NERRS Science Collaborative Progress Report for the Period 09/01/13 through 02/28/14

Project Title: Carbon Management in Coastal Wetlands: Quantifying Carbon Storage and Greenhouse Gas Emissions by Tidal Wetlands to Support Development of a Greenhouse Gas Protocol and Economic Assessment
Working Title: Bringing Wetlands to Market: Nitrogen and Coastal Blue Carbon (BWM: NCBC)
Principal Investigator(s): Alison Leschen, Manager, Waquoit Bay National Estuarine Research Reserve
Project start date: November 15, 2011
Report compiled by: Alison Leschen, Reserve Manager, Waquoit Bay National Estuarine Research Reserve.
Contributing team members and their role in the project:

- Omar Abdul-Aziz (Modeler), Florida International University (FIU)
- Steve Emmett-Mattox, (Intended User Representative), Restore America's Estuaries (RAE)
- Kate Harvey (Collaboration Assistant), Waquoit Bay National Estuarine Research Reserve (WBNERR)
- Kevin Kroeger (Applied Science Investigator), United States Geological Survey (USGS)
- Alison Leschen (Principal Investigator, Manager), Waquoit Bay National Estuarine Research Reserve (WBNERR)
- Jordan Mora (Research Assistant), Waquoit Bay National Estuarine Research Reserve (WBNERR)
- Kate Morkeski (Research Assistant and Applied Science Investigator), Marine Biological Laboratory (MBL)
- Serena Moseman-Valtierra (Applied Science Investigator), University of Rhode Island (URI)
- James Rassman (Stewardship Coordinator), Waquoit Bay National Estuarine Research Reserve (WBNERR)
- Tonna-Marie Surgeon Rogers (Collaboration Lead, CTP Coordinator), Waquoit Bay National Estuarine Research Reserve (WBNERR)
- Jim Tang (Applied Science Investigator), Marine Biological Laboratory (MBL)
- Thomas Walker, (Economist, Intended User Representative) Manomet Center for Conservation Sciences (Manomet)

A. PROGRESS OVERVIEW

This project is designed to address the interaction of two of the most critical management issues currently facing coastal communities - climate change and eutrophication caused by excess nitrogen loading. The project will generate information and tools that coastal decision makers can use to manage nitrogen pollution, design effective wetlands protection and restoration projects, and create policy frameworks and economic incentives to reduce greenhouse gas (GHG).

The fifth reporting period of project implementation (09/01/13 – 2/28/14) included: continuation and completion of field data collection, further analysis of data, delineation of habitats in the marshes, continued testing and honing of the model, information gathering and refinement of the plan for the economic analysis, and submission of the Methodology to the VCS for review.

Below is a summary of progress on project goals during this reporting period. Further details are in the narrative that follows.

Project Goals	Reporting period tasks and accomplishments
A. Quantify carbon sinks and GHG fluxes in tidal wetlands, and assess the impact of anthropogenic nitrogen loading, sea level rise, and climate on both carbon sequestration and net GHG emissions in tidal wetlands.	▪ Continued to collect data on chemical parameters and water fluxes (lateral flux) ▪ Began investigating use of dissolved CO_2 sensor. ▪ Began coring study to measure rates of soil C storage. ▪ Continued analysis of particulate carbon concentrations and stable isotope ratios. ▪ Continued and finished vertical flux measurements of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) across four N gradient sites. ▪ Continued and finished field measurements of soil pH, soil moisture, soil salinity, plant height, and plant density. ▪ Continued and finished porewater sample collections. ▪ Continued automatic data collection of weather data and soil temperature ▪ Finished processing belowground cores for root and rhizome biomass and bulk density. ▪ Continued analysis of greenhouse gas, soil, and plant data
B. Develop a carbon sequestration and GHG emissions model for tidal wetlands using the collaboration between end-users and scientists to identify the specific data needs for it, and apply the model to aid the development of a tidal wetlands GHG offset protocol.	▪ Continued testing and development of the model. ▪ Development of a simple, systematic data-analytics approach to analyze observational data and determine the relative linkages of wetland GHG fluxes with different climatic, hydrologic, biogeochemical and ecological drivers.
C. Connect the conservation community with guidance on management of carbon and nitrogen and with carbon markets by providing a GHG offset protocol (methodology) that will be adopted by climate registries.	▪ Completion of Methodology and submission to VCS for review.
D. Provide to intended users (resource managers, project developers, policymakers, land use planners, and those involved with carbon markets) data and a GHG offset model that can inform planning for tidal wetlands preservation and restoration.	• Developed an e newsletter as an avenue to share information with stakeholders about the project. While no stakeholder workshops were organized in the last period, team members presented at various conferences and contributed to development of a teacher training curriculum.
E. Conduct an economic assessment of the carbon sequestration and GHG benefits of tidal wetlands, including the impact of nitrogen loading, to assess the financial relevance to land conservation decisions.	▪ Shifted the economic and policy analysis from a focus on potential carbon flux benefits of reducing nitrogen loadings to an analysis of GHG reduction benefits associated with restoring tidal flows to freshwater marshes—with an emphasis on avoided methane. ▪ Identified of the large Herring River wetland in

	Wellfleet as a possible case study site.
F. Advance the ability of the NERRS, building on its System-Wide Monitoring Program, Biomonitoring and Sentinel Site efforts, to monitor the effects of climate change on coastal ecosystems.	▪ Completed a second Transfer of Ideas workshop at South Slough NERR. ▪ Presented session on Blue Carbon and this project at NERRS annual meeting ▪ Habitat delineation done for this project will also be incorporated into the Reserve Habitat Mapping and Change Plan. ▪ Data loggers purchased for this project will be used in the future for monitoring climate (wind speed/direction, PAR, solar radiation, and rain precipitation) and water level at WBNERR's Sentinel Site.

B. WORKING WITH INTENDED USERS

Stakeholder engagement occurred on different fronts over the last six months. RAE continued outreach at the national level on blue carbon and the methodology, project team members provided feedback on development of a TOTE module being developed for teachers and also developed an e-newsletter to share updates about the project with stakeholders. Science team member, Kevin Kroeger and project economist, Tom Walker and Collaborative Lead, Tonna-Marie Rogers also held an initial meeting with staff at the Cape Cod National Seashore related to scoping a potential direction for the economic and policy analysis. Team members also provided lectures at various conferences and meetings.

Certain stakeholder engagement activities that we anticipated doing during the last six month periods were pushed back given the status of work on various components of the project. In particular, the wetlands and wastewater workshop was pushed back given that analysis of field data has been slower than anticipated given intense focus on field and lab work in the previous period. We felt it would be better to convene this workshop later to enable incorporating results from our field research. In addition, we also opted to push back road show presentations in order to allow time for certain project milestones to be reached so that these presentations could be more impactful.

