Seagrass Vulnerability to Climate Change in Barnegat Bay
Barnegat Bay Partnership
Quality Assurance Project Plan

Barnegat Bay Partnership
August 2017

Approved by: ______________________ Dr. Jessie Jarvis, Principal Investigator University of North Carolina at Wilmington	8-18-17 date
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QAPP distribution list

Signed copies of this Quality Assurance Project Plan (QAPP) and all subsequent revisions will be sent to the following individuals by electronic mail:

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1. Project Objectives, Organization, and Responsibilities

1.1. Purpose of Study and Background Information

Seagrasses are an important component of estuarine ecosystems worldwide, including in temperate estuaries along the eastern coast of the United States (Short et al. 2007). Seagrasses serve as habitat and food for many recreationally and commercially important estuarine and marine species (*e.g.*, bay scallop [*Argopecten irradians*], blue mussel [*Mytilus edulis*], blue crab [*Callinectes sapidus*], and weakfish [*Cynoscion nebulosus*]) (Hughes et al. 2009). Seagrass beds also play a significant role in nutrient cycling, carbon sequestration, filtering of essential elements, and wave dampening (Orth et al. 2006). Within New Jersey coastal waters the vast majority of seagrasses are found within the Barnegat Bay-Little Egg Harbor complex. Eelgrass (*Zostera marina*) was historically the dominant species in the southern and central portion of the estuary, while widgeon grass (*Ruppia maritima*) was found in the northern section. Eelgrass biomass in the bay has declined substantially over the last 30 years, with the lowest recorded biomass occurring in 2010 (Fertig *et al*. 2013). While sampling in 2015 appeared to show a slight increase in eelgrass biomass, there was also a compositional change in the central portion of the bay, with widgeon grass becoming more dominant (Barnegat Bay Partnership 2016).

The abundance and distribution of seagrasses are impacted by a variety of environmental parameters (Short et al. 2007). Short-term, episodic events such as ice scouring, damage from boat props and anchors, disease, light intensity fluctuations caused by dredged or storm-tossed sediments, and algal blooms or overgrowth can all limit the extent of seagrass within Barnegat Bay. However, longer-term, chronic stressors, such as those brought on by climate change, present an even greater hazard to seagrass communities in Barnegat Bay. In particular, *Z. marina* is sensitive to water temperatures above 28 °C (Marsh *et al*. 1986). Seagrasses are vulnerable to increasing water temperatures which limit growth and survival through increased respiration (Marsh et al. 1986), increasing water depths due to sea level rise which reduce light availability below minimum requirements for survival (Duarte 1991), and changes in salinity due to increased/changed precipitation patterns (Short and Neckles 1999, Orth *et al.* 2006).

Large scale die-backs in eelgrass due to temperature and light stress have already been observed in Chesapeake Bay (Moore and Jarvis 2008, Moore *et al*. 2014). Gradual reductions in the distribution of *Z. marina* to depths < 2m have been attributed to low light conditions limiting photosynthesis (Dennison 1987). Additional episodic die-offs have been attributed to a two-week time period between July and August where water temperatures were 2 ºC warmer than average (Moore and Jarvis 2008), as can occur in shallow systems during droughts or heat waves. These *in situ* observations are supported by modeling scenarios where water temperatures were increased 1 ºC above average for a period of three years in Chesapeake Bay *Z. marina* meadows. Model outputs predict that, following the depletion of the viable sediment seed bank, a complete loss of *Z. marina* biomass would occur after two consecutive years of such temperature stress (Jarvis *et al*. 2014). Using space as a proxy for time, these fluctuations in the southern *Z. marina* populations show that small changes in water temperatures predicted to occur in New Jersey coastal estuarine systems can have lasting impacts on the resilience and survival of *Z. marina*, especially when light is also limiting.

On average, ocean temperatures in the upper 75 m have increased 0.11 ± 0.02 ºC per decade between 1971 and 2010 (Rhein *et al*. 2013). In the waters off of New Jersey, water temperatures have increased more rapidly, between 1 and 1.5 °C (1.8 – 2.7 °F) from 1901 – 2015 (U.S. EPA 2016). This has been reflected in higher mean water temperatures at the Little Egg Inlet in the southern end of the bay (Able and Fahay 2010). This, combined with sea levels that are expected to rise 45 cm in the next 100 years along the New Jersey coast, would put additional stress on *Z. marina* that could potentially severally limit its growth and survival (U.S. EPA 2016).

