

From: [Denice Kronau](#)
To: [Jill Vieth](#); [Christopher Glowacki](#); [Denice Kronau](#); [Joanna E. Roche](#); [Joseph Grause](#); [Peter McEachern](#); [Peter Schaeffer](#); [Stephen Maury](#); [George Harrington](#)
Cc: [Mariya Basheva](#)
Subject: Fw: Article 80 - Amendment to HDC Special Act
Date: Sunday, February 6, 2022 12:28:06 PM
Attachments: [image001.png](#)
[MEMO re Article 80 proposed HDC Special Act Amendment.pdf](#)
[HDC Solar Guidelines.pdf](#)
[Renewable Energy & the Nantucket HDC.PDF](#)
[image003.png](#)

From: Holly Backus
Sent: Friday, February 4, 2022 9:10 AM
To: Denice Kronau
Subject: Article 80 - Amendment to HDC Special Act

Good Morning Denice,

I wanted to thank you and the Finance Committee for the opportunity to speak on behalf of the HDC last night. In lieu of not having an HDC Compliance Coordinator/Administrator, I've been stepping up to assist in many additional administrative issues/concerns. However, as Preservation Planner, and technical staff liaison to the Commission, the issue of solar and the request of amending our Special Act, which was one of the first in the country, is of great concern.

My apologies for the tardiness of the HDC memo last night. They had met yesterday afternoon and discussed the article, with their adjournment at 240pm, it didn't give much time to write and send before your meeting. I appreciate your acceptance of their written comments.

In addition to the memo, I have attached the Solar Guidelines out of the "Sustainable Preservation" addendum to *Building with Nantucket in Mind*. I have also attached a pdf of a PowerPoint presentation I gave at the Nantucket Preservation Trust's 2021 Symposium on "Rescuing History: Nantucket in Response to Rising Seas." I feel this is important as it gives an overview of how the Nantucket Historic District and its policies that are currently in place, are in line with both local and national sustainability and resiliency efforts. In addition, as the Hazard Mitigation Plan Coordinator, I would be remiss if I didn't pass this along. Specifically slides 7, 8, 12 through 19 address solar.

The applicant for this proposed Citizen Warrant Article described the issue surrounding a particular application that was not approved outside of the OHDs. However, any denial of solar is the sheer fact that the application did not address the specific guidelines that are in place for the entire local and national historic district. Very few applications are denied, as the Commission prides itself in working with applicants to meet the guidelines.

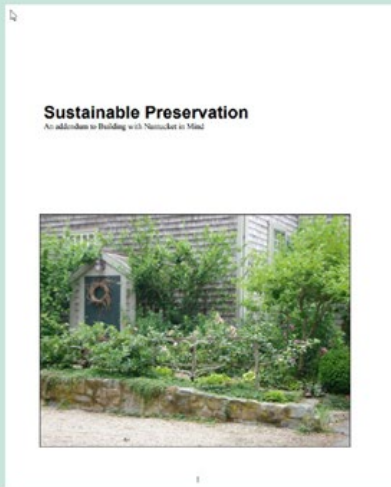
I also wanted to address the MGL CH40C that was brought up in discussion last night. It should be noted that Nantucket's Special Act of 1955 was developed prior to the National Historic Preservation Act of 1966 and therefore, any state laws for historic districts. This is part of what makes Nantucket so unique. Should Nantucket wish to amend the Special Act to include language from MGL or any other changes, it should be done collaboratively with the HDC at the head of the discussion.

Finally, you mentioned the discussion will be picked up at your Tuesday, February 8th meeting. I understand that posted agenda will be amended to include this article. The HDC has there regularly scheduled commission meeting on Tuesday at 5pm. I am respectfully requesting the Article 80 discussion to be placed at the top of the agenda, if at all possible. I understand if that cannot be done, however wanted to ask.

Again, I greatly appreciate the opportunity to provide both the Commission's views and staff's views on this important proposed amendment and the unintended consequences it may bring.

Thank you,

"Energy Efficiency, Renewable Energy & Historic Preservation: A Guide for Historic District Commissions"



Top outcomes for SOLAR:

- ✓ Not on a primary structure (secondary or ancillary)
- ✓ Not on a Main Mass
- ✓ Minimum visual impact (with screening)
- ✓ Higher level of scrutiny on contributing properties & within the OHD / SOHD
- ✓ Color of the panels in keeping with surrounding roof materials

Holly E. Backus
Preservation Planner**
Local CLG Coordinator
Local Hazard Mitigation Plan Coordinator

Town of Nantucket
Planning & Land Use Services
2 Fairgrounds Road
Nantucket, MA 02554

Tel: 508-325-7587 X 7026
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hbackus@nantucket-ma.gov

Check out our adopted "Resilient Nantucket" Design Guidelines:

[RESILIENT NANTUCKET: Designed for Adaptation](#)

HDC Advisory Board meetings can be accessed here:

[SCONSET ADVISORY \(SAB\)](#)

[HISTORIC STRUCTURES \(HSAB\)](#)

**Staff liaison to the Nantucket Historic District Commission (HDC) & Nantucket Historical Commission (NHC)





HISTORIC DISTRICT COMMISSION

2 Fairgrounds Road
Nantucket, Massachusetts 02554

Telephone: 508.325.7587

Fax: 508.228.7298

MEMO

To: Finance Committee

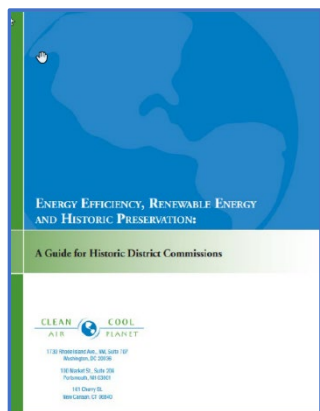
From: Holly E. Backus, Preservation Planner / Local CLG Coordinator

cc: Historic District Commission Members
Esmeralda C. Martinez, PLUS Administrative Specialist

Date: February 3, 2022

Re: Review of Article 80: Home Rule Petition: Amend the Historic District Commission enabling legislation to encourage the adoption of solar power & renewable energy systems

At the February 3, 2022 Historic District Commission meeting, the Commission discussed the proposed Citizen Warrant Article to amend the HDC's Special Act A301-4. The Special Act was created in 1955 to "to promote the general welfare of the inhabitants of the Town of Nantucket through the preservation and protection of historic buildings, places and districts of historic interest through the development of an appropriate setting for these buildings, places and districts and through the benefits resulting to the economy of Nantucket in developing and maintaining its vacation-travel industry through the promotion of these historic associations." Since 1972, the HDC Special Act has been amended (11) eleven times, however if there is to be an amendment again, it should be done collectively and thoughtfully done.



The Historic District Commission has Solar Design Guidelines called "Sustainable Preservation" – an addendum to *Building with Nantucket in Mind* that were reviewed and adopted in 2009. Nantucket's solar guidelines were created in part by *Clean Air Cool Planet* and Sponsored by "Sustainable Nantucket;" where Nantucket's Historic District's practices are used as a Case Study for other Historic Districts throughout the country. The guide is called "Energy Efficiency, Renewable Energy and Historic Preservation: A Guide for Historic District Commissions." As with all historic district design guidelines, the Nantucket Historic District's solar guidelines follow the Secretary of the Interior's Standards on Sustainability for Rehabilitating Historic Buildings for recommended placement of solar.

In FY2019, the HDC approved 55 Solar installations, where in FY2020, the HDC approved 81 solar installations. The existing guidelines work for the entire local and national historic district of Nantucket.

Staff notes that it's important to analyze whether solar technology can be used successfully and will benefit a historic building without compromising its character or the character of the site or the surrounding historic district. Further, the existing guidelines that are used by the Historic District Commission were not created in a vacuum; rather they were created with local energy staff/committee members, HDC members, preservation specialists, and energy professionals by working together.

During the meeting today, the Historic District Commission members notated the following:

- The Special Act should be left alone;
- There should not be any changes to the Special Act just to suit special interest groups;
- The current design guidelines for solar: “Sustainable Preservation” – an addendum to Building with Nantucket in Mind, work;
- The current design guidelines already provide the commission to “reasonably allow” solar panels and renewable energy systems outside of the Old Historic Districts;
- Any appeals to the Select Board for Solar have been submitted in opposition to the written guidelines the Commission uses;
- The proposed language for the amendment is “sloppy” and inserting these words into the Special Act may have unintended consequences;
- The proposed language is written in a way to “mandate” review of solar installations vs. determining their appropriateness;
- Lastly, the Historic District Commission noted that the applicant did not present the proposed amendment to the commission for any consideration or discussion.

Thank you for the opportunity to provide input on this proposed amendment.

Renewable Energy & the Nantucket Historic District Commission



Holly E. Backus
Preservation Planner
Local HMP Coordinator
Local CLG Coordinator
Town of Nantucket

2021 Nantucket Preservation Symposium
Rescuing History: Nantucket in Response to Rising Seas
September 9 & 10, 2021

“The greenest building is one that is already built”

- Carl Elefante (2007)

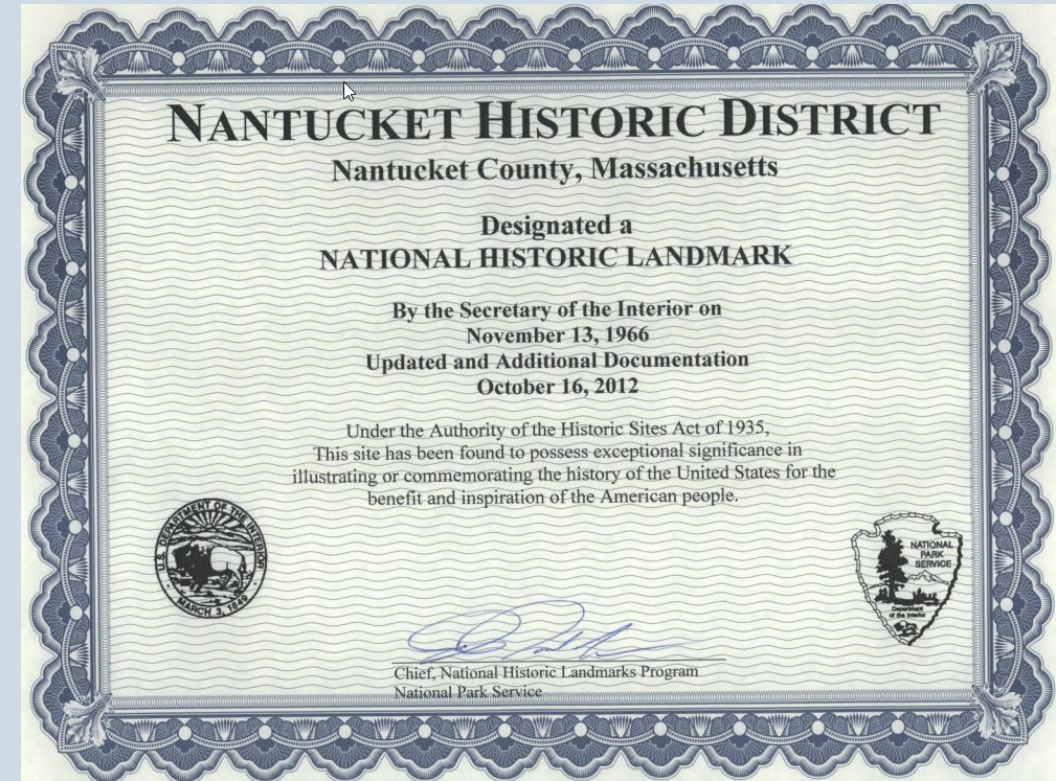
- It takes 65 years for an energy-efficient building to save the amount of energy lost when an existing building is demolished.
- U.S. Energy Information Agency data indicates that buildings constructed before 1920 are more energy-efficient than those built at any time afterward, except for those built after 2000.
- The General Services Administration examined its building inventory in 1999 and found that utility costs for historical buildings were 27% less than for more modern buildings.



