Quality Assurance Project Plan

Blue Carbon Storage in Natural Estuarine Wetlands and Living Shorelines of Delaware and New Jersey

Barnegat Bay Partnership
with
Academy of Natural Sciences at Drexel University,
Center for Inland Bays and
Partnership for the Delaware Estuary
June 2016 – Dec 2017

1.0. Project Management

Approvals

Management Approvals:

Signature indicates that this QAPP is approved and will be implemented in conducting the research of this project.

Erin Reilly Project Manager	*Signature*	10/24/16 *Date*
Martha Maxwell Doyle Quality Assurance Officer	*Signature*	10/24/16 *Date*
Elizabeth Watson Principal Investigator Academy of Natural Sciences at Drexel University	*Signature*	10/24/16 *Date*
Danielle Kreeger Principal Investigator Partnership for the Delaware Estuary	*Signature*	10/25/16 *Date*
Marianne Walch Principal Investigator Center for Inland Bays	*Signature*	11/1/16 *Date*

Quality Assurance:

Signature indicates that this QAPP meets the quality requirements of EPA.

James Vasslides BBP Quality Management Plan Coordinator	*Signature*	10/26/16 *Date*

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3.0 Distribution List

Erin Reilly, Field and Lab Coordinator
Barnegat Bay Partnership
ereilly@ocean.edu
732-914-1049

Martha Maxwell Doyle, Project Coordinator
Barnegat Bay Partnership
mmdoyle@ocean.edu
732-914-8108

James Vasslides, Program Scientist
Barnegat Bay Partnership
jvasslides@ocean.edu
732-914-8107

David Velinsky, Vice President for Research
Academy of Natural Sciences Drexel
djv23@drexel.edu
215-299-1147

Elizabeth Watson, Wetlands Section Leader
Academy of Natural Sciences Drexel
ebw49@drexel.edu
215-299-1109

Kirk Raper, Wetland Project Coordinator
Academy of Natural Sciences Drexel
klr323@drexel.edu
215-299-1025

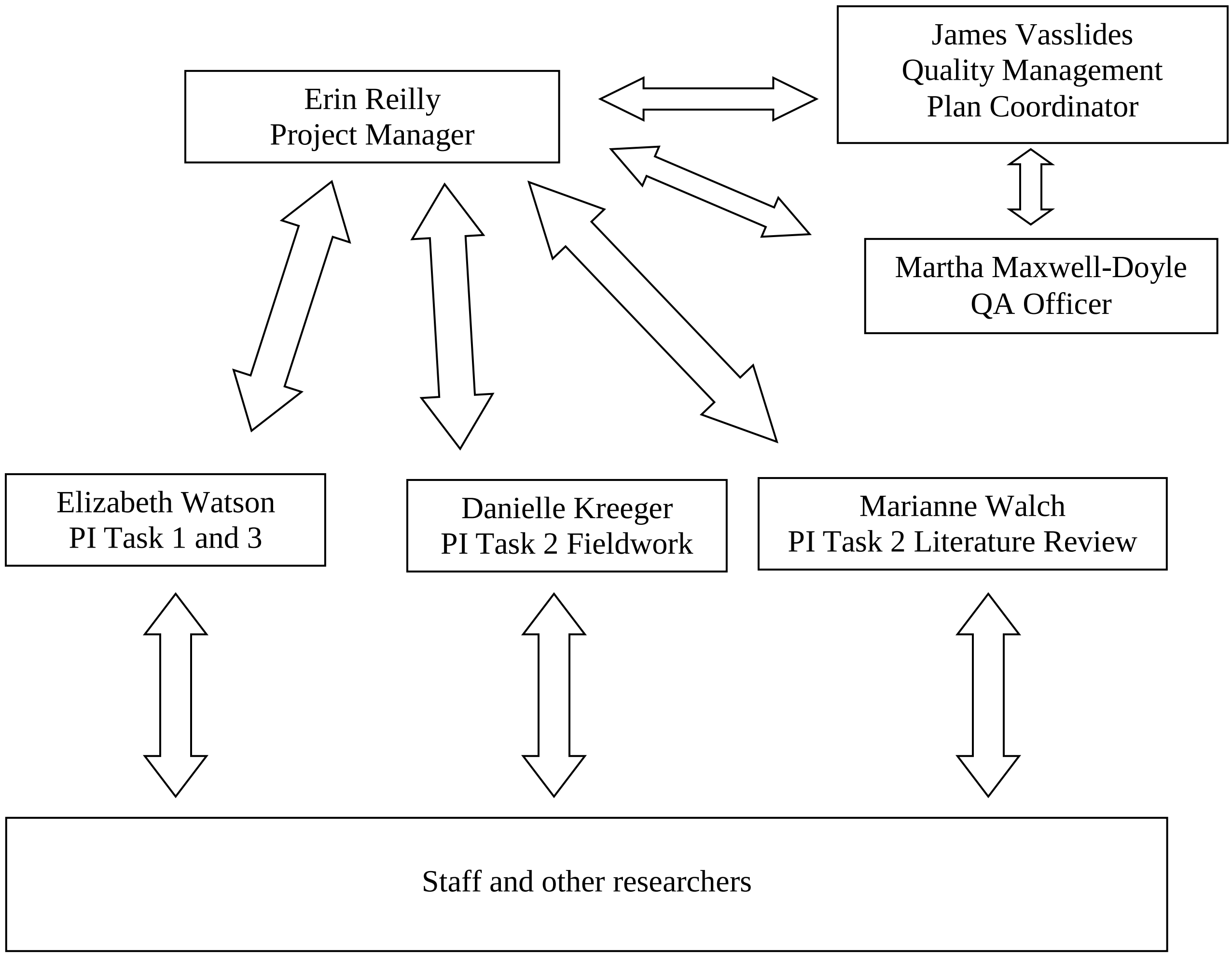
Danielle Kreeger PhD, Science Director
Partnership for the Delaware Estuary
dkreeger@delawareestuary.org
302-655-4990 x 104

LeeAnn Haaf, Wetland Specialist
Partnership for the Delaware Estuary
lhaaf@delawareestuary.org
302-655-4990 x 116

Marrianne Walch, Program Scientist
Center for Inland Bays
science@inlandbays.org
302-226-8105 x105

Sunny Jardine, Assistant Professor
University of Delaware
jardine@udel.edu
302-831-1503

4.0 Project /Task Organization



5.0 Special Training Requirements/Certifications

5.0.a Task 1

Task one requires experience and training in core analysis. Dr. David Velinksy will be overseeing this work. Dr. Velinsky has over 25 years of experience in sediment and water biogeochemistry and has cored in various environments, including the Anacostia River, Delaware Estuary, and Potomac River. Dr. Velinsky is currently the Director and Vice President of the Patrick Center for Environmental Research and Senior Scientist of the Environmental Geochemistry Section within the Center (see http://www.ansp.org/research/pcer/index.php for more details).

