Office of Science

Research Project Summary

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Rutgers University - Assessment of Eutrophication in the Barnegat Bay Little Egg Harbor System: Use of SAV Biotic Indicators of Estuarine Condition

Authors

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Abstract

Seagrass is an important indicator of estuary condition. Results of a comprehensive investigation of the seagrass demographics in the Barnegat Bay-Little Egg Harbor (BB-LEH) Estuary during 2008 indicate ongoing degradation of seagrass habitat associated with increasing eutrophic conditions. Surveys of seagrass beds in BB-LEH from spring to fall in 2008 show that the seagrass (predominantly *Zostera marina*) beds have not yet recovered from the marked reduction of plant biomass (g dry wt m^{-2}), density (shoots m^{-2}), blade length, and percent cover recorded in 2006. Quadrat, core, and hand sampling, as well as digital camera imaging at 120 transect sites in 4 disjunct seagrass beds of the estuary during the June-November period in 2008, as in 2004, 2005, and 2006, reveal distinct changes in demographic patterns that can lead to significant shifts in ecosystem services. In 2008, seagrass was found at less than 50% of the survey sites (46.3%) during the June-July sampling period when the median aboveground and belowground biomass values were a maximum. The percent cover of seagrass was lowest in June-July (23%), highest in August-September (36%), and intermediate in October-November (27%). Seagrass biomass, density, and areal cover measurements in comparison to previous years, were higher at interior transect sampling sites closest to the seagrass bed margins (i.e. areas of seagrass beds away from margins) than at exterior transect sampling sites (i.e. outermost area of seagrass beds), which be attributed to edge effects and environmental conditions less optimal for overall survival. These values are consistent with those measured during 2004, 2005, and 2006. The percent cover of macroalgae was significantly lower than that of seagrass, declining markedly from June to November. The mean percent cover of macroalgae decreased from 20% during the June-July period to 10% during the August-September period and 5% during the October-November period. The nitrogen content of *Z. marina* blades measured at field transplantation sites ranged from 2.97% to 4.33%. Nitrogen Pollution Index values calculated for *Z. marina* in the estuary ranged from 0.58 to 2.55.

Introduction

Eutrophication poses the most serious threat to the long-term health of the Barnegat Bay-Little Egg Harbor Estuary (Kennish et al., 2007a). Nutrient enrichment and associated organic carbon loading in this shallow, coastal lagoon have been linked to an array of cascading environmental problems such as increased micro- and macroalgal growth, harmful algal blooms (HABs), altered benthic invertebrate communities, impacted harvestable fisheries, and loss of essential habitat (e.g., seagrass and shellfish beds). The net insidious effect of progressive eutrophication is the potential for the permanent alteration of biotic communities and greater ecosystem-level impacts. For example, hard clam (*Mercenaria mercenaria*) stocks in BB-LEH declined by two-thirds between 1986 and 2001, and the hard clam harvest declined by more than 95% between 1975 and 2005. Recurring brown tide (*Aureococcus anophagefferans*) blooms occurred between 1995 and 2002, with monitoring for brown tide being discontinued after 2004 (Olsen and Mahoney, 2001; Gastrich et al., 2004). The biomass of seagrass beds in the BB-LEH Estuary decreased by 50-87.7% over the 2004-2006 period (Kennish et al., 2007b).

Since the BB-LEH Estuary is shallow, poorly flushed, and bordered by highly developed watershed areas, it is particularly susceptible to nutrient loading. Seagrass subsystems, which are excellent indicators of estuarine sediment and water quality conditions, have been on the decline not only in estuaries in the mid-Atlantic region but also in many other regions worldwide due to nitrogen and phosphorus loading associated with human activities (Nixon, 1995; Rabalais, 2002; Orth et al., 2006; Valiela, 2006). Most of the seagrass beds in New Jersey (~75%) occur in the BB-LEH Estuary. While more than 6,000 ha. of seagrass habitat have been reported in this system (McLain and McHale 1997), some studies indicate that significant losses of seagrass have taken place during the past 30 years, possibly reducing the beds by 30-60% (Bologna et al., 2000). According to Lamote and Dunton (2006), more than 70% of the large-scale decline in seagrass habitats reported in recent studies is ascribed to eutrophication. A GIS spatial comparison analysis of SAV surveys in BB-LEH by Lathrop et al. (2001) suggests that a contraction of the seagrass beds to shallow subtidal areas (< 2 m) may have occurred during this period due to a decrease in available light in response to phytoplankton and macroalgal blooms as well as epiphytic attenuation. Eutrophy has progressively increased in the estuary. Over two-thirds of U.S. estuaries are experiencing moderate to high eutrophic conditions as a result of nutrient over-enrichment (Bricker et al., 1999, 2007).

