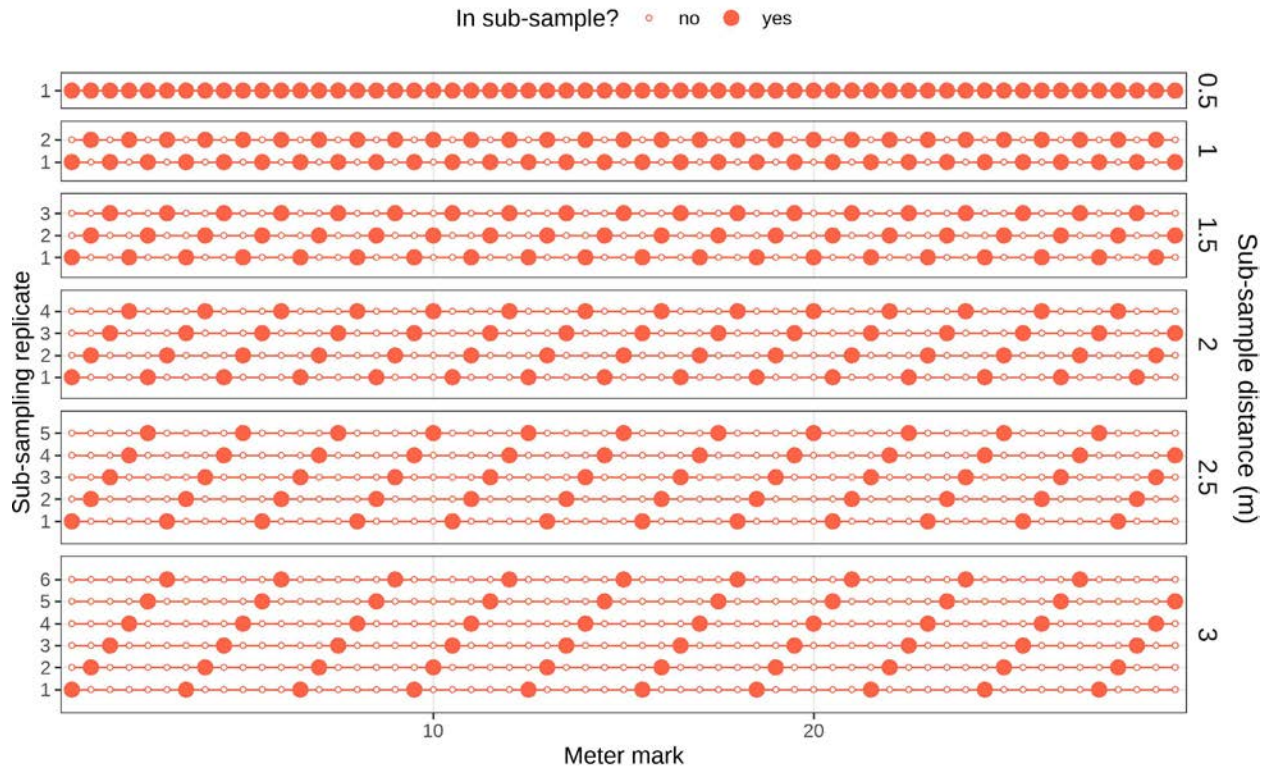


Figure 3: Schematic of the method for creating sub-samples of existing transect data. The full survey with sampling at half-meter intervals is shown at the top, with increasing sampling intervals from top to bottom. Replicates for each sample interval show the unique points that were selected.

The relative reduction in effort associated with each half-meter increase along a transect is shown with Figure 4. The rate of the percent reduction of the original effort with each half-meter reduction in sampling effort decreases from 1 meter to 10 meter sampling, with the largest reduction occurring on the left-side of the x-axis (e.g., half-meter to 1 meter sampling) and the smallest reductions on the right side of the x-axis (e.g., 9.5 meter to 10 meter sampling).

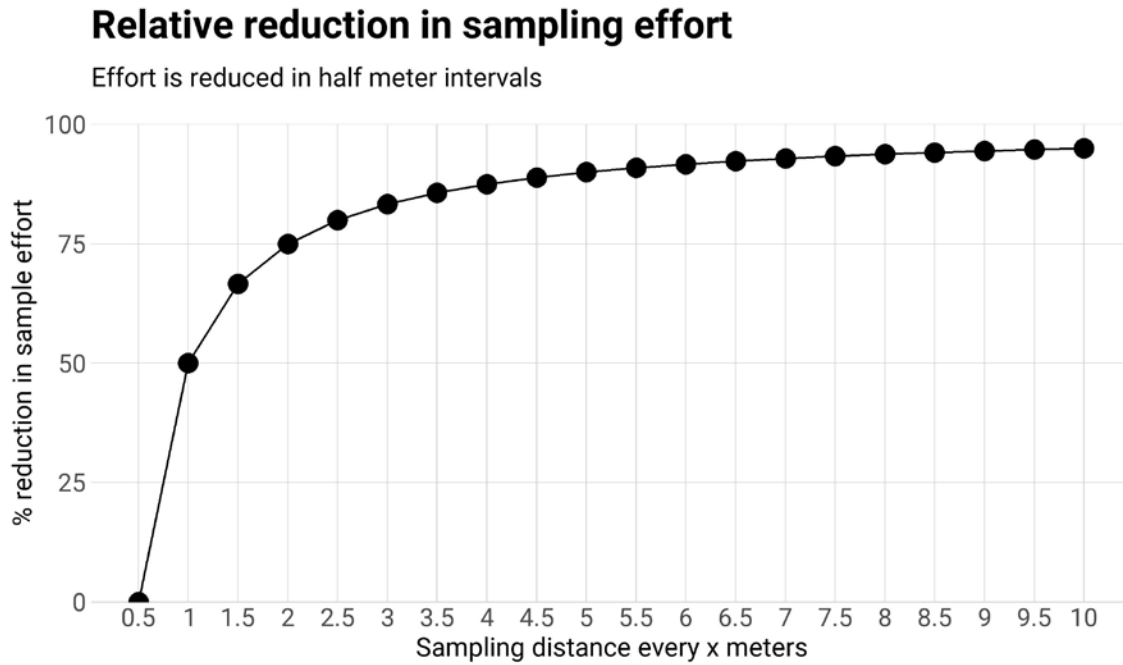


Figure 4: Percent reductions in sampling effort as a function of the sample interval. For example, sampling every 1 meter represents a 50% reduction in effort from half-meter sampling.

For each site and sample year, relevant vegetation metrics were estimated from the transect that was sub-sampled following the methods above. Estimates of species richness at each site and species richness in each vegetation zone were calculated for each sub-sample. The elevations at which key species occurred were also estimated for each level of sampling effort. Three mangrove species that commonly occur in tidal wetlands in Florida (red mangroves, *Rhizophora mangle*, white mangroves, *Laguncularia racemosa*, and black mangroves, *Avicennia germinans*) were assessed as key species expected to be affected by climate change (e.g., landward expansion to higher elevation, colonization of salt marshes and salt barrens, and changes in species distributions, Comeaux et al., 2012; Osland et al., 2022). Elevation measurements from the RTK surveys were combined with the vegetation data and cumulative distribution functions (CDF) of the elevations were calculated for all points in a sub-sample where a key species was found. The 95th percentile of the elevation estimates for each CDF were used to identify an approximate elevation limit for each species and sub-sample. Lastly, the number of unique zones

at each site and the meter mark at which a zone began were also estimated from each sub-sample.

All replicates for each level of sampling effort were considered independent samples and results of each summary metric were averaged across replicates to provide a single estimate for the level of effort. The variance across the estimates was also estimated to describe how each metric varied depending on the level of effort and which meter mark was chosen as the start of the transect. For most metrics, additional characteristics of the data were also evaluated to identify potential factors that contributed to the greatest changes with reductions in effort. For example, estimates at sites with many rare species and potentially higher species richness may be disproportionately affected by reductions in sampling effort (Miller and Ambrose, 2000; Zhang et al., 2019). Metrics were evaluated as total change and the relative percent change from the initial value at half-meter sampling to identify these potential effects. Metrics were also evaluated by comparing total change from half-meter to 10 meter sampling as a function of site-level characteristics, e.g., total richness.

All analyses were conducted using the R Statistical Programming Language (R Core Team, 2022) using custom routines created by the authors. Analysis workflows, source data, and additional online content are available at <https://github.com/tbep-tech/ccha-sampling-effort>.

3 Results

3.1 Species richness estimates

Total species richness estimates at each site and for each year of sampling decreased as expected with reductions in effort (Figure 5). The rate of reduction in the species richness estimates decreased as the sampling intervals increased, in agreement with the level of effort as a percentage of the total shown in Figure 4. Each point in Figure 5 is the average estimate across replicates for the sampling distance shown on the x-axis. The lines are polynomial smooths to show the trend and the size of each point is in proportion to the variance of the species richness estimate across the replicates. The subplots are arranged left to right, top to bottom based on the greatest reduction in species richness as a percentage of the total. Tabular results for selected sampling intervals in Figure 5 are shown in Table 1.

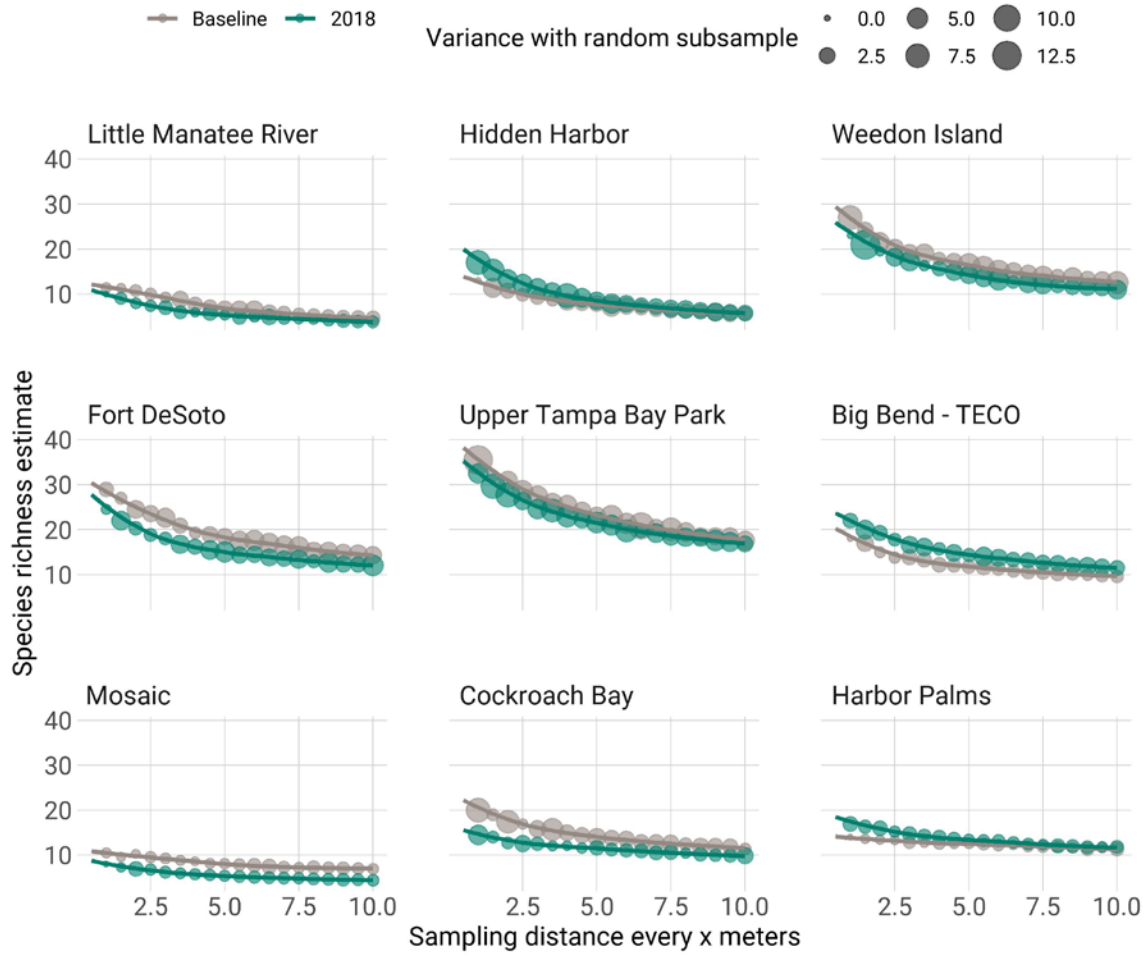


Figure 5: Species richness estimates by sampling distance for all sites and each year of sampling. Point size shows the variance across the replicates for each level of sampling effort.

Table 1: Species richness estimates by selected sampling distances for all sites and each year of sampling. The total species richness is shown for the complete surveys at half meter sampling and the mean species richness plus the percent reduction in parentheses are shown for reduced effort in the remaining columns.

