



Application of Multimetric Index, and Trend & Power Analysis for Salt Marsh Monitoring

Northeast Coastal and Barrier Network

Natural Resource Report NPS/NCBN/NRR—2021/2316



ON THE COVER

Salt Marsh Monitoring seasonal biotechs stand along the edge of a salt marsh at Gateway NRA's Sandy Hook Unit.
Image by Robin Baranowski

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Abstract

As part of the Northeast Coastal and Barrier Network (NCBN) vital signs monitoring program, salt marsh vegetation and nekton monitoring data have been collected within Cape Cod National Seashore (CACO), Fire Island National Seashore (FIIS), Sagamore Hill National Historic Site (SAHI), Gateway National Recreation Area - Sandy Hook Unit (GATE-SHU), and Assateague Island National Seashore (ASIS). This report summarizes the observed salt marsh conditions present within each park using both a multimetric index (MMI) and individual metrics such as percent cover, species richness, and relative abundance for select vegetation and nekton species. Trends in each metric for the period of 2008 to 2018 are quantified using regression analysis. Consistent with the Inventory and Monitoring (I&M) Program Guidance, power simulations are also performed to assess whether the data collected to date can meet the protocol's objectives.

Section 1. Background Information

Salt marsh vegetation and nekton monitoring data have been collected from five national parks within the Northeast Coastal and Barrier Network (NCBN) as part of the network-wide vital signs monitoring program (Stevens et al. 2005). Marsh study units (MSUs) were established at Cape Cod National Seashore (CACO), Fire Island National Seashore (FIIS), Sagamore Hill National Historic Site (SAHI), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Assateague Island National Seashore (ASIS) (Figure 1). During the period of 2008 to 2018, data collection was performed on a biennial basis (except CACO, which was sampled every 3–5 years) following a standardized monitoring protocol (Rocks and Stevens 2018; James-Pirri, Roman, and Nicosia 2012). In collaboration with USGS scientists, the NCBN developed a salt marsh multimetric index (MMI) that is used to determine marsh condition and is provided to park managers (Nagel et al. 2017).

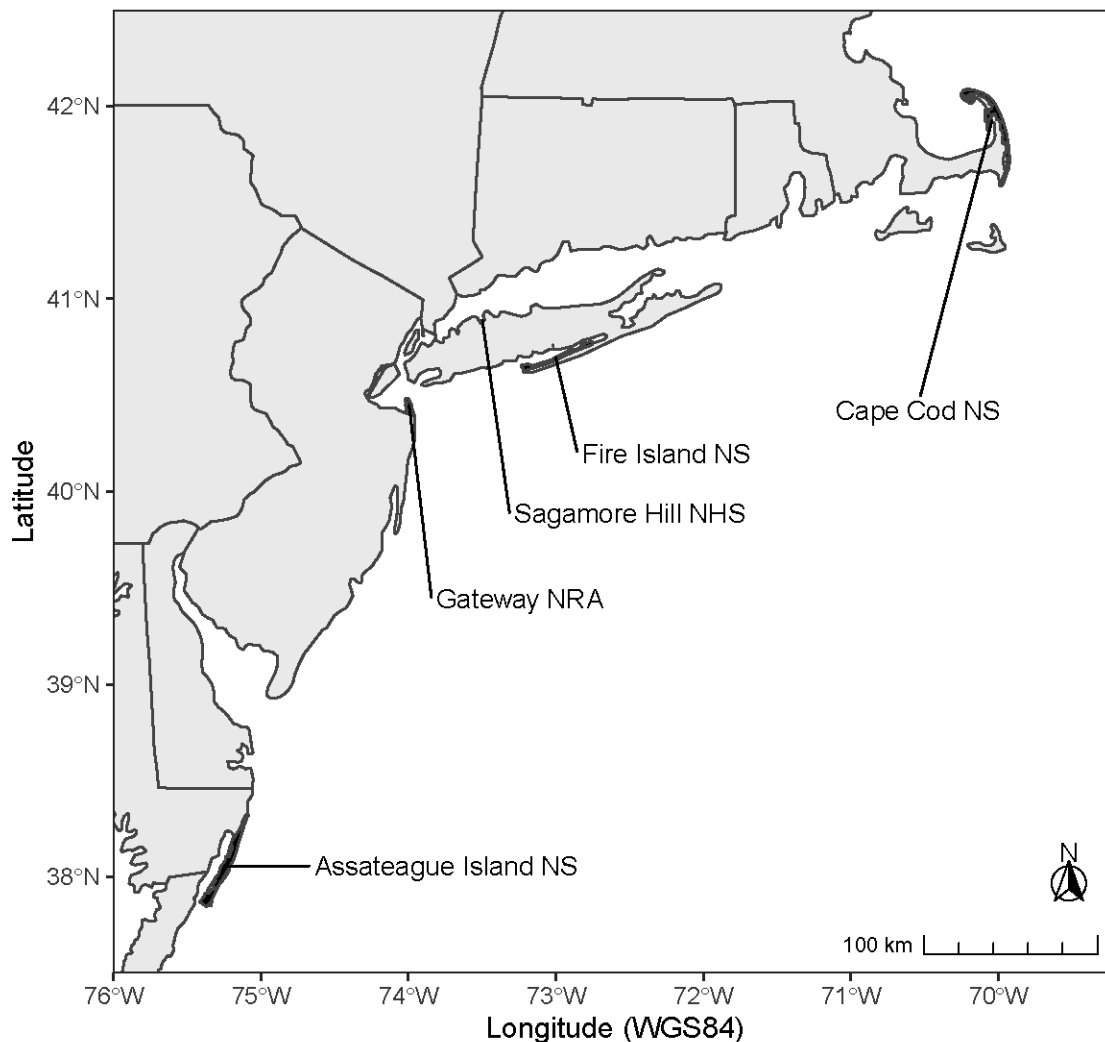


Figure 1. Locations of sampled National Parks Service parks (black filled polygons) within the Northeast Coastal and Barrier Network.

Section 2. Analysis Summary

As part of the Northeast Coastal and Barrier Network (NCBN) vital signs monitoring program, salt marsh vegetation and nekton monitoring data have been collected within Cape Cod National Seashore (CACO), Fire Island National Seashore (FIIS), Sagamore Hill National Historic Site (SAHI), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Assateague Island National Seashore (ASIS). This report summarizes the observed salt marsh conditions and quantifies the extent to which conditions changed for the period of 2008 to 2018. Consistent with the I&M Program Guidance, simulations were also conducted to assess whether the data collected to date can meet the protocol's objectives.

Section 3: Multimetric Index (MMI) VN24 summarizes salt marsh condition within each national park using the salt marsh multimetric index (MMI) developed by the NCBN in collaboration with USGS scientists. MMI scores range from 0 to 10 and are correlated with high to low levels of human disturbance, respectively. Changes in ecosystem condition over time and space can be assessed visually by inspecting plots of MMI scores. For example, Figure 2 displays the MMI scores for all sampled marshes within ASIS during the period of 2008 to 2018. In this plot, each marsh is represented by a different combination of color and plotting character. Marsh condition oscillated during the years of 2008 to 2014 but has been improving with lesser amounts of human disturbance (i.e., higher scores) since 2014. Some notable observations from the plot include: (1) scores tend to increase/decrease consistently across marshes year-to-year; and (2) the magnitude of scores across marshes within a given year is relatively similar (note: this observation is based on comparisons relative to other parks; see section 3.2). In addition to visually assessing how individual marsh scores changed over time, it is also useful to characterize how scores changed on a parkwide basis. To quantify this, a regression model was fit to all individual marsh scores within ASIS. As indicated by the positive slope of the blue regression line in Figure 2, it is estimated that the parkwide mean score improved during the period of 2008 to 2018. A benefit of utilizing a statistical model is that we were able to also quantify several sources of uncertainty related to this estimate. First, the degree of uncertainty in the mean score at any given time is depicted visually by the width of the shaded blue confidence interval. Second, we were able to compute a 95% confidence interval for the trend coefficient, thus providing a range of plausible values for the trend. Confidence intervals contain information that is equivalent to some aspects of a hypothesis test. For example, if the confidence interval contains zero, we are unable to statistically conclude that the true trend in MMI score differs from zero (i.e., no change in score over time). Note, this is equivalent to failing to reject the null hypothesis corresponding to a two-sided test (at the 0.05 alpha level) that the trend coefficient equals zero. For ASIS, the trend coefficient was estimated to be 0.039 with 95% confidence interval (–0.020, 0.098). Therefore, we fail to reject the null hypothesis that the true trend in marsh condition is zero. Regardless of a trend's statistical significance, it is recommended that decision makers consult the plot containing the MMI scores that the trend is based on. This is because biologically meaningful change could be occurring even though we are unable to statistically detect it. Additionally, comparisons to other park's trend estimates, and uncertainty provides useful context for a particular park's results.

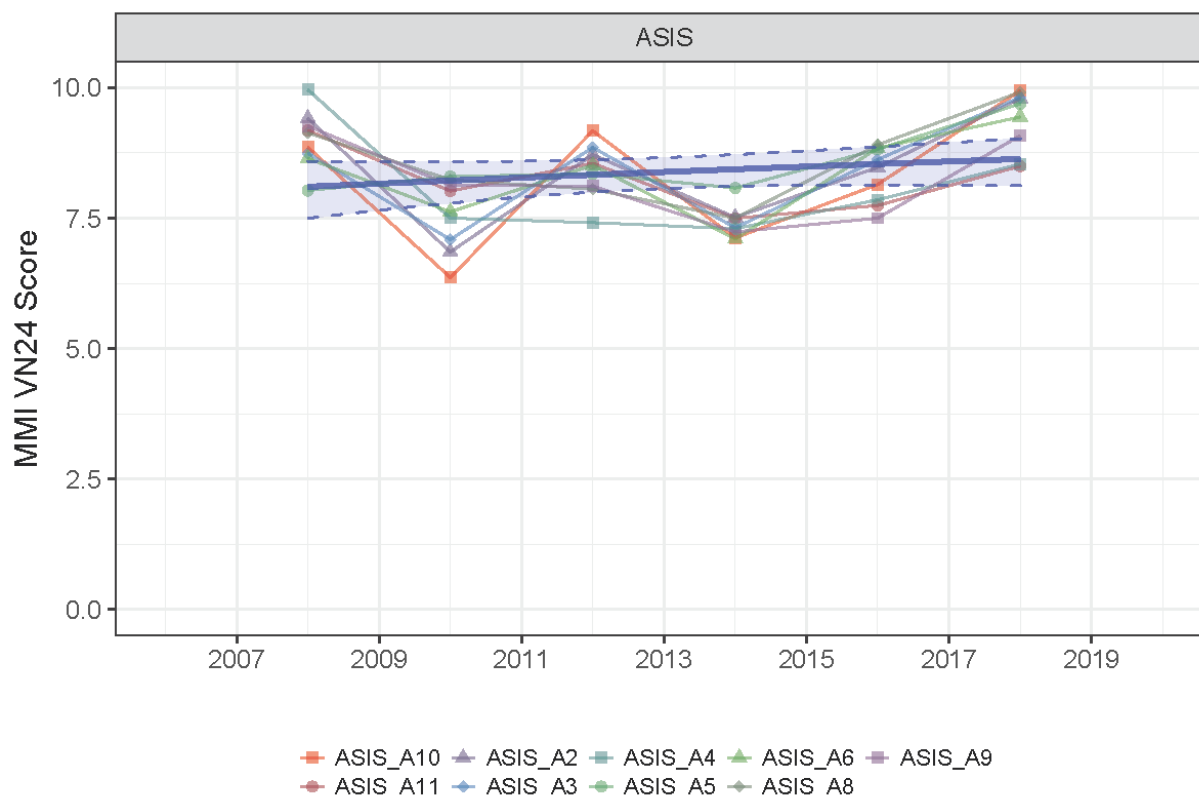


Figure 2. Estimated mean VN24 multimetric index (MMI) score within Assateague Island National Seashore (ASIS) as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

In addition to the MMI scores, six additional metrics were explored in *Section 4: Additional Metrics of Interest* to assess the health of salt marsh vegetation and nekton communities. The metrics include: (1) percent cover of *Spartina patens*, (2) percent cover of *Salicornia* species, (3) percent cover of high salinity-tolerant species, (4) percent low salinity-tolerant species richness, (5) nekton native species richness, and (6) relative abundance of *Palaemonetes* species. Interpretation of trends for these metrics mirrors that of the MMI scores detailed previously.

When designing or modifying a monitoring program, it is often of interest to know: “How many samples do we need to detect a trend?” One of the main objectives for the work presented here is to assist in the assessment of sample adequacy regarding the amount of data being collected in each park. In this context, sample adequacy relates to the degree of certainty associated with the ability to see differences in a metric through time. In general, more data corresponds to more certainty, but the variability of the response mediates the magnitude of the sample effort needed to see differences. Responses with less variability will require fewer samples to detect a trend. In essence, the signal to noise ratio is higher for response variables with less variability through time. To provide some quantitative support for the consideration of potential sampling effort that may be implemented in the future, we developed a simulation-based power analysis.

Section 5: Power Analysis #1 provides the details associated with the methods used to estimate statistical power under varying levels of sampling effort. In this context, the statistical power quantifies the ability to detect a trend that exists. The higher the power, the more likely it is that a given sampling effort will be able to detect a trend. The specifics of a sampling effort include aspects like the sampling frequency and the number of sites sampled. As an example of this simulation-based power analysis approach, Table 1 provides the estimated power for detecting a trend in mean percent cover of *Spartina patens* within ASIS. The rows in this table correspond to the results for the different magnitudes of sampling effort. Rows at the top correspond to fewer samples. The columns in this table correspond to the sampling interval. The column on the far right corresponds to annual sampling. Each cell in the table of values contains the estimated power associated with the assumed sampling interval (columns) and number of sampled marshes (rows) considered. The bottom-right most cell, for example, is in the column that corresponds to sampling every year and the row that corresponds to sampling 12 marsh study units (MSUs). The value of 0.86 indicates that the probability to detect a trend that exists (assuming 12 marshes are sampled concurrently every year for ten years) is 86%. The best use for the simulated power analysis presented here is optimization of future sampling efforts given finite resources. As an example, suppose there are available resources to sample every three years, and collect data on up to 12 marshes. Based on Table 1, when sampling every three years the highest probability of detecting a trend that exists is 56%. Typically, power is preferred to be at least 80% which suggests that the proposed sampling effort for this metric is inadequate. This could be remedied by decreasing the sampling interval. If a power of 80% is required, then annual sampling is the only frequency that allows it.

Table 1. Empirical power estimates for detecting a -5% per year trend (logit scale) in mean percent cover of *Spartina patens* within Assateague Island National Seashore (ASIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.02	0.05	0.10	0.19
3	0.07	0.11	0.17	0.29
4	0.13	0.17	0.24	0.38
5	0.18	0.23	0.31	0.47
6	0.24	0.28	0.36	0.56
7	0.28	0.32	0.42	0.62
8	0.31	0.38	0.47	0.68
9	0.37	0.42	0.53	0.74
10	0.41	0.47	0.58	0.78
11	0.45	0.52	0.62	0.83
12	0.49	0.56	0.66	0.86

The results in Table 1 correspond to the ability to detect changes similar to what is currently being observed in ASIS (see section 4.2). This is relevant since this magnitude of trend corresponds to the signal part of the signal to noise concept. Trends with a larger magnitude are easier to detect for a given level of sampling effort. In the example above, there was not sufficient power to detect a trend in mean percent cover of *Spartina patens* within ASIS with available resources to sample every three years and collect data on up to 12 marshes. However, it is possible that a trend with a stronger impact could be detected with sufficient power under these sampling constraints. One of the advantages of this type of power analysis is the ability to assess the change in the necessary sampling effort for different trend magnitudes. With respect to the ability to design efficient sampling plans, additional power analyses can be used to determine the minimum detectable trend for a given sampling effort. In this way, the optimal sampling effort is estimated, and additional resources are not used to increase sampling effort beyond what is desired.

Section 6: Power Analysis # 2 details the method used to estimate the power of detecting differences in community composition between marshes under varying levels of sampling effort. In the context of this analysis, sampling effort refers to the number of plots sampled within a marsh. The degree to which the compositions of two marshes are similar was summarized by a single value called the similarity index, where smaller values indicate higher degrees of similarity. The ability to detect a difference is inversely related to the degree of similarity between two marshes. That is, our ability to detect a difference between marshes increases when the marshes are less similar. Because there are numerous potential comparisons that can be made within a park, power was estimated for a range of similarity index values. For example, Figure 3 displays the estimated power of detecting differences in vegetation composition under varying levels of sampling effort. Within each panel, the black dots correspond to the empirical power (y-axis value) computed for a pair of marshes with a known level of similarity (x-axis value). The blue curve in each panel represents the estimated power as a function of similarity. The adequacy of an assumed level of sampling effort can be assessed by considering the estimated power over the range of similarity values that we expect to observe. If there is sufficient power (i.e., at least 80%) to detect differences for most of these comparisons, it is reasonable to conclude that the level of sampling effort is sufficient. For vegetation community composition, the results depicted in Figure 3 indicate that sampling within a marsh could be reduced to 30 plots (from the current effort of 50 plots) while still maintaining statistical power of at least 80% for most potential comparisons.

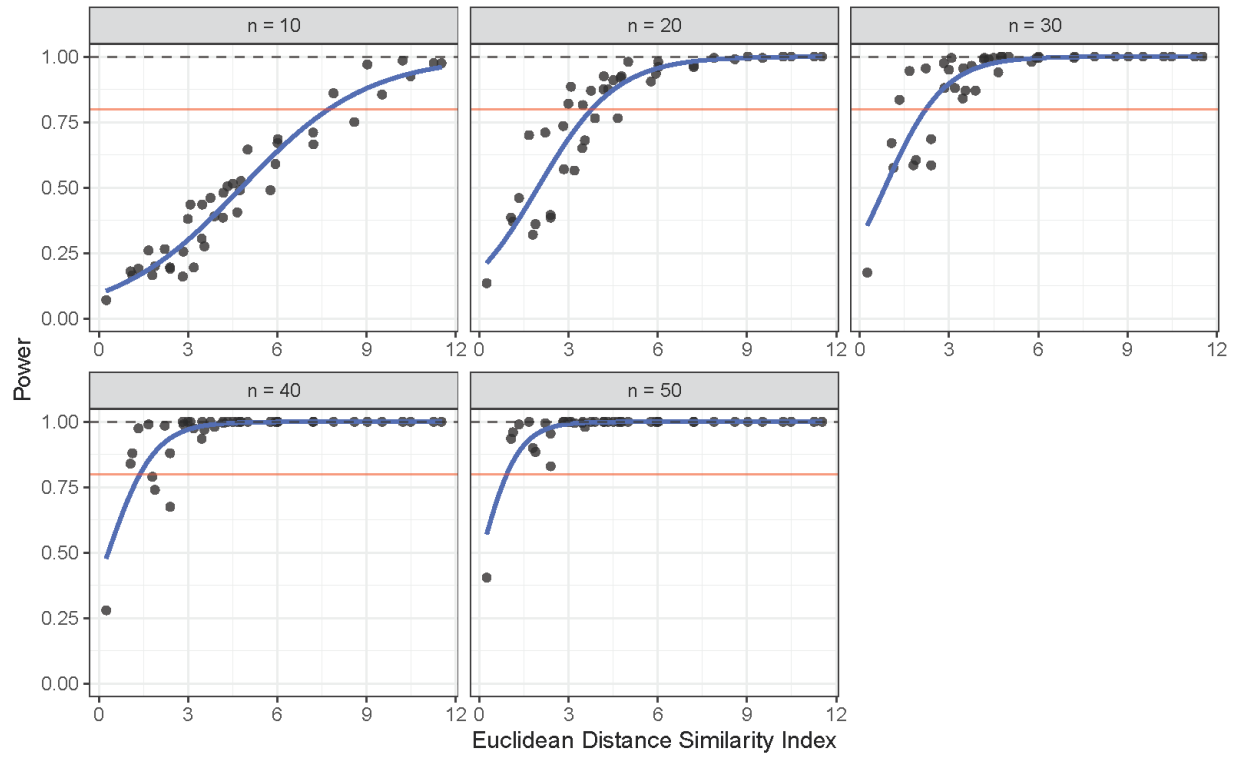


Figure 3. Empirical power estimates for detecting differences in vegetation community composition between two marsh pairs with $n = 10, 20, 30, 40, 50$ sampled plots per marsh. Distance was calculated as the Euclidean distance similarity index between each marsh's average cover class for each unique species present. Superimposed blue curves are provided to assist in visual identification of the sample size necessary to achieve 80% power (red line) for a given similarity distance.