5.0.b Task 2

Field staff will need to be trained in the proper methodologies for sample collection or processing. This training will be provided by LeeAnn Haaf, Wetland Specialist at the Partnership for the Delaware estuary, who has been previously trained in these methods under the umbrella QAPP entitled "Intensive Monitoring and Assessment Program for Tidal Wetlands of Delaware, New Jersey & Pennsylvania, Version 1.0 (see Appendix A - SSIM Umbrella QAPP section 5.0)

5.0.a Task 3

Task 3 requires experience and training in using Picarro G2508 gas chambers. Dr. Elizabeth Watson of ANS-PCER and Drexel University will be responsible for project oversight, greenhouse gas emission measurements, geospatial analyses, data synthesis, interpretation, and report writing. She has over 15 years of experience in sediment core analysis and has collected and analyzed sediment cores for organic content, carbon content, sediment density and other metrics from over two hundred locations along the U.S. Pacific and Atlantic coasts and in Mexico. Dr. Watson has a Ph.D. in geography, experience conducting research using remote sensing and geospatial analysis techniques, and has been measuring gas fluxes in wetlands for over five years. Dr. Watson is an assistant professor in the department of Biodiversity, Earth & Environmental Sciences Department at Drexel University and a senior scientist in the Patrick Center for Environmental Research, Academy of Natural Sciences.

6.0 Problem Definition/Background

6.1 Problem Definition

The overall goal of the research and outreach activities outlined by this proposal is to evaluate the carbon dioxide mitigation benefits provided by natural and restored (living shoreline) coastal wetlands in Delaware and New Jersey, including the study regions of three National Estuary Programs (Barnegat Bay Partnership [BBP], Center for Delaware Inland Bays [CDIB], Partnership for the Delaware Estuary [PDE]). Specific research objectives are three-fold: (1) to estimate the overall carbon stock and rates of sequestration through compilation of extensive archived data; (2) contrast carbon stocks between natural wetlands and living shoreline projects through compilation of literature data and pilot field measurements; and (3) preliminarily quantify offsets of carbon mitigation benefits that coastal wetlands provide due to elevated methane or nitrous oxide emissions.

6.2 Background

Coastal wetlands are a top priority of the three National Estuary Programs that are collaborating on this project because they are extensive, foundational habitats that supply diverse ecosystem services critical to the region, including fish and wildlife habitat, water quality, flood protection, and carbon storage. Although vegetated coastal habitats cover less than one fraction of one percent of the earth's surface (~0.1%), they efficiently sequester organic carbon (C) due to high rates of primary production and soil profiles that do not become saturated in C. Rather, vegetated coastal habitats aggrade in response to sea level rise, and organic carbon buried by sediment accumulation is sequestered under anoxic conditions. The burial of organic carbon in coastal wetland and seagrass beds has been termed 'blue carbon', and has been estimated at ~100 Tg C yr-1, ten times greater than C burial by the deep sea, and of similar magnitude to the C sequestered by terrestrial forests and burial on the continental shelf (Hopkinson et al., 2012). Saline tidal wetlands are especially valuable as carbon sinks as their net climate forcing is not reduced by emissions of the potent greenhouse gas methane, which is given off by fresh and brackish wetlands, and has a higher global warming potential (25xs) than carbon dioxide (Moseman-Valtierra, 2012).

Several state-based and global initiatives aim to monetize carbon sequestered by protected and restored tidal wetlands as an effective climate-change mitigation strategy (Murray et al., 2011), and opportunities for carbon payments to protect sequestered blue carbon already exist (CEC, 2013). Despite being two of the smallest states, Delaware and New Jersey contain extensive coastal wetlands, but these critical habitats are being lost at high rates (e.g., ~1 acre per day in the Delaware Estuary; PDE, 2012a). Loss of salt marsh might lead to a short term pulse of carbon dioxide due to metabolism of eroded peat, as well as lost future carbon capture. Hence, efforts to stem coastal wetland losses, such as via new living shoreline tactics, have the potential to avert peat metabolism and/or sustain future C sequestration.

Accurate assessment of the carbon stocks in Delaware and New Jersey's coastal wetlands will contribute to the economic valuation of this beneficial ecosystem service. Additionally, the expansion of carbon markets will increase investment in coastal habitat conservation, and accurate data on existing carbon stocks and sequestration rates will be necessary to wisely guide investments such as living shoreline project designs.

7.0 Project Description

This project consists of three tasks. Task 1: Carbon Stocks, Current & Historical Sequestration Rates; Task 2: Carbon Stocks and Accumulation Rates in Living Shorelines and Task 3: Pilot Evaluation of Mitigation Offsets from Methane and Nitrous Oxide Emissions.

7.1 Task Description

7.1.a Task 1 - Carbon Stocks, Current & Historical Sequestration Rates – Academy of Natural Sciences at Drexel University

An integrated assessment of the magnitude of the soil carbon stock for New Jersey's estuarine wetlands will be conducted using existing and archived sediment core data, and soil core data collected over the last five to eight years as part of a regional assessment funded by the Delaware River Basin Commission and New Jersey Department of Environmental Protection (Velinsky and Sommerfield, unpublished data; Velinsky *et al.*, 2010) and EPA-funded site specific intensive monitoring at a network of coastal wetland sentinel sites (PDE, 2012b). Although collected for other purposes, and not currently published, data for soil C, N and P accumulation rates for yearly to centennial time scales is archived by researchers at the Academy of Natural Sciences of Drexel University and University of Delaware. Over a dozen soil cores dating back 100-200 years (or longer) have been collected from wetlands in Barnegat Bay and Delaware Bay (*i.e.*, across the salinity regime of the estuary) over the past eight years and analyzed for CNP density using recommended methods (Howard *et al.,* 2014 and others).