**National Trust *for*
Historic Preservation®**
Save the past. Enrich the future.

Nantucket National Historic Landmark

- Local Historic District was enacted in 1955, Special Act
- National Historic Landmark District was nominated on November 13, 1966 for “its association with the American Whaling Industry and survival of the architecture and ambiance of the early whaling port.”
- Update nomination on October 16, 2012 for “the national significance of tourism and historic preservation” and to include in their entirety, the Islands of Nantucket, Tuckernuck and Muskeget.



Nantucket Historic District

Nantucket HDC's Mission under the Special Act:

"To promote the general welfare of the inhabitants of the Town of Nantucket

- (1) through the preservation and protection of historic buildings, places, and districts of historic interest,*
- (2) through the development of an appropriate setting for these buildings, places and districts and,*
- (3) through the benefits resulting to the economy of Nantucket in developing and maintaining its vacation-travel industry through the promotion of these historic associations."*

(1) [Special Act of 1955](#) – revised by Act of 1970, Chapter 395, as amended

(2) Design Guidelines – [Building With Nantucket In Mind](#)



Building With Nantucket in Mind

- Policies set a common understanding and agreement on forms of construction and design features.
- “No new construction can be considered as an isolated object, either in time or space.”
- “Designs should exhibit the repose and unpretentiousness that belong to this weathered island.”
- **BWNIM** follows the Secretary of the Interior’s Standards for preservation, restoration, reconstruction & rehabilitation.



Building with Nantucket in Mind

Building With Nantucket in Mind

- “The community takes responsibility for its architectural heritage through the commissioners of the HDC”...”to enjoy the individual as well as collective structural richness that defines the town.”
- BWNIM:
 1. Preservation on Nantucket Island
 2. Understanding Nantucket’s Architectural Heritage
 3. Building Within an Existing Context
 4. Building in Outlying Areas
 5. Commercial Development



Building with Nantucket in Mind

Renewable Energy & the Nantucket Historic District Commission

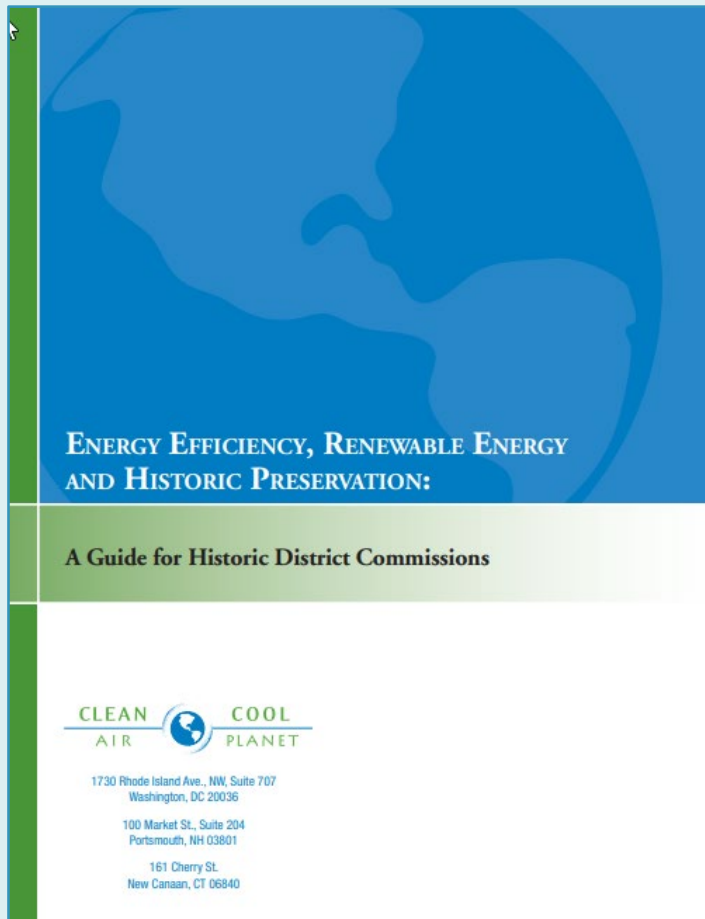


“The people of Nantucket have recognized that natural resource conservation and long-germ sustainability are essential to the island’s continued vitality.”

–Clean Air-Cool Planet

1890s – Easy Street Boat Basin

“Energy Efficiency, Renewable Energy & Historic Preservation: A Guide for Historic District Commissions”

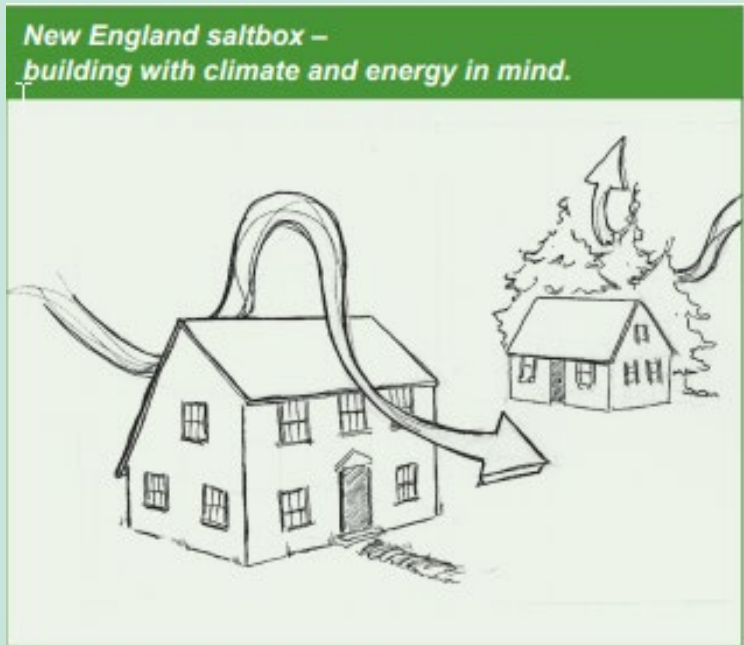


- By Clean Air Cool Planet & Sponsored by “Sustainable Nantucket”
- Case Study = Nantucket!
- The 2009 Nantucket HDC reviewed & adopted as an addendum to “Building with Nantucket in Mind.”
- Town’s website under “Sustainable Preservation:”

The Nantucket Energy Study Committee (made up of architects, designers, etc.) and Sustainable Nantucket, through the Clean Air-Cool Planet Climate Fellows Program created the Nantucket Case Study.



“Energy Efficiency, Renewable Energy & Historic Preservation: A Guide for Historic District Commissions”



Saltboxes built in New England (18th Century):

- Built with climate & energy in mind

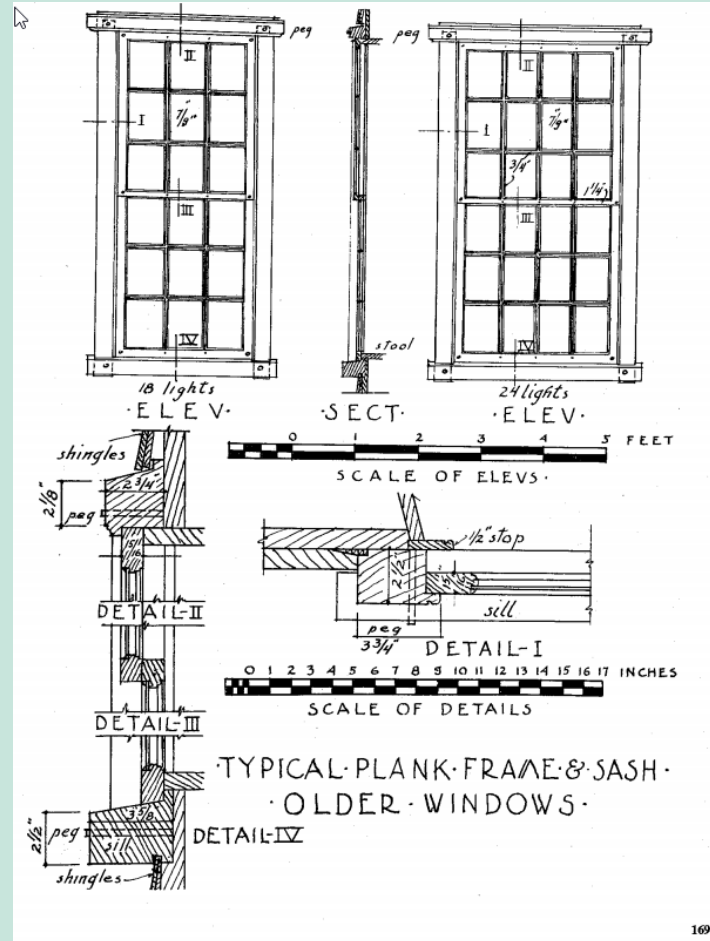
HOW?!

- ✓ Facing SOUTH
- ✓ Facing towards the WINTER SUN
- ✓ Facing away from WINTER WIND
- ✓ Limited windows on the NORTH elevations
- ✓ Roof is low, sloping – carries cold NORTH winds away
- ✓ Overhangs shade windows in SUMMER

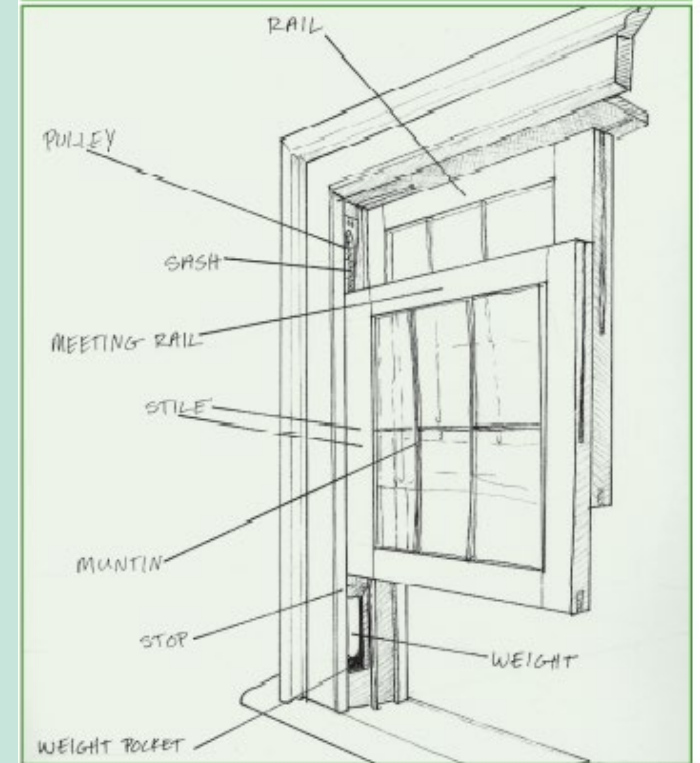


“Energy Efficiency, Renewable Energy & Historic Preservation: A Guide for Historic District Commissions”

Nantucket's unique historic architecture is known throughout the world.