Section 3. Multimetric Index (MMI) VN24

3.1 Methods

The NCBN Monitoring Program Salt Marsh Database was imported into R (R Core Team 2019) and the SQL queries provided by Dennis Skidds were translated into R code (see R script db_query.R). The resulting data frame was checked against Microsoft Access query output for consistency. Comparisons of this data frame to the data provided by NPS¹ revealed differences in the number of records per year (Table 2). Per email correspondence with Mr. Skidds, differences in years 2008–2013 are due to the data undergoing a thorough review and being cleaned up when the database was redesigned a few years ago. It is currently unclear why more substantial differences exist in the pilot data (i.e., years 2003–2007). However, since the pilot data is not utilized in the analysis, data reconciliation for this period was not pursued.

Table 2. Comparison between prior and current National Park Service records per year. Absolute differences are provided in the $|\Delta|$ column.

Year	Prior	Current	$ \Delta $	Prior	Current	$ \Delta $
1997	1233	1233	0	–	–	–
2000	1160	1160	0	–	–	–
2002	702	702	0	–	–	–
2003	1054	618	436	1880	467	1413
2004	1126	1011	115	1893	1189	704
2005	302	170	132	3812	3315	497
2006	433	433	0	1571	1511	60
2007	102	88	14	2185	2190	5
2008	5151	5151	0	4475	4484	9
2009	2668	2642	26	2809	2816	7
2010	3230	3230	0	5469	5476	7
2011	3097	3092	5	2373	2379	6
2012	3377	3378	1	2888	2901	13
2013	4441	4442	1	2683	2690	7

¹ Original Excel document and 2013 update files in folder Original_Flat_Files.

3.1.1 Metric Derivation

MMI VN24 from Nagel et al. (2017) is comprised of four individual metrics: (1) percent cover of native vegetation species; (2) percent cover of brackish border vegetation species; (3) relative abundance of resident shrimp; and (4) relative abundance of resident fish.

The vegetation community metrics, i.e., metrics (1) and (2) from above, were computed for each marsh study unit and year as follows:

1. Define individual plot sampling events using LocationID and StartDate values.
2. For each individual plot sampling event, do the following:
 - a. Subset data frame to include only plots that contain live vegetation. Note: both vascular plant and algal species are included in vegetation.
 - b. Use Supplemental Table 1 (Nagel et al. 2017) to determine the native status and assigned community class for each species present.
 - c. Transform visual estimates of Braun-Blanquet cover class to percent cover values using class midpoints.
 - d. Separately for native and brackish border vegetation species, sum the percent cover values for alive species within each sample plot and cap at 100%.
3. Average percent cover values over all sample plots.

The nekton community metrics, i.e., metrics (3) and (4) from above, were computed for each marsh study unit and year as follows:

1. Define individual plot sampling events using LocID2 and StartDate values.
2. For each individual plot sampling event, do the following:
 - a. Compute nekton species density by dividing SpeciesCount by NetArea. and subset data frame to include unique density values. Note: for each species present in a plot, there is a unique entry for each observed nekton, and SpeciesCount is equal to the total number of observed nekton in each respective species.
 - b. Use Supplemental Table 2 (Nagel et al. 2017) to determine the Resident/Transient type for each species.
 - c. Separately for resident fish and resident shrimp species, sum the densities within each sample plot to derive total density per sample.
3. Average total densities over all sample plots.

3.1.2 MMI VN24 Derivation

The multimetric index VN24 was calculated for each marsh and year of data collection during 2008–2018. For each marsh study unit and year of data collection, the metrics ($m_{i[j]}$, $i = 1, \dots, 4$, $j = 1, \dots, n$) detailed in Section 3.1 were first scaled to the $[0, 10]$ interval (denoted by s superscript on m) using a continuous scoring method:

$$m_{i[j]}^s = 10 \cdot \left(\frac{m_{i[j]} - L_i}{U_i - L_i} \right),$$

where L_i and U_i are the 2.5 and 97.5 percentile values of $m_{i[\cdot]}$ from the analysis by Nagel et al. (2017). Values that were less than L_i or greater than U_i were set to 0 and 10, respectively. Percent cover of brackish border vegetation species and relative abundance of resident shrimp are both positively correlated with the Human Disturbance Index (HDI). To ensure the MMI is negatively correlated with the HDI, both metric's scaled values were reflected (denoted by r superscript on m) about their midpoint (Schoolmaster Jr et al. 2013):

$$m_{i[j]}^{s,r} = \max\{m_{i[j]}^s : j = 1, \dots, n\} - m_{i[j]}^s.$$

VN24 was then computed for each marsh and year by averaging the respective scaled and reflected metric values. See R script `compute_mmi.R` for code used to compute VN24 values for each unit and year combination.

3.1.3 Trend

Trends in VN24 scores over time were quantified for each of the five national parks using regression analysis. The response variable in each regression was the VN24 score which is both continuous and restricted to the closed interval $[0, 10]$. Beta regression is well suited for this type of response (Ferrari and Cribari-Neto 2004; Douma and Weedon 2019) and individual regressions were fit using the **betareg** R package (Cribari-Neto and Zeileis 2010).

Prior to fitting each model, VN24 scores were first scaled to the $(0, 1)$ interval to match the support of the beta distribution. If the metric values (y_i , $i = 1, \dots, n$) assumed the extreme values of 0 and/or 1, the transformation

$$(y \cdot (n - 1) + 0.5)/n,$$

would be applied (Smithson and Verkuilen 2006). However, because no values of 0 or 1 were observed, further transformation was not necessary to fit the model.

It is assumed that the response variable y_i , ($i = 1, \dots, n$) is distributed according to a beta distribution parameterized by a mean μ_i and unknown precision ϕ : $y_i \sim \text{Beta}(\mu_i, \phi)$. The beta regression model is then defined as

$$g(\mu_i) = \mathbf{x}_i^\top \boldsymbol{\beta},$$

where $\boldsymbol{\beta}$ is a vector of unknown regression parameters, $\mathbf{x}_i^\top$ is the vector of covariates, and $g(\cdot)$ is the link function. In this application, the link function used was the logit link:

$$g(\mu) = \text{logit}(\mu) = \log\{\mu/(1 - \mu)\}.$$

The logit link was chosen due to: (1) the VN24 scores (and alternative metric values, see *Section 4: Additional Metrics of Interest*) are sometimes very close, or equal to, 0 and 1; (2) the need to evaluate new $\mathbf{x}$ values outside the range of observed values for a power analysis. In both cases, the logit link function assures that fitted values $\hat{\mu}$ will always be in the open interval (0, 1).

Trend was defined as the linear trend in time (years) on the logit scale:

$$\text{logit}(\mu_i) = \beta_0 + \beta_1 t_i,$$

where t_i is the i^{th} year since 2008. Given the chosen link function, the interpretation of the linear trend parameter β_1 necessitates careful consideration and wording because it is a non-linear function of year (Figure 4). The trend in mean VN24 score over time can be interpreted as the multiplicative change of $\exp(\beta_1)$ in the odds of the mean VN24 score for each 1-year increase in time. Given that the MMI is a proxy for the lack of human disturbance (since it is negatively correlated with human disturbance), the interpretation can be extended to include the odds of mean percent undisturbed area. In this case, the odds of percent undisturbed area equals the ratio of percent undisturbed to percent human-disturbed area in the park. For example, setting $\hat{\beta}_1$ equal to 0.05, the interpretation would be as follows: for every 1-year increase in time, the odds of mean percent undisturbed area increases by a factor of $\exp(0.05) = 1.051$.

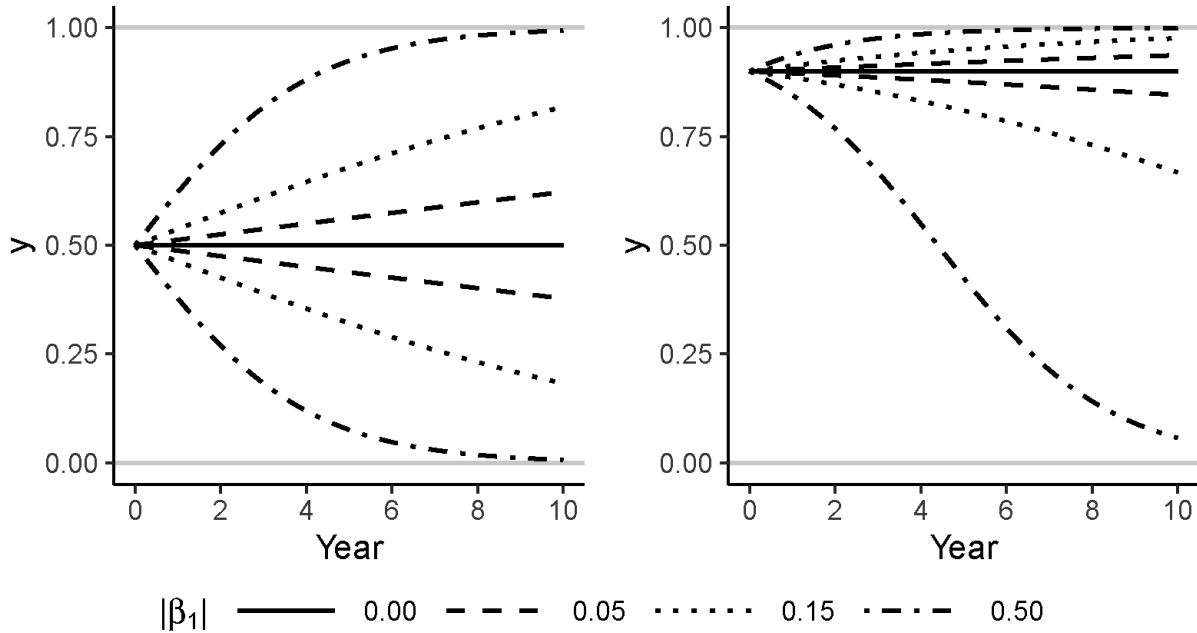


Figure 4. Predicted mean response for three different trend coefficient magnitudes (on link function scale), illustrating the non-linear function of year due to the logit transformation. Time zero mean response equal to 0.5 [left] versus 0.9 [right].

An approximate upper bound for the absolute trend coefficient estimated in *Sections 3.2 and 4.2* is 15% (i.e., $|\beta_1| \leq 0.15$). For estimated absolute trend coefficients less than or equal to this value, the change in the mean response over the course of a 10-year period is approximately linear (Figure 4). Therefore, an alternative approximation to the change in the mean response over time is to divide the change in the predicted mean response (Δ_{resp}) by the time span over which it occurred (Δ_{yr}). To this end, values for Δ_{resp} and Δ_{yr} have been included in each summary table.

It is acknowledged that some degree of spatial and/or temporal autocorrelation exists among observations given the nature of the data. However, due to both the limited amount of data and relatively short time frame over which data were collected within each DMA grouping, neither was addressed within the fitted statistical models.

3.2 Results

Trends in MMI VN24 scores within each park are depicted graphically in Figure 5 and summarized in Table 3.

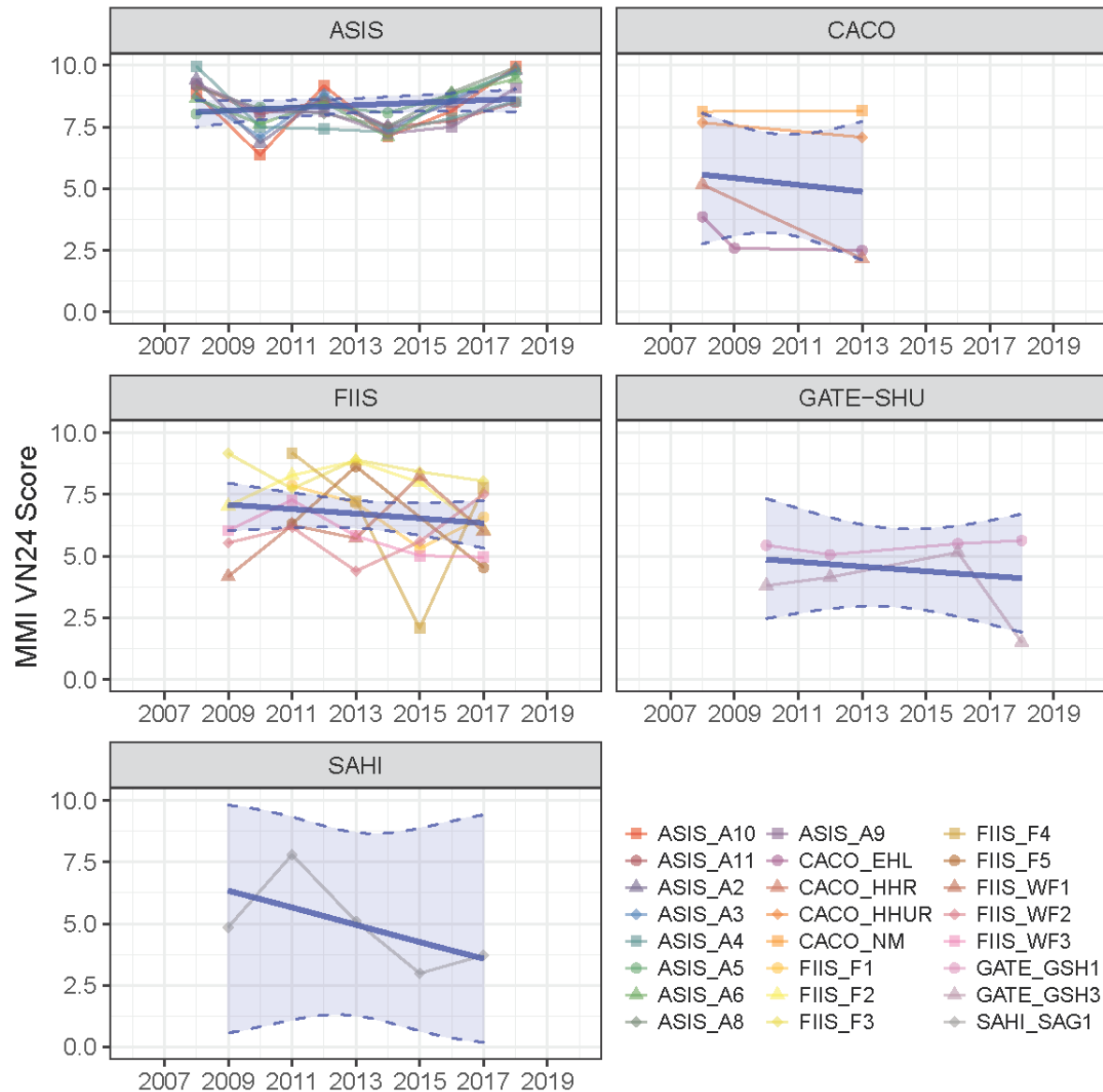


Figure 5. Multimetric index (MMI) VN24 scores for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park. Estimated mean VN24 score as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 3. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean multimetric index (MMI) VN24 score from a beta regression (logit link) fit to each monitored Northeast Coastal and Barrier Network (NCBN) park. If the 95% confidence interval (95% CI) for the trend coefficient contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean MMI VN24 score (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

NCBN Park	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Assateague Island National Seashore	54	0.039	0.029	(-0.020, 0.098)	1.040	0.532	10
Cape Cod National Seashore	9	-0.056	0.145	(-0.411, 0.300)	0.946	-0.692	5
Fire Island National Seashore	36	-0.043	0.045	(-0.134, 0.049)	0.958	-0.750	8
Gateway National Recreation Area – Sandy Hook Unit	8	-0.039	0.082	(-0.249, 0.171)	0.962	-0.766	8
Sagamore Hill National Historic Site	5	-0.141	0.160	(-0.831, 0.548)	0.868	-2.749	8

3.3 Discussion

Most parks appear to be exhibiting increased levels of disturbance over time (i.e., smaller VN24 score) except for ASIS. However, none of the estimated trend coefficients are statistically different from zero at the 5% level. In addition to an estimated positive trend coefficient, ASIS also has the highest observed VN24 scores and there is low among marsh (within park) variability. FIIS has high among marsh (within park) variability, which is contributing to the lack of significance for its parkwide trend estimate. In addition, CACO, GATE-SHU and SAHI have limited numbers of marshes informing the estimates. The values of the VN24 scores, however, are still useful for inferring relative health of a park's marshes compared to the other parks.

Section 4. Additional Metrics of Interest

4.1 Methods

4.1.1 Metric Derivation

In addition to the MMI VN24 scores, the following metrics are of interest: (1) percent cover of *Spartina patens*; (2) percent cover of *Salicornia* spp.; (3) percent cover of high salinity-tolerant species; (4) percent low salinity-tolerant species richness; (5) nekton native species richness; and (6) nekton relative abundance of *Palaemonetes* spp.

Metrics 1–3 (percent cover) and 6 (relative abundance) were computed using the respective metric derivation steps detailed in Section 3.1.1. For percent cover of *Salicornia* spp., the following species were present in the data and included in the metric: *Salicornia maritima*, *Salicornia bigelovii*, *Salicornia* sp., *Salicornia virginica*, and *Salicornia depressa*. Species' salinity tolerance for metric 3 was determined using Supplemental Table 1 from Nagel et al. (2017).

Percent low salinity-tolerant species richness was computed for each marsh unit and year as follows:

1. Define individual plot sampling events using LocationID and StartDate values.
2. For each individual plot sampling event, do the following:
 - a. Subset data frame to include only plots that contain live vegetation. Note: both vascular plant and algal species are included in vegetation.
 - b. Use Supplemental Table 1 (Nagel et al. 2017) to determine the salinity tolerance for each species present.
 - c. Count number of low salinity-tolerant species present and divide by total number of species present in plot.
3. Average species richness percent over all sample plots.

Nekton native species richness was computed for each marsh study unit and year as follows:

1. Define individual plot sampling events using LocID2 and StartDate values.
2. For each individual plot sampling event, do the following:
 - a. Use Supplemental Table 2 (Nagel et al. 2017) to determine which species are native.
 - b. Count number of native species present in plot.
3. Average native species counts over all sample plots.

4.1.2 Trend

Metrics 1–4 and 6 from Section 4.1.1 are both continuous and restricted to a closed interval. Therefore, trend over time in each of these metrics was assessed using beta regression (see Section 3.1.3 for trend definition and model details).

The nekton native species richness metric (i.e., metric 5) is computed as the average native species count over all sample plots within a marsh unit and year and values are both continuous and non-negative. Trend over time for this metric was assessed using a gamma generalized linear model (GLM) with log link. The log link is a common choice and was chosen to match the multiplicative trend assessed with metrics fit using beta regression. Although other options exist for modeling a continuous and non-negative response, the gamma GLM was chosen because of its flexibility and the response is modeled on its original scale.

It is assumed that the response variable y_i , ($i = 1, \dots, n$) is distributed according to a gamma distribution parameterized by a mean μ_i and unknown precision ϕ : $y_i \sim \text{Gamma}(\mu_i, \phi)$. The gamma GLM is defined as

$$\log(\mu_i) = \mathbf{x}_i^\top \boldsymbol{\beta},$$

where $\boldsymbol{\beta}$ is a vector of unknown regression parameters and $\mathbf{x}_i^\top$ is the vector of covariates.

Trend was defined as the linear trend in time (years) on the log scale:

$$\log(\mu_i) = \beta_0 + \beta_1 t_i,$$

where t_i is the i^{th} year since 2008. The trend in nekton native species richness over time can be interpreted as the multiplicative change of $\exp(\beta_1)$ in the the mean nekton native species richness for each 1-year increase in time.

Trends in each metric were assessed at the park-level for all parks except Cape Cod National Seashore. Due to differences in the sampling design, trends within CACO were assessed at the marsh-level (see Appendix B).

4.2 Results

4.2.1 Percent Cover of *Spartina patens*

Trends in percent cover of *Spartina patens* within each park are depicted graphically in Figure 6 and summarized in Table 4.