		Sample interval every x meters										
Site	Year	0.5	1	2	3	4	5	6	7	8	9	10
Little Manatee River												
	Baseline	12	11.5 (4)	10.8 (10)	9.3 (22)	7.8 (35)	6.7 (44)	6.3 (47)	5.8 (52)	5.3 (56)	4.8 (60)	4.7 (61)
	2018	11	10 (9)	8 (27)	7 (36)	6 (45)	5.4 (51)	5.1 (54)	4.6 (58)	4.4 (60)	4.1 (63)	3.8 (65)
Hidden Harbor												
	Baseline	14	13 (7)	10.8 (23)	9.3 (33)	8.4 (40)	7.9 (44)	7.4 (47)	6.6 (53)	6.2 (55)	6 (57)	5.7 (60)
	2018	21	17 (19)	13.2 (37)	11.2 (47)	9.6 (54)	8.5 (60)	7.8 (63)	7.3 (65)	6.6 (68)	6.1 (71)	5.8 (72)
Weedon Island												
	Baseline	30	27 (10)	21.5 (28)	19.2 (36)	17.9 (40)	16.5 (45)	15 (50)	14.5 (52)	13.9 (54)	13.3 (56)	12.6 (58)
	2018	27	23 (15)	19.5 (28)	17.3 (36)	15.8 (42)	14.3 (47)	13.2 (51)	12.3 (54)	11.9 (56)	11.6 (57)	11 (59)
Fort DeSoto												
	Baseline	30	29 (3)	24.5 (18)	22.7 (24)	19.4 (35)	18.5 (38)	17.6 (41)	16.4 (45)	15.2 (49)	14.9 (50)	14.3 (52)
	2018	29	24.5 (16)	20.2 (30)	18 (38)	16.2 (44)	15.1 (48)	14.6 (50)	13.6 (53)	13 (55)	12.4 (57)	12.1 (58)
Upper Tampa Bay Park												
	Baseline	39	35.5 (9)	31 (21)	27.5 (29)	25.5 (35)	23.1 (41)	21.4 (45)	20.6 (47)	19.5 (50)	18.6 (52)	17.6 (55)
	2018	36	32.5 (10)	27.8 (23)	24.7 (31)	23 (36)	21.6 (40)	19.8 (45)	19.2 (47)	18.2 (49)	17.6 (51)	16.8 (53)
Big Bend - TECO												
	Baseline	21	18 (14)	15 (29)	13.8 (34)	12.2 (42)	11.8 (44)	11.3 (46)	10.6 (49)	10.2 (51)	10.1 (52)	9.7 (54)
	2018	24	22 (8)	19.2 (20)	16.7 (31)	15.8 (34)	14.4 (40)	13.8 (43)	13.1 (45)	12.4 (48)	11.8 (51)	11.6 (52)
Mosaic												
	Baseline	11	10.5 (5)	10.2 (7)	9.3 (15)	8.6 (22)	8.1 (26)	7.8 (30)	7.4 (33)	7.3 (34)	7.1 (35)	7 (37)
	2018	9	8 (11)	7 (22)	6.2 (31)	5.8 (36)	5.4 (40)	5.2 (43)	4.9 (45)	4.7 (48)	4.6 (49)	4.4 (51)
Cockroach Bay												
	Baseline	23	20 (13)	17.5 (24)	15.8 (31)	15 (35)	14 (39)	13.6 (41)	12.8 (44)	12.4 (46)	12.2 (47)	11.4 (50)
	2018	16	14.5 (9)	12.8 (20)	12.5 (22)	12.1 (24)	11.7 (27)	11.1 (31)	10.6 (34)	10.4 (35)	10 (38)	9.9 (38)
Harbor Palms												
	Baseline	14	14 (0)	13.5 (4)	12.8 (8)	12.6 (10)	12.7 (9)	12.2 (13)	12 (14)	11.9 (15)	11.4 (18)	11.3 (19)
	2018	19	17 (11)	16 (16)	14.7 (23)	14 (26)	13.4 (29)	13.2 (30)	12.6 (34)	12.1 (36)	11.7 (38)	11.8 (38)

Figure 6 shows similar results as Figure 5, except richness is scaled as a percentage of the total at each site for full sampling effort. This plot allows a comparison of a reduction in the estimate independent of the overall species richness because the sensitivity of the change may vary depending on the total. The greatest percent reductions in the richness estimates with decreased sampling were observed at the Little Manatee River and Hidden Harbor sites.

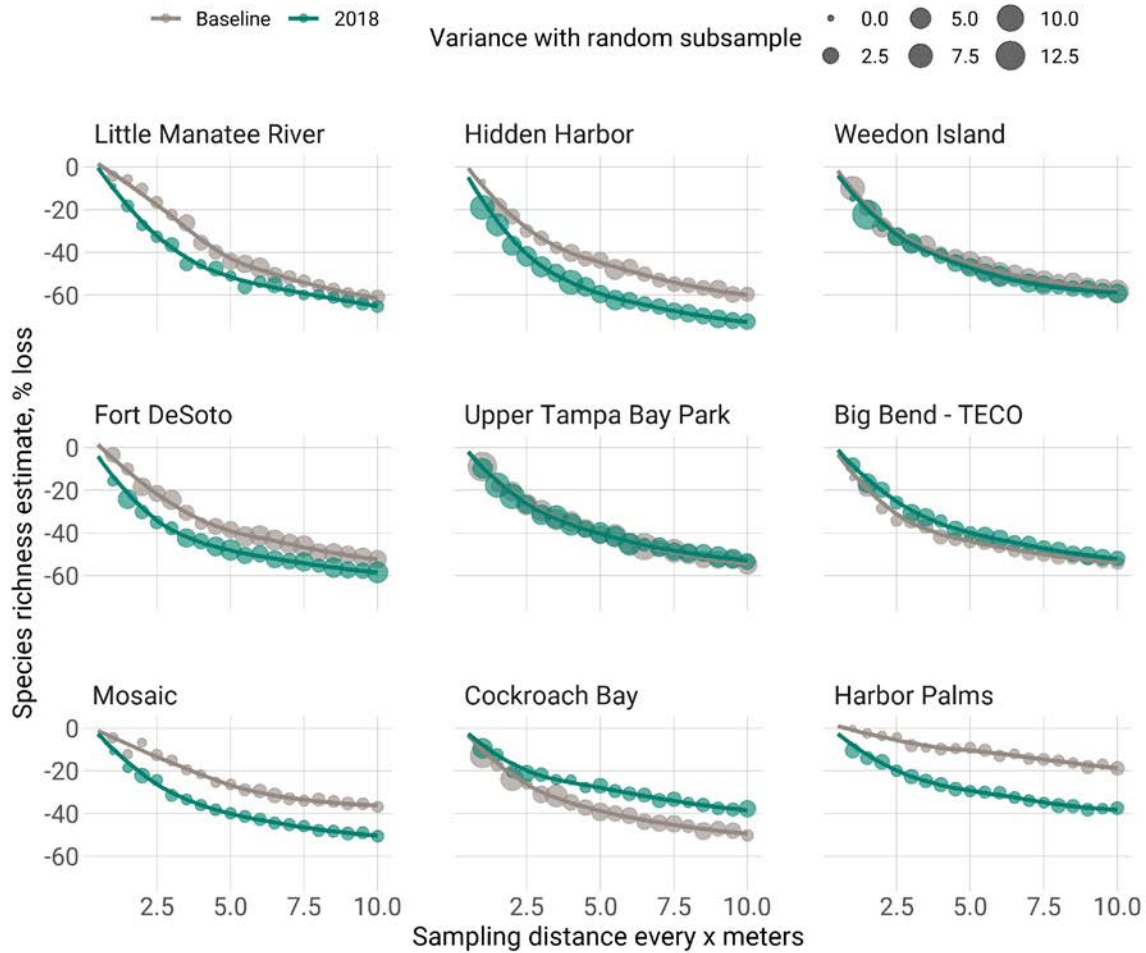


Figure 6: Relative percent reductions in species richness estimates with sampling distance for all sites and each year of sampling. Point size shows the variance across the replicates for each level of sampling effort.

An assessment of percent loss in the richness estimates from every half-meter to every 10 meters of sampling as a function of total species richness is shown in [Figure 7](#). This plot tests the assumption that estimates at sites with higher species richness will be affected more strongly by reductions in effort. There is some evidence that a greater reduction in species richness is expected at sites with higher richness, although a linear regression fit through the points shows the model is insignificant ([Figure 7](#)).

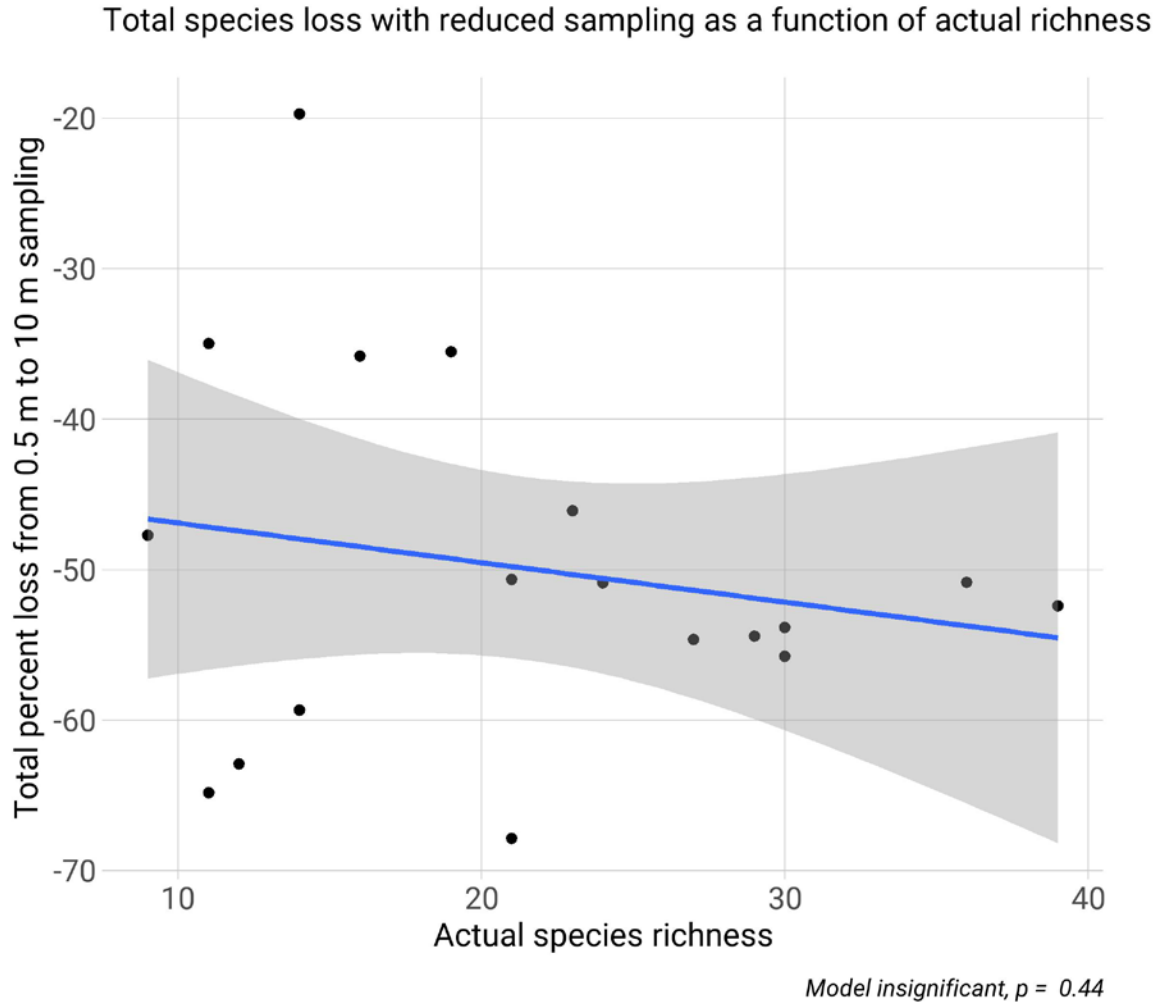


Figure 7: Total percent loss in species richness estimates from 0.5 to 10 meter sampling as a function of actual species richness at half-meter sampling.

3.2 Species richness estimates by zone

Similar to the species richness estimates at each site, species richness also declined with reduced sampling effort within the unique vegetation zones observed across all sites. A total of 28 vegetation zones were sampled across the nine sites, although inconsistent naming prevented a comparison of similar zones between sites. In general, the unique zones across all sites can be grouped as 1. Brazilian Pepper Berm and *Schinus terebinthifolius*; 2. Transitional wetland and transitional marsh; 3. High salt barren, unvegetated salt barren, and salt barren; 4. Short

mangrove, mangrove, mangrove fringe, immature mangrove fringe and 5. Open water (channel, freshwater pond, tidal creek, tidal mud flat). The following results retain unique zone names for each site and future sampling should use standardized zone names between sites.