Historic windows have many parts that may require repair.



Sheet _____ of _____

[illegible]

“Energy Efficiency, Renewable Energy & Historic Preservation: A Guide for Historic District Commissions”

Sustainable Preservation

An addendum to Building with Nantucket in Mind



Top outcomes for SOLAR:

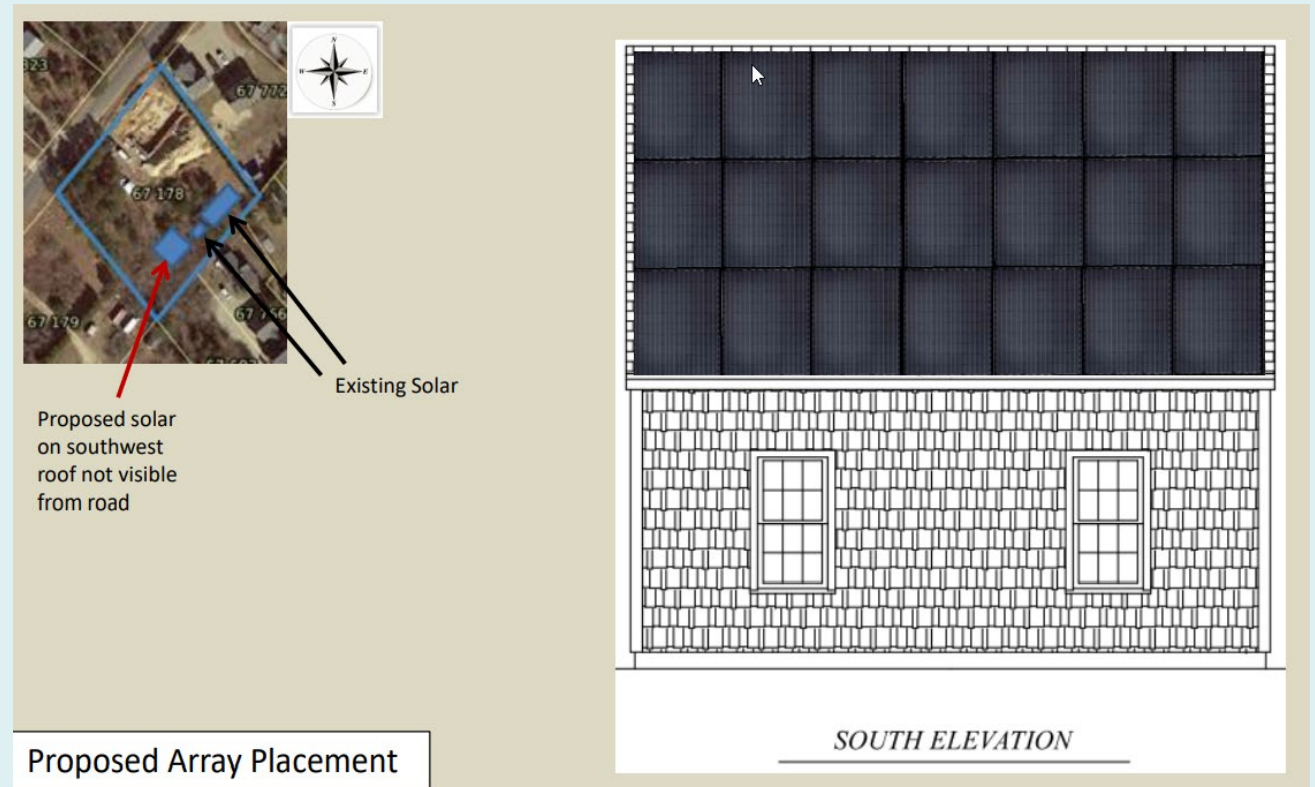
- ✓ Not on a primary structure (secondary or ancillary)
- ✓ Not on a Main Mass
- ✓ Minimum visual impact (with screening)
- ✓ Higher level of scrutiny on contributing properties & within the OHD / SOHD
- ✓ Color of the panels in keeping with surrounding roof materials

“Energy Efficiency, Renewable Energy & Historic Preservation: A Guide for Historic District Commissions”

How can the preservation community be a part of the answer?

By WORKING TOGETHER!

- ☐ Local energy staff/committee members
 - ☐ Historic District Commission members
 - ☐ Preservation Specialists
 - ☐ Energy Professionals
-
- ✓ On a non-contributing secondary structure
 - ✓ Minimum visual impact
 - ✓ Not within the “1955” OHDs
 - ✓ Color of panels matches roof
 - ✓ Panels fill entire roof plane



Nantucket

11 R South Shore Road

Ernest Weinhold, a respected and outspoken resident of Nantucket, has lived at 11 R South Shore Road in the heart of Nantucket for twenty-five years. During that time, Mr. Weinhold, or as he is more commonly known, Jack, has become a model for energy sustainability. Jack is one of the island's most vocal residents regarding energy sustainability, not only embracing Nantucket's famous landscape through photography but also trying to protect the environment through renewable energies.

System Specs:

Price: \$45,000
Number of Panels: 24
Capacity per Panel: 300W
Total Capacity: 7.2kW
Installer: ACK Smart

Jack began investing in sustainable energy starting with the purchase of his used Nissan Leaf. In January of 2015, he took the next step. Using an on-island installation company, ACK Smart, Jack installed a 10kW solar PV system on a large ground mounted array. By installing a ground mounted system, Jack was able to receive energy savings and enjoy ease-of-access for maintenance. In addition, he installed a moderate-sized solar hot water system that harnesses the power of the sun to heat his home's supply of hot water.

11 R South Shore

Jack's main motivation for installing these systems was the fact that it is a large aspect of the community. Much, residents like Jack desire to reduce the adoption of technologies like solar PV.

Like many, Jack was financially concerned about his ability to afford his system because at the time there were few financing options available. Prospective owners had two options: pay for the system out of pocket, or obtain a bank loan. Nowadays, owners have numerous options including a zero money down, 100% loan.

Jack's installation is far enough from the public view that the HDC had little issues and approved it almost immediately. As long as the public cannot see the panels and the installation looks sleek and professional, the HDC is usually quick to approve. His system is producing enough electricity to fully cover his electric use, and through the SREC incentive program, is actually earning some additional income each year. Jack is very enthusiastic about solar PV and residents like him will start a wave of adoption on Nantucket. According to Jack, "Solar PV is easy, it's quick, and it's not as expensive as you'd think."

Town of Nantucket

Stimulating Ownership &
Local Adoption of Renewables

SOLAR REBATE PROGRAM



Applications are available online:
Nantucket-MA.gov/SolarRebate

Nantucket

75 Pochick Ave

Mark and Barbara White are retired teachers who have lived on their property for thirty-nine years. They have always been conscious about the environment. Twenty years ago, they looked into going green by installing solar PV on their home, but both unreliability and the very high cost of technology back then put renewable energy on the back burner. As time went on, solar PV technology changed, becoming much more reliable and affordable, allowing them to install.

System Specs:

Price: \$34,092
Number of Panels: 24
Capacity per Panel: 300W
Total Capacity: 7.2kW
Installer: ACK Smart

Mark and Barbara decided two years ago that they would install solar PV on their property. They attended workshops to explore the possibilities and options for solar PV at the time. They visited Jack Weinhold's home and discussed the various installers and different ways they could install on their property. After exploring all the options, Mark and Barbara decided to use an on-island local installer, ACK Smart, to install their system. Looking into different spaces to install, they found that the space on the south facing roof was not enough land, however, their roof is on for solar panels.

The process of installing the solar PV system took very little time, although they decided to wait a couple of months for new panel technology to come out that would increase their efficiency by about 15%. Installation only took two days and the permitting process was completed soon afterwards.

Like many people, the Whites were worried about how they were going to pay for the system because although it helps save money in the long run, it does have a large upfront cost. The Whites explored the rebate options provided by state and federal entities, and decided to install their system, knowing they would receive the \$1,000 state rebate, 30% federal tax credit, and SREC payments.

Overall, the Whites have had a very positive experience with their solar PV system. Their system produces about 140% of their electric bill, which they use to net meter to their cottage next door. They want to see more solar PV installed on the island, to be more green and to be more self-sufficient.

Town of Nantucket – Energy Office – local solar rebate program

<https://www.nantucket-ma.gov/1156/Solar-Map-Resources>

Renewable Energy & the Nantucket Historic District Commission

- FY2019 – HDC approved **55 total SOLAR installations**
- FY2020 – HDC approved **81 total SOLAR installations**

136 NEW SOLAR PROJECTS!



It's important to analyze... whether solar technology can be used successfully and will benefit a historic building without compromising its character or the character of the site or the surrounding historic district.





THE SECRETARY OF THE INTERIOR'S STANDARDS FOR REHABILITATION &

ILLUSTRATED GUIDELINES ON **SUSTAINABILITY** FOR REHABILITATING HISTORIC BUILDINGS



U.S. Department of the Interior
National Park Service
Technical Preservation Services

The Secretary of the Interior's Standards...

- **TREATMENTS:**
 - **Restoration** – *museums or highly significant buildings – repairing rather than replacing*
 - **Preservation** – *retaining historic fabric – historical use of structure – changes are allowed to remain, if required own significant*
 - **Reconstruction** – *new construction to replicate a historic portion, but showing that its new*
 - **Rehabilitation** (*most flexible treatment*) *property can have a new use with minimal change to historic features*

THE SECRETARY OF THE
INTERIOR'S **STANDARDS FOR
REHABILITATION &**

ILLUSTRATED
GUIDELINES ON
SUSTAINABILITY
FOR REHABILITATING
HISTORIC BUILDINGS

Recommended:

- *Installing a solar device on the historic building in a manner that does not damage historic roofing material or negatively impact the building's historic character and is reversible.*
- *Installing a solar device in a compatible location on the site or on a non-historic building or addition where it will have minimal impact on the historic building and its site.*

NOT NANTUCKET!



THE SECRETARY OF THE
INTERIOR'S STANDARDS FOR
REHABILITATION &

ILLUSTRATED
GUIDELINES ON
SUSTAINABILITY
FOR REHABILITATING
HISTORIC BUILDINGS

NOT NANTUCKET!



NOT Recommended:

- *Installing a solar device on the historic building in a manner that damages historic roofing material or replaces it with an incompatible material and is not reversible.*
- *Installing a solar device in a prominent location on the building where it will negatively impact its historic character.*
- *Removing historic roof features to install solar panels.*
- *Altering a historic, character-defining roof slope to install solar panels.*
- *Installing solar devices that are not reversible.*
- *Placing a solar device in a highly-visible location where it will negatively impact the historic building and its site.*





1921

Wannacomet Water Company

Historic Preservation & Energy Efficiency

April 2021

KEY POINTS:

- (1) Demolitions cause more waste & energy than rehabilitation of older structures.
- (2) Historic Structures are exempt from energy building codes. HOWEVER, most people want to increase energy efficiency.
- (3) Sometimes the SECRETARY OF THE INTERIOR's Standards can deter energy efficiency.
- (4) SOI should be updated for renewable energy



ALIGNING
HISTORIC
PRESERVATION
AND ENERGY
EFFICIENCY

LEGAL REFORMS
TO SUPPORT THE
GREENEST BUILDINGS

April 2021
Sara C. Bronin

Kleinman Center
for Energy Policy

[Aligning Historic Preservation and Energy Efficiency: Legal Reforms to Support the Greenest Buildings \(upenn.edu\)](https://www.upenn.edu/greenest-buildings/) April 2021

Historic Preservation & Energy Efficiency

April 2021



ALIGNING HISTORIC PRESERVATION AND ENERGY EFFICIENCY

LEGAL REFORMS
TO SUPPORT THE
GREENEST BUILDINGS

April 2021
Sara C. Bronin

Kleinman Center
for Energy Policy

- “Older buildings that remain today were often constructed using more durable and longer-lasting traditional materials..”
- SOI – govern the majority of historic-building construction activity and **not** energy conservation building codes

[Aligning Historic Preservation and Energy Efficiency: Legal Reforms to Support the Greenest Buildings \(upenn.edu\)](#) April 2021



Other planning documents...