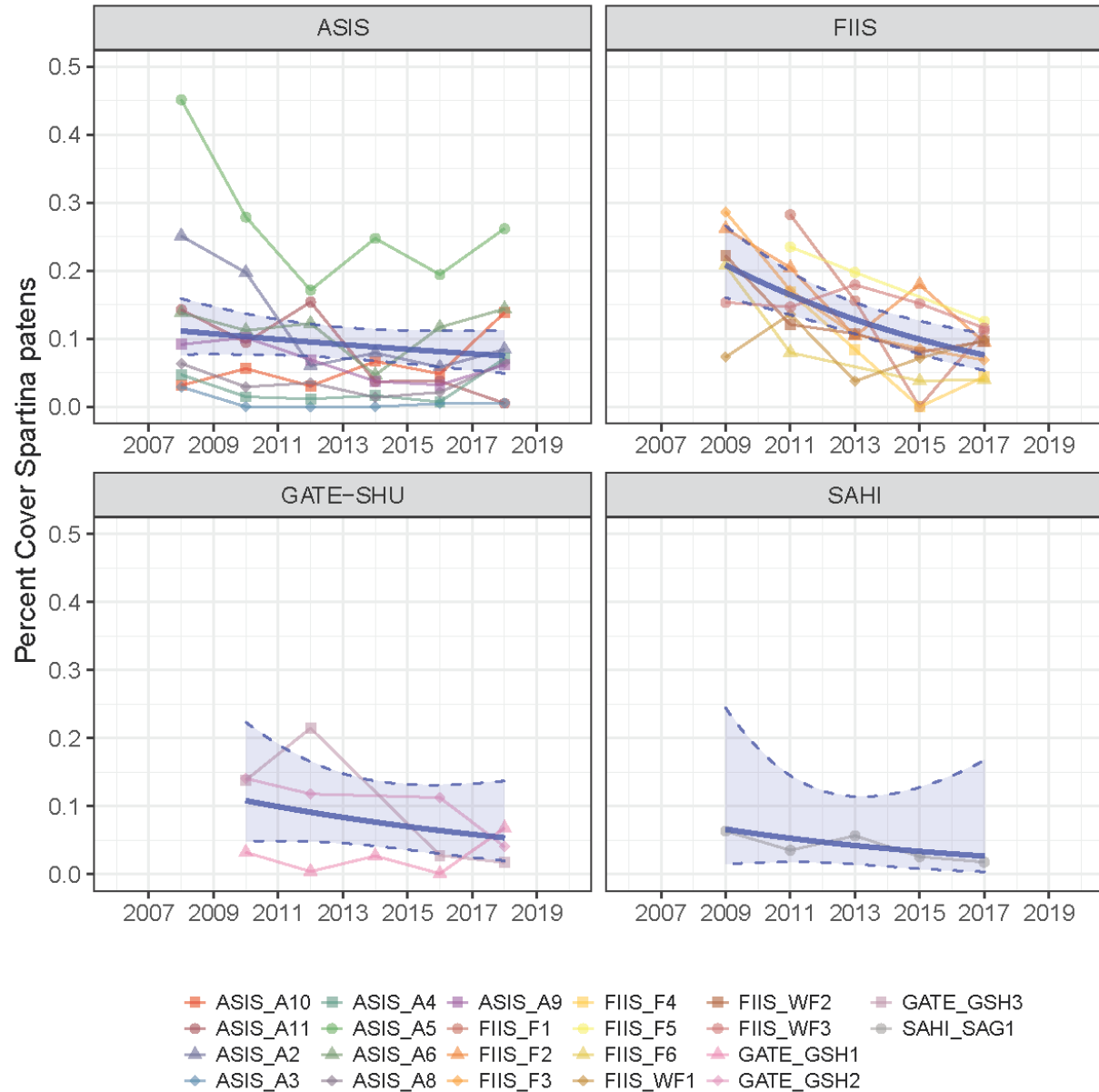


Figure 6. Percent cover of *Spartina patens* for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park. Estimated mean percent cover of *Spartina patens* as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent cover of *Spartina patens* from a beta regression (logit link) fit to each monitored Northeast Coastal and Barrier Network (NCBN) park. If the 95% confidence interval (95% CI) for the trend coefficient contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent cover (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

NCBN Park	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Assateague Island National Seashore	54	-0.044	0.033	(-0.110, 0.022)	0.957	-0.037	10
Fire Island National Seashore	40	-0.145	0.035	(-0.216, -0.074)	0.865	-0.132	8
Gateway National Recreation Area – Sandy Hook Unit	13	-0.095	0.078	(-0.268, 0.078)	0.910	-0.054	8
Sagamore Hill National Historic Site	5	-0.118	0.082	(-0.470, 0.234)	0.888	-0.039	8

4.2.2 Percent Cover of *Salicornia* spp.

Trends in percent cover of *Salicornia* spp. within each park are depicted graphically in Figure 7 and summarized in Table 5.

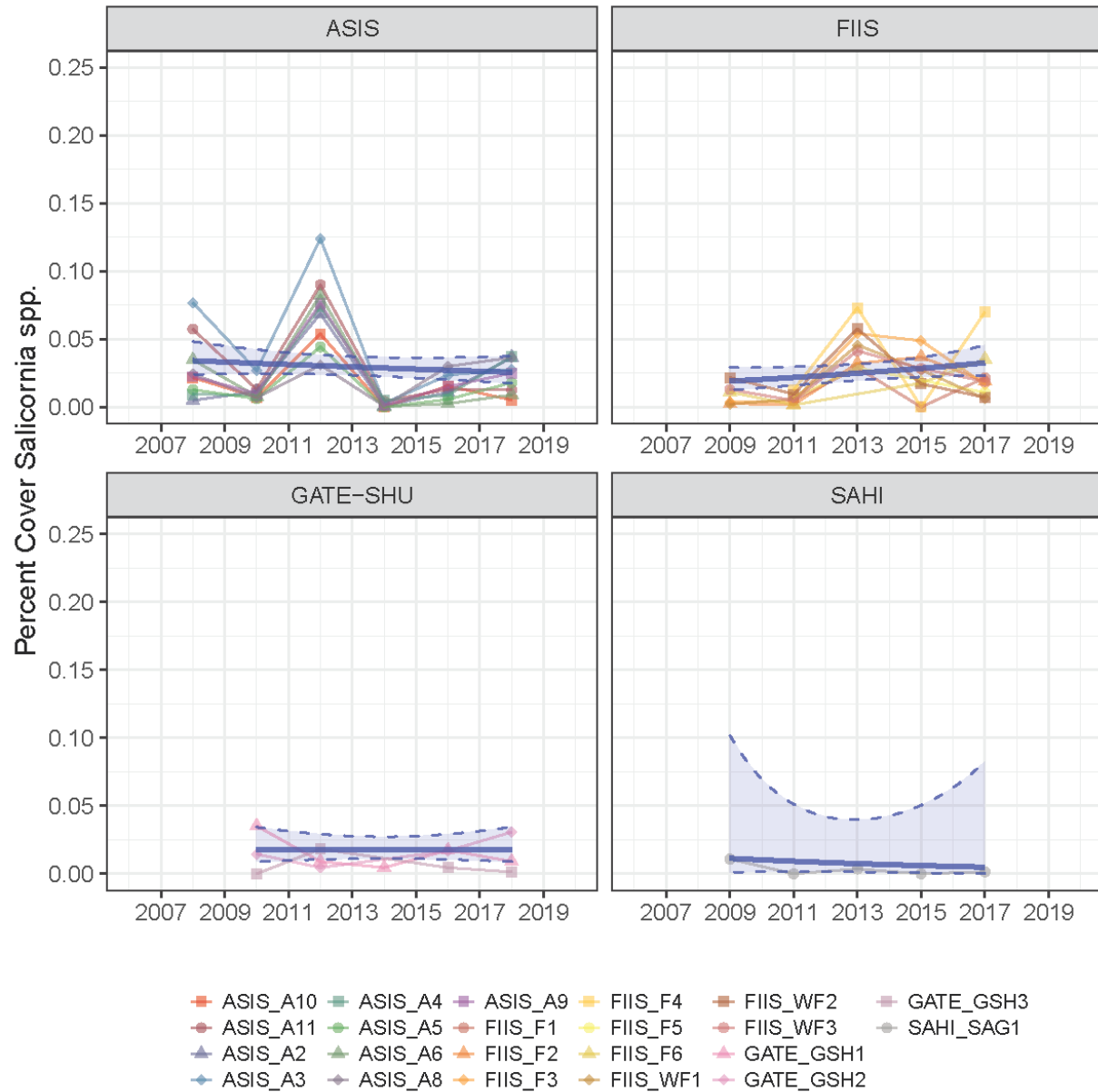


Figure 7. Percent cover of *Salicornia* spp. for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park. Estimated mean percent cover of *Salicornia* spp. as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 5. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent cover of *Salicornia* spp. from a beta regression (logit link) fit to each monitored Northeast Coastal and Barrier Network (NCBN) park. If the 95% confidence interval (95% CI) for the trend coefficient contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent cover (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

NCBN Park	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Assateague Island National Seashore	54	-0.030	0.029	(-0.088, 0.029)	0.971	-0.009	10
Fire Island National Seashore	40	0.069	0.038	(-0.008, 0.146)	1.071	0.014	8
Gateway National Recreation Area – Sandy Hook Unit	13	0.000	0.059	(-0.130, 0.131)	1.000	0.000	8
Sagamore Hill National Historic Site	5	-0.106	0.115	(-0.603, 0.390)	0.899	-0.006	8

4.2.3 Percent Cover of High Salinity-Tolerant Species

Trends in percent cover of high salinity-tolerant species within each park are depicted graphically in Figure 8 and summarized in Table 6.

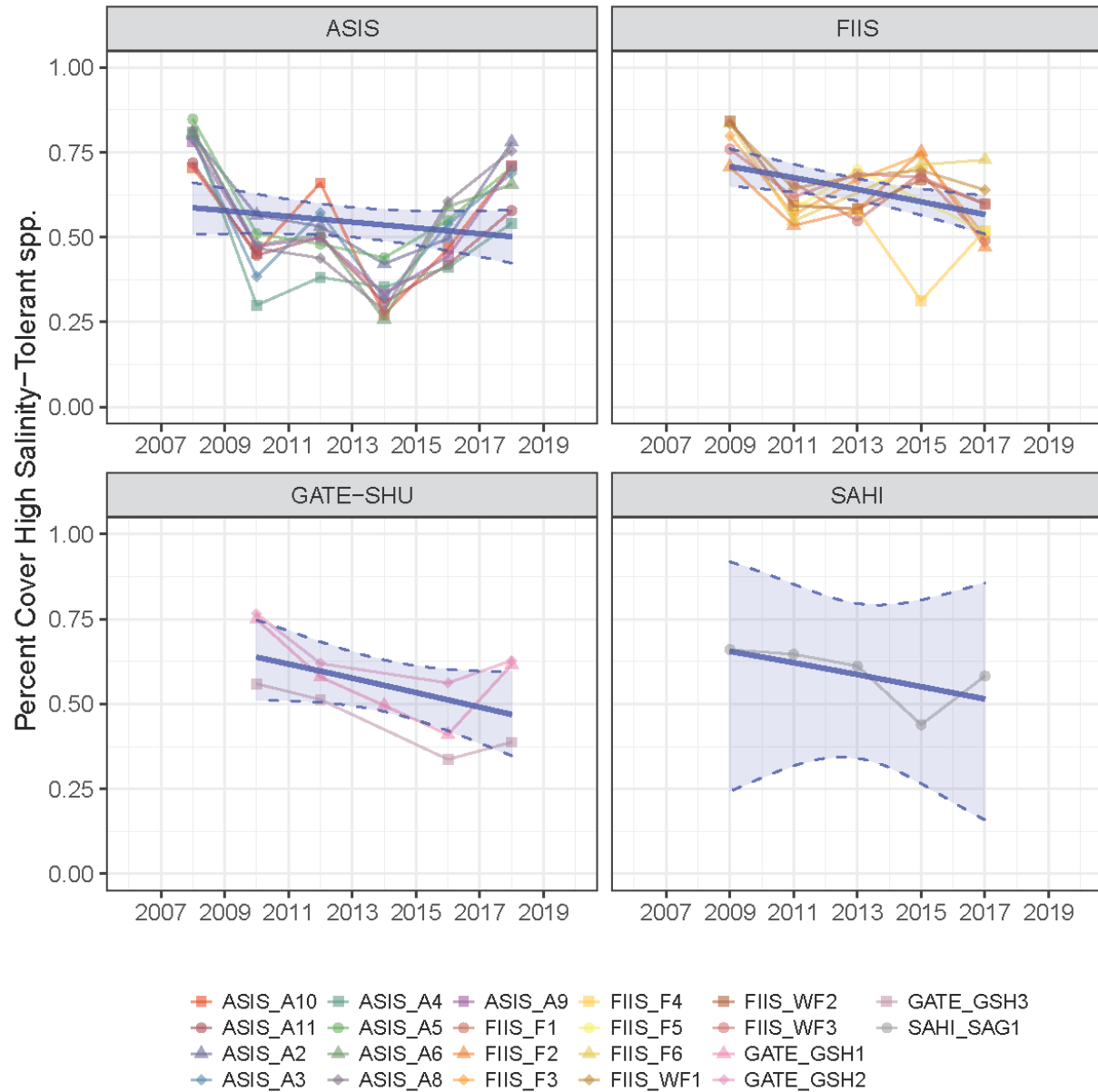


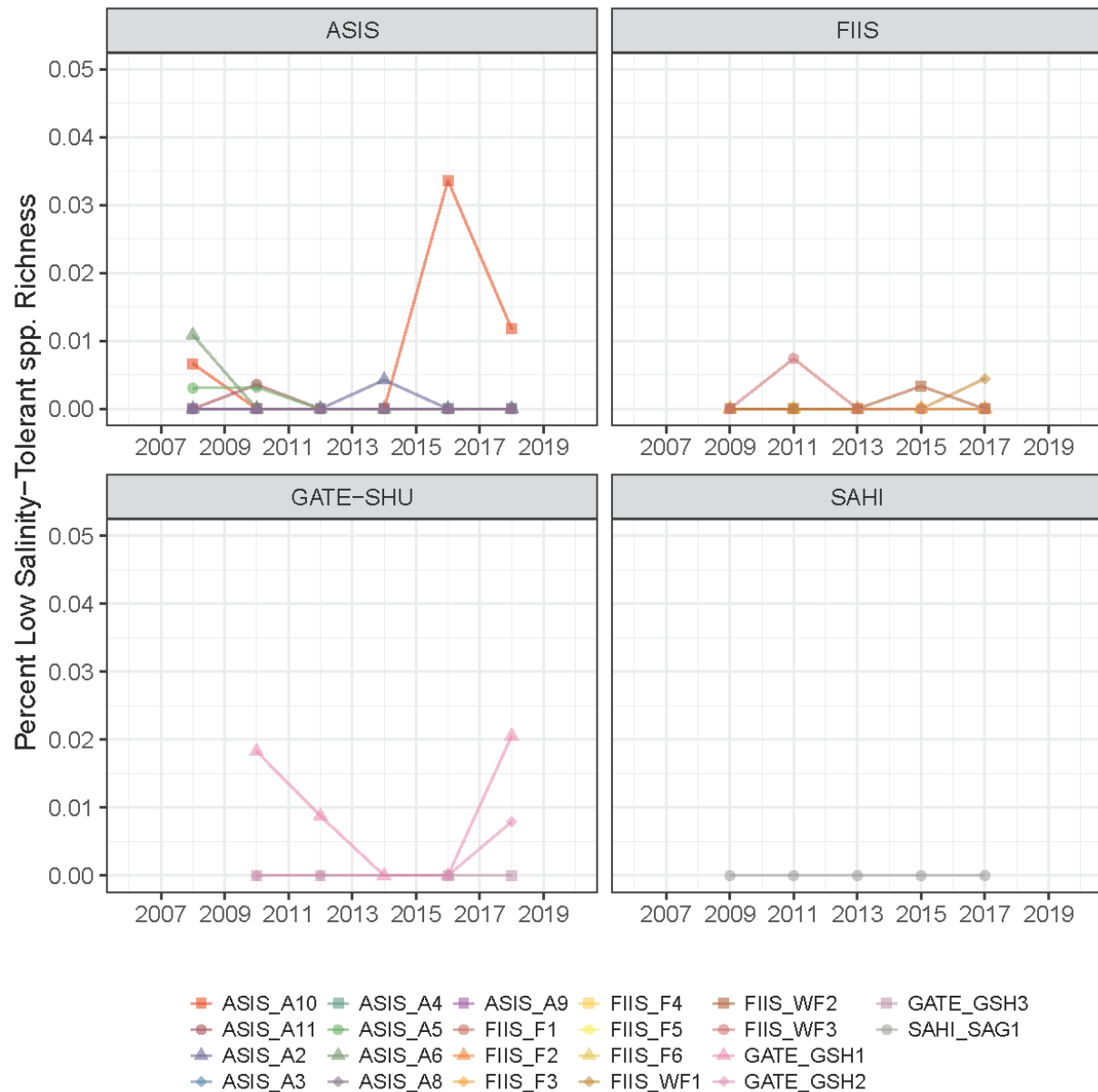
Figure 8. Percent cover of high salinity-tolerant species for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park. Estimated mean percent cover of high salinity-tolerant species as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 6. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent cover of high salinity-tolerant species from a beta regression (logit link) fit to each monitored Northeast Coastal and Barrier Network (NCBN) park. If the 95% confidence interval (95% CI) for the trend coefficient contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent cover (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

NCBN Park	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Assateague Island National Seashore	54	-0.034	0.026	(-0.086, 0.018)	0.966	-0.085	10
Fire Island National Seashore	40	-0.077	0.025	(-0.128, -0.026)	0.926	-0.141	8
Gateway National Recreation Area – Sandy Hook Unit	13	-0.086	0.046	(-0.189, 0.016)	0.917	-0.169	8
Sagamore Hill National Historic Site	5	-0.073	0.083	(-0.431, 0.286)	0.930	-0.140	8

4.2.4 Percent Low Salinity-Tolerant Species Richness

Observed percent low salinity-tolerant species richness within each park is depicted graphically in Figure 9.



4.2.5 Nekton Native Species Richness

Trends in nekton native species richness within each park are depicted graphically in Figure 10 and summarized in Table 7.

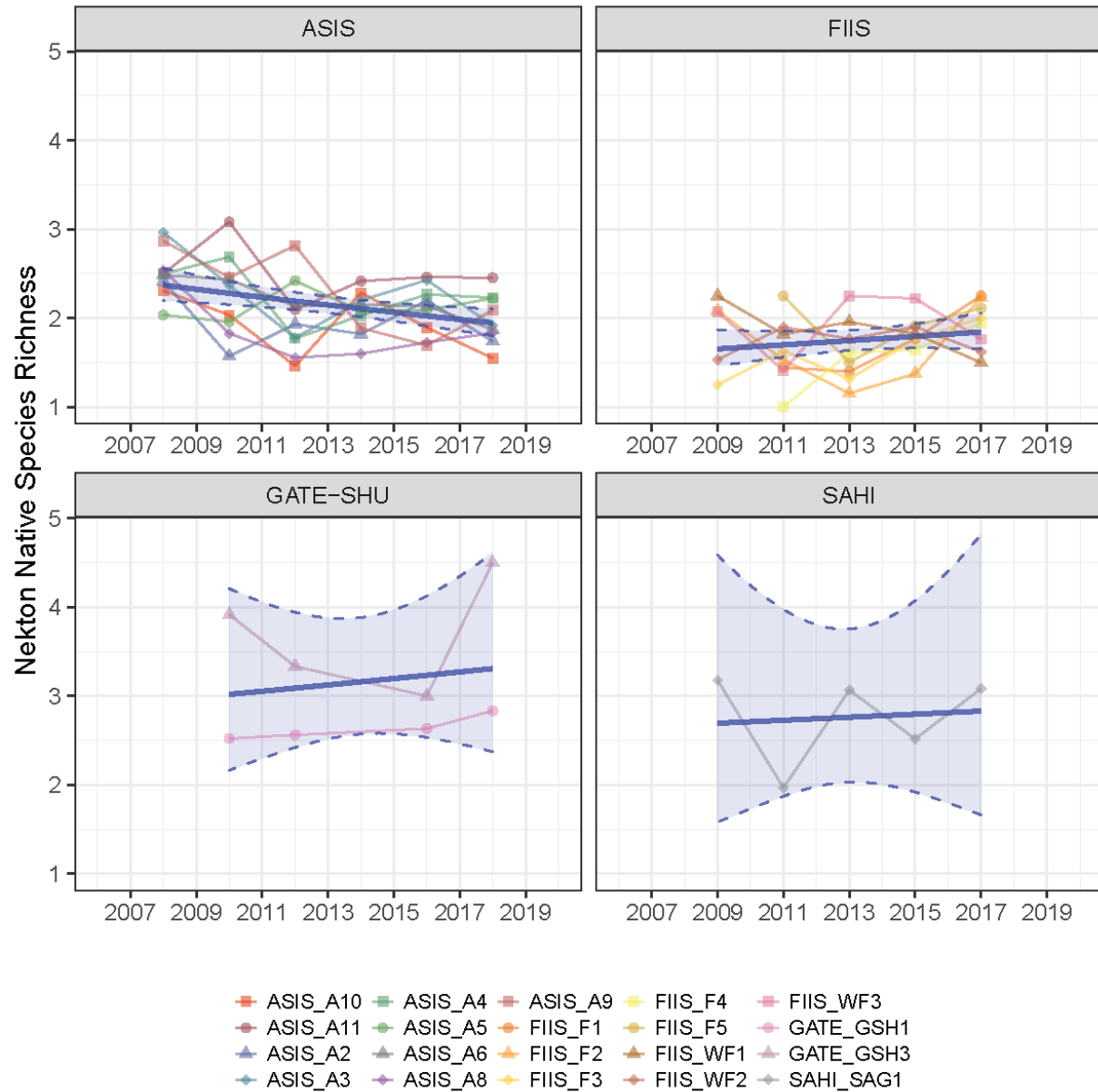


Figure 10. Nekton native species richness for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park. Estimated mean nekton native species richness as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 7. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in mean nekton native species richness from a gamma GLM (log link) fit to each monitored Northeast Coastal and Barrier Network (NCBN) park. If the 95% confidence interval (95% CI) for the trend coefficient contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean species richness (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

NCBN Park	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Assateague Island National Seashore	54	-0.020	0.006	(-0.032, -0.007)	0.980	-0.425	10
Fire Island National Seashore	37	0.014	0.012	(-0.010, 0.038)	1.014	0.191	8
Gateway National Recreation Area – Sandy Hook Unit	8	0.011	0.027	(-0.054, 0.077)	1.012	0.290	8
Sagamore Hill National Historic Site	5	0.006	0.034	(-0.103, 0.115)	1.006	0.136	8

4.2.6 Relative Abundance of *Palaemonetes* spp.

Trends in relative abundance of *Palaemonetes* spp. within each park are depicted graphically in Figure 11 and summarized in Table 8.

