Barnegat Bay Submerged Aquatic Vegetation Monitoring Program

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SUMMARY

The objective of this monitoring program is to provide ongoing quantitative measures on the health of the primary indicators, submerged aquatic vegetation (SAV), at multiple sites throughout northern, central and southern Barnegat Bay. Barnegat Bay experienced a noticeable decline in *Zostera marina* habitat over the past 15 years and based on results from this study, has yet to experience a recovery. The northern region continues to be dominated by *Ruppia maritima* and the southern region by *Zostera*. Southern regions are also impacted by large drift macroalgae mats and suspended sediment driven turbidity. In the central, transitional zone, one site (BB 12) experienced a significant increase in *Ruppia* compared to the 2015 study while another site (BB 10) did not significantly differ in *Zostera* and *Ruppia* cover. Overall, epiphytic coverage on *Zostera* was low and total organic content of soils was low. Continued monitoring of those parameters indicative and important for SAV health is necessary to elucidate trends in this important ecosystem, which provides water quality enhancement, shoreline stabilization and habitat provisioning for economically and ecologically important fish and invertebrates. In those central regions with increasing cover by *Ruppia*, future work is necessary to determine if *Ruppia* can provide equivalent habitat and ecosystem services as *Zostera*. Linkages between these basal primary producers and upper trophic levels is well documented and the future state of Barnegat Bay fauna will be determined by the resilience of this vegetation in the face of those stressors it faces.

PROJECT DESCRIPTION

Seagrass beds provide a diverse suite of services which increase the diversity and productivity of coastal ecosystems (Larkum et al., 2006; Moore, 2009). Seagrasses are also considered indicators of ecosystem decline (Orth et al., 2006; Burkholder et al., 2007) and recent losses of this essential fish habitat have been attributed to degradation of water quality. Since 2004, there has been a well-documented decline in *Zostera marina* within Barnegat Bay due to eutrophication (Kennish et al. 2008, 2010, 2012; Fertig et al., 2013). Aboveground and belowground biomass decreased by 50-88% over the 2004-2006 period (Kennish et al. 2007b, 2008, 2010) and results subsequent to 2006 indicated continued decline, with 2009 having the lowest seagrass biomass values recorded in the estuary since comprehensive in situ sampling of seagrass beds commenced in 2004. While efforts have been made to decrease nutrient loading in Barnegat Bay (e.g., Governor's 10-point Barnegat Bay Action Plan), monitoring these important SAV ecosystems after management strategies are implemented is necessary to assess the efficacy of these strategies and adapt them, as necessary. Monitoring information, including those abiotic and biotic parameters indicative of SAV health, are necessary to more accurately predict future trends in SAV bed coverage and therefore their contributions to ecosystem functioning.

The objective of this project was to provide ongoing quantitative measures on the health of the primary indicators, submerged aquatic vegetation, at multiple sites throughout northern, central and southern Barnegat Bay. These quantitative parameters included above and belowground biomass, canopy complexity, microalgal (or epiphytic) cover, macroalgal cover and sediment organic content. Results from this survey were compared to previous survey results from 2004-2015 in order to evaluate the status and trends of submerged aquatic vegetation within the Barnegat Bay estuary.

METHODOLOGY

Site Information

Sampling was conducted at the same nine sites as were sampled in 2015 and taken from a previously established set of 15 studied by Kennish et al. from 2004 – 2011 within Barnegat Bay (Kennish et al. 2013; Figure 1, Table 1). The subset of transects selected span the salinity, temperature, and nutrient gradients known to exist in Barnegat Bay, as well as represent the major submerged aquatic vegetation habitat (*Ruppia maritima* and *Zostera marina*) found in the northern, central and southern sections of the estuary. Sampling was completed in June and October of 2017 in order to document annual and inter-annual changes in submerged aquatic vegetation demographics.

Submerged Aquatic Vegetation Biomass

In order to collect aboveground and belowground biomass, five (5) 22 cm diameter cores were taken within 50 m of the original site coordinates at each site, using those GPS coordinates provided by Kennish et al. (2013). Each core was sieved through 1.0 cm mesh and washed clean of sediment before transport back to the Stockton Marine Field Station for continued processing. Vegetation was first separated by species, total number of shoots calculated and leaves separated from rhizomes and root hairs. Samples were dried in an air circulating oven at 50°C for a minimum of 24 hours before aboveground and belowground biomass was recorded as grams dry weight (DW) per m^{-2}. During the course of this study and for future monitoring efforts, two sites were also sampled with 11 cm diameter cores to determine if smaller cores, which have a smaller impact on beds and are easier to extract from beds, would provide equivalent results (n = 10 per site).

Habitat Visual Census

In order to determine areal coverage of each benthic cover (*Zostera marina, Ruppia maritima*, macroalgae, other) a visual census was completed using a m^2 quadrat haphazardly placed within a 50 m radius at each sampling site (n = 10). The percent cover of seagrass, macroalgae, or other was estimated in situ by a diver using a scale of 0 to 100 in increments of 5.

Macroalgae Biomass

Macroalgal biomass was collected from ten haphazardly placed 0.25 m^2 quadrats within a 50 m radius at each sampling site. Samples were separated by species and placed in an air circulating oven at 50°C to dry for a minimum of 24 hours before biomass of each identified genus was recorded as grams dry weight (g DW) per m^{-2} (Sidik et al., 2001).

Epiphytic Load

In order to determine epiphyte load, 15 individual *Z. marina* shoots were haphazardly collected within a 50 m radius at each sampling site. Each shoot was separated into individual blades, blade number, length and width recorded and epiphytes removed from both sides of each blade via razor blade held 90° to the leaf surface. All samples were placed in an air circulating oven at 50°C for a minimum of 24 hours and weighed in order to calculate biomass as g dry weight (g DW) per m^{-2} (Kendrick and Lavery, 2001).

