Recommendations for Sampling Effort of Vegetation Communities in the Critical Coastal Habitat Assessment

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## Acknowledgements

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## Executive Summary

## 1 Introduction

Native coastal habitats provide multiple ecosystem services for 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 communities. Habitat changes with projected estimates of sea-level rise are expected to manifest as substantial habitat loss or alteration and landward migration of intertidal species with changes in salinity. 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 decreases in 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. 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 works to develop science-based solutions to managing the estuary by creating consensus among regional managers on approaches for maintaining a healthy bay and watershed. The 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 based on 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 providing high-resolution surveys of emergent tidal wetlands (Moyer and Radabaugh, 2017; Price et al., 2017). Unlike the HMP that is based primarily on remote sensing products, the CCHA provides field-based estimates of coastal habitats at fixed sites for selected locations around Tampa Bay. Each of nine sites are sampled every 3-5 years using a transect design extending landward from the water to survey vegetation and tree communities, surface elevation, soil characteristics, interstitial porewater salinity, and faunal communities. The surveys also track discrete vegetation zones (e.g., mangrove fringe, coastal uplands, etc.) to assess potential landward shifts or reductions in habitats based on anticipated changes from sea-level rise. 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.

The CCHA 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 field crews in collecting useful information to inform 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 sampling vegetation within a 0.25 m quadrat every half meter 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 sample 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 is possible without sacrificing 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 at 0.5 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 at a site by vegetation zone
3. Elevation at which 95% of key species occur (e.g., mangroves)
4. Vegetation zone distances 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 1](#fig-transectdesign). The transects are perpendicular to the coastline and extend from the water to the uplands following bench-marked beginning and end locations that are fixed at each site. Each transect surveys the vegetation community at half-meter marks using a 0.25 m quadrat, where species richness and basal cover of each species is enumerated. Additional information collected at each transect includes tree surveys in 1 m quadrats (red boxes, [Figure 1](#fig-transectdesign)) using the Point-Center-Quarter method (Cottam and Curtis, 1956), elevation surveys along the length of the transect using Real Time Kinematic (RTK) satellite navigation via GPS, 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 burrow density of crabs (*Uca* spp.) and snails (*Littorina* spp.). Locations of the vegetation zones and the transitions between them were visually assessed and the meter marks where the transitions along the transects were recorded. Vegetation surveys represent a majority of the total sampling time at each transect.

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| Figure 1: Schematic of the sampling design at all CCHA sites (from Moyer and Radabaugh, 2017). Vegetation quadrats are placed every half meter along the main transect from the water to the landward end |

All existing CCHA vegetation surveys at each site and for both phases of sampling (baseline and 2018 surveys) were sub-sampled from the existing effort of sample plots every half meter. [Figure 2](#fig-subsampex) shows an example of the sub-sampling scheme, where effort was reduced in increments of a half meter, starting from the complete survey to an upper limit of sampling every ten meters. For simplicity, [Figure 2](#fig-subsampex) 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. 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 one meter, three every 1.5 meters, etc. The large red points in [Figure 2](#fig-subsampex) show which of the existing survey points were sub-sampled for the specified sub-sample distance.

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| Figure 2: Schematic of the method for creating sub-samples of existing transect data. The full survey with sampling at 0.5 meter intervals is shown at the top, wiht 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 3](#fig-releff). The total reduction in effort with each half-meter reduction in sample effort decreases from one meter to ten sampling, with the largest reduction in the former and the smallest reduction in the latter.

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| Figure 3: Percent reductions in sample effort as a function of the sample interval. For example, sampling every one meter represent a 50% reduction in effort form the original sample at 0.5 meters. |

For each site and sample year, the vegetation transect was sub-sampled following the methods above and relevant vegetation metrics were estimated. 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 sample effort. The three mangrove species that commonly occur in tidal wetlands (red mangroves, *Rhizophore mangle*, white mangroves, *Laguncularia racemosa*, and black mangroves, *Avicennia germinans*) were assessed as key species expected to show dramatic shifts with 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 estimates from the RTK surveys were combined with the vegetation data and cumulative distribution functions (CDF) 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 ability to identify each vegetation zone and the meter mark at which a zone began was also estimated from each sub-sample.

All replicates for each level of sampling effort were considered independent samples and results of each summary metric for replicates were averaged to provide a single estimate for the level of effort. The variance across the estimates was also estimated to provide an assessment of 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 sample effort. Metrics were evaluated as to total change and the relative percent changes to identify these potential effects. Metrics were also evaluated by comparing total change from 0.5 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 Richness estimates

These plots show the effect of down-sampling on richness estimates at each site, grouped by year of sampling. [Figure 4](#fig-richex) shows points as the average estimate at each down-sampled survey for the sampling distance shown on the x-axis. The lines are polynomial smooths to show the trend. The size of each point is in proportion to the variance of the species richness estimate for each random sub-sample at the specified level of sampling. Facets are arranged based on the greatest reduction in species richness as a percentage of the total.