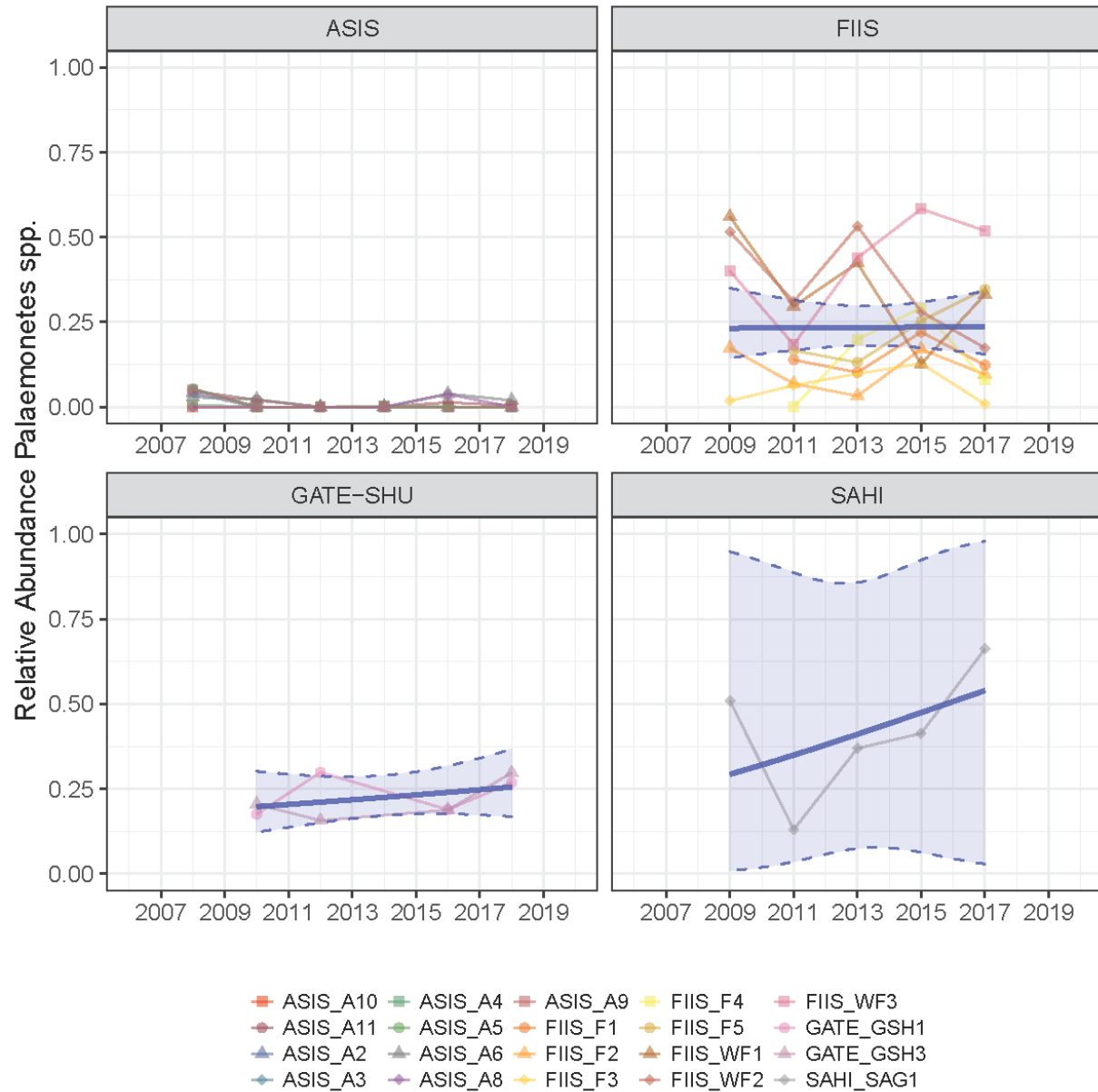


Figure 11. Relative abundance of *Palaemonetes* spp. for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park. Estimated mean relative abundance of *Palaemonetes* spp. as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: a beta regression was not fit to ASIS due to most of the observations equaling zero.

Table 8. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean relative abundance of *Palaemonetes* spp. from a beta regression (logit link) fit to each monitored Northeast Coastal and Barrier Network (NCBN) park. If the 95% confidence interval (95% CI) for the trend coefficient contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). Note: a beta regression was not fit to ASIS due to most of the observations equaling zero. The change in the predicted mean relative abundance (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

NCBN Park	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Fire Island National Seashore	37	0.003	0.054	(-0.108, 0.114)	1.003	0.004	8
Gateway National Recreation Area – Sandy Hook Unit	8	0.042	0.041	(-0.065, 0.148)	1.042	0.058	8
Sagamore Hill National Historic Site	5	0.130	0.177	(-0.632, 0.892)	1.139	0.247	8

4.3 Discussion

No trends were statistically significant at the 5% level for GATE-SHU and SAHI. However, there were a limited number of marshes informing estimates, ranging from 1 to 3 marshes. Additionally, metrics within these two parks tended to exhibit more year-to-year and within-park (as applicable) variation than did ASIS and FIIS. The metric values, however, are still useful for both inferring relative health of a park's marshes compared to the other parks and identifying parks that may warrant additional sampling.

Regardless of the statistical significance of each test, we default to the ecological subject-matter experts to determine whether the estimated linear trends represent biologically meaningful changes (see Table 9 for overview). It is possible that statistically significant changes in a metric might not translate to an ecologically meaningful change in the metric values over time. This is more likely to occur for metrics where most of the observations fall near the domain boundary of the metric (e.g., percent cover of *Salicornia* spp.). We refer the reader to Section 3.1.3 for recommendations on developing intuition about the changes on the response scale that correspond to the estimated trend coefficient.

Table 9. Summary of the sign of the trend coefficient (link function scale) for each metric of interest in each monitored Northeast Coastal and Barrier Network (NCBN) park (Assateague Island National Seashore (ASIS), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)). Trend coefficients that were found to be statistically different from zero (assuming $\alpha = 0.05$) are enclosed in parentheses. NAs indicate model was not fit due to a high proportion of observations equaling zero.

Metric	ASIS	FIIS	GATE-SHU	SAHI
Percent cover of <i>Spartina patens</i>	–	(–)	–	–
Percent cover of <i>Salicornia</i> spp.	–	+	+	–
Percent cover of high salinity-tolerant species	–	(–)	–	–
Percent low salinity-tolerant species richness	NA	NA	NA	NA
Nekton native species richness	(–)	+	+	+
Relative abundance of <i>Palaemonetes</i> spp.	NA	+	+	+

Section 5. Power Analysis # 1

5.1 Methods

Power analyses are a function of the following five parameters: (1) power: the probability of rejecting the null hypothesis when it is false; (2) sample size; (3) type I error rate (alpha level): the probability of rejecting the null hypothesis given that it is true; (4) magnitude of the trend coefficient; and (5) variance of the metric. Increasing the value of the sample size, type I error rate, or trend coefficient, while holding the remaining parameters constant, will result in increased power. Decreasing the variance, while holding the remaining parameters constant, will also result in increased power. If given values for four of the parameters, it is possible to solve for the remaining parameter value.

The empirical power to detect a linear trend in time (link function scale) of a given magnitude under varying levels of sampling effort was estimated using Monte Carlo simulation following the method detailed in Gelman and Hill (2006). The type I error rate was set equal to 0.05 and the variance of each metric was estimated from the observed data using the estimated dispersion parameter $\hat{\phi}$ from each regression fit in Section 4.2. The number of sampled marsh study units within a park varied from 2 to 12 units and it was assumed that all units are sampled concurrently. Additionally, the sampling interval was varied from every 1 to 5 years over the 10-year period. The magnitude of the trend coefficient was set approximately equal to the respective estimated trend coefficient from Section 4.2.

To estimate the empirical power for a given simulation scenario, ten thousand hypothetical time series were simulated according to the defined per year trend, on the link function scale, for a period of 10 years. Simulated variation from the conditional mean value was equal to the estimated residual variation from the regression analyses (i.e., the parameter $\hat{\phi}$, which is visually represented by the light blue shaded intervals in the conditional distribution figures provided in Appendix A). Regressions were fit to each simulated time series in accordance with the methods detailed in Section 4.1.2. Empirical power was estimated by computing the proportion of the ten thousand regressions that rejected the null hypothesis of $H_0: \beta_1 = 0$ in favor of $H_1: \beta_1 \neq 0$.

Empirical power was estimated for a subset of metrics within each park. NCBN scientists identified percent cover of *Spartina patens*, percent cover of high salinity-tolerant species, nekton native species richness, and relative abundance of *Palaemonetes* species as being the metrics of interest. Additionally, empirical power was not estimable for percent low salinity-tolerant species richness since regressions were not fit due to most of the observations equaling zero.

Consistent with Section 4, the analysis quantified the power to detect park-level trends in the metrics for all parks except Cape Cod National Seashore. Due to differences in the sampling design, power to detect trends within CACO were quantified at the marsh-level (see Appendix C).

5.2 Results

5.2.1 Assateague Island National Seashore

Empirical power estimates for detecting trends in ASIS metrics are summarized in Tables 10–12. Power was not estimated for relative abundance of *Palaemonetes* spp. due to large proportion of observations equaling zero.

Table 10. Empirical power estimates for detecting a –5% per year trend (logit scale) in mean percent cover of *Spartina patens* within Assateague Island National Seashore (ASIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.02	0.05	0.10	0.19
3	0.07	0.11	0.17	0.29
4	0.13	0.17	0.24	0.38
5	0.18	0.23	0.31	0.47
6	0.24	0.28	0.36	0.56
7	0.28	0.32	0.42	0.62
8	0.31	0.38	0.47	0.68
9	0.37	0.42	0.53	0.74
10	0.41	0.47	0.58	0.78
11	0.45	0.52	0.62	0.83
12	0.49	0.56	0.66	0.86

Table 11. Empirical power estimates for detecting a –4% per year trend (logit scale) in mean percent cover high salinity-tolerant species within Assateague Island National Seashore (ASIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.02	0.04	0.06	0.12
3	0.05	0.07	0.1	0.17
4	0.08	0.11	0.15	0.23
5	0.11	0.13	0.17	0.27
6	0.14	0.16	0.21	0.33
7	0.17	0.19	0.24	0.37

Table 11 (continued). Empirical power estimates for detecting a –4% per year trend (logit scale) in mean percent cover high salinity-tolerant species within Assateague Island National Seashore (ASIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
8	0.19	0.21	0.27	0.42
9	0.21	0.25	0.31	0.47
10	0.23	0.27	0.33	0.51
11	0.26	0.29	0.39	0.56
12	0.28	0.32	0.40	0.59

Table 12. Empirical power estimates for detecting a –2% per year trend (log scale) in mean nekton native species richness within Assateague Island National Seashore (ASIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.17	0.20	0.28	0.43
3	0.27	0.32	0.41	0.61
4	0.36	0.43	0.52	0.73
5	0.45	0.51	0.63	0.83
6	0.54	0.60	0.71	0.89
7	0.61	0.68	0.78	0.93
8	0.67	0.74	0.84	0.96
9	0.73	0.78	0.87	0.98
10	0.77	0.82	0.90	0.99
11	0.81	0.86	0.93	0.99
12	0.85	0.89	0.95	1.00

5.2.2 Fire Island National Seashore

Empirical power estimates for detecting trends in FIIS metrics are summarized in Tables 13–16.

Table 13. Empirical power estimates for detecting a –15% per year trend (logit scale) in mean percent cover of *Spartina patens* within Fire Island National Seashore (FIIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.28	0.59	0.86	0.99
3	0.79	0.91	0.99	1.00
4	0.96	0.99	1.00	1.00
5	0.99	1.00	1.00	1.00
6	1.00	1.00	1.00	1.00
7	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	1.00
9	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00
11	1.00	1.00	1.00	1.00
12	1.00	1.00	1.00	1.00

Table 14. Empirical power estimates for detecting a –8% per year trend (logit scale) in mean percent cover high salinity-tolerant species within Fire Island National Seashore (FIIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.09	0.21	0.39	0.69
3	0.33	0.48	0.65	0.89
4	0.55	0.65	0.81	0.96
5	0.69	0.79	0.89	0.99
6	0.82	0.87	0.95	1.00
7	0.88	0.93	0.98	1.00
8	0.93	0.95	0.99	1.00
9	0.96	0.97	0.99	1.00
10	0.98	0.99	1.00	1.00

Table 14 (continued). Empirical power estimates for detecting a -8% per year trend (logit scale) in mean percent cover high salinity-tolerant species within Fire Island National Seashore (FIIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
11	0.98	0.99	1.00	1.00
12	0.99	1.00	1.00	1.00

Table 15. Empirical power estimates for detecting a 2% per year trend (log scale) in mean nekton native species richness within Fire Island National Seashore (FIIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.13	0.14	0.20	0.31
3	0.19	0.22	0.29	0.45
4	0.26	0.29	0.39	0.56
5	0.33	0.36	0.45	0.66
6	0.39	0.44	0.53	0.73
7	0.45	0.49	0.60	0.80
8	0.51	0.55	0.67	0.85
9	0.55	0.60	0.72	0.90
10	0.60	0.65	0.76	0.92
11	0.65	0.70	0.80	0.94
12	0.68	0.74	0.83	0.96

Table 16. Empirical power estimates for detecting a 1% per year trend (logit scale) in mean relative abundance of *Palaemonetes* spp. within Fire Island National Seashore (FIIS) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.01	0.02	0.03	0.04
3	0.02	0.03	0.04	0.05
4	0.03	0.04	0.04	0.05
5	0.03	0.04	0.05	0.05
6	0.04	0.04	0.05	0.05
7	0.05	0.04	0.05	0.06
8	0.05	0.05	0.05	0.06
9	0.05	0.05	0.05	0.06
10	0.05	0.05	0.06	0.06
11	0.05	0.05	0.06	0.07
12	0.05	0.05	0.06	0.07

5.2.3 Gateway National Recreation Area – Sandy Hook Unit

Empirical power estimates for detecting trends in GATE-SHU metrics are summarized in Tables 17–20.

Table 17. Empirical power estimates for detecting a –10% per year trend (logit scale) in mean percent cover of *Spartina patens* within Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.07	0.17	0.33	0.62
3	0.28	0.40	0.56	0.83
4	0.46	0.58	0.73	0.92
5	0.62	0.72	0.84	0.97
6	0.73	0.80	0.90	0.99
7	0.81	0.87	0.95	1.00
8	0.87	0.93	0.97	1.00
9	0.91	0.95	0.98	1.00

Table 17 (continued). Empirical power estimates for detecting a –10% per year trend (logit scale) in mean percent cover of *Spartina patens* within Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
10	0.94	0.96	0.99	1.00
11	0.96	0.98	1.00	1.00
12	0.98	0.99	1.00	1.00

Table 18. Empirical power estimates for detecting a –9% per year trend (logit scale) in mean percent cover high salinity-tolerant species within Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.08	0.19	0.36	0.66
3	0.30	0.43	0.61	0.86
4	0.50	0.61	0.78	0.94
5	0.66	0.75	0.87	0.98
6	0.77	0.84	0.93	0.99
7	0.85	0.90	0.96	1.00
8	0.90	0.94	0.98	1.00
9	0.94	0.96	0.99	1.00
10	0.96	0.98	0.99	1.00
11	0.97	0.99	1.00	1.00
12	0.98	0.99	1.00	1.00

Table 19. Empirical power estimates for detecting a 2% per year trend (log scale) in mean nekton native species richness within Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.10	0.12	0.16	0.23
3	0.14	0.17	0.21	0.31
4	0.19	0.21	0.27	0.40
5	0.23	0.26	0.33	0.49
6	0.27	0.31	0.39	0.57
7	0.32	0.36	0.45	0.63
8	0.37	0.40	0.49	0.69
9	0.40	0.45	0.55	0.74
10	0.44	0.49	0.59	0.79
11	0.49	0.52	0.63	0.83
12	0.52	0.56	0.66	0.85

Table 20. Empirical power estimates for detecting a 5% per year trend (logit scale) in mean relative abundance of *Palaemonetes* spp. within Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.07	0.15	0.31	0.57
3	0.24	0.35	0.51	0.78
4	0.42	0.52	0.68	0.89
5	0.56	0.66	0.79	0.95
6	0.68	0.75	0.87	0.98
7	0.76	0.83	0.92	0.99
8	0.83	0.89	0.95	1.00
9	0.88	0.92	0.97	1.00
10	0.91	0.95	0.98	1.00
11	0.94	0.96	0.99	1.00
12	0.96	0.98	0.99	1.00

5.2.4 Sagamore Hill National Historic Site

Empirical power estimates for detecting trends in SAHI metrics are summarized in Tables 21–24.

Table 21. Empirical power estimates for detecting a –12% per year trend (logit scale) in mean percent cover of *Spartina patens* within Sagamore Hill National Historic Site (SAHI) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.67	0.95	1.00	1.00
3	1.00	1.00	1.00	1.00
4	1.00	1.00	1.00	1.00
5	1.00	1.00	1.00	1.00
6	1.00	1.00	1.00	1.00
7	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	1.00
9	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00
11	1.00	1.00	1.00	1.00
12	1.00	1.00	1.00	1.00

Table 22. Empirical power estimates for detecting a –8% per year trend (logit scale) in mean percent cover high salinity-tolerant species within Sagamore Hill National Historic Site (SAHI) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.06	0.13	0.28	0.52
3	0.22	0.33	0.48	0.74
4	0.38	0.48	0.64	0.86
5	0.51	0.61	0.75	0.93
6	0.63	0.72	0.83	0.96
7	0.73	0.80	0.89	0.98
8	0.79	0.85	0.93	0.99
9	0.84	0.89	0.95	1.00

Table 22 (continued). Empirical power estimates for detecting a –8% per year trend (logit scale) in mean percent cover high salinity-tolerant species within Sagamore Hill National Historic Site (SAHI) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
10	0.88	0.93	0.97	1.00
11	0.92	0.94	0.98	1.00
12	0.94	0.97	0.99	1.00

Table 23. Empirical power estimates for detecting a 1% per year trend (log scale) in mean nekton native species richness within Sagamore Hill National Historic Site (SAHI) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.06	0.07	0.08	0.10
3	0.08	0.09	0.09	0.13
4	0.10	0.10	0.12	0.16
5	0.11	0.12	0.14	0.19
6	0.12	0.13	0.16	0.21
7	0.14	0.14	0.16	0.25
8	0.15	0.16	0.18	0.27
9	0.16	0.18	0.21	0.30
10	0.17	0.19	0.22	0.32
11	0.18	0.20	0.25	0.36
12	0.21	0.22	0.26	0.39

Table 24. Empirical power estimates for detecting a 13% per year trend (logit scale) in mean relative abundance of *Palaemonetes* spp. within Sagamore Hill National Historic Site (SAHI) after 10 years of data collection assuming various levels of sampling effort.