The lines in Figures 8, 9, 10, 11, 12, 13, 14, 15, and 16 show the estimated reduction in the species richness estimates for individual zones at each site in the left plot and percent reductions in species richness estimates in the right plots. Species richness counts were pooled between the baseline and 2018 surveys. As for the site-level assessments, the rate of reduction decreased with increasing sampling distance within each zone. The highest overall richness was observed in the coastal upland zone at Big Bend -Teco (23 species, Figure 8) and transitional marsh at Cockroach Bay (21 species, Figure 9). Consequently, the zones at these sites had large decreases in total richness with reduced effort. Aquatic zones (channel, freshwater pond, and tidal creek) had very little vegetation (*Juncus roemerianus* or *Blutaparon vermiculare*) and did not show any changes with reduction in effort, as expected. Changes in richness with reduced effort varied considerably for the coastal uplands, where total richness differed by site (highest at Big Bend - Teco, Figure 8, lowest at Cockroach Bay, Figure 9).

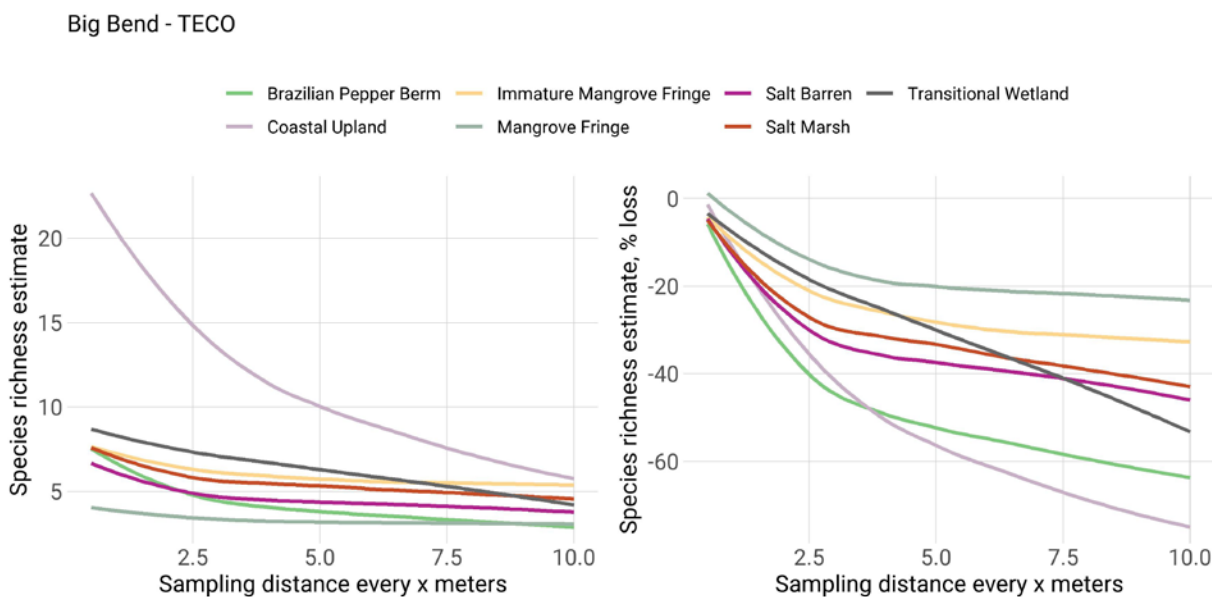


Figure 8: Species richness estimates by sampling distance for each zone at Big Bend - Teco. The left plot shows total species richness and the right plot shows relative percent reductions in species richness. Lines are colored by zones.

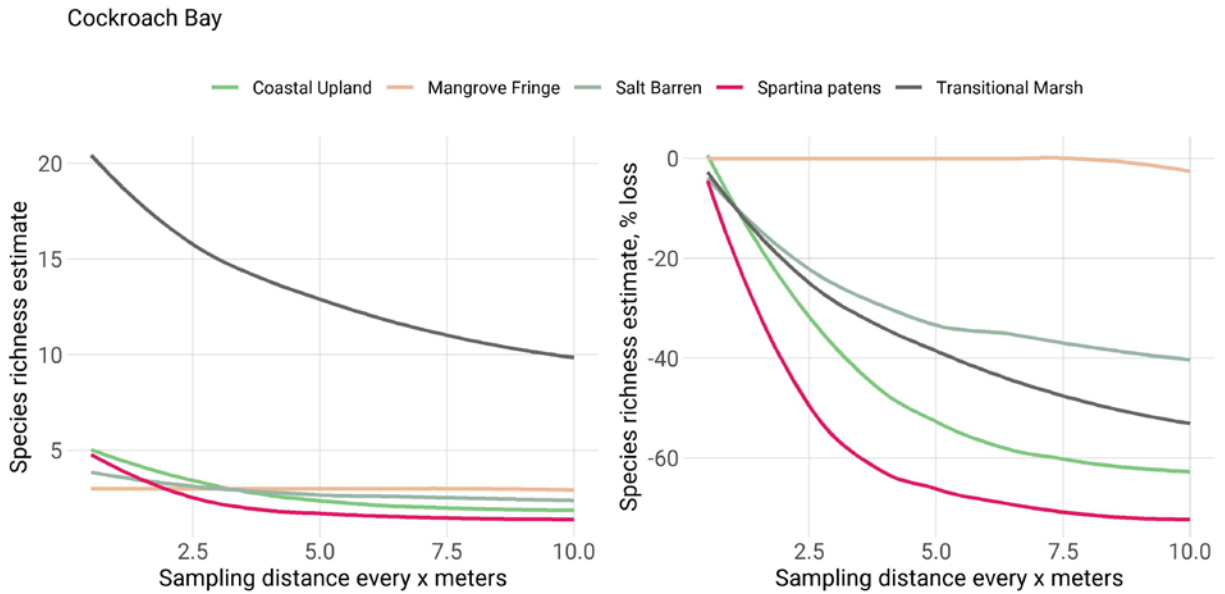


Figure 9: Species richness estimates by sampling distance for each zone at Cockroach Bay. The left plot shows total species richness and the right plot shows relative percent reductions in species richness. Lines are colored by zones.

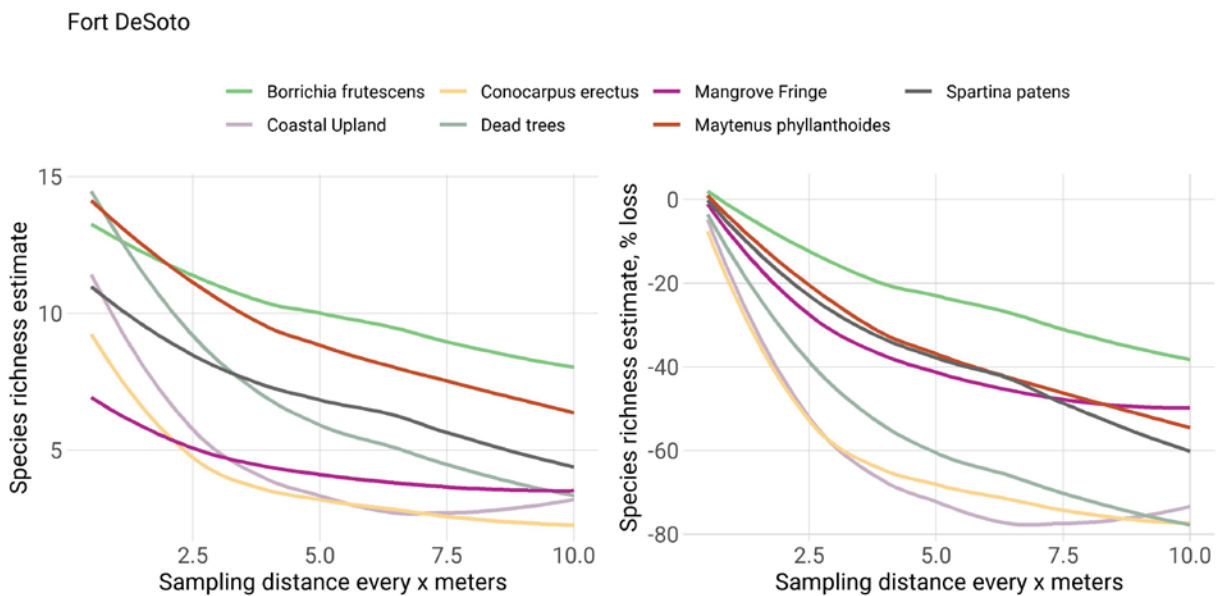


Figure 10: Species richness estimates by sampling distance for each zone at Fort DeSoto. The left plot shows total species richness and the right plot shows relative percent reductions in species richness. Lines are colored by zones.

Harbor Palms

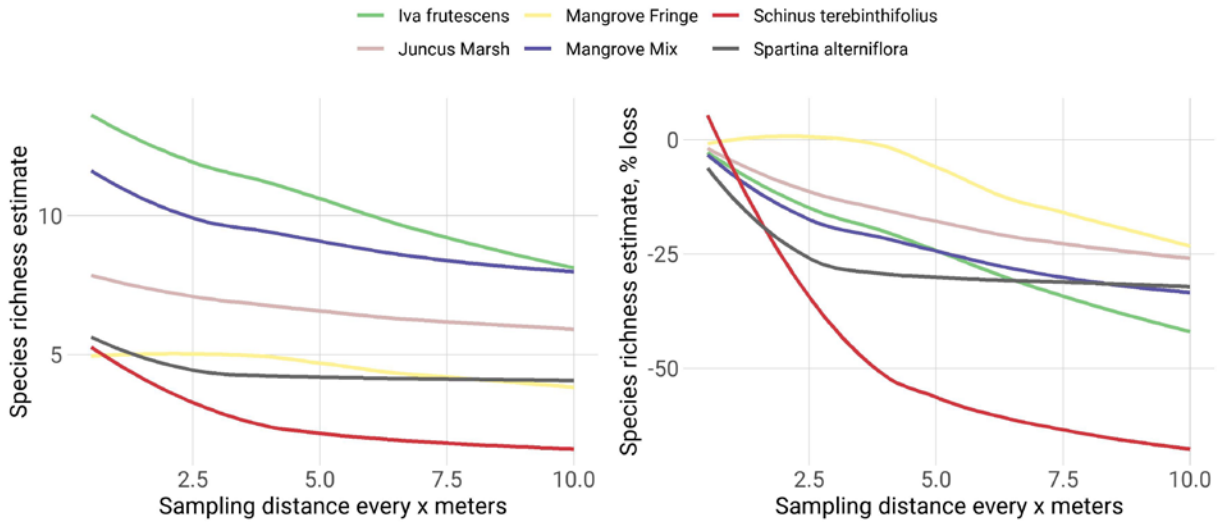


Figure 11: Species richness estimates by sampling distance for each zone at Harbor Palms. The left plot shows total species richness and the right plot shows relative percent reductions in species richness. Lines are colored by zones.

Hidden Harbor

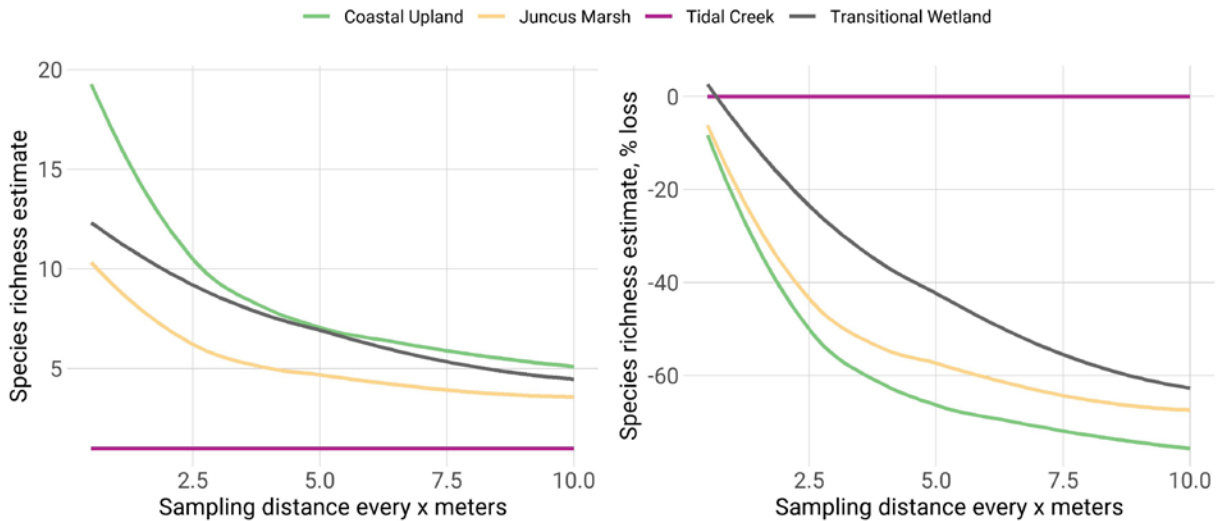


Figure 12: Species richness estimates by sampling distance for each zone at Hidden Harbor. The left plot shows total species richness and the right plot shows relative percent reductions in species richness. Lines are colored by zones.

