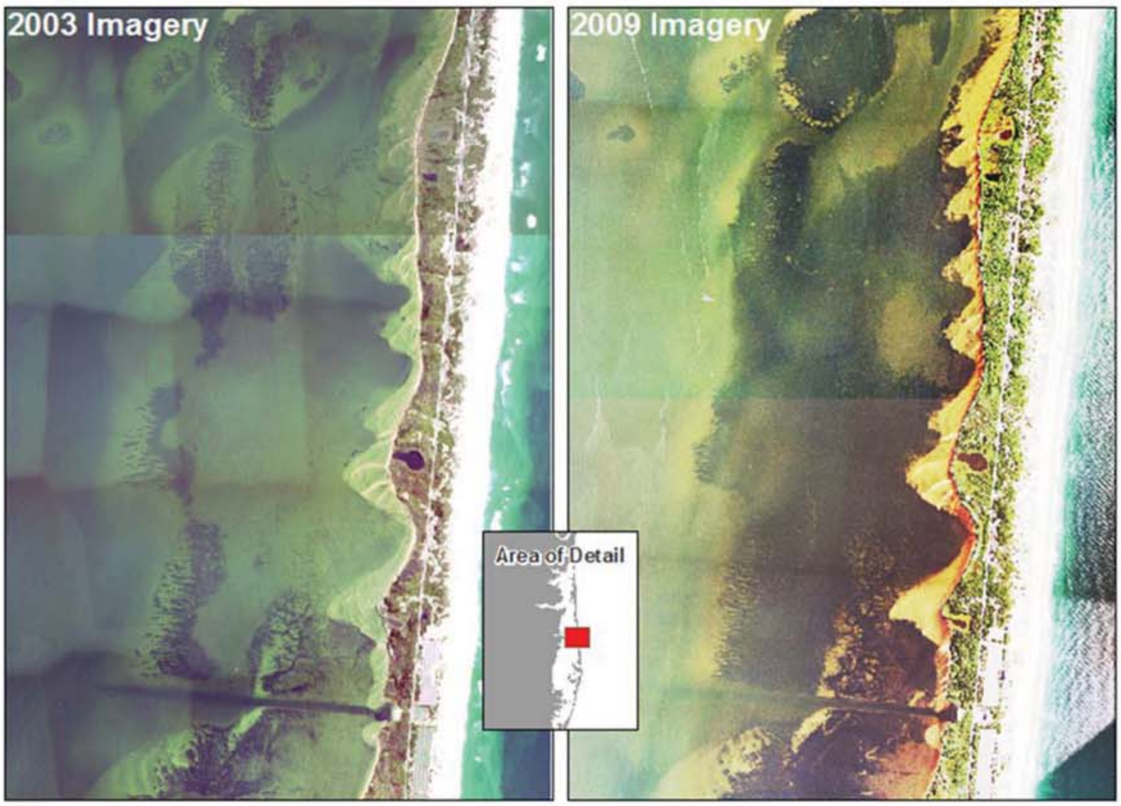
Assessment of Seagrass Status in the Barnegat Bay - Little Egg Harbor Estuary System: 2003 and 2009



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Executive Summary

The Barnegat Bay-Little Egg Harbor (BB-LEH) estuarine system located along the eastern shoreline of Ocean County, New Jersey contains ~ 75% of New Jersey's known seagrass habitat (Lathrop et al. 2001). Eelgrass (*Zostera marina*) is the dominant species while widgeongrass (*Ruppia maritima*) is also common in lower salinity and shallow regions of the BB-LEH. An estuary wide survey was conducted in the summer of 2009 to measure the current extant of seagrass habitat across the BB-LEH system. Aerial imagery collected during the months of July and August 2009 was interpreted and mapped using an object oriented image analysis techniques, similar to techniques used in the 2003 mapping survey. A boat-based *in situ* dataset was collected concurrently with the aerial photography to assist the image interpretation and for an independent accuracy assessment. Comparison of the classified seagrass presence/absence map and the *in situ* validation dataset showed an overall thematic map accuracy of 87% while the four class seagrass density map (absent, sparse, moderate, dense seagrass cover) has an overall accuracy of 70%.

Results of this work indicate that the overall amount of seagrass beds were similar in 2009 as compared to 2003 (5,122 ha in 2003 vs. 5,260 ha in 2009). Differences in the seasonal period of image acquisition account for some of the differences in the mapped area and type of seagrass. Imagery for the 2003 survey was acquired early in the growing season (May 4-5th) while the 2009 survey was acquired on June 28th, July 7th, and August 4th. Due to the later growing season imagery, confirmed by the in situ data, the 2009 survey mapped greater amounts of *R. maritima* as compared to the 2003 survey. We do not attribute the mapped increases in *R. maritima* to a "real" increase of *R. maritima* acreage but rather as an artifact of the difference in the timing of image acquisition.
Examination of the more detailed four class seagrass cover map shows a decline in the area of dense seagrass beds in 2009 vs. 2003 (i.e., 471 ha in 2009 vs. 2,074 ha in 2003; a nearly 60% decline). The extent to which this apparent thinning in the density of the seagrass beds is real or an artifact of the poor image quality in the 2009 imagery and the resulting lower accuracy in mapping dense seagrass beds is uncertain.

While the overall area of seagrass was similar, seagrass beds are dynamic features with beds expanding in some locations while declining or shifting in others. In directly comparing the two mapped data sets, there were areas of apparent gain and loss, though the bulk of the seagrass area was stable (i.e., was present in both 2003 and 2009). While every effort was made to collect imagery during peak seasonal seagrass biomass, low tide, low wind conditions, and low water turbidity to maximize the spectral difference between seagrass and other benthic habitats, image acquisition conditions during the 2009 growing season were not optimal. There is a trade-off between acquiring imagery earlier in the growing season (i.e., May) vs. later in the growing season (i.e., June-July) when peak seagrass biomass may be present but also higher levels of water turbidity.

The study shows that boat scarring, docks and dredging can have a direct and negative effect on seagrass beds. However, in terms of the area of direct impact in comparison to the overall area of seagrass, these disturbance factors are relatively minor and localized.

Assessment of seagrass status in the Barnegat Bay - Little Egg Harbor Estuary System: 2003 and 2009.

I. Introduction:

Seagrass habitat provides important ecosystem services, including essential habitat for shellfish and finfish, and sediment stabilization. The extent of seagrass habitats worldwide has been reduced through human induced habitat changes (Short and Wyllie-Echeverria 1996; Orth et al. 2010; Waycott et al. 2009). These impacts can be broken down into two categorical stressors: (1) direct impacts due to physical alteration of benthic habitat through channel dredging, inlet modification, boat scarring, dock building; (2) indirect impacts caused by nutrient enrichment and eutrophication (Burkholder et al. 2007). Because seagrass are vascular benthic autotrophs, they require clear water and high levels of benthic Photosynthetically Active Radiation (PAR). Therefore, the success of seagrass at specific locations through time provides a potential long-term integrator of water quality (Burkholder et al. 2007). As eutrophication increases through time, the dominant primary producers in shallow marine environments tends to move across a gradient from seagrass, to macroalgae, and finally to phytoplankton (Wazniak et al. 2007; Deegan et al. 2002).

The Barnegat Bay-Little Egg Harbor (BB-LEH) estuary located along the eastern shoreline of Ocean County, New Jersey contains ~ 75% of New Jersey's known seagrass habitat (Lathrop et al. 2001). Recent remote sensing and *in situ* surveys have indicated that seagrass habitat has contracted from historical levels (Lathrop et al. 2006; Kennish et al. 2008). The major focus of this research project is to assess the current extent of seagrass across the BB-LEH estuary system. The report is divided into two sections: the first section covers the assessment of the current (as of 2009) status of seagrass and characterization of changes as compared to 2003, and the second section looks more closely at various disturbance factors affecting seagrass health and distribution.

II. Study Area:

The Barnegat Bay-Little Egg Harbor (BB-LEH) estuary is located along the eastern edge of the New Jersey coast between 39º31'N and 40º06'N latitude and 74º02'W and 74º20'W longitude (Figure 1). The estuary forms a long, narrow, and irregular tidal basin that extends north-south for nearly 70 km, separated from the Atlantic Ocean by a narrow barrier island complex (i.e., Island Beach and Long Beach Island) that is breached at the Point Pleasant Canal in the North, Barnegat Inlet at mid bay, and Little Egg Inlet at the southern extremity. Ranging from 2 to 6 km in width and 1 to 6 m in depth with a mean low low tide depth of 1.5 m, this lagoonal estuary has a volume of ~3.5×10^8 m^3 and surface area of ~280 km^2 (Kennish 2001). Water temperature ranges from -1.5-30ºC, and salinity from ~10-32 psu (Moser 1997). Characterized by semidiurnal tides with a tidal range of <0.5-1.5 m, the estuary is well-mixed. Circulation is restricted by the extreme shallowness of the bay and the location of the barrier island complex. The shallowness of the open bay and, extensive shoals and marsh islands near the inlets restrict bay flushing times to between 60 and 120 days (Guo et al. 1997).

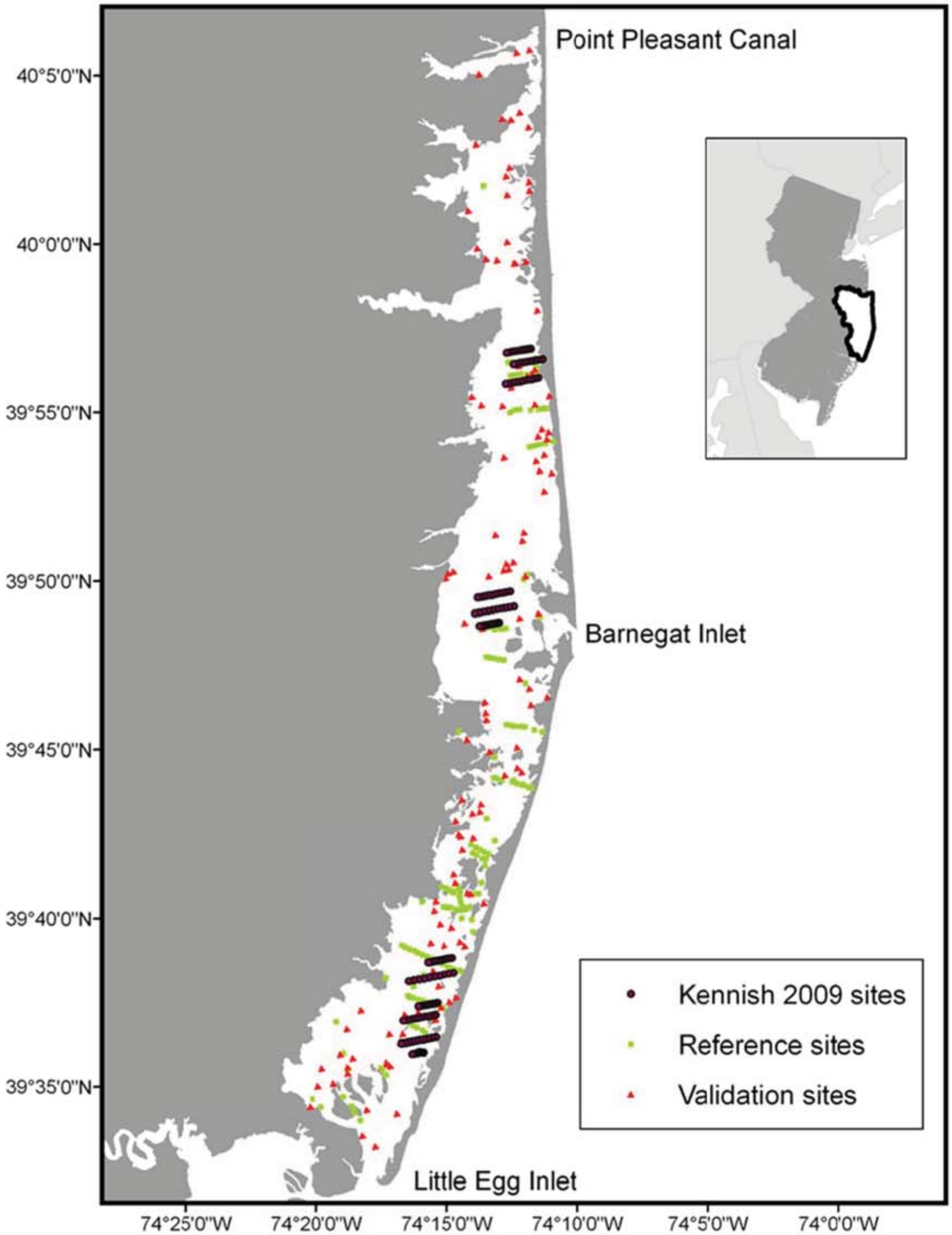

Figure 1. Location of *in situ* reference sites within the BB-LEH study area.

The Barnegat Bay watershed covers an area of 1730 km^2, with more than 500 km^2 classified as developed or urban lands (Lathrop et al. 1999). The ratio of the watershed area to the estuarine surface area is ~6.5 to 1. Small coastal plain rivers, streams, and creeks drain the watershed, and most of the freshwater discharge (>80%) is base flow derived from groundwater influx. Ocean County (which shares a similar spatial boundary to the Barnegat Bay – Little Egg Harbor watershed) has experienced exponential population growth from 30,069 people in 1900 to over 569,000 in 2008 (United States Census Bureau). Associated with this increase in population has been a rapid development of upland forest habitat to urban land cover with over 13,200 acres converted between 1995 – 2006 (Lathrop and Haag 2007). Riparian areas in some subwatersheds have been heavily altered, consisting now of over 40% urban, agriculture, or barren land (Lathrop and Haag 2007). The BB-LEH estuary faces multiple resource management issues including climate change and an associated rising sea level, increased nutrient enrichment and associated eutrophication, loss of critical habitat and species, inadequate stormwater management, and diminishing fresh water availability. To understand how these stressors are impacting the BB-LEH, it is necessary to conduct comprehensive assessments of key estuarine species and habitats.

III. Background:

Lathrop et al. (2001) summarized the known comprehensive seagrass habitat mapping efforts for the BB-LEH. These included maps created in the following years:

1) 1968, by the US Army Corps of Engineers (survey technique unknown but most likely boat based).
2) 1979, Earth Satellite Corporation produced a 1:24,000 scale map from panchromatic aerial photography flown in June-August (Macomber & Allen 1979).
3) 1985-1987, the NJDEP Joseph et al. (1992) collected data on .4 km grids for a shellfish survey that noted presence or absence of seagrass species,
4) 1996, 1997, 1998, and 1999 Boat based surveys. (McLain and McHale 1996; Bologna et al. 2000).

In 2003 Lathrop et al. (2006) mapped seagrass habitat using 1 m spatial resolution, multi-spectral (Infrared, Red, Green, and Blue) aerial photography collected on May 4-5. Their mapping effort showed 893 ha less seagrass then the previous mapping work collected between 1996 and 1999 by McLain and McHale (1996) and Bologna et al. (2000). However, because their methods were different (air photography vs. *in situ* boat-based) no definitive statement could be made on seagrass habitat loss or gain. The current study therefore provides the first consistent mapping methodology with the 2003 study.

Several researchers have looked at *in situ* seagrass health and abundance within the BB-LEH. In the most extensive project Kennish et al. (2007, 2008) examined seagrasss distribution from 2004-2006, 2008 and 2009 sampling at 120 fixed stations across for major seagrass beds. Kennish found that between 2004 and 2006 in Little Egg Harbor the mean seagrass aboveground biomass declined over 87.7% percent from 59.62 to 7.31

g m$^{\wedge-2}$ dry weight. This trend, albeit with a smaller percentage loss was also recorded between 2005 and 2006 at Barnegat Inlet with a loss from 32.04 to 16.03 g m$^{\wedge-2}$ g m$^{\wedge-2}$ dry weight. A decrease in aboveground biomass was also recorded estuary wide at all sampling locations and it represents the lowest values recorded in this estuary (Kennish et al. 2008). This episodic loss of seagrass habitat recorded between 2004 and 2006 is consistent with data collected by Bologna et al. (2001) who observed a large scale dieback of seagrass in Little Egg Harbor associated with blooms of several macroalgae species.

Gastrich et al. (2004) and Pecchioli et al. (2006) analyzed blooms of the phytoplankton species *Aureococcus anophagefferens* (brown tide) and showed that bloom densities were highest in Little Egg Harbor. The blooms were significantly different between years. High blooms were associated with warmer water temperatures, high salinity values, and low stream water flow. These results are most likely not physiological causative factors since *A. anophagefferens* blooms were also recorded in winter months. They found that *A. anophagefferens* blooms decreased Secchi disk values, indicting a reduction in solar energy for benthic fauna.

These results demonstrate that primary productivity in the BB-LEH estuary can undergo a sequence of dominant plant forms from benthic vascular plants to macroalgae (Bologna et al. 2006; Kennish et al. 2007), and finally to phytoplankton (Gastrich et al. 2004); Pecchioli et al. 2006). These changes can be seen as a gradient of eutrophication impacts (Wazniak et al. 2007). Moving along the gradient can take place very quickly through the multiplier effect and impacts of positive and negative feedback loops (Burkholder et al. 2007).

IV. Assessment of Status and Trends of Seagrass

Methods

Current (2009) extent of seagrass across the BB-LEH system

The first objective of this project was to quantify the location of seagrass across the BB-LEH estuary system for the 2009 growing season. To accomplish this, an aerial photography dataset was collected, processed into image objects (polygons), and classified to create a GIS dataset showing the location of seagrass across the BB-LEH. The following methods sections describe the steps used to create the output GIS dataset. In addition an accuracy assessment was undertaken to determine how well this GIS dataset maps seagrass across the BB-LEH.

a). *Aerial Photography Collection*

An aerial photography mission was undertaken during the summer of 2009 by Air Photographics, Inc. Film aerial photography was collected on June 28, July 7, and August 4, 2009 using a Navajo HS airplane equipped with a Leica RC30 camera, lens # 13234, focal length 152.720 mm, and a variable exposure time of 260-420 milli-seconds.