Stakeholder engagement objectives for the next six months

Given the current status of the various components of the BWM project, we anticipate the coming six months to be an intense period of stakeholder engagement involving all members of the project team. We are planning a team meeting in March at which we will be mapping out timing and linkages of the various stakeholder engagement efforts to be done between now and the end of the project in an effort to maximize stakeholder input and create tight linkages among the project components. More specifically our team will be involved in organizing and implementing the following activities:

<u>Upcoming Annual Team Meeting</u>

We will use our annual team meeting scheduled for the end of March to begin planning for efforts such as holding a blue carbon application workshop at the NERRS Annual Meeting, a large conference with stakeholders in early 2015, and final roll out of project tools and products. Early planning will help to synchronize various efforts and ensure that we are able to share results of this project with local and national stakeholders in a dynamic way.

At this meeting we intend to organize a focused roundtable discussion with RAE (Steve Emmett-Mattox and Steve Crooks), our project economist (Tom Walker), science team (Kevin Kroeger and Jim Tang), key staff from the Cape Cod National Seashore who are heavily involved in the Herring River restoration project as well as WBNERR staff. The goal of this exercise is to discuss how to use the Herring River restoration project as a case study for blue carbon application and gather input for the economic analysis.

Methodology and Guidance Document

We plan to hold another blue carbon sensitization workshop with a diverse group of stakeholders spanning restoration practitioners, conservation organizations, federal and state agency staff, non-profit organizations involved with wetlands protection and conservation and local municipalities (planning boards, natural resource managers and conservation commissions), to increase awareness about the importance of coastal blue carbon. We will seek to reach beyond the relatively small group of stakeholders that were involved in the blue carbon workshop that was convened through a transfer grant from the NERRS Science Collaborative. We will use communication products (videos and fact sheet) developed to highlight the project as well as the blue carbon template in this effort.

We also plan to convene a special blue carbon session for key agencies with an interest in wetlands restoration and nitrogen loading. This meeting will be tailored toward discussing and highlighting blue carbon application in Massachusetts towards achieving wetlands restoration goals and possibly gathering input on the aggregation of restoration efforts which will be further explored by RAE and the methodology team in the coming months. We intend to reach out to agencies and organizations like the Massachusetts Department of Ecological Restoration, the Massachusetts Department of Environmental Protection, the Massachusetts Office of Coastal Zone Management, the Nature Conservancy, the National Estuaries Program, the Executive Office of Energy and Environmental Affairs, the Cape Cod Commission, the US Fish and Wildlife Service, NOAA's Restoration Office, the Environmental Protection Agency, Massachusetts Association of Conservation Commissions as well RAE partners.

Model Development

Tonna-Marie Rogers and Kate Harvey will work with Omar Abdul-Aziz and the science team to convene a workshop to present a mock-up or draft version of the model being developed and gather feedback from intended users on the model interface and its utility. We will also further unpack who potential users of the model would be and how best to present the model to this user group. Before the model is finalized we intend to test it with intended users and use their input where possible to help shape the final product.

Economic and Policy Analysis

For this component of the project we will be holding a workshop with restoration practitioners and relevant state and local agencies to discuss the planned approach for the economic analysis and gather feedback that will be used to finalize the direction and approach of this aspect of the project. We will also communicate with stakeholders on lessons learned on economic tradeoffs related to the issue of nitrogen loading as it pertains to this aspect of the project (more information on this can be found in the section on the economic analysis below).

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We will continue to use our e-newsletter to communicate interesting findings from the field research with our stakeholder network. Findings from field research will also be folded into all the outreach efforts that are planned with stakeholders and any stakeholder workshops convened

Other

Project team members will be presenting and preparing for presentations and sessions at various upcoming meetings and conferences including the New England Estuarine Research Society and the Restore America's Estuaries conferences as well as others.

We envision carrying out a minimum of three road show presentations to the MA Department of Ecological Restoration, the MA Department of Environmental Protection and the Cape Cod Commission and potentially other agencies.

We will complete the project display board for use in the WBNERR Visitor Center and at conferences. We will also couple this with creating an interpretive sign about the field research for posting at the main project field site at Sage Lot pond. This area of the Reserve receives many visitors in the warmer months due to the popularity of South Cape Beach which is close to the project field site.

C. PROGRESS ON PROJECT OBJECTIVES FOR THIS REPORTING PERIOD
GREENHOUSE GAS METHODOLOGY
Lead: Steve Emmett-Mattox (RAE)

Methodology submission to VCS

In December, RAE submitted the draft "Methodology for Tidal Wetland and Seagrass Restoration" to the Verified Carbon Standard to begin the approval process.

The VCS released the methodology for a 30-day public review and comment period on February 11, 2014 (Methodology for Tidal Wetland and Seagrass Restoration) and held a webinar on February 19 to introduce the methodology. Steve Emmett-Mattox (RAE) and lead methodology author Igino Emmer presented during the webinar.

Following the public comment period, the methodology must be reviewed and approved by two independent third party validators, who are on the VCS-approved list. RAE has contracted with ESI to conduct the first validation. Following the double validation, the VCS will review and approve the methodology. The entire approval process is expected to take nine months (until fall, 2014). Brian Needelman is organizing a peer-reviewed publication documenting our approach to the methodology.

Flexibility of Methodology
Through the NERRS SC award, RAE planned to complete three main tasks: the methodology, methodology guidance, and integration of science results and the model into the guidance and methodology. As the project has unfolded, we have learned that to make changes to the methodology, once the approval process has begun, will be time-consuming and expensive - all changes would have to go through the entire approval process again. With this in mind, we drafted the methodology to allow for future developments in science and modeling. The structure of the methodology is such that it allows its users to apply published research and models where appropriate, so that new research can be incorporated into its application without changes to the methodology itself.

Blue Carbon workshops lead to Yr 3 change in scope
Through two NERRS SC Knowledge Transfer awards, RAE has had the opportunity to lead two blue carbon workshops for coastal managers and other restoration/conservation advocates and practitioners. The first has been previously reported (WBNERR, March 2013). The second workshop was held January 28, 2014 in Salem, Oregon and hosted by the South Slough NERR. Lead presenters Steve Emmett-Mattox and Dr. Steve Crooks learned a great deal about the challenges facing coastal managers in both regions. One of the key issues is the relatively small scale of available restoration opportunities. Carbon finance is more effective with larger scale projects (thousands of hectares), a size which is rare for coastal restoration in Massachusetts and Oregon. Under the rules of the VCS, however, an opportunity exists to "group" projects within an estuary or region to achieve economies of scale in the carbon accounting and transaction costs. For this reason, RAE is redirecting the emphasis of its year three work plan to assess the opportunity for grouped projects in estuaries, develop recommendations for coastal managers, and incorporate these aspects into the methodology guidance document.