Less is known about the long-term effects of warming temperatures on *R. maritima*, but changes in the seagrass community composition in the central portion of the bay observed over the past several years suggests that a transition to a more widgeon grass-dominated system may be underway. As a superior competitor in warmer environments, the current climate change induced temperature trajectory would appear to favor *R. maritima*, though changes in salinity associated with changes in freshwater inflow could temper or acerbate that advantage. It is currently unknown what effects a potential change in the dominant seagrass species in the bay will have on the aquatic communities these grasses support.

1.2. Project Objectives

Restoration and mitigation of seagrass beds in Barnegat Bay is currently conducted in a haphazard fashion, where each effort is based upon a set of criteria selected by the project team, often with no thought given to the long-term viability of restored/mitigation areas in the face of climate change. The overarching goal of this project is to provide regulatory agencies and coastal managers with the information and tools they need to successfully support the bay's seagrass communities in light of changing climatic conditions. A secondary goal of this project is to inform the Barnegat Bay Partnership's undergoing revision to their Comprehensive Conservation and Management Plan (CCMP), which is likely to directly address restoration goals for seagrass beds in the bay. To accomplish these goals, we have set forth the following objectives to be met by the end of the grant period:

1. The development of geographic information system (GIS)-based habitat suitability maps for *Zostera marina* and *Ruppia maritima* in Barnegat Bay under future climate scenarios;
2. The construction of a webpage with interactive maps and user's guide to disseminate the information obtained under objective #1 to the community of practice;
3. The creation of public-friendly infographics that will discuss the potential impacts that climate change will have on seagrass communities; and
4. The facilitation of a workshop with regulatory agencies to promote the use of these climate change sensitive tools as part of a comprehensive approach to the planning and review of seagrass restoration/mitigation activities.

1.3. Secondary Data Needed

The secondary data needed for the seagrass model parameterization include seagrass data and environmental data that affect seagrass condition. Seagrass data have been collected by various investigators (Kennish *et al*., Jarvis *et al.*, Lacey and Vasslides) in Barnegat Bay utilizing similar methodologies and often under approved QAPPs. Seagrass data that may be utilized include vegetative shoot biomass and vegetative root biomass for eelgrass and widgeon grass, epiphyte biomass, seed-bank density, seedling density, and seedling shoot and root biomass. Examples of environmental data sets that may be needed include water temperature, photoperiod, photosynthetically active radiation, water column chlorophyll, total suspended solids, water column and sediment dissolved inorganic nitrogen, water column and sediment dissolved inorganic phosphorous, sediment hydrogen sulfide content, and sediment carbon content. These environmental data have been collected as part of the seagrass research projects identified above and also as part of the discrete and continuous water quality modeling conducted by the State of New Jersey, Barnegat Bay Partnership, and Stockton University.

Secondary data needed for the construction of the seagrass distribution forecast model will include the current (or near current) distribution of seagrasses in the bay (Lathrop *et al*.) and model derived predictions of air and water temperature and water depth under future climate change scenarios.

1.4. Planned Approach

Seagrass Production Model
Using the Stella Professional modelling platform (isee systems inc.) seagrass production modeling equations and parameter estimates will be refined or developed as necessary for *Zostera marina* and *Ruppia maritima* populations in Barnegat Bay. Data from the literature and previously collected *in situ* measurements of water column, sediment, and seagrass data will be used to calibrate the seagrass production model developed by Jarvis *et al*. (2014) and modified by Straub *et al*. (2015) to Barnegat Bay environmental conditions and will expand the model from *Z. marina* only to include both *Z. marina* and *R. maritima*. To develop the equations necessary for the spatially explicit ecosystem model, the initial seagrass production model simulation period will

run 1.5 years (May 1 year 1 through December 31, year 2) with a time step (dt) of 0.125 days (Jarvis 2014).

Once the equations have been developed for both species and the model is calibrated to Barnegat Bay conditions, the equations and parameter estimates will then be validated with data collected at the same sites but at different time steps in Barnegat Bay. Parameter values will be left unchanged for verification, but forcing functions will be updated to reflect the appropriate sites data. Comparisons will be made between computed and observed values on a monthly average basis. The sensitivity of base model conditions to all parameter estimates and forcing functions will be analyzed by sequentially varying values by ± 5, 10, and 20%.