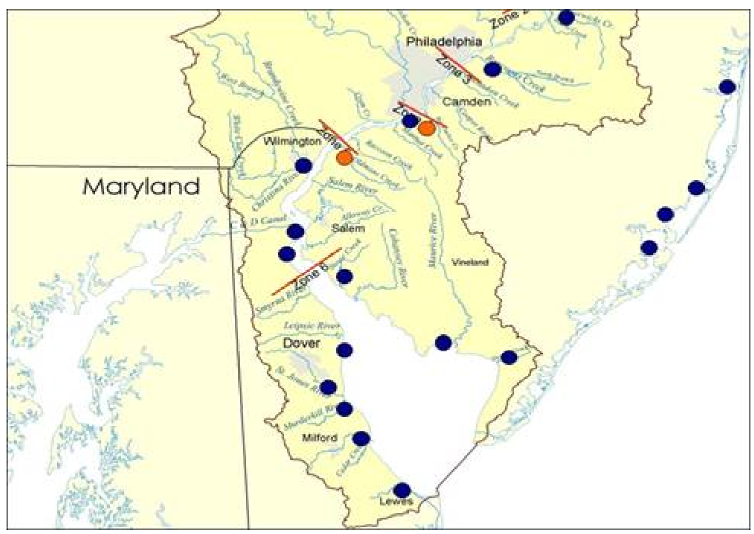


Figure 1. Coring locations throughout Delaware and NJ

These cores have been dated using a geranium well detector (Canberra, Meridian, CT, USA) for measurement of the radioisotopes ^{210}Pb, ^{226}Ra, and ^{137}Cs for calculation of sediment accumulation rates. In addition, seasonal to annual measures of soil C have been performed at 10 wetland sentinel sites over the past 3-5 years at stations set along transects perpendicular to the main watercourse. Furthermore, seasonal measures of accumulation rates, including estimates of C accumulation, have been performed above feldspar marker bed plots deployed at the same 10 wetland sentinel sites. These data sources comprise a unique and thorough compilation of soil C density and C sequestration rates from a number of sites that experience a range of salinity and inundation conditions, from macro- to micro-tidal and from fresh to saline. This meta-analysis of existing data will allow us to estimate soil C density and sequestration on various time scales for all of Delaware and Barnegat Bay, and to identify trends in CNP sequestration resulting from changes in wetland areal extent over past decades in response to anthropogenic development pressures and climate change impacts. Additionally, consideration of estuarine wetland C sequestration across such a broad range of environmental conditions (*i.e.*, tidal fresh to saline), and in relation to other monitoring data (*e.g.*, water quality, biomass) should allow us to identify controls on soil C density and sequestration that may be relevant for the design of restoration or conservation projects where carbon-capture or CO_2 mitigation is a primary focus.

7.1.b Task 2. Carbon Stocks and Accumulation Rates in Living Shorelines – Partnership for the Delaware Estuary and Center for Inland Bays

Living shorelines consist of a variety of tactics designed to stabilize and enhance the ecology of eroding coastal wetlands, but little is known regarding the carbon sequestration benefits of these new restoration practices because such projects have typically been implemented and assessed for their other ecosystem benefits (*e.g.*, coastal flood protection, fish and wildlife enhancement). We will first perform an extensive assessment of existing published and gray literature to parameterize the carbon sequestration processes and potential benefits of living shoreline projects compared with natural marshes. To support this review with local empirical data, carbon stocks and accumulation rates will also be assessed in existing and newly installed living shoreline projects as a pilot study of their carbon capture abilities. Numerous living shoreline projects have been installed since 2008 to enhance salt marshes in the study area, including at sites in all three National Estuary Program study areas. Some installations are recent (2014) and two are more mature (2008-2010). All living shorelines are being monitored in comparison to untreated controls, including feldspar marker horizons to assess surface accretion at some sites. To date, however, this monitoring has not included belowground cores to assess carbon stocks. As a pilot test to compare C storage and sequestration associated with living shoreline projects, soil C density and surface accretion will be added to existing seasonal monitoring and

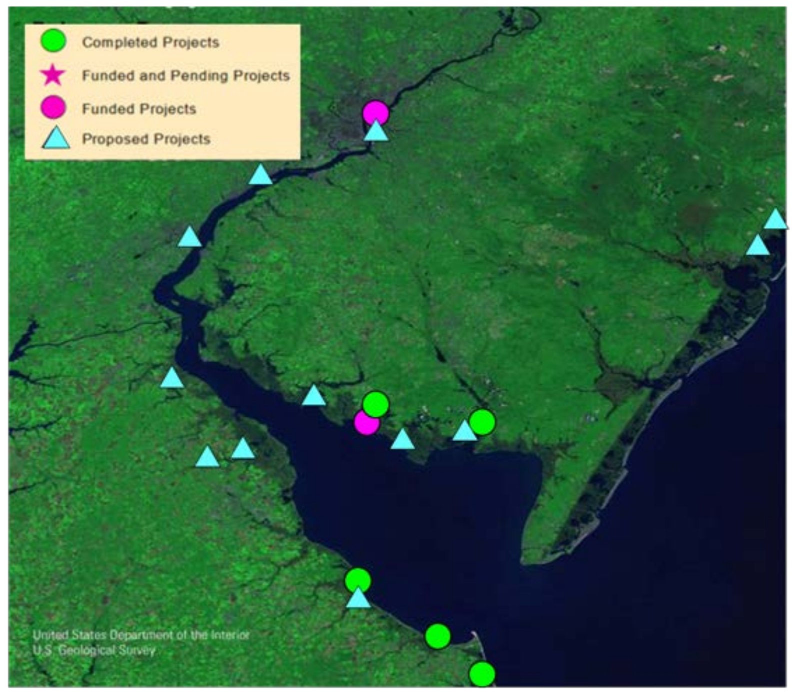


Figure 2. Various Living Shorelines proposed, completed and funded in Delaware and New Jersey.

contrasted among new living shoreline projects, aged living shoreline projects, and adjacent untreated controls. Results from Task 2 will also be compared with outcomes from Task 1 to understand how C capture processes may differ between the marsh platform and edge.

7.1.c Task 3. Pilot Evaluation of Mitigation Offsets from Methane and Nitrous Oxide Emissions – Academy of Natural Sciences at Drexel University

The net climatic benefits of carbon sequestration by coastal wetlands may be offset by wetland emissions of methane and nitrous oxide, which have 25 and 298 times the global warming potential of carbon dioxide (Moseman Valtierra, 2012). Coastal wetland methane emissions have been well studied in the region (Weston *et al.,* 2014), and net ecosystem fluxes may be estimated as a function of salinity for both estuaries. However, recent experiments have suggested that coastal wetlands subject to short-term amendment experiments produce and emit nitrous oxide as a byproduct of denitrification (e.g., Moseman-Valtierra *et al.*, 2011) at rates of up to several thousand times background ecosystem fluxes of nitrous oxide (Muñoz-Hincapié *et al.*, 2002). Because nitrous oxide absorbs radiation in wavelengths that differ from the more common atmospheric greenhouse gasses (water and CO_2), it is has a global warming potential of nearly 300 times that of carbon dioxide. These experiments suggest that in estuaries subject to high nutrient loads, wetlands may not provide the same global warming mitigation benefits as more pristine sites. Developing a better understanding of nitrous oxide emissions in nutrient-impacted estuaries is thus key for effectively siting carbon capture projects in estuaries, including protection or restoration projects such as living shorelines. A recently funded ($1.3 million) project aimed to help resolve this issue (NOAA, 2014), but the study sites chosen by collaborators on Cape Cod, MA, turned out to have lower nutrient loads and water column nutrient values than many other Northeastern estuaries (Narragansett Bay, Hudson-Raritan Estuary, Delaware Bay), leaving this question largely unresolved (Moseman-Valtierra, University of Rhode Island, *pers. comm.*). Thus, this pilot effort potentially provides new and useful information on nitrous oxide emissions that is relevant to national and international policy, and future carbon storage projects. We propose to monitor greenhouse gas emissions, including nitrous oxide, from multiple locations in Delaware and/or Barnegat Bay where monitoring programs have established that nutrient inputs and water column values are known to be high. At 10 plots per site, open-top collars with be established in the wetlands. Static chambers will be used to encompass plants, and a state of the art field based gas analyzer (Picarro G2508) will be used to measure changes in the concentration of carbon dioxide, water, ammonia, methane, and nitrous oxide concentration over time. Measures will be conducted in late summer in accordance with established methods (Chmura *et al.,* 2011). Measures of nitrous fluxes will then be converted to CO_2 equivalents. Results will be interpreted to guide potential expanded assessments at other wetland locations of the study region.

