Assessing the Status of Barnegat Bay Submerged Aquatic Vegetation

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ABSTRACT

Barnegat Bay has been experiencing a decline of *Zostera marina*, the important ecosystem engineer which provides a diverse suite of services which increase the diversity and productivity of coastal ecosystems. As efforts are made to reduce those stressors negatively impacting submerged aquatic vegetation health, primarily euthrophication, monitoring is necessary to assess the efficacy of these measures and the role of water quality on overall habitat resiliency. The objective of this project was to provide ongoing quantitative measures on the health of the primary indicators, submerged aquatic vegetation, at a subset of sites throughout northern, central and southern Barnegat Bay. The northern region was dominated by *Ruppia maritima* and the southern region by *Zostera marina*, with a transitional zone in the central region. Aboveground biomass of *Zostera marina* indicates there may be a recovering population within the Bay; however, this may be attributed to annual and seasonal variations rather than an upward trend. Continued monitoring is necessary to elucidate any trends. In those central regions with increasing cover by *Ruppia maritima*, future work is necessary to determine if *Ruppia maritima* can provide equivalent habitat and ecosystem services as *Zostera marina*. The majority of macroalgae sampled was in the form of clumped drift algae, which has a temporary impact on *Zostera marina* and *Ruppia maritima* health when compared to longer residence blooms. 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.

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 coupled with episodes of extreme stress from algal blooms. This water quality degradation decreases the light available for seagrasses to complete the photosynthetic processes necessary for growth, survival and reproduction. Since 2004, there has been a well-documented decline in eelgrass 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 ecosystems after management strategies are implemented is necessary to assess the efficacy of these strategies and adapt them, as necessary. In addition, monitoring of eelgrass bed health is necessary to assess the role of water quality on overall resiliency of these habitats within our region. Monitoring information, including those abiotic and biotic parameters indicative of eelgrass health, are necessary to more accurately predict future trends in eelgrass 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 a subset of sites throughout northern, central and southern Barnegat Bay. These quantitative parameters included above and belowground biomass, canopy complexity, micro- and macroalgal cover and sediment organic content. Results from this survey were compared to previous survey results from 2004-2013 in order to evaluate the status and trends of submerged aquatic vegetation within the Barnegat Bay estuary. This assessment was included in the 2016 State of The Bay report prepared by the Barnegat Bay Partnership (BBP).

METHODOLOGY

Site Information

Sampling was conducted at a subset of nine sites 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 and central/southern sections of the estuary, respectively. Sampling was completed in late June/early July and mid-October of 2015 in order to document annual and inter-annual changes in submerged aquatic vegetation demographics. Within 50 m of the original site coordinates at each site, temperature, salinity, pH, and dissolved oxygen was recorded via YSI and water clarity via secchi disc.

Submerged Aquatic Vegetation Biomass

In order to collect aboveground and belowground biomass, ten (10) 22 cm diameter cores were taken along a 20-meter transect laid out in an east-west direction 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. 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}.

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 = 5). 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. Within each quadrat, maximum seagrass blade height was measured.

Macroalgae Biomass

Macroalgal biomass was collected from five 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

For site data that was normally distributed, an ANOVA with Tukey HSD post hoc was used to test for significant differences between parameters (e.g. biomass, percent cover, epiphytic load, sediment TOC). Seasonal comparisons for normally distributed data were compared via student's t-test. Macroalgal biomass was not normally distributed and could not be transformed. General trends in macrolalgal biomass is presented from pooled data per $0.25m^2$ quadrat.

RESULTS

To determine the spatial extent of the submerged aquatic vegetation over the duration of the growing season in Barnegat Bay in 2015, a subset of 9 sites from the original 15 sites were sampled in June/July and October 2015. All sites were 1-2m in depth along a gradient of decreasing salinity. Highest salinities were recorded at sites 1, 3, 6 and 8 (28-30ppt), decreasing towards the northern segment to 19-22ppt (sites 10, 12-15). At those sites with lower salinities, both *Zostera marina* and *Ruppia maritima* were present. Sites with higher salinities had only *Zostera marina*.

At those sites dominated by *Zostera* (1, 3, 6, 8), cover by *Zostera* in June/July ranged from 74-94% with approximately 350 shoots of *Zostera* per m^2 (Figure 2a, Table 2). Density declined in October to 13-45% cover, with highly variable shoot density from 68-417 per m^2. At these four sites, *Ruppia* cover was 5% or less for both sampling events (Figure 2b). Macroalgae cover was less than 8% for both sampling events at both sites and was represented by *Ulva* and *Gracilaria* (Table 3). In the *Ruppia*-dominated habitat (15, 14, 13), cover by *Ruppia* in June/July ranged from 53-78% and declined to 3-23% in October. At all three of these sites, *Zostera* cover was less than 6% for both sampling events. Macroalgal cover was highest at the northernmost site in the *Ruppia*-dominated habitat and was dominated by *Gracilaria* and *Hypnea*. In transitional areas with a mixture of *Zostera* and *Ruppia*, one site (10) remained fairly constant between sampling events (62% *Zostera*), with an average shoot density range between sampling events of 243 - 328 per m^2. The other site in the transitional area (12) experienced a decline in *Zostera* (24% to 10% cover, 123 shoots/m^2 to 14/m^2) and an increase in *Ruppia* (41% to 76%).