Habitat suitability maps

The individual equations for *Z. marina* and *R. maritima* production will be made available for application in the development of a spatially explicit ecological model of Barnegat Bay. This model will be constructed using a Matlab script based on the Madden/Kemp model, which will then be updated using the Barnegat Bay specific parameters developed in the production model. We will translate seasonally driven changes in seagrass biomass to peak biomass measurements which will then be exposed to a variety of scenarios of air and water temperature at the model boundaries. The temperature range of those scenarios will be established using observed decadal trends, interannual variability, and/or future climatological modeling. Due to the uncertainty involved with modeling future geomorphic change, water depth will be varied offline and incorporated into the spatial parameter dataset. Once the model outputs have been verified, we will then calculate scenario specific suitability indices using model output and imposed depth changes over the summer growing season. This data will be combined to help develop interactive maps of potential climate change impacts on seagrass resources in Barnegat Bay.

Habitat Suitability Index

A habitat suitability index will be developed for seagrass meadows in Barnegat Bay based on changes in mean above-ground biomass, total meadow area, resilience indicators (flowering shoot biomass, viable seed bank density), and species composition using a modification of the method developed by Carter et al. (2015). Meadow condition will be divided into one of one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor) by comparing the current meadow condition against the baseline.

<u>*Baseline conditions*</u> for species composition and biomass will be based on average meadow conditions from 2004 – 2010 for *Z. marina* and 2010 conditions for *R. maritima* for the Northern, Central and Southern sections of Barnegat Bay as defined by Kennish et al. (2013). Meadow area baselined for each region will be based on 2009 aerial imagery (Lathrop and Haag 2011). Meadows will be classified as either single species dominated (one species comprising >80% of mean meadow biomass over the baseline period), or mixed species (all species comprise <80% of mean meadow biomass over the baseline period) (Carter et al. 2015).

A <u>*meadow classification system*</u> will be developed for biomass, area and species composition to account for the inherit range of stability of condition indicators within seagrass meadows as some indicators are historically stable, while in other meadows they are relatively variable (Carter et al.

2015). Through this classification system more sensitive thresholds can be applied to meadows that, based on their history, are not expected to vary greatly in terms of biomass, area or species composition, compared with more ephemeral meadows. The coefficient of variation (CV) will be used to determine the historical variability for each meadow and classify meadows as stable or variable for biomass and species composition. The CV will be calculated by dividing the standard deviation of the baseline by the baseline for each of the three condition indicators. Meadows with area, biomass, or species composition indicators with a CV < 40% will be classified as stable while meadows with a CV ≥ 40% will be classified as variable. Classifications will be used to define which set of threshold levels were appropriate to apply around each monitoring meadow's biomass, area and species composition baseline.

Threshold levels determining the condition of seagrass indicators (biomass, area, species composition) resulting from various climate model scenarios relative to the baseline will be selected based on meadow class (Carter et al. 2015). This approach will account for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region. Initial threshold levels will be based on published values (Table 3; Carter et al. 2015); however, several ranges of threshold values may be tested as part of this project to determine which ranges best fit the historical data, i.e. which ranges result in a grade that reflects our understanding of the condition of seagrasses for both stable and variable meadow types based.

Suitability indices will be based on a final score calculated between 0 and 1 for each condition indicator, in each meadow in each of the 3 regions. (Table 4; Carter et al. 2015). To calculate the score for each condition indicator for each model scenario, the scenario based grade for each indicator will be calculated. Then the score will be scaled for biomass, area or species composition against the prescribed score range for that grade. Scaling is required because the score range in each grade are not expected to be equal. To scale each score we will calculate the difference in the indicator (A_{diff}) between the model scenario indicator value (A_{model}) and the indicator value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$A_{diff} = A_{model} - A_{satisfactory}$$

Where $A_{satisfactory}$ or any threshold boundary will differ for each condition indicator depending on the baseline value, meadow class (stable, variable), and whether the meadow is dominated by a single species or mixed species. We will then calculate the range for area values (A_{range}) in that grade:

$$A_{range} = A_{good} - A_{satisfactory}$$

Where $A_{satisfactory}$ is the upper threshold boundary for the satisfactory grade. For species composition, the upper limit for the very good grade will be set as 100%. For area and biomass, the upper limit for the very good grade will be set as the mean plus the standard error (i.e. the top of the error bar) for the maximum recorded mean annual value for that indicator and meadow.