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| Figure 4: 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. |

[Figure 5](#fig-richperex) is similar to [Figure 4](#fig-richex), but richness is scaled as a percentage of the total at full sample effort. This allows for a comparison of a reduction in the estimate independent of the overall species richness. That is, the sensitivity of the richness estimate at a site may vary depending on overall species richness.

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| Figure 5: 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. |

There is some evidence that a greater reduction in species richness is expected at sites with higher richness, although the model is insignificant ([Figure 6](#fig-richloss)).

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| Figure 6: Total percent loss in species richness estimates from 0.5 to 10 meter sampling as a function of actual species richness at 0.5 meter sampling. |

### 3.2 Richness estimates by zone

[Figure 7](#fig-richzone) shows richness estimates for different zones at each site with a reduction of sample effort. The lines show the estimated reduction in the richness estimate for each site and the thick line is the average trend across all sites for each zone (points are not shown to reduce clutter). The panels are arranged based on the greatest percent reduction in richness from full to minimum effort across all sites in a zone.

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| Figure 7: Reductions in species richness estimates with sampling distance for each unique vegetation zone across all sites. Each line is a unique site and the black line shows the average trend for the zone. Panels are arranged based on the greatest percent reduction in richness from full to minimum effort. |

[Figure 8](#fig-richzoneper) is the same as [Figure 7](#fig-richzone), except richness estimates are scaled as a percentage of the total. This allows for a comparison of a reduction in the estimate independent of the overall species richness.

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| Figure 8: Relative percent reductions in species richness estimates with sampling distance for each unique vegetation zone across all sites. Each line is a unique site and the black line shows the average trend for the zone. Panels are arranged based on the greatest percent reduction in richness from full to minimum effort. |

[Figure 9](#fig-richzonesum) combines results from the previous plots into a single panel. The lines are each solid black line from the above plot as the average reduction in the richness estimates for all sites in each zone. The line thickness is in proportion to the average total species richness for all sites in a zone at full sampling effort.

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| Figure 9: Relative percent reduction in species richness with sampling distance for each unique vegetation zone across all sites. Each line represents the average percent reduction for each occurrence of a zone. |

There is strong evidence that a greater reduction in species richness is expected at zones with higher richness ([Figure 10](#fig-richzoneloss)).

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| Figure 10: Total percent loss of richness from 0.5 meter to 10 meter sampling as a function of average species richness within a zone. |

### 3.3 Elevation of key species

[Figure 11](#fig-elevex) shows elevation estimates for mangrove species (black mangrove *Avicennia germinans*, white mangrove *Laguncularia racemosa*, red mangrove *Rhizophore mangle*) with reductions in sampling every 0.5 m to every 10 m. For each level of sampling effort, the estimated elevation at which 95% of each species occurs is shown for each site. The variance in the estimated elevation is also shown for the repeated subsamples at each level of effort. Overall, the elevation estimates show a decrease with reductions in effort, although differences are observed for each species and site.

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| Figure 11: 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. |

[Figure 12](#fig-elevperex) is similar to [Figure 11](#fig-elevex), except the total elevation change for each species at each site is shown as percent change. This provides a comparison of changes where differences may be observed by starting elevation above sea level.

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| Figure 12: Reletive elevation estimates of three mangrove species as a percent change from the initial value at 0.5 meters to 10 meters sampling. Point size shows the variance across the replicates for each level of sampling effort. |

[Figure 13](#fig-foperelevex) shows that the change in the elevation estimate is a function of frequency occurrence. Species at a site with greater frequency occurrence are impacated less by reductions in sampling effort.

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| Figure 13: Total percent change in elevation estimates for three mangrove species from 0.5 meter to 10 meter sampling as a function of frequency occurrence of each species at 0.5 meters ampling. |

Similar to [Figure 13](#fig-foperelevex), [Figure 14](#fig-fovarelevex) shows that the variance (or certainty) in the elevation estimate is a function of frequency occurrence. Elevation estimates are more precise for species at a site with greater frequency occurrence.

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| Figure 14: Variance of the elevation esimates of three mangrove species at 10 meter sampling as a function of actual frequency occurrence. |

### 3.4 Zone identification

Estimates of the counts and distances for each zone along the transects are shown below for reductions in sample effort. [Figure 15](#fig-zonecnt) shows the number of unique zones identified with down-sampling. All zones are identified at each site for all levels of sample effort.

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| Figure 15: Number of unique zones identified at each site from 0.5 meter to 10 meter sampling. |

[Figure 16](#fig-zonedst) shows the estimated length of each zone at each site with reductions in sample effort. Each line represents a unique zone. Estimated zone lengths do not change with reduced effort. Points are sized by the variance of the estimates across the random subsamples at level of sample effort. Variance (or uncertainty) in the zone distances increases with reduced effort.