Little Manatee River

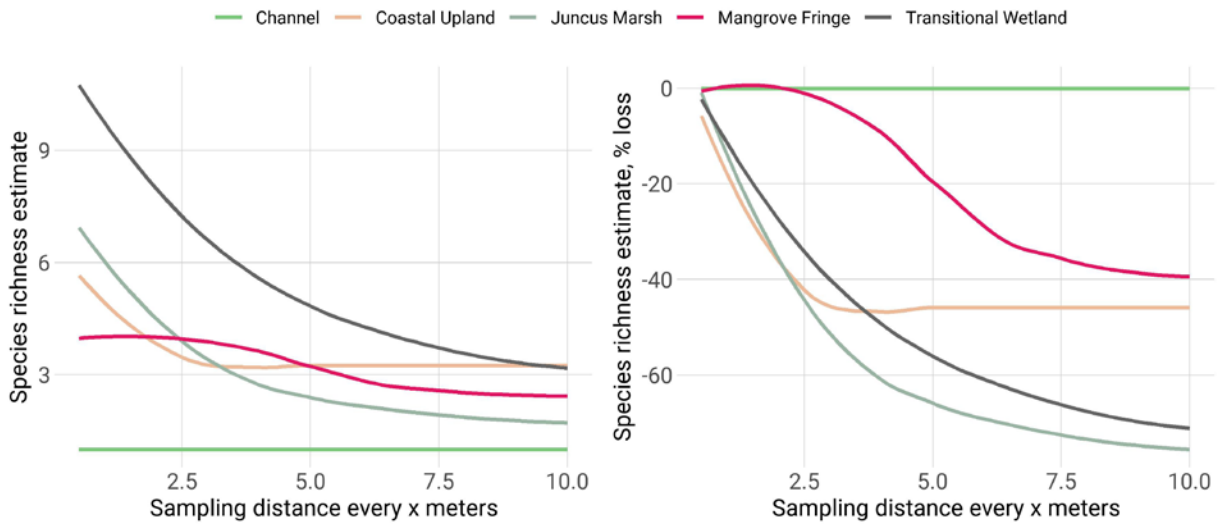


Figure 13: Species richness estimates by sampling distance for each zone at Little Manatee River. The left plot shows total species richness and the right plot shows relative percent reductions in species richness. Lines are colored by zones.

Mosaic

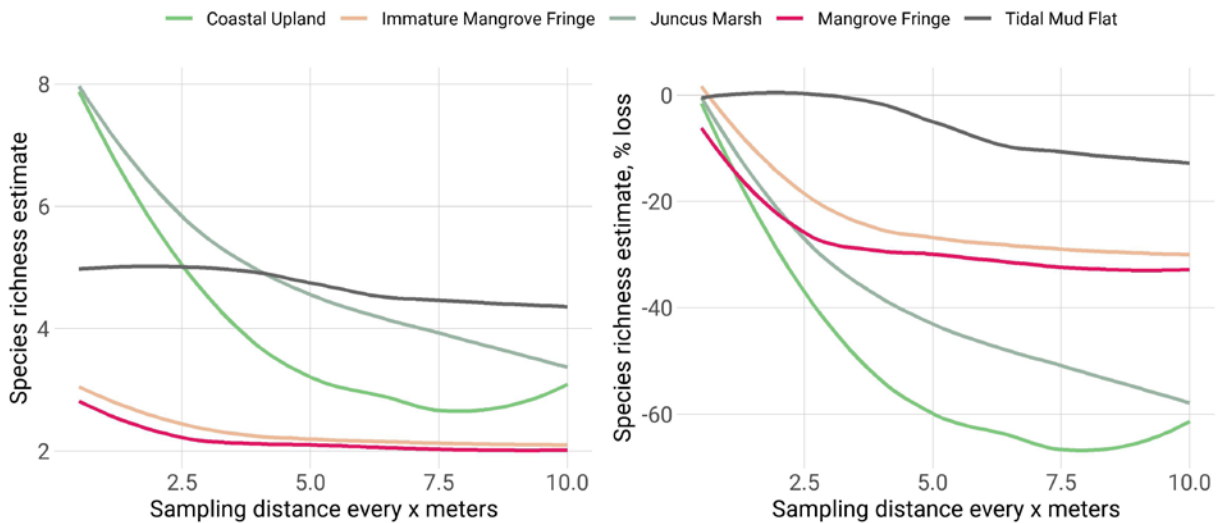


Figure 14: Species richness estimates by sampling distance for each zone at Mosaic. The left plot shows total species richness and the right plot shows relative percent reductions in species richness. Lines are colored by zones.

Upper Tampa Bay Park

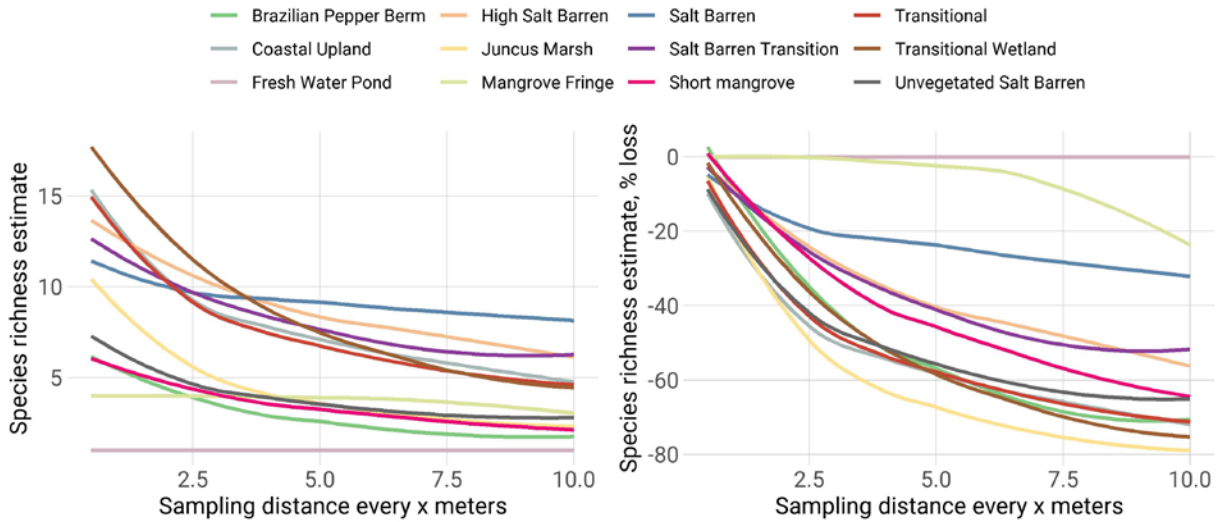


Figure 15: Species richness estimates by sampling distance for each zone at Upper Tampa Bay Park. The left plot shows total species richness and the right plot shows relative percent reductions in species richness. Lines are colored by zones.

Weedon Island

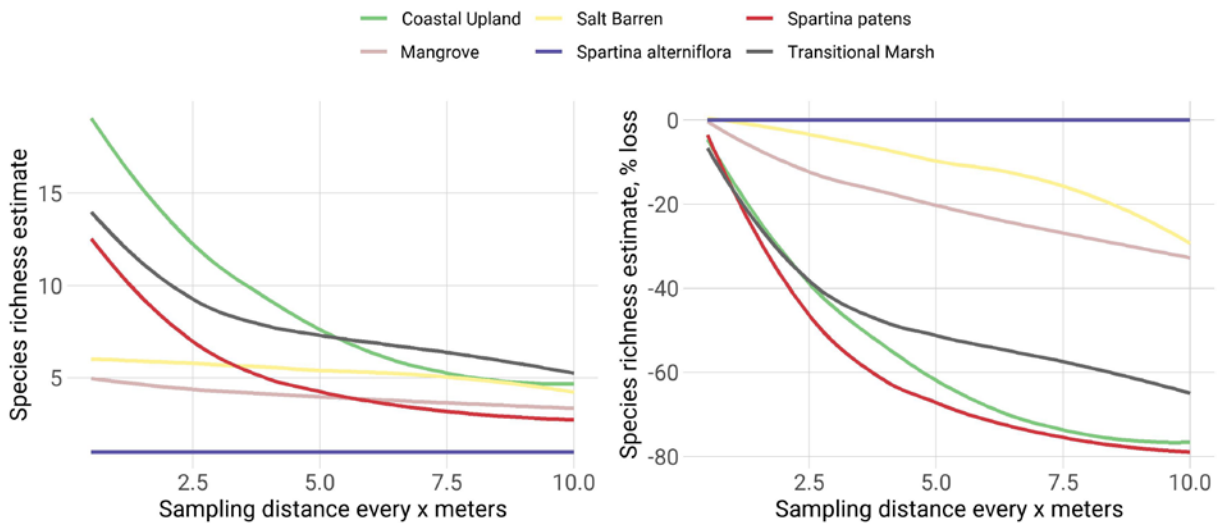


Figure 16: Species richness estimates by sampling distance for each zone at Weedon Island. The left plot shows total species richness and the right plot shows relative percent reductions in species richness. Lines are colored by zones.

Figure 17 shows the relationship between percent loss in species richness with actual species richness in the unique zones for each site. There is strong evidence that greater reductions in species richness estimates are expected for zones with higher actual species richness (linear fit was significant, $p < 0.05$).

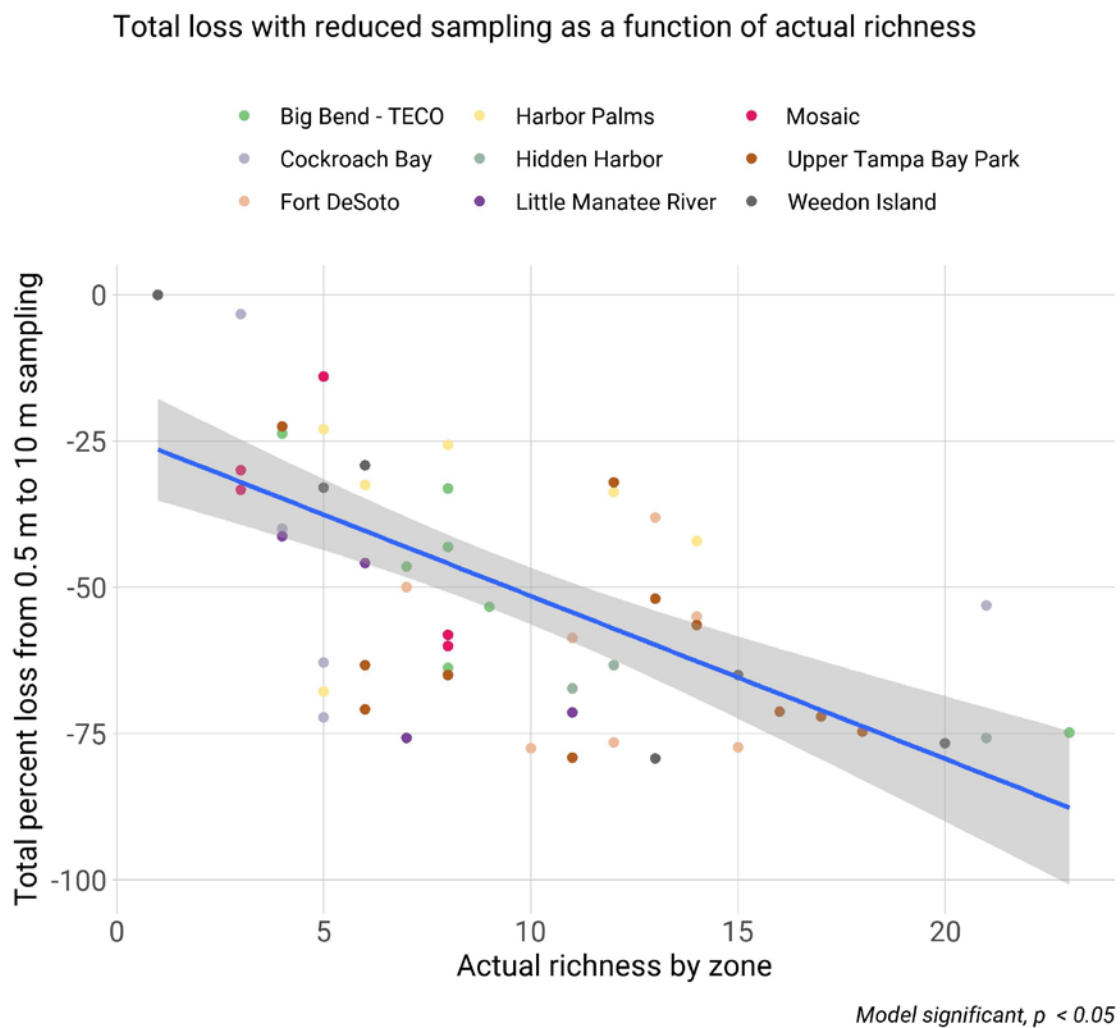


Figure 17: Total percent loss of richness from half-meter to 10 meter sampling as a function of actual species richness within a zone. Points are colored by site and each point represents a unique zone at a site.

