BRINGING WETLANDS to MARKET
Nitrogen & Coastal Blue Carbon

WAQUOIT BAY
NATIONAL ESTUARINE RESEARCH RESERVE

Greenhouse Gas Fluxes and Carbon Storage in Wetlands: Summary of BWM Science Findings

fact SHEET

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Why We Conducted This Research

Climate change and nutrient pollution from nitrogen (N) loading are two of the most pressing problems facing coastal communities today. Increasing atmospheric concentrations of three major greenhouse gases (GHG) – carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) - are the main drivers of climate change. Efforts to lower GHG emissions include protecting and restoring ecosystems that store more GHGs than they emit, including tidal wetlands (e.g. salt marshes, mangroves and seagrass beds). Tidal wetlands are prime candidates for such efforts as they sequester (i.e. capture) and store large amounts of carbon (referred to as "blue carbon") and store more carbon in their sediments compared to forests. Loss of wetlands through human impacts such as land conversion, sediment supply disruption, nutrient pollution and with sea level rise (SLR) reduces the capacity of the wetlands to store carbon in the future and places at risk stores of carbon that accumulated over past centuries. Additionally, there is evidence that in coastal wetlands nitrogen loading has two negative impacts: 1) contributing to climate change by producing N_2O and 2) reducing the production of root and soil matter by plants thereby leading to decreased carbon sequestration capacity and resilience of salt marshes to SLR. The effects of climate change, including increasing temperature and SLR, could reduce the amount of carbon stored in wetlands. Recognition of the important role coastal wetlands play in storing carbon has led to national and international efforts to develop blue carbon as a new tool for coastal management and to drive new private investment in coastal wetland protection and restoration. This is similar to the value placed on forests that has already promoted substantial forest restoration.

Based on this recognition, managing carbon stocks in coastal wetlands is a very important piece of the puzzle when it comes to addressing climate change and understanding the contribution of different ecosystems to the global carbon budget and cycle. One barrier to managing carbon stocks in coastal wetlands is lack of accurate data and knowledge regarding GHG fluxes and carbon storage.

Research Objectives

The Bringing Wetlands to Market (BWM) project led by the Waquoit Bay National Estuarine Research Reserve, was designed to provide scientific information for coastal decision makers that can inform 1) carbon and nitrogen management 2) wetlands protection and restoration strategies, and 3) development of policy frameworks and market-based mechanisms to reduce GHG and sequester carbon. The project addressed key information gaps preventing the incorporation of wetlands and restoration projects into the carbon market. The team's science goals were to: (i) develop and apply new techniques to quantify GHG emissions and carbon sequestration in coastal marshes, (ii) understand processes to predict fluxes across a range of environmental settings and under conditions of future change, and (iii) develop a user-friendly model to predict GHG emissions and carbon storage to help guide management and policy decisions. To both quantify and predict the effects of salt marshes and salt marsh restorations on atmospheric GHG concentrations, accurate measurements of carbon and GHG exchanges across time and a range of conditions is needed. In addition, it is critical to measure not only the net, long-term rate of carbon storage in soils, but also rates of CO_2, CH_4 and N_2O exchange between marsh and atmosphere (vertical gas fluxes) and rates of dissolved organic carbon and inorganic carbon exchange between marsh and adjacent seawater (tidal or lateral fluxes). Concerns about nitrogen pollution on Cape Cod (and in New England coastal communities) motivated our research to test the impact of nitrogen loading on salt marsh carbon burial and GHG fluxes.

How Greenhouse Gas Fluxes in Coastal Wetlands Work

GHG emissions from wetlands are known to reflect multiple dynamic processes and co-varying environmental conditions. CO_2 fluxes are the net result of plant photosynthesis (CO_2 uptake), plant respiration (CO_2 emissions) and microbial decomposition (CO_2 emissions). Wetland CH_4 emission is a net result of production by methanogenic bacteria under anaerobic (i.e. lack of oxygen) conditions and CH_4 oxidation by methanotrophic bacteria mainly under aerobic (i.e. in the presence of oxygen) or anaerobic conditions. N_2O fluxes from wetland soils are the net result of production, mainly through the microbial processes of nitrification of ammonium (NH_{4+}) and denitrification of nitrate (NO_{3-}), and microbial consumption of N_2O as a result of being transformed to inert nitrogen gas.