Sediment Organic Content

At all sites, nine clear acrylic cores (10.4 cm diameter by 10 cm depth) were haphazardly collected within a 50m radius at each site in order to quantify organic content. Each core was divided into three 2 cm horizontal sections (0-2 cm, 2-4 cm, and 4-6 cm) and returned to the Stockton Marine Field Station for further processing. In the lab each sub-section was placed into an air circulating oven at 50°C to dry until a constant dry weight was reached, approximately 48 – 72 hours. Samples were weighed, combusted at 400 °C for eight hours, and weighed again. Percent organic matter was calculated as the difference in weights pre- and post-ashing (Schumacher 2002).

Statistical Analysis

Data was normally distributed and analyzed via an ANOVA with Tukey HSD post hoc for significant differences between parameters by site (e.g. biomass, percent cover, epiphytic load, sediment TOC). Seasonal and interannual (2015 to 2017) comparisons were compared via student's t-test. Significance was determined at the 0.05 level.

RESULTS

All monitoring sites were 1-2 m in depth along a gradient of decreasing salinity BB 01 to BB 15. Highest salinities were recorded at sites 1, 3, 6 and 8 (27 - 31 ppt), decreasing towards the northern segment to 18 - 24 ppt (sites 10, 12-15). At those sites with lower salinities, mainly *Ruppia maritima* was present while sites with higher salinities had only *Zostera marina*. At those sites dominated by *Zostera* (01, 03, 06, 08), cover by *Zostera* in June ranged from 19-96% with approximately 224 shoots of *Zostera* per m^2 (Figure 2a, Figure 3b). Density declined in October to 9-49% cover, with 157 shoots per m^2. Significant reductions in percent cover from Spring to Fall occurred at all sites except BB 01, which experienced a 20% increase, while the maximum reduction was at site BB 06, which experienced a 61% reduction over the growing season. At these four sites, *Ruppia* cover was 0% for both sampling events (Figure 3a).

For *Zostera*, overall mean aboveground biomass was high in the southern region (BB 01, 03, 06 and 08), with a peak over 112 g dry weight/m^2 at Site 8 (Figure 4a), while the northern and central regions (BB 10, 12, 13, 14 and 15) had significantly lower aboveground biomass. In the Fall, all sites experienced a decline in aboveground biomass while Site 08 retained significantly higher aboveground biomass than all other sites, with 15 g dry weight/m^2. In the Spring, sites 03 and 06 had significantly higher belowground biomass than all sites (average 316 g DW/m^2). In the Fall, site 08 had significantly higher belowground biomass than all sites (119 g dry weight/m^2). The majority of sites experienced a decline or no significant change in belowground biomass with season. Overall at all sites and seasons, epiphytic load was less than 0.010 mg/cm^2 (Figure 5). In the Spring, Site 01 had significantly higher epiphytic load than all other sites and in Fall, BB 01, 03 and 06 had significantly more epiphytes than all other sites. The majority of the sites experienced a seasonal increase in epiphytic coverage. Macroalgae biomass was significantly higher at these sites for both sampling events (Figure 6; BB 01 & 03 in Spring, max 7.7 g DW/m^2 and BB 01 and BB 06 in Fall, max 20.8 g DW/m^2) and functional groups included coarsely branched (e.g., *Gracilaria, Hypnea*), finely branched or filamentous (e.g, *Polysiphonia*, *Ceramium*, *Acrosiphonia*) and laminar (e.g., *Ulva lactua*).

In the regions categorized as *Ruppia*-dominated habitat for the 2015 study (15, 14, and 13), *Zostera* cover averaged less than 3% over the survey period and cover by *Ruppia* in June ranged from 14-31% and increased to 26-48% in October (Figure 2b). Shoot counts of Ruppia averaged 901 shoots per m^2 at all sites in the Spring and trended downward to 817 shoots per m^2 in Fall (Figure 3b). For *Ruppia*, the mean aboveground biomass overall was low for all samples (< 20 g DW/m^2, Figure 4b). In Spring, there was no significant difference in aboveground or belowground *Ruppia* biomass between all sites dominated by *Ruppia* (sites 13, 14 and 15), averaging 6.7 g DW/m^2 and 4.6 g DW/m^2, respectively. In the Fall, Site 14 had significantly higher aboveground biomass than 13 and 15 (8.7 g DW/m^2) while only Site 15 had significantly higher belowground biomass (20.3 g DW/m^2). All sites experienced a significant decline or no significant change in above or belowground biomass, with the exception of Site 15, which experienced a significant increase in belowground biomass. No significant difference was found in biomass estimates for *Ruppia* or *Zostera* using the smaller cores. Macroalgae was not present or present in small quantities averaging 0 mg DW/ m^2 at all *Ruppia*-dominated sites (Figure 6).

At BB 10 & 12, the two sites classified as transitional between *Zostera* and *Ruppia* during the 2015 study, shoot counts trended lower seasonally for both sites; however, two different patterns were evident in percent cover and biomass. At BB 10, *Zostera* cover did not significant change between seasons (20% and 23%, respectively) while *Ruppia* cover increased significantly (14% to 26%). Aboveground biomass for both *Zostera* and *Ruppia* reduced significantly from Spring to Fall at BB 10. At BB 12, *Zostera* percent cover significantly reduced 11% to 2%, while *Ruppia* cover increased 14 to 39%. Aboveground biomass for *Zostera* and *Ruppia* did not significantly change between seasons.

Across all sites, seasons and depths, total organic content was low with the majority of samples less than 2% organic carbon (Figure 7). At the 0-2 cm depth profile, Site 08 had significantly higher organic carbon than all other sites in Spring while there were no clear trends in the Fall. At the 2-4 cm depth profile, Site 08 was significantly higher than some sites (6, 12 and 13) in the Spring while in Fall, sites 01, 03 and 06 were significantly different than sites 12, 13 and 14. At the 4-6 cm depth profile, there were no significant differences between sites in either season.