3.3 Elevation of key species

Elevation estimates from the CDF curves at which 95% of mangrove species were observed with reductions in sampling effort varied by site (Figure 18). These measures can be considered an approximate upper elevation limit at which mangrove species are observed at each site for each level of sampling effort. Consistent reductions in the elevation estimates with reduced sampling effort were observed for all species at some sites (e.g., Fort De Soto, Mosaic), whereas only some species showed reductions at some sites (e.g., only *Rhizophora mangle* showed a reduction in elevation at Big Bend - Teco). Additionally, the overall elevations at half-meter sampling varied by species at each site, such that red mangroves (which typically are found at lower elevations) were observed at higher elevations (Big Bend, Little Manatee River) or lower elevations (Cockroach Bay, Mosaic, Upper Tampa Bay Park) than the other two species. The variance in the estimated elevation across all species generally increased with reductions in sampling effort.

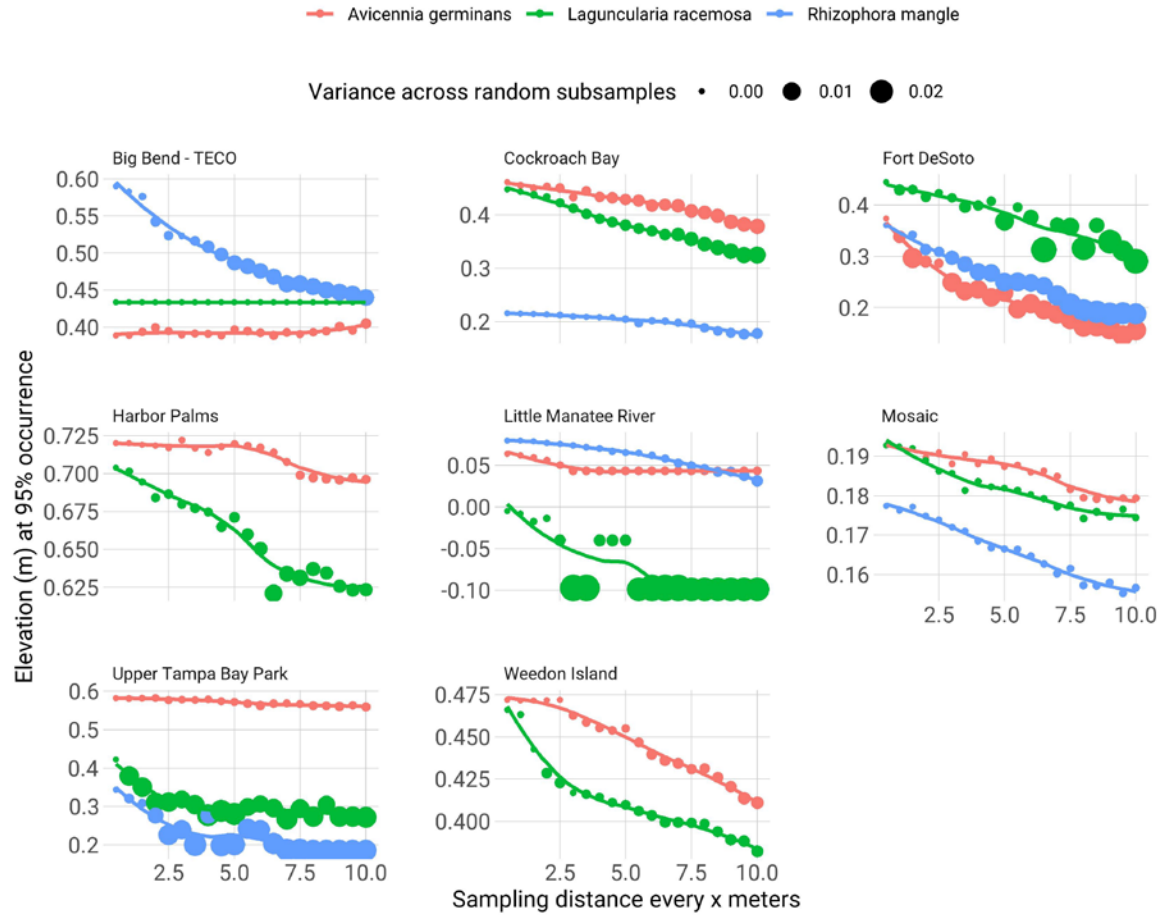


Figure 18: Elevation estimates of three mangrove species with sampling distance at each site. Point size shows the variance across the replicates for each level of sampling effort.

The total change in the elevation estimates as a percentage of the original was strongly influenced by overall frequency occurrence of each species at a site (Figure 19, $p < 0.05$). Species with greater frequency occurrence at a site have smaller changes in the elevation estimates with reductions in sampling effort. Lower variance among the estimates was observed for species with higher frequency occurrences, although the linear regression was not significant (Figure 20, $p > 0.05$).

Change in elevation estimate with frequency occurrence

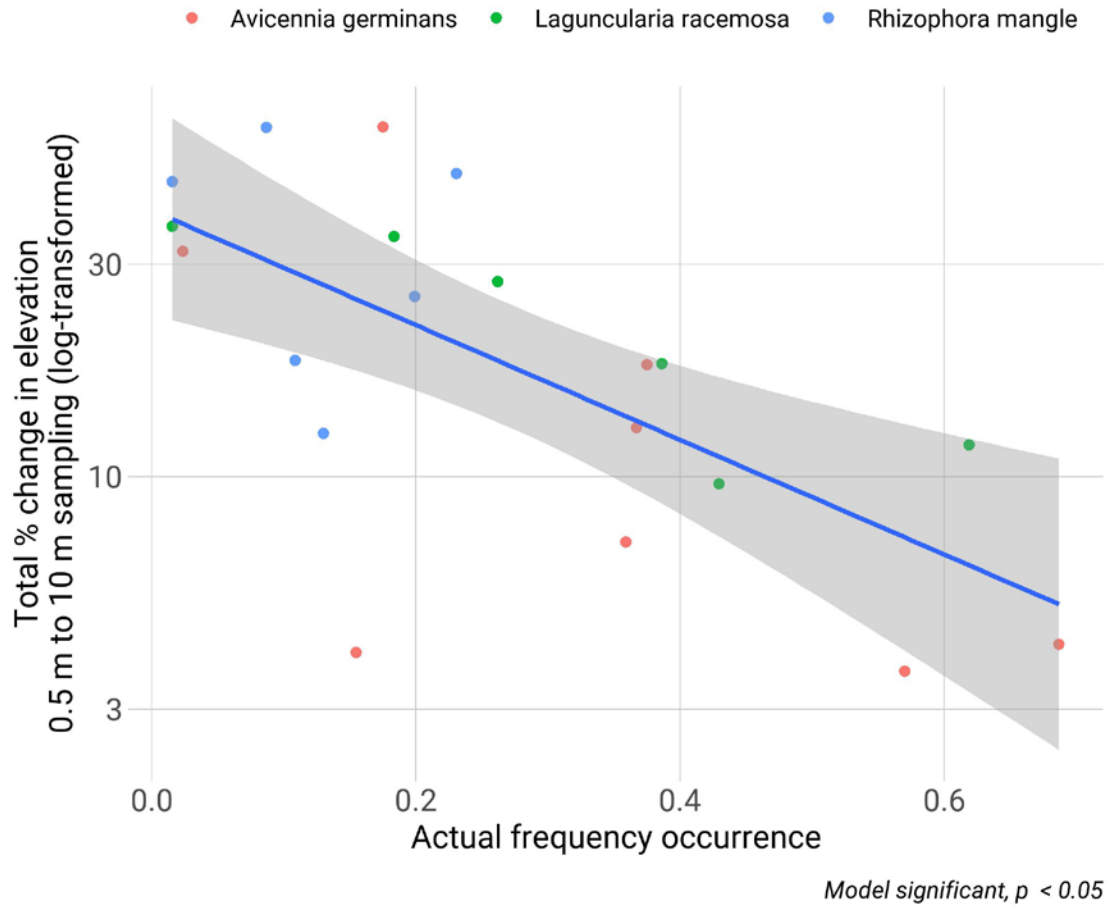


Figure 19: Total percent change in elevation estimates for three mangrove species from half-meter to 10 meter sampling as a function of actual frequency occurrence of each species at half-meter sampling.

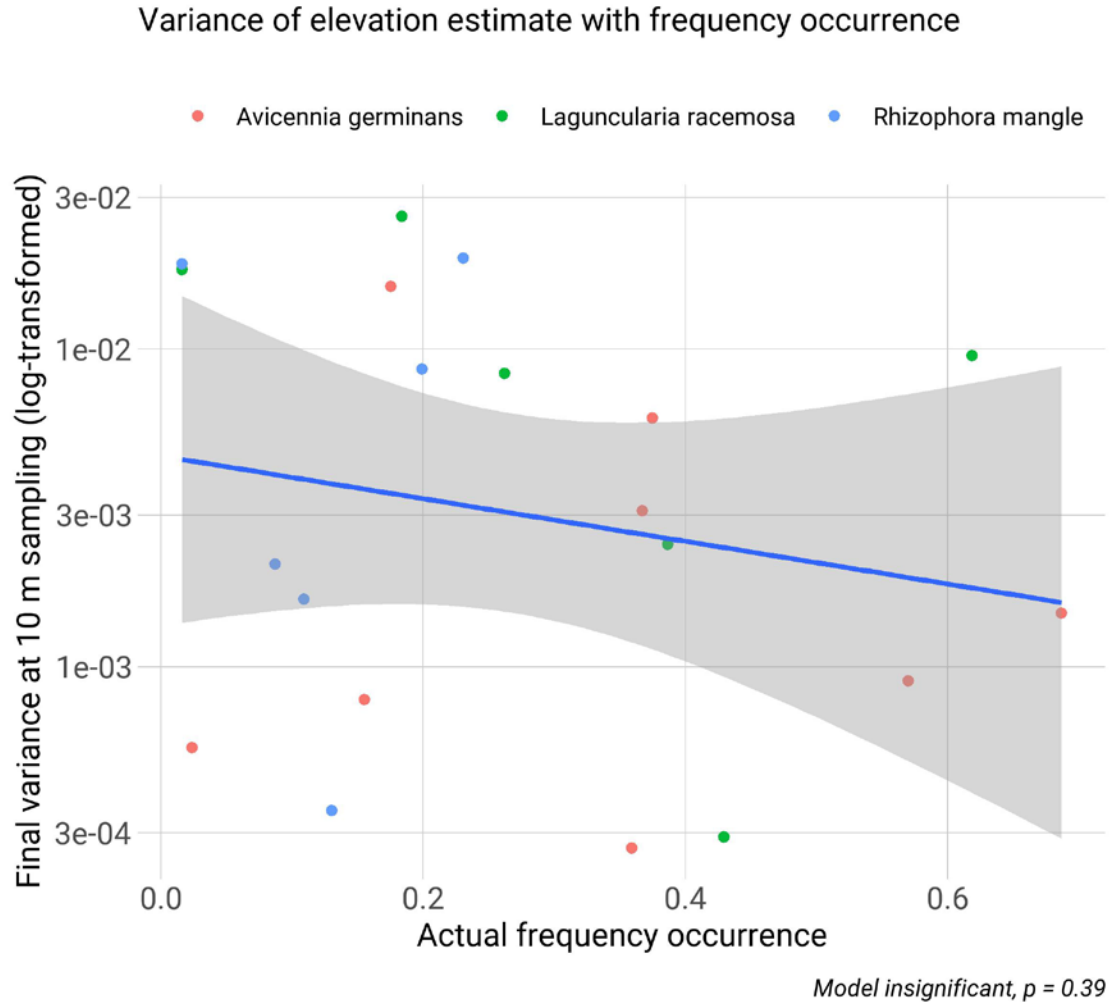


Figure 20: Variance of the elevation estimates of three mangrove species at 10 meter sampling as a function of actual frequency occurrence of each species at half-meter sampling.

3.4 Zone identification

The number of unique vegetation zones along each transect varied among the sites, with a maximum of twelve zones at Upper Tampa Bay Park and a minimum of four zones at Hidden Harbor. The minimum zone length observed was 1 meter for the tidal creek zone at Hidden Harbor and the maximum zone length was 102 meters for the *Juncus* marsh zone at Little Manatee River. Mean zone length across all sites was 23 meters. An assessment of the ability to sample all of the zones at a site with reduced sampling effort showed that at least one plot would

occur per zone for most intervals of sampling up to sampling every 10 meters (Figure 21). Each zone would include at least one quadrat at any level of sampling effort for Big Bend - TECO, Fort DeSoto, and Harbor Palms, whereas some zones were missed for the other sites depending on the sampling interval. For example, Hidden Harbor includes four zones, with the smallest zone 1 meter in length. An average zone count of less than four occurs when the sampling interval is greater than 1 meter, i.e., 1.5 meters, as that sampling interval excludes a quadrat in the tidal creek zone for some of the replicates. The length of the smallest zone for sites where the average count begins to decrease with reduced effort can be seen at the point where the curve is no longer constant at the true zone count. As such, all zones will include at least one quadrat if the sampling interval is less than the length of the smallest zone.

