CONNECTICUT SEA GRANT PROJECT REPORT

Please complete this progress or final report form and return by the date indicated in the emailed progress report request from the Connecticut Sea Grant College Program. Fill in the requested information using your word processor (i.e., Microsoft Word), and e-mail the completed form to Syma Ebbin (syma.ebbin@uconn.edu), Research Coordinator, Connecticut Sea Grant College Program. Do NOT mail or fax hard copies. Please try to address the specific sections below. If applicable, you can attach files of electronic publications when you return the form. If you have questions, please call Syma Ebbin at (860) 405-9278.

Please fill out all of the following that apply to your specific research or development project. Pay particular attention to goals, accomplishments, benefits, impacts and publications, where applicable.

Name of Submitter: Beth Lawrence

Date of Report submission: April 30, 2020

Project #: R/CMB-42-CTNY Check one: [ ] Progress Report [X] Final report

Duration (dates) of entire project, including extensions: From [3/1/2017] to [2/28/2020].

Project Title or Topic: How will sea level rise-driven shifts in wetland vegetation alter ecosystem services?

Principal Investigator(s) and Affiliation(s):

1. Beth Lawrence/University of Connecticut/Dept. of Natural Resources & Environment, Center for Environmental Science & Engineering

2. Ashley Helton/University of Connecticut/ Dept. of Natural Resources & Environment, Center for Environmental Science & Engineering

3. Chris Elphick/University of Connecticut/ Dept. of Ecology & Evolutionary Biology, Center of Biological Risk

A. <u>COLLABORATORS AND PARTNERS</u>: *(List any additional organizations or partners involved in the project.)*

- Kimberly Williams, Smithtown High School
- Cadence Cambrial, North Haven High School
- Natural Resources Conservation Academy
- Roger Wolfe, CT DEEP

B. PROJECT GOALS AND OBJECTIVES:

Our overarching objectives are to quantify carbon (C) and nitrogen (N) cycling services in Long Island Sound (LIS) tidal marshes, project how those services will change under sea-level rise (SLR) scenarios, and develop educational materials to better communicate these changes and their implications to high school students. Specifically, the original objectives of the project were to:

1. Quantify carbon- and nitrogen-based services provided by dominant coastal marsh plant species.
2. Forecast how shifts in dominant marsh species will alter ecosystem service provision of LIS coastal wetlands.
3. Promote understanding of the complex interactions among climate change, SLR, coastal wetlands, and ecosystem services among diverse audiences in the LIS region.

C. <u>PROGRESS</u>: (*Summarize progress relative to project goals and objectives. Highlight outstanding accomplishments, outreach and education efforts; describe problems encountered and explain any delays.)*

We were given a one-year no cost extension in order to meet the project objectives. We finished collection of empirical data via a field survey and marsh organ experiment related to Objective 1, developed ecosystem service maps (Obj. 2), developed the climate change outreach module with regional high school teachers (Obj. 3), and have submitted two manuscripts (four additional manuscripts in prep) for publication in the peer reviewed literature (Obj. 3).

<u>Year 1 (3/1/2017-2/28/2018)</u>: We developed and received EPA approval for our QAPP in April 2017. Two MS-level graduate students began working on the project during summer 2017 and were integral to the site selection process. We received permission to sample from candidate sites, and during August 2017, we began our coastal wetland field campaign to investigate the role of tidal restoration and vegetation zonation on carbon and nitrogen-based ecosystem services. We sampled a total of 20 sites (10 restored, 10 unrestored) for a range of biological (% plant cover, above- and below-ground biomass, microbial community composition), soil physical and chemical parameters (pH, EC, SO_4^-, Cl^-, NO_3^-, NH_4^+, %OM, total C and N), and microbial process rates (denitrification, substrate induced respiration, carbon mineralization).