Two types of film were used; a grey scale AGFA 80 and color film AGFA 100. The same plane and camera was used for all three imaging missions. The plane flew at an altitude ~ 3,658 m and speed of 180 km hr^{-1} per hour. The plane flew three survey lines, two in the southern estuary due to bay width and one in the northern estuary for both the June 28 and July 7 aerial flyover, the August 4 date was only flown to collect imagery in the northern part of the study area. Two passes were made per day, the first to collect black and white photography and the second to collect color photography. The resultant film was then processed and scanned through a high resolution scanner resulting in a digital image with 18,278 by 18,292 pixels in a scale of 1:2,000. These scans were ortho-rectified and projected into Universal Transverse Mercator (Zone 18 North, North American Datum 1983, GRS Spheroid of 1980) with a horizontal positional accuracy at root mean square error of ±1-2 meters. The resulting geotiffs were mosaicked into 15 larger blocks for later analysis.

b). *In situ* data collection

A number of *in situ* sites were visited to collect reference information to enable the interpretation of the aerial photography (Figure 1 & Appendix I). Reference sites were selected to match a subset of the *in situ* references sites selected during the 2003 Lathrop study (Lathrop et al. 2006). Reference sites were not selected in a random probabilistic manner, but rather targeted transects across the study area n = 167. In addition, 15 sample sites were selected for a late season review (October of 2009) for areas of uncertainty in the imagery. An additional 120 sample points were collected in June 2009 as part of an ongoing research project (Kennish 2009 unpublished data). These data points were also included in the study as field reference sites, although their collection used a different technique than the data points used in this study. A second *in situ* n = 124 dataset was collected to provide a validation dataset which was selected using a stratified random sampling design to focus on shallow water habitats mimicking the depth distribution of seagrass within the BB-LEH estuary. These points were distributed to match the depth distribution on the 2003 seagrass survey. To accomplish this, 2003 seagrass presence absence data from (Lathrop et al 2006) was intersected with the NOAA Nautical Charts Depth information (Charts 12324: edition 25, 1990 and 12316: edition 25, 1992 from Lathrop et al. (2001). For each 0.3048 meter depth (1 foot) category a number of field sites were randomly chosen to match the percentage of area of all seagrass habitat at that depth. This matched the random seagrass sites depth histogram to the depth histogram of the presence/absence seagrass data from 2003. These points were distributed to match the probability of finding seagrass at a specific depth. This validation dataset was not used in the image mapping and classification process but kept as an independent data set to compare with the wall-to-wall GIS map to create an error matrix, a producer's and user's accuracy assessment, and a Kappa statistic. As a secondary step after the accuracy assessment was completed the validation dataset was used to clean up the final GIS dataset.

For all of the *in situ* data collected for this project (the reference dataset n = 167 and the validation dataset n=124), field collection was accomplished as follows. The field survey was conducted from the Rutgers University Marine Field Station (RUMFS) using a 20 foot maritime skiff. Navigation to field locations was accomplished with a Garmin 530s marine GPS/Sonar system. Upon arrival at the preselected field locations, the boat weighed anchor. Next, an L shaped 4 meter x 5 meter grid made of 1.905 cm pvc was lowered over the side of the boat. A diver entered the water and affixed a GPS Magellan Mobile Mapper 6 (±2-5 meter horizontal accuracy) to the outside L of the survey grid (marked in Figure 2). A compass reading was taken along the left-hand axis of the sampling grid. The compass reading and the GPS position allowed precise placement of the sampling grid on the benthos to a higher level of accuracy than the boat-based GPS unit. The diver then visited grid 1 through 8 and recorded information on SAV presence / absence (yes no), percent cover of seagrass species (*R. maritima* and *Z. marina*) (0 to 100 in 10% increments), and percent coverage macroalgae (0 to 100 in 10% increments). This data was verbally relayed to the boat captain who recorded the data on write-in–the-rain paper. Upon completion of field data collection, the GPS unit was removed and the sampling grid returned to the boat. Field sheets were then signed, dated, and entered into a digital database. The precise location of each sampling grid was determined using Matlab™ and simple geometry using the GPS location in UTM coordinates and the compass bearing. A correction for magnetic declination (difference between the North Pole and the magnetic North Pole) was calculated using NOAA website (http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp for July 15th, 2009, 39.9745 N 74.1514 W magnetic declination equals 12 degrees and 47 minutes.

c) Image pre-processing

An important step in image classification is the clumping of similar pixels into image objects for classification. To accomplish that task, each image collected in 2009 was filtered using the aggregate command available in Arc Grid™ for a 2x2 grid window selecting the median cell value. This was done to remove areas of local light scatter from wave tops, Langmuir circulation lines, and to reduce the size of the imagery for processing. The median was selected over the mean to avoid skewing from light scattering which can cause areas of high image reflectance (white capping) and shadows.

The rectified mosaicked color photography was then imported into eCognition™ to support image segmentation and classification. eCognition™ is an image analysis software package that segments raster data in an unsupervised method minimizing the intra-polygon (image object) variance while maximizing inter-polygon (image object) variance. The user can control the weight of each imagery band by changing a coefficient between 0 and 1 (0 no input for that band 1 full input) by band and a unit less scale parameter which determines the average image object area. As the scale parameter increases greater spectral heterogeneity is allowed increasing the average size of the image objects. Multiple scale image objects can be created by running a multiple resolution segmentation procedure. Two-scale parameters were used for each image mosaic layer 1); a small scale parameter between 10-15; 2) a large-scale parameter 50-70 (Figure 3). The smaller scale parameter resulted in image objects with a mean size of .073 ha, mode of .045 ha, 25 percentile of .02 ha, and the 75 percentile at .09. This scale parameter was selected to meet the target minimum mapping unit of .05 ha (500 $m^{\wedge 2}$). The minimum mapping unit defines the smallest feature delineated in the map or the amount of detail a map contains. The band coefficients used were 1 for blue, 0.7 for green, and 0.5 for red. The coefficients were selected by trial and error by the operator to maximize the difference between seagrass and other benthic habitats.

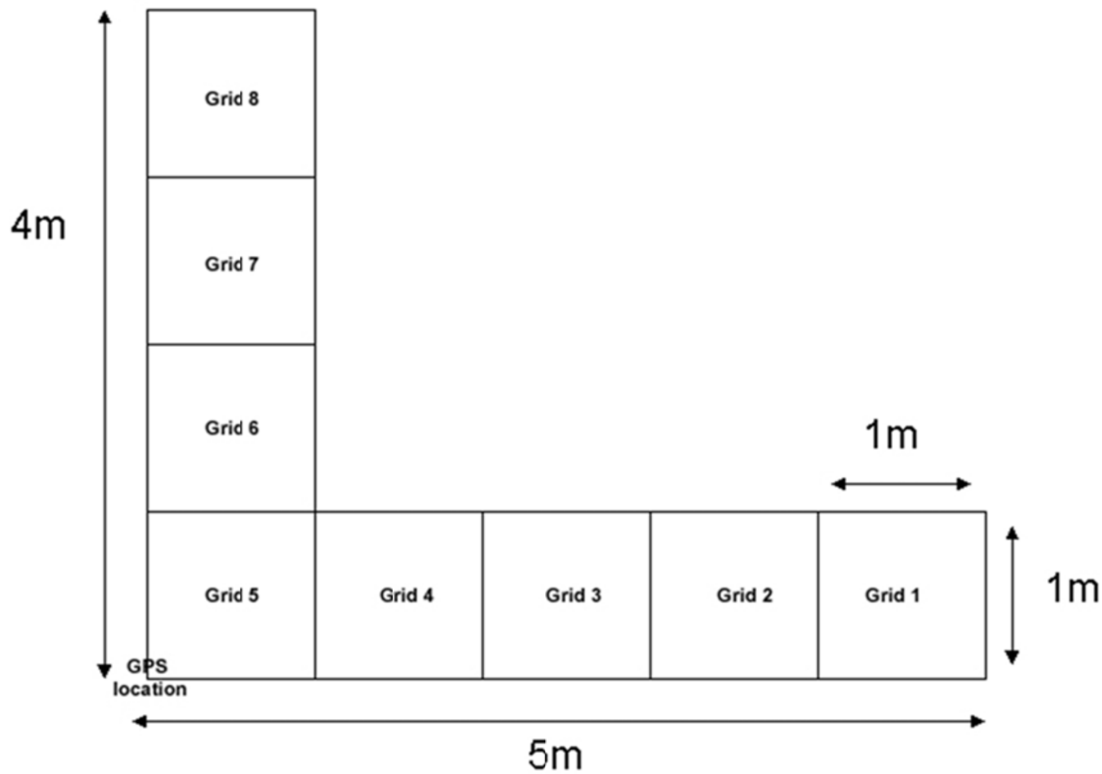

Figure 2. Sampling grid design used for the 2009 *in situ* seagrass survey.

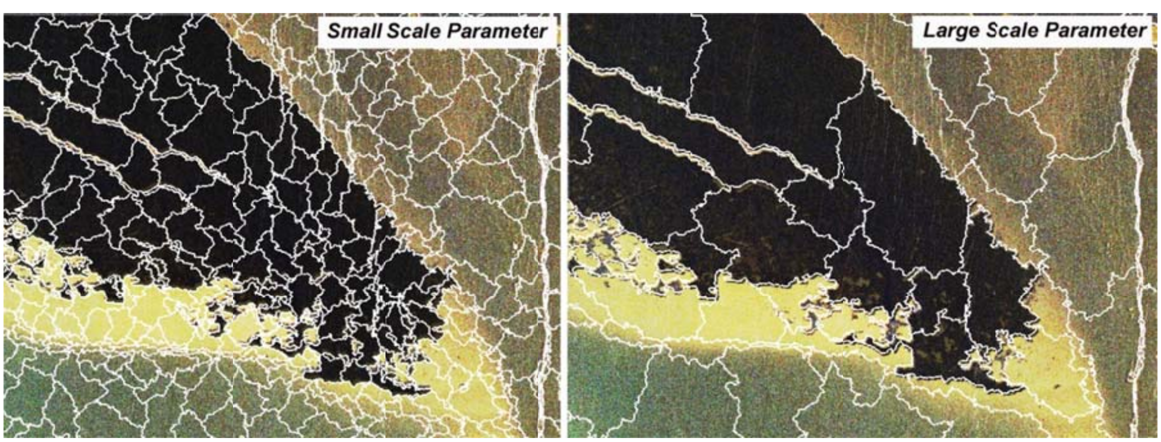

Figure 3. Graphical example of the difference in image objects size created by varying the scale parameter in the segmentation procedure. The left hand image shows the size of image objects with a scale parameter of 15. The right hand image

shows the size of image objects with a 70 scale parameter. Not all the smaller image objects are nested inside of the larger (share a common boundary).

d). *Image object classification*

A manual classification where each image object was visually interpreted and assigned to one of four classes of seagrass density (high 100-80% percent cover, medium < 80%-40% cover, sparse < 40% - 10% cover, and no seagrass <10% - 0%). The field reference data was used to inform the interpretation. The larger scale image objects (scale parameter 50-70) were first manually classified using eCognition™. The large image object classifications were then forced down into the smaller image objects (scale parameter of 10-15) based on the nested polygon structure. Smaller image objects on edge areas and internal to the larger image objects were then manually reclassified when necessary. This method sped up the manual classification effort allowing large contiguous areas of seagrass to be classified quickly while also allowing precise classification on seagrass edge and gap areas (Figure 4 from Lathrop et al. 2006). The reference data also contained information on seagrass species and macroalgae percent cover these categories were not mapped as part of the manual classification. To create the final GIS dataset and accuracy assessment dataset the finer-scale image objects were exported to Environmental Research Institute ESRI™ shapefile format.

To determine how well the image objects described seagrass presence/absence and density across the BB-LEH an accuracy assessment was undertaken. To accomplish this the classified image objects were compared to the validation dataset within a GIS to create an accuracy assessment matrix, error of omission and commission, overall accuracy assessment, and a Kappa coefficient. This is similar to the methods employed by Lathrop et al. (2006). The Kappa coefficient is a measure of agreement between two categorical datasets correcting for the random chance that categories will agree. These measures of accuracy were completed to determine how accurately seagrass vs. all other habitats were mapped, and to determine how well the maps reflected the density of seagrass habitat based on the *in situ* data.

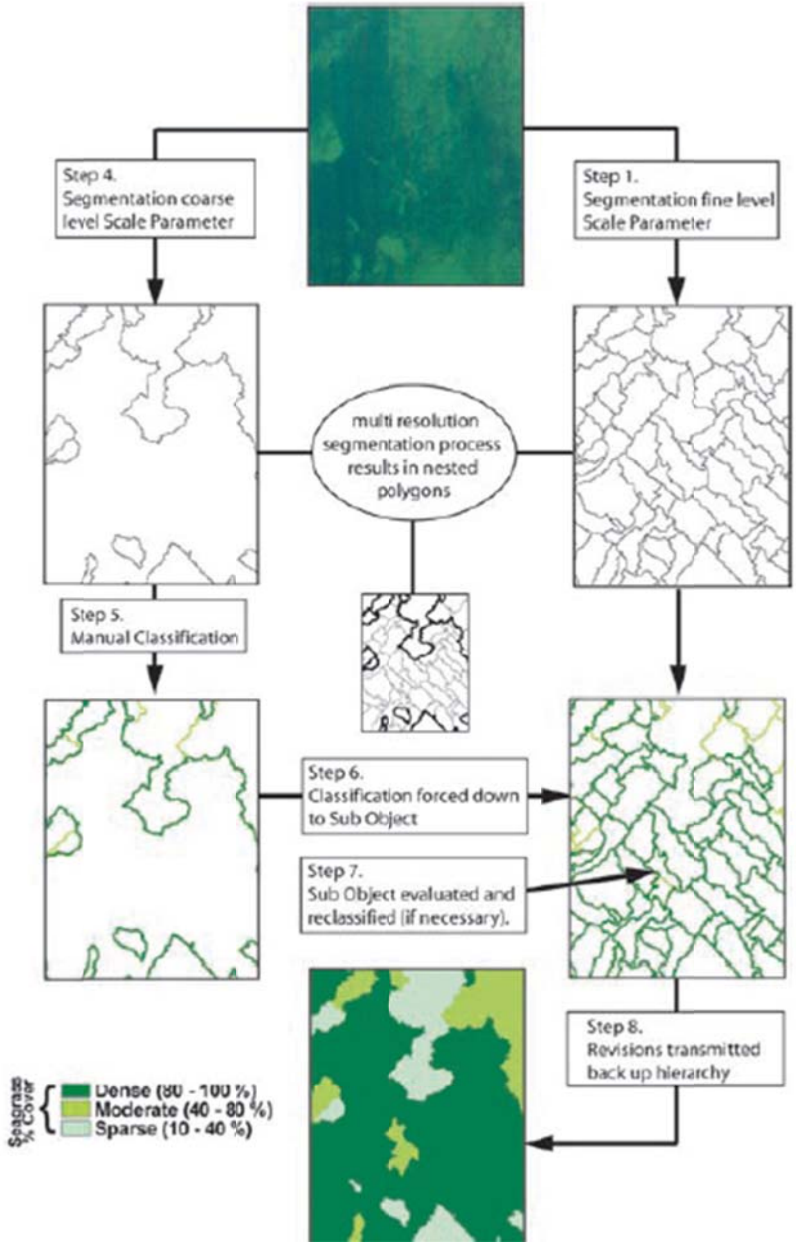

Figure 4. Process steps of the 2003 and 2009 manual seagrass classification. (Used with permission from Lathrop et al. (2006)).

Change Analysis between 2003 and 2009

To quantify how seagrass has changed through time both annually and seasonally in the BB-LEH estuary system a change detection analysis was done. To complete this analysis a number of historical imagery datasets from 2003-2008 were collected and compared to the 2009 imagery and classified image objects collected as part of Objective 1.

a). *Historical imagery datasets*

Geo-referenced imagery has been collected for a variety of projects across the entire study area in 2003, 2004, 2006, 2007, 2008, and 2009 (Table 1). Two of the imagery datasets (2003 and 2009) were collected specifically to map benthic habitat environments. The other imagery datasets were not collected with the expressed goal of mapping benthic habitat and thereby took no special considerations to collect imagery during periods of low tide, sun angle, and or wind conditions. A visual assessment of the 2004, 2006, 2007, and 2008 imagery datasets was conducted to determine the feasibility of using these image collections to map the change in the spatial distribution of seagrass habitat through time. It was determined that most of the BB-LEH imagery datasets did not provide a consistent view of the benthic environment. Therefore, instead of using this imagery to create wall-to-wall seagrass maps, the imagery was used where image quality was appropriate to verify *in situ* observations and to characterize the seagrass reflectance across the growing season.

Table 1. Ancillary photography collection data for the Barnegat Bay-Little Egg Harbor estuary.

Image Source	Collection Date	Sensor Type	Ground Resolution	Projection
CRSSA	May 4th-5th, 2003	Digital	1 m	UTM
Digital Globe Quickbird	October 4th, 2004	Digital	0.7 m	UTM
USDA	July 6th, 2006	Analog	1	UTM
NJ DEP	March 21st, 2007	Analog	1 foot	NJ State Plane
USDA	August, 5th-13th, 2008	Analog	1 m	UTM
CRSSA	June 28th, July 7th, August 4th, 2009	Analog	0.5 m	UTM

b). *Comparing the 2003 and 2009 image datasets*

In 2003, Lathrop et al. (2006) collected digital aerial photography across the entire LEH-BB estuarine system. This photography was collected on May 4 and 5, 2003 in both the early morning and late afternoon to minimize specular reflectance from the water surface. This digital aerial photography was processed using similar object oriented methods as the 2003 imagery (Figure 4 from Lathrop et al. 2006). The resulting classified vector data from the 2003 and 2009 classified seagrass maps were manually compared using a GIS system to ascribe a reason for areas mapped as a change (presence / absence) in seagrass habitat. Each image object was given a categorical reason why the imagery classification had changed based on the assessment of a trained image interpreter. Where possible *in situ* data collected from the 2003 (Lathrop et al. 2006) and 2009 seagrass survey were used to lend support to the manual classification. The categories with definitions are listed below;

1) 'Change in Season'. A seagrass bed that existed in 2003 that had not reached peak biomass due to the spring imagery collection in 2003 but that was clearly visible in the 2009 imagery. This classification mostly applies to *R. maritima* dominant seagrass beds in the northern portion of the BB-LEH.
2) 'Poor image quality'. When one or both of the source imagery dataset had poor image quality which did not allow the classifier to view the benthic habitat.
3) 'Misclassification'. Used when on further review of the source imagery it is believed an error of commission occurred.
4) 'Seagrass habitat gain'. Used when new seagrass habitat is found that did not exist in 2003.
5) 'Seagrass habitat loss'. Used when seagrass habitat is lost between the 2003 and 2009 imagery.

Change in seagrass presence/absence was further analyzed using five bay segments (Figure 5): (1) Little Egg Harbor (LEH) south of the Rt. 72 Bridge to the Tuckerton Peninsula; (2) southern Barnegat Bay (SBB) north of Little Egg Harbor to Barnegat Inlet; (3) Barnegat Inlet (BI) the area within 5 km of Barnegat Inlet; (4) central Barnegat Bay (CBB) from Barnegat Inlet to the Route 37 Bridge; (5) and northern Barnegat Bay (NBB) north of the Route 37 Bridge. For each of these segments the mapped seagrass in 2003 and 2009 was compared with the identified reason above for mismatch.