Increased nutrient loading to the BB-LEH Estuary has raised concern over potential impacts on seagrass, as well as biotic communities and other habitats in the system (Kennish, 2001). In this study, we examine the demographics of *Zostera marina* in the estuary over the 2008 study period to determine its status and trends. We also discuss the environmental factors responsible for changes in the structure and function of the seagrass beds. To this end, comprehensive in *situ* sampling of seagrass beds was conducted in the estuary during the spring-fall period in 2008, similar to surveys of the same beds conducted from 2004-2006.

Methods

Study Area:
Barnegat Bay-Little Egg Harbor is a lagoonal estuary located along the central New Jersey coastline (Figure 1). It forms an irregular tidal basin ~70 km long, 2-6 km wide, and 1.5 m deep. The surface area amounts to 280 km^2, and the volume, 3.54×10^8 m^3 (Kennish, 2001a). The location of the barrier island complex (Island Beach and Long Beach Island) restricts exchange of water with the coastal ocean; therefore, flushing times of the estuary are protracted, ~74 days in summer. Exchange of bay and ocean water occurs through Barnegat Inlet, Little Egg Inlet, and the Pt. Pleasant Canal.

Sampling Design:
Quadrat-and-transect sampling was conducted over the June to November sampling period in 2008, targeting the same seagrass beds and sampling stations in Barnegat Bay (~1550 ha) and Little Egg Harbor (~1700 ha) sampled during the 2004-2006 period (Kennish et al., 2007b, 2009). The purpose of this work was to determine if the status (i.e., characteristics) of seagrass habitat has changed since the detailed SAV surveys conducted during the 2004-2006 period. A total of 120 sampling sites along 12 transects (see Figure 1) in four disjunct seagrass beds (1-4) in BB-LEH were sampled during a 6-month period (June-November) in 2008. During each sampling period (June-July, August-September, and October-November), 80 of the 120 field sites (total n = 240 for all sampling periods) were randomly selected and sampled to determine seagrass density, biomass, and blade length. Areal cover measurements of seagrass and macroalgae were also made at all 120 sampling sites. In addition, diver observations were made at these sampling sites to determine the occurrence of epiphytic infestation and bay scallops. The following demographic data were recorded on all sampling dates: presence/absence of seagrass and macroalgae, aboveground and belowground biomass of seagrass, density of seagrass, percent cover of seagrass and macroalgae, seagrass blade length, and occurrence of bay scallops (*Argopecten irradians*). The percent cover of seagrass and macroalgae was estimated using the methods of Short et al. (2002).

In addition to data collected on the above biotic parameters, physicochemical data (temperature, salinity, pH, dissolved oxygen, turbidity, and depth) were also measured. Measurements were likewise collected in the survey area together with measurements of several nutrient parameters (i.e., nitrate plus nitrite, ammonium, total dissolved nitrogen, phosphate, and silica). More than 1000 biotic and abiotic measurements were obtained during the study period. Three seagrass transplantation sites were also established during this study. The purpose of these sites was to conduct a seagrass cross-transplant experiment within the study area to assess growth response. Nitrogen Pollution Index calculated from the seagrass blades was performed using the approach of Lee et al. (2004). Sampling periods (N = 3) commenced in June, August, and October and continued until all targeted stations were sampled. No samples were collected after November.

Coring methods also followed those of Short et al. (2002). The diver-deployed corer extended deep enough in the sediments to extract all belowground fractions (roots and rhizomes). Each core was collected separately and rinsed to separate plant material from the sediment. Seagrass samples were then stored and transported to the Rutgers University Marine Field Station (RUMFS) for laboratory analyses.