Outline of Guidance Document
In February 2014, RAE contracted with two lead authors for the methodology guidance and grouped project assessment - Igino Emmer of Silvestrum, and Brian Needelman at University of Maryland. Brian was a lead author for the methodology and has been at the forefront of blue carbon in Maryland for several years. An outline of the guidance document is as follows:
<u>Blue Carbon Practice Manual</u>

Executive Summary with Recommendations for Project Developers

- I. *Introduction: Blue Carbon and Blue Carbon Finance*
- II. *Background: Carbon Asset Generation and Carbon Projects in the Agriculture, Forestry and Other Land-Use (AFOLU) Sector*
- III. *The Verified Carbon Standard (VCS): A Lead Global Standard*
- IV. *First Steps: Feasibility Assessment, Site Selection and Prioritization*
- V. *Carbon Accounting and Documentation*
- VI. *Registration, Institutions and Stakeholders*
- VII. *Implementation*

VIII. *Carbon Markets and Carbon Asset Management*
IX. *Grouped Projects: Applicability and Recommendations*
X. *Conclusion*

Methodology Objectives for the next 6 months:
The guidance document, incorporating the study of grouped projects, will be completed within six months and widely announced and distributed as an electronic document. This will complete the three primary tasks for RAE under the NERRS SC award.

In addition, RAE is working with NERRA and NERRS to schedule a blue carbon workshop for the NERRS annual meeting in the fall of 2014. Separately, RAE will hold a blue carbon workshop in conjunction with the RAE National Summit, November 1-6, 2014 in the Washington, DC area.

WBNERR FIELD AND TECHNICAL SUPPORT
Leads: Jordan Mora, Jim Rassman, Chris Weidman (WBNERR)

Habitat delineation
Delineation of the different habitat types within three of the four nitrogen gradient sites began in the early part of 2013 when we generated automated segmentation layers of the 2012 RGB and NIR aerial photos from Nate Herold at the Coastal Services Center. However, we needed a finer scale segmentation to accurately represent the micro-scale variation in salt marsh habitat changes.

We received the finer scale segments in November 2013. In January 2014, we began the first iteration of habitat delineation based on the automated segmentations for Sage Lot Pond, Hamblin Pond, and Eel Pond. Because the spatial extent of the 2012 aerial photos is limited to the Waquoit Bay Estuary, the fourth site, Great Pond in East Falmouth, required a different means of habitat delineation. The Great Pond site has been digitized by hand based on field verification data.

Using the automated segmentations, we have delineated the following habitat zones for three of the nitrogen gradient sites: low marsh (dominated by *Spartina alterniflora*), high marsh (dominated by *Juncus gerardii, Distichlis spicata*, and/or *Spartina patens*), brackish species (low salt tolerant plants such as *Typha angustifolia* and *Schoenoplectus americanus*), marsh border (dominated by low flood tolerant species such as *Iva frutescens*), pools (largely unvegetated areas of standing water at low tide), and creeks (channels in the salt marsh platform which drain during low tide).

Great Pond was digitized by hand using habitat verification data collected in the field. On January 20th, 2014, the entire Great Pond salt marsh site was traversed using a handheld Trimble GPS and each habitat zone was outlined. The resultant GIS shapefile was used as a foundation for the habitat zone designation. Great Pond was delineated using the same zone classification scheme as described above.

Summary of data collected

The following area measurements are based on the first iteration of habitat delineation (completed on February 11, 2014). Also, the first draft of habitat delineation map is available below.

Table 1: Area measurements based on habitat delineation generated in ArcGIS 10.0.

Habitat Type	**Great Pond** (m^2)	**Eel Pond** (m^2)	**Hamblin Pond** (m^2)	**Sage Lot Pond** (m^2)
Low Marsh	12,957.6	2,107.5	40,811.0	19,039.8
High Marsh	1,823.0	0	909.1	4,858.8
Brackish Marsh	0	0	260.4	0
Marsh Border	4,686.5	985.9	5,111.4	9,348.1
Pool	4,058.1	695.7	1,101.5	9,962.5
Creek	1,002.7	27.6	5,184.7	706.5
Total Area	**24,527.9**	**3,816.7**	**53,378.1**	**43,915.7**

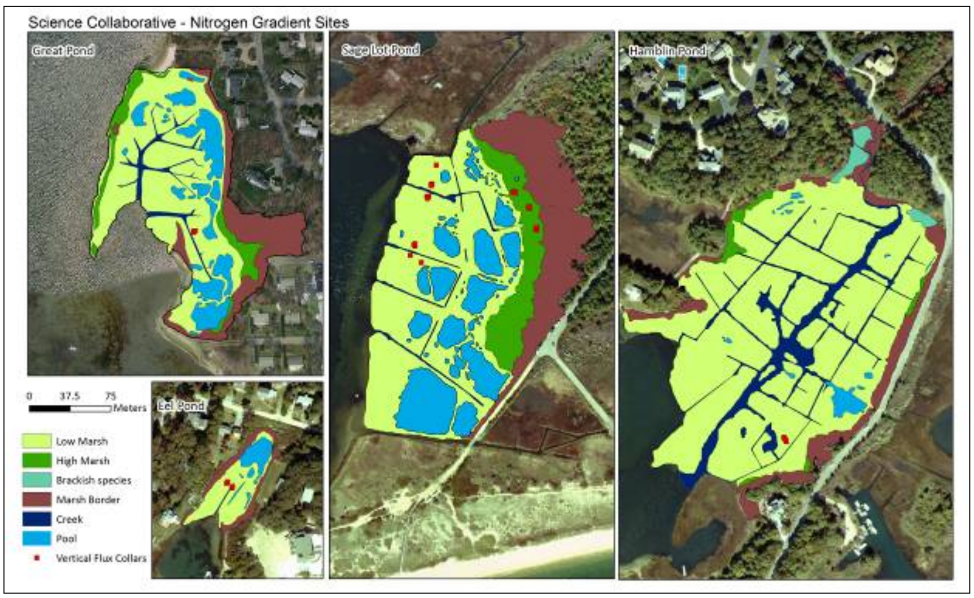

Figure 1: Maps of GIS-based habitat delineation of four salt marsh sites along a nitrogen gradient. This product represents the first iteration of habitat delineation before group feedback. GIS work completed by Jordan Mora, WBNERR. Aerial photographs (2012 Ortho) for Eel Pond, Sage Lot Pond, and Hamblin Pond obtained under private contract by the Waquoit Bay Reserve; funds provided by the NERRS Science Collaborative grant. Aerial background (2009 Ortho) for Great Pond acquired from the MassGIS website and made available by USGS.