Number of Marsh Study Units	Sampling Intervals (years)			
	5	3	2	1
2	0.04	0.09	0.18	0.34
3	0.14	0.21	0.31	0.51
4	0.24	0.31	0.43	0.65
5	0.34	0.41	0.53	0.76
6	0.43	0.50	0.61	0.84
7	0.50	0.57	0.70	0.89
8	0.57	0.63	0.76	0.92
9	0.64	0.70	0.81	0.95
10	0.68	0.75	0.85	0.97
11	0.74	0.80	0.89	0.98
12	0.77	0.83	0.91	0.99

5.3 Discussion

5.3.1 Key Question #1

We are currently sampling each marsh biennially, if we change the frequency of sampling to three or more years will we be able to detect similar trends as we are seeing with our existing design?

The impact of changes to sampling frequency on the ability to detect trends will depend on both the park and the metrics of interest. For example, if there is at least one metric within a park where the power to detect the specified trend is insufficient under reduced sampling, then we would conclude that reduced sampling within the given park is not advisable. This assumes that: (1) each of the four metrics utilized in the analysis are equally important to detect trends in and (2) that the magnitude of the assumed trend is practically/ecologically meaningful. As was detailed in *Section 5: Power Analysis #1*, increasing the magnitude of the trend coefficient, while holding all other power analysis parameters constant, will result in increased power. Therefore, the recommendation for or against reduced sampling frequency is heavily dependent on the assumed trend magnitude. To that end, each park has at least one metric where the current sampling frequency is insufficient to detect trends similar in magnitude to what is currently being observed. Therefore, it is not advisable to decrease the sampling interval in any of the parks under the current power analysis parameters.

ASIS currently samples 9 marshes on a biennial basis. There is sufficient power (i.e., power greater than 0.8) to detect trend in nekton native species richness under the current sampling effort. Reducing the sampling interval to every three or five years lowers the empirical power estimates to 0.77 and 0.73, respectively. There is currently insufficient power to detect trends in both percent cover of high salinity-tolerant species or percent cover of *Spartina patens*. Reducing the sampling interval for these metrics will further lower the power of detecting trends.

FIIS currently samples vegetation in 9 marshes and nekton in 8 marshes, both on a biennial basis. There is sufficient power to detect trends for both percent cover of high salinity-tolerant species and percent cover of *Spartina patens*. Reducing the sampling interval to every three or five years still yields empirical power estimates greater than 80%. There is currently insufficient power to detect trends in both relative abundance of *Palaemonetes* spp. and nekton native species richness. Reductions in the sampling interval will further lower the power of detecting trends in these metrics.

For SAHI, which currently only samples one marsh on a biennial basis, there is only sufficient power to detect a trend in percent cover of *Spartina patens*. If it is reasonable to assume that this metric will continue to decrease at the specified rate for the next 10 years, then the sampling interval could be extended to every three years while still maintaining power of at least 80%. Reductions to the sampling interval for the other three metrics will further lower the power of detecting trends.

GATE-SHU currently samples 3 marshes on a biennial basis. There is currently insufficient power to detect trends in all four metrics. Reducing the sampling interval will further lower the power of detecting trends.

5.3.2 Key Question #2

Are we sampling enough sites at each park to be able to extrapolate results parkwide?

The sampling method used to select both the sampling units (i.e., monitoring sites) and sub-sampling units (i.e., plots within monitoring sites) dictates whether results can be extrapolated parkwide. Because monitoring sites were sampled randomly from all potential monitoring sites within a park, parkwide inferences are valid if the plots within monitoring sites were selected in a manner that ensures they were representative of the monitoring site.

Regarding the strength of statistical inference, this is dependent on the metric of interest, the number of sampled sites, and the intended sampling interval. Assuming no change to the sampling interval, each park has at least one metric that would require sampling additional sites to detect trends of similar magnitude to those estimated in *Section 4.2*.

Section 6. Power Analysis # 2

6.1 Methods

The NCBN monitoring protocols for both vegetation and nekton recommend that a non-parametric multivariate community analysis (e.g., analysis of similarities) be used to ascertain whether community composition statistically differs between years within a given monitoring site. James-Pirri, Roman, and Heltshe (2007) and Raposa, Roman, and Heltshe (2003) conducted initial power analyses to determine the number of sampled plots necessary to detect changes in salt marsh vegetation and nekton, respectively. The recommendations from these analyses that were initially used while developing the protocols were $n = 20$ plots per marsh for vegetation and $n = 15$ plots per marsh for nekton.

A bootstrapped permutation procedure approach similar to that detailed in James-Pirri, Roman, and Heltshe (2007) was used to estimate the empirical power of detecting differences between successive sampling years at each monitoring site. The basic procedure to estimate empirical power can be summarized as follows:

1. Specify a monitoring site and subset the data to a pair of successively sampled years (e.g., ASIS_A10, years 2008 and 2010).
2. For each plot in each year, compute the following:
 - a. For vegetation: compute the percent cover for all unique vegetation species present during both sampling years (note: this includes categories for bare ground, wrack & litter, water, horse manure, pebble, rock, and dead plants). Exclude unknown species from the computation of percent cover. Convert percent cover to cover classes using the modified Braun-Blanquet scale where 0 = absent, 1 = 1–5%, 2 = 6–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100%.
 - b. For nekton: compute the density of all unique nekton species present during both sampling years. Exclude unknown species from the list of unique species. Log-transform (i.e., $\log(y + 1)$) each density value.
3. Compute the average of the cover class/log density values within each unique species category across plots within each year. Compute the Euclidean distance similarity index for the comparison of year 1 and year 2 as:

$$D_{12} = \sum_k (C_{1k} - C_{2k})^2,$$

4. where k indexes the unique species present, C_{1k} represents the average cover class/log density of species k in comparison year 1, and C_{2k} represents the average cover class/log density of species k in comparison year 2.

5. Within each comparison year, randomly sample with replacement from the available plots for a total of $n = 10$ plots (note: alternative sample sizes include $n = 20, 30, 40$, and 50 plots). The bootstrap sample in this step is consistent with the fully random sampling design used to select plots within a marsh.
6. Perform an analysis of similarities between the two comparison years in the previous step using the `anosim` function from the `vegan` R package (Oksanen et al. 2019). Record the p -value.
7. Repeat steps (4) and (5) 1000 times for each sample size.
8. Empirical power was estimated by computing the proportion of bootstrap replicates that rejected the null hypothesis of no difference between the two comparison years, assuming a type I error rate (α) of 0.05.
9. Repeat steps (1) through (7) for all successive year comparisons for each monitoring site.

6.2 Results

6.2.1 Vegetation Community Composition

Empirical power estimates for detecting differences in vegetation community composition between two marshes assuming varying levels of sampling effort are depicted graphically in Figure 12. Euclidean distance similarity index values for each marsh pair comparison are provided in Appendix D, Table D-1.

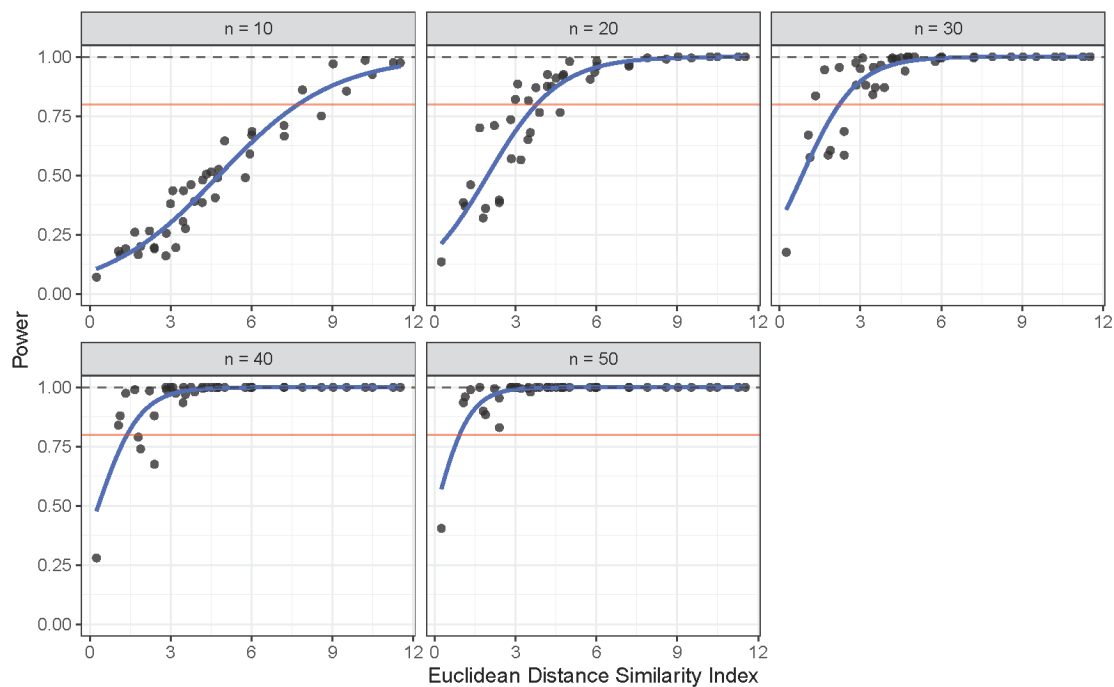


Figure 12. Empirical power estimates for detecting differences in vegetation community composition between two marsh pairs with $n = 10, 20, 30, 40, 50$ sampled plots per marsh. Distance was calculated as the Euclidean distance similarity index between each marsh's average cover class for each unique species present. Superimposed blue curves are provided to assist in visual identification of the sample size necessary to achieve 80% power (red line) for a given similarity distance.

6.2.2 Nekton Community Composition

Empirical power estimates for detecting differences in nekton community composition between two marshes assuming varying levels of sampling effort are depicted graphically in Figure 13. Euclidean distance similarity index values for each marsh pair comparison are provided in Appendix D, Table D-2.

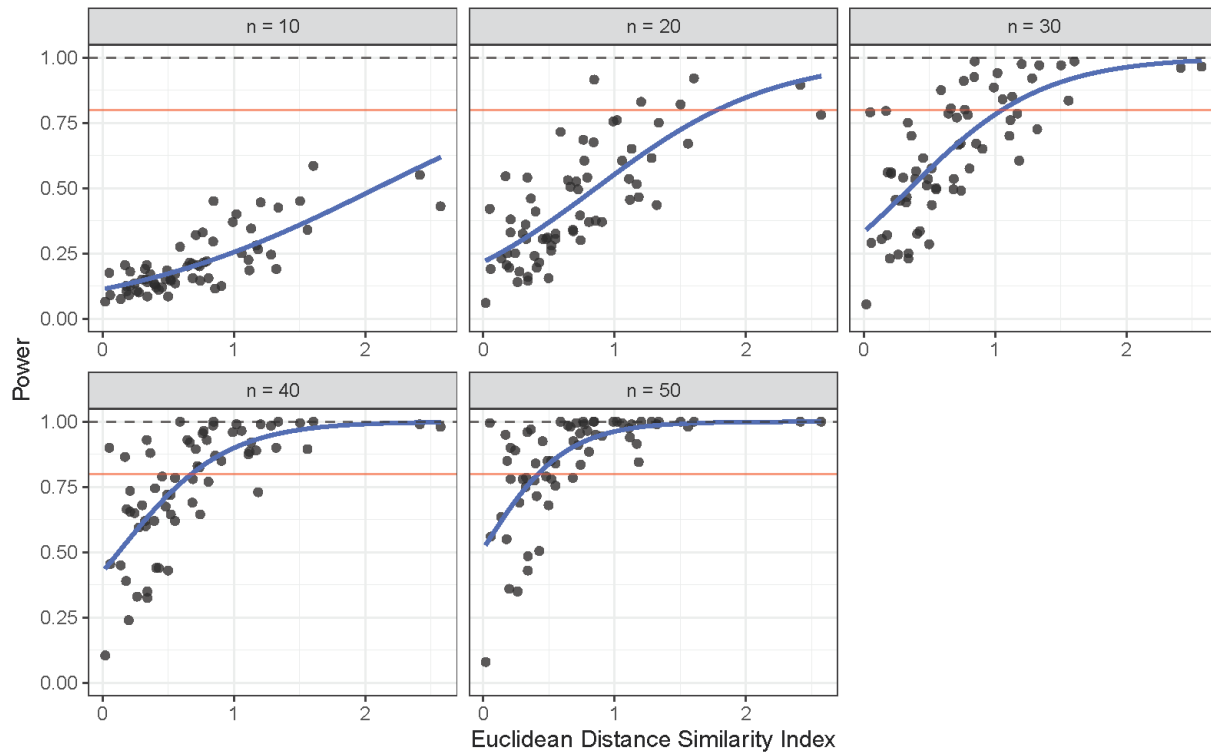


Figure 13. Empirical power estimates for detecting differences in nekton community composition between two marsh pairs with $n = 10, 20, 30, 40, 50$ sampled plots per marsh. Distance was calculated as the Euclidean distance similarity index between each marsh's average log density for each unique species present. Superimposed blue curves are provided to assist in visual identification of the sample size necessary to achieve 80% power (red line) for a given similarity distance.

6.3 Discussion

6.3.1 Key Question #3

**Currently we sample 50 plots on each 5–8-hectare marsh site, are we over or under sampling?
Can we detect trends in both vegetation and nekton community structure and composition
sampling less?**

For vegetation composition, sampling could be reduced to 30 plots per marsh while still retaining 80% power for most of the marsh-year combinations (Figure 12). For nekton composition, sampling should not be reduced below current levels unless a lower power standard is deemed acceptable (Figure 13).

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Appendix A. Conditional Response Distributions

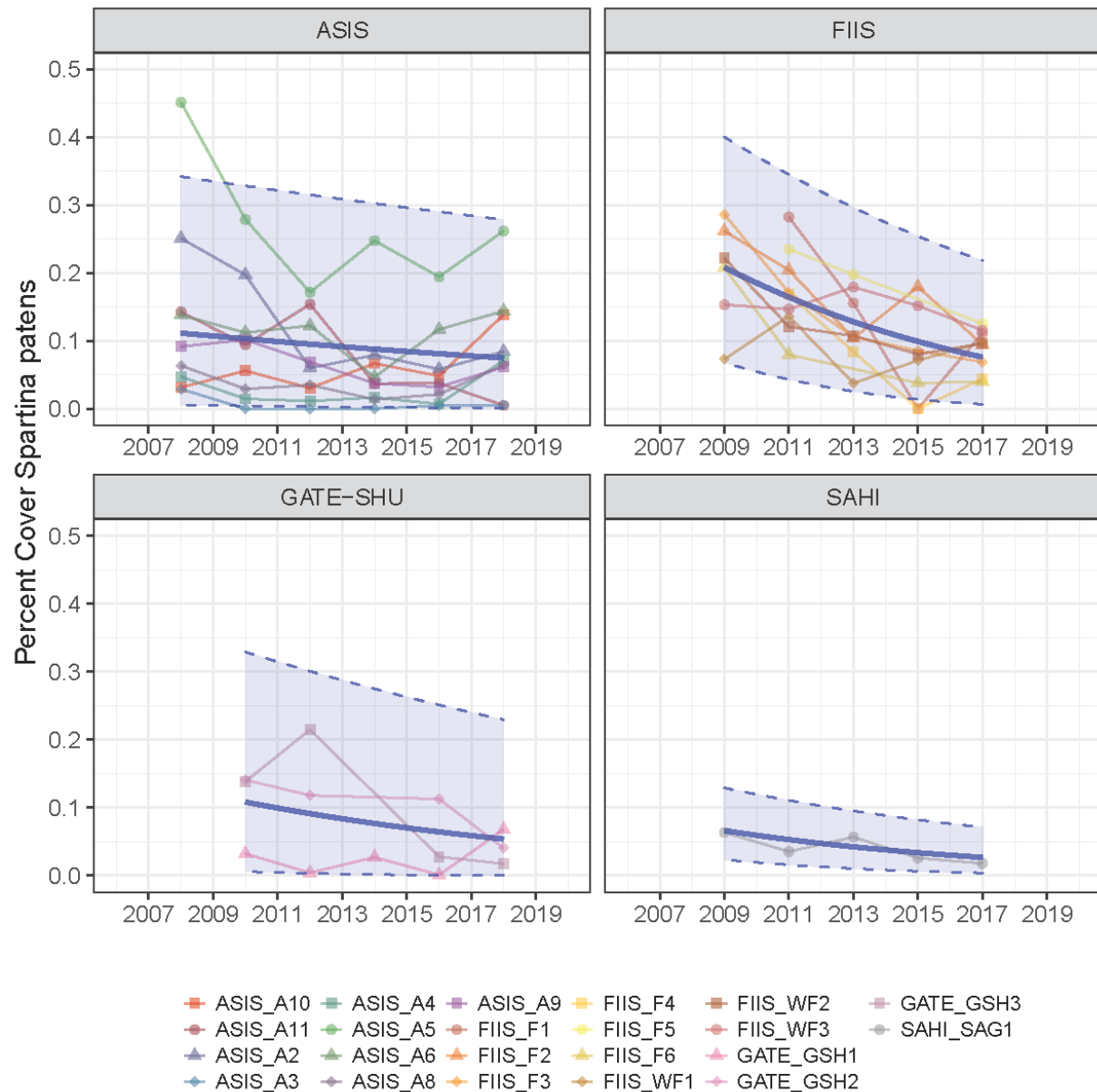


Figure A-1. Percent cover of *Spartina patens* for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park (Assateague Island National Seashore (ASIS), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)). Conditional mean of percent cover of *Spartina patens* as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

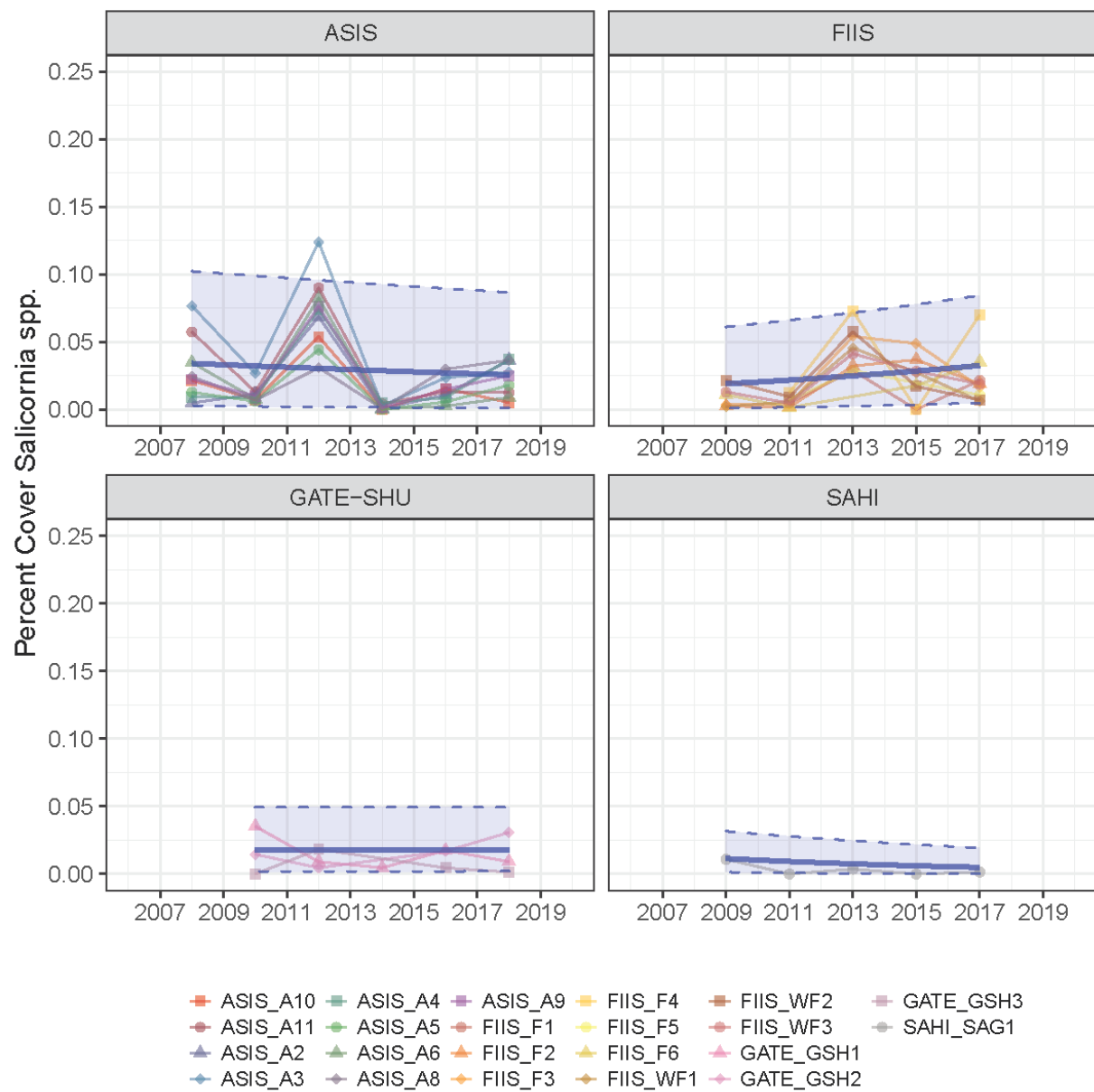


Figure A-2. Percent cover of *Salicornia* spp. for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park (Assateague Island National Seashore (ASIS), Fire Island National Seashore (FIIS), Gateway National Recreation Area - Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)). Conditional mean of percent cover of *Salicornia* spp. as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