Water quality parameters (temperature, salinity, dissolved oxygen, pH, and turbidity) were measured at all sampling stations, collected at a uniform depth (~10 cm) above the sediment-water interface. The data were obtained prior to biotic sampling at each sampling site. Water samples were also collected and analyzed for nutrient concentrations during each sampling period. Nitrate plus nitrite, ammonium, total dissolved nitrogen, phosphate, and silica concentrations were measured at sampling sites within the seagrass beds. Laboratory analysis of the nutrients followed standard methods. Nutrient samples (N = 72) were collected at all 12 transects in the estuary over the study period.

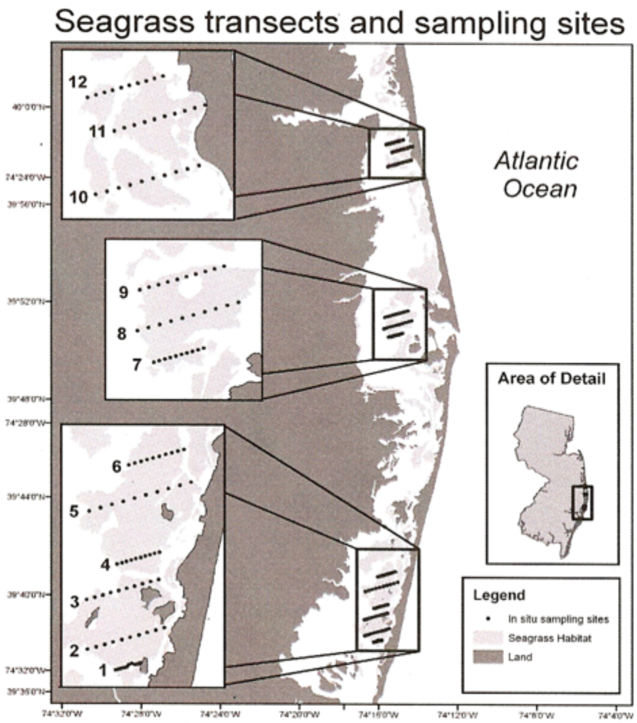

Figure 1. Map of the estuarine study area. Note disjunct seagrass beds, Transects (1-12), and sampling sites along transects.

Results

Physicochemical Conditions:

There was no significant difference in mean temperature, salinity, dissolved oxygen, pH and Secchi disk depth over the course of the study period between stations. Mean water temperature for the June-July sampling period (23.37 ºC) was slightly lower than that for August-September (23.99 ºC). However, it decreased markedly (19.08 ºC) for the October-November sampling period. In contrast, mean salinity was higher, and dissolved oxygen, pH, and Secchi disk depth lower, during the August-September sampling period compared to the June-July and October-November periods. These trends were not consistent for all previous years of water quality sampling (Kennish et al., 2007b).

Mean dissolved oxygen (DO) values amounted to 7.33 mg/l during June-July and 6.55 mg/l during the August-September sampling period. The pH values were consistent across the survey area in 2008. Mean pH measurements amounted to 8.09 for June-July and 7.95 for August-September. A slightly higher mean pH value of 8.00 was registered for the October-November sampling period. Secchi measurements were consistent across all sampling periods (i.e. sampling period Secchi values: mean = 1.21 m, June-July; mean = 1.09 m, August-September; mean = 1.28 m, October-November).

Nutrient concentrations in the water column were similar to those recorded in previous years, with low concentrations recorded for dissolved inorganic nitrogen and phosphorus components (nitrate, nitrite, ammonium, and phosphate) (Kennish et al., 2007). Nitrate plus nitrite levels were low, ranging from a mean of 0.04-0.32 μM, with highest values observed in October-November when plant growth was on the decline. Low concentrations reflect the effect of autotrophic uptake during the late spring to summer period. A wider range of ammonium values was recorded, with mean values ranging from 0.30-1.48 μM. Once again, the highest values were observed in the October-November period. The mean total dissolved nitrogen concentrations ranged from 12.73-16.50 μM. Similarly, mean phosphate values were low, ranging from 0.73-0.78 μM; the highest values were again recorded in the October-November period. Silica ranged from a mean of 8.51-22.0 μM, with peak levels observed during this period.

Seagrass Demographics:

Eelgrass (*Zostera marina*) was far more abundant than widgeon grass in the BB-LEH Estuary, especially in higher salinity areas. Widgeon grass (*Ruppia maritima*) was most abundant in lower salinity areas north of Toms River. Abundance, biomass and areal coverage of *Z. marina* varied considerably both in space and time during the entire study period. The highest density measurements were recorded during the August-September sampling period (mean = 466 shoots m^{-2}). Significantly lower densities of Z. marina were registered during the June-July and October-November sampling periods.