The proportion of the satisfactory grade (A_{prop}) that A_{model} takes up will then be calculated:

$$A_{prop} = \frac{A_{diff}}{A_{range}}$$

Finally, the indicator score for that meadow under each model scenario ($Score_{model}$) will be calculated by scaling A_{prop} against the Barnegat Bay score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

$$Score_{model} = LB_{satisfactory} + (A_{prop} \times SR_{satisfactory})$$

Where $LB_{satisfactory}$ is the Barnegat Bay defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.

Each overall meadow score will be determined by the lowest grade and score of the three condition indicators (biomass, area and species composition) within that meadow (Carter et al. 2015). The lowest score, rather than the mean of the three indicator scores, will be applied in recognition that a poor grade for any one of the three described a seagrass meadow in poor condition. Maintenance of each of these three fundamental characteristics of a seagrass meadow is required to describe a healthy meadow.

1.5. Project Organization and Responsibilities

The BBP Principal Investigator is responsible for overseeing the completion of this project, coordinating with the other PIs on specific activities. More details are provided in the following list of project participants and their responsibilities.

o **Principal Investigator**: Dr. James Vasslides, BBP

- Responsible for overseeing implementation of the project work plan, reviewing drafts of the products, managing the project budget, issuing contracts and agreements for any needed professional services, and processing invoices.
- Responsible for implementing the project work plan with assistance from PIs Jarvis and Ganju. Specific responsibilities include:
    - Assuring QAPP secondary data quality, performing data analyses where necessary and appropriate, overseeing the creation of maps and charts, providing the data, maps, and charts to the graphic designer, and working with the web developer to prepare a version of the output for the web site.

o **Principal Investigator**: Dr. Jessie Jarvis, UNCW

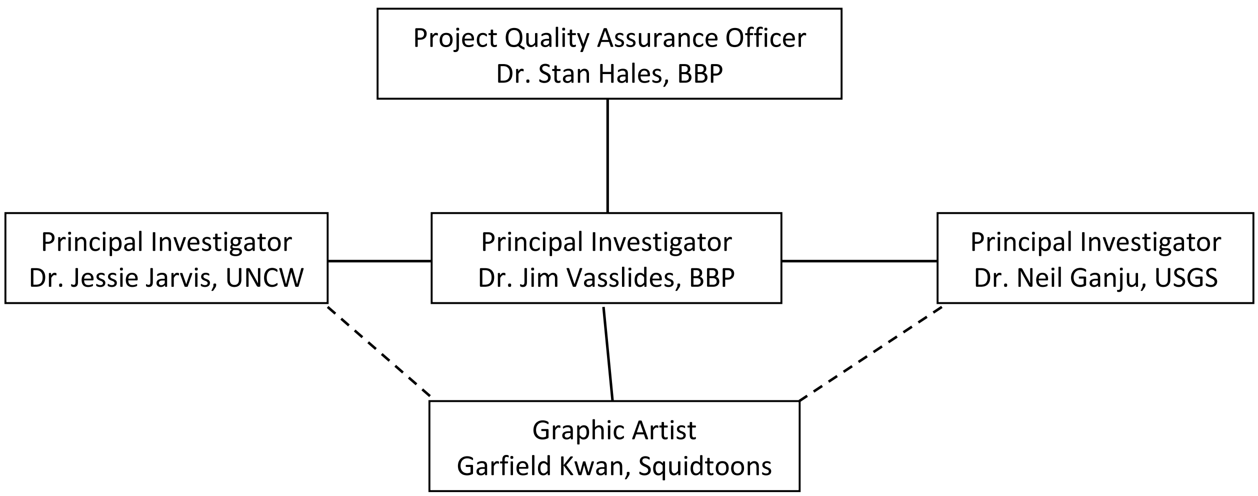
- Responsible for development, calibration, and validation of seagrass production modeling equations and parameter estimates, as well as the development of the habitat suitability index.

o **Principal Investigator**: Dr. Neil Ganju, USGS

- Responsible for the development of the spatially explicit seagrass distribution model and habitat suitability maps, including the integration of the seagrass production equations and configuring the hydrodynamic model to apply multiple scenarios of air and water temperature.

o **Project Quality Assurance Officer**: Dr. L. Stanton Hales Jr, Barnegat Bay Partnership
• Responsible for assuring QAPP secondary data quality.