CONCLUSIONS

Barnegat Bay experienced a noticeable decline in underwater vegetated habitat over the past 15 years and has yet to experience a recovery (Figure 8; Kennish et al. 2008, 2010, 2012; Fertig et al., 2013). Various factors (anthropogenic and natural) can be attributed to the heterogenous decline across the Bay (Kennish et al. 2008, 2010, 2012; Fertig et al., 2013) and can also be attributed to the changing species compositions within the bay. Of important note is the central, transitional region of Barnegat Bay, which contains both *Zostera marina* and *Ruppia maritima*, a submerged aquatic plant known to be more tolerant to water temperature, salinity and nutrient stressors than *Z. marina*. This region of Barnegat Bay has experienced an increase in *Ruppia*, which may be attributed to these stressors and the declining health of *Zostera.*

Overall, *Ruppia* aboveground biomass was low for all sites, but similar to previously reported biomass in the region (Kennish 2011). Previous studies (Lacey, 2015) identified both sites BB 10 and 12 as transitional areas, with BB 10 remaining relatively constant in percent cover of both species and BB 12 experiencing a decline in *Zostera* (24% to 10% cover) and an increase in *Ruppia* (41% to 76%) over the course of the 2015 study. For the 2017 study, BB 10 species composition continued to be a stable mix; however, BB 12 became dominated by *Ruppia* rather than *Zostera*. The stability of this shift is unknown and can only be elucidated through continued studies, particularly on the dynamics between these two species as they interact within the Barnegat Bay environment in comparison to other studied locations. Implications of this species shift on habitat provisioning, shoreline buffering, water quality improvement and other ecosystem services have also yet to be determined but warrant further efforts.

As further studies focus on the services provided by the submerged aquatic vegetation, it may become important to include alternative habitats such as drift macroalgae. Overall macroalgae biomass and cover was highly variable, but were present in highest densities in the southern region of Barnegat Bay, where *Zostera* cover is the highest. The majority of macroalgae sampled was in the form of clumped drift algae, which has a temporary impact on submerged aquatic vegetation health when compared to longer residence blooms of microalgae, which continuously shade the vegetation. Studies suggest that in some natural and bare areas, drift macroalage can form alternative habitats which support important, diverse invertebrate communities that would otherwise not be supported (Hernandez Cordero and Seitz 2014; Hernandez Cordero *et al.* 2012). Future research efforts should focus on monitoring the movement of these macroalgal mats within the Bay and the alternative habitat to *Zostera* and *Ruppia* they may provide.

The entire Bay contained low overall total organic carbon within the soil, with those regions dominated by *Ruppia* containing the lowest amount of organic carbon when compared to those regions with *Zostera,* as expected given the species morphological differences. For the purpose of monitoring SAV beds, no models exist which link soil organic carbon content to the long-term trajectories of SAV health and stability. Soil characterization maps exist for Barnegat Bay which use soil properties to select appropriate habitat for restoration efforts but continued monitoring of soil organic content is not a necessary parameter for the objective of an SAV monitoring program and will no longer be included.

Throughout Barnegat Bay, results from this and previous studies indicate that seagrass distribution continues to be patchy within the Bay and no significant recovery has occurred in any region. While some regions have maintained consistent coverage by SAV, it is unclear the extent of coverage with limited funding for monitoring and no funding for mapping current distributions. Continued monitoring is necessary to track any potential recovery and the impact of returning, favorable water conditions and efforts should be made to expand the monitoring program to include additional stations, particularly within these transitional areas. Linkages between these basal primary producers and upper trophic levels is well documented and the future state of Barnegat Bay fauna, including recreationally and commercially important fish and invertebrate species, will be determined by the resilience of this vegetation in the face of changing water quality parameters.