Aboveground biomass of *Zostera marina* in the BB-LEH Estuary peaked during August-September (mean = 30.83 g dry wt m^{-2}), with lowest values (mean = 22.91 g dry wt m^{-2}) recorded during October-November (Figure 2). Intermediate aboveground biomass values (mean = 25.01 g dry wt m^{-2}) were documented during the June-July sampling period. Highest biomass values were observed during August-September. Of the 240 stations surveyed for from June to November, only 125 aboveground biomass measurements were recorded. During 2008, the mean aboveground biomass of *Z. marina* was highest for transect 3 (65.1 g dry wt m^{-2}), transect 7 (54.2 g dry wt m^{-2}), and transect 9 (51.2 g dry wt m^{-2}). The lowest mean aboveground biomass value (1.4 g dry wt m^{-2}) was recorded for transect 12. The biomass data were also assessed on the basis of values recorded at interior transect sites (3, 4, 5, 6, 7, and 8) versus exterior transect sites (1, 2, 9, and 10). The mean aboveground biomass values for the interior transect sampling sites were substantially greater than those recorded at the exterior transect sampling sites. This pattern was consistent with that observed for previous survey years (2004-2006) (Kennish et al., 2007b).

Similar to the aboveground biomass values, the highest belowground biomass values were observed during the August-September sampling period. Belowground biomass measurements of *Z. marina* were markedly higher than the aboveground biomass measurements during all three sampling periods in 2008. Belowground biomass decreased sharply during October-November, after a period of relatively consistent levels during the June-July and August-September sampling periods. The highest mean belowground biomass of *Z. marina* samples was observed during June-July (81.31 g dry wt m^{-2}), and the lowest mean belowground biomass was found during October-November (39.86 dry wt m^{-2}). As in the case of aboveground biomass values, belowground biomass values were much greater at interior than exterior transect sites, especially during the first two sampling periods.

The highest mean seagrass blade length (19.88 cm) was observed during the October-November sampling period. The mean length of the blades was lowest (14.57 cm) during the August-September sampling period, and slightly higher (15.35 cm) during the June-July sampling period. Blade length values were not significantly different during the sampling periods.

Percent Cover - Seagrass and Macroalgae:
The mean percent cover of seagrass during period 1 (June-July), period 2 (August-September), and period 3 (October-November) in 2008 was 23%, 36%, and 27%, respectively (Table 1). Percent cover was considerably higher at interior transect sampling sites than exterior transect sampling sites for all sampling periods (Figure 3). By comparison, mean percent cover by macroalgae during these periods was substantially less, averaging 20% (June-July), 10% (August-September), and 5% (October-November) (Figure 4). Considerable variation of macroalgal cover was evident among transects, particularly between the interior and exterior transect sites.

Seagrass Experimental Transplantation Plots:
Reciprocal transplanting of Z. marina plants was performed between three sites located in the northern, central, and southern segments of the estuary on May 29, 2008. Two of the sites (northern and central segments) were located in Barnegat Bay, and one site (southern segment), was located in Little Egg Harbor. At each site, nine seagrass samples were extracted from the estuarine bottom sediment using the aforementioned methods, yielding a total of 27 plugs. Intact plugs were extracted at each site containing complete leaf, root, rhizome, and sediment components. The three sites were subsequently visited the same day in reverse order from north to south (sites 3 – 2 – 1), and the pots were transplanted within hours of collection. Transplantation sites were revisited on September 16, 2008. However, no peat pots were found at sites 1 and 2, having been lost to weather events, high currents, or anthropogenic factors. The peat pots were found only at site 3 on this date, and a subset of the blades were sampled at this location. This site was later visited again on November 12, 2008, and plant blades in five of the peat pots were sampled and measured in the laboratory for length, leaf mass, and nitrogen content. A Nitrogen Pollution Index (NPI) was calculated based on these later measurements.