For *Zostera*, overall mean aboveground biomass was high in the southern region, with a peak over 120 g dry weight/m^2 at Site 8 (Figure 3a). In the Spring, Site 8 had significantly higher aboveground biomass than other sites while Sites 12 and 14 had significantly lower biomass. In the Fall, Sites 1 and 3 had significantly higher aboveground biomass than all other sites. In the Spring, sites 1, 3, 6 and 8 had significantly higher belowground biomass than sites 10, 12, 14 and 15. In the Fall, sites 6 and 8 had significantly higher belowground biomass than sites 10, 12, 14 and 15. In the Spring, Site 3 had significantly longer blade lengths, while Site 10 had significantly shorter blade lengths ($p < 0.01$). In the Fall, Site 8 had significantly longer blade lengths, while Site 3 had significantly shorter blade lengths ($p < 0.01$). Overall at all sites and seasons, epiphytic load was less than 0.010 mg/cm^2. In the Spring, Site 1 had significantly higher epiphytic load than Sites 8, 10 and 12 but no other statistically significant differences were found between sites. In the Fall, sites did not significantly differ in epiphytic load.

For *Ruppia*, the mean aboveground biomass overall was low for all samples (< 20 g dry weight/m^2, Figure 3b). In Spring, there was no significant difference in aboveground *Ruppia* biomass between all sites with *Ruppia* and site 14 had significantly higher belowground biomass than the other sites. In the Fall, Site 12 had significantly higher aboveground and belowground biomass than all other sites.

Across all sites, seasons and depths, total organic content was low with the majority of samples less than 3% organic carbon. At the 0-2 cm depth profile, Site 12 and 14 had significantly lower organic carbon than other sites in Spring but there were no significant differences between sites in the Fall. At the 2-4 cm depth profile, there were no significant differences between sites in either season. At the 4-6 cm depth profile, Sites 12 and 14 were significantly lower in Spring, while Site 14 was significantly higher in Fall.

DISCUSSION

Barnegat Bay has been experiencing a noticeable decline in underwater vegetated habitat over the past 15 years (Kennish et al. 2008, 2010, 2012; Fertig et al., 2013), although this decline is not homogenous across the Bay. Results from this study indicate that sites in the southern region and portions of the central region have higher *Zostera marina* biomass both above and belowground and low epiphytic loads throughout the entire bay. For *Ruppia*, overall the mean aboveground biomass was low for all sites, but similar to previously reported biomass in the region (Kennish 2011). The entire Bay contained low overall total organic carbon within the sediments, with those regions dominated by *Ruppia* containing the lowest amount of organic carbon buried within the sediments. Low macroalgae cover and highly variable macroalgal biomass is indicative of the high prevalence of drift algae and the clumped nature of this type of growth form.

It is well documented that the southern region of Barnegat Bay experiences less anthropogenic stressors than the northern region (Kennish et al. 2008, 2010, 2012; Fertig et al., 2013), and these differences drive the variation in submerged aquatic vegetation habitat across the Bay. In the northern region, declining water quality has largely driven declines in *Zostera marina* and supported the prevalence of *Ruppia maritima*, which is more tolerant to water temperature, salinity and nutrient stressors. While this survey does report significantly higher aboveground biomass than previous studies, seasonal fluctuations and the natural decline of the eelgrass over the course of the summer eliminates any significant difference in biomass when compared Fall biomass numbers are compared to these previous studies. Future monitoring is necessary to track any potential recovery and the impact of returning, favorable water conditions.

The central, transitional region of Barnegat Bay has experienced an increase in *Ruppia maritima*, which may be attributed to these stressors and the declining health of *Zostera marina*. Future work is necessary to determine if *Ruppia maritima* can provide equivalent habitat to *Zostera marina* for recreationally and commercially important fish and invertebrate species. Based on the results from this study, the low carbon content in the sediments of regions dominated by *Ruppia maritima* may indicate they do not provide equivalent carbon sink ecosystem services that *Zostera marina* may provide.

Overall macroalgae cover was low but highly variable, which may have equally variable impacts on submerged aquatic vegetation health throughout the Bay. The majority of macroalgae sampled was in the form of clumped drift algae, which has a temporary impact on *Zostera marina* and *Ruppia maritima* health when compared to longer residence blooms. Recent research suggests that some drift algae, even exotics such as *Gracilaria*, can form alternative habitats which support important, diverse invertebrate communities (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 they may provide.