7.2 Timeline:

Task	Sub-Task	Time frame
Task 1 Carbon Stocks, Current and Historical Sequestration Rates	Data Analysis	July 2016– January 2017
Task 2 Carbon Stocks and Accumulation Rates in Living Shorelines	Literature Review	Summer- Winter 2016
	Field assessment of living shoreline and control sites	August 2016
	Processing of Biomass Cores	August 2016- January 2017
	Soil Sample Processing	August 2016 – January 2017
	Data Analysis	August 2016 – January 2017
Task 3 Pilot Evaluation of Mitigation Offsets from Methane and Nitrous Oxide Emissions	Greenhouse gas emissions measurements	July 2016
	Data Analysis	July 2016 – January 2017
Task 4 Final Report Writing and dissemination		January 2017 – June 2017

Table 1. Summary of timeline, milestones and roles for tasks and sub-tasks.

8.0 Quality Objectives and Criteria for Measurement Data

The project quality objective is to collect accurate and precise data in order to evaluate carbon dioxide mitigation benefits provided by natural and restored (Living Shorelines) coastal wetlands in Delaware and New Jersey. Data that will be collected include below ground biomass, soil C density and surface accretion at living shoreline sites and control sites along untreated marsh edges (Task 2), and greenhouse gas emissions (CO_2, CH_4, N_20) from Barnegat Bay, Delaware Bay, and Delaware's Inland Bays (Task 3).

8.1 Precision

8.1.a – Task 1

Samples are not being collected and analyzed as part of this project. Sample analysis was conducted under Quality Management and Quality Assurance Plans approved by the Delaware Natural Resources and Environmental Control, the Delaware River Basin Commission and the New Jersey Department of Environmental Protection (QA procedures can be found in Appendix B). Precision of samples analyzed for bulk density and organic carbon was reported as relative percent difference (RPD) as:

$$RPD = \frac{(C_1 - C_2)}{(C_1 + C_2)/2} \times 100$$

where C1 represents the first measured value and C2 represents the second measured value.

8.1.b - Task 2

Precision is the measure of the degree to which two or more measurements are in agreement. Precision will be assessed through the collection and measurement of field replicates. Relative Percent Difference (RPD) shall be calculated for each of the replicates collected for all the parameters analyzed. Precision in the laboratory is assessed through the calculation of RPD for matrix spikes and matrix spike duplicates and of the field split samples.

RPD is calculated using the equation $RPD = \frac{S - D}{0.5(S + D)} \times 100$

Where:

S = Amount in Spike 1 or concentration of parameter in original

D = Amount in Spike 2 or concentration of parameter in replicate

Large inherent variability in parameters prohibits a strict acceptability criteria. Any unusual or exceptionally high RPD value will be noted and discussed with the PI, PM, and QAO.

8.1.c - Task 3

Precision is the degree of agreement among repeated measurements of the same characteristic on the same sample or on separate samples collected as close as possible in time and place. Repeat measurements of greenhouse gas emissions, with the expectation of identical numbers, are not possible in the field because in full sun conditions polycarbonate chambers may be overheated after 10 minutes, meaning that repeated measurements under identical circumstances are not possible (Butterbuch-Bahl et al. 2015). To reduce uncertainty in emission measurements, 10 measurements per site will be conducted.

8.2 Bias

8.2.a Task 1

Samples are not being collected and analyzed as part of this project. Sample analysis was conducted under Quality Management and Quality Assurance Plans approved by the Delaware Natural Resources and Environmental Control, the Delaware River Basin Commission and the New Jersey Department of Environmental Protection (QA procedures can be found in Appendix B). Bias detection was performed using standard reference materials and method blanks.

8.2.b Task 2

Systematic or persistent distortion of a measurement process causing errors in one direction (bias) is not anticipated in analyses. Sample extraction location within treatment areas (living shorelines) will be carefully selected by the PI, to ensure representativeness. Biomass material sorting will be performed by a team of 2-3 individuals which will be cross analyzed/double checked during the analysis process. In addition, the final report will describe the manner in which bias was evaluated for the project.

8.2.c - Task 3

Greenhouse gas fluxes are known to covary with temperature (Schaufler et al. 2010). Both in-chamber and soil temperature will be measured, and if fluxes vary as a function of temperature, fluxes will be normalized to a standard temperature (Watson et al. 2015).

8.3 Representativeness

8.3.a Task 1

Samples are not being collected and analyzed as part of this project. Sample analysis was conducted under Quality Management and Quality Assurance Plans approved by the Delaware Natural Resources and Environmental Control, the Delaware River Basin Commission and the New Jersey Department of Environmental Protection (QA procedures can be found in Appendix B).

8.3.b Task 2

Representativeness expresses the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. Representativeness is dependent upon the proper design of the sampling program and will be satisfied by ensuring that the sampling and analysis plan is followed and that proper scientifically vetted sampling techniques are used.
To cater to representativeness, 3 previously installed living shorelines in two different states (Delaware and New Jersey) will be sampled. Each site was chosen based on its age, to capture the effects of maturity and how carbon stocks would change post installation.

8.3.c - Task 3

Representativeness refers to the extent to which data actually depict the true environmental condition, characteristic of a population, parameter variations at a sampling point or process condition. 10 measurements will be collected per site and samples will be collected at 4 sites throughout the region.

8.4 Comparability

8.4.a Task 1

Samples are not being collected and analyzed as part of this project. Sample analysis was conducted under Quality Management and Quality Assurance Plans approved by the Delaware Natural Resources and Environmental Control, the Delaware River Basin Commission and the New Jersey Department of Environmental Protection (QA procedures can be found in Appendix B). The use of accepted sampling procedures and analytical methods procedures will assure representativeness of the data compared to local, regional and international studies and monitoring (Sommerfield and Madsen 2004; Sommerfield 2005; Church et al. 2006).

8.4.b Task 2

Comparability is an expression of the confidence with which one data set can be compared with another. Comparability is dependent upon the proper design of the sampling program and will be satisfied by ensuring that the field sampling plan is followed by all personnel and that proper training and measuring techniques are used consistently. Resulting data will be determined to be comparable when similar sampling and analytical methods are used and documented in the QAPP. Comparability is also dependent on similar QA objectives.

8.4.c - Task 3

Comparability is the extent to which data from one study can be compared directly to either past data from the current project or data from another study. The use of accepted sampling procedures and analytical methods used elsewhere in the 'Blue Carbon' community will ensure comparability of the data. Accepted analytical methods used in other studies include Bresney et al. 2015; Martin and Moseman-Valtierra 2015, Brannon et al. 2016, and other studies (Wigand et al. 2010; Chmura et al. 2011), using cavity ring-down spectroscopy to make multiple field based measurements per site. The use of accepted sampling procedures and analytical methods procedures will assure representativeness of the data compared to local, regional and international studies and monitoring (Rochette and Eriksen-Hamel 2008; Sander and Wassmann 2014). These methods include duration of chamber closure (<30 minutes), number of replicates (>3), avoiding chamber heights lower than 10cm, using an vented base and chamber device, and testing for nonlinearity of changes in headspace concentration with time.