Organizational Chart. Connecting lines represent the proper lines of communication between individuals. Dotted lines represent general guidance and feedback



1.6. Project Schedule

The tentative schedule for the project is provided in Table 1.

Table 1: Timeline for the Seagrass Vulnerability to Climate Change in Barnegat Bay project

	Task	Start Date	End Date
QAPP	QAPP preparation	July 2017	July 2017
Seagrass production equations	Collect and review data	July 2017	August 2017
	Develop and validate equations	July 2017	August 2017
Habitat suitability maps	Configure hydrodynamic model	July 2017	August 2017
	Integrate seagrass equations	August 2017	October 2017
	Create model outputs	September 2017	November 2017
Habitat Suitability Index	Develop baseline conditions	August 2017	October 2017

	Compare habitat suitability maps	October 2017	December 2017
Graphic production	Provide initial information to artist	July 2017	November 2017
	Produce 1st draft	November 2017	February 2018
	Final product	February 2018	June 2018

2. Sources of Secondary Data

2.1. Data Sources

This project will rely entirely on existing data, which will be obtained primarily from agencies, institutions and companies already conducting seagrass and water monitoring programs such as the United States Geological Survey, New Jersey Department of Environmental Protection's Bureau of Marine Water Monitoring, the BBP, and academic institutions. Data sources include published reports, unpublished data, and, most frequently, databases. Databases can typically be downloaded in their entirety, or queried for specific subsets of data, either by the user or by the data generators/managers via a formal or informal data request.

It is possible that additional data sources will be identified during the course of the project, as we interact more closely with scientists and experts. In addition, not all data obtained will necessarily be used, even if of adequate quality. All data sources will be fully referenced, including links to databases, and any documentation of data quality.

2.2. Data Generators

Data generators are, generally speaking, the agencies, research institutions, and other organizations that collect (or have collected) suitable (in terms of type of data being relevant to this project, covering an adequate geographic and temporal scale, and being of adequate quality) environmental data.

2.3. Hierarchy of Data Sources

In general, data carried out by trusted agencies, universities, or research institutions and with known and adequate quality control and quality assurance procedures will be preferred. Any limitations and gaps in data included in the project will be fully disclosed. Even if data are not of the best quality, they may represent the best available knowledge within the system and may not only provide a glimpse into current and future conditions, but also point to the need for improved data collection efforts.

2.4. Rationale for Selecting Data Sources

Given the specificity of this project's data needs (*i.e.*, various types of seagrass and environmental monitoring data collected from the Barnegat Bay, covering several years), in many cases there may be a single data source available. If more than one data source is available, all will be evaluated and the highest quality, most complete (in terms of spatial and temporal coverage) data sources will be used.

2.5. List of Sources of Secondary Data

The sources of all secondary data presented will be identified in any report or other project deliverables. Links to published data or online databases will be provided.

3. Quality of Secondary Data

3.1. Quality Requirements

Data should meet the following quality requirements. However, given the limited amount of certain seagrass and environmental data within our study area, it is likely that some datasets will not meet one or more requirements. These data may still be valuable for our purposes and, if used, any shortcomings will be noted.

- Data were generated by a reliable source. Although the identity of the data generator does not guarantee data quality, it provides a simple screening criterion when multiple data sources are available. The following are indicators of data source reliability.
  - Data generator is generally trusted and respected (federal, state, and local agencies, or research institutions; examples include, but are not limited to, U.S. EPA, NOAA, USGS, NRCS, NJDEP, Rutgers University, Stockton University).
  - Data are published in peer-reviewed articles or publications.

- Data have been collected for purposes similar to ours; *i.e.*, to assess the condition of seagrass.

- The project has a QAPP or similar plan documenting quality assurance and quality control procedures to ensure data accuracy, precision, representativeness, and comparability.

- Data have been widely used and/or trusted by scientists and professionals in the subject.