Given time and logistical constraints, we were unable to sample the total number of sites that we had intended to sample; we had proposed to sample 30 sites (10 unrestored sites, 10 tidally restored, 10 *Phragmites*-herbicide sites), but only sampled 20 (10 unrestored, 10 tidally restored). The *Phragmites* management sites were typically brackish marshes (more inland) where tidal flow restoration was not an option, and did not have all three plant species of interest (*Spartina alterniflora, Spartina patens*, and *Phragmites*). The on-the-ground reality of the marshes did not conform to our proposed experimental design. We considered sampling the *Phragmites* management sites differently, by comparing herbicide-managed areas with *Phragmites*-dominated areas and native-dominated areas within each site. However, this experimental design addresses a different question than the one we proposed; thus, given time constraints, we were unable to pursue it.

Year 2 (3/1/2018-2/28/2019): We conducted a marsh organ experiment at Barn Island WMA (Stonington, CT) during the 2018 growing season to test the interactive effects of sea-level rise and plant species composition. Manipulating the elevation of the marsh by installing PVC pipes of different heights allowed us to examine how different flooding frequencies altered plant biomass allocation patterns, as well as the suite of soil physical and chemical parameters measured during Year 1 of the project. Our findings indicate that carbon-based microbial processes were more greatly affected by plant treatment than by SLR treatments, highlighting the importance of plant-mediated ecosystem services.

We made significant progress on Objective 3 in Year 2. We presented our research findings to a wide variety of audiences during ten oral presentations in 2018 (see list below). MS students Aidan Barry and Sean Ooi served as "community partners" for the Natural Resources Conservation Academy's Conservation Ambassador Program, mentoring a high school student on a salt marsh ecology project. Additionally, we had a kickoff workshop with partner teachers in January 2019 to develop plans for the interactive climate change module; we identified learning objectives, outlined module components, created a time line and assigned tasks.

Year 3 (3/1/2019- 2/28/2020): Both graduate students associated with the project successfully defended their MS theses in June 2019. Additionally, two undergraduate research students associated with the project (Kayleigh Granville, Alaina Bisson) completed honors theses that are associated with project objectives. We are in the process of finalizing six manuscripts for publication in the peer-reviewed literature; we recently submitted two manuscripts (Barry et al., Donato et al. are appended) and we are actively working on four additional manuscripts that we intend to submit in the coming six months. We worked with regional high school teachers to finalize our interactive climate change module and began publicly disseminating the resource in January 2020 (see below).

D. PROJECT PUBLICATIONS, PRODUCTS, PRESENTATIONS AND PATENTS:
(Include published materials with complete references, as well as those which have been submitted but not yet published and those in press. Please attach electronic versions of any journal articles, reports, and abstracts not previously provided.)
[%]product is appended to this document; [**]undergraduate student, [*]graduate student

Journal Articles (List URLs):

- [%]Barry, A., Ooi, S., Elphick, C., Helton, A., Stevens, B. and B. Lawrence. Vegetation zonation drives salt marsh soil carbon mineralization and microbial communities. Submitted to Ecosystems on April 29, 2020.
- [%][**]Donato, M., [*]Johnson, O., Steven, B., Lawrence, BA. Nitrogen enrichment stimulates wetland plant responses whereas salt amendments alter sediment microbial communities and biogeochemical responses. Originally submitted to PLOS ONE January 31, 2020; revised version submitted April 23, 2020.

Conference Papers: NA

Proceedings or book chapters: NA

Web sites, Software, etc.:

- %Cambrial, C, Lawrence, B., Williams, K. 2020. Salt marsh-climate change teaching module: Impacts of climate change on Long Island Sound marshes: https://climate.uconn.edu/wp-content/uploads/sites/126/2020/01/Salt-marsh_Climate-change_module_final.pdf.

Technical Reports/Other Publications: NA

Other Products (including popular articles):

- "Connecticut's Marshes: Past, Present, and Uncertain Future." UConn Today article, available at: https://today.uconn.edu/2018/11/connecticuts-marshes-past-present-uncertain-future/
- "Scientists investigate effects of sea level rise on coastal wetlands." Naturally@UConn article (College of Agriculture, Health and Natural Resources), available at: https://naturally.uconn.edu/2017/07/04/scientists-investigate-effects-of-sea-level-rise-on-coastal-wetlands/

Publications planned / in progress:

- Ooi, S., Barry, A., Elphick, C., Lawrence, B., and A. Helton. *In prep.* Potential denitrification rates vary with dominant vegetation zones in southern New England coastal salt marshes. Target journal: Ecological Applications
- Granville, K, Ooi, S., Koenig, L., Lawrence, B., Elphick, C., Helton, A. *In prep.* Seasonal patterns of denitrification and N20 production in salt marshes. Target journal: Wetlands
- Barry, A., Ooi, S., Elphick, C., Helton, A., Stevens, B. and B. Lawrence. *In prep.* Plant-mediated carbon turnover overrides effects of sea level rise in a salt marsh field experiment. Target journal: Estuaries and Coasts
- Bisson, A., Barry, A., Meadows-McDonnell, Elphick, C., A. Helton, Lawrence, B. *In prep.* Impacts of salt marsh vegetation and sea level rise on soil carbon stability. Target journal: Plant and Soil.

Patents: *(List those awarded or pending as a result of this project.)*: NA

Presentations and Posters: *(Include name and date of the conference or meeting, whether it was a talk or poster, if it was invited, and who the presenter was.*):
NOTE: We had several planned presentations this spring at the Connecticut Conference on Natural Resources as well as the Society for Wetland Scientists meeting in Montreal, Quebec that were cancelled due to the COVID-19 pandemic. **indicates graduate student, **undergraduate student*

1. Lawrence, B. (presenter), Helton, A, Elphick, C., *Ooi, S., *Barry, A. How do vegetation shifts alter carbon and nitrogen based ecosystem services in southern New England salt

marshes? Coastal Estuarine Research Federation (invited talk); Advances in understanding sea level rise and coastal landscape change (Symposium). November 4, 2019. Mobile, AL.

2. *Barry, A. (presenter), *Ooi, S., Helton, A., Elphick, C, Steven, B., Lawrence, B. Plants drive carbon turnover under sea-level rise. May 30, 2019. Society for Wetlands Scientists Annual meeting (talk). May 30, 2019. Baltimore, Maryland.
3. *Ooi, S. (presenter), *Barry, A., **Granville, K., Lawrence, B., Elphick, C., Helton, A. Using vegetation zones to predict salt marsh denitrification. Society for Wetlands Scientists Annual meeting (talk). May 30, 2019. Baltimore, Maryland.
4. **Bisson, A. (presenter), Lawrence, B. Impacts of salt marsh vegetation and sea-level rise on soil carbon stability (poster). Society for Wetland Scientists Annual Meeting. May 30, 2019.
5. **Liu, F. (presenter), Helton, A., Elphick, C, Lawrence, B. How does sea level rise alter salt marsh plant biomass allocation and nitrogen content? UConn Frontiers in Undergraduate Research (poster). April 11, 2019, Storrs, CT
6. **Bisson, A. (presenter), Lawrence, B. Impacts of salt marsh vegetation and sea-level rise on soil carbon stability. UConn Frontiers in Undergraduate Research (poster). April 11, 2019, Storrs, CT.
7. **Granville, K. (presenter), *Ooi, S., Lawrence, B, Elphick, C., Helton, A. Seasonal patterns of denitrification in salt marshes. UConn Frontiers in Undergraduate Research (poster). April 11, 2019, Storrs, CT.
8. *Barry, A. (presenter), *Ooi, S., Helton, A., Elphick, C, Steven, B., Lawrence, B. Plants drive carbon turnover under sea-level rise. Connecticut Conference on Natural Resources (talk). March 2019. Storrs, Connecticut.
9. **Bisson, A. (presenter), Lawrence, B. Impacts of salt marsh vegetation and sea level rise on soil carbon stability. Connecticut Conference on Natural Resources (talk). March 2019. Storrs, Connecticut.
10. **Granville, K. (presenter), *Ooi, S., Lawrence, B, Elphick, C., Helton, A. Seasonal patterns of denitrification in salt marshes. Connecticut Conference on Natural Resources (talk). March 2019. Storrs, Connecticut.
11. *Ooi, S. (presenter), *Barry, A., **Granville, K., Lawrence, B., Elphick, C., Helton, A. Using vegetation zones to predict salt marsh denitrification. Connecticut Conference on Natural Resources (talk). March 2019. Storrs, Connecticut.
12. *Barry, A. (presenter), Ooi, S., Helton, A., Elphick, C, Steven, B., Lawrence, B. Plants drive carbon turnover under sea-level rise. Long Island Sound Study Research Conference (talk). March 2019. Port Jefferson, New York.
13. *Ooi, S. (presenter), *Barry, A., **Granville, K., Lawrence, B., Elphick, C., Helton, A. Using vegetation zones to predict salt marsh denitrification. Long Island Sound Study Research Conference (talk). March 2019. Port Jefferson, New York.
14. Lawrence, B. (presenter), Helton, A, Elphick, C. How will sea-level rise driven shifts in wetland vegetation alter carbon and nitrogen based ecosystem services? Long Island Sound Study, Science Technical Advisory Committee meeting (invited talk). November 16, 2018, Groton, CT.
15. Lawrence, B. (presenter). Marsh madness: invasive macrophytes and ecosystem service tradeoffs during wetland restoration. Carey Institute of Ecosystem Studies Fall Seminar Series (invited talk). November 2, 2018, Millbrook, NY