Nitrogen Pollution Index:
Seagrass samples were collected at transplantation site 3 to develop a NPI. The following expression was applied to develop the index:

$$NPI = \frac{\text{Leaf N (\%)}}{\text{Normalized Leaf Mass (mg dry wt cm}^{-1}\text{)}}$$

The ratio of leaf nitrogen to leaf mass has been shown to provide an accurate integrated measure of environmental nitrogen exposure by eelgrass in other estuarine systems (Lee et al., 2004). Lee et al. (2004) found that area normalized leaf mass (mg dry wt cm^{-1}) exhibited a strong negative relationship with leaf tissue N, rather than plant morphological characteristics alone (e.g. number of leaves per shoot, blade width, and leaf and sheath length), showing evidence of a significant response to estuarine nutrient gradients. Seagrasses from low nutrient waters have significantly higher carbon:nitrogen (C:N) and carbon: phosphorus (C:P) ratios than plants growing in high nutrient environments, resulting in increased tissue nutrient content as compared to other aquatic plant species growing in the same environment (Lee et al., 2004). Studies have demonstrated (Short, 1983) a stalwart link between seagrass morphology and nutrient availability (e.g. eelgrass growth and sediment N). Thus, in combination with evaluated seagrass morphological parameters, leaf N, and measured nutrient concentrations in varying estuarine locations (e.g. down-estuary vs. up-estuary), a robust indicator of nutrient pol-

Table 1. Percent cover of seagrass and macroalgae on the Barnegat Bay-Little Egg Harbor estuarine floor during three sampling periods in 2008.

Sample Period	Percent Cover Seagrass (std dev)	Percent Sites with Seagrass	Percent Cover Macroalgae (std dev)
1 (June - July)	23% (30.4)	52%	20% (29.0)
2 (Aug. – Sep.)	36% (38.4)	62%	10% (9.6)
3 (Oct. – Nov.)	27% (32.0)	58%	5% (7.9)

lution (via nitrogen enrichment) can be devised (Lee et al., 2004).

Morphometric measurements were made in the laboratory on the plants/leaf blades. The blade tissue was used to determine leaf N content employing an elemental analyzer. A matrix of values was developed for the eelgrass leaf nitrogen content and assessed for environmental nitrogen exposure which the plants experienced. The NPI values for site 3 are listed in Table 2.

NPI values ranged from 0.58 to 2.52 (Table 2). These values are generally higher than those reported by Lee et al. (2004) for Narragansett Bay (RI: 0.3-0.6) and Waquoit Bay (MA: 0.3-0.8), indicating higher nitrogen loadings as compared to these locations. However, BB-LEH values are close to the range reported by Lee et al. (2004) for Great Bay Estuary (NH: 0.4-2.2); areas sampled in the upper estuary were found to have higher values than seaward (down-estuary) locations.

Table 2. Leaf nitrogen concentrations and Nitrogen Pollution Index values for seagrass at transplantation site 1 in the Bamegat Bay-Little Egg Harbor Estuary during 2008.

Site	Normalized Leaf Mass (mg dry wt cm^{-1})	Leaf Surface Area (cm^2)	Mean % Nitrogen (N)	Nitrogen Pollution Index - NPI (Leaf N %:Leaf Mass)
Transplant 1 (3-4)	2.1	0.88	4.33	1.82
Transplant 1 (3-1)	3.2	2.06	3.92	2.52
Transplant 1 (2-4)	5.2	0.83	3.62	0.58
Transplant 1 (2-5)	4.3	1.76	2.97	1.22
Transplant 1 (2-9)	3.6	1.07	4.11	1.22