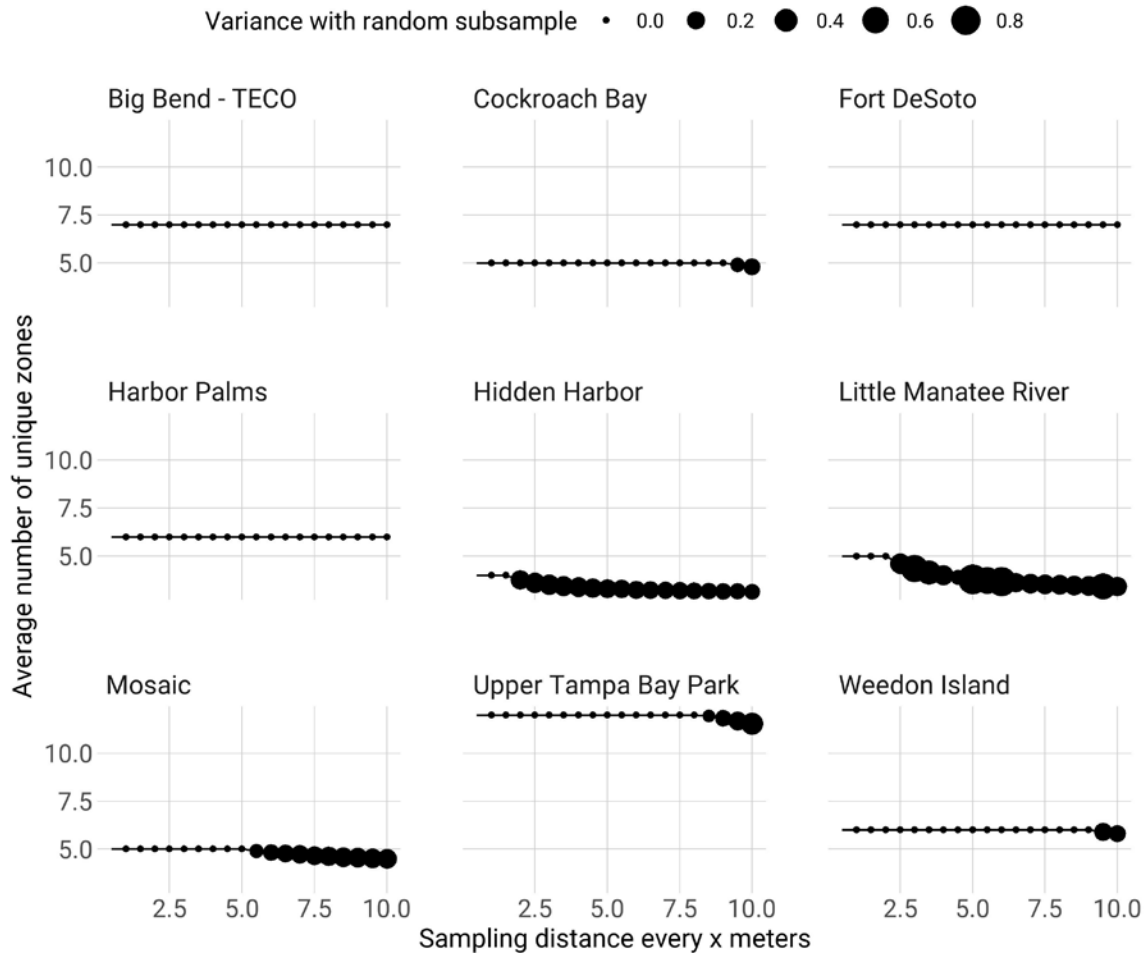


Figure 21: Number of unique zones with at least one quadrat at each site from half-meter to 10 meter sampling. Point size shows the variance across the replicates for each level of sampling effort.

Although the zone lengths can be accurately determined in the field using the distances between zone markers, the following shows how length estimates may vary with reduced sampling effort if based on the distances spanned by the quadrats in each zone. Following the latter, estimated lengths of each zone did not change systematically, although the variance of the estimates increased with reduced sampling effort (Figure 22). The change in variance was non-linear, such that it generally increased with reduced effort, but often was estimated at low or zero variance depending on the sampling interval. An example from Big Bend - TECO demonstrates how variance of the distance estimates changes across each zone with the sampling effort (Figure 23).

The total zone length is shown at the top of each subplot. The variance estimates in a zone fall to zero when the zone distance can be evenly divided by the sampling interval, i.e., the same distance estimate is obtained for each sub-sample at the specified sampling interval. Variance estimates peak between zero values when the remainder of the zone distance divided by the sample distance is not zero, i.e., each sub-sample estimates a different length for the zone distance.

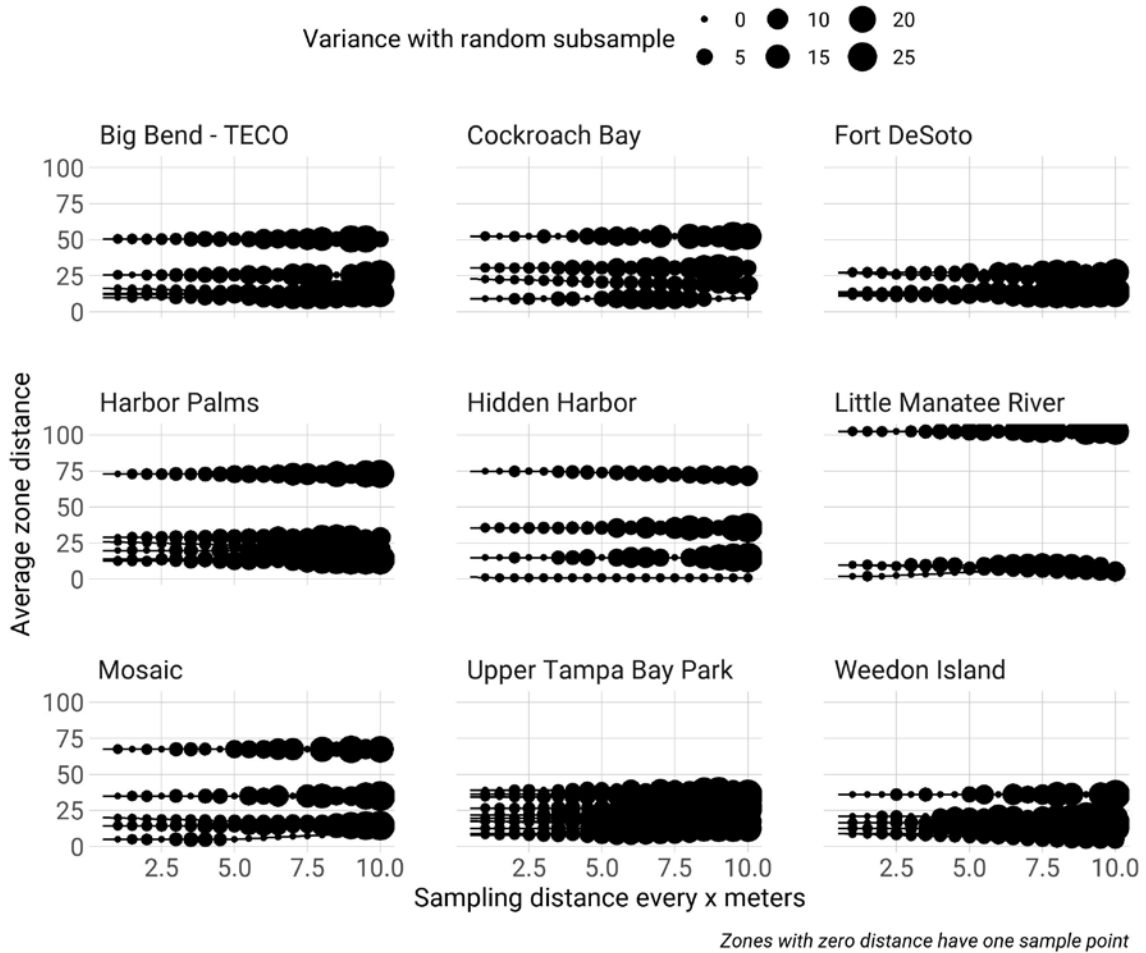


Figure 22: Total distance spanned by quadrats within each zone at each site from half-meter to 10 meter sampling. Each line is a unique zone. Point size shows the variance across the replicates for each level of sampling effort.

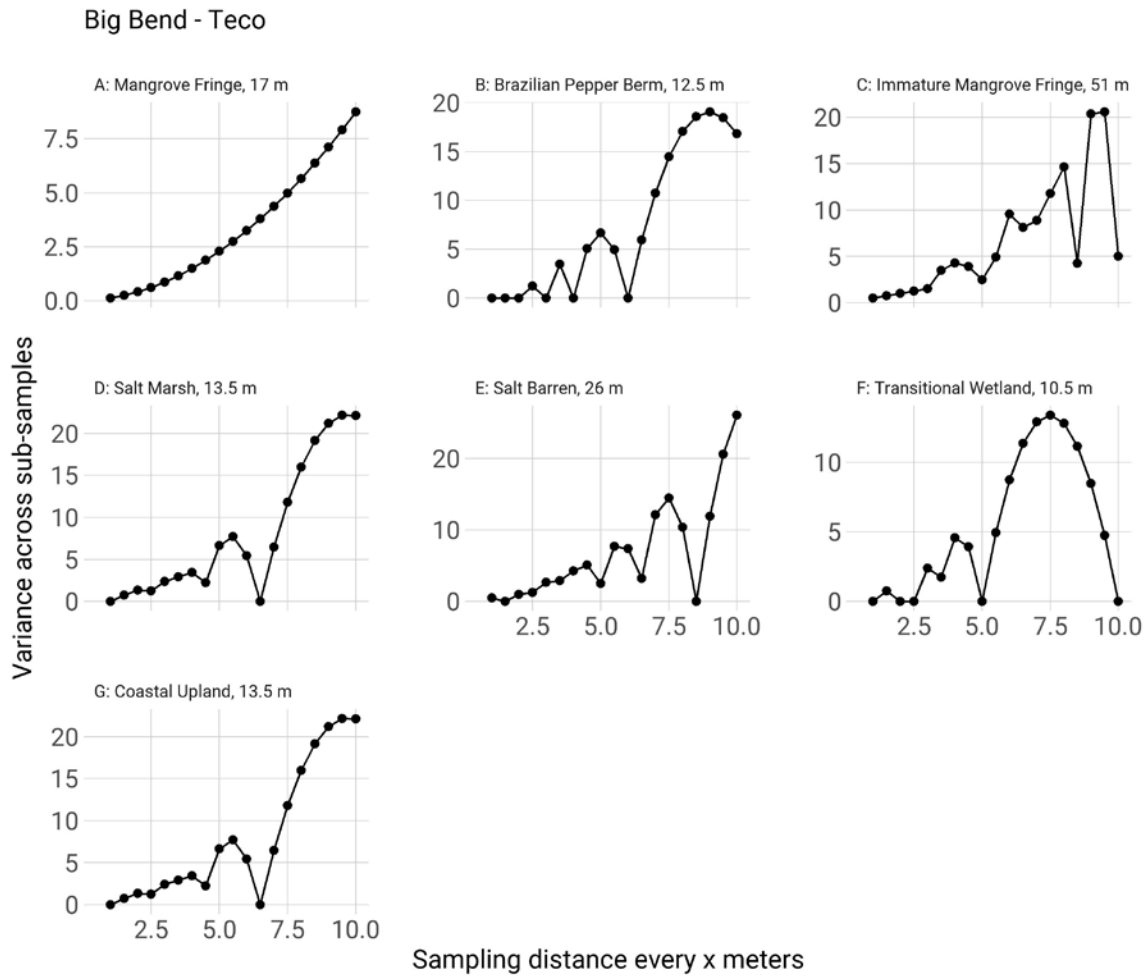


Figure 23: An example of the variance of the distances spanned by quadrats across sub-sample replicates for each zone at the Big Bend - TECO site from half-meter to 10 meter sampling.

Detailed results for the zone lengths estimated from distances spanned by quadrats at each site are shown in Figures 24, 25, 26, 27, 28, 29, 30, 31, and 32. The shaded areas represent the true zones at half-meter sampling and the points show the estimates of the starting location for each zone at the specified sampling interval. The horizontal bars show the variance across the sub-samples for each level of sampling effort. The figures clearly show a reduction in precision for the zone lengths and an inability to identify some zones (overlap of estimates) with decreasing sampling effort.