Throughout Barnegat Bay, results from this study indicate that in 2015 *Zostera marina* biomass was higher than historically recorded levels in Spring but not significantly higher by Fall. Whether any upward trends will continue throughout the season in subsequent years remains to be seen but these results do emphasize the importance of continued monitoring in tracking any recovery. 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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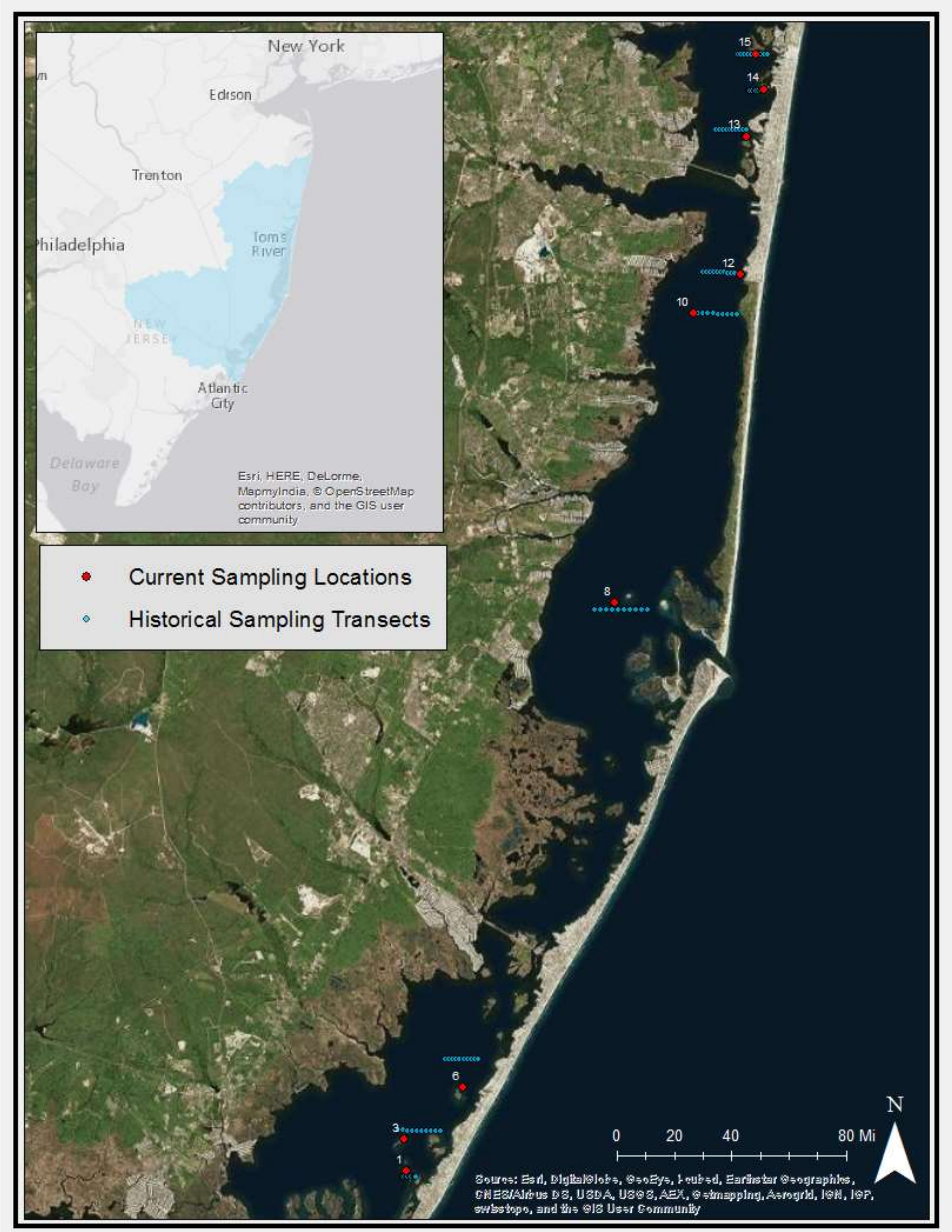


Figure 1. Barnegat Bay-Little Egg Harbor Estuary showing all historic sampling transects in green dots (from Kennish et al 2013). Transects are numbered from south to north. We will sample at Transects 1, 3, 6, 8, 10, 12, 13, 14, and 15.