Unanticipated outcomes and challenges

Working with the Coastal Services Center was an unanticipated outcome of the grant. Additionally, using watershed-scale software for habitat-scale segmentation has proved challenging. The output from the automated software contains large pixel size (greater than the resolution of the photo) with frustratingly limited polygon flexibility. Larger scales provide larger polygons while smaller scales provide smaller polygons. These combined constraints result in the need for many segmentation layers of various scales depending on the habitat type being delineated. For example, salt marsh pools require very small polygon size for accurate representation; however, it's easier to delineate the low marsh areas with large polygon sizes. Also, some transition zones are more easily identified in higher scales, such as the high marsh and marsh border boundaries.

WBNERR field and technical support for the next 6 months
The first draft, or iteration, of the salt marsh habitats have been sent to the Science Collaborative team for review. Once feedback has been received, the habitat maps will undergo further editing before area measurements are used for carbon storage and total biomass estimates.

SCIENCE INVESTIGATION AND FIELD RESEARCH
Leads: Kevin Kroeger (USGS), Serena Moseman-Valtierra (URI), Jim Tang, (MBL)

Lateral flux measurements
During this period our team (Table 2) has continued sensor deployments and sample collections, with a goal of measuring seasonal and annual budgets of tidal material exchange at three salt marshes (Table 3). Sensor deployments have been deployed during the majority of the reporting period at the Sage Lot Pond, Great Pond and Hamblin Pond sites. Sensors include 2 YSI EXO2 multiport optical sondes, a Wetlabs Triplet optical sensor coupled with a YSI sonde measuring non-optical parameters, 3 Sontek IQ ADCPs for measurements of water flow. With regard to lateral flux measurements, at the Sage Lot Pond site we now have near continuous data on several chemical parameters beginning in April 2012 until present, and near continuous water fluxes beginning in July 2012 until present. In addition, at Hamblin and Great Ponds we now have nearly continuous sensor deployments beginning May and June 2013. To calibrate sensors and to calculate net exchanges of carbon and GHG between marsh and estuary, we have conducted comprehensive sample collections, including measurements of dissolved GHG using the Picarro gas analyzers, during 14 hour full tidal cycle deployments at Sage Lot Pond in April, July and November 2012, once per month June to August 2013 at Sage Lot Pond, Hamblin Pond, and Great Pond, and October 2013 at Sage Lot Pond and Great Pond.

Dissolved CO_2 measurement
In summer 2013 we began investigating use of a dissolved carbon dioxide sensor to allow continuous measurement of that key GHG and an additional component of the DIC system. During summer 2013, two interns, Julia Signell and Alterra Sanchez, participated in our field research and focused their efforts on deploying a ProOceanus CO_2 sensor, and testing sensor performance based on laboratory analysis of CO_2 concentrations (in collaboration with Aleck Wang of Woods Hole Oceanographic Institution.). Corrected sensor CO_2 data (Fig 2) reasonably approximated laboratory measured CO_2, though with significant error. In August and September, 2013 we conducted tests of the sensor under controlled laboratory conditions. Since that time we have made high-precision measurements of DIC, pH and alkalinity, to allow calculation of pCO_2 during the laboratory sensor test, and are currently engaged in interpreting the sensor test results. CO_2 sensor deployments continued into fall 2013.

Soil carbon storage

In October 2013, Meagan Eagle-Gonneea initiated research on the BWM project, with support from a NSF Postdoctoral Fellowship. Her role will be to lead the coring study to measure rates of soil carbon storage. Approaches include measure of ^{137}Cs and ^{210}Pb profiles to measure soil accretion rate, and measurements of carbon source indicators including bulk stable isotope ratios, lipid composition analyses, and compound specific isotope measurements.

Other activities

Other activities during this reporting period included: analysis of particulate carbon concentrations and stable isotope ratios; analysis of particulate carbon lipid compositions; continued methods development for analysis of DOC and DIC carbon stable isotope ratios (J. Pohlman); stakeholder interaction with CCNS National Park Service personnel to initiate economic analysis of the proposed Herring River restoration (Walker, Kroeger, Surgeon-Rogers).

Table 2. Direct participants in lateral fluxes effort

Name	Role	Institution
Kevin Kroeger	Principle Investigator	USGS Woods Hole
Neil Ganju	Co-Principle Investigator	USGS Woods Hole
John Pohlman	Co-Principle Investigator	USGS Woods Hole
Adrian Green	Research Technician	USGS Woods Hole
Sandra Baldwin	Research Technician	USGS Woods Hole
Wally Brooks	Research Technician	USGS Woods Hole
Michael Casso	Research Technician	USGS Woods Hole
Aleck Wang	Collaborator—inorganic carbon system analyst	Woods Hole Oceanographic Institution
Amanda Spivak	Collaborator—organic carbon system analyst	Woods Hole Oceanographic Institution
Linda Kraemer	Laboratory analyses of lipid and carbonate system samples	USGS, emeritus volunteer
Thomas Kraemer	Laboratory analyses of lipid and carbonate system samples	USGS, emeritus volunteer
Meagan Gonneea	NSF Postdoctoral Fellow	USGS Woods Hole

Table 3. Parameters monitored at each site using sensor deployments

Parameter	Proxy for:	Manufacturer

Integrated water velocity	Water flux	Sontek
CDOM	Dissolved organic carbon	YSI or WetLabs
Suspended particles	Particulate organic carbon; sediment	YSI or WetLabs
pH	Carbon dioxide (under investigation)	YSI
Chlorophyll a	Phytoplankton biomass	YSI or WetLabs
Dissolved oxygen		YSI
Salinity		YSI
Temperature		YSI
Oxidation/reduction potential		YSI
Pressure	Water depth	YSI
pCO_2	Respiratory carbon dioxide; possibly DIC proxy with pH	Pro Oceanus

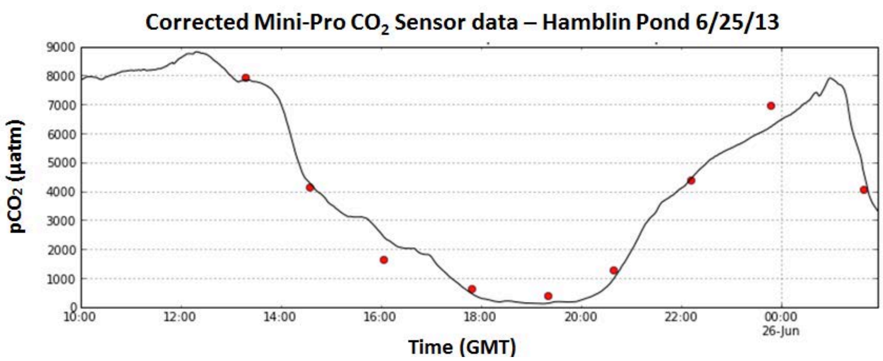

Fig. 2. ProOceanus Mini Pro CO_2 sensor data from 25 June 2013 at Hamblin Pond were corrected based on laboratory-determined pCO_2 in bottle samples collected throughout a full tidal cycle. Red circles signify calculated pCO_2 from bottle samples. The black line indicates corrected CO_2 sensor readings as 5-minute averages of data collected at 2-second intervals.