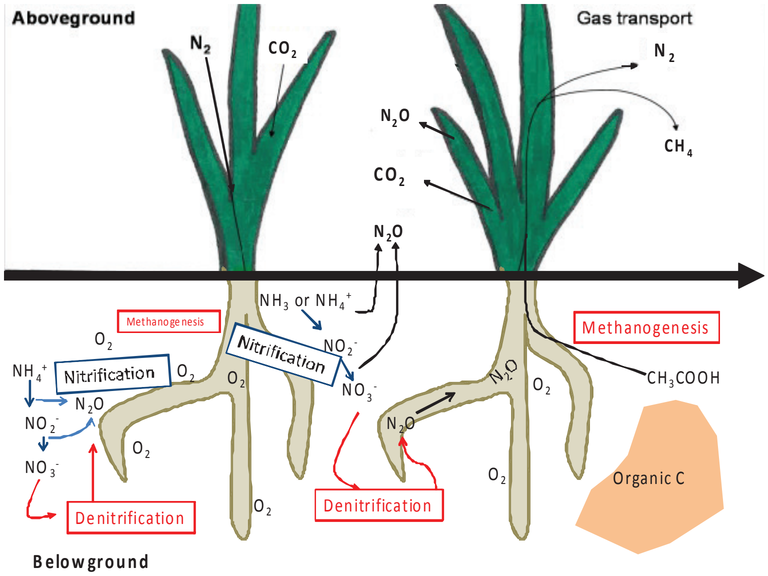


Diagram of GHG emissions, nitrogen cycling, and carbon storage in coastal wetlands

Nitrogen availability strongly affects coastal ecosystems. Although salt marshes have historically been nitrogen limited, increases in nitrogen inputs from human sources (sewage, fertilizers, fuel combustion) have recently been linked in some studies to loss and degradation of marsh habitat. At high levels, nitrogen can increase decomposition of critical organic soils (needed to maintain marsh elevation against SLR) while decreasing production of root matter belowground. Nitrogen can also stimulate microbial production of GHGs. At low rates of nitrogen supply, New England *Spartina patens* salt marshes can be a sink for N_2O from the atmosphere. However, experimental nitrogen additions quickly can shift the marsh soils into sources of N_2O emissions.

How We Conducted Our Research

To learn more about the rates of carbon storage and GHG fluxes in coastal wetlands, the BWM team led research on carbon storage in soils, the vertical and lateral GHG and carbon exchanges, the relationship of GHG fluxes with plant communities and soil properties, and the impacts of SLR on carbon storage. This research is described below.

Vertical Fluxes

Vertical fluxes are defined as GHG exchanges between the salt marsh and the atmosphere. Vertical fluxes include plant photosynthesis (CO_2 uptake), plant respiration (CO_2 emissions), microbial decomposition (CO_2 emissions), CH_4 net emissions, and N_2O emissions. Measuring these instantaneous flux components enables us to understand the detailed carbon processes and their variations over hours and to quantify the net result of these fluxes over a year.

After measuring total plant photosynthesis (defined as gross primary production, or GPP), ecosystem respiration, the sum of plant and microbial respiration (R), CH_4 emissions (F(CH_4)), and lateral fluxes (F(L)), we calculated the carbon storage rate, defined as the net ecosystem carbon balance (NECB):

NECB = GPP – R – F(CH4) – F(L)

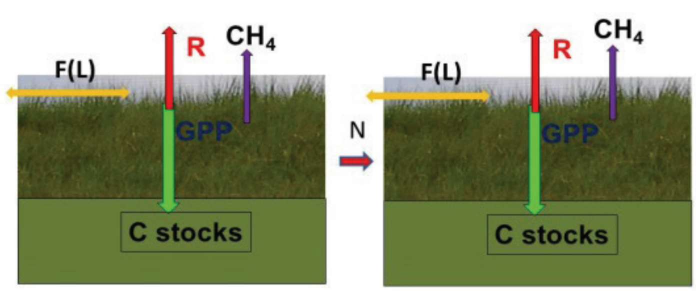
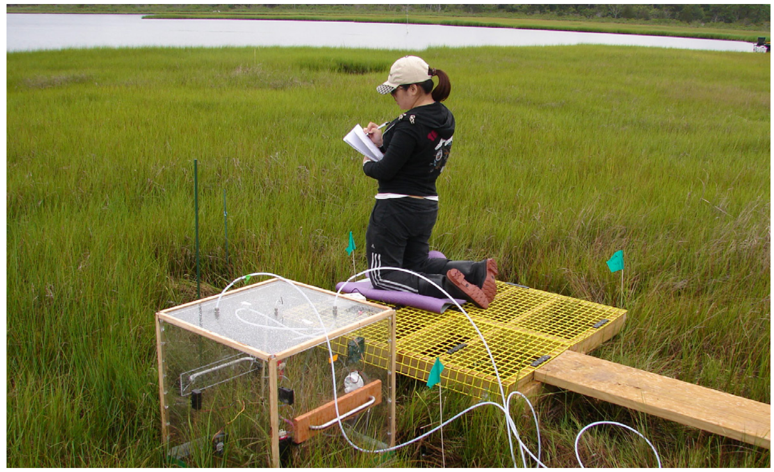