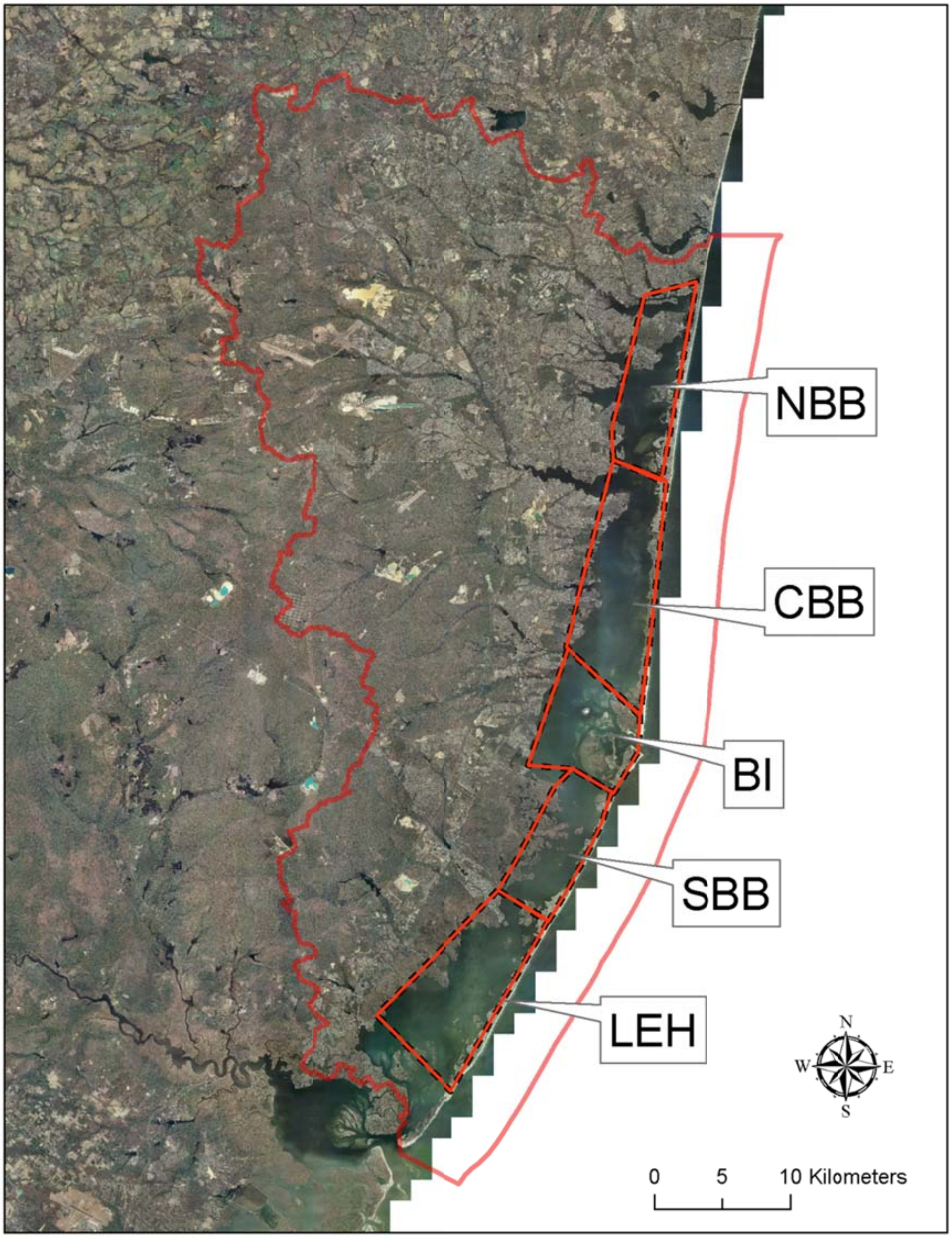

Figure 5. Location of bay segments across the study area.

Results and Discussion

2009 status of seagrass in the Barnegat Bay-Little Egg Harbor estuary

The 2009 seagrass Remote Sensing Survey of BB-LEH classified 5,260 ha of seagrass (2,266 ha of sparse, 2,523 ha of moderate, and 471 ha of dense cover) (Table 2). Figure 6 shows the spatial distribution of seagrass across the entire BB-LEH. An accuracy assessment was conducted using the 124 validation sites for both a presence absence and categorical values (sparse, moderate or dense) (Table 3 & Table 4). In addition, an un-weighted Kappa statistic was used to normalize the influence of categories that cover a disproportionate area. A high level of agreement was obtained between the mapped and in situ data with an overall accuracy of 87% and a Kappa value of 73%. For the four class seagrass density map (Table 4), an overall accuracy of 70% and a Kappa statistic of 47% was obtained, representing a moderate level of agreement.

NOAA protocols (Finkbeiner et al., 2001) suggest that overall thematic accuracy should be greater than 85% and a kappa of > 0.5. The seagrass presence/absence map meets these criteria, while the four class seagrass density map is slightly below. Table 3 suggests that most of the errors of omission (i.e., producer's accuracy) and commission (i.e., user's accuracy) for the presence/absence seagrass map are similar. Table 4 suggests that the four class map does not consistently differentiate between moderate and dense seagrass habitat and would appear to underestimate the amount of dense seagrass. While every effort was undertaken to reduce the spatial error in relating the field reference data to the imagery (i.e., ±1-2 meters for imagery georegistration and ±2-5 meters for geolocating the field reference data collection location), this positional error coupled with the fine scale patchiness of some seagrass beds can result in a disagreement between the reference data and the mapping.

The procedure to select the validation sites (random vs. targeted) can drive which error (omission and commission vs. categorical) is better constrained. In the 2009 survey, we opted to more randomly sample across the entire estuary to provide a better estimate on the total errors of omission and commission of seagrass presence/absence. Consequently, the sample sizes within the individual seagrass density categories (i.e., spare, moderate and dense) were limited. Future work should attempt to collect a larger number of samples in known seagrass habitat to provide more information on the accuracy of the categorical nature of the GIS maps (if this knowledge is deemed important).

The 2009 imagery collection was a challenge due to meteorological events (cloud cover), which caused two separate imaging attempts before good aerial photography could be obtained. Some areas of high water turbidity were observed in LEH and southern Barnegat Bay, obscuring the clear delineation of bottom features and complicating the interpretation of the seagrass beds. On further analysis of historical Landsat satellite imagery, it was noted that these areas routinely experience higher turbidity events than other parts of the BB-LEH estuarine system. In future image missions to monitor seagrass in BB-LEH particular attention should be paid to the eastern ICW near the Route 72 Bridge (-74 15 W 39 42 N) to determine if water clarity is sufficient to discern

Table 2. Area of seagrass cover types mapped during the 2009 remote sensing survey.

Seagrass Type	class (ha)	Total Seagrass
Sparse (10-40%)	2,266	43%
Moderate (40-80%)	2,523	48%
Dense (80-100%)	471	9%
Total Seagrass	5,260	

Table 3. Presence / absence accuracy assessment matrix for the 2009 seagrass survey.

		Field Reference		
		Seagrass Absent	Seagrass Present	User's Accuracy
GIS MAP	Seagrass Absent	**69**	9	88%
	Seagrass Present	7	**39**	85%
	Producer's Accuracy	91%	81%	**87%**

Un-weighted Kappa statistic 73%

Table 4. Class accuracy assessment matrix for the 2009 seagrass survey**.**

		Field Reference				
		Seagrass Absent	Seagrass Sparse	Seagrass Moderate	Seagrass Dense	User's Accuracy
GIS MAP	Seagrass Absent	**69**	7	2	0	88%
	Seagrass Sparse	5	**7**	4	1	41%
	Seagrass moderate	2	4	**6**	10	27%
	Seagrass dense	0	0	2	**5**	71%
	Producer's Accuracy	91%	39%	43%	31%	**70%**

Un-weighted Kappa statistic 47%

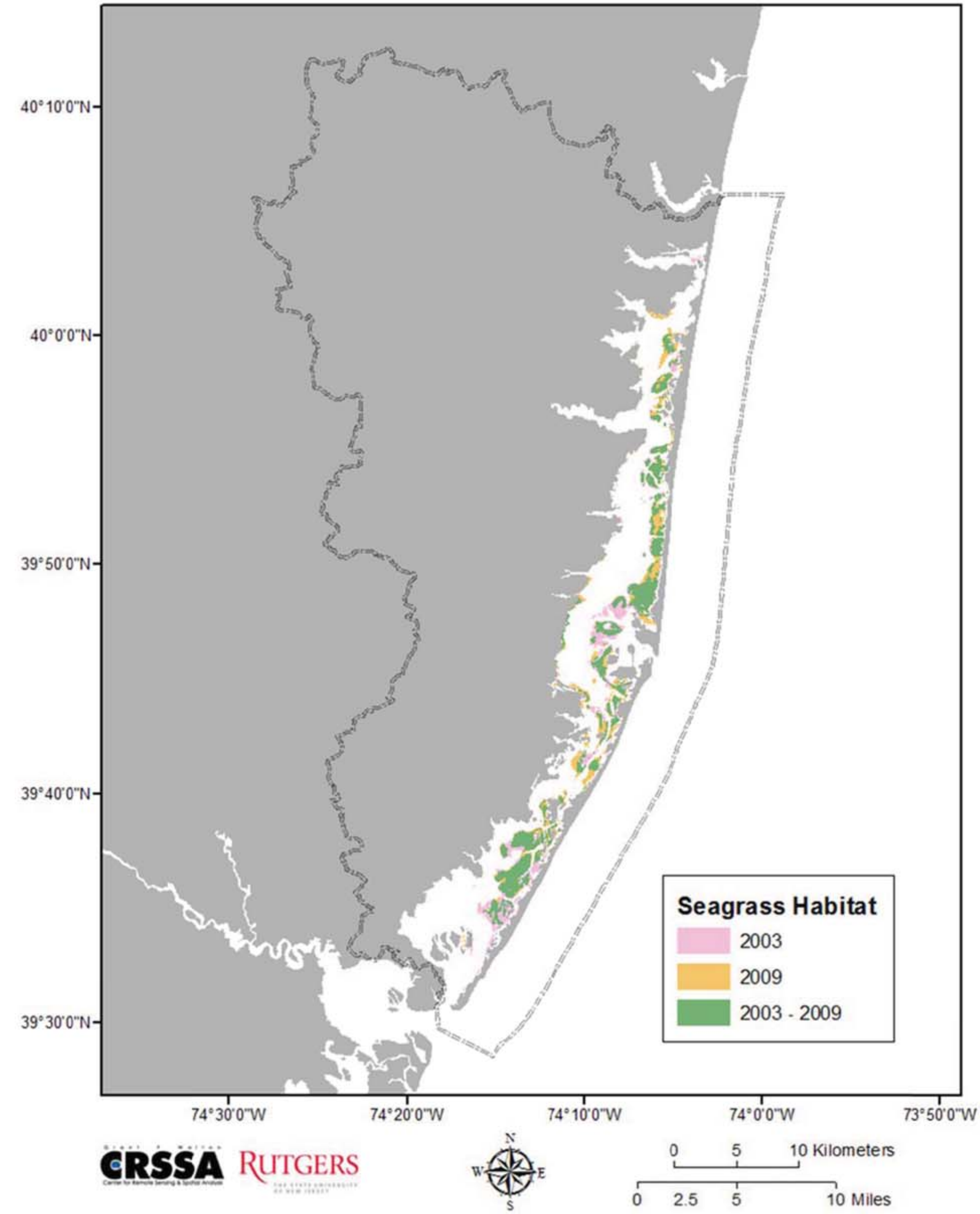

Figure 6. Seagrass habitat mapped in 2003 and 2009 over the study area.

features on the bottom of the Little Egg Harbor and Southern Barnegat Bay (SBB) estuary as this is the area that was observed to have the highest frequency of turbidity events. Due to the nature of aerial photography, it should also be noted that there may be slight discontinuities in mapping at the edge of the aerial photograph frames.

Comparison of 2003 and 2009 seagrass surveys

The following comparison discusses the results of the change detection analysis conducted between the 2003 and 2009 seagrass surveys. Where possible, ancillary information from outside research projects were used to provide supporting evidence of the trends found within the comparison of the 2003 and 2009 imagery classifications.

The area of total seagrass mapped across the estuary in 2009 was 5,260 ha which represents an increase of 138 ha over the 2003 survey (Tables 2 and 5a). This increase in seagrass occurred in specific spatial areas as displayed in Figure 6. This map is divided into three seagrass areas: (1) the areas mapped in 2003 only (1,463 ha); (2) the area mapped in 2009 only (1,601 ha); (3) the area and mapped in both 2003 and 2009 (3,659 ha) (Table 5b). Across the entire estuary a total of 563 ha of seagrass were mapped as loss, with an additional 785 ha of seagrass mapped as gain.

Some of the difference in area represents real change in seagrass distribution and some represents an artifact of differences between imagery dates, water transparency, tidal stage and other uncontrolled factors. There is a trade-off between acquiring imagery earlier in the growing season (i.e., May) vs. later in the growing season (i.e., June-July) when peak seagrass biomass may be present but also higher levels of water turbidity.

Examination of the more detailed 4 class seagrass cover map shows a decline in the area dense seagrass beds in 2009 vs. 2003 (i.e., 471 ha in 2009 vs. 2,074 ha in 2003; a nearly 60% decline) (Tables 2 and 5a). The extent to which this apparent thinning in the density of the seagrass beds is real or an artifact of the poor image quality in the 2009 imagery (at some locations) is uncertain. As stated above, the accuracy assessment suggests that the 2009 mapping underestimated the areal amount of dense seagrass beds (as compared to the 2009 *in situ* surveys), which suggests that at least some portion of the apparent decline may be an artifact.

For a more detailed analysis, the estuary was subdivided into five sections and will be discussed below. Table 6 shows the results of the detailed analysis to differentiate the reason different areas were mapped as seagrass between the 2003 and the 2009 surveys. Table 7 shows the changes in mapped seagrass area between 2003 and 2009 for each of the five study sections.

Table 5a. Area of seagrass cover types mapped during the 2003 remote sensing survey.

Seagrass Type	Class (ha)	Total Seagrass
Sparse (10-40%)	1,955	38%
Moderate (40-80%)	1,093	22%
Dense (80-100%)	2,074	40%
Total Seagrass	5,122	

Table 5b. Total area of seagrass mapped during in 2003 but not in 2009, 2009 but not in 2003, and in both the 2003 and 2009 remote sensing.

Year	Area (ha)
2003 only	1,463
2009 only	1,601
Both 2003 - 2009	3,659

Table 6. Possible cause of classification change in seagrass presence absence between 2003 and 2009 for the BB-LEH estuary system.

Reason	Year Mapped	Estuary wide (ha)	LEH (ha)	SBB (ha)	BI (ha)	CBB (ha)	NBB (ha)
True Loss	2003	563	86	26	384	61	0
True Gain	2009	785	135	146	109	297	0
Change in Season	2003	90	0	0	0	14	76
Change in Season	2009	338	0	0	0	51	287
Misclassification	2003	412	313	66	0	23	0
Misclassification	2009	19	0	5	0	14	0
Poor Image Quality	2003	169	132	4	0	8	24
Poor Image Quality	2009	195	20	169	0	4	3

Table 7. Change in mapped seagrass area between 2003 and 2009

Location	Year(s) Mapped	Area (ha)
Northern Barnegat Bay	2003	102
-	2009	290
-	2003/2009	277
Central Barnegat Bay	2003	180
-	2009	436
-	2003/2009	1,226
Barnegat Inlet	2003	423
-	2009	128
-	2003/2009	460
Southern Barnegat Bay	2003	131
-	2009	362
-	2003/2009	359
Little Egg Harbor	2003	627
-	2009	235
-	2003/2009	1,240

a). *Little Egg Harbor (LEH)*

The most southern section is Little Egg Harbor (LEH) which lies between 39 40 00 and 39’ 32 00 N. LEH contains shallow flats on the eastern shore extending 2.6 – 1.3 km from the barrier island complex to the deeper benthic habitats on the western side of the estuary (Figure 7). In 2009, LEH contained 1,475 ha of mapped seagrass habitat and 1,867 ha of mapped seagrass in 2003. This 380 ha reduction in the extent of mapped seagrass habitat between 2003 and 2009 was mostly due to a misclassification in the 2003 remote sensing project (Tables 6 & 7). This misclassification occurred when a shallow dark benthic habitat was confused with seagrass habitat. Direct comparison between the 2003 and 2009 imagery provides some indication that seagrass habitat is similar between 2003 and 2009, but in specific areas it is expanding and or contracting. Figure 8 shows the loss of a seagrass bed between 2003 and 2009 in an area adjacent to the ICW. Overall, seagrass habitat appears stable between 2003 and 2009 in LEH. However, it should be noted that differences in the image acquisition period could be driving some of the mapped increase in seagrass habitat.

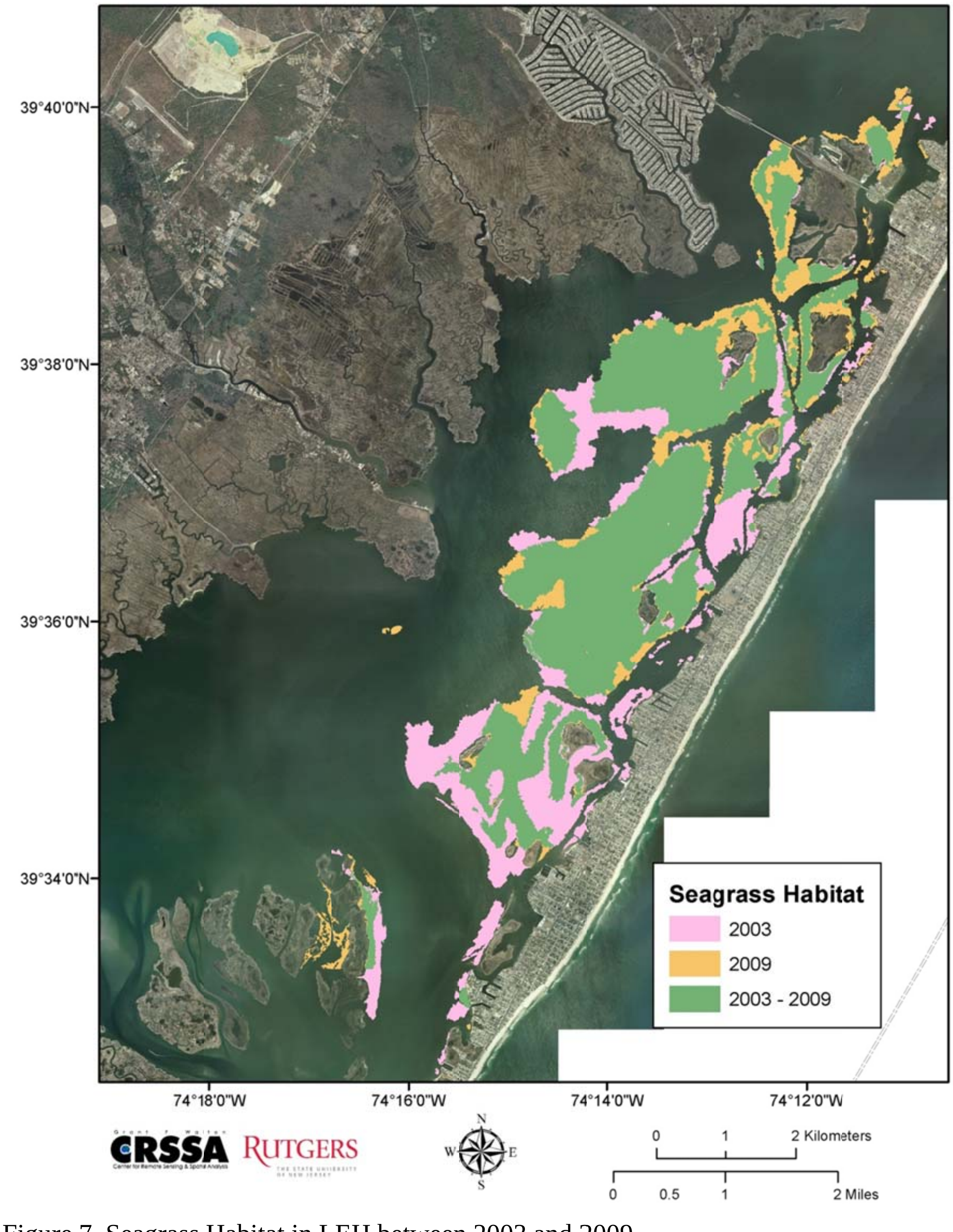

Figure 7. Seagrass Habitat in LEH between 2003 and 2009.