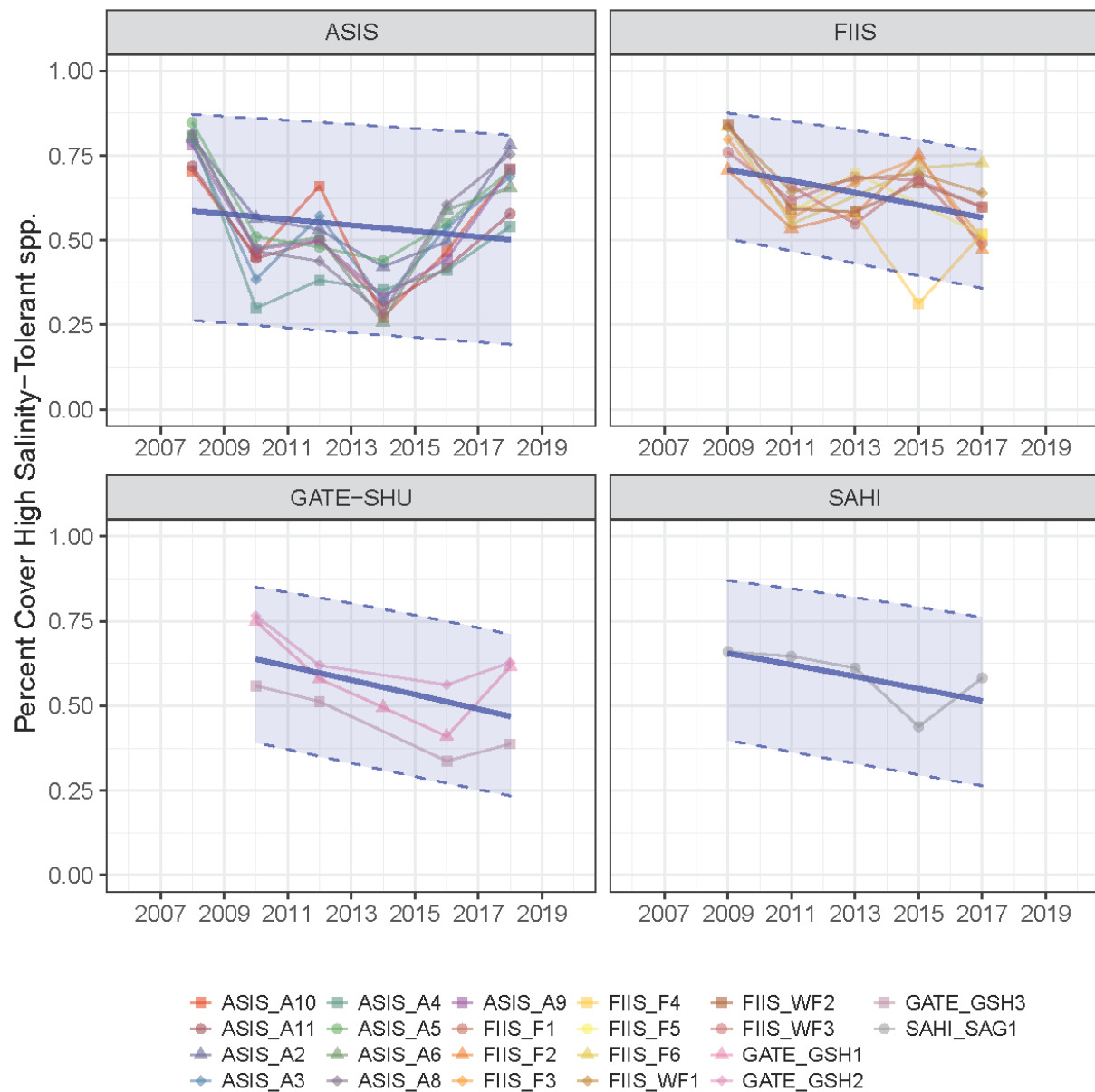


Figure A-3. Percent cover of high salinity-tolerant species for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park (Assateague Island National Seashore (ASIS), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)). Conditional mean of percent cover of high salinity-tolerant species as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

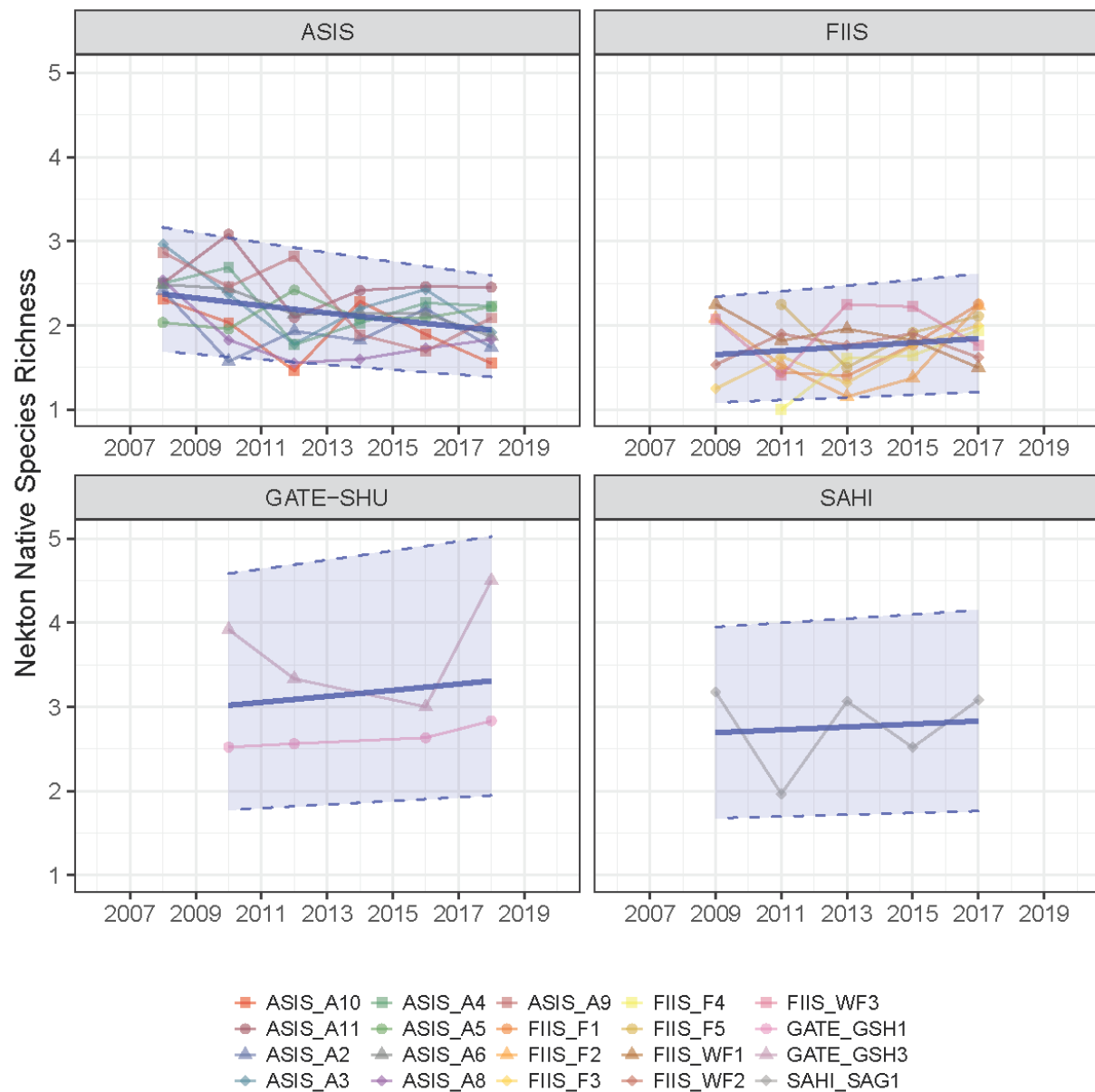


Figure A-4. Nekton native species richness for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park (Assateague Island National Seashore (ASIS), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)). Conditional mean of nekton native species richness as a function of year plotted in blue with 95% interval of the conditional gamma distribution of the response shaded in light blue and bound by dashed lines.

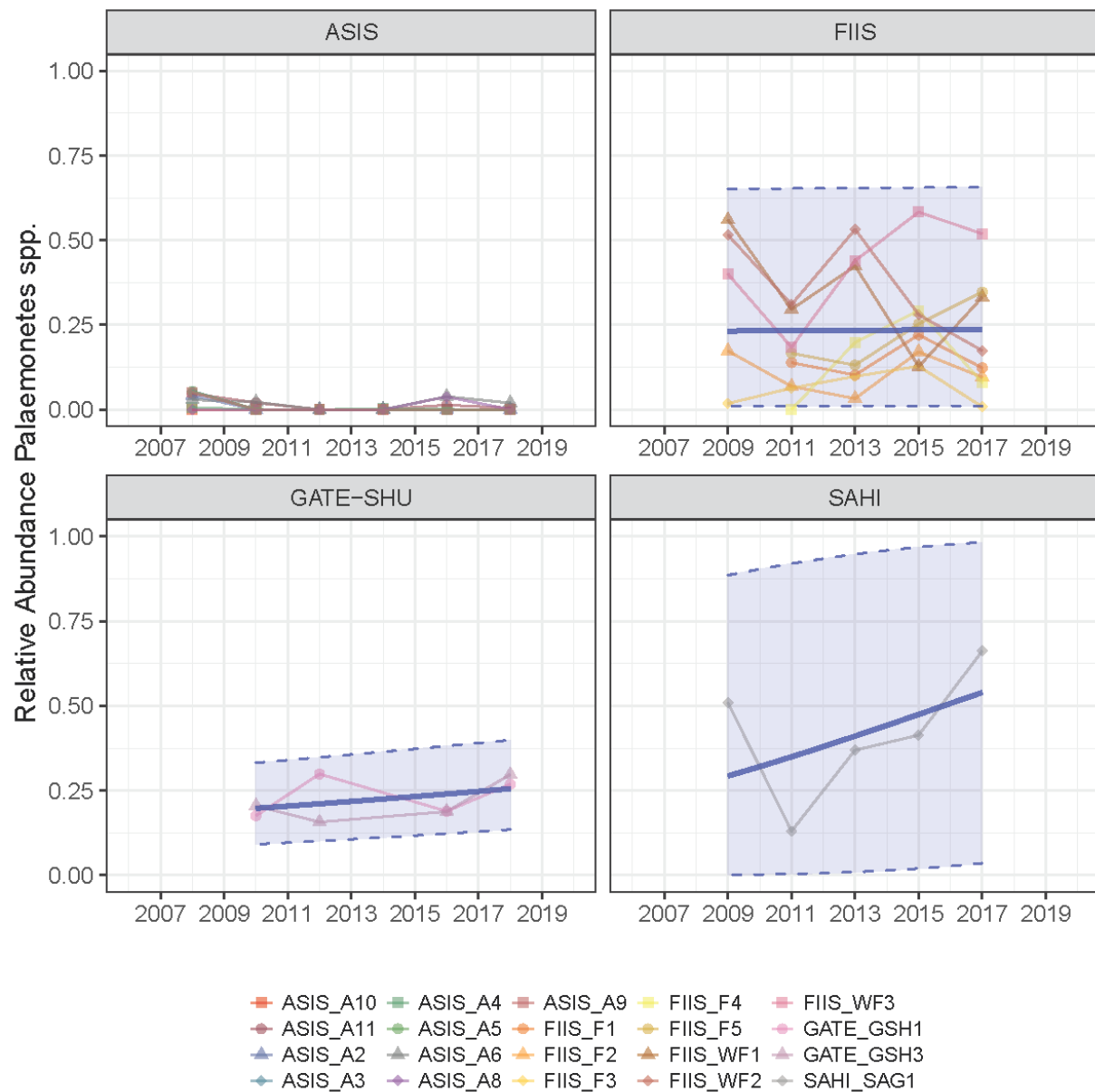


Figure A-5. Relative abundance of *Palaemonetes* spp. for each marsh study unit sampled within each monitored Northeast Coastal and Barrier Network park (Assateague Island National Seashore (ASIS), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)). Conditional mean of relative abundance of *Palaemonetes* spp. as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines. Note: a beta regression was not fit to ASIS due to most of the observations equaling zero.

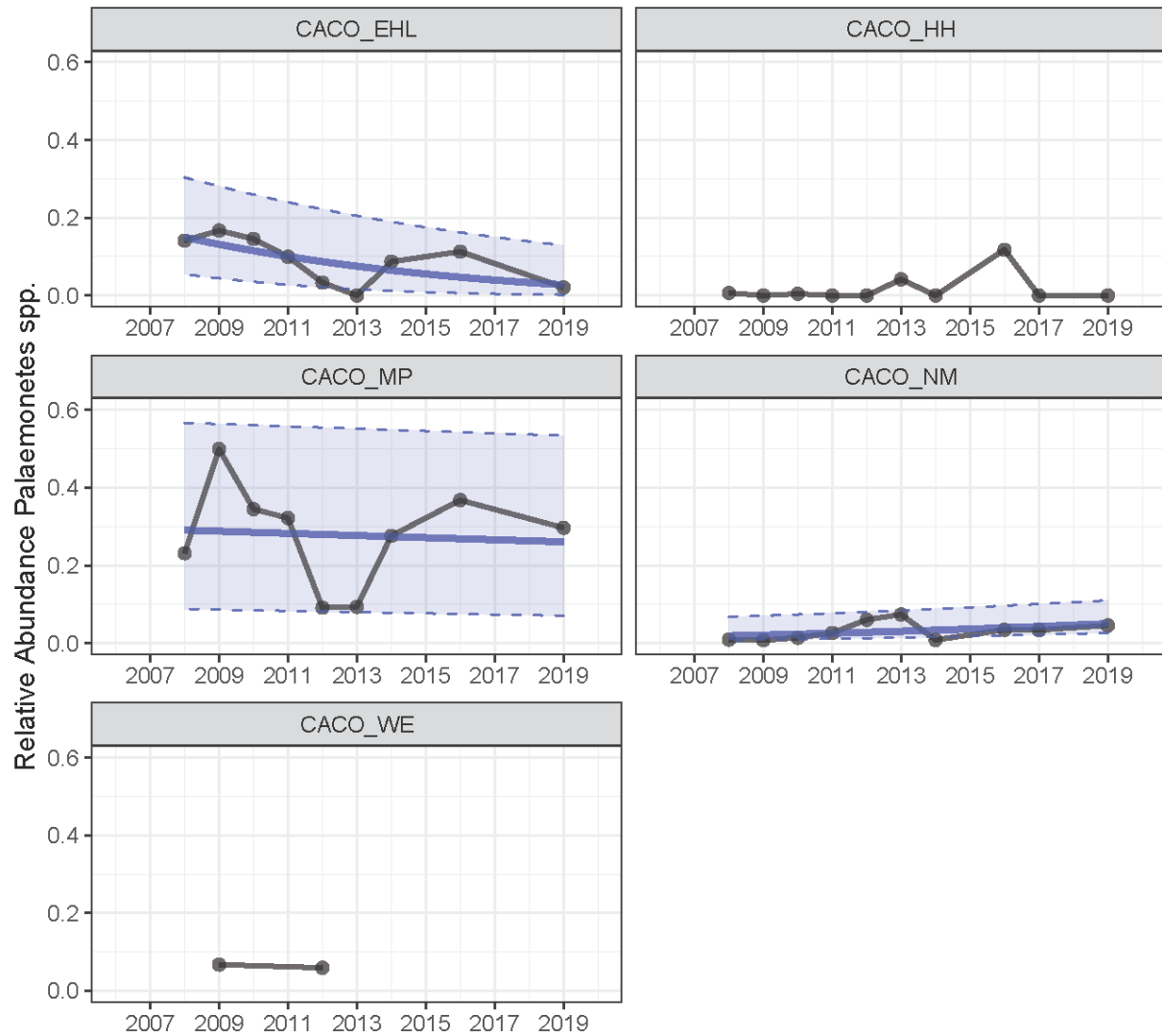


Figure A-6. Relative abundance of *Palaemonetes* spp. for each marsh study unit sampled within Cape Cod National Seashore (CACO). Conditional mean of relative abundance of *Palaemonetes* spp. as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines. Note: a beta regression was not fit to CACO_HH or CACO_WE due to most of the observations equaling zero and limited sample size, respectively.

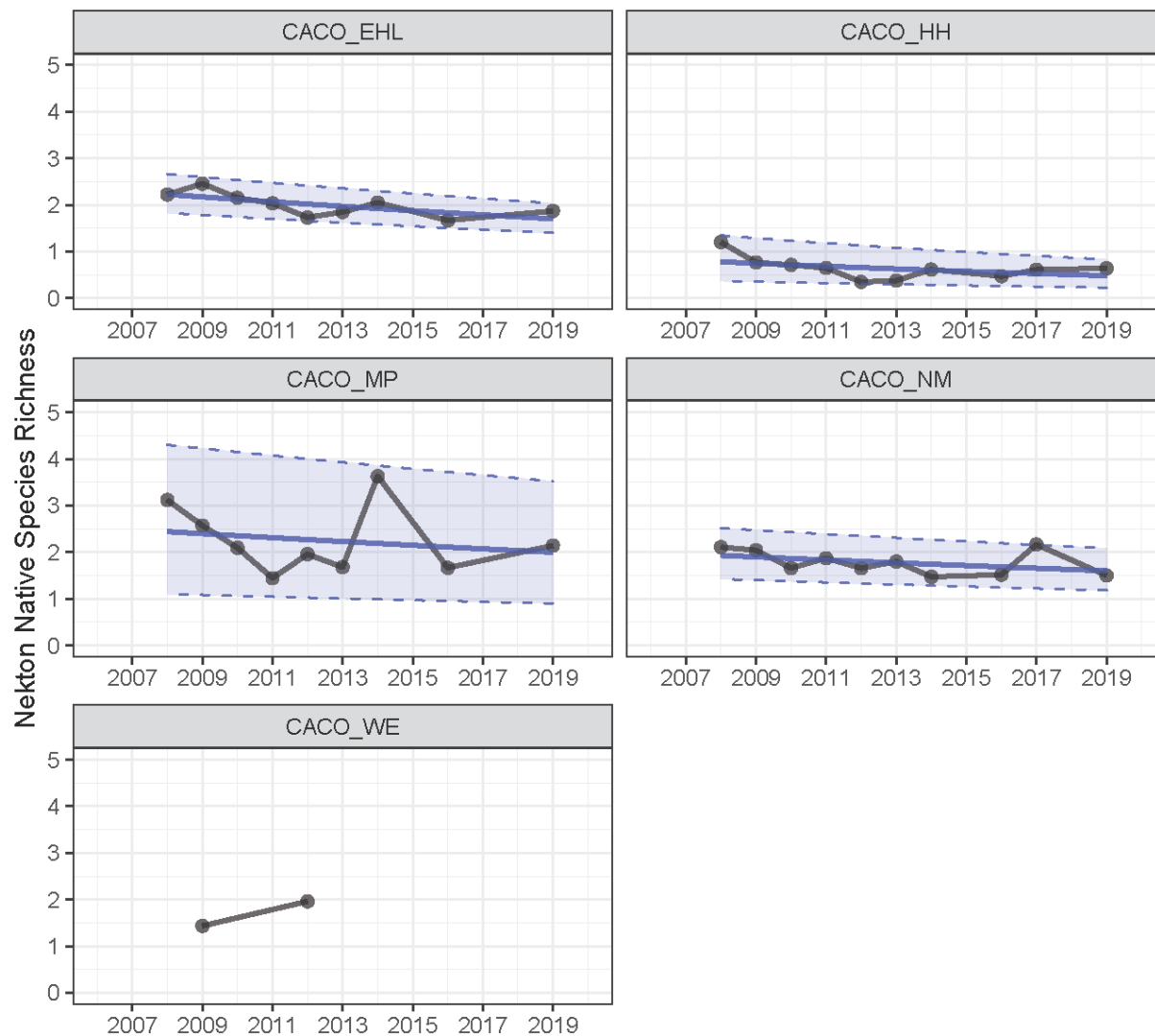


Figure A-7. Nekton native species richness for each marsh study unit sampled within Cape Cod National Seashore (CACO). Conditional mean of nekton native species richness as a function of year plotted in blue with 95% interval of the conditional gamma distribution of the response shaded in light blue and bound by dashed lines. Note: a gamma GLM was not fit to CACO_WE due to limited sample size.