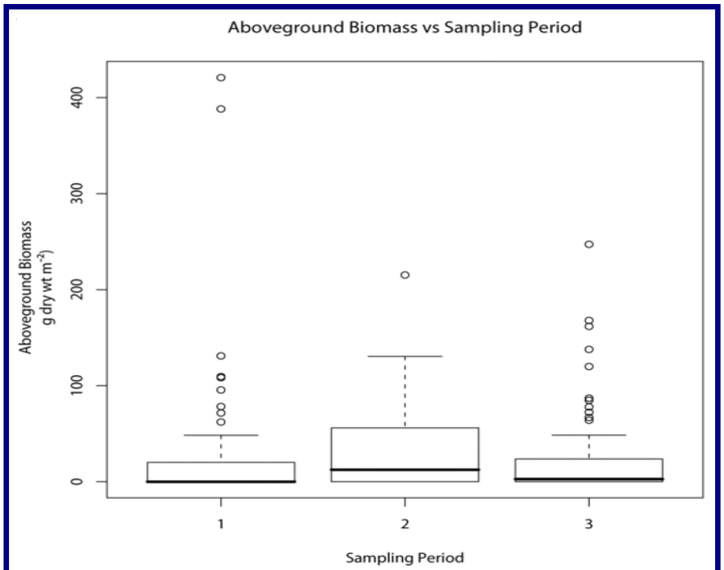

Figure 2. Box plots showing aboveground biomass values of *Zostera marina* samples collected in the Barnegat Bay-Little Egg Harbor Estuary during all three sampling periods in 2008. Highest values were observed during the August-September sampling period. Sampling period 1, June-July; sampling period 2, August-September; and sampling period 3, October-November.

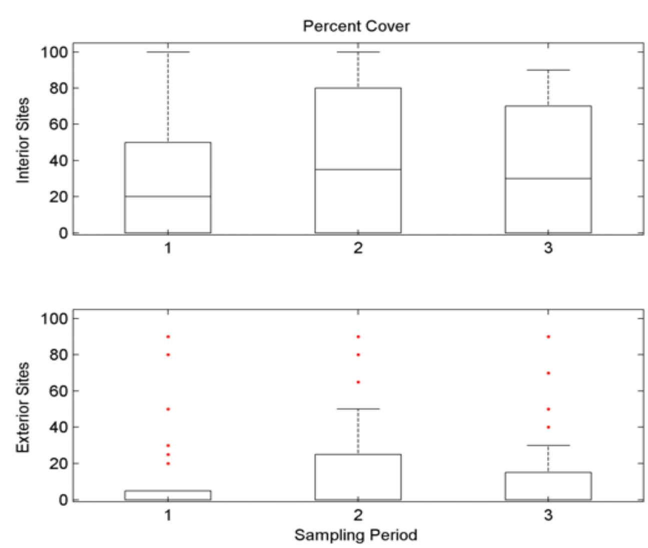

Figure 3. Mean percent cover of eelgrass at interior sampling sites (3-8) and exterior sampling sites (1, 2, 9, and 10) on transects in the Barnegat Bay-Little Egg Harbor Estuary during three sampling periods in 2008. Sampling period 1, June-July; sampling period 2, August-September; and sampling period 3, October-November.

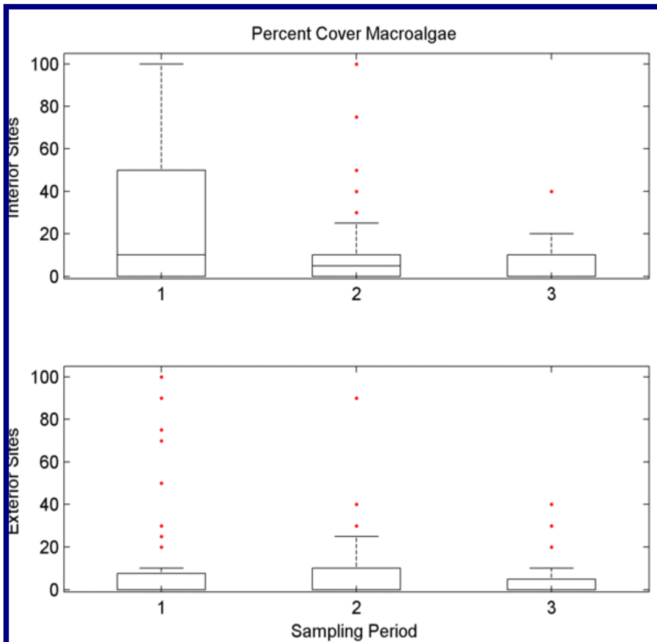

Figure 4. Mean percent cover of macroalgae at interior sampling sites (3-8) and exterior sampling sites (1, 2, 9, and 10) on transects in the Barnegat Bay-Little Egg Harbor Estuary during three sampling periods in 2008. Sampling period 1, June-July; sampling period 2, August-September; and sampling period 3, October-November.