*“To mitigate the detrimental impacts of natural hazards to Nantucket, while maintaining and enhancing the Island’s **quality of life**, historic essence, aesthetic beauty, and natural and habitat resources”*
– HMP UPDATE 2019



Areas of Concern:

- ☐ Access to the Mainland
- ☐ Isolation within the Island
- ☐ **Historical & Cultural Resources**
- ☐ **Power Supply Resiliency**
- ☐ **Climate Change**

Update on our National Historic Landmark!

- Became a Certified Local Government through the National Park Service in March 2021
 - Federal Grant funding to help update outdated historic surveys & other preservation related projects – received for FY2022 – reviewing RFQ responses
 - SHPO assistance (Massachusetts Historical Commission)
 - **Joint collaboration with the HDC & NHC**



Update on our National Historic Landmark!



Design Guidelines
unanimously adopted by
the HDC
June 11, 2021

<https://nantucket-ma.gov/1634/Resilient-Nantucket>





Nantucket National Historic Landmark District

- Historic Preservation is sustainable
- Historic Preservation promotes reuse of structures
- Our oldest buildings are **GREEN & SUSTAINABLE**
- Nantucket HDC has clear guidelines for SOLAR that follow the Secretary of the Interior's Guidelines for Sustainability
- It's important to minimize and the adverse effects of solar upon the structure's existing historic fabric



Thank you!

Holly E. Backus
Preservation Planner
Local HMP Coordinator
Local CLG Coordinator
Town of Nantucket
[**hbackus@nantucket-ma.gov**](mailto:hbackus@nantucket-ma.gov)
***Staff Liaison to the HDC & NHC**

Solar Technologies

Photovoltaic Systems

At the time of publication of this addendum, there are only two prevailing types of photovoltaic (PV) collectors: photovoltaic panels and building integrated photovoltaics (BIPV). Both systems exist to convert the sun's energy into electricity. BIPV can be considered because it typically makes less of a visual impact on a structure. Unfortunately, this technology is currently not as efficient as photovoltaic panels. The following guidelines should therefore be applied to any style of PV system that has been deemed appropriate according to each building owner's unique circumstances, keeping in mind that it is always preferable to use the least visible technology.

Solar Thermal Systems

Solar Thermal refers to any system that harnesses the power of the sun to heat a liquid medium for specific applications such as domestic hot water, space heating, and pool heating. As of the publication of this addendum, there are a number of different technologies that are designed to help lower energy bills by utilizing solar thermal systems. Some technologies are available that allow collectors to be hidden entirely within the roof structure, and should be considered (especially for new construction) because of their minimal visibility. However, this guideline will primarily focus on technologies incorporating collectors (whether evacuated tubes or panels) that require direct sunlight.



Figure 7: Photovoltaic Ground Array

Placement & Design of Photovoltaic and Solar Thermal Systems

The utilization of “energy producing” technologies, such as photovoltaics and solar thermal, should only be considered after every effort to reduce a structure's energy consumption have been made. It is appropriate to consider placement of PV or solar thermal arrays elsewhere on the property before considering mounting this technology onto the primary structure. This is especially important in Nantucket's Old Historic District, in Siasconset's Old Historic District, on contributing buildings or in historically important landscapes, where the use of this technology may have a higher degree of visual impact. When determining where to place PV or solar thermal collectors, it is important to attempt to minimize any adverse effects upon a structure's existing fabric, as well as to mitigate the visual impact these panels and all of their supplementary equipment may have upon the surrounding area. As eventual wearing out of parts is expected with these technologies it is important to note that equipment must be replaced with like kind. The HDC will consider any replacement that is not exactly like the original to be

Not Recommended

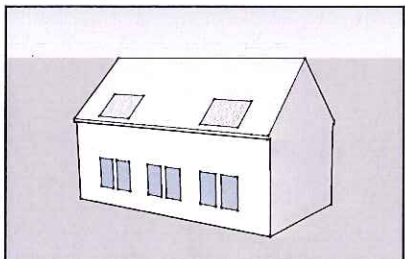


Figure 10: Panels on lower 2/3 of roof.

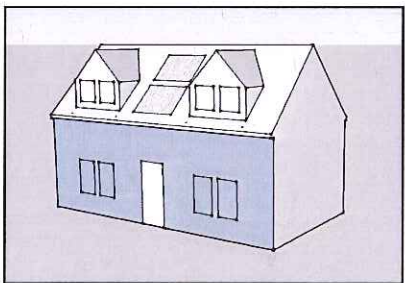


Figure 9: Panels located on primary facade and highly visible.

Recommended

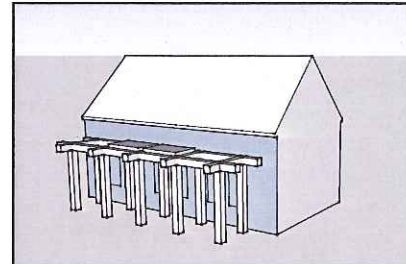


Figure 8: Solar panels incorporated into trellis

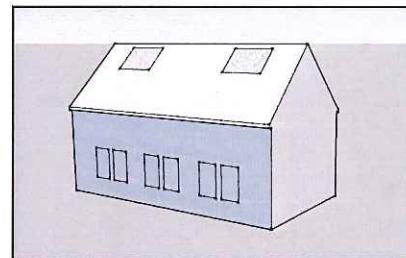


Figure 11: Panels placed on upper 2/3 of roof and aligned with windows.

a change in design, which requires a new application of appropriateness.¹³

When beginning an investigation regarding where best to incorporate PV or solar thermal collectors onto a property, the owner of any structure should always fully consider the principles of *minimum intervention* and *reversibility*.^{*} The entire site must be fully examined for its potential to accommodate these technologies effectively. The most preferable placements for these technologies will have no physical impact on the primary structure and have negligible visual impact upon the site as a whole. Therefore whenever possible, the least visible installation of ground arrays is preferred. If it is necessary for an array to be placed on a structure, it is encouraged that the array to be placed somewhere other than on the primary structure. For example, placement on any non-contributing ancillary structures (such as detached garages or sheds) would stand a greater chance of approval than an installation proposed only on the primary

^{*} **Minimum intervention** is the principle that the less change or alteration done to a historic resource the more integrity that resource retains. **Reversibility** is the principle that nothing should be done to a historic resource that cannot be undone or reversed without permanent damage to the resource.

building.* The creative placement of PV and solar thermal collectors may be encouraged, if such placement limits any adverse impact of the array (e.g. in an existing skylight).

Because the sloped roofs typical of Nantucket's built environment are such a character-defining feature of the island's cultural heritage, rooftop equipment installations should be carefully designed and positioned on any roof. The basic elements of design to consider are: balance, proportion, color, rhythm, and scale. Additionally, PV and solar thermal collectors should be kept on the same plane as the roof, with the color of the panels in keeping with the surrounding roofing materials.

Recommended

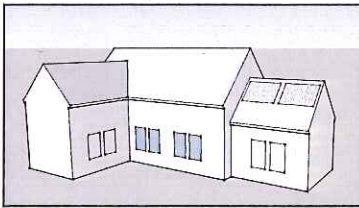


Figure 12: Panels on secondary massing

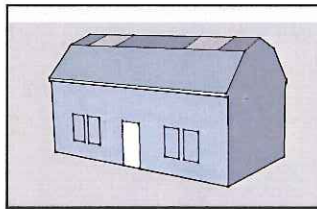


Figure 13: Panels placed with minimal visual impact.

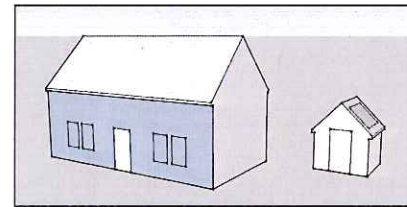


Figure 14: Panel placed on non-contributing ancillary structure

* A **non-contributing structure** is defined as a building, which is not an intrusion but does not add to a historic district's sense of time, place and historic development.

Photovoltaic and Solar Thermal Guidelines

Applications for Photovoltaic and Solar Thermal systems in the Old Historic District, Siasconset Old Historic District, and those on contributing properties are likely to attract a higher level of scrutiny. This also is true for installations on contributing buildings, and where lack of vegetation makes an installation visible from surrounding areas.

Existing Buildings and New Construction:

- The least visible application of technologies and their supplementary equipment is recommended. If the array is located on the ground, appropriate screening may be necessary.
- Applications of these systems as a ground array or on non-contributing ancillary structures (as opposed to on the primary structure) are encouraged.
- The appropriateness of a photovoltaic or solar thermal system will be based upon the historic character and architectural significance of the individual structure and its relation to its surroundings.
- Photovoltaic and solar thermal installations need to be designed carefully and positioned to be in scale with the structure's roofline, while maintaining a balance, scale, proportion, and rhythm with other features of that elevation.
- Systems should be on the same plane as the roof with the color of the panels in keeping with the surrounding roofing materials.

Recommended Application Materials:

Applications for renewable energy systems should include materials adequate to describe the proposed equipment, the structure, and the surrounding area. These may often include:

- A sample of the product and supporting documentation if available.
- Photographs of the installation site and surrounding area.
- A scaled drawing of the proposed system including all supplementary equipment.
- If the system is being proposed on the primary structure the applicant should be prepared to discuss why placements with less visibility or less impact-were not used.

From: [Emily Molden](#)
To: [Mariya Basheva](#)
Cc: [Denice Kronau](#)
Subject: Fwd: Fertilizer Ban - Additional Studies
Date: Wednesday, February 2, 2022 11:10:43 PM
Attachments: [NLC Letter Fertilizer Ban Eelgrass Health Studies 01_24_22.pdf](#)

Hello Mariya,

Please find attached below, a comment letter for the Finance Committee's meeting on February 8th.

Thanks very much,
Emily

----- Forwarded message -----

From: **Emily Molden** <emily@nantucketlandcouncil.org>
Date: Tue, Jan 25, 2022 at 2:06 PM
Subject: Fertilizer Ban - Additional Studies
To: Denice Kronau <dkronau@nantucket-ma.gov>
Cc: Thaïs Fournier <tfournier@nantucket-ma.gov>, Joseph Minella <jminella@nantucket-ma.gov>

Dear Denice,

Please find attached for the Finance Committee's reference, a letter describing the Nantucket Land Council's research on eelgrass health and nitrogen sources in the harbors. RJ Turcotte just informed me that he provided you with one of these studies following a request last week. This letter provides additional context as well as the subsequent Madaket Harbor research that was completed. The research reports are both attached to the letter. I am happy to answer or address any questions.