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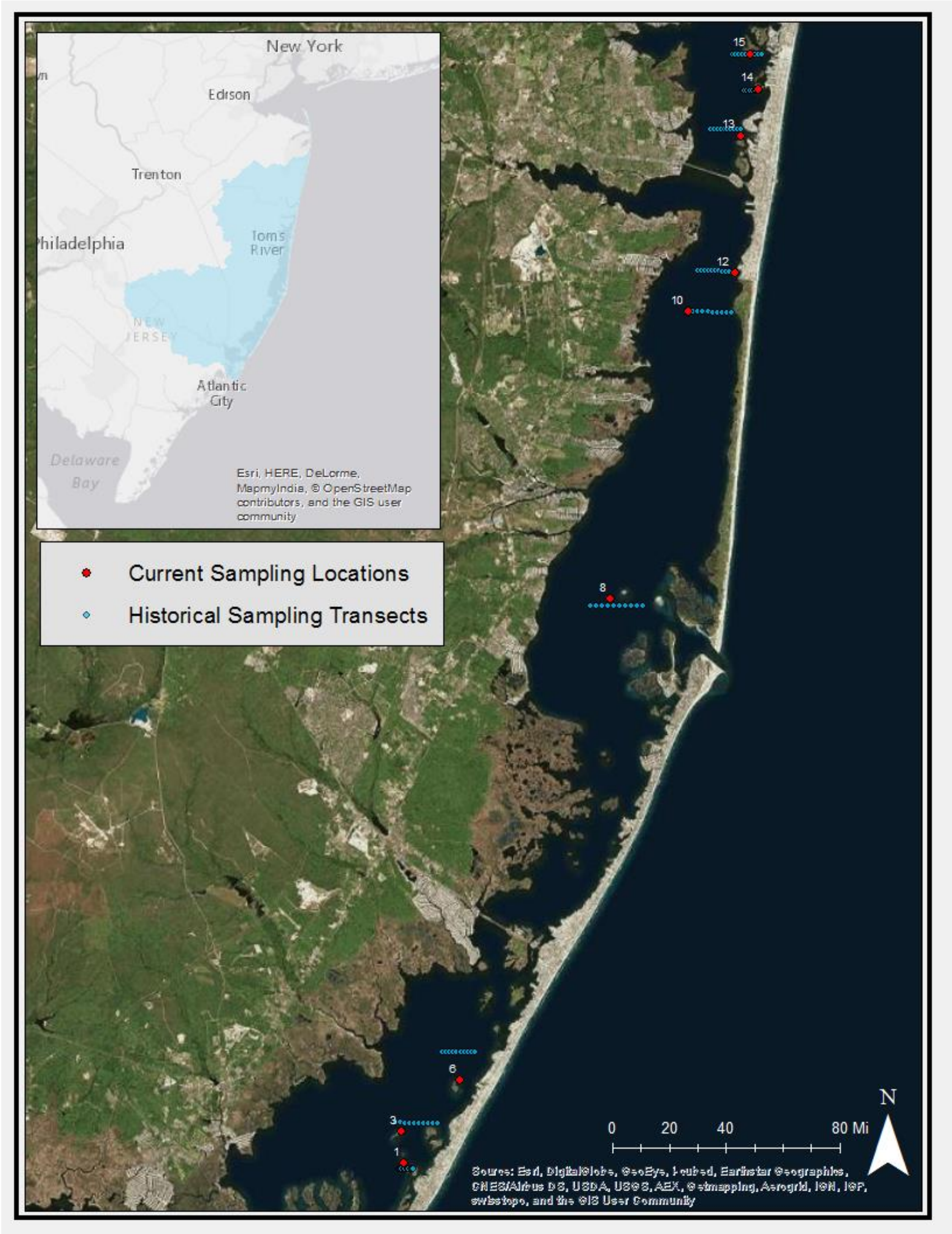


Figure 1. Barnegat Bay-Little Egg Harbor Estuary showing all historic sampling transects in green dots (from Kennish et al 2013). Transects are numbered from south to north. We will sample at Transects 1, 3, 6, 8, 10, 12, 13, 14, and 15.

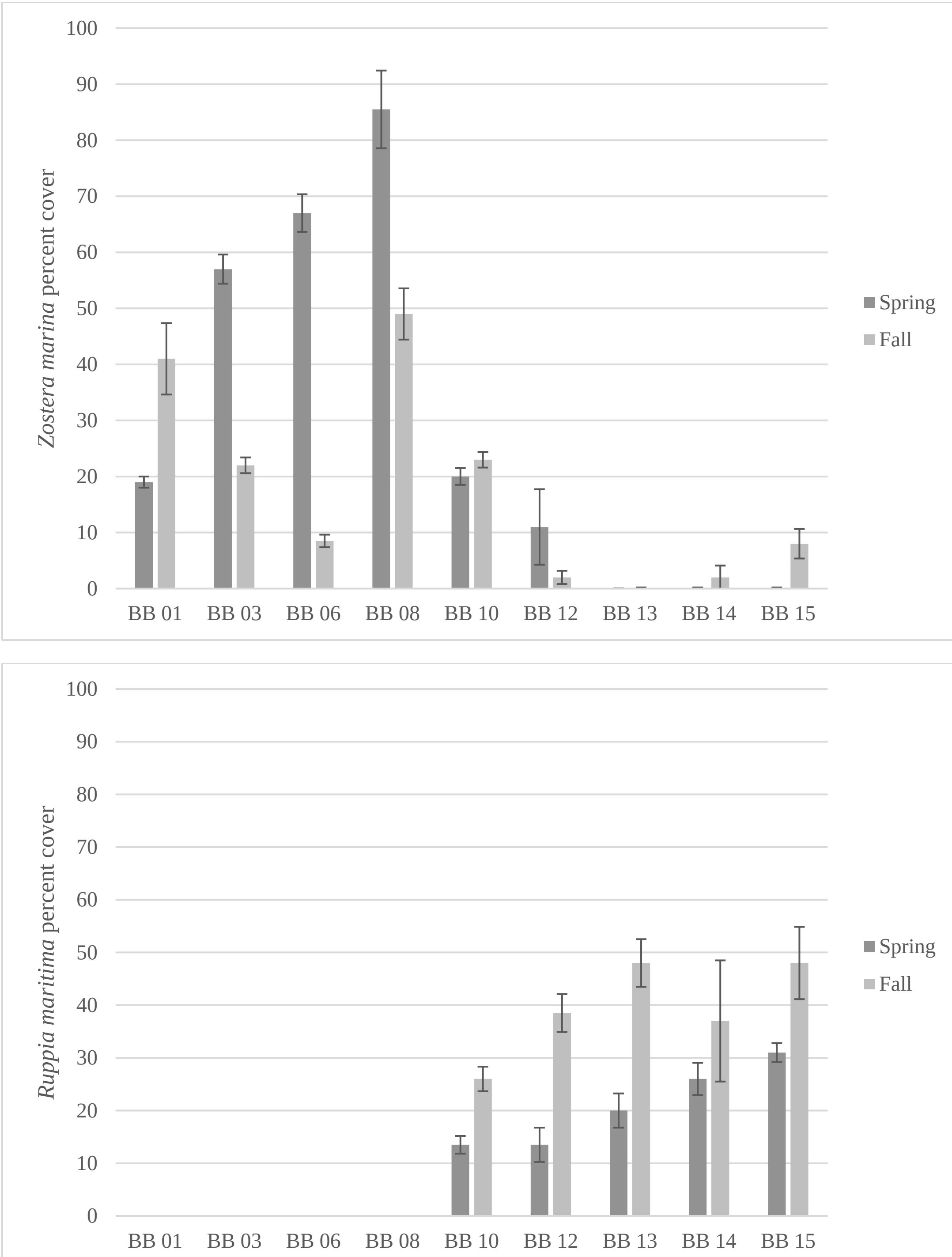
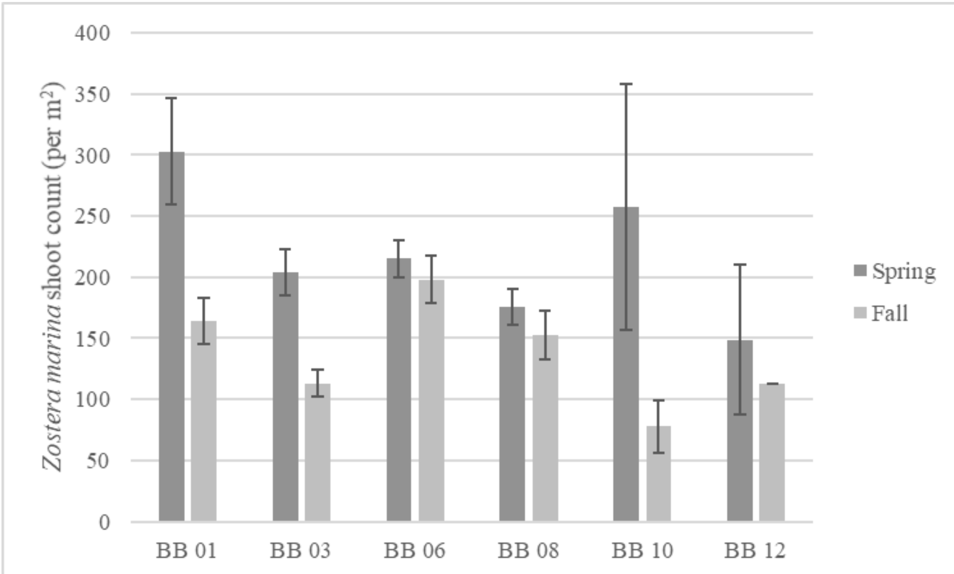