Discussion & Conclusions

The BB-LEH Estuary is a highly eutrophic lagoonal estuary. Symptom expressions of eutrophication include low dissolved oxygen, particularly in the northern perimeter, declining seagrass habitat, epiphytic overgrowth, nuisance/toxic algal blooms, and markedly reduced fisheries (i.e., hard clams). Seagrass beds in this coastal lagoon have exhibited degraded conditions for years (Bricker et al., 1999, 2001; Kennish, 2001, 2007a), and based on surveys conducted in 2004-2006 and 2008, declining conditions appear to be worsening. Extensive areas of the northern estuary have recently (2008) experienced low dissolved oxygen levels. The aboveground and belowground biomass of seagrass in the estuary decreased by 50-88% over the 2004-2006 period, underscoring the ongoing degradation. Seagrass density, blade length, and areal cover also showed statistically significant reductions over this three-year period (Kennish et al., 2007b). Accelerated growth of drifting macroalgae (e.g., *Ulva lactuca*) has periodically caused extensive benthic mats that have attenuated light, leading to detrimental conditions for seagrass growth and survival. The decrease in seagrass areal coverage has eliminated essential habitat for bay scallops, hard clams (*Mercenaria mercenaria*), and many other benthic organisms. Blooms of the sea nettle (*Chrysaora quinquecirrha*), possibly coupled to increasing eutrophic conditions, have likewise occurred in the estuary since 2000.

The biomass of seagrass beds in the BB-LEH Estuary during 2008 exhibited important temporal and spatial patterns similar to those reported for the 2004-2006 period. The density as well as the aboveground and belowground biomass of seagrass varied considerably during the spring to fall period, but were generally highest during the June-September period as in previous seagrass demographic surveys. In 2008, and over the entire June-November sampling period, the mean aboveground biomass declined slightly from 25.01 g dry wt m^{-2} to 22.91 g dry wt m^{-2}, while the mean belowground biomass decreased markedly (by 51%) from 81.31 g dry wt m^{-2} to 39.86 g dry wt m^{-2}. The aboveground biomass values were low throughout this study period. Seagrass was found at less than 50% of the survey sites sampled during June-July when the median aboveground and belowground biomass values were 0. The fewest number of seagrass samples were recovered at the Little Egg Harbor sampling sites. These data indicate that seagrass habitat conditions have not recovered from the devastating losses in 2006.

Peak density of *Z. marina* occurred during August-September when the aboveground biomass also peaked.The density range of the plants (239-436 shoots m^{-2}) was similar to that observed in 2005 (163-479 shoots m^{-2}) but greater than that in 2006 (171-378 shoots m^{-2}). The blade lengths of *Z. marina* were relatively consistent during 2008 (mean values: 15.35 cm June-July, 14.57 cm August-September, and 19.88 cm in October-November), but were the shortest on record even when compared to the heavily impacted year of 2006. For example, the mean blade length of *Z. marina* in Little Egg Harbor during 2004 was 34.0 cm in June-July, 32.2 cm in August-September, and 31.8 cm in October-November. In 2006, the mean blade length of Z. marina in the estuary was 19.4 cm in June-July, 18.6 cm in August-September, and 18.6 cm in October-November. The nitrogen content of eelgrass blades measured during the 2008 surveys ranged from 2.97% to 4.33%.

The percent cover of seagrass in the study area gradually declined over the June-November period for all years of sampling except 2008, dropping from 45% to 21% in 2004, 43% to 16% in 2005, and 32% and 19% in 2006. In 2008, the percent cover of seagrass was lowest in June-July (23%), highest in August-September (36%), and intermediate in October-November (27%). As observed in this study, seagrass grows best away from the bed border areas. Specifically, seagrass biomass, density, and areal cover in 2008 were higher at interior transect sampling sites (3, 4, 5, 6, 7, and 8) than at exterior transect sampling sites (1, 2, 9, and 10). These values are consistent with those measured during 2004, 2005, and 2006. Macroalgae percent cover decreased significantly from June to November in 2008. For example, the mean percent cover of macroalgae declined from 20% during the June-July period to 10% during the August-September period and 5% during the October-November period. During bloom conditions, macroalgae completely cover extensive areas of the estuarine floor, which can impact seagrass abundance and distribution due to the attenuation of sunlight. This pattern indicates that seagrasses located near the margin of their distribution are more likely to be exposed to less optimal conditions for growth and survival.

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RESEARCH PROJECT SUMMARY

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