Thanks very much,
Emily

--
Emily Molden
Executive Director
Nantucket Land Council
planning - protecting - preserving
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--
Emily Molden
Executive Director



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January 24, 2022

Denice Kronau, Chair
Nantucket Finance Committee
37 Washington Street
Nantucket, MA 02554

Re: Proposed Fertilizer Ban

Dear Chair Kronau,

I attended the Finance Committee meeting on Thursday, January 13th and participated in the discussion around the citizen warrant article proposing a fertilizer ban. I am writing to provide the Finance Committee with additional information relative to that discussion of the proposed ban and the need to address nitrogen sources in our harbors.

The Nantucket Land Council (NLC) is a non-profit conservation organization with a mission to help protect and preserve Nantucket's natural resources. The NLC conducted eelgrass health assessments in Nantucket Harbor (2018) and Madaket Harbor (2020) with Dr. Alyssa Novak, Research Assistant Professor at Boston University. In addition to assessing the physiological health of eelgrass meadows throughout the harbors, these studies used stable isotope analysis to evaluate nutrient enrichment and the sources of nitrogen found in eelgrass tissue.

Attached please find a copy of the reports, *Health Assessment for Eelgrass in Nantucket Harbor*, and *Assessing Eelgrass Health in Madaket Harbor*.

The research demonstrated that eelgrass throughout Nantucket Harbor is both light limited and thermally stressed during the growing season indicating that it is declining as a result of both cultural eutrophication (high nutrient loading) and warming waters. While water temperature is not something that can be directly controlled, eelgrass can still survive if other environmental conditions that support growth and expansion are optimal. This includes a reduction of nutrient inputs that exacerbate nuisance algal growth limiting light availability. The isotope analysis of eelgrass indicated nitrogen derived from a variety of sources, especially that of atmospheric deposition and fertilizer.

The results of the Madaket Harbor analysis were similar in that they demonstrated portions of Madaket Harbor are also light limited and thermally stressed. The nitrogen content of eelgrass samples in Madaket also indicated a combination of sources including fertilizer, atmospheric deposition and wastewater, though the results suggest a greater fertilizer influence exists in Nantucket Harbor.



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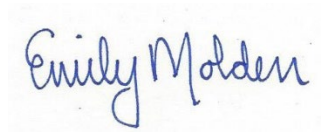
While these studies represent important baseline information that can be used to monitor the health of the eelgrass and changes to the system in the future, they also reconfirm the over-enrichment of nutrients in these systems. It is clear that our harbors are over-enriched with nitrogen from the extent of macroalgae growing throughout the waters. Additional sampling and analysis of macroalgal tissue was performed in Madaket and Nantucket Harbors. While this supplementary data is not included in the attached reports, several of these samples strongly indicated fertilizer as a nitrogen source for the algae.

We cannot directly address climate change impacts or atmospheric deposition, but we can address fertilizer and wastewater contributions. It is imperative that Nantucket act now to reduce those sources of nitrogen that we can control if we want to save our eelgrass and the fisheries that depend on them.

The NLC staff participated extensively in the Fertilizer Committee which was established as a result of Article 68 in 2010 that proposed to regulate the use of fertilizers. This Committee drafted the Best Management Practices for Fertilizer Use on Nantucket, which were ultimately adopted as our fertilizer regulations under the Board of Health. In the context of the proposed fertilizer ban, if the Town department(s) responsible for implementing and enforcing the existing regulations make the determination that they are not enforceable, another avenue must be taken to eliminate or reduce fertilizer input that is enforceable. Ongoing education and outreach is extremely important, but the Town must ultimately commit the resources necessary for implementation and enforcement.

Thank you for your time and attention to this important matter. I am happy to address additional questions on these reports and this topic in general.

Sincerely,



Emily Molden
Executive Director

Enclosures

CC: Thaïs Fournier

HEALTH ASSESSMENT FOR EELGRASS IN NANTUCKET HARBOR, NANTUCKET MASSACHUSETTS

FINAL REPORT TO NANTUCKET LAND COUNCIL

submitted by

Alyssa Novak, Research Assistant Professor, Boston University

&

Holly Plaisted, Biologist, National Park Service

Introduction

Eelgrass (*Zostera marina* L.) is a marine flowering plant that forms extensive meadows in the shallow coastal waters of Massachusetts. The value of eelgrass meadows is well documented and includes stabilizing sediments, improving water quality and clarity, mitigating for CO₂ emissions, and providing habitat to a number of commercially important and/or endangered species (Orth et al. 1984; Heck et al. 1989; Hughes et al. 2002; Lazarri and Tupper 2002). Nantucket Island, located 30 miles off the coast of Cape Cod, supports over 2,000 acres of eelgrass (Costello 2015) that serve as essential habitat to a number of different species including the last commercially viable “wild” bay scallop fishery in the U.S. The abundance of eelgrass, however, has diminished from historic levels in some areas, potentially threatening the future ecology and economy of this system.

Declines in eelgrass in Nantucket over the last decade have been mostly confined to Nantucket Harbor (Costello and Kenworthy 2011; Costello 2015). The loss in size and density of eelgrass in the harbor is likely due to an increase in nutrient loading (Curley 2002). In the Executive Summary of the Massachusetts Estuaries Project report, it was noted that to maintain or preserve eelgrass meadow health, a nitrogen threshold of 0.350 mg N L⁻¹ should not be exceeded. Nitrogen levels in East Polpis Harbor in 2006 were 0.361 mg N L⁻¹ and eelgrass had recently disappeared from most of the area (Shellfish Report 2012), indicating that this is an accurate threshold. At present, it is believed that Nantucket Harbor has reached its nitrogen loading threshold (Howes et al. 2006) and is eutrophied (over-enriched with nutrients; Conant et al., 2006).

Nitrogen loading to Nantucket Harbor results primarily from on-site disposal of wastewater. The Town has a centralized wastewater treatment facility, but there are a number of areas on septic that contribute nitrogen to the system both through transport in direct groundwater discharges to estuarine waters and

through small surface water flows to the fresh and saltwater marshes that are located along the harbor shore (e.g. Mill Brook discharging to Polpis Harbor). In addition to residential septic systems, other nutrient sources include runoff from roads and lawn fertilizers, groundwater discharge, and natural areas such as salt marshes and ponds (Howes et al. 2006; Shellfish Report 2012). In 2013 a Town of Nantucket Board of Health regulation went into effect to control the content and application of fertilizer containing phosphorus and nitrogen into Nantucket's waters and wetlands through an organized educational program, licensure and regulations of practice (Nantucketlandcouncil.org). The effectiveness of these efforts on nitrogen loading in the system has yet to be determined.

Eutrophication can have negative impacts on seagrasses. As eutrophication progresses, macroalgae (in shallow waters) or phytoplankton (in deeper waters) dramatically increase and become dominant resulting in declines of seagrass. Direct underlying mechanisms for declines include competition for light/nitrogen, nitrate inhibition or ammonium toxicity, with light playing a more important role in advanced eutrophication stages (Orth and Moore, 1983; Twilley et al., 1985; Dennison et al., 1993; Harlin, 1993; Lapointe et al., 1994; Short et al., 1995; Hauxwell and Valiela, 2004; Ralph et al., 2006). Many indicators of seagrass plant health and environmental quality have been identified in previous monitoring studies and workshops to help assess the impacts of eutrophication on seagrass. Seagrass cover, above-ground biomass, leaf length and width have been shown to be affected by nutrient loading and shading (Erftemeijer 1994; Lee and Dunton 2000; Burkholder et al. 2007; van Katwijk 2010) along with epiphyte content on blades (Bohrer et al. 1995; Uku and Bjork 2001). In addition, stable isotope analysis is being increasingly used to monitor the health status and nutrient pollution sources of various ecosystems. For example, Cole et al. (2006) showed that water derived from sewage on Cape Cod typically has ^{15}N values of +10 to +20 ‰, while water influenced by atmospheric deposition has values of +2 to +8, and water loaded with fertilizer features values between -3 to +3. Thus, using these parameters, stable isotope analysis can be used to detect the presence of sewage-derived or agricultural nitrogen (N) in the tissues of eelgrass that continually uptake nutrients from their environment.

The purpose of our study was to assess the health of eelgrass meadows at six sites (i.e., Monomoy, Pimny's Point, Fulling Mill, Quaise, Pocomo, Wauwinet) in Nantucket Harbor influenced by nutrient input. Our objective was accomplished by collecting information on various plant and environmental parameters at each site between May and August 2019. In addition, environmental data was used to identify potential mechanisms responsible for reported declines of eelgrass in this system.

Methods

Eelgrass plant health was assessed by collecting information on meadow structure and nutrient content in leaf tissue and sediment.

Eelgrass morphology and meadow structure

In July 2018, when plants had reached peak biomass, information on meadow structure was collected at 6 sites in Nantucket Harbor (i.e., Monomoy, Pimny's Point, Fulling Mill, Quaise, Pocomo, Wauwinet) as well as at a reference location on Tuckernuck Island (Figure 1). At each site, one 50 m cross transect was laid parallel to the shore. Five 0.25 m² quadrats were then haphazardly tossed along the transect and information was collected on percent cover, canopy height, and shoot density. In addition, two representative shoots with roots and rhizomes were collected from each quadrat for morphological measurements (number of leaves, leaf width, above/below-ground weight, and internode length).

Nutrient Content in Leaf Tissue

The influence of nitrogen on eelgrass was assessed by measuring nitrogen (%N), carbon (%C) and stable isotopes of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in leaves, as well as calculating C:N ratios and a Nutrient Pollution Indicator (NPI) for eelgrass at each site (Lee et al. 2004). In May 2018, during a period of increased precipitation, ten representative eelgrass shoots were sampled at each of the 6 sites in Nantucket Harbor, with at least 1 m between any two sampled shoots. In July 2018, during a period of decreased precipitation, sampling was repeated at each of the 6 sites in Nantucket Harbor as well as the reference location on Nantucket (Figure 1.) After each sampling event, shoots were returned to the lab for measurements.

In the lab, leaf mass was determined on the second and/or third youngest leaves of each shoot. All epiphytes were removed from leaves. Six 10 cm long sections of constant width were then cut from each leaf to obtain samples of mature leaf tissue. The cleaned leaf sections were dried at 60 °C to a constant weight and leaf mass was quantified. Each leaf segment was then assessed for %C and %N content and stable isotopes of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ using an Eurovector CN analyzer (see stable isotope section below).

The ratio of the leaf nitrogen content (%N) to area normalized leaf mass mg dry weight cm⁻² was used to calculate a Nutrient Pollution Indicator value as developed by Lee et al. (2004)

$$\text{NPI} = \frac{\text{Leaf nitrogen content (\%N)}}{\text{Area normalized leaf mass (mg dry weight cm}^{-2}\text{)}}$$

Area normalized leaf mass (mg dry wt cm⁻²)

Sediment Samples

One 5 cm sediment sample was taken from each site including the reference using a syringe for sediment grain-size analyses. In addition, sediment cores were taken at 3 sites (i.e., Monomoy, Fulling Mill, and Wauwinet) to assess sediment and nutrient characteristics. The corer (length: 50 cm, diameter: 70 mm) was manually driven to a depth of 25 cm or point of refusal, extracted, capped at both ends under water, and kept in a vertical position during transport to shore. Cores were divided into sections (1 cm sections for the first 10 cm and 5 cm sections for the remaining core) and used to measure dry bulk density, %C, %N, analyze stable isotopes of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, and determine age of sediments (see methods below).