- Completeness
  - Spatial coverage
    - Dataset provides good coverage of the geographic area of interest.
  - Temporal coverage
    - For seagrass production equations, the data are of sufficient length and sampling frequency to capture the full range of seagrass life history.

3.2. Data Review and Evaluation

The quality of the secondary data will be based on data quality requirements defined in Section 3.1 of this document. In determining data quality, the completeness of the dataset will be assessed first, by inspecting data description (usually metadata) or the dataset itself (whichever is more easily available). If completeness is deemed adequate, other quality requirements will be assessed by inspecting the QAPP, other QA/QC documentation, metadata, and/or other information obtained from data providers.

3.3. Disclaimers

All project deliverables will inform of the existence of this QAPP. As stated previously, any limitations in data quality will be fully disclosed. If a decision is made to use data of unknown quality, this will be indicated in a disclaimer that will be added to any project deliverable.

4. Data Reporting, Data Reduction, Data Validation, and Records Management

4.1. Data Reduction

In general, data will be manipulated as little as possible, except where required for modeling needs.

The following are some examples of anticipated or possible data reduction procedures (provided that adequate data are available):

- Data units may need to be changed for report consistency and/or to allow comparisons across data sources

- Certain datasets may be reduced and presented as percentages (*e.g.*, percentage of time a beach was closed during the swimming season, or percentage of water open to shellfish harvesting)

- Some data reduction may also be needed to display data in map form (maps will normally be intended to summarize some of the available information). Possible data reductions include the following.
  - Average values for a given water quality parameter (*e.g.*, fecal coliform cell concentrations) across sampling locations within a sub-region of the Estuary (*e.g.*, Manahawkin bay) at a given date.

4.2. Data Validation

The reporting of accurate project data will generally be ensured by carefully conducting and clearly expressing data reduction (if and when needed) and visual inspection of data before including in final report. Specifically, we will follow the following validation process.

- A copy of every original dataset obtained from each data source will be saved as a read-only, protected file in the event the integrity of the working datasets is compromised.

- Working data will be stored in spreadsheet format and will include all relevant raw data, which will be locked for editing.

- Data manipulation will be minimized to decrease the chances of inadvertently introducing errors. If any data reduction or manipulation is needed, it will be calculated starting from the raw, protected dataset. All data for analysis will be converted into a secondary .csv file and then analyzed in R. All formulas, along with units and conversion factors, will be shown in annotated script in R. The formulas used will be checked by the PI and/or BBP Quality Assurance Officer, as will 10 percent of the calculations. If errors are encountered the percentage to be checked will increase to 25.

- In rare occasions, a dataset may only be available in hard copy format. In these cases, data will be manually entered into a spreadsheet. To ensure an error-free copy, summary statistics will be checked if possible, and 10 percent of the data will be spot-checked by the PI and/or BBP Quality Assurance Officer. If errors are encountered the percentage to be checked will increase to 25.

4.3. Deliverables

The deliverable of this project will be a report and a series of digital graphic pieces. Both the report and the graphics will be available in hard copy and online.

4.4. Records Management

The following project-related documents and records will be kept by the Barnegat Bay Program office for as long as possible and for a minimum of three years from the date of the final Financial Status Report to EPA, as stipulated by 40 CFR § 31.42:

- Original files and materials (either electronic or in print) obtained from the data providers, including datasets, data quality information, reports, and other relevant information pertaining the data and data interpretation;

- Working data spreadsheets which will document any data reduction, anomalous data removal, and other issues;

- Draft and final versions of the report;

- Files exchanged with graphic designer, printer, and other contractors; and

- Other relevant documents and materials.

5. References

Carter AB, Jarvis JC, Bryant CV & Rasheed MA (2015). Development of seagrass indicators for the Gladstone Healthy Harbour Partnership Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research Publication 15/29, James Cook University, Cairns, 71 pp.

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Lathrop RG & Haag SM (2011) Assessment of seagrass status in the Barnegat Bay – Littler Egg Harbor Estuary System: 2003 and 2009. CRSSA Technical Report, Rutgers University, New Brunswick, NJ, 56 pp.

Straub P, Jarvis JC, Evert S (2015) Modelling *Zostera marina* restoration potential in Barnegat Bay New Jersey. Barnegat Bay Partnership Final Report. 38 pp.