16. *Barry, A (presenter), *Ooi, S., Elphick, C., Helton, A. Steven, B., Lawrence, B. Salt marsh vegetation influence on carbon-based services and microbial communities. Connecticut Symbiosis Symposium (invited talk). October 2018. Connecticut Agricultural Experiment Station, New Haven, Connecticut
17. *Ooi, S, Barry A (co-presenters), Steven B, Elphick C, Helton A, Lawrence B. Effects of salt marsh tidal restoration on soil microbial process rates. Society of Ecological Restoration- New England Chapter Meeting (poster). October 2018. New Haven, CT
18. Lawrence, B. (presenter), Helton, A, Elphick, C. How will sea-level rise driven shifts in wetland vegetation alter carbon and nitrogen based ecosystem services? New York-Connecticut Sea Grant & Long Island Sound Study Principal Investigator Forum (invited talk). August 6, 2018, Groton, CT
19. *Barry, A. (presenter), *Ooi, S., Elphick, C., Helton, A. Steven, B., Lawrence, B. Salt marsh vegetation influence on carbon-based services and microbial communities. Society of Wetland Scientists Annual meeting (talk). June 2018. Denver, Colorado.
20. Lawrence, B (presenter). Towards a conceptual framework for understanding tradeoffs in biodiversity and carbon function in coastal wetlands. Society of Wetland Scientists Annual meeting (talk). June 2018. Denver, Colorado.
21. *Ooi, S. (presenter), *Barry, A., Lawrence, B., Elphick, C., Helton, A. Potential denitrification rates vary with salt marsh vegetation zones. Society of Wetland Scientists Annual meeting (talk). June 2018. Denver, Colorado.
22. *Barry, A (presenter), *Ooi, S., Elphick, C., Helton, A. Steven, B., Lawrence, B. Salt marsh vegetation influence on carbon-based services. New England Estuarine Research Society Spring 2018 Meeting (talk). April 27, 2018. Portsmouth, New Hampshire.
23. *Ooi, S. (presenter), *Barry, A., Lawrence, B., Elphick, C., Helton, A. Potential denitrification rates vary with salt marsh vegetation zones. New England Estuarine Research Society Spring 2018 Meeting (talk). April 27, 2018. Portsmouth, New Hampshire.
24. *Barry, A. (presenter), *Ooi, S., Elphick, C., Helton, A. Steven, B. Lawrence, B. Salt marsh vegetation influence on carbon-based services. Connecticut Conference on Natural Resources (talk). March 12, 2018. Storrs, Connecticut.
25. *Ooi, S. (presenter), *Barry, A., Lawrence, B., Elphick, C., Helton, A. Potential denitrification rates vary with salt marsh vegetation zones. Connecticut Conference on Natural Resources (talk). March 12 2018. Storrs, Connecticut.
26. **Donato, M., Lawrence, B. Effects of plant traits and water quality on carbon gas fluxes from freshwater wetlands. Connecticut Association of Wetland Scientists. March 8, 2018.
27. *Ooi, S. (presenter),*Barry, A., Helton, A., Elphick, C, and Lawrence, B. How does shifting wetland vegetation influence nutrient cycling in Connecticut coastal marshes? Joint Natural Resources and Environmental Engineering Graduate Student Symposium (poster). September 2017. University of Connecticut, Storrs, CT.
28. Lawrence, B. (presenter), Helton, A, and Elphick, C. How will sea-level driven shifts in wetland vegetation alter carbon and nitrogen based ecosystem services? Connecticut Institute for Resilience and Climate Adaptation Forum (invited poster). May 2017. University of Connecticut, Storrs, CT.