Appendix B. Cape Cod National Seashore – Additional Metrics of Interest

Percent Cover of *Spartina patens*

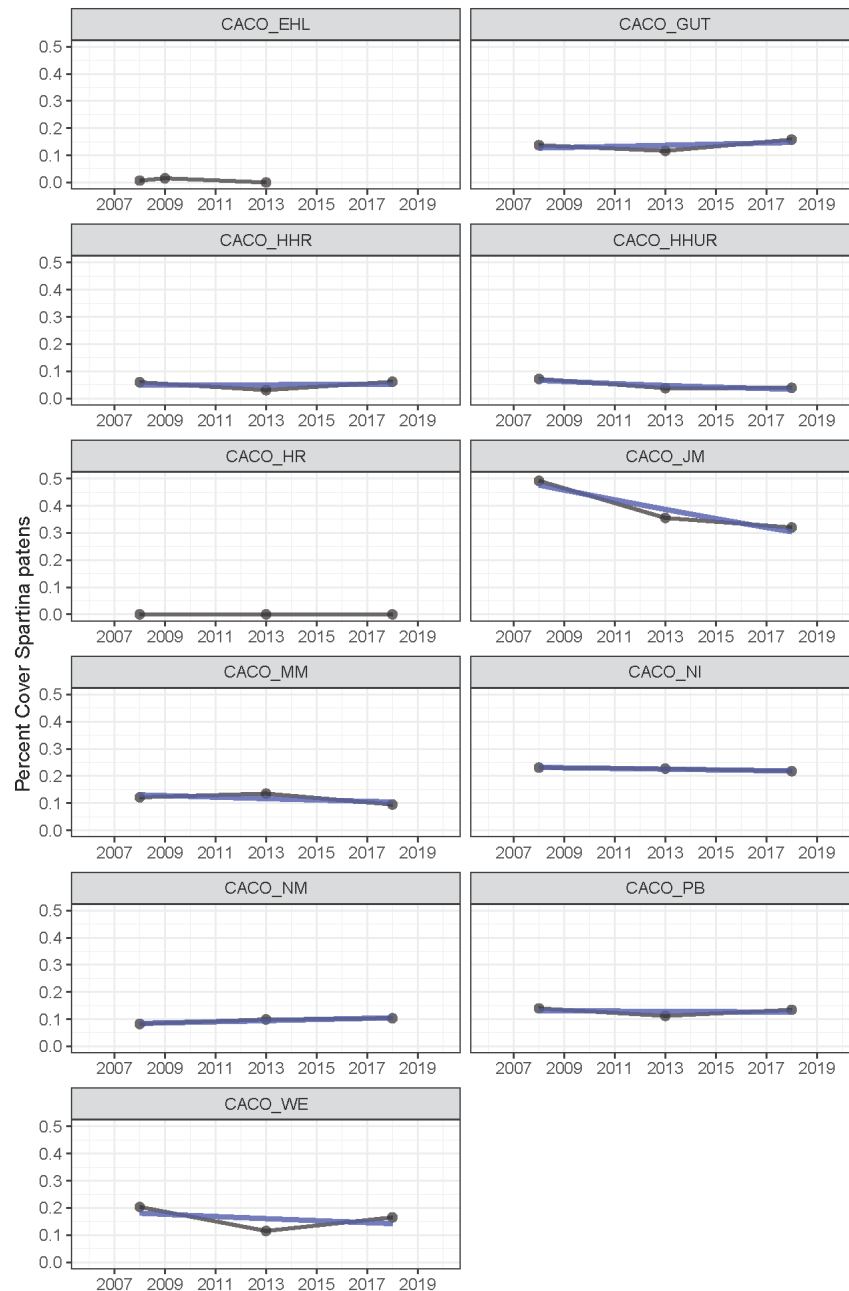


Figure B-1. Percent cover of *Spartina patens* for each marsh study unit (MSU) sampled within Cape Cod National Seashore (CACO). Estimated mean percent cover of *Spartina patens* as a function of year plotted in blue. Note: (1) unable to compute 95% confidence interval due to limited sample size; (2) a regression was not fit to CACO_EHL and CACO_HR due to most of the observations equaling zero.

Table B-1. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent cover of *Spartina patens* from a beta regression (logit link) fit to each marsh study unit (MSU) sampled within Cape Cod National Seashore (CACO). Note: due to the limited sample size, a 95% confidence interval cannot be computed (i.e., cannot test whether there is a trend: $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent cover (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

MSU	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CACO_GUT	3	0.018	0.018	–	1.018	0.021	10
CACO_HHR	3	0.004	0.044	–	1.004	0.002	10
CACO_HHUR	3	–0.071	0.023	–	0.931	–0.033	10
CACO_JM	3	–0.073	0.014	–	0.930	–0.172	10
CACO_MM	3	–0.026	0.017	–	0.975	–0.026	10
CACO_NI	3	–0.007	0.001	–	0.993	–0.013	10
CACO_NM	3	0.024	0.005	–	1.025	0.021	10
CACO_PB	3	–0.005	0.015	–	0.995	–0.005	10
CACO_WE	3	–0.028	0.035	–	0.972	–0.038	10

Percent Cover of *Salicornia* spp.

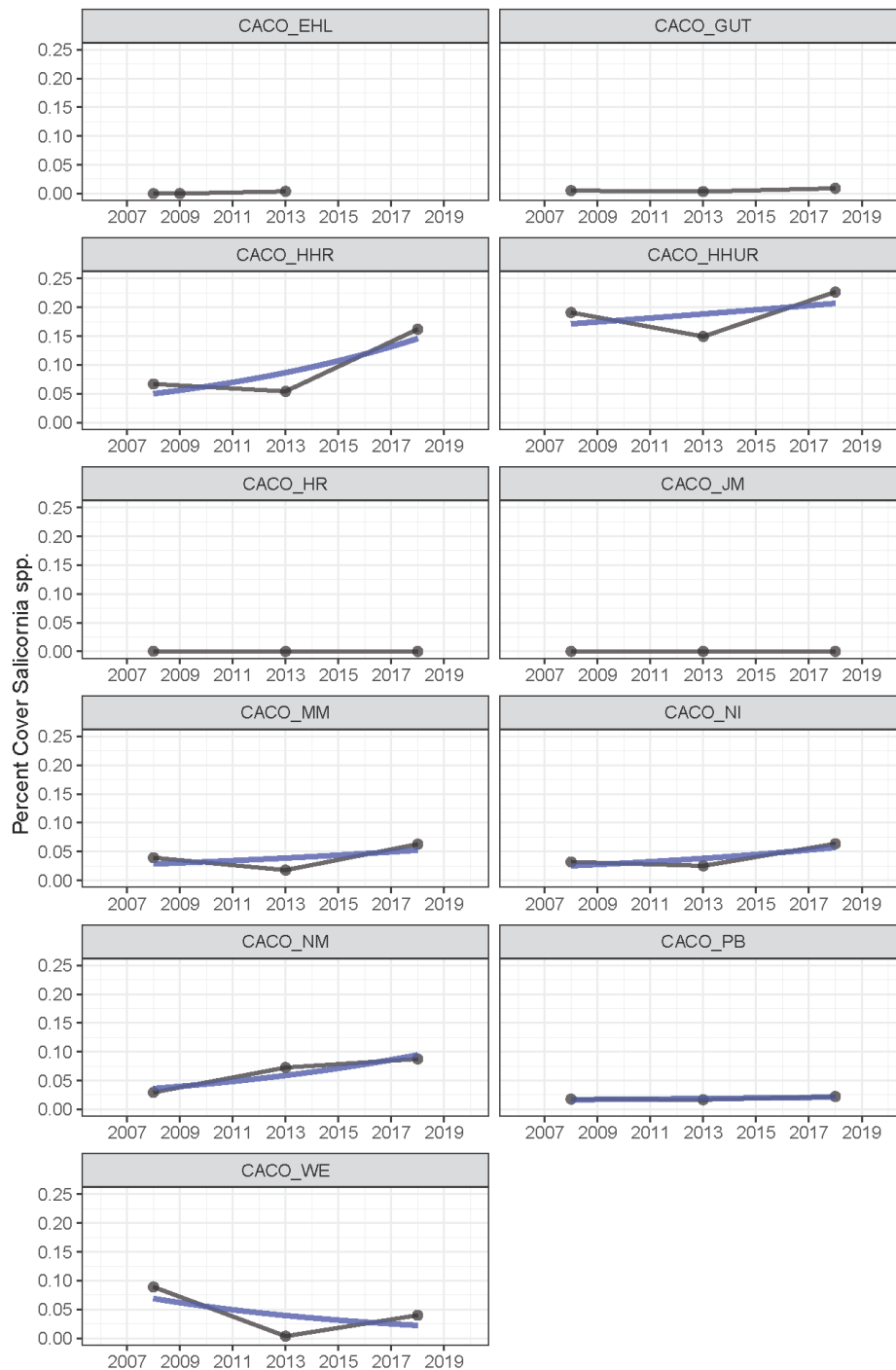


Figure B-2. Percent cover of *Salicornia* spp. for each marsh study unit (MSU) sampled within Cape Cod National Seashore (CACO). Estimated mean percent cover of *Salicornia* spp. as a function of year plotted in blue. Note: (1) unable to compute 95% confidence interval due to limited sample size; (2) a regression was not fit to CACO_EHL, CACO_GUT, CACO_HR, or CACO_JM due to most of the observations equaling zero.

Table B-2. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent cover of *Salicornia* spp. from a beta regression (logit link) fit to each marsh study unit (MSU) in Cape Cod National Seashore (CACO). Note: due to the limited sample size, a 95% confidence interval cannot be computed (i.e., cannot test whether there is a trend: $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent cover (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

MSU	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CACO_HHR	3	0.117	0.046	–	1.125	0.096	10
CACO_HHUR	3	0.023	0.026	–	1.024	0.036	10
CACO_MM	3	0.063	0.062	–	1.065	0.024	10
CACO_NI	3	0.085	0.038	–	1.088	0.032	10
CACO_NM	3	0.102	0.025	–	1.108	0.058	10
CACO_PB	3	0.024	0.012	–	1.024	0.004	10
CACO_WE	3	–0.118	0.114	–	0.889	–0.047	10

Percent Cover of High Salinity-Tolerant Species

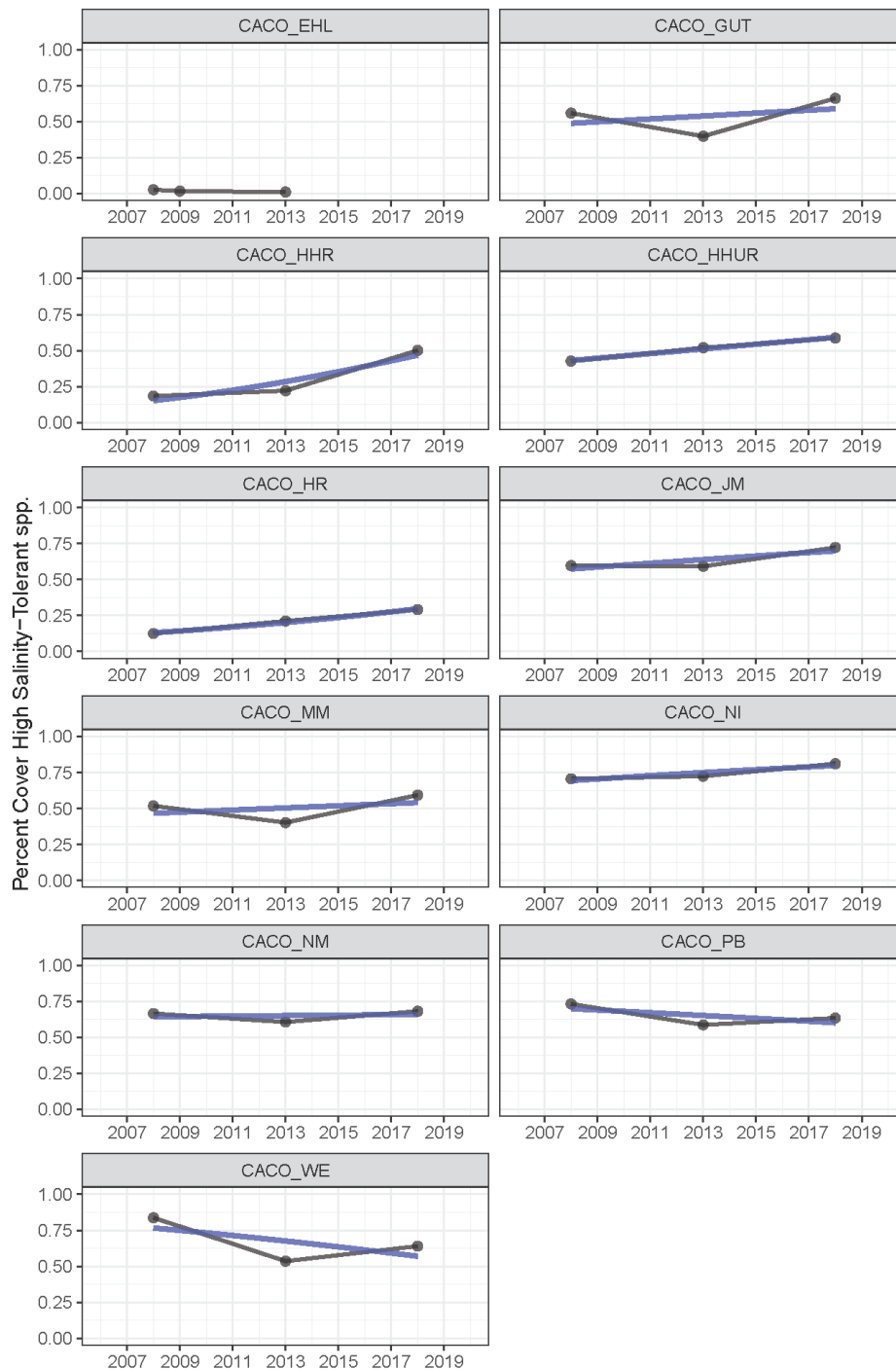


Figure B-3. Percent cover of high salinity-tolerant species for each marsh study unit (MSU) sampled within Cape Cod National Seashore (CACO). Estimated mean percent cover of high salinity-tolerant species as a function of year plotted in blue. Note: (1) unable to compute 95% confidence interval due to limited sample size; (2) a regression was not fit to CACO_EHL due to most of the observations equaling zero.

Table B-3. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent cover of high salinity-tolerant species from a beta regression (logit link) fit to each marsh study unit (MSU) in Cape Cod National Seashore (CACO). Note: due to the limited sample size, a 95% confidence interval cannot be computed (i.e., cannot test whether there is a trend: $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent cover (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

MSU	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CACO_GUT	3	0.041	0.056	–	1.042	0.101	10
CACO_HHR	3	0.159	0.035	–	1.172	0.316	10
CACO_HHUR	3	0.065	0.003	–	1.067	0.160	10
CACO_HR	3	0.103	0.007	–	1.109	0.166	10
CACO_JM	3	0.055	0.020	–	1.056	0.126	10
CACO_MM	3	0.030	0.041	–	1.030	0.074	10
CACO_NI	3	0.056	0.014	–	1.057	0.105	10
CACO_NM	3	0.007	0.020	–	1.007	0.016	10
CACO_PB	3	–0.043	0.029	–	0.958	–0.098	10
CACO_WE	3	–0.090	0.063	–	0.914	–0.196	10

Percent Low Salinity-Tolerant Species Richness

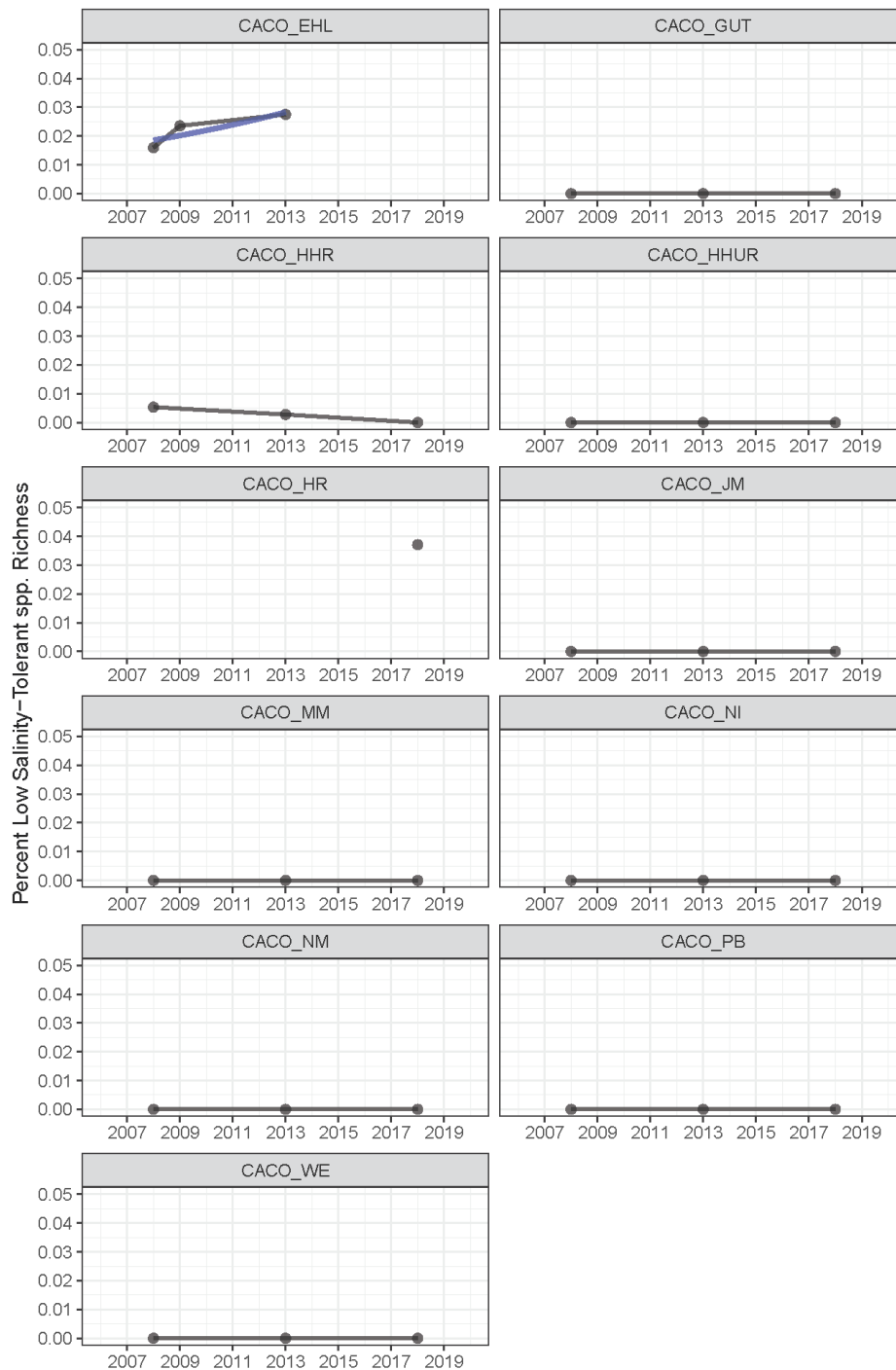


Figure B-4. Percent low salinity-tolerant species richness for each marsh study unit (MSU) sampled within Cape Cod National Seashore (CACO). Estimated mean percent low salinity-tolerant species richness as a function of year plotted in blue. Note: (1) unable to compute 95% confidence interval due to limited sample size; (2) regressions were not fit to a majority of MSUs due to most of the observations equaling zero.