Big Bend - TECO

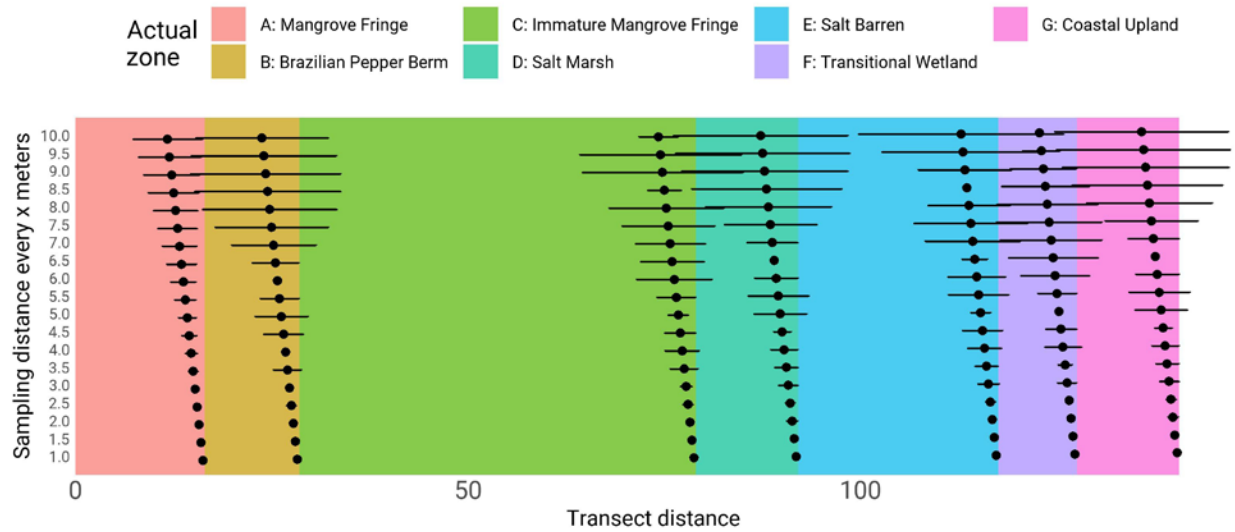


Figure 24: Estimates and variance of the estimates in the zone starting locations at Big Bend - Teco at 1 meter to 10 meter sampling for the distances spanned by the quadrats. The colored regions indicate the zone delineations at half-meter sampling.

Cockroach Bay

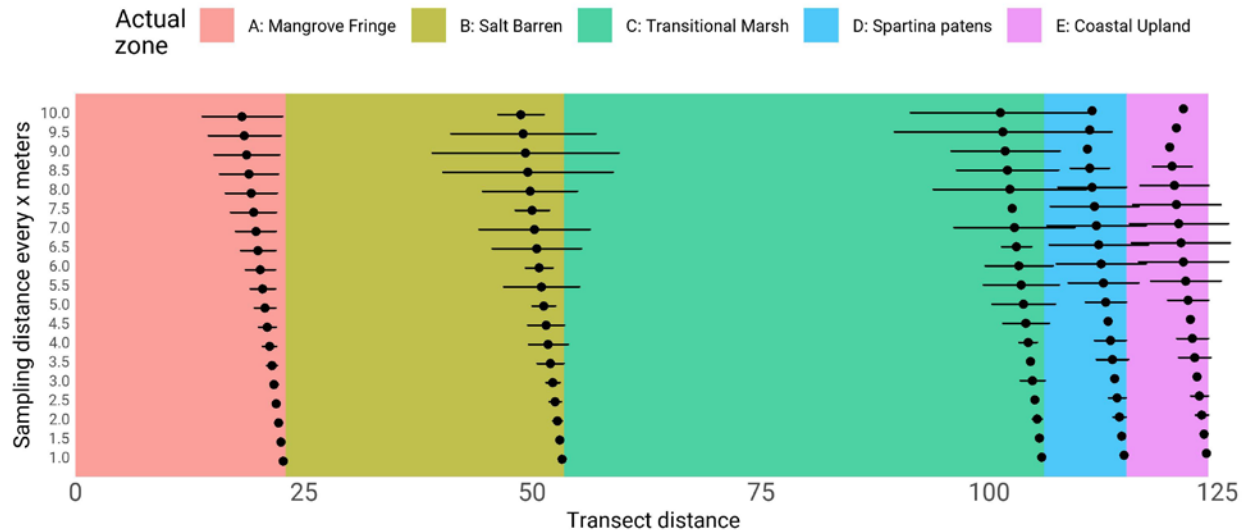


Figure 25: Estimates and variance of the estimates in the zone starting locations at Cockroach Bay at 1 meter to 10 meter sampling for the distances spanned by the quadrats. The colored regions indicate the zone delineations at half-meter sampling.

Fort DeSoto

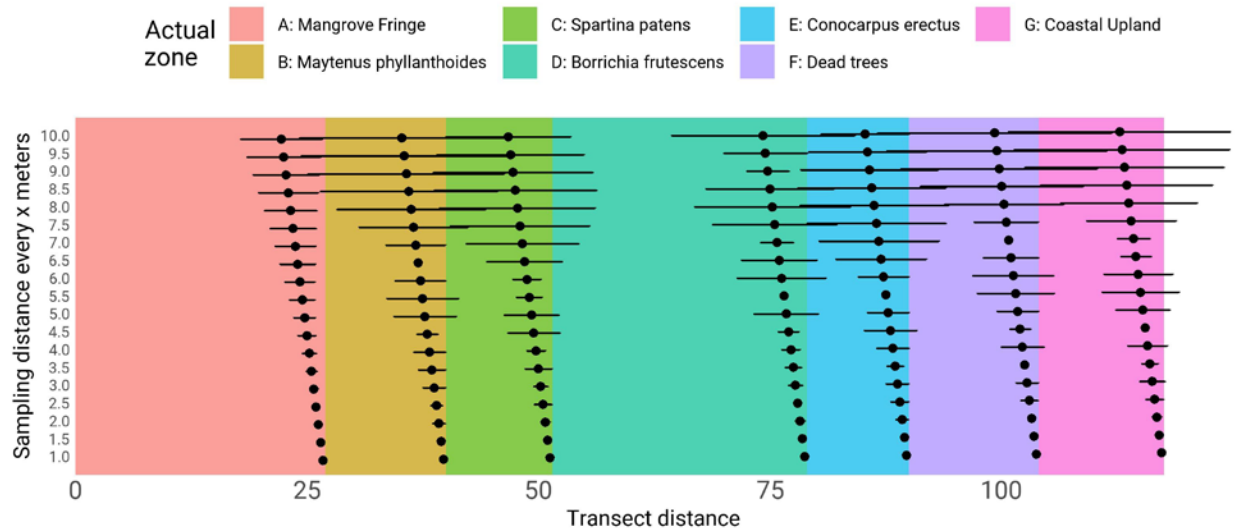


Figure 26: Estimates and variance of the estimates in the zone starting locations at Fort DeSoto at 1 meter to 10 meter sampling for the distances spanned by the quadrats. The colored regions indicate the zone delineations at half-meter sampling.

Harbor Palms

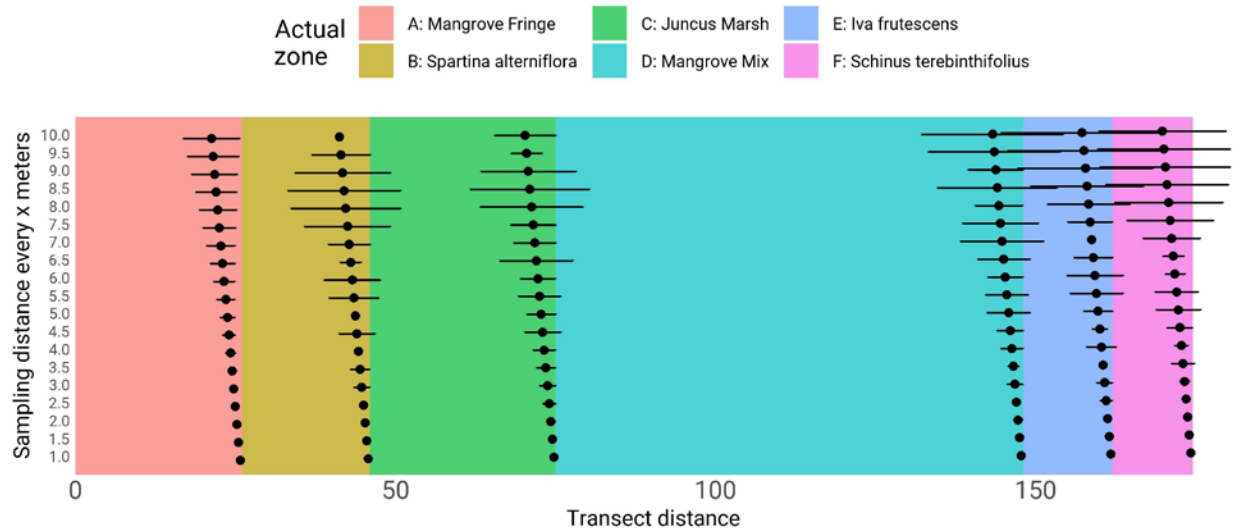


Figure 27: Estimates and variance of the estimates in the zone starting locations at Harbor Palms at 1 meter to 10 meter sampling for the distances spanned by the quadrats. The colored regions indicate the zone delineations at half-meter sampling.

Hidden Harbor

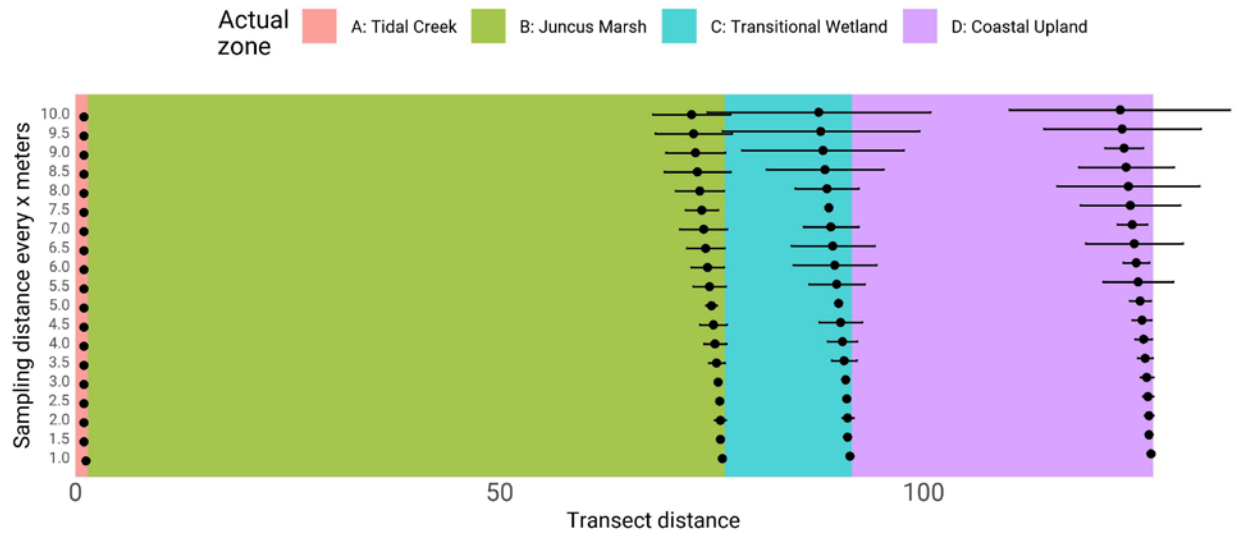


Figure 28: Estimates and variance of the estimates in the zone starting locations at Hidden Harbor at 1 meter to 10 meter sampling for the distances spanned by the quadrats. The colored regions indicate the zone delineations at half-meter sampling.

Little Manatee River

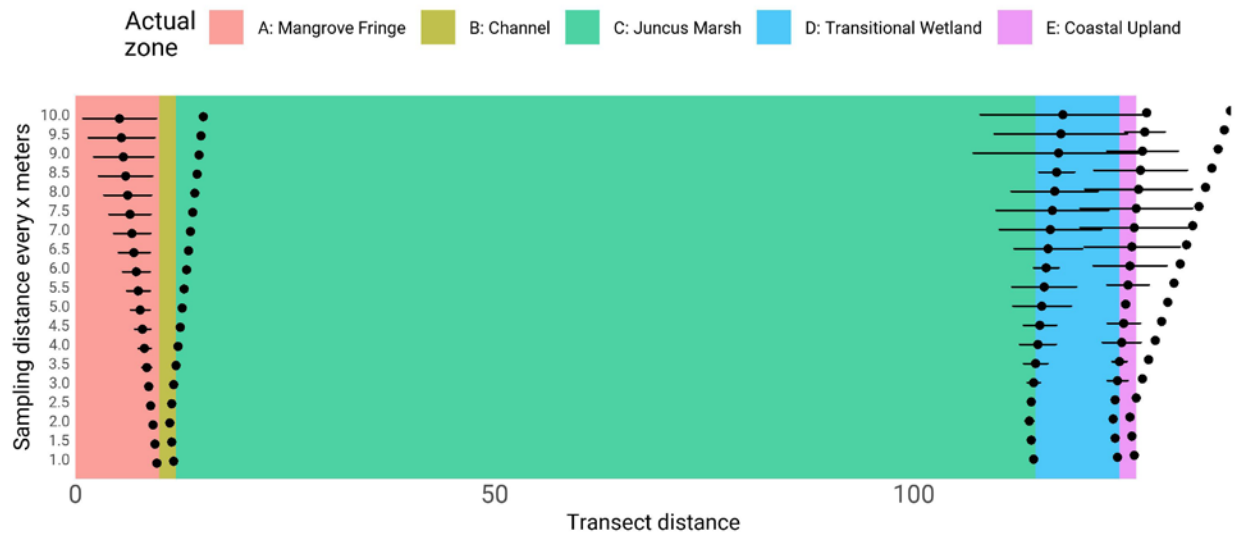


Figure 29: Estimates and variance of the estimates in the zone starting locations at Little Manatee River at 1 meter to 10 meter sampling for the distances spanned by the quadrats. The colored regions indicate the zone delineations at half-meter sampling.