Illustration of the exchange of gases that occurs in a salt marsh.

Key Measurements

(Taken over a two year period across the four selected marshes)

- GHG flux (CO_2 CH_4 N_2O)
- solar radiation
- pH
- temperature
- salinity
- water level
- plant biomass
- pore water nitrogen



To do this work, we developed a state-of-the-art system for measuring vertical fluxes by assembling laser-based gas analyzers that can measure gas fluxes in a small area (~1 m^2) on site. Prior to the start of the BWM project these types of on-site gas measurements were lacking but very much needed.

Relationship of GHG Fluxes with Plant Communities and Soil Properties

Salt marsh landscapes are defined by distinct plant communities, ranging from smooth cordgrasses *(Spartina alterniflora)* in the lowest tidal zones to mixed communities in higher zones that include salt marsh hay *(Spartina patens)*, salt meadow rush *(Juncus gerardii)* and spike grass (*Distichlis spicata)*. Each community of plants is adapted to environmental conditions in its particular tidal range and a unique suite of animals, such as salt marsh sparrows in the higher zone and fiddler crabs and mussels in the lower zone, rely on those plants for habitat. We compared GHG fluxes, plant biomass, and soil conditions (pH, moisture, salinity, sulfide) between the high and low marsh plant zones. We also compared gas fluxes in those zones to ones from permanently inundated pools on the marsh landscape and from zones with the invasive reed *Phragmites australis*.

Lateral Carbon and GHG Fluxes

Lateral fluxes of carbon and GHG refer to movement of those materials from one ecosystem to another. In a salt marsh, lateral fluxes occur primarily as a result of tidal exchange with an adjacent estuary. On a rising tide, carbon may be imported to the salt marsh as sediment and organic particles are transported from the estuary and deposited onto the marsh surface. On a falling tide, export occurs from marsh to estuary as detrital dissolved organic carbon molecules (DOC) and dissolved gases resulting from respiration and metabolism of plants and microorganisms (CO_2, CH_4 and N_2O) are carried out of the marsh by the tide. CO_2 from metabolism reacts with seawater to produce a set of dissolved inorganic carbon molecules referred to as DIC. Our objective was to measure net exchange, import and export, of dissolved organic and inorganic carbon, particulate organic carbon, CO_2, CH_4 and N_2O. Due to large variability over time in carbon and GHG exchanges, it was necessary to develop new methods to measure concentrations and fluxes at high frequency and over seasonal and annual cycles. We deployed a suite of sensors to measure water flow and water chemical and physical parameters and used statistical relationships between carbon concentrations and water chemistry to estimate carbon concentrations at high frequency. With those methods, we developed unique high-resolution flux data and improved estimates of annual fluxes.

Carbon Storage and Sea Level Rise

Globally, salt marshes act as a significant carbon sink, however, as SLR increases it may impact salt marsh carbon burial. This is a key consideration in the northeast U.S. where SLR is accelerated. Salt marshes grow at an optimal elevation within the tidal frame. As SLR occurs, this optimal elevation also rises, creating an *"accommodation space"* for salt marshes to grow into. To optimally use this accommodation space and keep pace with SLR, organic matter and sediment must accumulate at the same rate. Salt marshes that are resilient to SLR have a large capacity to bury carbon, since as water levels increase, so does the accommodation space in which they can bury carbon. Salt marshes that maintain vertical growth rates equivalent to SLR may have an enhanced capacity to bury carbon.

We evaluated the salt marsh response to recent sea level rise rates with high temporal resolution records of salt marsh accretion. We used a naturally occurring radioactive isotope, lead-210, whose decay through time allows us to date sediments since 1900. The power of this approach is that accretion is not assumed to be constant, rather variability in sediment concentrations of 210Pb are due to both radioactive decay and dynamic accretion rates. The organic rich marshes within the microtidal Waquoit Bay estuary have limited sediment supply and a small tidal range, two factors hypothesized to make marshes most vulnerable to SLR. Changes in the marsh elevation relative to mean high water through time were evaluated from sea level records and the dated marsh surface.