Figure 2: Percent cover (±SE) of (a) *Zostera marina* and (b) *Ruppia maritima* in Spring and Fall.



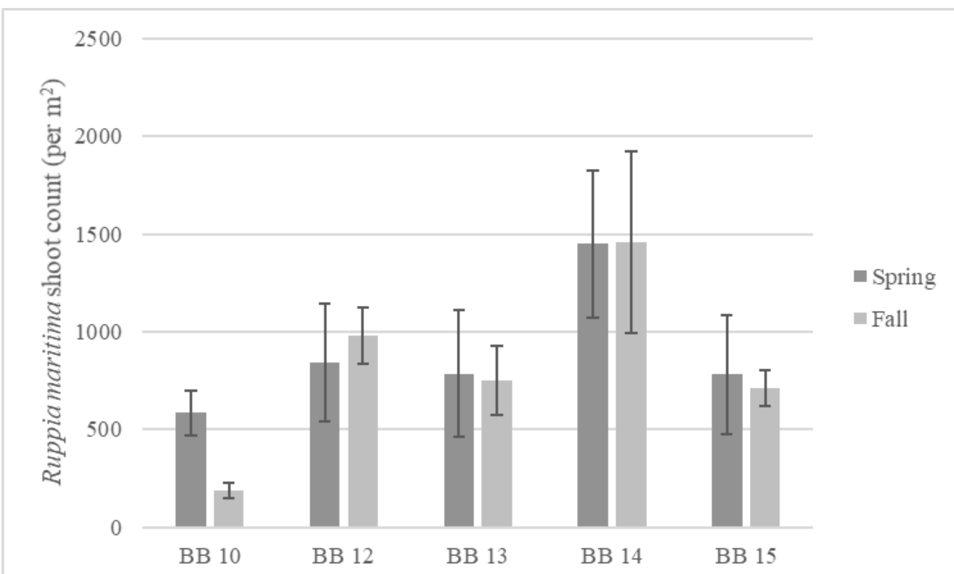


Figure 3: Shoot counts (± SE) of (a) *Zostera marina* and (b) *Ruppia maritima* (note differences in x- and y-axis) in Spring and Fall.