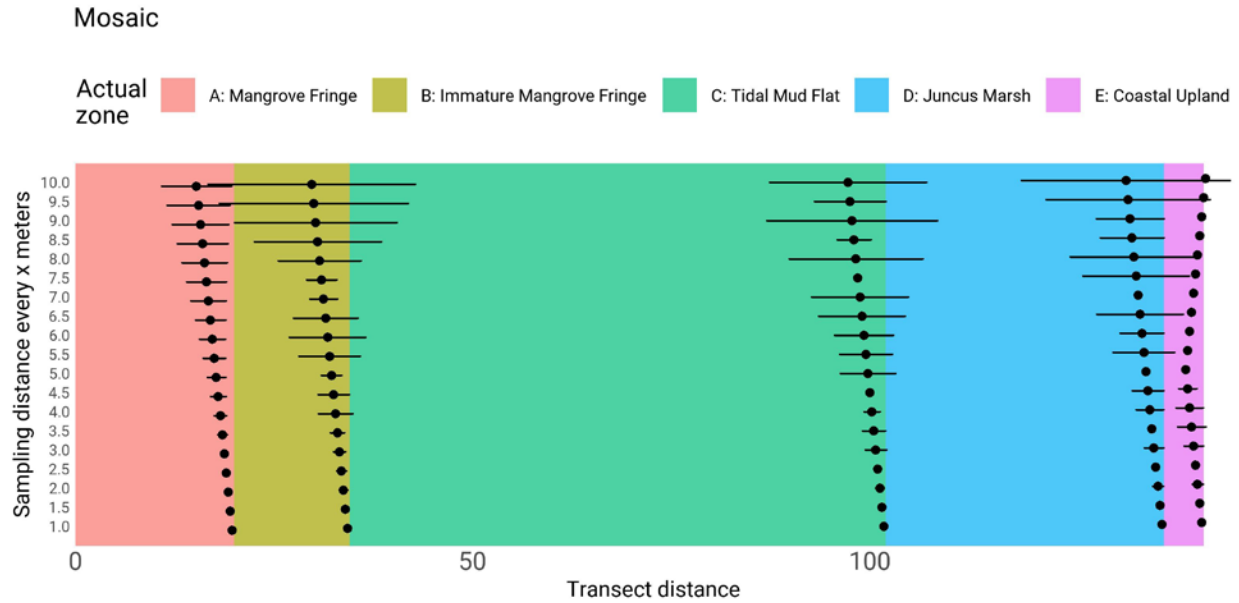


Figure 30: Estimates and variance of the estimates in the zone starting locations at Mosaic at 1 meter to 10 meter sampling for the distances spanned by the quadrats. The colored regions indicate the zone delineations at half-meter sampling.

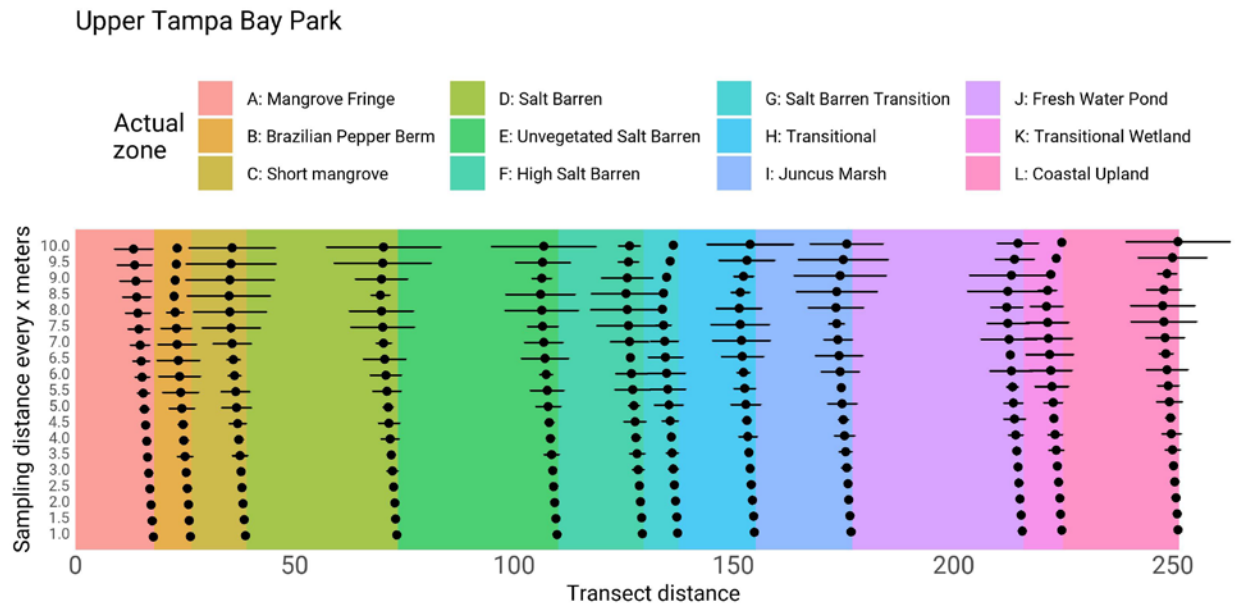


Figure 31: Estimates and variance of the estimates in the zone starting locations at Upper Tampa Bay Park at 1 meter to 10 meter sampling for the distances spanned by the quadrats. The colored regions indicate the zone delineations at half-meter sampling.

Weedon Island

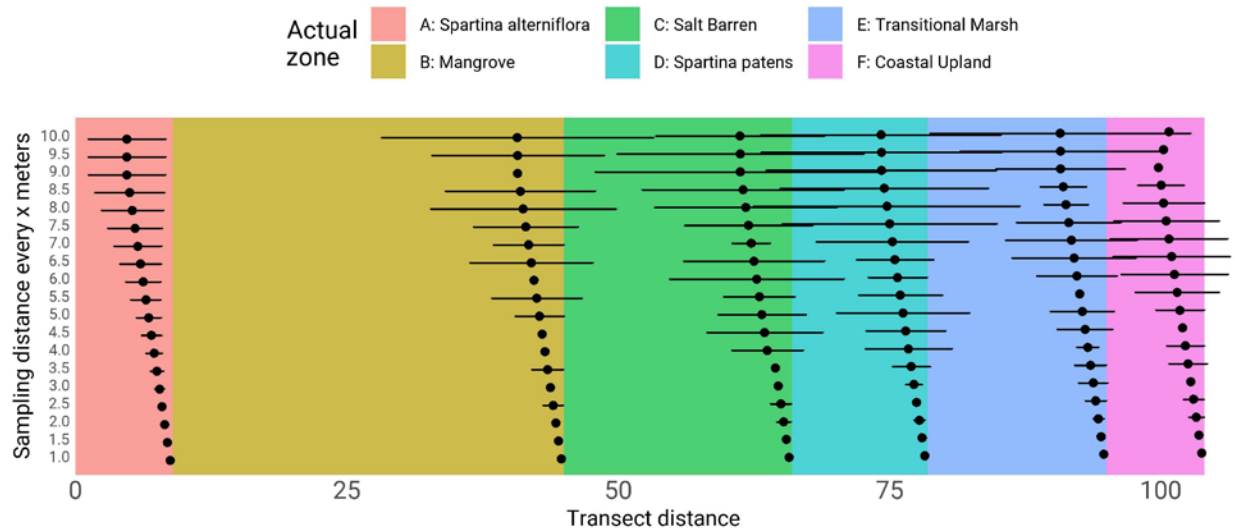


Figure 32: Estimates and variance of the estimates in the zone starting locations at Weedon Island at 1 meter to 10 meter sampling for the distances spanned by the quadrats. The colored regions indicate the zone delineations at half-meter sampling.

4 Conclusions and Recommendations

An assessment of the relative sampling effort required to obtain a representative sample can inform the utility and feasibility of a long-term monitoring program. A tradeoff exists between detail and effort, where an optimal level exists between too much and too little sampling. Highly intensive surveys may not provide novel information relative to the level of effort, compared to less intensive surveys that are efficient but may not provide an accurate sample of a population. Because the CCHA is expected to continue for several decades, identifying an optimal level of effort that provides sufficient information while minimizing time and resources collecting the data is critical to longevity of the program. This report provided a quantitative assessment of an optimal level of effort for sampling the vegetation community at each of nine monitoring sites. Results from this report can be used to justify amended sampling designs for future surveys.

Based on the results herein, sampling the vegetation community every meter along each transect is recommended. This level of effort is a 50% reduction in sampling from the original half meter sampling used during the baseline and 2018 CCHA surveys. This recommendation is expected to dramatically improve overall sampling efficiency given that the vegetation transects are the most time intensive component of all CCHA sampling. All of the key metrics used to characterize the

vegetation community and vegetation zones did not change dramatically from half-meter to 1 meter sampling. Although richness estimates declined with decreased sampling effort, large changes at all sites were not observed at 1 meter sampling. Species likely to be missed by reduced sampling are those with low frequency occurrence (Miller and Ambrose, 2000; Zhang et al., 2019), especially within each unique vegetation zone. However, identifying rare species is not a goal of the CCHA and a general assessment of vegetation communities in emergent tidal wetlands will not be compromised at 1 meter sampling.

The estimated elevation at which mangrove species are observed did not show consistent patterns across sites by species, although a general decrease was observed with reduced effort. This result was unexpected and it is unclear why reduced effort resulted in lower elevation estimates. Elevation generally increases along a transect and the sub-sampling method does not consistently sample lower elevations. An additional notable result was differences among the species for the elevations at half-meter sampling across the sites. In general, the three mangrove species are expected to follow an elevation gradient where red mangroves are more tolerant of polyhaline conditions (18-30 ppt) and more frequent inundation at lower elevations closer to the shoreline, black mangroves are intermediate, and white mangroves prefer mesohaline conditions (5-18 ppt) and less frequent inundation at higher elevations (Odum and McIvor, 1990). Some sites showed red mangroves at higher elevations than black and white mangroves, which was not expected, although these differences could be related to site-specific characteristics of the elevation gradient and porewater salinities. Regardless, the elevation metrics showed considerable changes with relative sampling effort, although they were very minor with a 50% reduction in effort at 1 meter sampling. Any changes as a function of sampling effort will also be notably less for mangrove species with high frequency occurrence at a site (Figures 19 and 20).

Tracking changes in vegetation zones and their relative sizes is an additional component of CCHA sampling that is expected to shift with sea-level rise and temperature changes. One quadrat will still be present within each zone at reduced sampling effort, so long as the sample interval is less than the length of the smallest zone at a site. The precision of the distance spanned by quadrats in each zone decreases with reductions in sampling effort, but the decrease is not linear and is affected by the actual zone length and sample interval. These issues are inconsequential for 1 meter sampling. However, zones are currently identified in the field by

visual assessment, with markers placed at approximate transitions between zones. The desktop analysis provided herein assumed a naive process for zone identification that is not verified in the field. The results above are less critical if information on zones is based on field verification independent of the vegetation surveys. Zone distances and transitions reported by field crews should be used independently of distances based on meter marks from the vegetation transect. Further, it is anticipated that zone markers placed in the field will be reassessed each survey and moved appropriately to track potential changes. This information should be used as the basis of tracking zone changes related to climate change. Consistent zone names between sites could also be chosen *a priori* or identified objectively through a multivariate assessment of the vegetation communities. Consistent naming could facilitate a comparison of zones between sites, whereas the assessments herein only evaluated zone changes within each site due to naming differences.

Overall, placing quadrats at 1 m intervals instead of 0.5 m intervals will result in a 50% reduction in sampling effort without compromising the ability to track long-term changes in vegetation communities in the CCHA. Any additional proposed changes to the CCHA methods should be supported through quantitative analyses and vetted through appropriate advisory committees. The results herein were vetted through the TBEP Technical Advisory Committee in October 2022 (meeting materials can be viewed [here](#)) and appropriate changes were made to the EPA-approved Quality Assurance Project Plan (QAPP, Flaherty-Walia, K. E. and Radabaugh, K. R., 2022). Additional changes in the QAPP not described here, but accepted by the TAC, included modification of the tree survey design using methods more appropriate for the CCHA habitats.

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