Present day salt marsh

Salt marshes maintain their position within the tidal frame through vertical growth supported by *organic matter* and *mineral sediment burial*. Important factors include:

1) Above and below ground productivity
2) Organic matter decomposition
3) Sediment supply
4) Tidal range and wave action

Response to sea level rise

Current rates of SLR in New England are 2-3 millimeters per year.

Soil accomodation space Is the region where salt marsh sediment accumulates as the marsh grows vertically in response to SLR. This region represents an increase in *carbon storage* as the marsh keeps pace with sea level.

Key Findings:

CO_2 Storage and Fluxes: Salt Marshes Store Significant Amounts of CO_2

- The studied salt marsh is storing significant amounts of CO_2 in the sediment and the net vertical flux of carbon is about 370 gC $m^{-2}year^{-1}$. This is a first of its kind, accurate measurement of the flux of carbon.
- A proportion of the salt marshes carbon stock is washed away as lateral fluxes. The residual will be buried in the sediment as the net carbon storage that accumulates over years.
- CO_2 uptake was higher in the low marsh zone than in the high marsh, but- surprisingly- it was the greatest in the invasive *Phragmites* zones.
- Pools with bare standing water, where plants had died, were sources of CO_2 rather than sinks, indicating that SLR may threaten carbon storage functions of salt marshes. Future research is needed to confirm if this is the case over long time periods and to test how marshes functionally recover from water logging.
- DOC is exported from the marshes at a rate that is similar to the rate of new carbon storage (sequestration) in the soil.
- DIC exports from respiration are larger than DOC fluxes and substantially greater than has been estimated in a small number of previous studies.

CH_4 and N_2O Storage and Fluxes

- CH_4 and N_2O emissions are small compared with CO_2 fluxes.

Nitrogen and Carbon Fluxes

- Within the range of N loading to coastal ecosystems that we examined in this study (1-12 gN $m^{-2}y^{-1}$), increasing N load did not change either GHG emissions or C burial. This range of N loading is representative of loads across Cape Cod estuaries and of loads in many other parts of the world. Although loads at the high end of that range cause dramatic changes in the ecology and water quality of estuaries, that level of loading does not appear to have a detectable effect on the salt marsh processes examined in this study. However, salt marshes in some parts of the world receive nitrogen loads more than 100 times higher. Globally, in highly urbanized areas estuaries in which salt marshes reside have been found to receive nitrogen inputs (largely from human sources) that are as high as 1500 kg N/ ha/ y.