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| Figure 16: Total distance of each zone at each site from 0.5 meter to 10 meter sampling. Point size shows the variance across the replicates for each level of sampling effort. |

The variance (or uncertainy) of the distance estimates increases with reductions in effort, but the increase is not linear. An example for Big Bend - TECO is shown in [Figure 17](#fig-zonevarex). Although variance increases across the zones, the variance estimates fall to zero when the actual zone distance (facet label shown in meters) is divisible by the sample interval with no remainder. Points of maximum variance are between intervals with no remainder.

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| Figure 17: An example of the variance of the zone distances for each zone at the Big Bend - TECO site from 0.5 meter to 10 meter sampling. |

Detailed results for each site are shown in Figures [18](#fig-zoneestbb), [19](#fig-zoneestcb), [20](#fig-zoneestfd), [21](#fig-zoneesthp), [22](#fig-zoneesthh), [23](#fig-zoneestlmr), [24](#fig-zoneestm), [25](#fig-zoneestutbp), and [26](#fig-zoneestwi). The shaded areas represent the true zones 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.

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| Figure 18: Estimates and variance of the estimates in the zone starting locations at Big Bend - Teco for 1 meter to 10 meter sampling. The colored regions indicate the zone delineations at 0.5 meter sampling. |

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| Figure 19: Estimates and variance of the estimates in the zone starting locations at Cockroach Bay for 1 meter to 10 meter sampling. The colored regions indicate the zone delineations at 0.5 meter sampling. |

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| Figure 20: Estimates and variance of the estimates in the zone starting locations at Fort DeSoto for 1 meter to 10 meter sampling. The colored regions indicate the zone delineations at 0.5 meter sampling. |

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| Figure 21: Estimates and variance of the estimates in the zone starting locations at Harbor Palms for 1 meter to 10 meter sampling. The colored regions indicate the zone delineations at 0.5 meter sampling. |

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| Figure 22: Estimates and variance of the estimates in the zone starting locations at Hidden Harbor for 1 meter to 10 meter sampling. The colored regions indicate the zone delineations at 0.5 meter sampling. |

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| Figure 23: Estimates and variance of the estimates in the zone starting locations at LIttle Manatee River for 1 meter to 10 meter sampling. The colored regions indicate the zone delineations at 0.5 meter sampling. |

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| Figure 24: Estimates and variance of the estimates in the zone starting locations at Mosaic for 1 meter to 10 meter sampling. The colored regions indicate the zone delineations at 0.5 meter sampling. |

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| Figure 25: Estimates and variance of the estimates in the zone starting locations at Upper Tampa Bay Park for 1 meter to 10 meter sampling. The colored regions indicate the zone delineations at 0.5 meter sampling. |

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| Figure 26: Estimates and variance of the estimates in the zone starting locations at Weedon Island for 1 meter to 10 meter sampling. The colored regions indicate the zone delineations at 0.5 meter sampling. |

## 4 Conclusions and Recommendations

* Richness estimates for a site are reduced with lower sample effort
* The amount of reduction in the richness estimated was weakly associated with total species richness at a site
* Richness estimates for a zone are reduced with lower sample effort
* Richness estimates will be systematically lower with reduced effort for zones with overall higher richness. These include zones…
* Frequency occurrence estimates for individual species will not be systematically different at lower sample effort, but the estimates are imprecise
* Species with higher frequency occurrence will have less precise estimates with reduced effort compared to those with lower frequency occurrence
* Zone identification at each site is not affected by sample effort, although distance estimates decrease slightly.
* Precision of the distance estimates for each zone decreases with reductions in sample effort, but the decrease is not linear and is affected by the actual zone length and sample interval
* The estimated elevation at which mangrove species are observed will decrease with reductions in sampling effort. The magnitude and uncertainty of the reduction will increase for species with lower frequency occurrence at a site.

## References

Burke, M., Carnahan, L., Hammer-Levy, K., and Mitchum, G. (2019). Recommended projections of sea level rise for the Tampa Bay region (update). St. Petersburg, Florida: Tampa Bay Estuary Program Available at: <https://drive.google.com/file/d/1c_KTSJ4TgVX9IugnyDadr2Hc0gjAuQg2/view?usp=drivesdk>.

Cavanaugh, K. C., Dangremond, E. M., Doughty, C. L., Williams, A. P., Parker, J. D., Hayes, M. A., et al. (2019). Climate-driven regime shifts in a mangrove-salt marsh ecotone over the past 250 years. *Proceedings of the National Academy of Sciences* 116, 21602–21608. Available at: <https://doi.org/10.1073/pnas.1902181116>.