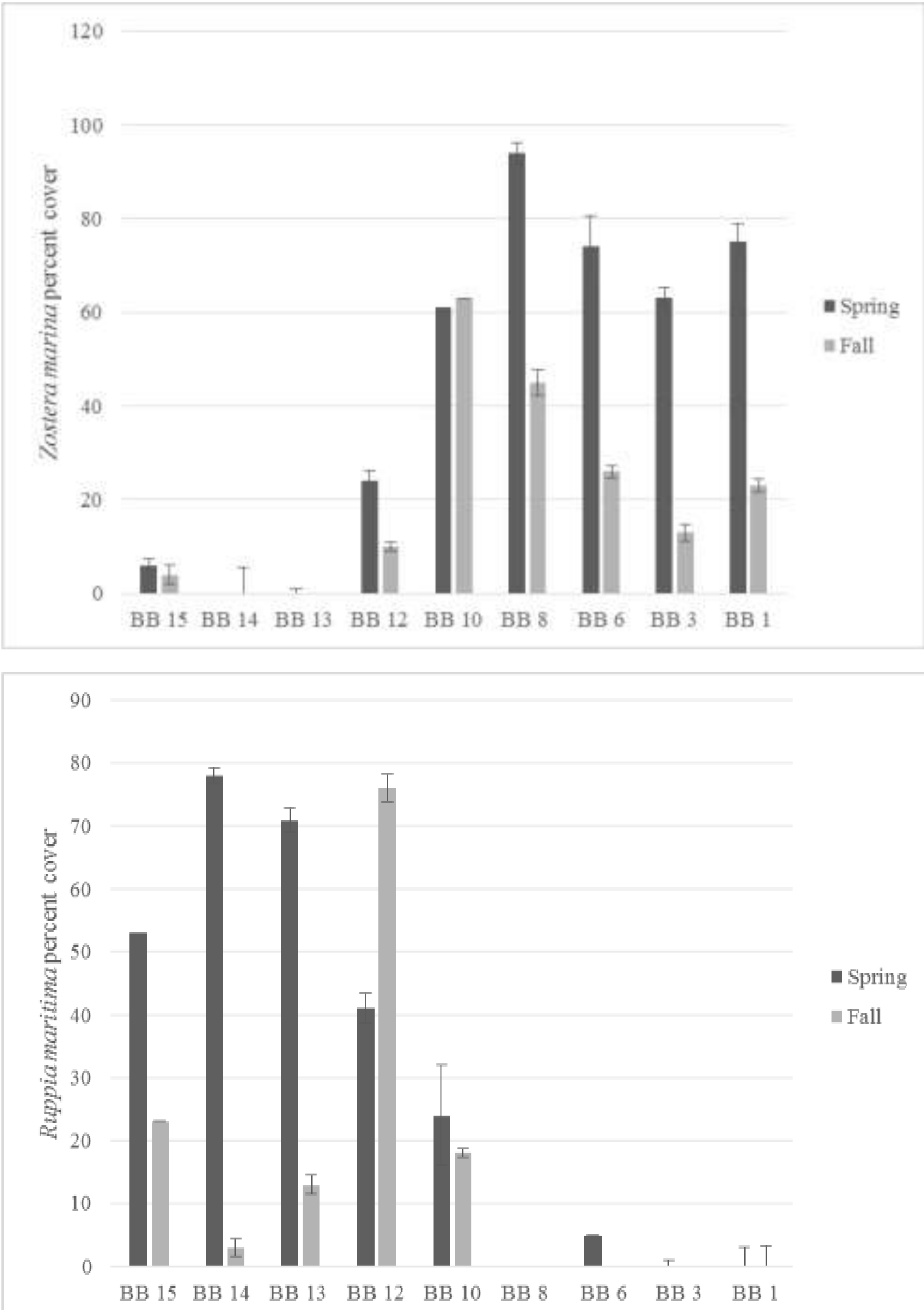


Figure 2: Percent cover of (a) *Zostera marina* and (b) *Ruppia maritima* (note difference in y-axis)