E. FUNDS LEVERAGED: *(If this Sea Grant funding facilitated the leveraging of additional funding for this or a related project, note the amount and source below.)*

- We received 25% match ($79,457) for this project from Connecticut Institute for Resilience and Climate Adaptation (CIRCA)
- UConn 2018 Summer Undergraduate Research Fellowships received by Kayleigh Granville and Alaina Bisson ($4000 each)
- B. Lawrence received Development Funds ($2,981) from Connecticut Sea Grant. "Translating climate science to high school audiences: developing a regionally relevant climate change module for southern New England." November 30, 2018- September 1, 2019.
- UConn Work-Study program. Undergraduate research assistant processing project-related samples (~8 hours/week x 14 weeks x 2 semesters= ~224 student technician hours x $10/hour = ~$2240). August 2018- May 2019.

F. STUDENTS: ***(****Document the number and type of students supported by this project.)*
*Note: **"Supported"** means supported by Sea Grant through financial or other means, such as Sea Grant federal, match, state and other leveraged funds. "**New"** students are those who **have not** worked on this project previously. "**Continuing"** students are those who **have** worked on this project previously. If a student volunteered time on this project, please use section G, below.*

Total number of **new*** K-12 students who worked with you: 1
Total number of **new** undergraduates who worked with you: 5
Total number of **new** Masters degree candidates who worked with you: 2
Total number of **new** Ph.D. candidates who worked with you: 0

Total number of **continuing**** K-12 students who worked with you: 0
Total number of **continuing** undergraduates who worked with you: 0
Total number of **continuing** Masters degree candidates who worked with you: 0
Total number of **continuing** Ph.D. candidates who worked with you: 0

Total number of volunteer hours: 80

*(Note: *__New__ students are those who have not worked on this project previously.*
***__Continuing__ students are those who have worked on this project previously.)*

In the case of graduate students, please list student names, degree pursued, and thesis or dissertation titles related to this project.

Student Name: Aidan Barry
Degree Sought: MS
Thesis or Dissertation Title: Salt Marsh Vegetation Influence on Carbon-based Services and Microbial Communities
Date of thesis completion: June 2019
Expected date of graduation:

Student Name: Sean Khan Ooi
Degree Sought: MS
Thesis or Dissertation Title: Potential denitrification rates vary with dominant vegetation zones in southern New England coastal salt marshes
Date of thesis completion: June 2019
Expected date of graduation:

G. VOLUNTEER HOURS:
An undergraduate student helped collect and process samples during 2017 (80 hours).

H. PICTORIAL: Please provide high resolution images/photos of personnel at work, in the field or laboratory, equipment being used, field sites, organism(s) of study. Attach images as separate files (do not embed). Include links to websites associated with the research project. Please include proper photo credits and a caption with date, location, names of people, and activity. These images are useful to document your project in future CTSG publications, websites and presentations.

- Lawrence Lab website: https://lawrencelabuconn.weebly.com/projects.html
- Attached photo ("Sean lab"): UConn MS student Sean Ooi quantifies salt marsh denitrification potential in the lab. Date: August, 2017. Photo credit: Beth Lawrence
- Attached photo ("Marsh organ"): Experimental marsh organ to test how flooding frequency and plants alter carbon and nitrogen-based ecosystem services. Date: May 2018. Photo credit: Beth Lawrence
- Attached photo ("Marsh org group"): UConn MS students Aidan Barry and Sean Ooi, with BS students Alaina Bisson and Kayleigh Granville at Barn Island NWR (Stonington, CT) in front of experimental marsh organ.