8.5 Completeness

8.5.a Task 1

Samples are not being collected and analyzed as part of this project. Sample analysis was conducted under Quality Management and Quality Assurance Plans accepted by the Delaware River Basin Commission and the New Jersey Department of Environmental Protection (See attached). The amount of carbon sequestration data being made available as part of this project - while very extensive – is very limited compared to the area of wetlands in Barnegat and Delaware Bay. To accurately estimate carbon sequestration, error analysis (based on the square root of the sum of squares of the fractional errors; Taylor 1982) will be used to propagate uncertainties in carbon sequestration values, based on site-to-site variability in carbon sequestration, spatially.

8.5.b Task 2

Completeness is a measure of the amount of valid data obtained from a measurement system compared to the amount of data that was expected to be obtained under normal conditions. Field completeness is a measure of the amount of valid measurements obtained from all the measurements taken in the field. The goal for this project would be to collect 10 (2 per each of the 5 sites) biomass cores and 10 bulk density samples, then analyze for dead biomass and carbon content via loss on ignition in order to estimate carbon stocks. However because half of the samples are replicates, the overall completeness goal would be at least 60%, with one valid sample per each site.

Completeness will be calculated as the ratio of the number of sample results to the total number of samples analyzed with a specific matrix and/or analysis. Following completion of all data collections for a given station sampling or project, the percent completeness will be calculated by the following equation:

$$Completeness = \frac{V}{P} \times 100$$

Where:

V = Number of valid measurements.

P = Number of planned measurements.

8.5.c - Task 3

Completeness is the fraction of planned data that must be collected in order to be sufficient for the intended use of the data. Here, we are collecting 10 measurements per site. The minimum number of samples to be collected in order to detect differences in fluxes between sites will vary depending on the flux values – the magnitude and their variability. It is therefore not possible to *a priori* determine the number of measurements needed at sites.

8.6 Sensitivity

8.6.a Task 1

Samples are not being collected and analyzed as part of this project. Sample analysis was conducted under Quality Management and Quality Assurance Plans approved by the Delaware Natural Resources and Environmental Control, the Delaware River Basin Commission and the New Jersey Department of Environmental Protection (QA procedures can be found in Appendix B). The lower detection limit of the Flash 2000 elemental analyzer is approximately 0.1% (Thermo Scientific 2016), much lower than the range of wetland soils found in Delaware and Barnegat Bay, where soils are generally 5% organic carbon (Weston et al. 2014).

8.6.b Task 2

The sensitivity for each analytical metric can be found in the appropriate SOP (Table 2 for a list of SOP which can be found in Appendix C). If the minimum concentration cannot be measured that specific sample will not be used in analysis. If it is determined that a sampling protocol is not capturing a majority of samples then the metric will be reevaluated by the project team.

Analytical Metric	SOP #
Below Ground Biomass	PDE 39
Above Ground Biomass	PDE 38
Loss on Ignition	PDE 33

Table 2: Analytical Metric and SOP #

8.6.c - Task 3

Sensitivity is the capability of methodology or instrumentation to discriminate among measurement responses for quantitative differences of a parameter. The sensitivity of the Picarro G2508 to methane and nitrous oxide fluxes were found to be 9.0 x 10-4 ppb s^{-1} and 4.5 x 10-2 ppb s^{-1}, respectively for a 360 chamber incubation period (Brannon et al. 2016). For comparison, the use of headspace samples and gas chromatography using a Chimadzu GC-2014 was only able to detect emissions of 0.5 ppb s^{-1} for nitrous oxide and 5 ppb s^{-1} for methane. The performance specifications of the Picarro G2508 are shown below.

Performance Specifications in Air	N_2O	CH_4	CO_2	NH_3	H_2O
Precision Raw (1σ)	< 25 ppb + 0.05 % of reading	< 10 ppb + 0.05 % of reading	< 600 ppb + 0.05 % of reading	< 5 ppb + 0.05 % of reading	< 500 ppm
Precision 1 min (1σ)	< 10 ppb + 0.05 % of reading	< 7 ppb + 0.05 % of reading	< 300 ppb + 0.05 % of reading	< 3 ppb + 0.05 % of reading	< 250 ppm
Precision 5 min (1σ)	< 5 ppb + 0.008 % of reading	< 5 ppb + 0.02 % of reading	< 200 ppb + 0.05 % of reading	< 1 ppb + 0.05 % of reading	< 100 ppm
Guaranteed Spec Range	0.3-200 ppm	1.5-12 ppm	380-5000 ppm	0-300 ppb	0-3 %
Operating Range	0-400 ppm	0.5-15 ppm	0.02-2 %	0-2 ppm	0-7 %
Measurement rate	< 8 seconds	< 8 seconds	< 8 seconds	< 8 seconds	< 8 seconds
Typical Gas Response (Rise-Fall 10-90%, 90-10%)	~8 seconds	~8 seconds	~8 seconds	See Note below	See Note below
Report dry mole fraction	Yes	Yes	Yes	No	N/A

Table 3: Performance specifications of Picarro G2508

9.0 Data Acquisition Requirements (Non-direct Measurements)

9.0.a – Task 1

This project makes use of previously collected soil core data to estimate carbon storage by estuarine wetlands in Delaware Bay and Barnegat Bay. Soil cores that were collected and dated using gamma spectroscopy and analyzed for organic carbon and sediment bulk density will be used in combination with NOAA CCAP estuarine wetland extent data to estimate contemporary rates of soil carbon storage in these estuaries. This secondary data was collected as part of projects sponsored by DRBC, NJDEP, and DENREC. This data was collected and analyzed by project PI David Velinsky using analytical chemistry methods (e.g., analysis of duplicates, blanks, and reference materials, with rejection of values that fall outside 10% of expected) and under Quality Management and Quality Assurance Plans approved by the Delaware Natural Resources and Environmental Control, the Delaware River Basin Commission and the New Jersey Department of Environmental Protection (QA procedures can be found in Appendix B). Therefore the data quality is known to be acceptable. We do not anticipate use of additional secondary (sedimentary) data sources.

B9.b - Task 2 - Literature Synthesis

A white-paper literature synthesis will be developed that compares the effects of shoreline management types (including living shoreline management techniques) on ecosystem components and services. The review will also focus on the economics of the techniques, using local/regional data. This synthesis will include an assessment of existing published and gray literature to parameterize the carbon sequestration processes and related ecosystem service benefits of living shoreline projects compared with natural marshes.

This portion of the project will be performed by Dr. Sunny Jardine, University of Delaware College of Earth, Ocean, and Environment (Literature Review Lead) and a graduate student working under her direction. Dr. Marianne Walch, Delaware Center for the Inland Bays, will provide overall management of the task.

The Literature Review Lead is responsible for:

- identification, review and assessment of data and literature relevant to the research questions posed;
- tracking and recording data and literature associated with this literature review; and
- conducting the verification and validation checks described below; and
- providing a completed literature synthesis for inclusion in the final project report.