Sea Level Rise and Carbon Storage

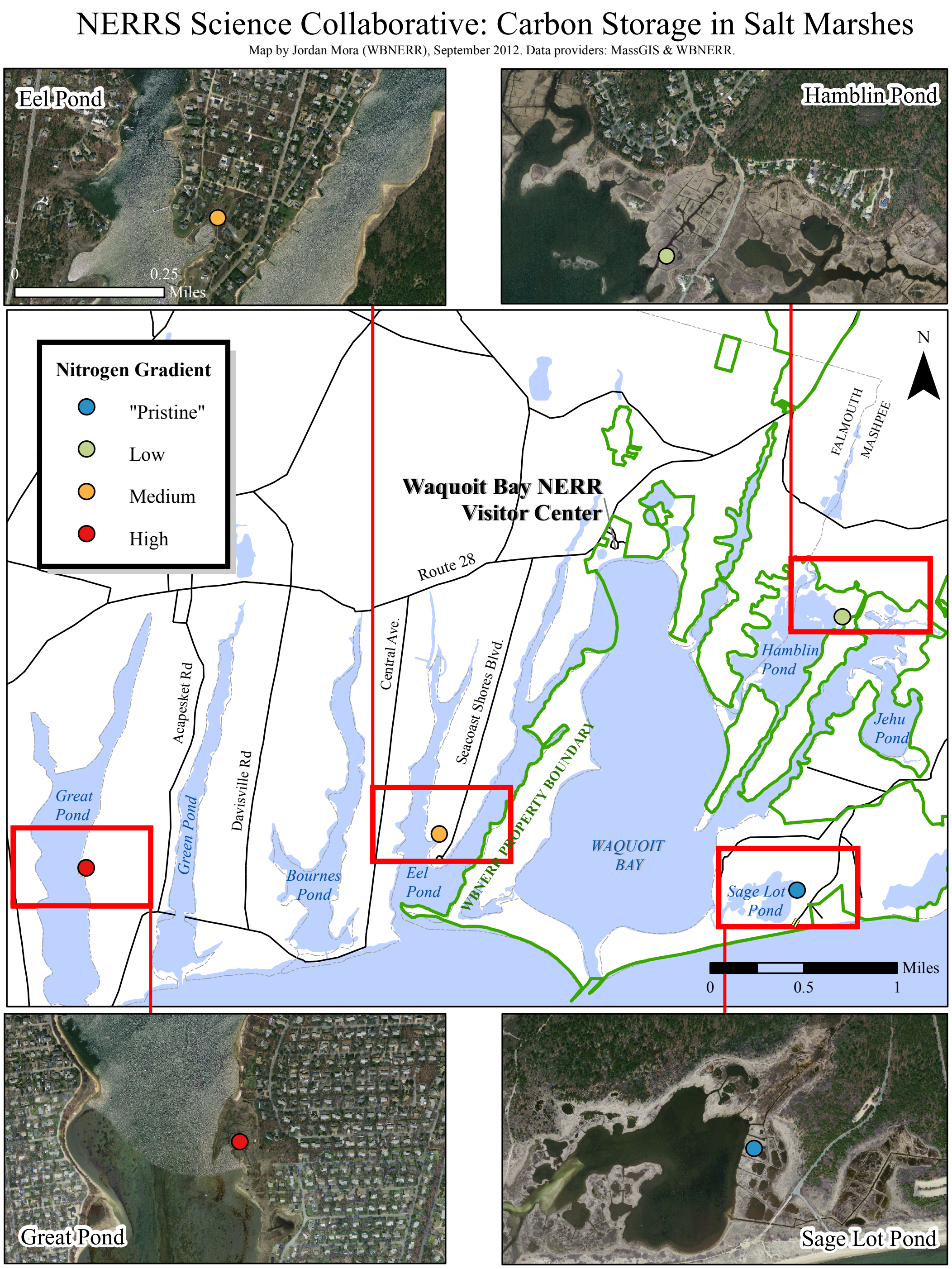
- We observed an increase in accretion from ~1 to 4 millimeters per year, with modern rates up to four times greater than those in the early 1900's.
- Both elevation and vegetation type appear to influence marsh accretion capacity.
- The two marsh zones that showed the smallest increase were: 1) the high marsh, dominated by *Distichlis* and *Juncus* and 2) the marsh at the lowest elevation, dominated by short form *Spartina alterniflora*.
- In recent decades, marsh position within the tidal frame has stabilized, despite ongoing SLR, suggesting that marsh growth has accelerated in response to SLR. Carbon burial over the same period has increased from 50 -100 in 1900 to 75 -250 g C m^{-2} y^{-1} in modern sediments, driven primarily by increased accretion rates, not changes in soil carbon content.

Other

- Sediment supply in these wetlands is extremely low, a condition commonly associated with low accretion rates. Our finding of high and accelerating rates of soil accretion might suggest greater potential for accretion and survival in the context of accelerating SLR, of marshes with low sediment supply.

Learn More

Greenhouse Gas Fluxes and Carbon Storage in Wetlands: Summary of BWM Science Findings is part of a series of informational resources developed under the Bringing Wetlands to Market Project (BWM), which was led by the Waquoit Bay National Estuarine Research Reserve (WBNERR), The BWM Project examined the relationship between salt marshes, climate change, and nitrogen pollution and provided cutting edge science and tools to help coastal managers and policy makers leverage blue carbon to achieve broader wetlands management, restoration, and conservation goals through verified carbon markets and climate and conservation policy avenues. Learn more about the project and other available resources at: Bringing Wetlands to Market – Project Webpage: https://www.waquoitbayreserve.org/research-monitoring/salt-marsh-carbon-project/.



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WAQUOIT BAY NATIONAL ESTUARINE RESEARCH RESERVE

National Estuarine Research Reserve System Science Collaborative

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Restore America's Estuaries

NERRA National Estuarine Research Reserve Association

USGS science for a changing world

FIU Florida International University

MBL Biological Discovery in Woods Hole
Founded in 1888 as the Marine Biological Laboratory

MANOMET Center for Conservation Sciences

Waquoit Bay National Estuarine Research Reserve

The University of Rhode Island