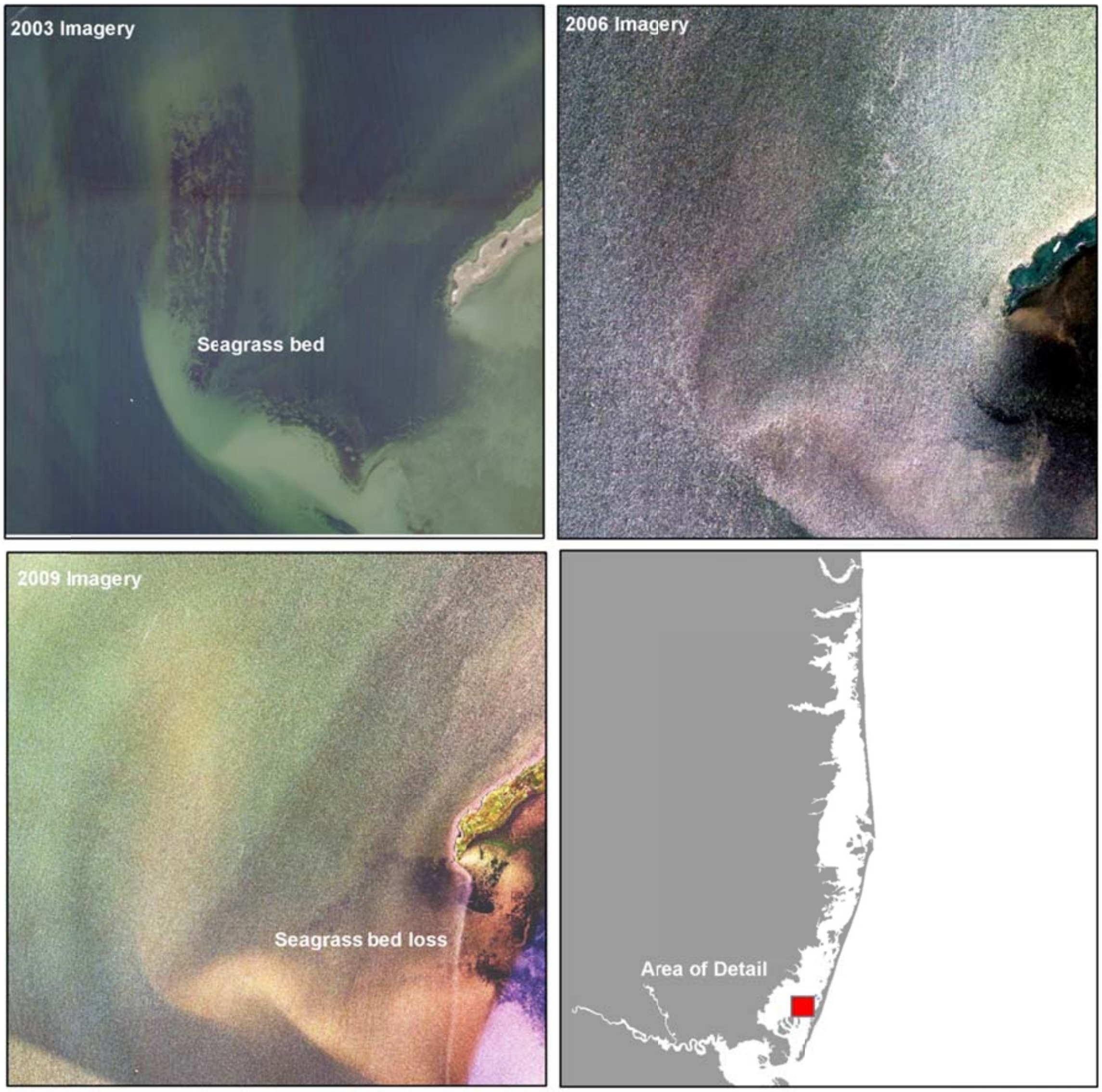

Figure 8. Aerial images showing changes in seagrass habitat in Little Egg Harbor between 2003 and 2009. The seagrass bed show in the 2003 imager (top left) is not found in the 2009 imagery (bottom left). The 2006 imagery (top right) is difficult to interpret due to surface reflectance.

LEH was the site of extensive *in situ* seagrass surveys by Kennish between 2004 and 2009 (Kennish et al. 2008; Kennish unpublished data). In addition, Gastrich et al. (2004) and Pecchioli et al. (2006) mapped extensive brown tide blooms within this estuarine system that covered known seagrass habitat in 2000, 2001, and 2002. The NJ DEP brown tide monitoring program was stopped after the 2004; therefore no data is available after 2004. The 2002 brown tide bloom in LEH was the most severe of the five years of monitoring period with an average of 281,900 cells/ml. This increase of brown tide was correlated with reduced Secchi disk value and higher water turbidity. Thus, increases in seagrass habitat in the northern part of LEH could be caused by the cessation of brown tide blooms during 2008 and 2009 and associated increase in light penetration.

In situ data collected by Kennish et al. (2008) for 2004, 2006, and 2008 show a decline in benthic submerged aquatic vegetation, including seagrass and macroalgae between 2004 and 2006. Unfortunately, because the brown tide monitoring program did not collect data after 2004, no information exists on brown tide bloom density or extent for 2006. The brown tide densities in 2004 compared to 2000-2002 were low with an average cell density of (15,700 cells/ml). In 2006, Kennish et al (2007) found an average secchi value of 0.97 m, which is between the values found by Pecchioli et al 2006 for average secchi depths during brown tide blooms (0.8 m during 2001-2002) and for non-bloom years (1.2 m for 2003-2004). Therefore, it cannot be shown conclusively that 2006 was a brown tide bloom year, but based on the Kennish et al. (2007) *in situ* data, it is clear that macrobenthic primary producers (submerged aquatic vegetation) were severely reduced from the previous year(s).

The August 2006 aerial photography collected by the U.S. Department of Agriculture (USDA) can elucidate some of the spatial trends of this apparent seagrass dieback. The August 2006 USDA NAIP photography was not optimized to record information on seagrass habitat and health; nonetheless, one specific bed (Figure 9) can clearly be seen for that year. It shows large-scale seagrass dieback in 2006, with a significant amount of internal bed loss with large areas denuded of submerged aquatic vegetation. This corresponds to what was observed *in situ* by Kennish et al. (2007) in 2006 and lends further credence to a system-wide decrease in submerged aquatic vegetation for that year. The 2006 July and August temperature data was the highest over the 2000-2008 time periods. In addition to possible brown tide impacts, high water temperatures in 2005 and 2006 during the mid-summer peak in *Z. marina* could have caused the 2006 dieback surveyed by Kennish et al. (2007). Temperature could be either causative or correlative factor or both for *Z. marina* within the BB-LEH estuary system.

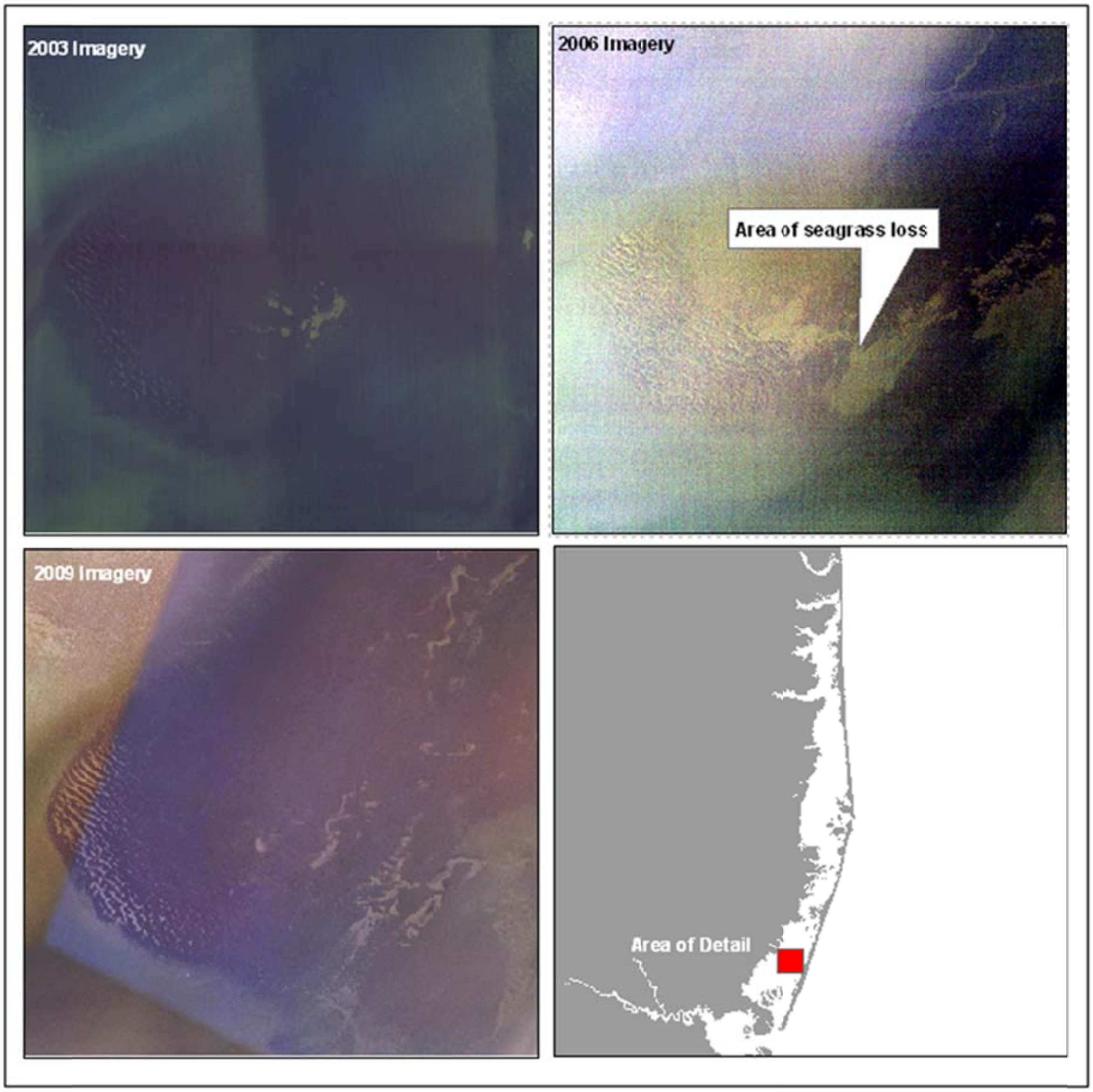

Figure 9. May 2003, July 2006, and August 2009 imagery showing a seagrass bed in 2003, dieback in 2006, and subsequent expansion in 2009. The 2003 imagery (top left) and the 2009 imagery (bottom left) show as dense seagrass bed while the 2006 imagery (top right) shows several large denuded areas within the larger seagrass bed.

b). *Southern Barnegat Bay (SBB)*

The second area of interest is the southern portion of Barnegat Bay located south of Barnegat Inlet and north of LEH 39 40' 00''and 39 44' 30'' (Figures 10 and 11). This portion of the BB-LEH system has a total of 721 ha of seagrass mapped in 2009 vs. 490 ha mapped in the 2003 seagrass survey. Through closer analysis, 146 ha of the total change in area represent seagrass habitat expansion mapped in 2009, but not in 2003 (Table 5). A total of 26 ha of seagrass habitat were lost between 2003 and 2009, mostly in the northern portion adjacent to the Barnegat Inlet and the ICW. The increase of mapped seagrass area between the 2003 and 2009 study periods is likely to be higher, but due to water turbidity this could not be conclusively demonstrated. A total of 169 ha of seagrass mapped in 2009 could not be verified as seagrass gain due to poor image quality in the 2003 remote sensing survey. Again, much like LEH there is an apparent gain in seagrass area between the 2003 and 2009 survey periods.

Southern Barnegat Bay (SBB) (Figures 10 and 11) shows similar results to LEH. Brown tide blooms occur at their highest values in SBB and LEH, which suggests higher bay water residence time with an associated increase in nutrient retention. Unlike LEH, there is no extensive record of *in situ* data, and the 2006 NAIP photography provided no information on benthic habitats. Nonetheless, SBB could have had a significant dieback of seagrass in 2006 because it shares many of the same characteristic as LEH. This part of the estuary has been extensively dredged on the eastern edge adjacent to Long Beach Island for both boat access and sediment mining. The sediment mining was likely done to provide material to Long Beach Island after the Ash Wednesday Nor'easter of 1962 which caused substantial erosion to Long Beach Island LBI (Psuty, personal communication 2010). Seagrass habitat most likely extended to the tidal flats in a similar fashion at Island Beach State Park prior to the extensive alteration to the benthic environment.

More work needs to be done to assess the seasonal and annual variation in seagrass habitat within the SBB segment of the BB-LEH. This portion of the BB-LEH appears susceptible to multiple stressors including harmful algal blooms, dredging, and direct impacts from boat scarring. This remains one of the least studied parts of BB-LEH in regard to seagrass habitat condition.

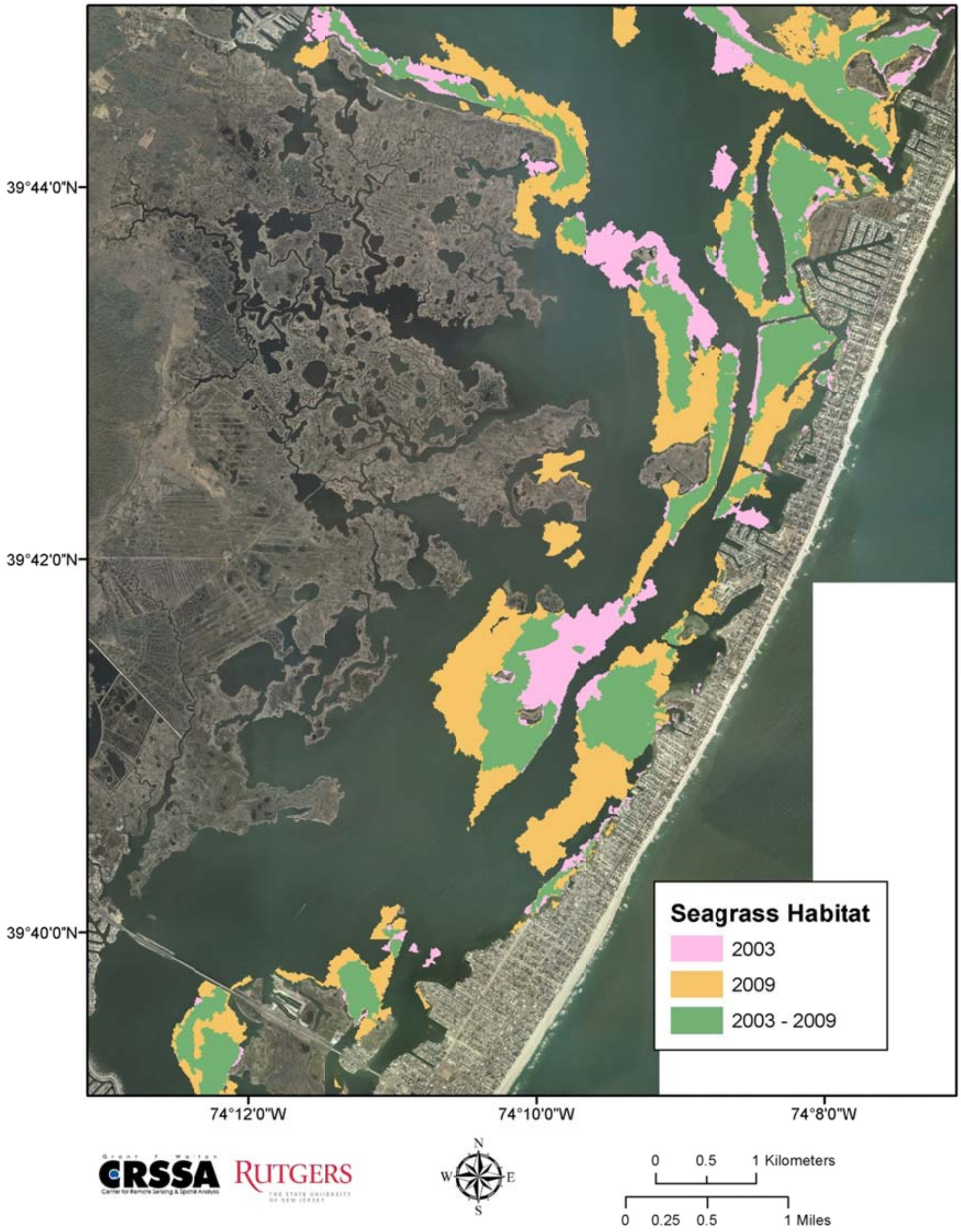

Figure 10. Seagrass habitat in Southern Barnegat Bay between 2003 and 2009.