I. HONORS AND AWARDS: *(List any honors or awards received during the reporting period, for anyone working on the project. This can be for best paper or poster, university awards, etc.*) Specify:

- Beth Lawrence (PI) received the Early Career Teaching Excellence Award from UConn-American Association of University Professors; March 2020
- Sean Khan Ooi received the Graduate Student Excellence in Research and Creativity Award from the College of Agriculture, Health, and Natural Resources, University of Connecticut; March 2019
- Sean Ooi and Aidan Barry (MS students associated with project) received a best poster award at the Society for Ecological Restoration (New England Chapter); October 2018
- Alaina Bisson and Kayleigh Granville (undergraduate students associated with the project, mentored by Beth Lawrence and Ashley Helton, respectively) both received a Summer Undergraduate Research Fellowship ($4000 each) to pursue independent research related to project objectives; summer 2018

- Aidan Barry (MS student) was awarded a research grant ($1000) to support analysis of sediment microbial communities from the Society of Wetland Scientists- New England Chapter; May 2018
- Kayleigh Granville (undergraduate student) was accepted as a UConn "University Scholar," a prestigious undergraduate program at UConn that will allow her to pursue in-depth research related to project objectives; December 2017
- Ashley Helton (co-PI) received UConn's College of Agriculture Health and Natural Resources Kinsmen Teaching Award for excellence in undergraduate teaching and mentoring; April 2017
- Mary Donato and Kayleigh Granville (undergraduate students associated with the project, mentored by Beth Lawrence and Ashley Helton, respectively) received a Connecticut Association of Wetland Scientists Micheal Leflor Award ($1000 each) to pursue independent research related to project objectives; March 2017

FOR FINAL DEVELOPMENT AND RESEARCH GRANT REPORTS, PLEASE COMPLETE THIS SECTION:

J. PROJECT OUTCOMES AND IMPACTS

RELEVANCE OF PROJECT: *(Describe briefly the issue/problem / identified need(s) that led to this work.)*

Coastal marshes fringing the Long Island Sound are dynamic ecosystems positioned at the interface between land and sea, and provide an array of essential ecosystem services to society associated with improved water quality, carbon sequestration, and disturbance regulation. However, these valuable wetlands are increasingly altered by rising seas and invasive species, and have been altered by historical management efforts such as tidal manipulation. Direct effects of altered salinity and hydroperiods have been linked to changes in carbon and nitrogen cycling. Sea level rise and tidal restoration also alters plant species composition, which can affect carbon cycling and nitrogen removal rates. Our research fills a knowledge gap and will improve coastal management by explicitly quantifying the direct (elevated salinity and hydroperiod) and indirect (changes in plant species composition) effects of sea level rise and tidal restoration on carbon and nitrogen cycling.

RESPONSE: *(Describe briefly what key elements were undertaken to address the issue, problem or need, and who is/are the target audience(s) for the work.)*

We used field surveys, experimental manipulations, and modeling to quantify and forecast carbon and nitrogen ecosystem services that could be impacted by ecosystem management and sea level rise in Long Island Sound coastal marshes. We conducted a survey of 20 Connecticut salt marshes (10 tidally restored, 10 unrestricted references) in 2017 to quantify carbon mineralization, denitrification potential, microbial community composition, and a suite of plant and sediment characteristics. To disentangle the effects of vegetation, soils and hydrology on carbon and nitrogen cycling, we set up an manipulative "marsh organ" experiment in 2018 to test how the tidal hydrology of three sea level rise scenarios and plant composition altered carbon and nitrogen processes underlying key ecosystem services. We also used SLAMM models to

forecast vegetation composition under different sea level scenarios and scaled our empirical denitrification data to the Connecticut coast.

The target audiences for our work are land managers, fellow scientists, and students (high school, university undergraduate and graduate students). Our research questions centered on how sea level rise, invasive species, and tidal restoration alter the provision of carbon and nitrogen-based ecosystem services, which are focal issues with high relevance to coastal managers. Our work also strengthens our scientific understanding of the linkages between abiotic (hydroperiod, salinity) and biotic (plant and sediment microbial composition) factors, and the processes (carbon cycling, denitrification) underlying many salt marsh ecosystem services. Finally, our project aimed to improve understanding of the complex interactions among climate change, sea level rise, coastal wetlands, and ecosystem services among diverse audiences. We created curriculum for high school science teachers, mentored a high school student research project, mentored four undergraduate researchers, and two graduate students.