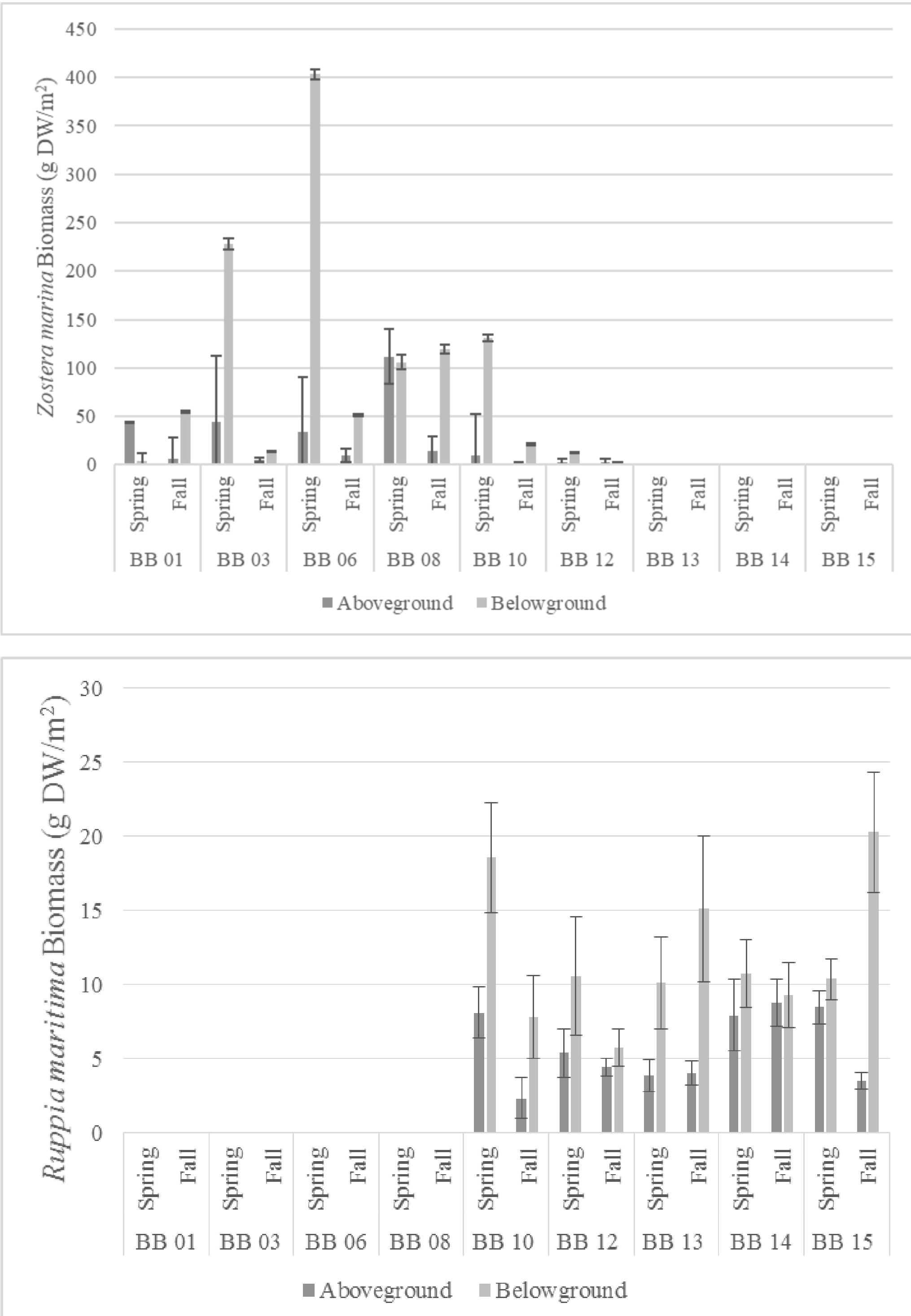


Figure 4: Aboveground and belowground biomass (g DW/m^2) ± SE of (a) *Zostera marina* and (b) *Ruppia maritima* (note difference in y-axis) in Spring and Fall.

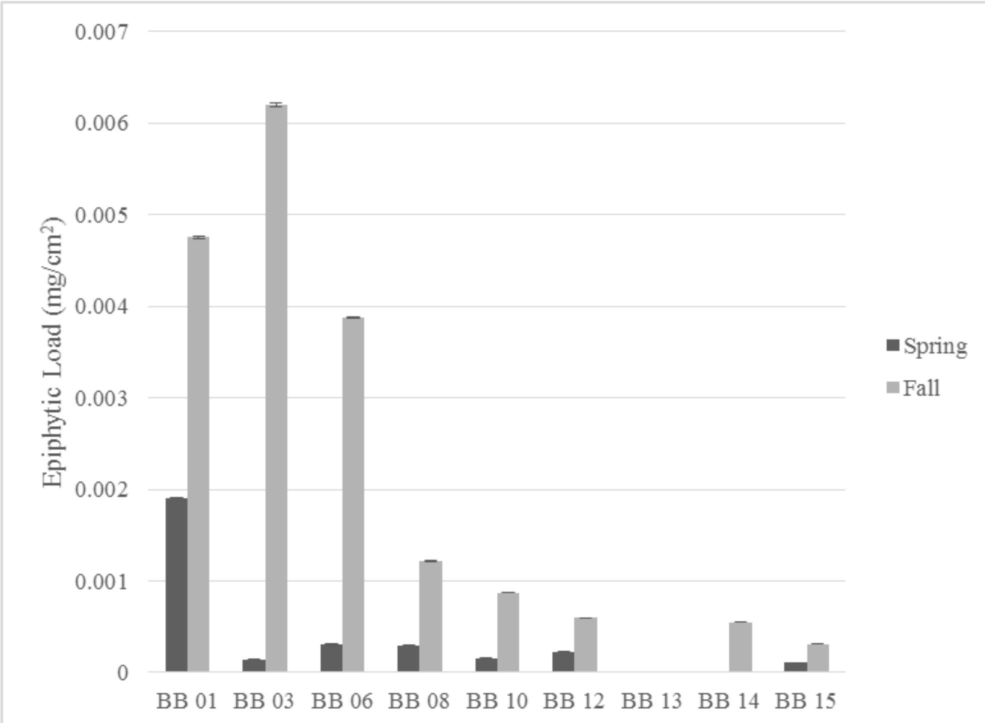


Figure 5: Epiphytic load (mg DW/ cm^2) ±SE on *Zostera marina* in Spring and Fall.