Table B-4. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent low salinity-tolerant species richness from a beta regression (logit link) fit to each marsh study unit (MSU) in Cape Cod National Seashore (CACO). Note: due to the limited sample size, a 95% confidence interval cannot be computed (i.e., cannot test whether there is a trend: $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent species richness (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

MSU	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CACO_EHL	3	0.087	0.031	–	1.090	0.010	5

Nekton Native Species Richness

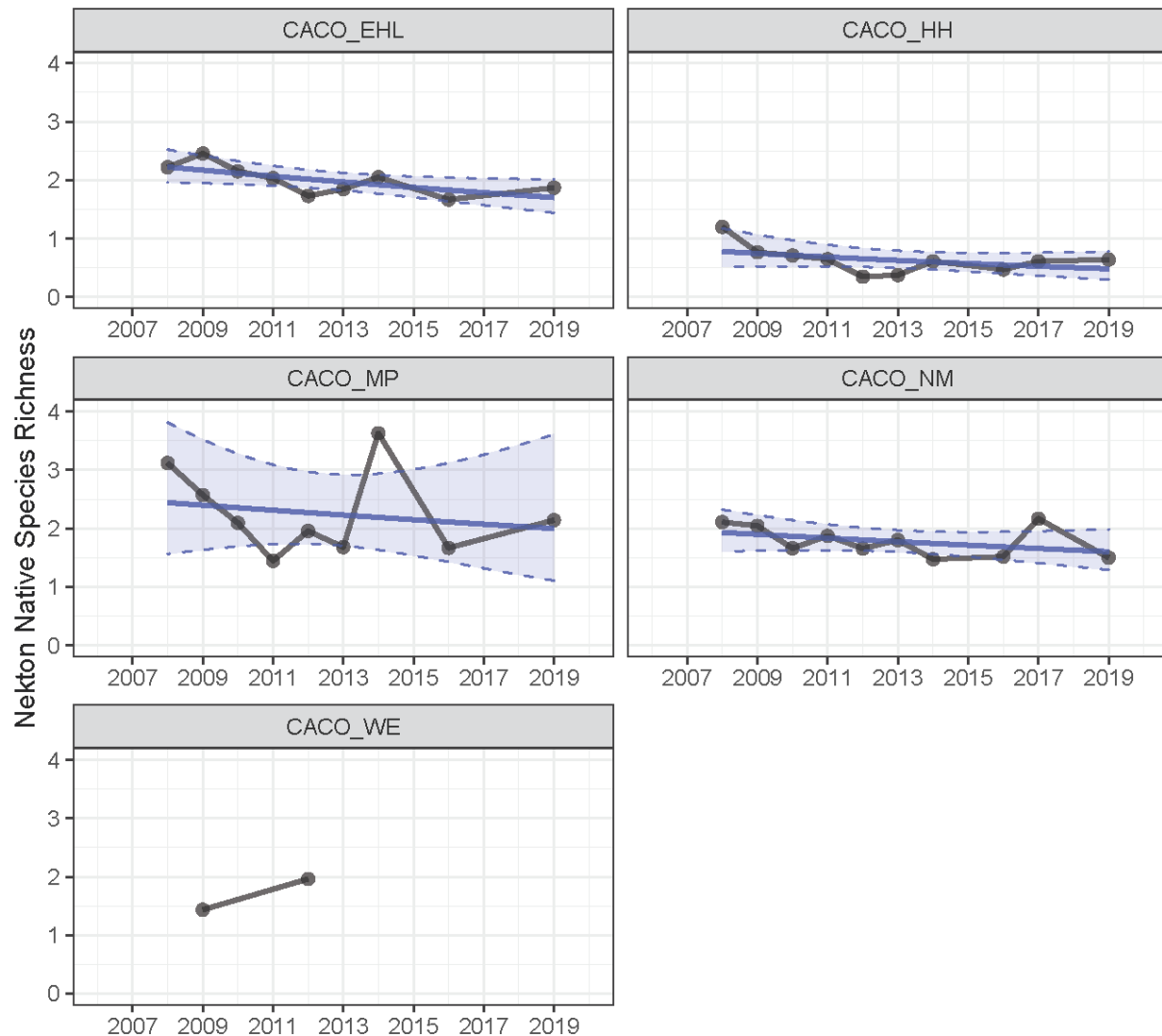


Figure B-5. Nekton native species richness for each marsh study unit (MSU) sampled within Cape Cod National Seashore (CACO). Estimated mean nekton native species richness as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: regression was not fit to CACO_WE due to not enough observations.

Table B-5. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in mean nekton native species richness from a gamma GLM (log link) fit to each marsh study unit (MSU) in Cape Cod National Seashore (CACO). If the 95% confidence interval (95% CI) for the trend coefficient contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean species richness (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

MSU	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CACO_EHL	9	-0.024	0.010	(-0.047, -0.002)	0.976	-0.522	11
CACO_HH	10	-0.044	0.030	(-0.112, 0.025)	0.957	-0.298	11
CACO_MP	9	-0.018	0.034	(-0.099, 0.062)	0.982	-0.443	11
CACO_NM	10	-0.017	0.013	(-0.048, 0.014)	0.983	-0.329	11

Relative Abundance of *Palaemonetes* spp.

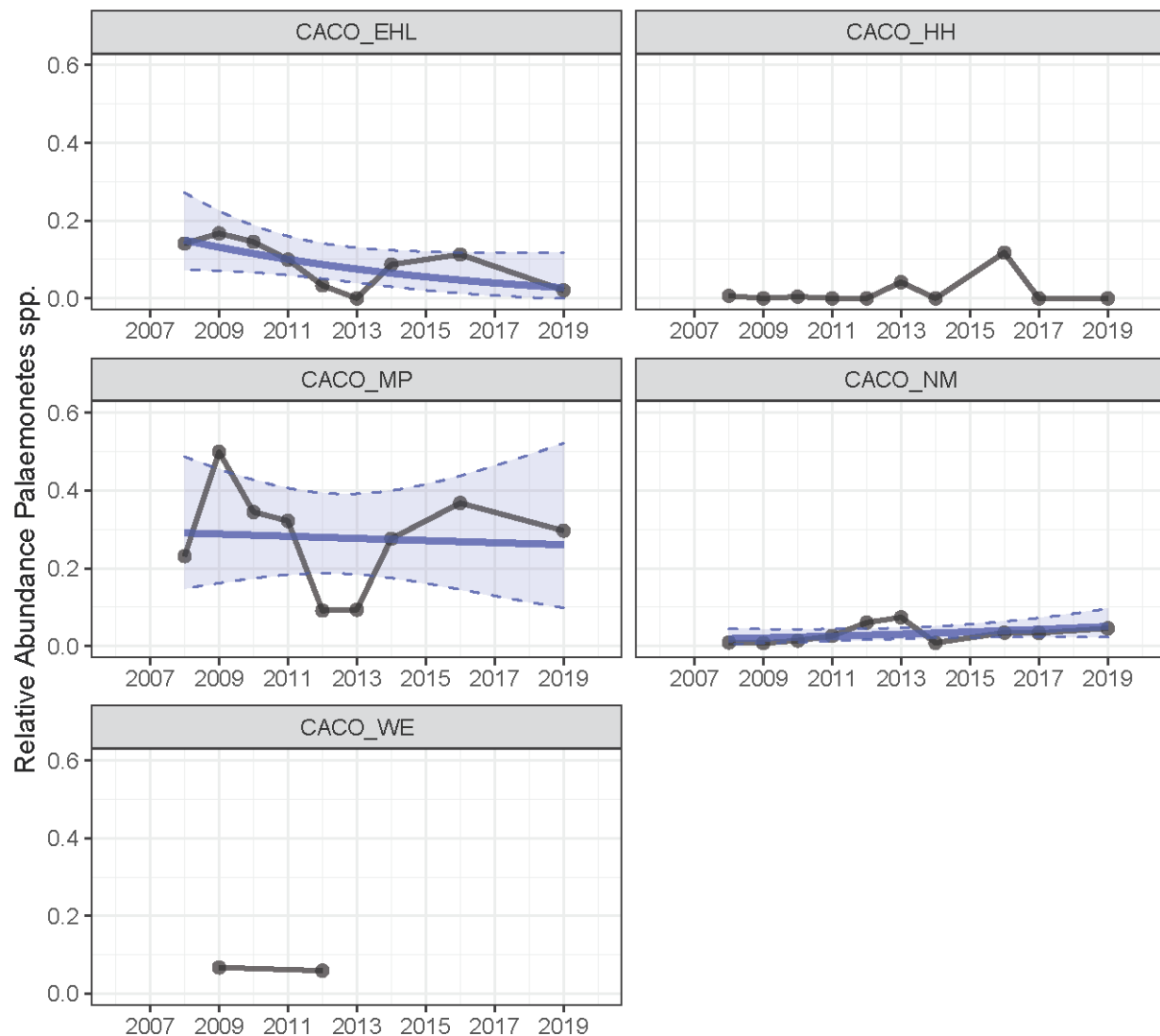


Figure B-6. Relative abundance of *Palaemonetes* spp. for each marsh study unit (MSU) sampled within Cape Cod National Seashore (CACO). Estimated mean relative abundance of *Palaemonetes* spp. as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: regressions were not fit to CACO_HH or CACO_WE due to most of the observations equaling zero and not enough observations, respectively.

Table B-6. Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean relative abundance of *Palaemonetes* spp. from a beta regression (logit link) fit to each marsh study unit (MSU) in Cape Cod National Seashore (CACO). If the 95% confidence interval (95% CI) for the trend coefficient contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean relative abundance (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

MSU	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CACO_EHL	9	-0.139	0.063	(-0.293, 0.016)	0.870	-0.119	11
CACO_MP	9	-0.013	0.060	(-0.161, 0.134)	0.987	-0.029	11
CACO_NM	10	0.066	0.039	(-0.026, 0.157)	1.068	0.031	11

Appendix C. Cape Cod National Seashore – Power Analysis #1

Methods

The power simulation method used for the marsh-level analysis is identical to the method detailed in *Section 5.1*, except for how the dispersion parameter was estimated for the vegetation metrics. Vegetation is sampled every five years within Cape Cod National Seashore (CACO), currently resulting in only three observations within each marsh study unit (MSU). Due to the long duration between sampling events and the low temporal variation in measurements, regression estimates of the residual variation are extremely low for most marshes. For example, each blue regression line in Figure D-1 is barely distinguishable from the lines connecting observations. As such, the estimates of the residual variation are not likely a reliable quantification of the temporal variation we'd expect had a shorter sampling interval been utilized and would therefore result in unrealistically high estimates of power. Alternatively, the estimated residual variation from the MSU exhibiting the largest degree of residual variation was utilized in the power analysis for every MSU. For example, in the power analysis for percent cover of *Spartina patens*, the estimated dispersion parameter from CACO_WE was utilized to estimate power for each MSU.

Results

Table C-1. Empirical power estimates to detect a trend ($\beta_1^{(sim)}$; approximately equal to the respective estimated trend coefficient from Table B-1) in the mean percent cover of *Spartina patens* within individual Cape Cod National Seashore (CACO) marsh study units (MSUs) after 10 years. Estimates are provided for several assumed sampling intervals.

MSU	$\beta_1^{(sim)}$	3-years	2-years	1-year
CACO_GUT	0.02	0.02	0.13	0.20
CACO_HHR	0.01	0.02	0.08	0.10
CACO_HHUR	-0.07	0.10	0.70	0.95
CACO_JM	-0.07	0.10	0.69	0.95
CACO_MM	-0.03	0.03	0.21	0.39
CACO_NI	-0.01	0.01	0.08	0.10
CACO_NM	0.02	0.02	0.13	0.21
CACO_PB	-0.01	0.01	0.07	0.11
CACO_WE	-0.03	0.03	0.22	0.39

Table C-2. Empirical power estimates to detect a trend ($\beta_1^{(sim)}$); approximately equal to the respective estimated trend coefficient from Table B-3) in the mean percent cover of high salinity-tolerant species within individual Cape Cod National Seashore (CACO) marsh study units (MSUs) after 10 years. Estimates are provided for several assumed sampling intervals.

MSU	$\beta_1^{(sim)}$	3-years	2-years	1-year
CACO_GUT	0.04	0.02	0.11	0.18
CACO_HHR	0.16	0.08	0.64	0.94
CACO_HHUR	0.06	0.03	0.17	0.33
CACO_JM	0.10	0.05	0.36	0.64
CACO_MM	0.05	0.02	0.14	0.24
CACO_NI	0.03	0.02	0.09	0.13
CACO_NM	0.06	0.02	0.17	0.32
CACO_PB	0.01	0.01	0.06	0.07
CACO_WE	-0.04	0.02	0.11	0.18

Table C-3. Empirical power estimates to detect a trend ($\beta_1^{(sim)}$); approximately equal to the respective estimated trend coefficient from Table B-5) in the mean nekton native species richness within individual Cape Cod National Seashore (CACO) marsh study units (MSUs) after 10 years. Estimates are provided for several assumed sampling intervals.

MSU	$\beta_1^{(sim)}$	3-years	2-years	1-year
CACO_EHL	-0.02	0.15	0.27	0.50
CACO_HH	-0.04	0.08	0.13	0.22
CACO_MP	-0.01	0.05	0.05	0.06
CACO_NM	-0.01	0.06	0.08	0.10

Table C-4. Empirical power estimates to detect a trend ($\beta_1^{(sim)}$); approximately equal to the respective estimated trend coefficient from Table B-6) in the mean relative abundance of *Palaemonetes* spp. within individual Cape Cod National Seashore (CACO) marsh study units (MSUs) after 10 years. Estimates are provided for several assumed sampling intervals.

MSU	$\beta_1^{(sim)}$	3-years	2-years	1-year
CACO_EHL	-0.14	0.04	0.35	0.65
CACO_MP	-0.01	0.01	0.06	0.07
CACO_NM	0.07	0.02	0.14	0.25

Appendix D. Community Composition Comparisons

Table D-1. Vegetation community comparisons performed for each marsh study unit in Northeast Coastal and Barrier Network parks (Assateague Island National Seashore (ASIS), Cape Cod National Seashore (CACO), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)) in *Section 6.2.1*. Distance (D_{12}) was calculated as the Euclidean distance similarity index between each marsh's average cover class for each unique species present.

MSU	Year 1	Year 2	D_{12}
ASIS_A10	2008	2010	5.94
ASIS_A10	2012	2014	3.55
ASIS_A10	2014	2016	5.77
ASIS_A10	2016	2018	2.40
ASIS_A11	2008	2010	3.46
ASIS_A11	2012	2014	3.20
ASIS_A2	2008	2010	4.75
ASIS_A2	2010	2012	10.48
ASIS_A3	2008	2010	4.51
ASIS_A3	2014	2016	3.08
ASIS_A3	2016	2018	1.07
ASIS_A4	2016	2018	1.89
ASIS_A5	2008	2010	11.52
ASIS_A5	2010	2012	7.21
ASIS_A5	2012	2014	6.02
ASIS_A5	2014	2016	5.00
ASIS_A5	2016	2018	0.25
ASIS_A6	2008	2010	4.66
ASIS_A8	2008	2010	10.22
ASIS_A8	2010	2012	9.03
ASIS_A8	2012	2014	3.48
ASIS_A8	2014	2016	6.01
ASIS_A9	2008	2010	7.22
ASIS_A9	2010	2012	9.52
CACO_EHL	2008	2009	2.83

Table D-1 (continued). Vegetation community comparisons performed for each marsh study unit in Northeast Coastal and Barrier Network parks (Assateague Island National Seashore (ASIS), Cape Cod National Seashore (CACO), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)) in *Section 6.2.1*. Distance (D_{12}) was calculated as the Euclidean distance similarity index between each marsh's average cover class for each unique species present.

MSU	Year 1	Year 2	D_{12}
FIIS_F1	2009	2011	1.67
FIIS_F1	2011	2013	8.59
FIIS_F2	2013	2015	2.84
FIIS_F2	2015	2017	4.33
FIIS_F3	2009	2011	4.17
FIIS_F3	2011	2013	4.78
FIIS_F4	2013	2015	4.19
FIIS_F4	2015	2017	3.00
FIIS_F5	2013	2015	1.13
FIIS_F5	2015	2017	1.33
FIIS_WF1	2013	2015	3.89
FIIS_WF1	2015	2017	2.40
FIIS_WF2	2013	2015	11.26
FIIS_WF2	2015	2017	3.75
SAHI_SAG1	2011	2013	1.80
SAHI_SAG1	2013	2015	2.22
SAHI_SAG1	2015	2017	7.89

Table D-2. Nekton community comparisons performed for each marsh study unit (MSU) in Northeast Coastal and Barrier Network parks (Assateague Island National Seashore (ASIS), Cape Cod National Seashore (CACO), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)) in *Section 6.2.2*. Distance (D_{12}) was calculated as the Euclidean distance similarity index between each marsh's average log density for each unique species present.

MSU	Year 1	Year 2	D_{12}
ASIS_A10	2008	2010	0.91
ASIS_A10	2010	2012	0.39
ASIS_A10	2012	2014	1.17
ASIS_A10	2014	2016	0.69
ASIS_A10	2016	2018	0.30
ASIS_A11	2008	2010	2.57
ASIS_A11	2012	2014	0.20
ASIS_A11	2014	2016	0.26
ASIS_A11	2016	2018	0.74
ASIS_A2	2008	2010	0.86
ASIS_A2	2010	2012	0.14
ASIS_A2	2012	2014	0.17
ASIS_A2	2014	2016	0.34
ASIS_A2	2016	2018	0.24
ASIS_A3	2008	2010	0.55
ASIS_A3	2010	2012	0.36
ASIS_A3	2012	2014	1.20
ASIS_A3	2014	2016	0.66
ASIS_A3	2016	2018	1.13
ASIS_A4	2008	2010	1.56
ASIS_A4	2012	2014	0.76
ASIS_A4	2014	2016	0.59
ASIS_A4	2016	2018	0.48
ASIS_A5	2008	2010	0.02
ASIS_A5	2010	2012	0.40
ASIS_A5	2016	2018	0.32
ASIS_A6	2008	2010	0.81

Table D-2 (continued). Nekton community comparisons performed for each marsh study unit (MSU) in Northeast Coastal and Barrier Network parks (Assateague Island National Seashore (ASIS), Cape Cod National Seashore (CACO), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)) in *Section 6.2.2*. Distance (D_{12}) was calculated as the Euclidean distance similarity index between each marsh's average log density for each unique species present.

MSU	Year 1	Year 2	D_{12}
ASIS_A6	2010	2012	0.84
ASIS_A6	2012	2014	0.65
ASIS_A6	2014	2016	0.34
ASIS_A6	2016	2018	0.52
ASIS_A8	2008	2010	0.49
ASIS_A8	2010	2012	1.60
ASIS_A8	2012	2014	1.02
ASIS_A8	2014	2016	0.72
ASIS_A8	2016	2018	0.43
ASIS_A9	2010	2012	1.18
ASIS_A9	2012	2014	0.84
ASIS_A9	2014	2016	0.33
ASIS_A9	2016	2018	1.06
CACO_EHL	2008	2009	0.77
FIIS_F1	2009	2011	0.21
FIIS_F1	2011	2013	1.11
FIIS_F1	2013	2015	0.41
FIIS_F1	2015	2017	1.28
FIIS_F2	2009	2011	0.79
FIIS_F2	2011	2013	0.05
FIIS_F2	2013	2015	0.34
FIIS_F3	2009	2011	0.18
FIIS_F3	2011	2013	0.06
FIIS_F3	2013	2015	0.18
FIIS_F4	2009	2011	0.21
FIIS_F4	2011	2013	0.99
FIIS_F4	2013	2015	0.71

Table D-2 (continued). Nekton community comparisons performed for each marsh study unit (MSU) in Northeast Coastal and Barrier Network parks (Assateague Island National Seashore (ASIS), Cape Cod National Seashore (CACO), Fire Island National Seashore (FIIS), Gateway National Recreation Area – Sandy Hook Unit (GATE-SHU), and Sagamore Hill National Historic Site (SAHI)) in *Section 6.2.2*. Distance (D_{12}) was calculated as the Euclidean distance similarity index between each marsh's average log density for each unique species present.

MSU	Year 1	Year 2	D_{12}
FIIS_F4	2015	2017	2.42
FIIS_F5	2009	2011	0.45
FIIS_F5	2011	2013	0.50
FIIS_F5	2013	2015	1.12
FIIS_WF1	2011	2013	0.28
FIIS_WF1	2013	2015	1.34
FIIS_WF1	2015	2017	0.55
FIIS_WF2	2011	2013	0.52
FIIS_WF3	2009	2011	1.50
FIIS_WF3	2015	2017	0.68
GATE_GSH1	2016	2018	0.74
SAHI_SAG1	2013	2015	1.32

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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