Comeaux, R. S., Allison, M. A., and Bianchi, T. S. (2012). Mangrove expansion in the Gulf of Mexico with climate change: Implications for wetland health and resistance to rising sea levels. *Estuarine, Coastal and Shelf Science* 96, 81–95. Available at: <https://doi.org/10.1016/j.ecss.2011.10.003>.

Cottam, G., and Curtis, J. T. (1956). The Use of Distance Measures in Phytosociological Sampling. *Ecology* 37, 451–460. doi: [10.2307/1930167](https://doi.org/10.2307/1930167).

Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I., and Marbà, N. (2013). The role of coastal plant communities for climate change mitigation and adaptation. *Nature Climate Change* 3, 961–968. doi: [10.1038/nclimate1970](https://doi.org/10.1038/nclimate1970).

Fu, X., Song, J., Sun, B., and Peng, Z.-R. (2016). “Living on the edge”: Estimating the economic cost of sea level rise on coastal real estate in the Tampa Bay region, Florida. *Ocean & Coastal Management* 133, 11–17. doi: [10.1016/j.ocecoaman.2016.09.009](https://doi.org/10.1016/j.ocecoaman.2016.09.009).

Gilby, B. L., Weinstein, M. P., Baker, R., Cebrian, J., Alford, S. B., Chelsky, A., et al. (2020). Human Actions Alter Tidal Marsh Seascapes and the Provision of Ecosystem Services. *Estuaries and Coasts* 44, 1628–1636. doi: [10.1007/s12237-020-00830-0](https://doi.org/10.1007/s12237-020-00830-0).

Kennedy, V. S. (1990). Anticipated Effects of Climate Change on Estuarine and Coastal Fisheries. *Fisheries* 15, 16–24. doi: [10.1577/1548-8446(1990)015<0016:aeocco>2.0.co;2](https://doi.org/10.1577/1548-8446(1990)015<0016:aeocco>2.0.co;2).

Moyer, R., and Radabaugh, K. (2017). Phase 2: Critical Coastal Habitat Assessment Final Report. St. Petersburg, Florida: Tampa Bay Estuary Program Available at: <https://drive.google.com/file/d/1bDZ0JmuD2_1RM6VkSrsAR3g8bciQaf3F/view?usp=drivesdk>.

Osland, M. J., Hughes, A. R., Armitage, A. R., Scyphers, S. B., Cebrian, J., Swinea, S. H., et al. (2022). The impacts of mangrove range expansion on wetland ecosystem services in the southeastern United States: Current understanding, knowledge gaps, and emerging research needs. *Global Change Biology* 28, 3163–3187. doi: [10.1111/gcb.16111](https://doi.org/10.1111/gcb.16111).

Price, R., Loy, D., and Robison, D. (2017). Phase 1: Critical Coastal Habitat Assessment: Baseline monitoring report. St. Petersburg, Florida: Tampa Bay Estuary Program Available at: <https://drive.google.com/file/d/122AvajD3fxOVORHfO5HQUMdXkLNoQm48/view?usp=drivesdk>.

R Core Team (2022). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing Available at: <https://www.R-project.org/>.

Robison, D., Ries, T., Saarinen, J., Tomasko, D., and Sciarrino, C. (2020). Tampa Bay Estuary Program: 2020 Habitat Master Plan Update. St. Petersburg, Florida: Tampa Bay Estuary Program Available at: <https://drive.google.com/file/d/1Hp0l_qtbxp1JxKJoGatdyuANSzQrpL0I/view?usp=drivesdk>.

Sherwood, E. T., and Greening, H. S. (2012). Critical Coastal Habitat Vulnerability Assessment for the Tampa Bay Estuary: Projected Changes to Habitats due to Sea Level Rise and Climate Change. St. Petersburg, Florida: Tampa Bay Estuary Program Available at: <https://drive.google.com/file/d/11tu2-0y7wdAHsdvMYE8bNb68mgvcpWbK/view?usp=drivesdk>.

Sherwood, E. T., and Greening, H. S. (2014). Potential impacts and management implications of climate change on Tampa Bay Estuary critical coastal habitats. *Environmental Management* 53, 401–415. doi: [10.1007/s00267-013-0179-5](https://doi.org/10.1007/s00267-013-0179-5).

Spalding, M. D., Ruffo, S., Lacambra, C., Meliane, I., Hale, L. Z., Shepard, C. C., et al. (2014). The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean & Coastal Management* 90, 50–57. doi: [10.1016/j.ocecoaman.2013.09.007](https://doi.org/10.1016/j.ocecoaman.2013.09.007).

Toimil, A., Díaz-Simal, P., Losada, I. J., and Camus, P. (2018). Estimating the risk of loss of beach recreation value under climate change. *Tourism Management* 68, 387–400. doi: [10.1016/j.tourman.2018.03.024](https://doi.org/10.1016/j.tourman.2018.03.024).