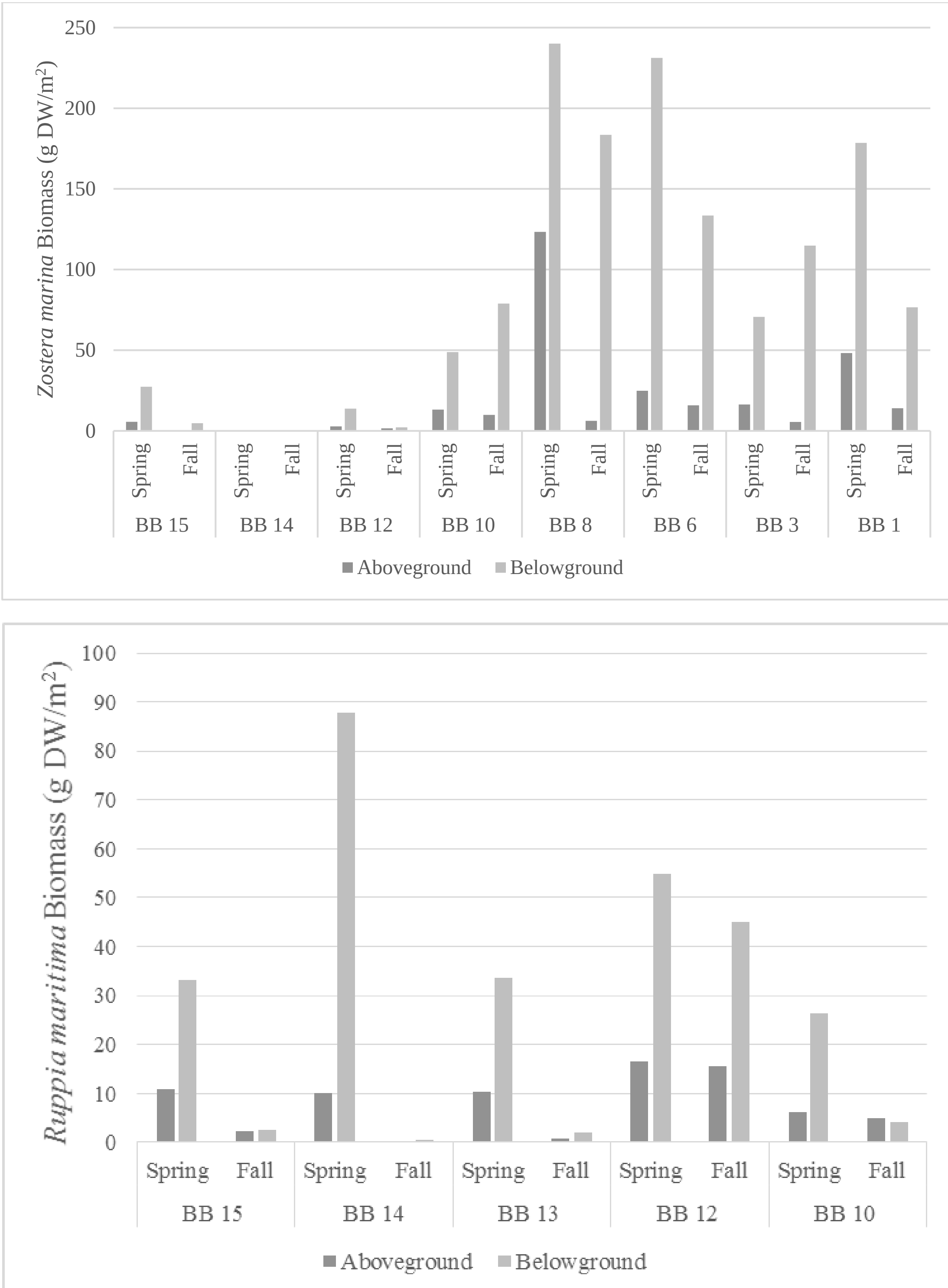


Figure 3: Aboveground and belowground biomass (g DW/m^2) of (a) *Zostera marina* and (b) *Ruppia maritima* (note difference in y-axis)

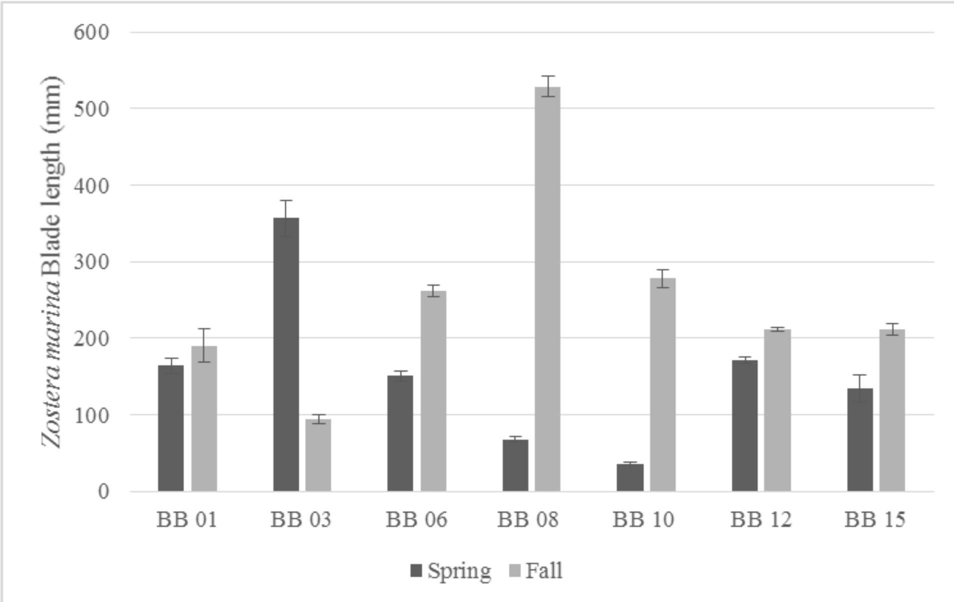


Figure 4: *Zostera marina* blade length (mm)