Vertical Flux Measurements (Jim Tang, Kate Morkeski, Jordan Mora, MBL)

The vertical flux team (Tang, Morkeski, Mora) completed the following toward their goal of quantifying carbon sinks and GHG fluxes in tidal wetlands, and assessing the impact of anthropogenic nitrogen loading, sea level rise, and climate on both carbon sequestration and net GHG emissions in tidal wetlands:

- Continued and finished biweekly (September – October 2013) and monthly (November – December 2013) vertical flux measurements of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) across four N gradient sites.
- Continued and finished field measurements of soil pH, soil moisture, soil salinity, plant height, and plant density.

- Continued and finished porewater sample collections.
- Continued automatic data collection of wind speed/direction, rain precipitation, PAR (photosynthetically active radiation), solar radiation, air temperature, and soil temperature (three depths; surface, 15cm, 30cm).
- Finished processing belowground cores for root and rhizome biomass and bulk density.
- Continued analysis of greenhouse gas, soil, and plant data gathered in first and second field seasons (fall 2012 – spring 2013).
- Started analysis of aboveground and belowground biomass collected between June and August 2013.

In September, Jordan Mora, field and technical support member at the Waquoit Bay NERR, shifted to part-time employment at MBL in order to train with Kate Morkeski, who would be leaving in December on maternity leave. Mora shadowed Morkeski during field measurements in September learning the skills necessary to operate the cavity ring-down spectrometer (CRDS) greenhouse gas analyzers and lead the field team in soil, plant, and porewater measurements. In October, Mora began leading the field visits with reduced supervision from Morkeski. Also, due to the start of the academic year, there was almost complete turnover in available field assistants. Table 4 lists the active participants in field measurements between September and December 2013.

Table 4: Direct participants in vertical fluxes effort (four of them provided in-kind support for this project from Tang's lab at MBL)

Name	Role	Institution
Jordan Mora	Research Assistant	MBL/WBNERR
Kate Morkeski	Research Assistant	MBL
Jessie Gunnard	Research Assistant	MBL
Hualei Yang	Graduate Student	MBL
Zhunqiao Liu	Graduate Student	MBL
Aizhen Liang	Post-doctoral Student	MBL
Jennifer Fanzutti	Research Assistant	MBL

Following the end of the growing season and the start of plant senescence, each site was visited once per month in November and December. December marked the end of vertical flux measurements and soil, plant, and porewater data collection for this project. Throughout January and February 2014, the focus shifted towards data management and analysis. More specifically, field notes and data continue to be converted into electronic spreadsheet formats and organized. The greenhouse gas measurements (CO_2, N_2O, and CH_4) continue to be analyzed empirically using Matlab software. As of mid-February 2014, gas fluxes have been computed for data collected through April 2013.

Table 5 provides a list of parameters measured or collected in the field since the last reporting period and the dates when each measurement occurred.

Table 5: List of parameters measured or collected in the four salt marsh nitrogen-gradient sites.

Variable	September		October			
Gas Chamber	Week 1	Week 2	Week 1	Week 2	November	December
CO_2	x	x	x	x	x	x
CH_4	x	x	x	x	x	x
N_20	x	x	x	x	x	x
CO	x	x	x	x	x	x
Air Moisture	x	x	x	x	x	x
Soil Properties						
pH	x	x	x	x	x	x
Salinity	x	x	x	x	x	x
Moisture	x	x	x	x	x	x
Plant Properties (25 x 25cm quadrat)						
Height	x	x	x			
Stem Count	x					
Water Level						
Groundwater Level	x	*(only Sage Lot has groundwater level until December)*				
Porewater Samples						
Ammonium (not processed yet)	x	x	x	x	x	x
Nitrate (not processed yet)	x	x	x	x	x	x
Meteorology						
Wind Speed/Direction	x					x
Photosynthetically Active Radiation	x	x	x	x	x	x
Solar Radiation	x					x
Soil Temperature	x	x	x	x	x	x
Air Temperature	x	x	x	x	x	x
Rain Precipitation	x					x

Although we have not had the opportunity to run statistical analyses on the biomass data from the summer 2013 field season, we do have additional raw data to present since the last reporting period. The belowground biomass data shows growth in the 0-10cm and 20-30cm soil depth intervals between June and August 2013 (Figure 3).