Existing literature and data will be identified using a variety of methods and sources, including:

- Review of published papers and journals;
- Relevant literature reviews;
- Symposium/conference proceedings;
- Academic theses;
- Search of online databases plus federal, state, and stakeholder websites for recent materials (articles, technical papers, reports, and abstracts);
- Literature already accessed by project researchers to date; and
- Input from other experts and stakeholders;

Literature and data identified in the course of the search strategy above will be evaluated using the five assessment factors outlined by the Science Policy Council in *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (US EPA, 2003). Those factors are defined by the following criteria for the purposes of this task.

Factor	Criteria
Applicability	Document provides information useful for assessing the ecosystem service benefits of shoreline management practices.
Review	Document has been peer-reviewed.
Soundness	Document relies on sound scientific theory and approaches, and conclusions are consistent with data presented.
Clarity/completeness	Document provides underlying data, assumptions, procedures, and model parameters, as applicable, as well as information about sponsorship and author affiliations.
Uncertainty/variability	Document identifies uncertainties, variability, sources of error and/or bias and properly reflects them in any conclusions drawn.

Table 4: Criteria used to determine inclusion in a literature review

The objective will be to cite literature that conforms in full to all five criteria, where possible. However, the preponderance of literature on some topics will not fully conform to some aspect of the outlined criteria. For instance, there are many white papers and reports in technical areas in which independent peer-review is not standard practice or is not well documented. Should such references address topics not found in the peer reviewed literature, provide useful background information, or corroborate conclusions in the peer reviewed literature, they may be cited with clear explanation.

High reliability will be ascribed to publications with high levels of review and evaluation and where extensive tabulation of supporting information is often available. Similarly, some agencies (e.g., EPA, USGS, etc.) are known to follow extensive quality assurance and review procedures for documents they produce. Non peer-reviewed publications may provide useful information as long as they enhance understanding from peer-reviewed sources, or if peer-reviewed sources prove too scarce or insufficient to answer the research questions by themselves. Since workshop and conference papers may be abbreviated, and may present works-in-progress, these are not expected to form the sole basis of conclusions presented in the report. Generally, these publications may be of most use to support results presented from peer reviewed work, to identify promising ideas of investigation and to discuss further in-depth work needed. The Literature Review Lead is responsible for deciding to include these data or references, documenting the rationale for inclusion, and providing all available background information on these data in order to place these results in the appropriate context.

The Literature Review Lead will be responsible for reviewing all tables and figures created from existing literature and data sources to ensure that the data were correctly transcribed. References cited in the synthesis report will be verified by checking against the original sources to ensure that the report text accurately reflects the information in the original source.

10.0 Measurement / Data Acquisition

10.1 Sampling Process Design (Experimental Design)

10.1.a Task 1

There are no new measurements or data acquisition occurring for the completion of this task.

10.1.b Task 2

Carbon stocks, based on soil carbon content and contribution of plant material, will be assessed at 5 different sites (3 test living shorelines and 2 controls; See table 5). Living shoreline sites were selected based on their relative age (7, 6, and 2 years) and control sites were selected to be representative of the area adjacent to the living shoreline, but unaffected by it. Site selection was ultimately controlled by the existence of already installed living shorelines implemented by PDE, which also have additional monitoring data (vegetation, accretion, etc…). Sampling will take place mid to late August, 2016.

Within each site, variability is likely low, but best effort will be made to identify sample extraction sites that are representative of the site at large. A list of sample numbers and sites is shown below in table 5. Spatial variability among sites may exist, but nearby long term monitoring station data may be incorporated to potentially test what factors of the local area are influencing the variability among living shorelines and/or driving statistical differences (e.g. suspended sediment concentration, eutrophication, plant productivity, etc…). If long term monitoring station data is used, this data is covered under an approved QAPP (See SSIM QAPP in Appendix A for more information).

Site Name	Type of Sample	Number of Samples
Matt's Landing, Maurice River	Above Ground Biomass	2
	Biomass Core	2
	Soil Core	2
D Cell, Maurice River	Above Ground Biomass	2
	Biomass Core	2
	Soil Core	2
Maurice Control	Above Ground Biomass	2
	Biomass Core	2
	Soil Core	2
Lewes	Above Ground Biomass	2
	Biomass Core	2
	Soil Core	2
Lewes Control	Above Ground Biomass	2
	Biomass Core	2
	Soil Core	2

Table 5: Sampling design for Task 2

10.1.c - Task 3

The purpose of this field monitoring is to conduct pilot measurements of nitrous oxide and methane emissions in coastal wetlands in order to determine the net greenhouse gas mitigation benefits of coastal wetlands. This project makes use of a Picarro G2508, a high precision cavity ring-down spectrometer, which simultaneously measures nitrous oxide, carbon dioxide, methane, water, and ammonia in atmospheric air at natural concentrations, and at sensitivities 500 times better than gas chromatography (Brannon et al. 2016).

In addition, the impacts of wetland management strategies will be assessed. The number of monitoring locations will be constrained by the budget provided, and sums to six days of fieldwork; thus, six sites will be visited. Measurements will be conducted during the summer or early fall, in line with previous efforts (Chmura et al. 2010). Greenhouse gas emissions are expected to be highest during the summer and fall as microbial processing is a function of temperature, thus highest emission rates are usually associated with the highest temperatures (Weston et al. 2014). Ideally, year-round measurements would be performed, but the available budget does not permit additional measurements, and secondly, seasonal variability in coastal wetland greenhouse gas emissions have been reported for sites in Delaware Bay and New England (Weston et al. 2014; Martin 2016), which will enable us to model seasonal fluxes if maximum summer rates are known.

We will focus on sites where long-term monitoring of wetland attributes and functions is conducted due to the wealth of background information. We will conduct chamber incubations at 10 locations within each site. Sites will be spread out around sediment elevation tables, where soils have been assessed for carbon density, and where accumulation and marsh surface elevation change have been measured over the past five years. Horizontal and vertical positions of sampling sites will be established using a survey grade GPS.

10.2 Sampling Methods

10.2.a Task 1

There are no new measurements or data acquisition occurring for the completion of this task.

10.2.b Task 2

In late August, at the end of peak growing season, cores and soil samples replicates will be taken from each site using identical extraction techniques. Extraction locations will be along the shorelines in between coir logs, or along the landward site of a single coir log, and along adjacent shorelines of similar elevations for controls. Elevations will be determined using a Trimble R6 real time kinematic (RTK) GPS.

A 0.25 m^2 quadrat will be laid on the area of extraction, then above ground plant materials will be removed for biomass analysis. T Biomass cores will be taken using pre labeled 4” PVC barrels, 30 cm long with a beveled bottom edge to reduced compaction when pounding the core into the marsh surface. Once the top of the barrel is flush with the marsh surface, the core will be extracted with a shooter shovel, and placed into a plastic garbage bag with an additional water resistant label. Biomass cores will be kept cool, out of the sun until being returned to the processing location, where they will be kept refrigerated until analysis. Soil cores will be taken in tandem with biomass cores, but are 2” in diameter and 40 cm long. These cores will be placed upright in a cooler for transport to the lab and then kept refrigerated until analysis.