RESULTS: *(Summarize findings and significant achievements in terms of the research and any related education or outreach component; cite benefits, applications, and uses stemming from this project, including those expected in the future. Include qualitative and quantitative results.)*

Vegetation zonation is an important determinant of coastal wetland processes underpinning carbon and nitrogen-based ecosystem services. In our survey of 20 Connecticut salt marshes, we quantified carbon mineralization, potential denitrification, root-zone bacterial 16S rRNA genes, above and belowground biomass and a suite of sediment characteristics (soil pH and specific electrical conductivity, soil moisture, soil organic matter, and soil $SO4^{2-}$, Cl^-, NH_4^+ concentrations). While none of our parameters differed between unrestricted and tidally restored marshes, we observed strong differences among vegetation zones, with vegetation being a top predictor of microbial respiration and potential denitrification rates. Based on sea-level rise model projections, the replacement of *S. patens* by short-form *S. alterniflora* is expected to be widespread across the Connecticut coastline, decreasing statewide potential denitrification from the low-to-high marsh transitional zone by at least 121 kg N/ hr by 2085. Our results suggest that changes in vegetation zones can serve as landscape-scale predictors of the response of denitrification rates to rapid changes occurring in salt marshes.

To determine how sea-level rise (SLR) may impact carbon cycling and nitrogen removal rates among dominant salt marsh vegetation zones, we manipulated marsh elevation and vegetation composition using a marsh organ experiment. We quantified carbon fluxes (net ecosystem exchange, ecosystem respiration, soil carbon mineralization), and potential denitrification rates in response to three SLR-scenarios (present day, ~10-year SLR (+7.5cm), ~20-year SLR (+15cm)) and five vegetation treatments (*Spartina alterniflora*, *Spartina patens, Phragmites australis*, two unvegetated controls). Interestingly, most carbon flux metrics, denitrification rates, and soil parameters (electrical conductivity, soil moisture, SO_4^-, Cl^-, NH_4^+) were not responsive to our SLR treatments. In contrast, our vegetation treatments affected all carbon flux measurements; *S. alterniflora* and *S. patens* had greater CO_2 uptake and respiration rates compared to *P. australis*. Similar to our field survey, carbon mineralization assays indicated that soils associated with *Spartina* spp. emitted more CO_2 than *P. australis*, but potential denitrification did not vary among treatments. As marshes flood more frequently with projected

SLR, marsh vegetation composition is predicted to shift towards more flood-tolerant *Spartina* spp., which may lead to increased carbon turnover rates. While hydrologic conditions and tidal flow may influence the location of marsh vegetation, our findings suggest that plants, more so than incremental flooding, play a critical role in driving carbon cycling within a salt marsh.

Our data were quality assured by our Quality Assurance Officer, Dr. Lauren Koenig; please see appended letters detailing the results of her review of our data sets.

We currently have two project-related manuscripts in review (see appended Barry et al. and Donato et al.) and intend to submit an additional four manuscripts in the coming six months. Note that three of the six of these manuscripts will have undergraduates as lead authors, and the other three will have graduate students as lead authors. We have given at least 28 project related presentations during the project period to a diversity of audiences including management focused outlets and academic conferences. We have also created an interactive climate change teaching module for high school teachers, highlighting ecological responses of salt marshes to rising seas, socio-economic aspects of coastal management, and different approaches to studying climate change in coastal wetlands (see below for more details).

Consider the following as they apply to your research and any related outreach/education.

- What new tools, technologies, methods or information services were developed from this work? Have any been adopted / implemented for use and by whom?
  - We developed a climate change teaching module for high school science teachers that aligns with Next Generation Science Standards and Ocean Literacy Essential Principles. We worked with two regional educators (Candice Cambrial, Kimberly Williams) to develop a five-day interactive module (includes case studies, Mystery Scientist videos, etc.) that focuses on coastal wetlands of the Long Island Sound. The module engages students with regionally relevant examples of how global issues impact our local environment and how scientists study various aspects of climate change. It is publically available here: https://climate.uconn.edu/tools-assistance/teachers/
  - We released this to the public on January 29, 2020 and have disseminated it to our broad network of educators. We are unaware if any teachers have adopted it yet, but it is unlikely given the current Covid-19 pandemic.