Grain Size

Grain size was determined for sediment samples taken at each site including the reference using the Malvern Mastersizer 2000 with the Hydro 2000S wet dispersion unit (Malvern Instruments, Malvern, UK) system. Sediment samples were homogenized and extruded through a 2 mm sieve into a beaker, then deionized water was added to the sample to create a suspension that was then analyzed.

Dry Bulk Density

Bulk density reflects the size, shape and arrangement of particles and voids (soil structure) and gives a good indication of the suitability for root growth and sediment permeability. Bulk density generally increases with compaction and tends to increase with depth. Sandy substrate is also more prone to high bulk density. Dry bulk density was determined for sediment core section take at Monomoy., Fulling Mill, and Wauwinet using the mass of sediments dried at 60°C for 7 days divided by the volume of the sediment section. Following bulk density measurements, the sample was sub-divided using a sediment splitter to obtain a smaller portion for stable isotope and ²¹⁰Pb analyses.

Sediment Accumulation and Core Age

Sedimentation rates for at three sites (i.e., Monomoy, Fulling Mill, Wauwinet) were obtained by analyzing core samples for ²¹⁰Pb radioisotopes using gamma spectroscopy. Samples were packed in Petri dishes and sealed with electrical tape and paraffin wax 30 days prior to analysis to allow for equilibration between ²²⁶Ra and its daughter isotopes (²¹⁴Pb and ²¹⁴Bi). Radioisotopic concentrations were determined for all samples along each core using a Canberra GL 2020 low energy germanium detector (Virginia Institute of Marine Science, Gloucester Point, VA). The concentrations of excess ²¹⁰Pb used to obtain the

age models were determined as the difference between total ^{210}Pb and ^{226}Ra (supported ^{210}Pb). The Constant Rate of Supply (CRS) model was used to calculate mean sedimentation rates over the last 100 years at all sites (Appleby and Oldfield, 1978). These rates were calculated using the following formula:

$$A = A(0)e^{-\lambda t}$$

where A is the excess (unsupported) ^{210}Pb inventory below a given core section, $A(0)$ is the excess ^{210}Pb inventory for the entire core profile, and λ is the ^{210}Pb decay constant. This was used to calculate t , the time a now-buried section of core was at the surface.

The formula from Kaste et al. (2011) was used to calculate error for the CRS model:

$$1\sigma = \sqrt{n/n}$$

where n = the number of detected counts.

Carbon, Nitrogen, and Stable Isotope Analyses

Carbon (%C), nitrogen (%N) and stable isotope analyses on plant and sediment samples was carried out in a Eurovector CN analyzer. During each sequence run by the mass spectrometer, each sample was flash combusted at 1800°C and the combustion products (CO_2 , N_2 and H_2O) were separated chromatographically and introduced into the mass spectrometer, with water removed in a chemical trap. The gases of interest were then introduced into the mass spectrometer for isotope analysis and the rest pumped away. The sample isotope ratio was compared to a secondary gas standard, whose isotope ratio has been calibrated to international standards. For ^{13}C the gas will be calibrated against NBS 20 (Solenhofen Limestone), NBS 21 (Spectrographic Graphite), and NBS 22 (Hydrocarbon Oil); for ^{15}N the gas was calibrated against atmospheric N_2 and IAEA standards N-1, N-2, and N-3 (all are ammonium sulfate standards). Elemental content of leaf tissue was calculated on a dry weight basis and elemental ratios on a molar basis (QA/QC BU Stable Isotope Lab 2013).

Environmental Conditions

Environmental conditions at each of the six sites were also assessed. Two Hobo light/temperature sensors (<http://www.onsetcomp.com/sensors>) were deployed in an array at each site for 2-week intervals from mid-May to the end of August 2018 (peak growing season). Each array included a light sensor at the bottom and a second sensor 0.3 m higher to determine light available to eelgrass at the site and light attenuation due to the water column. One sensor was deployed on land, attached in an unobstructed

location to a fence at Monomoy. The sensors measured and recorded temperature and light every 15 minutes. For comparison between sites, a subset of the light data was collected in a 4-hour period around solar noon (10:00 to 14:00) for two weeks each month for analyses. All the temperature data between May and August.

Statistics

To assess differences among sites in plant and environmental parameters, one way ANOVAs were performed. All data were tested for homogeneity of variances using Cochran's test. Tukey's post-hoc tests were used to determine groupings in the analysis of stable isotope data. Differences among nitrogen data were not assessed for May and July due to unequal sample sizes.

Results

Eelgrass morphology and meadow structure

Morphological and structural characteristics of the meadow were significantly different among sites in July 2018 (Figures 2 & 3; one-factor ANOVA: leaves/shoot $F_{6,63} = 4.4663$, $p < 0.0008$; leaf width $F_{6,63} = 2.1807$, $p = 0.0565$; internode length $F_{6,63} = 3.6630$, $p = 0.0035$; above-below ground weight $F_{6,63} = 3.6630$, $p = 0.0035$; canopy height $F_{6,63} = 30.6118$, $p < 0.0001$; percent cover $F_{6,20} = 5.6475$, $p = 0.0014$; shoot density $F_{6,20} = 2.4752$, $p = 0.0591$.) There were no consistent patterns in shoot morphology and/or meadow structure observed among sites in Nantucket Harbor. However, Tuckernuck, the reference site, had larger shoots with longer leaves than plants from Nantucket Harbor.

Influence of Nitrogen on Leaf Tissue

May

Analysis of eelgrass leaf N content for May samples revealed significant differences in mean leaf %N. (ANOVA: %N $F_{5,6} = 4.1072$, $p = 0.050$) with %N in tissue ranging from 1.2% to 1.9% (Figure 4). There were no obvious patterns indicating a gradient towards higher or lower areas of nutrient enrichment or loading between the six sites. No differences among sites were observed for $\delta^{15}\text{N}$ values, C:N or NPI (ANOVA: $\delta^{15}\text{N}$ values $F_{5,6} = 4.3232$, $p = 0.0516$; C:N $F_{5,6} = 1.7658$, $p = 0.2539$; NPI $F_{5,6} = 1.1683$, $p = 0.4286$). Mean $\delta^{15}\text{N}$ for the system was 4.03 ± 0.39 while C:N for the system was 22.4 ± 0.54 and mean NPI for the system was 0.421 ± 0.028 (Figure 4).

July

Analysis of eelgrass leaf N content for July samples revealed significant differences in mean leaf N, C:N, NPI, and $\delta^{15}\text{N}$ among sites (Figure 5; ANOVA: %N $F_{6,63}=4.9518$, $p=0.0003$; C:N $F_{6,63}=3.6588$, $p=0.0035$; NPI $F_{6,63}=3.8674$, $p=0.0024$; $\delta^{15}\text{N}$ $F_{6,66}=54.57$, $p<0.0001$). Leaf N ranged from 0.849 % to 1.2%, C:N ranged from 32.3 to 45.8 and NPI ranged from 0.161 to 0.244. July $\delta^{15}\text{N}$ values ranged from 3.08 to 5.08‰. Tuckernuck had an average value of 7.46 ‰, which was significantly higher than the other sites (Figure 5). There were no obvious patterns indicating a gradient towards higher or lower areas of nutrient enrichment and/or type of loading between the six sites and/or the reference site. C:N ratio differences among sites were driven by differences in N content as there was no difference in carbon content among sites.

Sediment Samples

Grain-Size

All sediment samples from Nantucket Harbor and Tuckernuck, consisted of 98 to 99 % sand-sized grains. The highest percentage of coarse sand was found at Fulling Mill (44%) while the highest portion of fine to very fine sand was found at Monomoy (20%) and Pimny's Point (22%). The predominant sediment type was medium to fine-grained sand with lesser amounts of medium and fine sand (Figure 6). Eelgrass grows well in sediment that consists of <70 percent silt to clay so the sediment grain-size distribution was not unexpected.

Bulk Density

The bulk density measurements are comparable to other eelgrass meadows in the region (Plaisted, pers. comm.). The density ranged from 1.25 to 2 g/cm³ and slightly increased with depth at each site. Dry bulk density at Monomoy (1.6 ± 0.03 g cm⁻³) was similar to Fulling Mill (1.7 ± 0.01 g cm⁻³) and Wauwinet (1.5 ± 0.01 g cm⁻³; Figure 7). The large fluctuation in bulk density values at the top 5 cm at each site can be attributed to the high mobility of substrate in this dynamic system.

Sedimentation Rates and Core Age

The three cores that were dated ranged in age from 64 to 98 years. The highest depth integrated sedimentation rate and youngest core were found in Wauwinet (7.1 ± 1.15 mm/yr; 64 years in the upper 25 cm). Monomoy had a depth integrated sedimentation rate of 6.4 ± 1.6 mm/yr and core age of 98 years in the upper 25 cm. In contrast, Fulling Mill had the lowest depth integrated sedimentation rate (3.95 ± 0.5 mm/yr) and a core age of 82 years in the upper 25 cm (Figure 8). The large variability in

sedimentation rates in the upper 5-10 cm of each core can be attributed to high mobility of substrate within the system (e.g., shoaling).

Stable isotopes

Sediment core material $\delta^{15}\text{N}$ ranged from -3.08 ‰ to 6.81 ‰ while $\delta^{13}\text{C}$ ranged from -28.63 ‰ to -7.10 ‰ (Figures 9 & 10). Each core showed variability with depth for $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$. Cole et al. (2006) showed that water derived from sewage typically has $\delta^{15}\text{N}$ values of +10 to +20 ‰, while water influenced by atmospheric deposition has values of +2 to +8, and water loaded with fertilizer features values between -3 to +3. Phytoplankton and particulate organic matter have $\delta^{13}\text{C}$ ranging from -15 ‰ to -28 ‰ while eelgrass have $\delta^{13}\text{C}$ ranging from -5 ‰ to -10 ‰ (Fry and Wainwright, 1991; Fry, 2006; Novak et al., in review).

Environmental Conditions

Light

The average daily light available to eelgrass relative to ambient land conditions between May and August ranged from 0.03% measured at the bottom of the canopy located at Pimny's Point up to 45.9% measured at the top of the canopy Fulling Mill. Large quantities of algae were consistently found in the eelgrass meadow at Pimny's Point. Algae was also observed at the other sites, but mats were not as dense. In June and July, the bottom light sensor at Fulling Mill and the top and bottom light sensors at Pocomo were lost/damaged (Figures 11 & 12).

Temperature

The average monthly temperature measured between May and August ranged from 17.7°C measured at Monomoy in May and up to ~31°C measured at Wauwinet in July. During the months of July all sites were above 25°C more than 50% of the time. In August, Quaise, Pocomo and Wauwinet were above 25°C more than 50% of the time (Figure 13).

Discussion

Recent studies show that the abundance of eelgrass has diminished from historic levels in Nantucket Harbor (Costello and Kenworthy 2011; Costello 2015). The loss in size and density of eelgrass in the Harbor is believed to be due to an increase in nutrient loading to the system (Curley 2002). In our study, we assessed the health of eelgrass meadows at six sites in Nantucket Harbor influenced by high nitrogen

loadings by collecting information on various plant and environmental parameters and identified mechanisms of declines. Our results show that eelgrass meadows in Nantucket Harbor are light-limited and thermally stressed during the peak growing season, suggesting that long-term loss of eelgrass in this system is due to the joint effect of cultural eutrophication (high nutrient loadings) and warming waters.