10.2.c - Task 3

Greenhouse gas emissions will be monitored using the attached Laboratory Operating Procedure (Appendix C). Briefly, collars will be set into the soil surface, and clear chambers will be placed into the collars to measure net ecosystem exchange of greenhouse gasses. The analyzer pulls continuous air samples through connective tubing for analysis. The static chamber, tubing, and analyzer cavity form a closed system through which air circulates. Chambers will be composed of polycarbonate and contain a battery-operated fan to maintain air mixing, and a one way valve to maintain equilibration of chamber pressure. Air-tight seals between the chamber and its collar (set into the marsh) will be made using a saran wrap or water. Measurements will be made at each static chamber for a period of 6 minutes after accounting for transit time through the tubing. The Picarro takes measures every 2-seconds.

10.3 Field Quality Control

10.3.a Task 1

There are no new measurements or data acquisition occurring for the completion of this task.

10.3.b – Task 2

In the field, cores with >10% compaction as measured by a change in height, will not be accepted. Shovels and extraction tools (wood 2x4, mallet, hands) will be rinsed between sampling locations in creek/river water. All tools (corers, shovels, *etc*.) will be rinsed thoroughly with fresh water at the processing location before use at different sites.

Analyte	DQI	Field QC	Frequency of Collection	Acceptance Criteria	Corrective Action
Label legibility	Completeness	Labels written clearly	1x (August)	Labels written clearly	Rewrite labels
Tool cleanliness	Bias and precision	Mud free tools	1x (August)	No observable debris or mud	Rinse, scrub, repeat until clean
Sample preservation	Representativeness	Core temperature	1x (August)	<33°C	Cover from sun, place in cooler, place ice packs
Corer sample completeness	Completeness, representativeness, comparability, and precision	Corer full to 30 cm	1x (August)	Core depth = 30 cm	Discard and take new core

Table 6: Field quality control procedures for Task 2

10.3.c - Task 3

Field quality control will maintain good data collection. While in the field, workers will watch for fans that stop running during a chamber incubation, take care not to allow tubing to kink, chambers should be allowed to return to background gas concentrations between measurements, and care should be taken to not tread near collars or during active measurement. If any of these problems occur, chamber measurements should be repeated.

11.0 Analytical Methods

11.1 Analytical Methods

11.1.a Task 1

To estimate estuarine-wide carbon sequestration, sequestration values will be calculated for all estuarine coring sites as the product of accumulation rates and soil carbon density (Callaway et al. 2012). Potential spatial patterns in carbon soil density and carbon storage will be analyzed through spatial interpolation mapping, performed in ArcGIS, version 10, and examined as a function of potential predictors, such as above and belowground biomass, tidal range, elevation, and salinity. Bulk sequestration rates will be multiplied by the area of estuarine emergent wetlands mapped by NOAA CCAP, and converted to CO2 equivalents (EPA 2016).

11.1.b Task 2

For more information, please see SOPs in Appendix C and the SSIM Umbrella Quality Assurance Project Plan in Appendix A.

Analyte	SOP #	Sample Matrix	Analytical Method	Detection Limit	Lab Reporting Limit
Above ground biomass	38	Culm mass	Manual sorting	100 mg	1 g
Below ground biomass	39	Root/ rhizomes mass	Manual sorting	100 mg at 2 mm	1 g
Root/rhizome C content	39	Carbon (as lost on ignition)	LOI	<1%	1%
Soil C content	33	Carbon (as lost on ignition)	LOI	<1%	1%

Table 7: Analytical Quality Control Parameters for Task 2

i. Biomass

Biomass cores will be cut into two 15 cm depths (0-15, 15-30 cm). Each depth will be washed, sorted by live and dead root/rhizomes, then each fraction will be dried at 60°C until constant weight. Samples will then be ground and analyzed for carbon content via LOI.

Plant biomass will be taken back to the lab, washed and sorted into species-specific categories of live and dead. Belowground biomass will be washed through a mesh sieve to capture all biomass that will not wash through a 1mm screen. Biomass samples will be dried at 60°C until a constant weight. A subsample of each category of biomass will be ground and placed into a muffle furnace at 450°C four 8 hours. The percent of weight loss on ignition (LOI) will allow us to calculate the ash-free dry weight of the biomass, with inorganic sediments factored out.

ii. Soils

Soil cores will be sectioned into six depth sections of 0-5, 5-10, 10-15, 15-20, 20-25, 25-30 cm. A polyethylene syringe will be used to obtain a fixed volume of soil to calculate bulk density. Samples will be ground, dried at 60°C until constant weight, then analyzed for carbon content via LOI. Drying will take place in a gravimetric drying oven (held at 60°C) and LOI will be analyzed in a muffle furnace (at 550°C).

11.1.c - Task 3

Field measures of greenhouse gases in chamber headspaces will be modeled using changes in gas concentration over time and using the ideal gas law:

$Flux = {}^{dC}/_{dt} \, ({}^{PV}/_{RAT})$ where

V = chamber volume (must include analyzer internal volume and volume of tubing used)
R = Gas constant
T = Field-measured air temperature
P = Field-measured pressure
A = Chamber footprint

Fluxes will be fit to changes in concentration over time utilizing the Picarro soil flux calculator (Alstad et al. 2015), which provides a flexible user interface for chamber flux error estimation, including error from incorrect model selection and evaluation of error from instrumental and procedural variability. Fluxes will be downloaded to a spreadsheet file, and will be stored on the Academy of Natural Sciences Server, which is backed up daily. The figure below shows idealized changes in greenhouse gas concentrations in a static chamber incubation. The flux is calculated as the linear fit of measured change in concentration as a function of time.

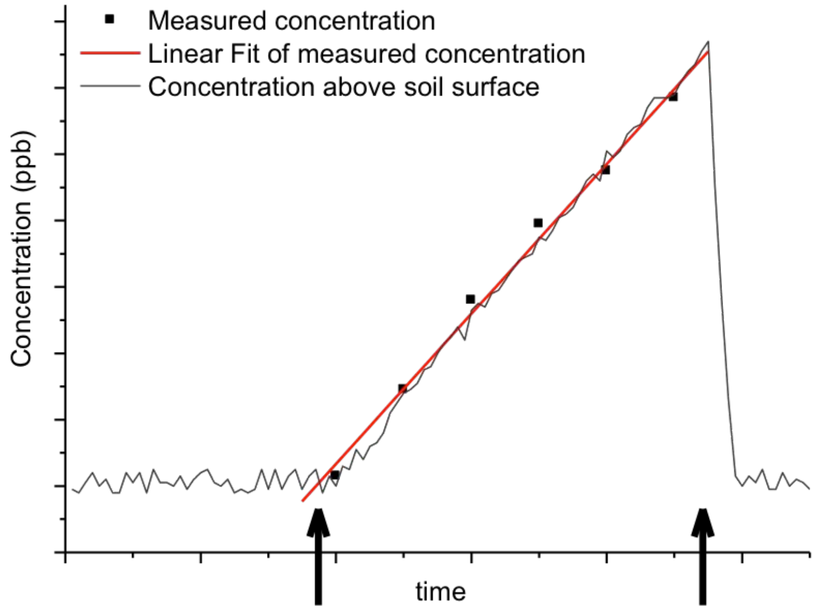


Figure 3: Theoretical evolution of the concentration of a gas being emitted from the soil upon use of a static chamber. Concentration of the gas above the soil surface (black line) remains at a relatively constant level; at the moment when the chamber is closed (left arrow), the concentration in its headspace begins to rise. The gas flux is modeled as the change in concentration over time, usually using a linear fit. (Adapted from Butterbuch-Bahl et al. 2015.)