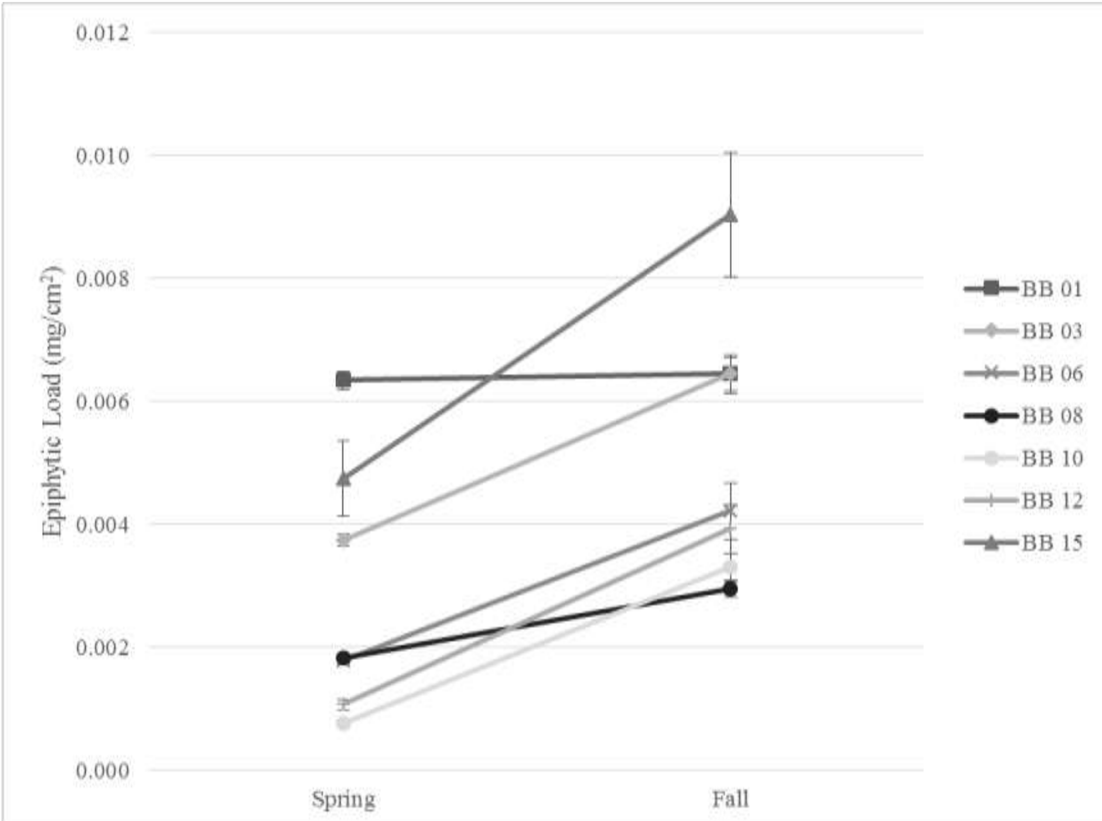
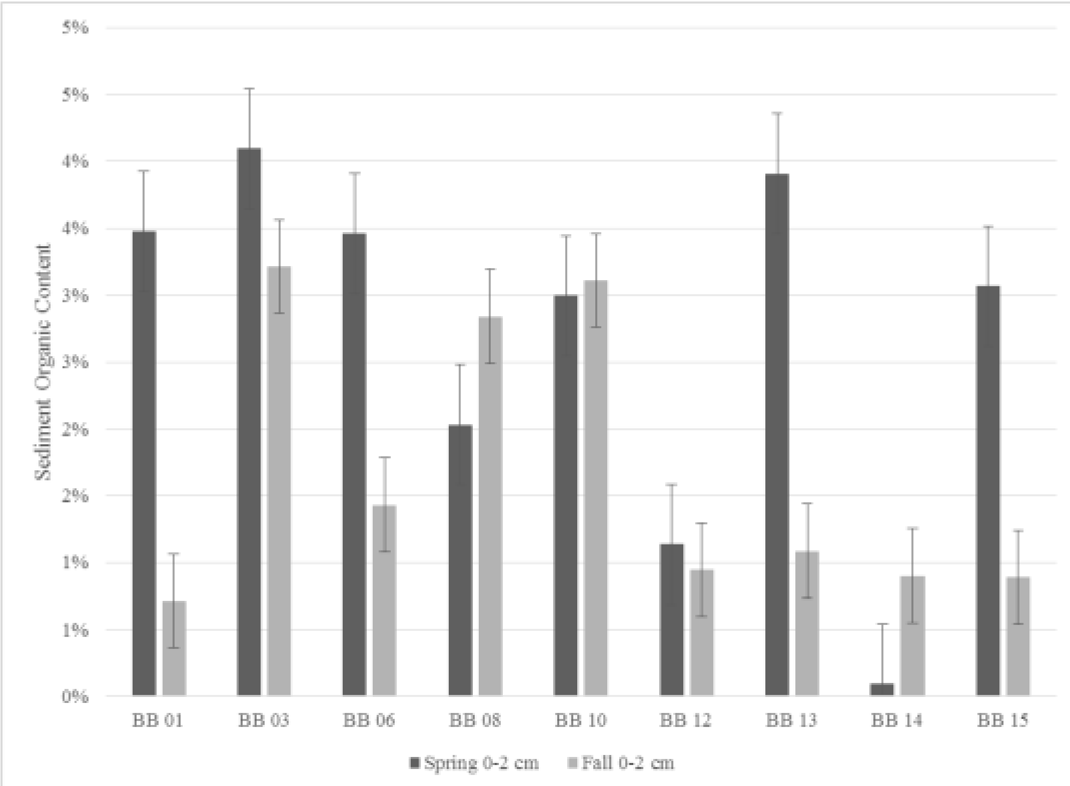