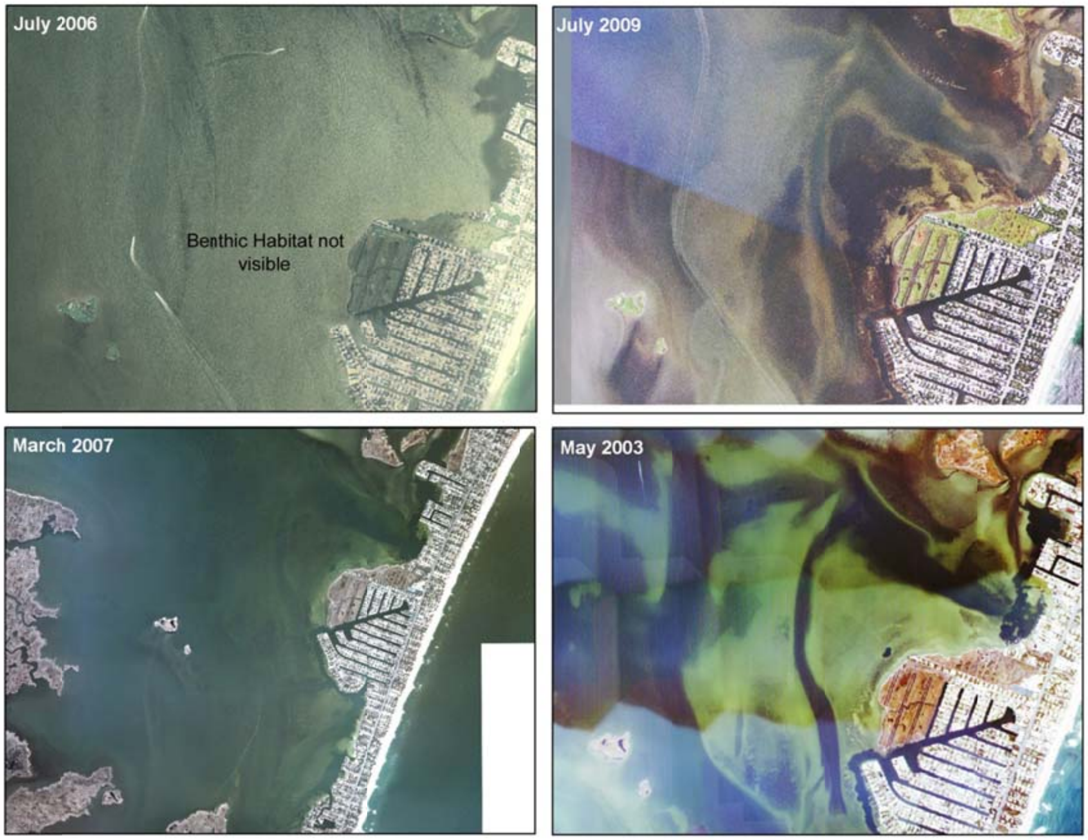

Figure 11. Comparison of the 2003, 2006, 2007, and 2009 imagery for Southern Barnegat Bay (SBB). This comparison shows that due to sunglint, the 2006 imagery (top left) does provide useful benthic habitat information. Note that there appears to be greater amounts of seagrass in March 2007 and July 2009 than the corresponding imagery for May 2003 (shallow bars in center of image appear much brighter in May 2003). Note that the March 2007 image is not to the same scale and covers a larger area.

c). *Barnegat Inlet (BI)*

The Barnegat Inlet (BI) region has undergone obvious changes between 2003 and 2009 (Figures 12 and 13) due mostly to shifting sand bars, ongoing dredging for channel navigation, and modifications to stabilize the inlet. A total of 384 ha of mapped seagrass was lost between 2003 and 2009 but at the same time there was a corresponding gain of 109 ha (Table 7). Some of this gain might be due to high blue mussel spat in 2008 which overwintered and was visible in the 2009 imagery. High densities of blue mussels could result in areas incorrectly mapped as seagrass beds or cause an overestimation of seagrass bed density. This could have caused some overestimation of seagrass habitat in 2009 for both presence / absence and percent cover because blue mussel spat was found within seagrass habitat during *in situ* site visits. Other confounding factors include *R. maritima* growth on shallow sand flats. This could account for seagrass habitat that was present in 2003 but not mapped due to the early image acquisition period. The Barnegat Inlet region is primarily composed of well sorted sand because high current speeds transport darker organic detritus into the deeper estuary or out the inlet and into the coastal ocean. Higher water transparency (low water turbidity) in this section resulted in high image quality for both the 2003 and 2009 imagery acquisitions.

The U.S. Army Corps of Engineers has undertaken extensive alteration of Barnegat Inlet to keep it open for recreational and commercial boat transit. This included placing a geo-textural tube across the northern part of the inlet in the late 1999 and early 2000 (Kennish, personal communication 2010) and dredging the ICW. This appears to have funneled current flow to the west, shifting the coarse grained sediments over the top of the two large seagrass beds. This loss of seagrass habitat could be classified as an indirect disturbance resulting from alterations to the Barnegat Inlet form and function.

Because the Barnegat Inlet region is flushed twice daily with ocean water by semi-diurnal tides it would appear less susceptible to nutrient loading and associated algal blooms. Seagrass habitats in Barnegat Inlet that were not physically altered by shifting sediments increased in area. This would lend support to the observation that the physical effects of Barnegat Inlet are impacting the extent of seagrass habitat in this local area. It should be noted that these impacts occurred in areas within 3-5 km of the inlet and did not extend north or south into Barnegat Bay proper.

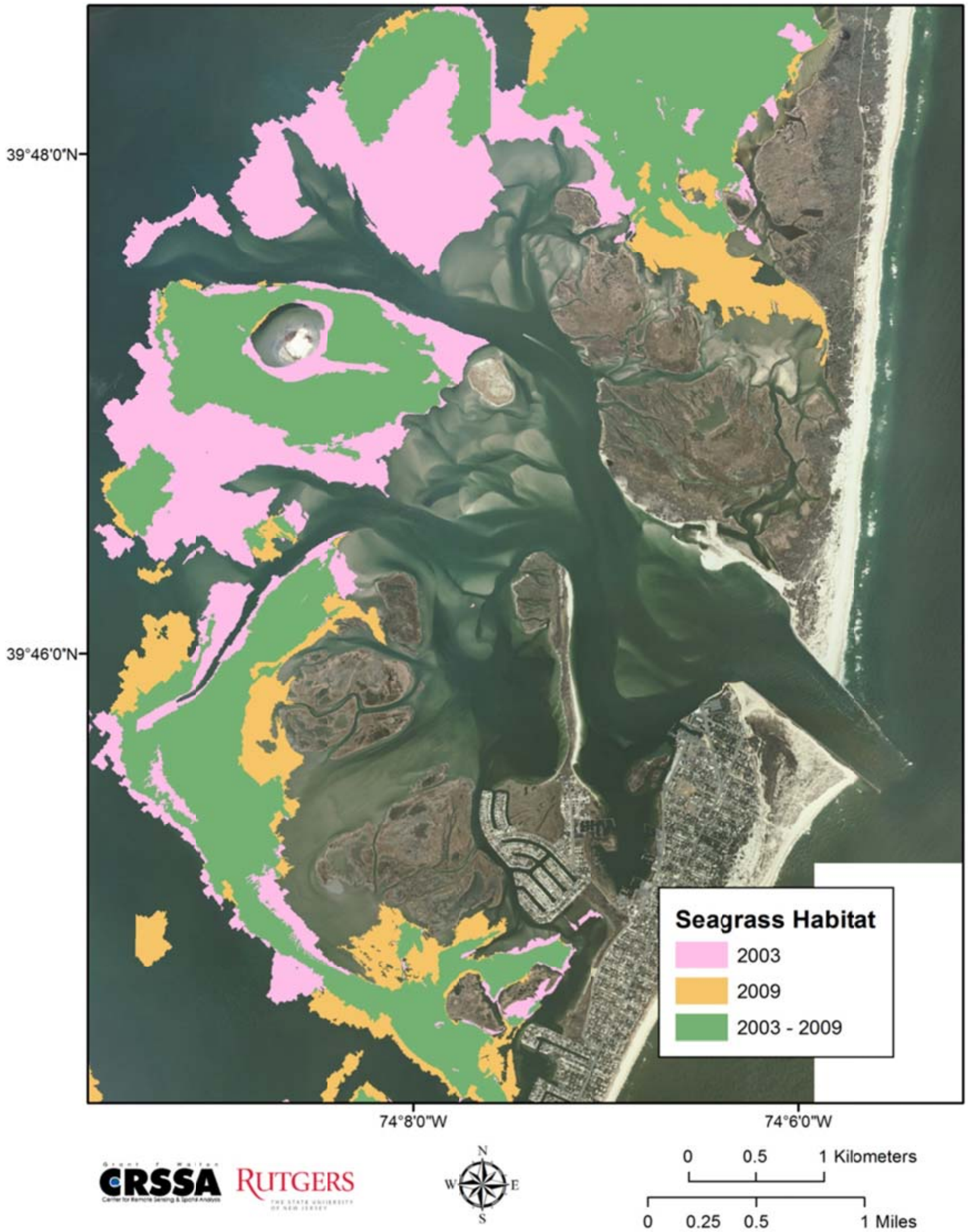

Figure 12. Seagrass habitat in Barnegat Inlet between 2003 and 2009.

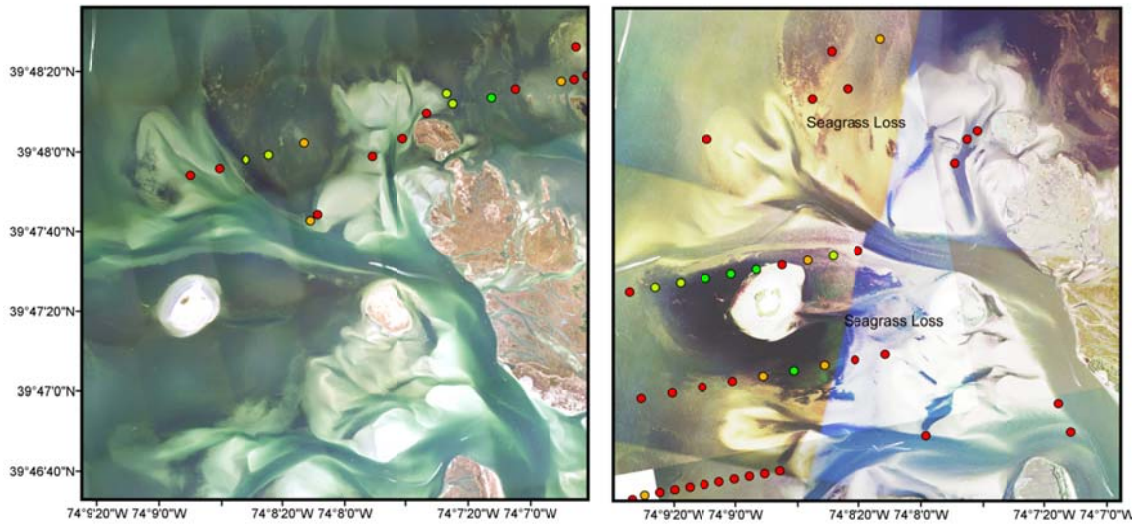

Figure 13. Imagery and *in situ* sites in 2003 (left) and 2009 (right) showing seagrass habitat decline at Barnegat Inlet.

d). *Central Barnegat Bay (CBB)*

The Central Barnegat Bay (CBB) (Figure 14 & Figure 15) section of Barnegat Bay north of Barnegat Inlet and south of the Route 37 Bridge represents a transition zone from *Z. marina* dominated habitat, to *R. maritima* dominated habitat in the north. The western edge of CBB contains little seagrass habitat vs. the extensive shoals extending 1- 1.5 km into the estuary from the eastern barrier island complex (Figure 14). In total, the CBB section contained 1,662 ha of seagrass in 2009 up from 1,406 ha in 2003. The 297 ha was deemed new seagrass growth, or bed expansion. A total of 50 ha was mapped as seagrass due to a change in season, and represents *R. maritima* beds visible in the later growing season 2009 imagery collection. A total of 61 ha of seagrass loss occurred mostly near the outer edges of seagrass beds representing a contraction of seagrass habitat into shallower water. The majority of the new seagrass habitat identified in the 2009 imagery is located along the shallow water sand flats adjacent to Island Beach State Park (Figure 15). Seagrass habitat therefore shifted to shallow habitat within the CBB region between 2003 and 2009. It is unclear why the sand flats adjacent to Island Beach State Park were denuded of seagrass in 2003 but heavily covered with seagrass in 2009 (for example, refer to the cover illustration). Some of the difference could have been caused by increasing density of *R. maritima* between the 2009 and 2003 imagery datasets.

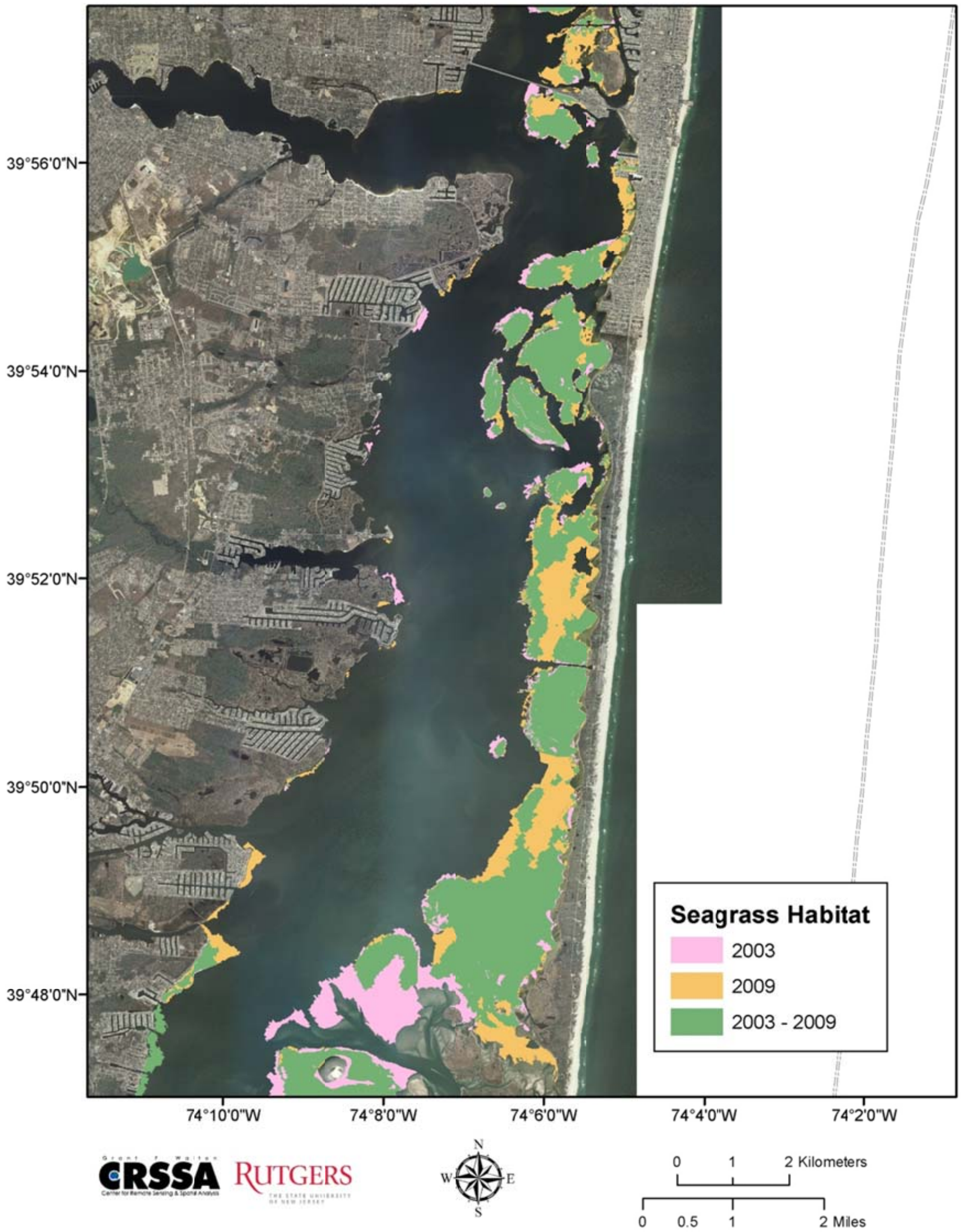

Figure 14. Seagrass habitat in Central Barnegat Bay between 2003 and 2009.

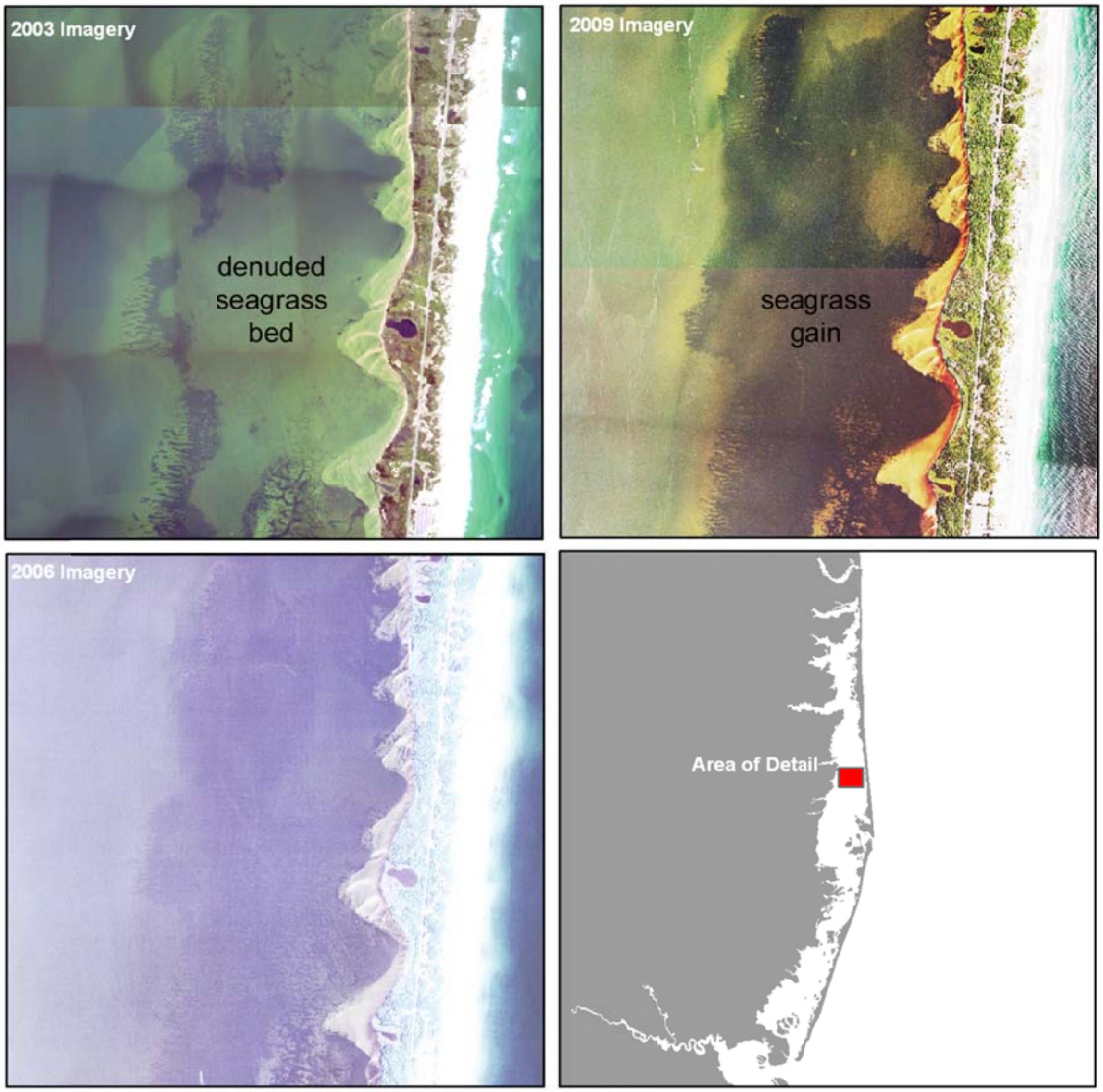

Figure 15. Imagery in 2003 (top left), 2006 (bottom left), and 2009 (top right) showing seagrass habitat decline in Central Barnegat Bay.

e). *Northern Barnegat Bay (NBB)*

The northern-most portion of the BB-LEH system NBB (Figure 16 & Figure 17) is dominated by low salinity waters and heavy inputs of freshwater from the Toms River watershed (NJ DEP data 1989-2009). The majority of the seagrass habitat in this portion of the estuary was dominated by *R. maritima* with small pockets of *Z. marina.* A total of 567 ha of seagrass were mapped within NBB in 2009. This represents an increase of 188 ha of seagrass habitat vs. the 2003 data. All of this mapped increase in seagrass area most likely does not represent 'true' change but is attributed to a change in the growing season or poor image quality. It is difficult to compare imagery collected in May to imagery collected in July with respect to *R. maritima* habitat. Figure 17 shows a *R. maritima* bed with photography from May 4-5th 2003, August 2006 and July 2009. It is apparent through the *in situ* data that *R. maritima* was growing in both 2003 and 2009, but it was not visible in the May 2003 imagery.