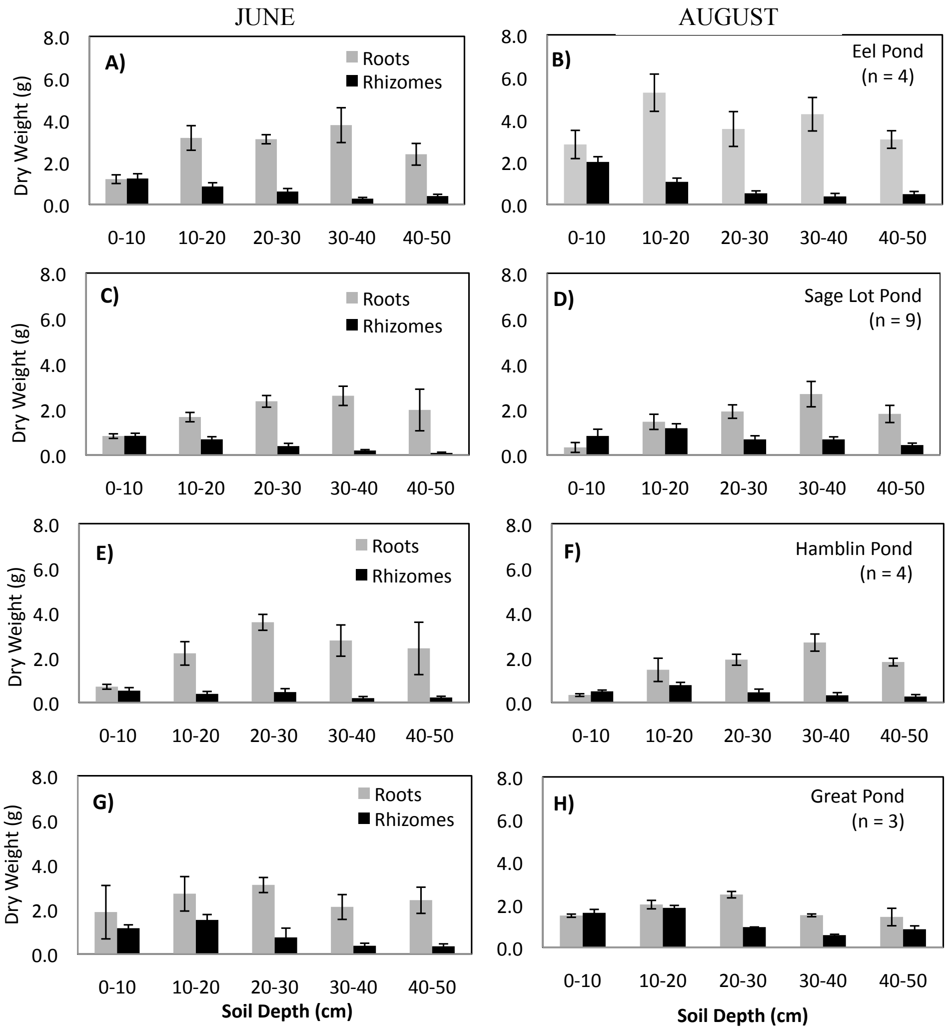

Figure 3: Root and rhizome dry weight results from four salt marsh sites. A) June 2013 sampling at Eel Pond (n = 4); B) August 2013 sampling at Eel Pond (n = 4); C) June sampling at Sage Lot Pond (n = 9); D) August 2013 sampling at Sage Lot Pond (n = 9); E) June 2013 sampling at Hamblin Pond (n = 4); F) August 2013 sampling at Hamblin Pond (n = 4); G) June 2013 sampling at Great Pond (n = 3); H) August 2013 sampling at Great Pond (n = 3). Error bars show ± 1 standard error.

We also have calculated greenhouse gas flux for the entire 2012-2013 winter season. Based on our results (Figures 4-6), carbon dioxide and methane fluxes are minimal during the coldest winter months of January and February. Nitrous oxide does not show a seasonal trend; however, Eel Pond does appear to emit more nitrous oxide, on average, than the other sites.

Negative carbon dioxide flux signifies an uptake in carbon dioxide by the salt marsh plants (Figure 4). Great Pond was the only site which showed uptake in carbon dioxide in December 2012 indicating that the plants have largely stopped photosynthesizing by December. Photosynthesis does not appear to start again until after April as we do not see any uptake of carbon dioxide in the early months of spring. Methane is the only gas which we have consistent flux measurements across all four sites throughout the winter. Methane emissions are greatly diminished and hover around zero between January and March (Figure 5). Nitrous oxide does not show any consistent seasonal trends (Figure 6). However, if we compare between sites, on average Eel Pond appears to emit more nitrous oxide than the other sites.

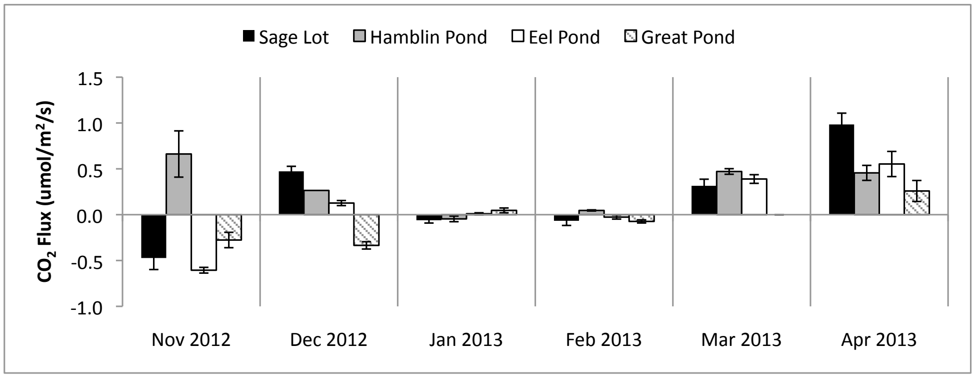

Figure 4: Carbon dioxide (CO_2) flux measurements from four salt marsh sites along a nitrogen gradient located near or within the Waquoit Bay Estuary, Cape Cod. Error bars show ± 1 standard error.

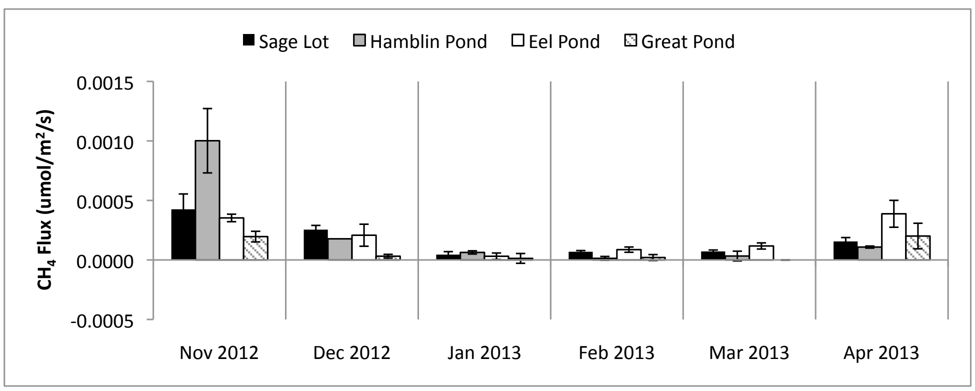

Figure 5: Methane (CH_4) flux measurements from four salt marsh sites along a nitrogen gradient located near or within the Waquoit Bay Estuary, Cape Cod. Error bars show ± 1 standard error.

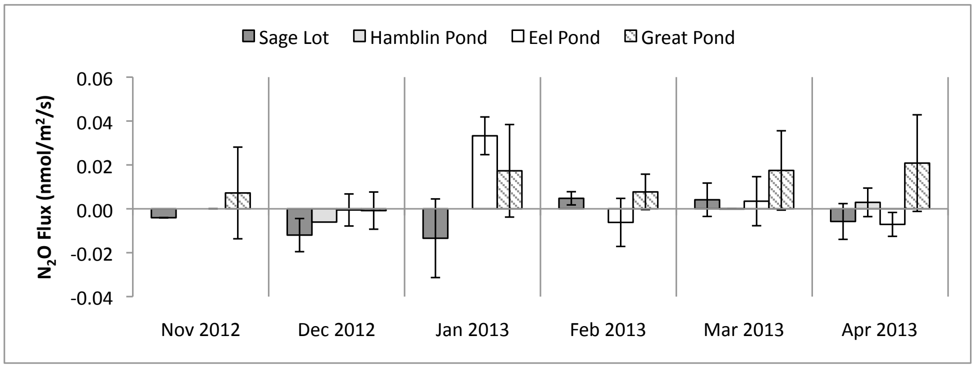

Figure 6: Nitrous oxide (N_2O) flux measurements from four salt marsh sites along a nitrogen gradient located near or within the Waquoit Bay Estuary, Cape Cod. Error bars show ± 1 standard error.