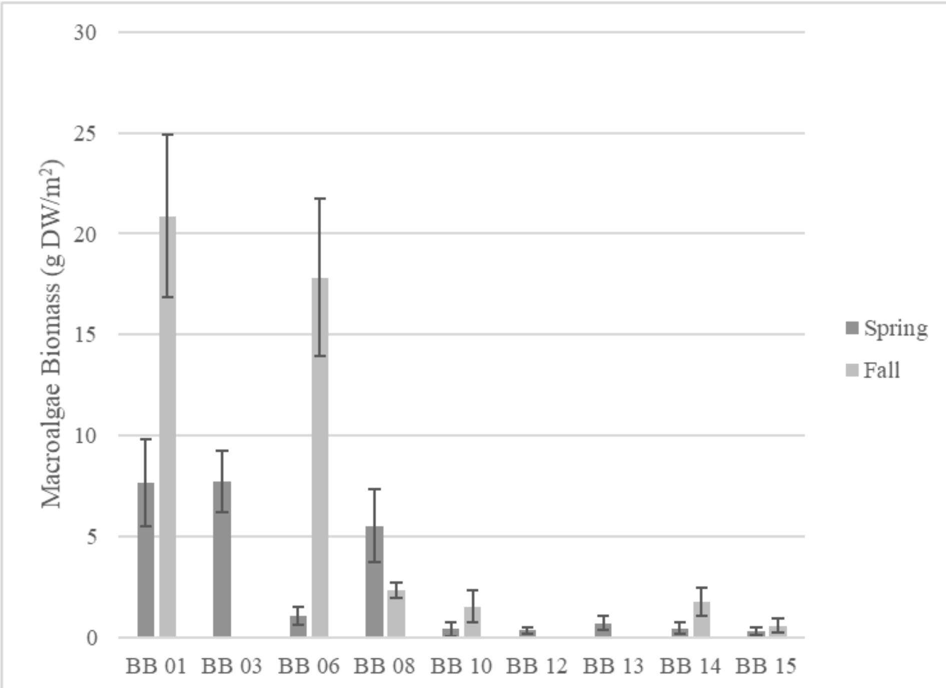
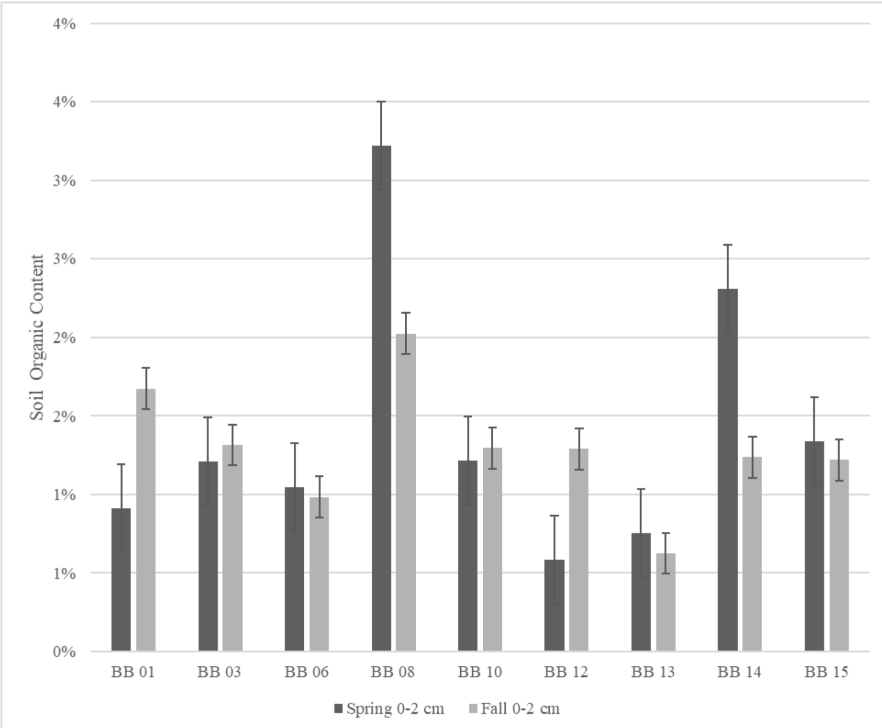
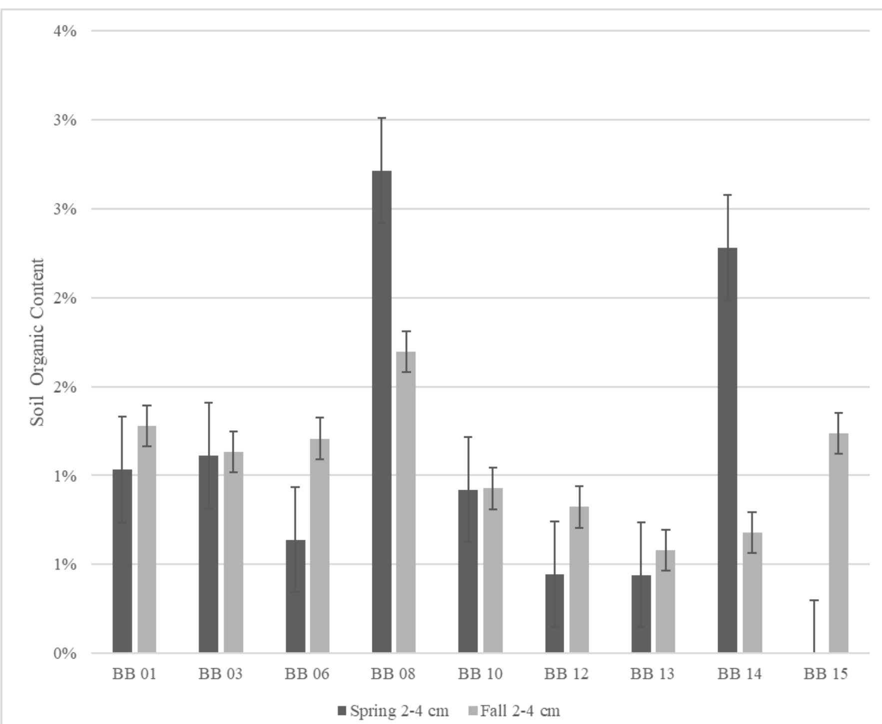


Figure 6: Macroalgae biomass (g DW/m^2 ± SE) in Spring and Fall.