In addition, the full tidal cycle for the entire BB-LEH estuary system is ~ 2.5 hours. Low tide at Barnegat Inlet does not occur at the same time as low tide in northern Barnegat Bay. Because imagery was collected in a relatively short period of time, the entire estuary was not at a low tide during collection. Areas with shallow water and bright sand as a backdrop did not suffer much from this issue, but northern Barnegat Bay has darker organic soils with associated lower albedos which make it more difficult to photo interpret than other regions. Because of these reasons no definitive gain or loss of seagrass habitat within northern Barnegat Bay could be determined based on the 2003 and 2009 aerial photography. Furthermore, as in the case of Southern Barnegat Bay, Northern Barnegat Bay does not have an exhaustive *in situ* dataset. This remains a high priority data gap to provide a full understanding of seagrass habitat health across the entire BB-LEH.

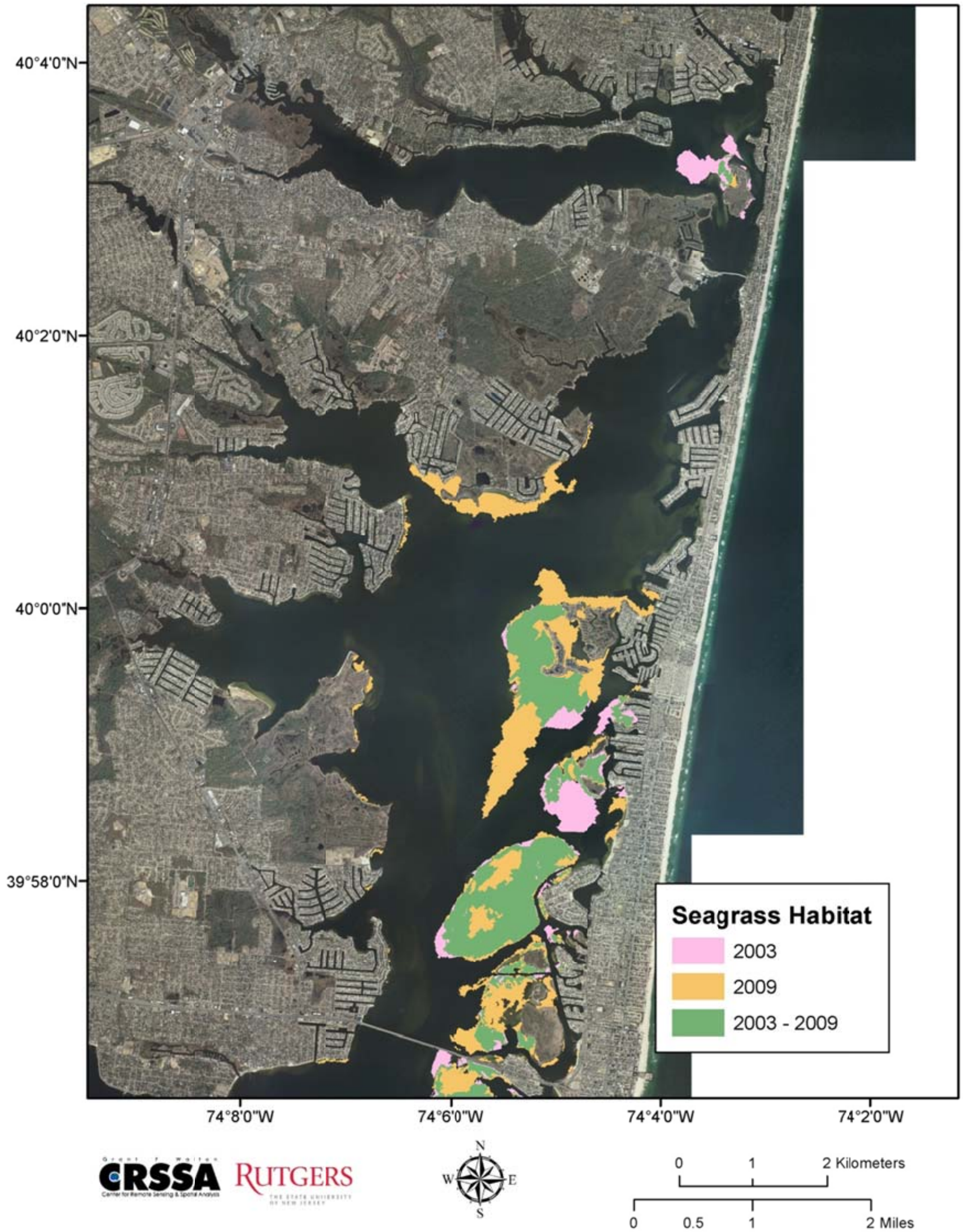

Figure 16. Seagrass habitat in Northern Barnegat Bay between 2003 and 2009.

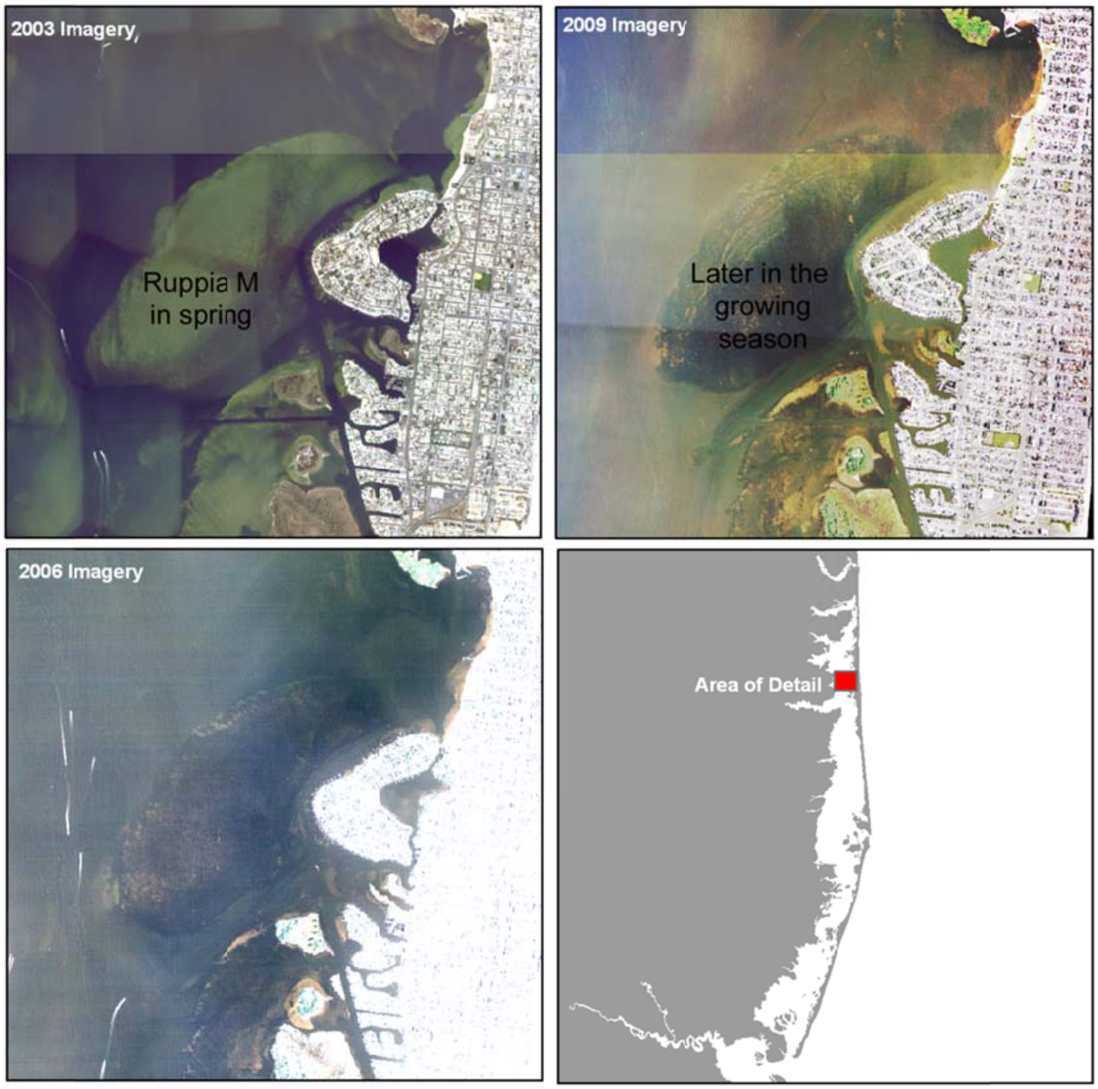

Figure 17. Imagery for March 21st 2003 (top left), August 5th, 13th 2006 (bottom left), and July 7th 2009 (top right) showing a *R. maritima* bed through the growing season.

V. Assessment of Direct Disturbance to Seagrass

Methods

Impacts of boat scarring

To identify areas of boat scarring the 2009 high-resolution (0.5 m horizontal) aerial photography was manually examined for linear marks and scars. Particular attention was paid to areas adjacent to the Intracoastal Waterway (ICW) and local channels by layering them in a GIS on top of the 2009 aerial photography. Areas that showed signs of boat scarring were delineated using a linear GIS file. The length in meters of identified boat scars was then totaled. It should be noted that many boat scars will be under the detectable limit for the 2009 imagery based on their small width. The 2009 aerial photography was collected at a 0.5m cell size. Because boat scars are long irregular features it was felt that they could be found below the imagery's 0.5 m cell size. This has not been shown empirically for this study. In addition, when seagrass is located within areas of low sediment albedo or dense macroalgae assemblages, boat scars may not appear to be different spectrally from seagrass beds. Imagery collected in the northern part of the BB estuary had Langmuir circulation lines which closely resemble the spectral pattern of boat scars. These lines were different from boat scars in that they all were aligned in the same direction with equal spacing and thus could be confidently distinguished.

Impact of docks

The impact of boat docks on seagrass habitat in Barnegat Bay and Little Egg Harbor was assessed using the 2009 aerial photography. Boat docks can negatively affect adjacent seagrass by reducing solar illumination of the seagrass beds through direct shading. Docks on tidal creeks and within lagoonal developments were excluded because they would not naturally shade seagrass habitat. For docks that had boats present, the boat itself was included in the outline of the dock. The 2009 aerial photography had a cell size of 0.5 m and therefore few if any docks are below the minimum detectable limit. Boats located at the dock in July would likely be present all summer long and therefore would shade out any local seagrass habitat. Docks were then buffered by 2 m to represent the total area of shading as the sun angle changes throughout the day. As a secondary analysis, the area of docks within 100 m of mapped seagrass habitat was quantified; 100 m was used to represent the broader possible impact of enhanced boat traffic (i.e. into and out of a dock).

Deepwater dredged areas

Areas of deep water created through dredging adjacent to boat docks or part of boat channels (ICW) and local channels to and from the ICW) were mapped using the 2003, 2007, and 2009 photography where visible. All of these image datasets were used to create a vector file showing areas of dredged deepwater location on the eastern side of the BB-LEH estuary system.

Results and Discussion

Boat scarring was found throughout the entire BB-LEH estuary (Figure 18). Specific areas of the estuary, Tice's Shoal (Figure 19) for example have higher incidence of boat scarring. A total of 42.9 km of linear boat scars were mapped across the entire study areas (Table 8). In most cases these boat scars were on the order of 1 m wide with only a few cases with widths approximating or over 2.5 m wide. If each scar is assumed to be 1 meter in width, this represents a total of 4.29 ha of scarred habitat, a very small percentage of the entire estuary seagrass habitat. It is likely that a large percentage of boat scars were not found in this analysis, but even if the amount was underestimated by an order of magnitude, it would still appear that boat scarring does not play a significant role in the reduction of seagrass habitat. In addition, it does not appear that boat scars are expanding in size after the initial formation. Therefore, in this estuarine system, boat scars most likely represent ephemeral impacts to seagrass habitat.

A total of 1,468 docks were mapped within the BB-LEH estuarine system proper. The total area of all of these docks is 30.7 ha and 53.7 ha for docks and the 2 meter buffer zone. Out of the 1,468 mapped docks, 684 were within 100 m of mapped seagrass habitat (in either 2003 or 2009). This represents a total of 31.2 ha of buffered docks adjacent to mapped seagrass habitat (Table 8). Compared to the mapped extent of seagrass habitat (5,260 ha in 2009) within the BB-LEH, this represents a small fraction of the overall seagrass habitat. Secondary effects of these boat docks include changes in the current flow, sedimentary budget, boat scarring, and dredging for boat channels. The direct impact of the boat docks on the areal extent of seagrass habitat is minor in this system. The minimal amount of seagrass impacted by boat docks can be partially explained by the fact that the NJ DEP regulates dock construction to minimize the impact to seagrass habitat (N.J.A.C. 7:7E). It should be pointed out that the vast majority of seagrass habitat is not located adjacent to land and would therefore not be at risk to impact by the dock proper. On the other hand increasing water turbidity and dredging as a result of dock construction could have an impact on adjacent seagrass habitat.

Dredged areas of the BB-LEH estuary system covered extensive areas adjacent to mapped seagrass habitat on the eastern edge of the barrier island complex (Figure 9). The mapped extent of dredged areas covered 790 ha (Table 7), excluding the western shore. In areas where no dredging has occurred (Island Beach State Park) seagrass habitat extends almost to the intertidal flats. Dredging for sediment and boat access could account for a large reduction in available habitat for seagrass within the BB-LEH estuarine system though in the longer term - outside the immediate time period of this study. The extensive non-linear dredged on the western side of the barrier island complex could be attributed to the Ash Wednesday Noreaster which occurred on March 6^{th}-8^{th} 1962. An analysis of older photography from the early 1930s do not show these expansive dredged sites (Figure 21).

The CBB portion of the BB-LEH estuary has minimal amounts of boat dredging vs. the southern three segments and the northern segment, mostly because the majority of the barrier island on the eastern edge is part of Island Beach State Park and therefore has a limited amount of boat docks. It is interesting to note that the protection and conservation of Island Beach State Park appears to have also protected large swaths of seagrass habitat that could otherwise have been dredged for boat navigation and sediment mining, and/or impacted by bulkheading or boat docks. The CBB does have boat scars, one directly adjacent to Tice's Shoal was 700 m in length (Figure 19). These boat scars, while dramatic in the photography, were not found with widths over 2.5 m and do not appear to be widening through time. While the effect of individual boat scars to the seagrass beds appear to be ephemeral, repeated scarring events would likely have a negative impact over the longer term.

Table 8. Total area of seagrass habitat in the Barnegat Bay-Little Egg Harbor estuary impacted by dredging, boat docks, and scars

Impact	**Result**
Boat Dock	53.7 ha
Boat Dock within 100 m of mapped seagrass habitat	30.7 ha
Boat Scarring	42.9 km
Dredging	790 ha

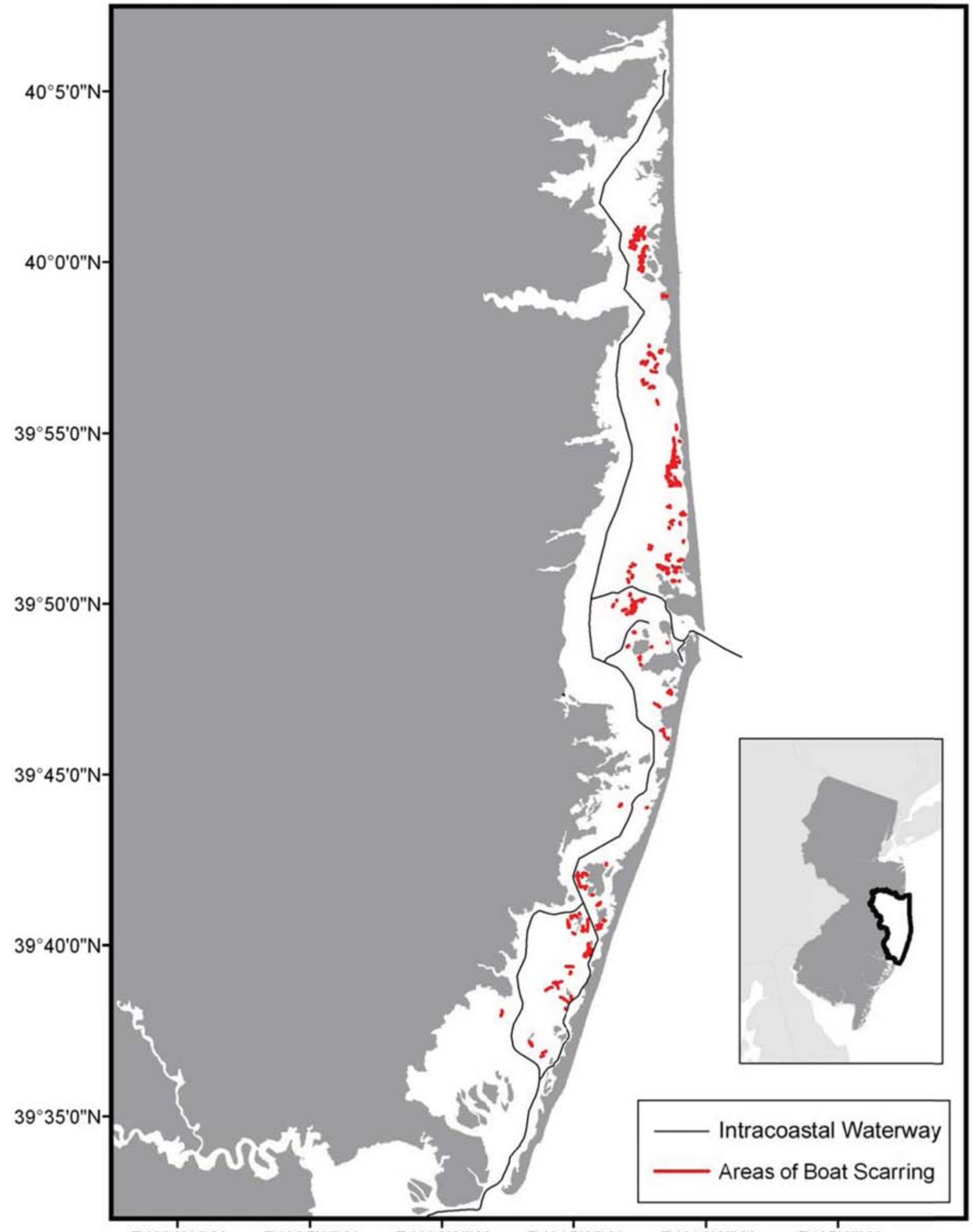

Figure 18. Areas of boat scarring manually delineated in the 2009 aerial photography.