Challenges

We had technical challenges in the field during this reporting period whereby several automatic data loggers failed, resulting in lost climate and water level data. The meteorological station, which measures rain precipitation, two forms of radiation, and wind speed/direction, failed in September and was not replaced until December. Additionally, two water level recorders, placed in 50 centimeter wells as a means to record changes in groundwater level, failed during a two month recording period starting in September and the data was irretrievable. Sage Lot (reference site) was the only site which successfully logged groundwater level until December. All water level recorders have been removed in an attempt to prevent further technological losses. The replaced meteorological station and temperature probes have successfully logged data since the December launch. These sensors are periodically checked and downloaded throughout the winter.

Talks given in this reporting period:

Are salt marshes sinks or sources of greenhouse gases? How shifts in greenhouse gas fluxes from coastal ecosystems may affect the promise of Blue Carbon. Serena Moseman-Valtierra, Jianwu Tang, Kate Morkeski, Katharine Egan, Timothy Lima, Kevin Kroeger. CERF, 2013

Investigating time variations in DOC concentrations for salt marsh carbon budgets:
Testing continuous CDOM measurements as a proxy. Elizabeth Brannon, Kevin Kroeger, John Pohlman, Adrian Green, Neil Ganju. CERF, 2013

Anticipated activities during the next 6-months

The lateral flux team anticipates the following work during the next 6 months:

- Continue investigation of DIC system and CO_2 sensor performance (in collaboration with A. Wang);
- Maintain the suite of sensor deployments during spring and summer 2014;
- Continue sensor and water chemistry data analysis from the past year, to calculate carbon and gas flux rates;
- Continue analysis of lipid compositions of particulate and dissolved organic matter (in collaboration with A. Spivak);

- Continue coring study of soil carbon storage rate and source (M. Gonneea lead);
- Analyses of DOC and DIC carbon stable isotope ratios to aid in source identification (J. Pohlman lead);
- Continue processing aqueous gas concentration data based on GC and CRDS data.
- The vertical flux team will continue to process the greenhouse gas flux measurements and organize the other soil and plant data. Our goal is to prepare a full year of collected and processed data (July 2012 through June 2013) for the annual meeting in the spring of 2014 (date to be determined). Additionally, the next series of processed data will be submitted to Omar Abdul-Aziz for the ecosystem-based model development following the annual meeting deadline. Abdul-Aziz suggested that all the data be made available by mid-summer 2014 in order for the model and end-user interface to be fully developed and piloted by January 2015. Our hope is to have all the data to Abdul-Aziz's team before the July 2014 deadline.
- Furthermore, we have planned to analyze a subset of aboveground and belowground samples (stems, roots, rhizomes, and sediment) for isotopes N15 and C13 as well as total percent volume of nitrogen and carbon. Marshall Otter, Senior Research Assistant at the MBL, has agreed to complete this analysis for us under contract with the USGS. However, the first step is to grind all the samples using available grinding equipment at the MBL. Our projected timeline for this analysis involves grinding and packaging the samples by mid-March 2014.
- Lastly, Kate Morkeski should be returning from maternity leave sometime in March 2014. Given her background and expertise in laboratory analyses, she will likely process the rest of our porewater samples for ammonium and nitrate once she returns. However, no specific date or timeline has been suggested for this part of the project.

The following abstracts are for talks planned in the upcoming reporting period:
Special session: 055 - Carbon Cycling and Fluxes in Coastal Vegetated Wetlands. Organizers ZA Wang, KD Kroeger, S Moseman-Valtierra, RM Martin. Joint Aquatic Sciences Meeting, Portland, OR, May 18-23, 2014

Kroeger, KD, Pohlman, JP, Ganju, NK, Spivak, AC, Wang, ZA, Green, A, Brooks, TW, Baldwin, S, Moseman-Valtierra, S, Tang, J. 2014. Salt Marsh Carbon Budgets: FLUXES and sources of dissolved and particulate organic carbon in tidal exchanges. Abstract, Joint Aquatic Sciences Meeting, Portland, OR, May 18-23, 2014

Wang, ZA, Kroeger, KD, Green, A, Hoering, KA, Pohlman, JP, Ganju, NK, Moseman-Valtierra, S, Tang, J. 2014. Salt Marsh Carbon Budgets: biogeochmistry of The co2 system and tidal exchanges of inorganic carbon and Alkalinity. Abstract, Joint Aquatic Sciences Meeting, Portland, OR, May 18-23, 2014.

BIOGEOCHEMICAL MODEL

Lead: Omar Abdul-Aziz

As a part of the proposed user-friendly GHG emissions and C-sequestration model, we have developed a simple, systematic data-analytics approach to analyze observational data and determine the relative linkages of wetland GHG fluxes with different climatic, hydrologic, biogeochemical and ecological drivers. Multivariate techniques such as the principal component analysis (PCA) and factor analysis (FA) were utilized to classify and group process variables based on their similarity and interrelation patterns. Power-law based partial least squares regression models were developed to predict GHG fluxes, estimating their relative linkages with the process drivers and stressors. Artificial neural network based data-driven predictions were also explored to allow a flexible model structure. In the last 6 months, we tested and finalized the methodology by using large (canopy) scale, half-hourly GHG flux data for 2006-11, as gathered from the Ameriflux network. The GHG data included (i) vertical CO_2 fluxes for 8 deciduous forest sites of northeastern USA, and (ii) net ecosystem exchanges (NEE) for 6 different vegetation types of eastern USA. Concurrent data for 11 climate/environmental variables were also gathered for the same ecosystems. Impressive modeling performance for different sites indicated that data-driven, empirical models can be useful and much user-friendly tools, compared to their more complex process-based counterparts, for predicting ecosystem GHG fluxes under a changing climate and environment. The results were presented with two posters in the Fall Meeting of American Geophysical Union held in December 2013 at San Francisco, CA. We have prepared two manuscripts (currently undergoing internal review) to publish in peer-reviewed journals. We have already started to apply the developed data-analytics and modeling tool on the data sets that were collected from the four sites of WBNERR during 2012. Since the 2012 data set is yet to be completed by the field science team, we leveraged regional climate and water level stations to supplement climate (e.g., radiation, air temperature, vapor pressure, relative humidity) and water level data for our sites.