11.2. Analytical Quality Control

11.2.a Task 1

There are no new measurements or data acquisition occurring for the completion of this task. See Attached QAPP in Appendix B for more information.

11.2.b Task 2

Laboratory equipment (mortar and pestle, syringes, crucibles) will be wiped with DI water and/or ethanol (or isopropanol) to limit cross contamination.

11.2.c Task 3

Quality control will be performed to appraise calculated fluxes. First, plots of gas concentrations over time will be trimmed to remove the time it takes for the air to move through the tubing from the beginning of the dataset, using the analyzer flow rate of 230 standard cc per minute. The slopes for all three gases will be inspected visually for unusual peaks or dips, especially those that are consistent across gases. These likely indicate kinked tubing or chamber disturbance and these fluxes should be discarded. Fluxes must be defined as zero, or non-detectable, if they are below detection limits, or have changes in concentration over time that are poorly fit by linear models.

12.0. Sample Handling and Custody Requirements

12.0.a Task 1

There are no new measurements or data acquisition occurring for the completion of this task. See Attached QAPP in Appendix B for more information.

12.0.b Task 2

PDE's field crew leader will be collecting samples, transporting them to the processing location, and leading the analyses for each sample. Samples will be stored at <4°C until processed, then dried at 60°C; LOI processing occurs at temperatures >500°C. PDE collected samples will remain in PDE custody throughout processing and analysis. Datasheets are utilized as a checklist to make sure that each sample is fully processed (Appendix C).

12.0.c Task 3

In situ field analysis of greenhouse gas emissions will not involve sample handling.

13.0 Testing, Inspection, Maintenance and Calibration Requirements

13.1 Instrument/Equipment Testing, Inspection, and Maintenance

13.1.a Task 1

There are no new measurements or data acquisition occurring for the completion of this task. See Attached QAPP in Appendix B for more information.

13.1.b Task 2

PDE equipment will be a refrigerator, a freezer, a drying oven, two balances (readability of 0.01 and 0.0001), and a muffle furnace. Maintenance of each includes regular cleaning. The freezer and drying oven are equipped with a digital temperature displays, which will be monitored to ensure temperatures are within storage or processing requirements. Refrigerator temperatures are monitored with a standard glass thermometer. If incomplete ignition occurs, muffle furnace will be inspected and serviced. Balance accuracy will be assessed with calibration weights.

13.1.c Task 3

Default settings will be maintained for the Picarro G2508, in accordance with manufacturer requirements. Preventative maintenance requirements described by the manufacturer in the instrumentation manuals shall be complied with at all times (Picarro User Manual).

13.2 Instrument Calibration and Frequency

13.2.b Task 1

There are no new measurements or data acquisition occurring for the completion of this task. See Attached QAPP in Appendix B for more information.

13.2.b Task 2

Refrigerator/freezer temperatures will be monitored daily to ensure cool temperatures are maintained, but also recorded weekly to ensure ranges are maintained. Balances will be tested weekly if used on a weekly basis, otherwise tested on the occasions of its use.

13.2.c Task 3

All default settings will be maintained for the Picarro G2508 (Brannon et al. 2016), with gas concentrations verified using known standards bracketing expected field concentrations before and after each field deployment. Factory calibration will be performed when measures deviate from standards by >10%.

13.3 Inspection/Acceptance Requirements for Supplies and Consumables

This does not apply to this grant.

14.0 Data Management

Data recording QA/QC practices will be carried out before and after data analysis. Data will be stored as original and duplicates (hard copies) as well as in electronic form in Microsoft Excel. Data will be analyzed in R Statistical software. Spatial information will be analyzed in ArcGIS. Data and analyses will be shared electronically with partners and hard copies sent as requested.

15.0 Assessment/Oversight

Preparation for each field outing will initiate with a check of equipment functionality as well as a review of the task checklist. To ensure accuracy and precision all field crew members will have been trained prior to working. If problems arise the field leader will note so in the log book.

All field assessments and schedules will routinely be shared with the Project Manager and QA Officer. The QA Officer will conduct a site visit for each of the tasks. If the proper assessments are not being performed, further data collection will be stopped until proper procedures can be followed.

Field teams will be audited by the QA Officer at least once to ensure that field protocols are being implemented without error. This will be documented by the QA Officer by performing checks in the field that all SOPs are being properly followed. Any deviation observed and documented in the field notebook, and any suspect data will be flagged by adding additional notations into notebooks (or inserted, colored comments in electronic data spreadsheets) and then will be resolved between the recorder and data checker. Any data entry errors will be corrected if unequivocally resolvable, and non-resolvable data will be removed from final datasets but tracked in raw data files to archive any problems. Periodic quality assurance reviews will be performed to check for consistency among field teams.

The Project Managers, Principal Investigators, and the QA Officer will meet (in person or via conference call) annually to discuss the project's progress and ensure that all approved assessment procedures are being followed. If corrective actions need to be made, then the Project Manager, Principal Investigators and QA Officer will work jointly to address any changes deemed necessary.

16.0 Data Validation and Usability

16.1 Data Review, Verification, and Validation

All data will be recorded electronically or manually and will be checked for accuracy by the Principal Investigator for each task. Regardless of the means with which data were initially recorded, all field data will be entered into a computer system within one week after collection. 10% of data entered into a database will be checked for transcription errors. If found errors will be reconciled and noted. The person logging data and the person checking for transcription errors will both initial and date all datasheets upon completion.

Any incomplete data or deviations will be reported on the quality assurance audits or the analytical report. The Project Manager will verify the content of the reports and will flag any data that fails to meet the QA requirement.

Any problems, incomplete data or deviations will be flagged by the Project team or Project Manager and will be discussed with the QA Manager, Project Manager and the project team. This group will then determine if any parts of the data need to be adjusted or discarded because of any documented errors, field constraints, or equipment malfunctions. All derivations from the QAPP requirements will be documented and reported to the Project Manager.

16.2 Reconciliation with User Requirements

Data will be QA checked according to this document. Since any changes or omissions of original data may limit the utility of study results by scientists and managers, any such alterations of data or data products will be fully disclosed to anyone who procures the data.

17.0 Reports, Documents, and Records

Each PI will be responsible for maintaining the original data sheets for their task. Electronic copies of all data and calibration records collected under this QAPP will be sent to the Barnegat Bay Partnership and held on their servers. Products from the secondary data analyses will also be sent to the Barnegat Bay Partnership and held on their servers. Any flagged data, derivations from QAPP requirements or other notes associated with this project will be stored with the data on the Barnegat Bay Partnership Server.

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