Ochieng et al. (2010) demonstrated that eelgrass plants in New England require 58% surface irradiance (SI) and above to grow and expand and are light-limited at 34% SI and below (Ochieng et al. 2010). Kenworthy et al. (2014) further suggested that the threshold for survival is 13.9% based on measurements at the deep edge (2.56 m) of eelgrass meadows in Nantucket Harbor. In our study, all sites received less than 34% SI from May to August except for Fulling Mill, which received more than 45% during the month of August (Figures 11&12). These results indicate that eelgrass meadows in Nantucket Harbor are not receiving enough light throughout the peak growing season to maintain a positive carbon balance and allow growth and expansion of meadows. The causes of light-limitation can be attributed to large quantities of drift macro-algae collecting in eelgrass meadows and reducing the light available to eelgrass through shading. Large quantities of algae were especially prevalent at Pimny's Point from May thru August. In addition to algae, sediment resuspension due to the loss of eelgrass in the system, as well as moored boats may be further reducing light levels in eelgrass meadows and causing declines.

Temperatures above 25°C have previously been identified as another stressful threshold for eelgrass (Greve et al. 2003; Reusch et al. 2005). At 25 °C, water temperatures cause rates of respiration to exceed photosynthesis, resulting in a negative carbon balance (Marsh et al. 1986; Moore et al. 1997). At 28 °C, large scale declines in eelgrass cover have been observed at the southern range of this species distribution (Shields et al. 2019). During the month of July, all study sites in Nantucket Harbor had an average water temperature above 25 °C and were exposed to temperatures above 28 °C for ~13% of the time. In August, only Quaise, Pocomo, and Wauwinet had an average water temperature above 25°C. However, all sites spent more than 50% of the time above the 25°C and more than 3% of the time above 28 °C (Figure 13). The warm water temperatures in Nantucket Harbor during the summer months is higher than temperatures in nearby eelgrass meadows located in shallow subtidal waters on Cape Cod. Between 2003 and 2015, Pleasant Bay (Orleans) and Duck Harbor (Wellfleet) were exposed to temperatures above 25°C less than 16% of the time and above 28 °C less than 2% (NPS, SeagrassNet data). Based on the results of this study, it appears as though eelgrass meadows are also thermally stressed in this system possible due to climate change.

C:N, NPI, and % N in leaves have been used as indicators of nutrient enrichment in seagrass meadows. C:N ratios less than 20 in leaves, NPI values greater than 0.3, and/or leaf nitrogen values above 1.6 % have been found in nutrient enriched systems such as Great Bay (NH), Waquoit Bay (MA), and Narragansett Bay (RI; Heminga and Duarte 2000; Lee et al. 2004). In our study, Pimny's Point had %N values in leaves greater than 1.6% during May (Figure 4). However, all sites had higher C:N, and lower NPI, and %N values during the month of July than nutrient enriched systems (Figure 5). The lower values of %N in eelgrass during the July 2018 sampling could be a result of seasonal nitrogen availability and eelgrass growth rates (Duarte 1990, Fourqurean et al. 1997). Nitrogen is typically limited in the nearshore during summer growing seasons and growth rates are often elevated increasing plant biomass while reducing total nutrient concentrations. Moreover, the extensive algae mats found throughout the system may be reducing the amount of nitrogen available to eelgrass during the summer months; Alexandre et al. (2017) found that some species of algae have higher uptake capacities for nutrients than eelgrass.

Stable isotopes analysis of plant material offers the possibility of detecting the biological role of groundwater flow in the marine environment or the impact of sewage effluent before major ecological changes occur (Mac Clelland et al. 1997; Mac Clelland and Valiela 1998). It is particularly useful in areas where a small nutrient increase could have a significant impact on the ecosystem especially where this nutrient increase is undetectable in the water due to, for example, a low sewage load or rapid dilution in the surrounding environment (Gartner et al. 2002; Yamamuro et al. 2003). In Waquoit Bay (Massachusetts, USA), isotopic studies have permitted the attribution of an isotopic signature to nitrates from waste water, from fertilizer and from atmospheric deposition (MacClelland et al. 1997). In our study, July $\delta^{15}\text{N}$ values ranged from 3.08 to 5.08‰ in Nantucket Harbor and there was no obvious pattern indicating a gradient towards higher or lower areas of nutrient enrichment and/or type of loading among the six sites. Tuckernuck, a relatively preserved site, had a high $\delta^{15}\text{N}$ of 7.46‰ (Figure 5). The lack of differentiation between $\delta^{15}\text{N}$ sources in July in Nantucket Harbor suggest multiple inputs (i.e., fertilizer and atmospheric deposition). Likewise, the high values in eelgrass tissues from Tuckernuck are not necessarily the reflection of sewage or ground water impacts. For example, Fourqurean et al. (1997) measured the increase of $\delta^{15}\text{N}$ values of eelgrass from the mouth to the head of Tomales Bay in California. In this relatively preserved bay, groundwater discharge is considered low. The high $\delta^{15}\text{N}$ values (+12‰) are attributed to the occurrence of denitrification processes in Tomales Bay marine waters, which may have resulted in the ^{15}N enrichment of the remaining inorganic N pool and, consequently, a ^{15}N enrichment of plants which incorporate inorganic N from the water column.

Recommendations

Our study provides baseline information on eelgrass health for Nantucket Harbor and identifies mechanisms for reported declines. As the climate continues to warm, eelgrass in Nantucket Harbor will continue to be exposed to increased water temperatures and periods of thermal stress. However, eelgrass can survive if other environmental parameters that promote growth and expansion are optimal. Below are some recommendations for future work, as well as management actions that will improve eelgrass health and facilitate recovery in the harbor

Restoration of eelgrass meadows in Nantucket Harbor is one suggested strategy to facilitate recovery in this system even in the face of climate change. Restoration involves improving environmental conditions (e.g. water quality) to encourage natural regeneration and/or seeding/transplanting plants from donor meadows. We recommend managers improve water quality within the harbor by reducing land-based pollution and decreasing nutrient and sediment run-off, reducing or eliminating the use of fertilizers and persistent pesticides and increasing filtration of effluent. The reduction in nutrients within the system will lead to a reduction in nuisance algae which limit the amount of light available to eelgrass for growth. Moreover, if plants are no longer light stressed they will be able to tolerate longer periods of thermal stress. In addition, to improving water quality, we recommend continuing transplanting efforts in well flushed areas with low quantities of algae. In September 2018, the Nantucket Land Council along with Boston University began transplanting 1/4 acre plots of eelgrass at Monomoy. This location was selected because it is well-flushed and has historically supported eelgrass (Shellfish Report, 2012). The establishment of eelgrass within this area should help “kick start” natural recovery within the Monomoy section of the harbor. In addition, newly transplanted eelgrass in this area is expected to further improve water quality and clarity through nutrient uptake and suspended sediment deposition (Duarte, 1995).

In addition to restoring eelgrass in Nantucket Harbor, we also recommend monitoring existing eelgrass meadows in the harbor using a hierarchical framework to detect and predict changes so that appropriate management strategies can be developed. The monitoring approach would include three tiers that are integrated across spatial scales and sampling intensities (see Neckles et al. 2012). Tier 1 monitoring would involve mapping eelgrass in Nantucket Harbor every three-five years to provide large-scale information on seagrass distribution and meadow size. Costello (2015) has already developed an appropriate mapping process for this system that involves the acquisition of high resolution digital imagery captured within strict environmental conditions. Tier 2 monitoring would involve bay-wide, quadrat-based assessments of eelgrass percent cover and canopy height at permanent sampling stations

following a spatially distributed random design. The National Park Service on Cape Cod has a design that is used to monitor Pleasant Bay that could be adapted to this system. Tier 3 monitoring would involve high-resolution measurements of seagrass condition (percent cover, canopy height, total and reproductive shoot density, biomass, and seagrass depth limit) at a representative index site in the system. SeagrassNet is an example of a program that collects more detailed Tier 3 data and could be easily implemented in the harbor (<http://www.seagrassnet.org/>). If a hierarchical approach to monitoring is not feasible for Nantucket Harbor at this time, light and temperature data, as well as percent cover of algae and eelgrass should be monitored at multiple sites within the system.

Costello (2015) showed a slight decline in eelgrass in Madaket while eelgrass was stable to increasing on Tuckernuck. The decline in Madaket was along the deeper edges South of Eel Point and possibly due to storm and tidal current action. A complete loss of habitat in the inner Madaket Harbor area on both sides of the channel and in the upper reaches of the inner harbor was also noted. Water quality issues were suspected in those losses as the contributing watershed seems to have experienced increased development. To increase our understanding of the factors responsible for eelgrass declines and the conditions required to facilitate eelgrass growth and expansion on Nantucket we suggest conducting eelgrass plant health assessments in Madaket Harbor and Tuckernuck utilizing the methodology outlined in this study. Specifically, information on meadow structure and nutrient content in leaf tissue and sediment as well as light and temperature data should be collected at multiple sites in Madaket Harbor and Tuckernuck and compared to the data collected in Nantucket Harbor. We suggest collecting in both spring and summer months.

Lastly, we recommend raising awareness about the socio-economic and ecological values of eelgrass as it is critical in building support for seagrass conservation. Engaging local communities and stakeholders is essential in any conservation strategy. Volunteer monitoring programs can be effective in increasing public awareness of the value of eelgrass meadows and the threats to their survival. Community monitoring programs, such as SeagrassNet, successfully promote stewardship, reinforce the value of eelgrass habitats and collect data about the condition of this species. Public education programs should identify actions that individuals can take to reduce stresses on eelgrass in this system. For example, individuals can help reduce threats to water quality by preventing pollutants (e.g. fertilizers, paint, gasoline, solvents and garden chemicals) from entering storm-water drains. To reduce sediment and nutrient run-off into waterways, individuals can maintain vegetation on riverbanks and adjacent to the harbor, create retention ponds or ditches to reduce high-discharge flows or plant a buffer strip of plants in

these areas. Boaters can also avoid anchoring and running their propellers through eelgrass meadows. Mooring in eelgrass meadows appears to be a serious problem across the island.

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Figure 1. Map showing the location of sampling sites in Nantucket Harbor as well as a reference site near Tuckernuck Island.