Anticipated activities during the next 6-months
In the next 6 months, we will apply the empirical modeling framework to the latest and reconstructed 2012 data for our wetland study sites. We will present our results at the 2014 Joint Aquatic Sciences Meeting that will be held in Portland, Oregon during May 18-23. Omar Abdul-Aziz will also work with Tonna-Marie Rogers and Kate Harvey to begin more direct stakeholder engagement around the model and timing for testing the draft model with potential intended users.

ECONOMIC ANALYSIS
Lead: Thomas Walker (Manomet)

During this period, we continued to refine the scope and nature of the economic and policy analysis. Based on discussions with MA Division of Ecological Restoration, review of DER data on tidal restoration projects, and analysis of initial carbon flux insights from our project and the available literature, the team decided to shift the economic and policy analysis from a focus on potential carbon flux benefits of reducing nitrogen loadings to an analysis of GHG reduction benefits associated with restoring tidal flows to freshwater marshes—with an emphasis on avoided methane. The revised plan is to conduct a case study of the potential economic benefits resulting from restoration of tidal flows to the large Herring River wetland in Wellfleet.

Herring River lies mostly within the bounds of the Cape Cod National Seashore and the National Park Service (NPS) is the lead government agency for the project.

During this reporting period, we reviewed available literature on methane reductions from salt marsh restorations and assembled initial information on values for methane flux as a function of salinity. In addition, we met with NPS staff, conducted a site visit to Herring River and evaluated site-specific information on the project. We also assembled information on the social cost of carbon that will be applied in the analysis.

The goal of the case study will be to estimate the economic value of the GHG benefits associated with the Herring River project and provide an analysis of the implementation costs of packaging carbon credits for sale under the recently proposed VCS salt marsh carbon protocols. This will assist the National Park Service, which is the lead government agency for the project, in determining whether the carbon benefits can be monetized and therefore reduce the net cost of the restoration.

Information collected
During this period, the following information was assembled and reviewed:

- Ongoing and completed tidal restoration projects in Massachusetts.
- Salinity modeling data for available tidal restoration projects conducted by MA DER.
- Social cost of carbon.
- Fixed and variable cost data associated with the sale of carbon credits.

The key insight from work during this period is that reductions in methane releases associated with restoring tidal flows to freshwater wetlands have the potential to yield quite significant economic benefits, particularly on a per hectare basis. Where freshwater wetlands are replaced with salt marsh, currently available data suggest reductions of approximately 35 tonnes of CO_2-equivalents per hectare per year. Over the life of the project, the per-hectare benefits could be in the tens of thousands of dollars. In addition, for larger projects, these credits have the potential to be monetized through sale in established carbon markets. But even where they cannot be monetized, the GHG benefits are potentially very significant and will likely be an important contributor to the overall benefits of salt marsh restoration projects (to be confirmed in our analysis).

While the conceptual analytical framework has not changed, the focus of the stakeholder analysis has been shifted to government organizations and NGOs involved in salt marsh restoration. Based on initial analysis, we believe the results of the project will be most useful to these groups.

Lessons learned
Finding the most appropriate targets of opportunity for the economic and policy analysis has been challenging in light of the team's developing understanding of salt marsh GHG fluxes. One initial lesson is that the impacts of reducing nitrogen loadings are probably not that substantial

from an economic benefits perspective, thereby reducing the direct utility of results to stakeholders currently struggling to address non-point loadings to Cape Cod estuaries.

Plans for the next six months?

- Conduct additional stakeholder outreach to groups involved in tidal restoration efforts.
- Estimate carbon fluxes at Herring River in both the baseline and with project scenarios in order to determine changes in GHGs.
- Estimate the social value of these GHG benefits.
- Conduct the analysis of implementation costs associated with marketing carbon credits from the Herring River restoration. Seek to generalize this for restoration projects of different sizes.

D. BENEFIT TO NERRS AND NOAA

This project continues to generate interest in the NERRS and within NOAA. South Slough NERR applied for and received a transfer-of-ideas grant from NSC which enabled them to host a Blue Carbon Dialogue and Demonstration workshop similar to the one held at Waquoit Bay last March. Steve Emmett-Mattox and Steve Crooks put on the workshop.

Tonna-Marie Rogers and Alison Leschen from WBNERR, and Steve Emmett-Mattox on the phone, gave a talk on the project in a session on Ecosystem Services in the NERRS at the annual NERRS meeting in West Virginia in November 2014. Their description of the project was well-received by a good-sized audience, many of whom had been unfamiliar with blue carbon and its importance. Kristin Wilson, Wells Reserve Research Coordinator, was inspired to apply for transfer grant funds to host a Blue Carbon workshop that would lead to a New England Blue Carbon working Group.

Various team members have been invited to speak at a number of conferences. Each of these helps get the NERRS name out into the scientific and other communities.

E. Describe any activities, products, accomplishments, or obstacles not addressed in other sections of this report that you feel are important for the Science Collaborative to know.

TOTE curriculum

A transfer grant connected to this project funded development of a BWM curriculum and the piloting of it at a TOTE workshop. From September 2013 until the call back session on November 15, the TOTE teachers engaged their students in the Adopt-a-Wetland Stewardship Field Study and chose another classroom or on-line activity from the Bringing Wetlands to Market curriculum to try out with their students. At the call-back session on November 15, the teachers enthusiastically shared what their students did and traded ideas and suggestions with each other. After lunch, we conducted a focus group to gather feedback on the "Bringing Wetlands to Market curriculum. During January we implemented the teachers' suggestions and readied the curriculum for posting on the BWM website. In February, the curriculum was organized, an index was created, and it was posted on the website. We began to disseminate the link for the curriculum (on the project website) which has a Survey Monkey link to gather any new input.

Articles
Steve Emmett-Mattox and Steve Crooks co-authored an article in a special discussion issue of the National Wetlands Newsletter on coastal blue carbon. The article was based on the blue carbon template for coastal managers that they developed as part of the NERRS SC knowledge transfer award last year.

Additional research
As an illustration of the ongoing and future research spawned by this project, the following activities are planned by the science team:
To better explain our vertical flux data over the season and across the sites and generate more funding in the future to continue this project, we are planning three initiatives:

1) To explain the variation of GHG fluxes over the season and among sites, we plan to make leaf-scale GHG flux measurement in this growing season. We will only focus on the Sage Lot site. We will design a leaf chamber to measure gas fluxes from *Spartina* leaves.
2) We plan to install a camera at Sage Lot to automatically record phenology and growth of the salt marsh. The image data will be used to explain the seasonal pattern of GHG fluxes.
3) We are planning to initiate a warming experiment at Sage Lot by using open-top chambers to warm up small plots and then measure the response of GHG fluxes to elevated temperature. This will be partially supported by a funded project to Jim Tang and Kevin Kroeger. A post doc will work on this.

Last but not least
The Team produced three really cute babies during this reporting period: two girls and a boy. Congratulations Serena, Kate, and Kate!