4%
4%
3%
3%
2%
2%
1%
1%
0%
Soil Organic Content
BB 01
BB 03
BB 06
BB 08
BB 10
BB 12
BB 13
BB 14
BB 15
Spring 0-2 cm
Fall 0-2 cm


4%
3%
3%
2%
2%
1%
1%
0%
Soil Organic Content
BB 01
BB 03
BB 06
BB 08
BB 10
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Spring 2-4 cm
Fall 2-4 cm

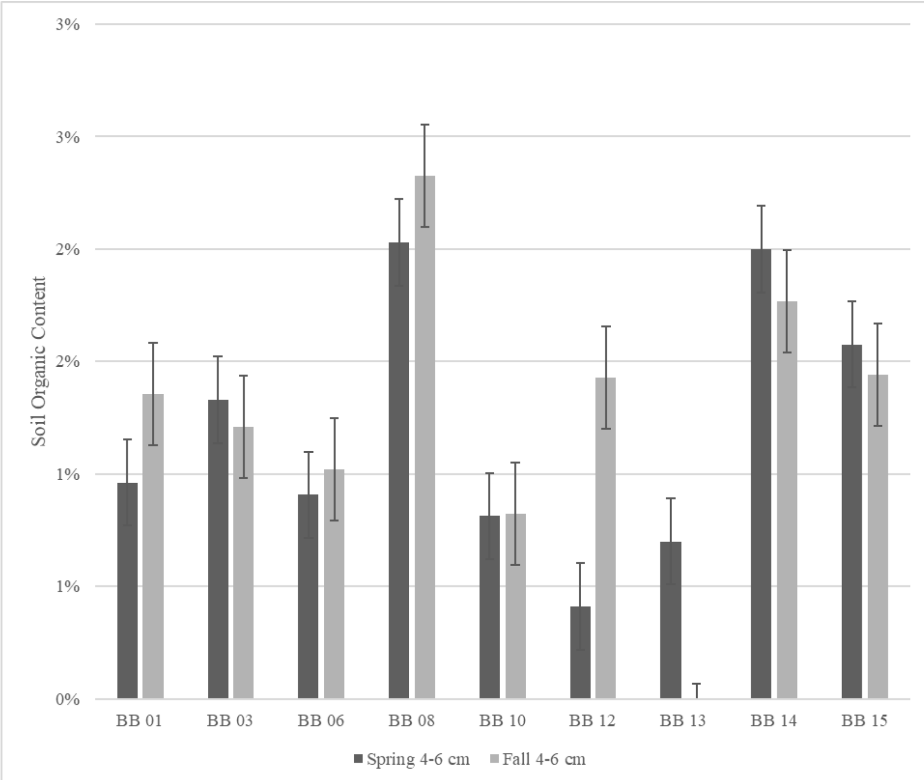

Figure 7: Percentage soil organic content (±SE) in Spring and Fall at (a) 0 – 2 cm, (b) 2 -4 cm, (c) 4 – 6 cm depth.

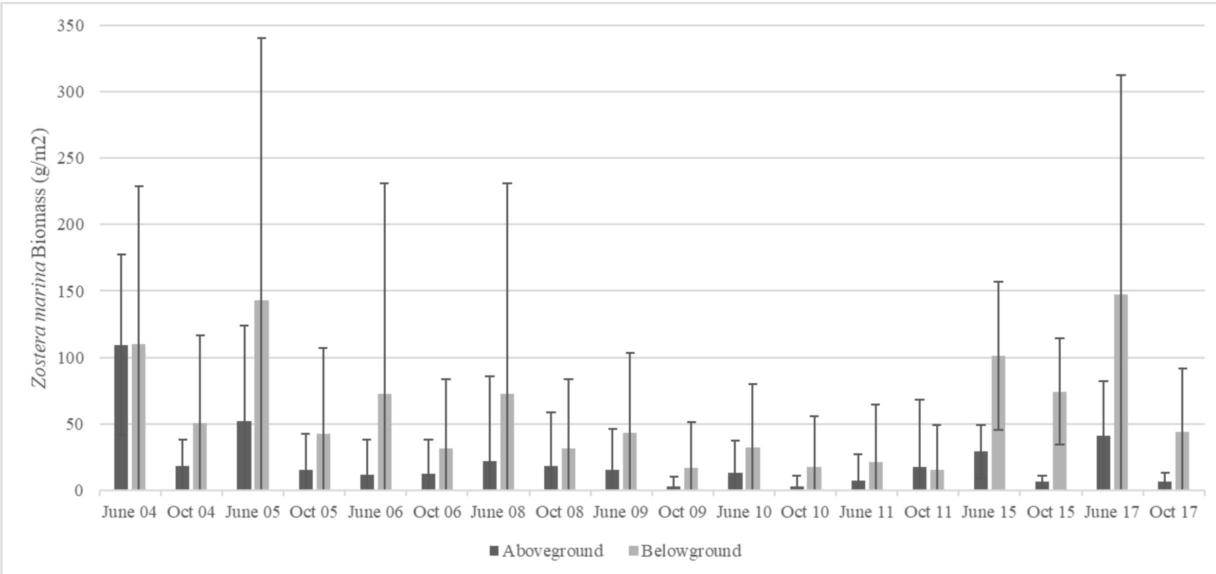

Figure 8: Average *Zostera marina* aboveground and belowground biomass (g DW/m^2 ± SD) throughout Barnegat Bay (data taken from NEIWPCC and the 2015 & 2017 BBP studies).

Table 1: Coordinates (Decimal degrees) of sampling stations. Site number refers to location in relationship to previously established research transects. See Figure 1 for representation of all transects and current sampling sites.

Latitude	**Longitude**	**Site #**
39.57246	74.25129	1
39.58443	74.25255	3
39.6039	74.22392	6
39.78495	74.14985	8
39.89312	74.11174	10
39.90771	74.08906	12
39.95913	74.08618	13
39.9767	74.0773	14
39.98976	74.08128	15