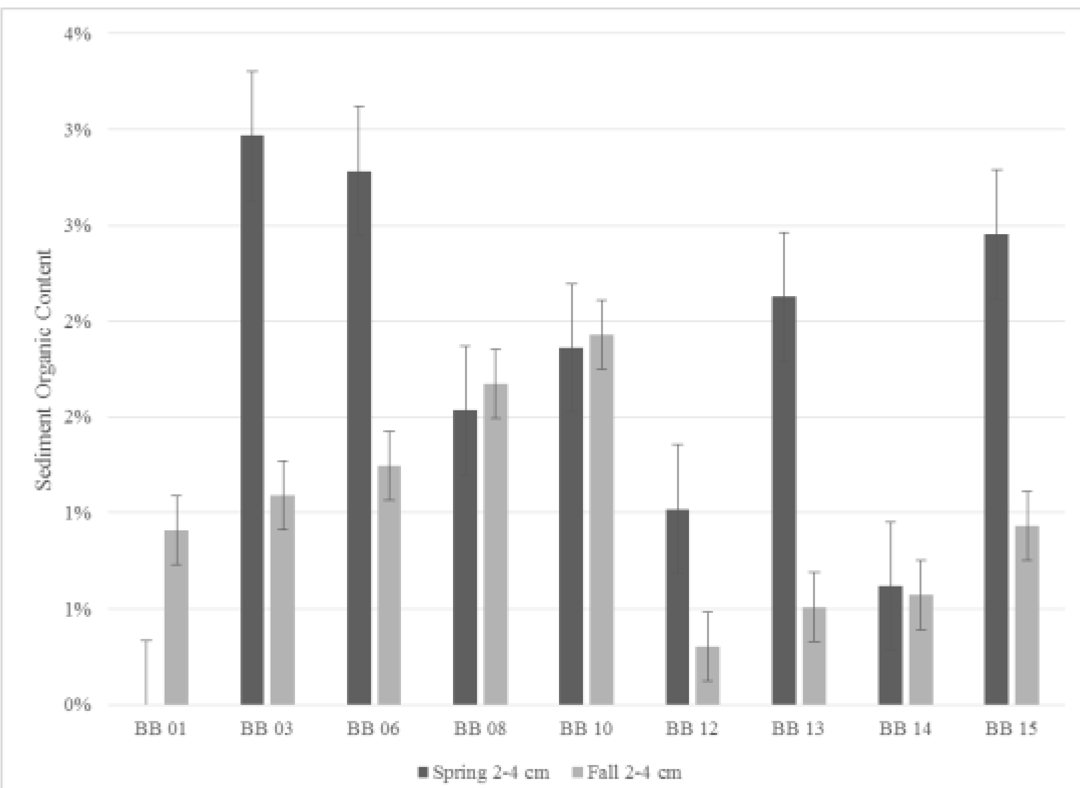