- What are the environmental benefits of this work? Have policies been changed? How has conservation (of ecosystems, habitats or species) been improved?
  - We found no difference between tidally restored and unrestricted reference marshes in soil chemistry, plant biomass, soil carbon respiration, potential denitrification rates, or microbial communities, indicating that tidal restoration efforts over the past 40 years in Connecticut have not deviated from reference site levels. However, since tidal restoration and sea level rise change the composition and areal extent of salt marsh vegetation, scaling of empirical estimates to wetland extent would better reflect how tidal restoration alters carbon- and nitrogen-based processes at site and regional scales (Ooi et al. *in prep*). Our research suggests that vegetation could be utilized to do such scaling in southern New England coastal marshes, as we observed soil carbon mineralization and potential

denitrification rates across coastal Connecticut were strongly dependent on the dominant vegetation. Soils associated with *Phragmites australis* had lower rates of carbon mineralization and higher denitrification rates than *Spartina alterniflora* zones, suggesting potential environmental benefits associated with invasive *Phragmites.* While we are unaware of any policy changes based on our work, our findings clearly have management implications that could influence conservation practices, including invasive species management.

- What are the social payoffs of this work? Who has benefited from this work? Have attitudes / behaviors of target audience changed? Elaborate. Have policies been changed?
  - The most likely direct benefactors of this work are the students involved. The project fostered the professional development of five undergraduates and two graduate students. We designed our climate change teaching module to promote easy adoption and expect that it will be implemented by high school teachers throughout the region, which would greatly broaden the impact of our work.

- What are the economic implications / impacts of this work? (Where possible, please quantify.) Have new businesses been created /or existing businesses retained as a result of this research? Have new jobs been created or retained? Are new businesses or jobs anticipated?
  - Managers spend millions of dollars annually to control invasive *Phragmites australis* in the U.S. However, our work suggests that this species has some environmental benefits including enhanced carbon sequestration and nitrogen removal. Thus, while our work has not directly created new jobs or stimulated business activity, it contributes to the growing understanding that there are environmental trade-offs associated with controlling invasive *Phragmites*. For some wetlands, funds targeting control efforts should be reallocated to other conservation initiatives in light of the carbon accrual and nitrogen removal benefits associated with *Phragmites.*

K. Stakeholder Summary (This is an abstract of your research and findings written for a lay audience)

Coastal marshes provide an array of ecosystem services, including carbon sequestration and improved water quality via nitrogen removal, but the consequences of elevated sea level rise and ecosystem management on wetland vegetation and the provision of salt marsh services are unclear. We examined how sea level rise and tidal restoration alter carbon and nitrogen-based services in three dominant vegetation zones- *Spartina alterniflora* (low marsh), *Spartina patens* (high marsh), *Phragmites australis* (brackish marsh), using a 20-site field survey of coastal Connecticut, a manipulative experiment, and sea level rise models (i.e. Sea Levels Affecting Marsh Migration, SLAMM). While none of our parameters differed between unrestricted and tidally restored marshes, we observed strong differences among vegetation zones, with vegetation being a top predictor of microbial respiration and potential denitrification rates. Interestingly, invasive *Phragmites* zones had higher nitrogen removal rates and carbon sequestration indices than *Spartina alterniflora.* Likewise, when we manipulated species composition under three sea level rise scenarios (present day, 10 year, 20 year) using a marsh organ experiment, carbon responses differed among vegetation, but not sea level rise treatments.

Based on SLAMM projections, the replacement of *S. patens* by short-form *S. alterniflora* is expected to be widespread across the Connecticut coastline, decreasing statewide potential denitrification from the low-to-high marsh transitional zone by at least 121 kg N/ hr by 2085. Our results suggest that changes in vegetation zones can serve as landscape-scale predictors for rapid changes occurring in salt marshes. To convey the importance of salt marsh ecosystems and highlight the ecological consequences of sea level rise to diverse audiences, we developed a publically available, interactive climate change teaching module for high school teachers.