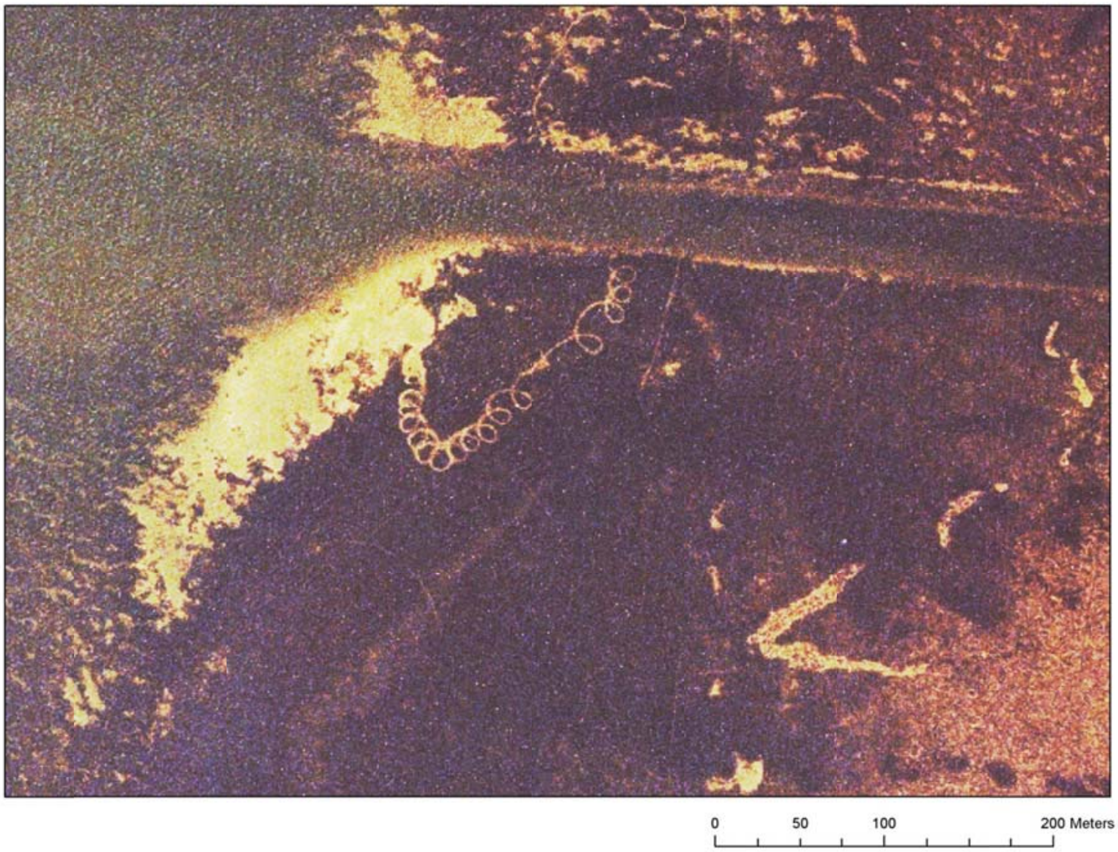

Figure 19. Image of large boat scar adjacent to Tice's Shoal to the west of Island Beach State Park in Central Barnegat Bay (CBB).

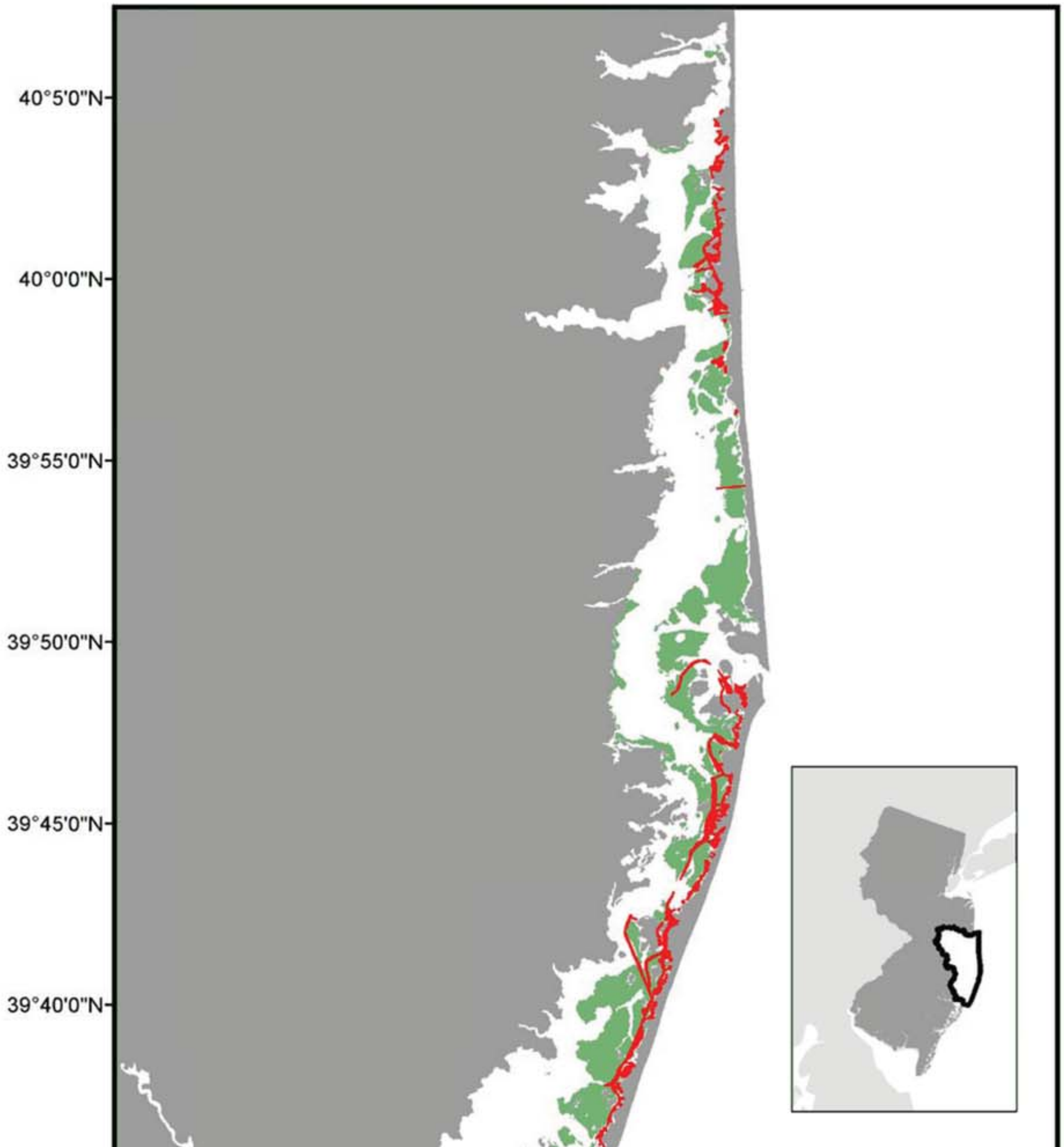

Figure 20. Location of dredging sites on the eastern side of the Barnegat Bay-Little Egg Harbor estuary. Determined through manual interpretation of 2003 and 2009 aerial photography.

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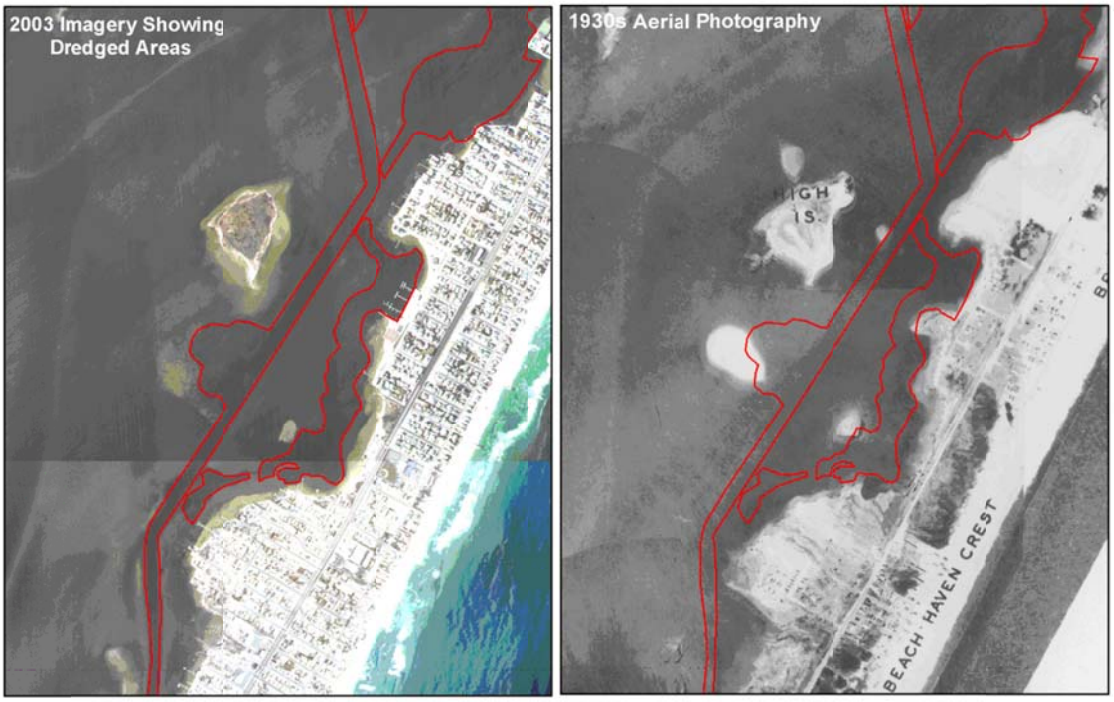

Figure 21. Dredged areas red in 2003 and the early 1930s on the eastern side of Long Beach Island (early 1930s image data source: NJDEP).

VI. Conclusions

The health and spatial extent of seagrass within the BB-LEH estuary serves as a biological indicator of water quality and the impacts of eutrophication through time and space. Short (2007) found that *Zostera m.* biomass and percent cover has declined in Great Bay, NH between 1995-and 2005 while seagrass distribution has remained relatively constant. To characterize the spatial extent, health, and density of seagrass beds across the entire estuary, it is therefore necessary to combine synoptic remote sensing surveys concomitantly with comprehensive *in situ* assessment. This study produced a high level of agreement between classified imagery and an *in situ* validation dataset. This is a time intensive process which required a large time investment from a trained image interpreter (3 months for this study). We suggest that future projects to map seagrass apply a hybrid method by first manually classifying a percentage of the image objects for each aerial photograph and then using those classified images as a training dataset within a Classification and Regression Tree (CART) model. This proposed method has several benefits including an increase in the size of the training dataset with a modest increase in cost. In addition the number of *in situ* training points would also be reduced by using this hybrid approach.

Comparing different types of imagery from scanned analog photography to digital imagery shows that the number one constraint in accurately mapping seagrass is the timing of imagery acquisition to both maximize seagrass standing biomass and minimize water turbidity and water depth. It was determined that aerial photography not collected to support benthic habitat mapping could not provide system-wide or region-wide information on seagrass habitat, rather it was only useful for specific areas of high image quality. It is important to understand both intra and inter annual variability in seagrass habitat to better understand differences in imagery acquired during different periods of the growing season. Long-term trends over many years and decades should therefore take particular care to collect aerial photography during similar periods of the year to prevent seasonal bias. This can be challenging due to adverse conditions (wind, tide, cloud cover and rain) that prevent consistent imagery collection.

The comparison of the 2003 vs. 2009 remote sensing surveys suggests that the overall area of mapped seagrass cover was similar between the 2 time periods. In directly comparing the two mapped data sets, there were areas of apparent gain and loss, though the bulk of the seagrass area was stable (i.e., was present in both 2003 and 2009). Some of the areas mapped as “gain” in 2009 may be due to an artifact of the later seasonal date of imagery collection (July 7th 2009) as compared to the 2003 aerial photography which was collected early in the spring before peak seagrass biomass (May 4-5th). Direct impacts to seagrass habitat including dredging, boat docks and scarring were mapped to assess their contributions to diminishing seagrass habitat. Boat docks and boat scarring contribute a minor reduction in seagrass habitat when compared to the overall areal extent within the BB-LEH estuary. Historical dredging has significantly reduced the amount of available habitat across most of the estuarine system. A decline in seagrass habitat was observed between 2003 and 2009 in the vicinity of Barnegat Inlet. We attribute this decline to the direct physical alteration of the Inlet. Examination of the more detailed four class seagrass cover map shows a decline in the area of dense seagrass beds in 2009 vs. 2003 (i.e., 471 ha in 2009 vs. 2,074 ha in 2003; a nearly 60% decline). The extent to which this apparent thinning in the density of the seagrass beds is real or an artifact of the poor image quality in the 2009 imagery (in some locations) and the resulting lower accuracy in mapping dense seagrass beds is uncertain. A greater frequency in mapping is needed to more conclusively assess the status and trends in seagrass coverage and density.

Determining the causative factors for seagrass decline and expansion can be difficult in that seagrass habitat integrates the ecological signal over a larger period of time than the original stressor. For example, in 2003 the seagrass extent was still rebounding from negative effects suffered from the 2000-2002 brown tide blooms. This temporal lag is one reason that seagrass is such a good indicator of estuarine water quality, but it also shows the need for more consistent data collection to more fully understand the impact of various stressors on seagrass habitat. Collecting aerial photography later in the growing season provides more information on the extent of *R. maritima* habitat and allows *Z. marina* to reach peak biomass. Unfortunately imagery collected later in the growing season is more likely to be impacted by poor water quality, making the timing of imagery collection a trade-off.

Work done in the intervening years (2004-2008) by Kennish (Kennish et al. 2007; & Kennish et al. unpublished data) showed a significant decline in submerged aquatic vegetation (seagrass and macroalgae) across the estuary. These results were corroborated by examination of the 2006 August aerial photograph which showed extensive areas of seagrass dieback as compared to the 2003 and 2009 imagery. The 2006 aerial photography as examined in this study was not useful for large areas of the BB-LEH estuary because it was not collected to maximize the ability to view benthic habitats like the 2003 and 2009 imagery. In specific areas, it does provide a snapshot view of the estuarine benthic environment. The 2006 imagery and the Kennish et al. (2007) *in situ* data therefore show that seagrass habitat has not been expanding in a linear fashion between 2003 and 2009.

Orth et al. (2010) published a review of seagrass monitoring in Chesapeake Bay discussing the historical distribution and present range of *Z. marina.* Of particular importance is the existence of a multi–decadal aerial photography database and remote sensing survey program that has collected and processed aerial photography specifically to map seagrass habitat annually between 1984 and 2007. This longitudinal dataset has allowed researchers within the Chesapeake Bay to assess the trends in seagrass distribution through time, compare the success of various transplant and relocation efforts, and compare seagrass decline to *in situ* water quality parameters. These types of analyses are not possible in the BB-LEH because the necessary base imagery collected specifically to monitor benthic habitat do not exist with high enough temporal frequency (i.e., on an annual basis). We found that imagery not collected for the purpose of mapping benthic habitats to be inadequate for mapping the baywide distribution of seagrass habitat.

VII. Future Considerations

Seagass habitats worldwide have been reduced through human induced habitat changes (Short and Wyllie-Echeverria 1996; Orth et al. 2010; Waycott et al. 2009). As the nutrient flux from upland habitats continue to be altered both in terms of new urban lands and mitigation attempts, it will be important to track the biological response within the BB-LEH and other similar estuary systems. In particular, seagrass habitat should be targeted as the primary ecological indicator of eutrophication in estuaries that have a history of supporting seagrass (Wazniak et al, 2007; Burkholder et al. 2007). *Zostera m.* areal extent within the mid Atlantic bight is highly dynamic with some locations showing new growth and expansion of existing beds, such as the Virginia and Maryland Coastal Bays (Orth et al, 2007; Wazniak et al, 2007) while others areas such as Great Bay NH and Chesapeake bay have shown a decline in extent (Short, 2007; Orth et al. 2010). The primary cause for seagrass decline and or expansion is related to site specific changes in water quality, temperature, direct alterations, and or disease. (Orth et al, 2010; Burholder et al, 2007; Short, 2007). To understand what causative factors drive seagrass distribution and health and in a specific estuary it is necessary to have a dedicated monitoring program. This should be done on an annual or semiannual basis to avoid missing major changes in the extent and health of seagrass habitats as this study and other studies have shown (e.g., Orth et al, 2010).