Figure 5: Epiphytic load (mg DW/ cm^2) on *Zostera marina*


5%
5%
4%
4%
3%
3%
2%
2%
1%
1%
0%
Sediment 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%
Sediment Organic Content
BB 01
BB 03
BB 06
BB 08
BB 10
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BB 13
BB 14
BB 15
Spring 2-4 cm
Fall 2-4 cm

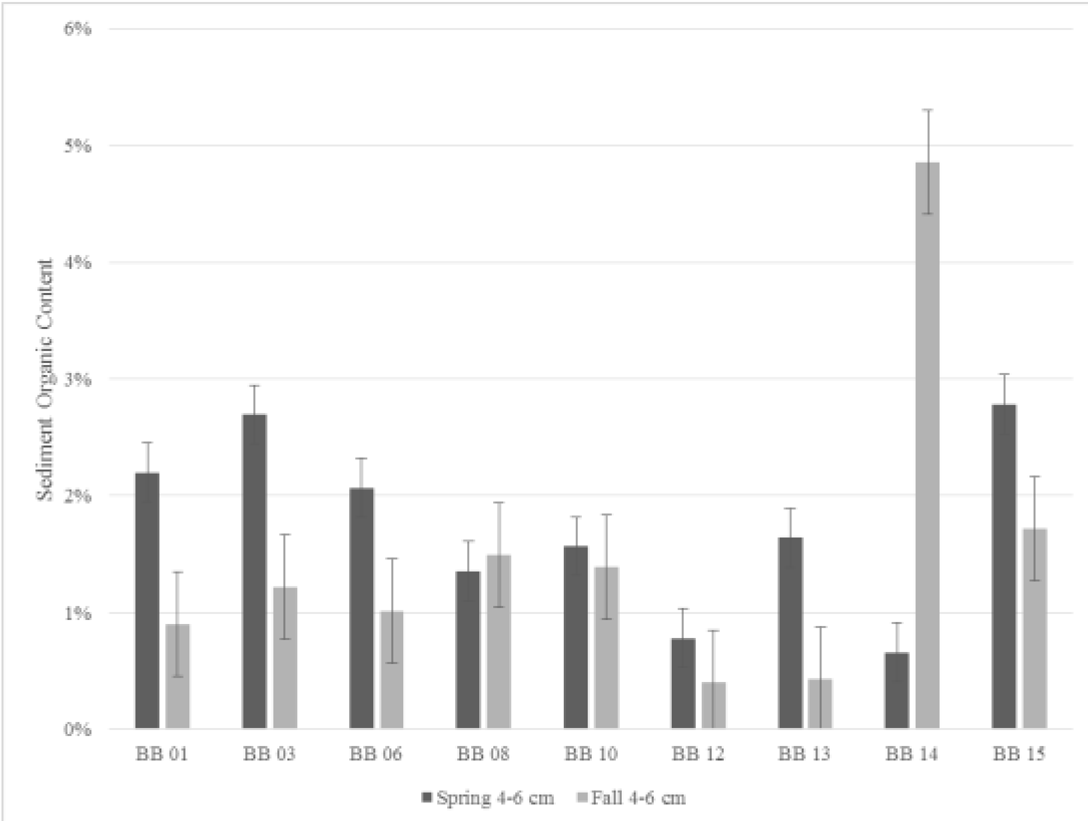

Figure 6: Percentage sediment organic content in Spring and Fall at (a) 0 – 2 cm, (b) 2 -4 cm, (c) 4 – 6 cm depth.

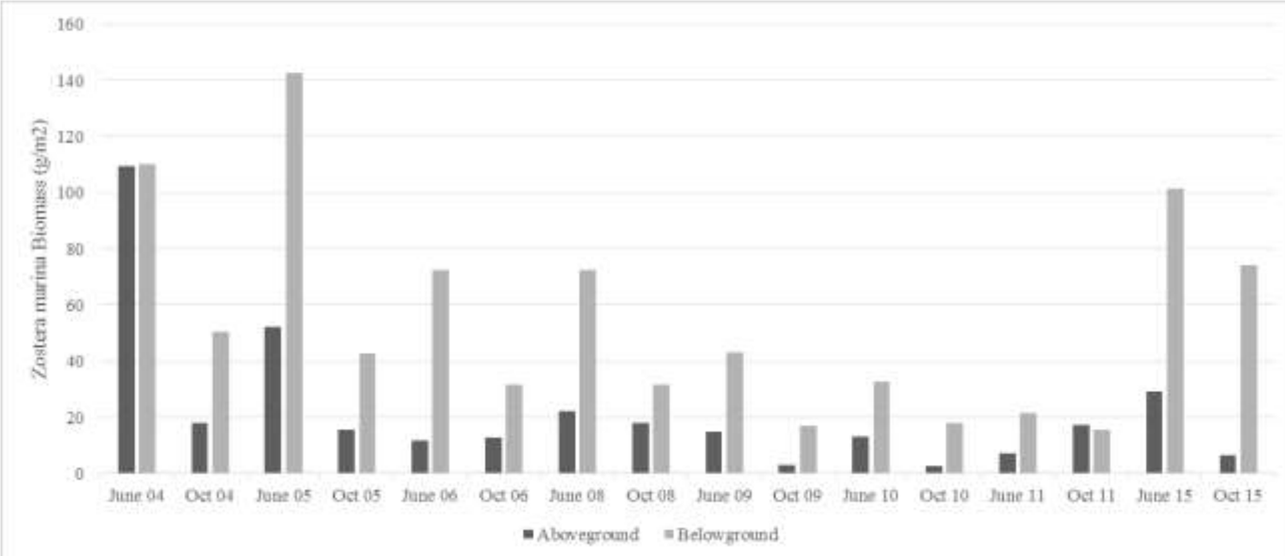

Figure 6: Average *Zostera marina* aboveground and belowground biomass (g DW/m^2) throughout Barnegat Bay (data taken from NEIWPCC and this study).

Table 1: Coordinates (Decimal degrees) of seagrass sampling stations. Site number refers to location in relationship to previously established research transects (#1-15). 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

Table 2: *Zostera marina* shoot counts

	Spring	Fall
BB 15	182	31
BB 14	0	3
BB 13	0	0
BB 12	123	14
BB 10	243	328
BB 8	410	68
BB 6	297	264
BB 3	290	197
BB 1	496	417

Table 3: Macroalgae genera present and biomass range (g/m^2) per site and season

Biomass range per site	Spring (g/m^2)	Fall (g/m^2)	Genera
BB 01	0-2.05	0-1.84	*Gracilaria, Ulva, Hypnea*
BB 03	0-5.02	0-1.46	*Polysiphonia, Agardhiella, Ulva*
BB 06	0-7.41	0	
BB 08	0	0	
BB 10	0.03-1.02	0-0.07	*Gracilaria, Polysiphonia*
BB 12	0-0.74	0	*Gracilaria, Polysiphonia*
BB 13	0-0.78	0	
BB 14	0-1.58	0-0.23	*Polysiphonia*
BB 15	0.65-1.28	0-4.25	*Agardhiella, Spermothamnion*