Future seagrass monitoring projects focused on change detection should incorporate a method to provide a level of the certainty of habitat change (confidence interval around the estimates of seagrass area). A useful approach would be to delineate a number of seagrass beds in the field using a GPS system, and then to apply a ratio estimator to estimates errors of omission and commission (Lathrop 2006). This would allow resource managers a better means to assess the statistical as well as real world significance of mapped changes created by remotely sensed surveys and to provide a more informed view of the impact of ecosystem level changes on seagrass habitats. Long-term attempts to increase seagrass habitat should focus on upland strategies to lower the amount of nutrient loading vs. system wide *in situ* restoration attempts that focus on very small portions of the estuarine. This study suggests that under present conditions that the seagrass beds display a high degree of resilience with strong capacity to rebound. Part of this resilience might lie in the seagrass seed bank that allows seagrass habitat to recolonize areas after a disturbance (Harwell and Orth, 2002). However, this does not suggest that the seagrass beds will continue to be able to respond to extended years of high turbidity or otherwise impaired growth conditions. If a tipping point is reached such that the seagrass beds are extirpated estuary wide, then restoration might make sense if the seed bank is determined to be unviable (Harwell and Orth, 2002). This agrees with the conclusions of Orth et al. (2010) who state ”Restoration efforts can be important for initiating or accelerating a recovery but only if water quality is improved, and these conditions are maintained”.

To more fully understand the spatial patterns of seagrass loss and gain in relationship to the watershed nutrient inputs, a greater understanding of the spatial and temporal dynamics of bay circulation and flushing are warranted. A network of instrumented buoys would provide much needed information on bay water temperature, salinity, and algal indicators to supplement the recommended seagrass monitoring program.

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IX. References Cited

Bologna, P., Able, K., Lathrop, R. G. & Bowers, P. (2000). Assessment of the health and distribution of submerged aquatic vegetation from Little Egg Harbor, New Jersey. Technical Report #2000-11, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey.

Bologna, P. & Heck. K., (2000). Impacts of seagrass habitat architecture on bivalve settlement. *Estuaries* 23:449–457.

Bologna, P. , Wilbur, A., and Able, K., (2001). Reproduction population structures, and recruitment failure in a bay scallop (Argopectan irradians) population from a coastal New Jersey, USA. Journal of Shellfish Research 20:89-96.

Bologna, P., (2006). Assessing within habitat variability in plant demography, faunal density, and secondary production in an eelgrass (Zostera marina L.) bed. Journal of Experimental Marine Biology and Ecology V. 329 122–134.

Burkholder, J., Tomasko, D., & Touchette, B., (2007). Seagrass and Eutrophication. Journal and Experimental Marine Biology and Ecology 350: 46-72.

Deegan, L., Wright, A., Ayvazian, S., Finn, T., Golden, H., Merson, R., & Harrison, J., (2002). Nitrogen loading alters seagrass ecosystem structure and support of higher trophic levels. Aquatic Conservation: Marine and Freshwater Ecosystems. 12: 193-212.

Finkbeiner, M, B. Stevenson, and R. Seaman. 2001. Guidance for benthic habitat mapping: an aerial photographic approach. NOAA CSC 20117-PUB. http://www.csc.noaa.gov/benthic/mapping/pdf/bhmguide.pdf

Gastrich, M. D., Lathrop, R., Haag, S., Weinsteinn, M. P., Danko, M., Caron, D., Schaffner, R. (2004). Assessment of brown tide blooms, caused by Aureococcus anophagefferens, and contributing factors in New Jersey Coastal Bays: 2000-2002. Harmful Algae, Special Issue Brown Tides, 3, 305-320.

Harwell, M., Orth, R. (2002). Seed Bank Patterns in Chesapeake Bay Eelgrass (*Zostera marina*): A Bay-wide perspective. Estuaries. 25, 1196-1204.

Joseph, J., Purdy, K., & Figley, B. (1992). The influence of water depth and bottom sediment on the occurrence of eelgrass in Barnegat, Manahawkin and Little Egg Harbor bays. Marine Fisheries Administration, New Jersey Department of Environmental

Kennish, M. J., Haag, S., & Sakowicz, G. (2007). Demographic investigation of SAV in the Barnegat Bay-Little Egg Harbor Estuary with assessment of potential impacts of benthic macroalgae and brown tides. Technical Report 107-15, 47 Institutes of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey. 366 pp.

Kennish, M., Haag, S., & Sakowicz, G. (2008). Seagrass demographic and Spatial Habitat Characterization in Little Egg Harbor, New Jersey, Using Fixed Transects. Journal of Coastal Research, Special Issue 55, 148-170.

Kennish, M. J. (2001). Barnegat Bay-Little Egg Harbor, New Jersey: Estuary and Watershed Assessment. *Journal of Coastal Research*, Special Issue No. 32, 280 pp.

Lathrop, R., & Bognar, J. A., Hendrickson, A.C., & Bowers, P.D. (1999). Data Synthesis effort for the Barnegat Bay Estuary Program: Habitat Loss and Alteration in the Barnegat Bay Region, CRSSA Technical Report.

Lathrop, R.G. and Bognar, J.A. (2001). Habitat Loss and Alteration in the Barnegat Bay Region. Journal of Coastal Research, 32, 212-228.

Lathrop, R., & Conway, T,. (2001). A Build-out Analysis of the Barnegat Bay Watershed. CRSSA technical report. 1-11.

Lathrop, R., Montesano, P., & Haag, S. (2006). A muli-scale segmentation approach to mapping seagrass habitat using airborne digital camera imagery. Photogrammetric Engineering and Remote Sensing, 72(6), 665-675.

Lathrop, R., & Haag, S. (2007). Assessment of Land Use Change and Riparian Zone Status in the Barnegat Bay and Little Egg Harbor Watershed: 1995-2002-2006. Technical Report Barnegat Bay National Estuary Program (BB NEP), 1-27.

Macomber, R. T. & Allen D. (1979). The New Jersey submerged aquatic vegetation distribution atlas final report. Earth Satellite Corporation, Washington, D.C

Mclain, P. & McHale, M. (1996). Barnegat Bay eelgrass investigations 1995–1996, p. 165–172. *In* G. Flimlin and M. Kennish (eds.), Proceedings of the Barnegat Bay EcosystemWorkshop Rutgers Cooperative Extension, Toms River, New Jersey.

Moser, F. C. 1997. Sources and sinks of nitrogen and trace metals, and benthic macrofauna assemblages in Barnegat Bay, New Jersey. Ph.D. Thesis, Rutgers University, New Brunswick, New Jersey.

NOAA website for Magnetic delineations
http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp

Orth, J. R., Marion, S., Moore, K., and Wilcox, D., (2010). Eelgrass in the Chesapeake Region of the Mid Atlantic Coast of the USA: Challenges in Conservation and Restoration. Estuaries and Coast, 33, 139-150.

Pecchioli, J.A., Lathrop, R., & Haag, S. (2006). Brown Tide Assessment Project in NJ coastal waters: a comparison of three bloom years (2000-2002) to non bloom years (2003-2004). Research Project Summary, NJDEP.

Short, F. T., & Wyllie-Echeveria, S. (1996). Natural and human induced disturbances of seagrass. Environmental Conservation. 23(1), 17-27.

United States Census Bureau quick facts website
http://quickfacts.census.gov/qfd/states/34/34029lk.html

Waycott, M., Duarte, C., Carruthers, T., Orth, R., Dennison, W., Olyarnik, S., Calladine, A., Fourqurean, J., Heck, K., Hughes, R., Kendrick, G., Kenworthy, J., Short., F., & Williams, S. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceeding of the National Academy of Science. 106. 12377 – 12381.

Wazniak, C.E., Hall, M. R., Carruthers, T. J., Sturgis, B., Dennison, W. C., & Orth, R. J. (2007). Linking Water Quality to Living Resources in a Mid-Atlantic Lagoon System, USA. Ecological Applications, 17(5), 64-78.

X. Appendix

In situ reference data collected as part of the 2009 seagrass mapping effort.

percent cover *Z. marina*	percent cover *R. maritima*	percent cover macroalgae	percent cover seagrass	validation site (1 = yes, 0 = no, 2 outside image collection area)	UTM X	UTM Y
0	0	30	0	0	564437	4383598
0	0	0	0	0	564527	4383493
65	0	5	65	0	564678	4383433
50	0	14	50	0	564957	4383278
49	0	16	49	0	565162	4383169
50	0	24	50	0	565378	4383051
50	0	12	50	0	565639	4382920
62	0	9	62	0	565850	4382787
4	0	5	4	0	566189	4382590
0	0	0	0	0	566256	4382530
9	0	11	9	0	566246	4382584
6	0	0	6	0	567593	4384424
11	0	0	11	0	567486	4384469
6	0	21	6	0	567229	4384587
5	0	6	5	0	567080	4384688
22	0	0	22	0	566895	4384827
5	0	3	5	0	566656	4384994
32	0	2	32	0	566650	4385005
38	0	1	38	0	566427	4385146
29	0	1	29	0	566225	4385288
5	0	7	5	0	566037	4385440
1	0	11	1	0	565839	4385567
2	0	6	2	0	565622	4385723
1	0	2	1	0	565412	4385856
28	0	0	28	0	565242	4386009
81	0	3	81	0	564974	4386131
5	0	4	5	0	564780	4386294
0	0	4	0	0	564618	4386428
1	0	2	1	0	563394	4384794
0	0	2	0	0	563921	4382319
10	0	2	10	0	564020	4382251
75	0	10	75	0	564253	4382087
14	0	4	14	0	564397	4381898
77	0	13	77	0	564384	4381903
69	0	10	69	0	564584	4381760
9	0	7	9	0	564867	4381560
35	0	8	35	0	565005	4381357
2	0	7	2	0	569438	4391267
4	8	8	12	0	569681	4391053

6	1	6	7	0	569876	4390901
23	2	4	25	0	570060	4390744
36	0	8	36	0	570287	4390603
1	0	1	1	0	571349	4394740
2	0	1	2	0	571484	4394657
1	14	7	15	0	571760	4394537
2	1	4	3	0	572407	4394398
0	0	4	0	0	572315	4394311
7	3	6	10	0	572554	4394198
38	1	4	39	0	572807	4394102
74	0	3	74	0	572859	4394060
7	0	3	7	0	572870	4394035
15	2	6	17	0	573287	4393821
0	0	0	0	0	573219	4393836
0	0	0	0	0	573122	4393884
4	2	7	6	0	574431	4396744
32	0	3	32	0	574040	4396924
0	0	0	0	0	573542	4397192
0	0	4	0	0	573296	4397259
27	0	0	27	0	572979	4397342
84	0	0	84	0	572796	4397426
18	0	7	18	0	572582	4397504
12	0	18	12	0	572133	4401440
16	0	19	16	0	572339	4401370
40	0	41	40	0	572559	4401283
95	0	2	95	0	572797	4401186
2	20	25	22	0	573065	4401087
1	0	10	1	0	571998	4403190
0	0	12	0	0	572119	4403044
12	0	0	12	0	572297	4403077
3	1	8	4	0	572513	4403047
0	0	0	0	0	572883	4402874
0	0	0	0	0	572797	4403001
0	0	0	0	0	573048	4402936
0	0	0	0	0	573273	4402829
6	0	12	6	0	573504	4402831
0	0	0	0	0	574956	4405339
0	0	0	0	0	575174	4405559
0	0	0	0	0	576529	4417399
82	0	0	82	0	576332	4417404
2	0	0	2	0	576287	4417424
31	2	1	33	0	576700	4427354
96	2	0	98	0	576941	4417362
91	3	0	94	0	577177	4417342
94	2	0	96	0	577435	4417340
66	17	0	83	0	577699	4417372
0	0	0	0	0	577773	4417374
96	1	0	97	0	577942	4417337
3	20	0	23	0	578102	4417332
0	0	0	0	0	577803	4416945

80	2	0	82	0	577783	4416906
0	0	0	0	0	577730	4416485
0	0	0	0	0	577676	4416409
58	13	0	71	1	577419	4416553
7	7	0	14	0	577179	4416575
56	3	0	59	0	576821	4416655
75	0	0	75	0	576561	4416660
4	0	0	4	0	576285	4416675
1	0	0	1	0	576184	4414731
0	0	1	0	0	576457	4414713
0	0	0	0	0	575891	4414621
0	0	0	0	0	577043	4414569
90	1	0	91	0	577658	4414560
4	2	0	6	0	577472	4414521
74	0	0	74	0	577752	4414533
0	0	0	0	0	577893	4414494
1	14	0	15	0	577939	4412610
52	6	4	58	0	577519	4412579
26	11	2	37	0	577244	4412586
66	0	2	66	0	577035	4412562
4	4	3	8	0	576785	4412561
0	0	1	0	0	576597	4412531
0	0	0	0	0	567261	4388138
12	0	5	12	0	567462	4388082
74	0	0	74	0	567554	4388051
51	0	11	51	0	567710	4388025
16	0	9	16	0	567917	4387879
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0	0	0	0	0	568286	4387760
14	0	7	14	0	568336	4387966
12	0	11	12	0	568436	4387876
11	0	6	11	0	568547	4387785
24	0	5	24	0	568718	4387852
48	0	1	48	0	568295	4388249
70	0	3	70	0	569362	4388503
0	0	0	0	0	569188	4388527
74	0	0	74	0	568298	4388482
69	0	1	69	0	568377	4388786
68	0	4	68	0	568314	4389061
32	0	8	32	0	568015	4388785
0	0	0	0	0	567939	4388857
0	0	0	0	0	567832	4388963
0	0	0	0	0	567800	4389001
0	0	2	0	0	567610	4389121
0	0	0	0	0	567376	4389225
12	7	0	19	0	569436	4390796
48	0	4	48	0	569625	4390641
46	0	8	46	0	569891	4390373
3	0	5	3	0	570771	4391263
69	0	2	69	0	570118	4390353

3	0	0	3	0	569996	4389953
5	0	0	5	0	569636	4389076
0	0	0	0	0	569622	4389072
59	0	6	59	0	568724	4387158
81	0	0	81	0	568186	4387328
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0	0	15	0	0	560347	4377713
0	0	5	0	0	560265	4378089
0	0	18	0	0	559881	4378697
0	0	1	0	0	558153	4378879
0	0	0	0	0	558553	4378340
0	0	2	0	2	557505	4379874
0	0	5	0	0	560409	4380150
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2	0	5	2	0	566185	4382586
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72	0	4	72	0	562325	4379820
71	0	24	71	0	562455	4379470
69	0	1	69	0	574001	4399597
0	0	0	0	1	561142	4375660
0	0	0	0	1	560552	4376377
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0	0	1	0	1	558587	4379560
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0	0	0	0	1	558989	4380483
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0	0	1	0	1	560421	4380290
0	0	1	0	1	560794	4380734
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0	0	0	0	1	560755	4382391
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59	0	9	59	0	566144	4388630
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38	0	4	38	1	564824	4382599
0	0	0	0	1	566708	4388060

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80	0	1	80	1	566896	4387239
96	0	1	96	1	567533	4386926
9	0	32	9	0	568679	4386489
0	0	0	0	1	568070	4385771
24	0	4	24	1	567849	4386060
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0	0	0	0	1	564053	4382604
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0	0	0	0	1	563033	4381695
0	0	0	0	1	563514	4381135
0	0	0	0	1	562567	4380176
0	0	0	0	1	562550	4380081
0	0	0	0	1	562758	4379942
36	0	9	36	0	562265	4379866
0	0	1	0	1	562644	4377247
0	0	74	0	1	571298	4403537
0	0	32	0	1	572206	4403055
0	0	0	0	1	574352	4403271
0	0	0	0	0	575473	4403095
0	0	0	0	1	575419	4403332
4	22	2	26	1	573735	4399918
14	0	0	14	1	574169	4399292
37	0	6	37	1	574105	4398382
1	0	10	1	1	575079	4398639
66	5	9	71	1	571617	4398985
2	0	7	2	1	571537	4398370
6	0	0	6	1	571522	4397982
0	0	0	0	1	570244	4397097
0	0	0	0	0	569906	4397609
0	0	0	0	1	571370	4396215
1	8	0	9	0	571589	4395848
55	0	7	55	1	572895	4396173
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61	0	4	61	1	572722	4395065
4	0	4	4	1	571963	4394783
0	0	0	0	1	570386	4393416
0	2	2	2	1	569389	4393864
1	1	0	2	1	570231	4393027
2	1	4	3	1	569821	4392979
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0	0	0	0	0	570553	4392547
1	0	0	1	1	569624	4391646
1	0	6	1	1	568951	4391837
0	0	4	0	1	568862	4391973
94	0	0	94	1	568739	4388669
3	0	0	3	1	568909	4391107
89	0	0	89	1	568189	4389837
27	0	5	27	1	568194	4389345

82	0	2	82	1	568932	4388567
20	0	56	20	1	569536	4387962
0	0	0	0	1	567075	4383054
0	37	0	37	1	577889	4426660
0	18	0	18	1	579143	4426673
0	0	0	0	1	579213	4427124
0	91	0	91	1	578012	4427665
10	80	0	90	1	578296	4428100
0	0	0	0	1	579733	4430156
0	0	0	0	1	579389	4431066
1	0	12	1	1	580554	4434422
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0	0	2	0	1	577571	4433563
0	0	8	0	1	578856	4430734
0	0	0	0	1	578384	4430878
0	13	0	13	1	576679	4429727
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0	0	0	0	2	574725	4428223
0	0	0	0	2	574631	4427328
0	0	0	0	2	574646	4426704
0	0	0	0	1	575612	4426183
0	74	0	74	1	577422	4424066
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0	0	0	0	1	575714	4424010
0	0	0	0	1	576099	4423334
0	0	0	0	1	576682	4423170
0	14	0	14	1	577585	4422819
0	45	0	45	1	577662	4422808
0	0	0	0	1	578257	4422802
0	0	0	0	1	578385	4419989
0	0	0	0	2	571881	4421902
0	0	0	0	2	573722	4421066
94	5	0	99	1	576188	4416031
0	0	0	0	1	578185	4415176
76	8	12	84	1	577316	4414854
7	25	50	32	1	577455	4413430
2	1	0	3	1	577776	4413181
63	11	9	74	1	577619	4412809
9	28	29	37	1	577153	4413052
21	14	0	35	1	577311	4411997
1	1	0	2	1	576818	4411722
49	8	5	57	1	576903	4411170
21	24	6	45	1	577549	4410915
0	0	2	0	1	576948	4409989
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0	0	0	0	1	575527	4415088
0	0	0	0	1	574393	4415351
61	6	0	67	1	573956	4415898
0	0	0	0	1	577187	4416483
88	4	4	92	1	577461	4416555

89	0	0	89	1	577656	4416772
78	6	6	84	1	576817	4417144
0	0	0	0	1	573854	4408093
91	1	1	92	1	575427	4407923
31	6	12	37	1	575278	4407493
11	0	10	11	1	571186	4406470
83	0	0	83	1	570901	4406421
94	0	0	94	1	570701	4406189
1	0	1	1	1	573083	4405872
5	0	23	5	1	573947	4406036
1	0	14	1	1	574233	4406066
5	0	36	5	1	574162	4406378
11	0	39	11	1	574559	4406402
0	0	0	0	1	575084	4405509