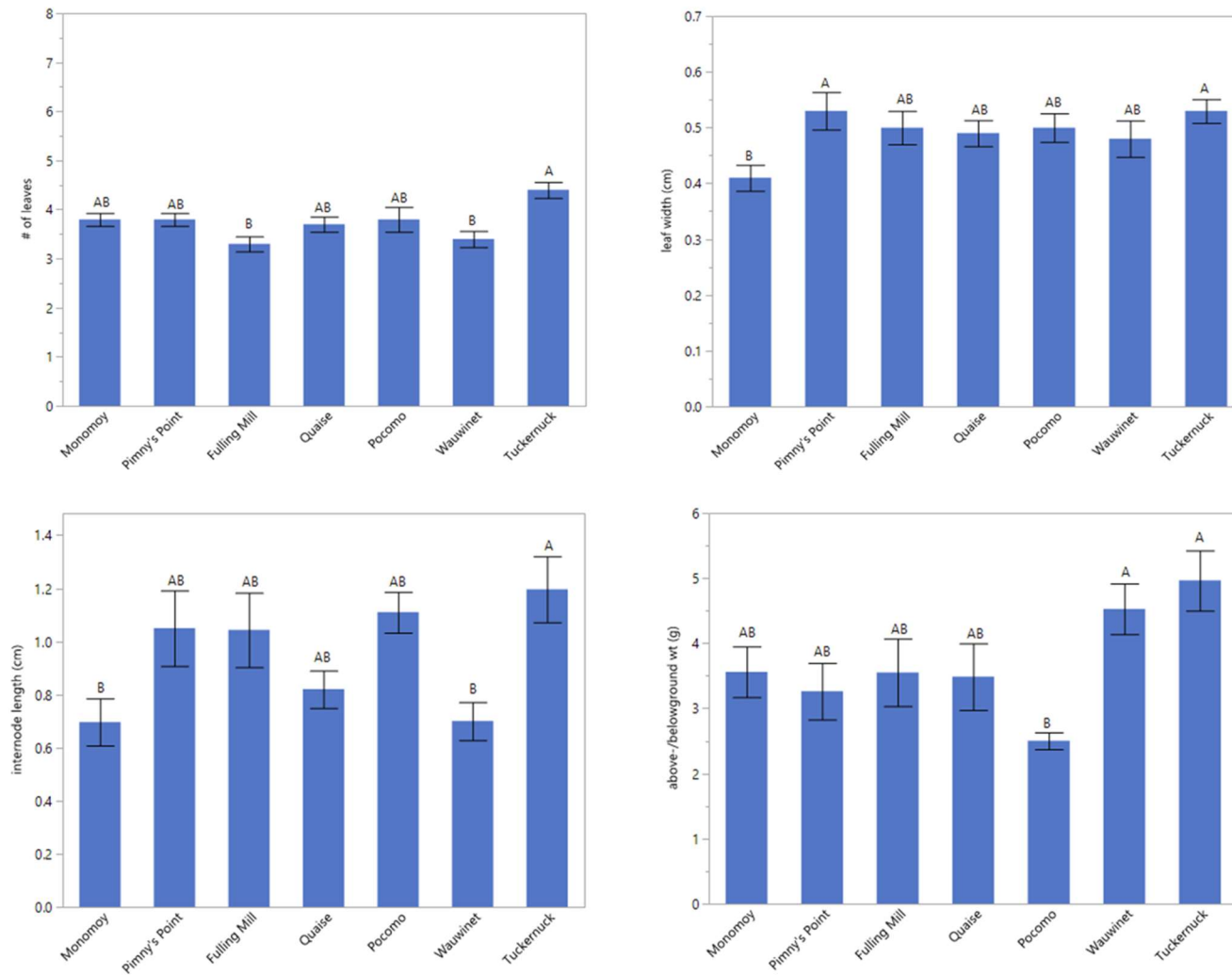


Figure 2. Significant differences in morphological characteristics were observed among sites in July 2018 (means $\pm$ SE). Different letters A-B denote Tukey's test results for significant differences among sites at $P < 0.05$.

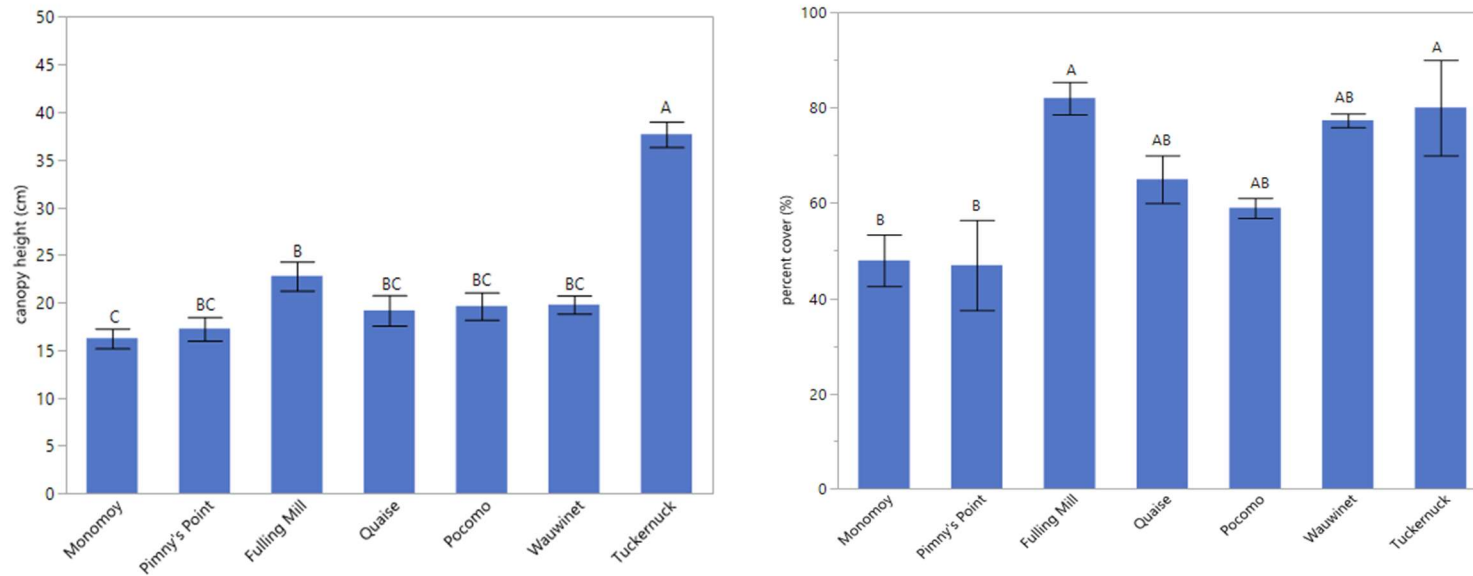


Figure 3. Significant differences in structural characteristics of the meadow were observed among sites for canopy height and percent cover in July 2018 (means $\pm$ SE). Different letters A-C denote Tukey's test results for significant differences among sites at $P < 0.05$.

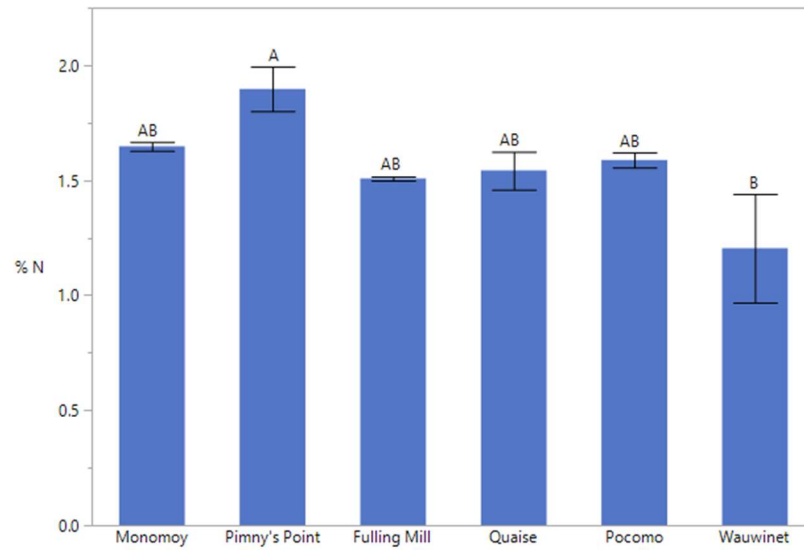


Figure 4. Significant differences in %N were observed among sites during the Spring of 2018 (means $\pm$ SE). Different letters A-B denote Tukey's test results for significant differences among sites at $P < 0.05$.

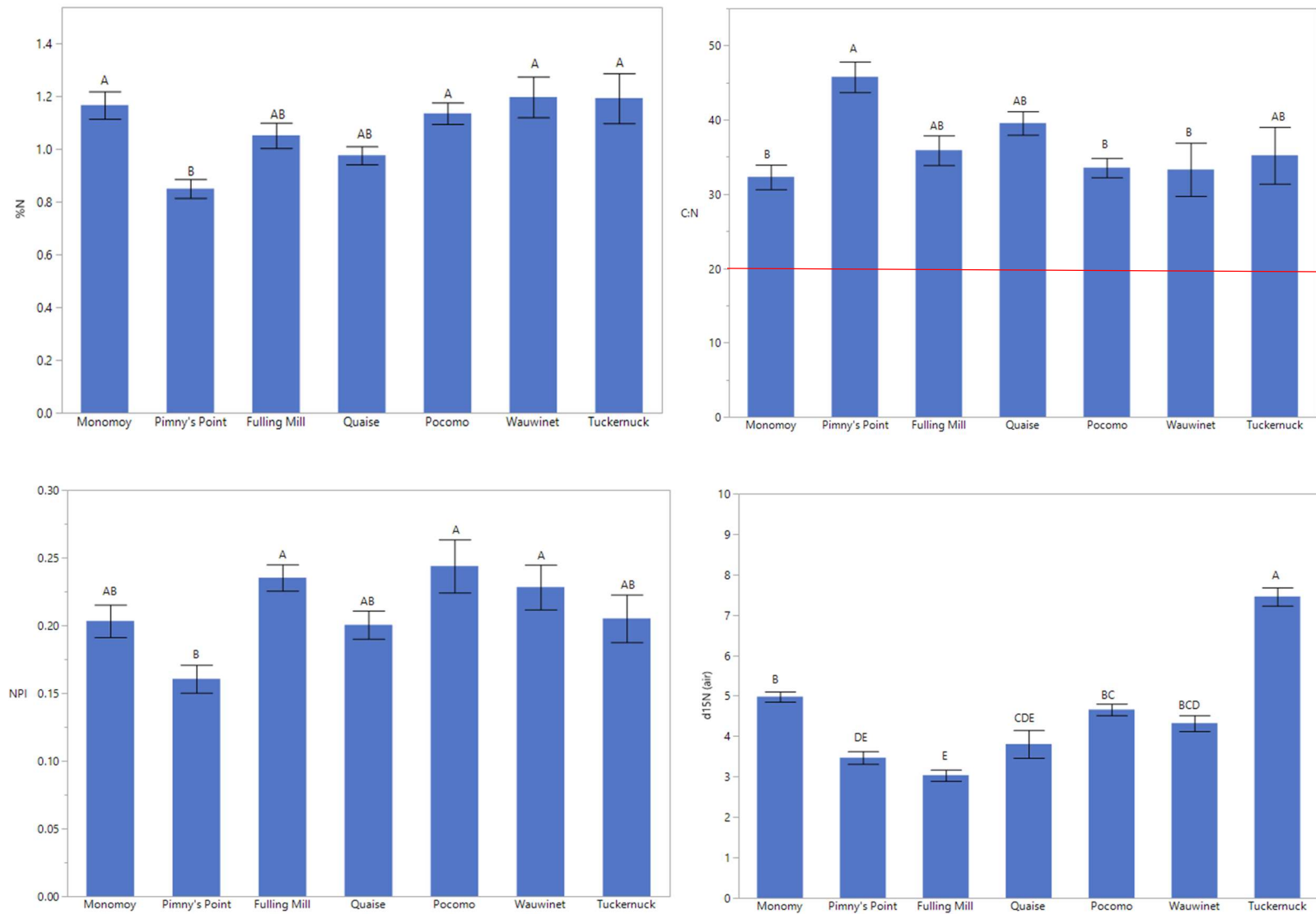


Figure 5. Significant differences in %N, C:N, NPI, and $\delta^{15}\text{N}$ were observed among sites during the Summer of 2018 (means $\pm$ SE). Different letters A-E denote Tukey's test results for significant differences among sites at $P < 0.05$. C:N values < 20 indicate nitrogen enrichment (red line).

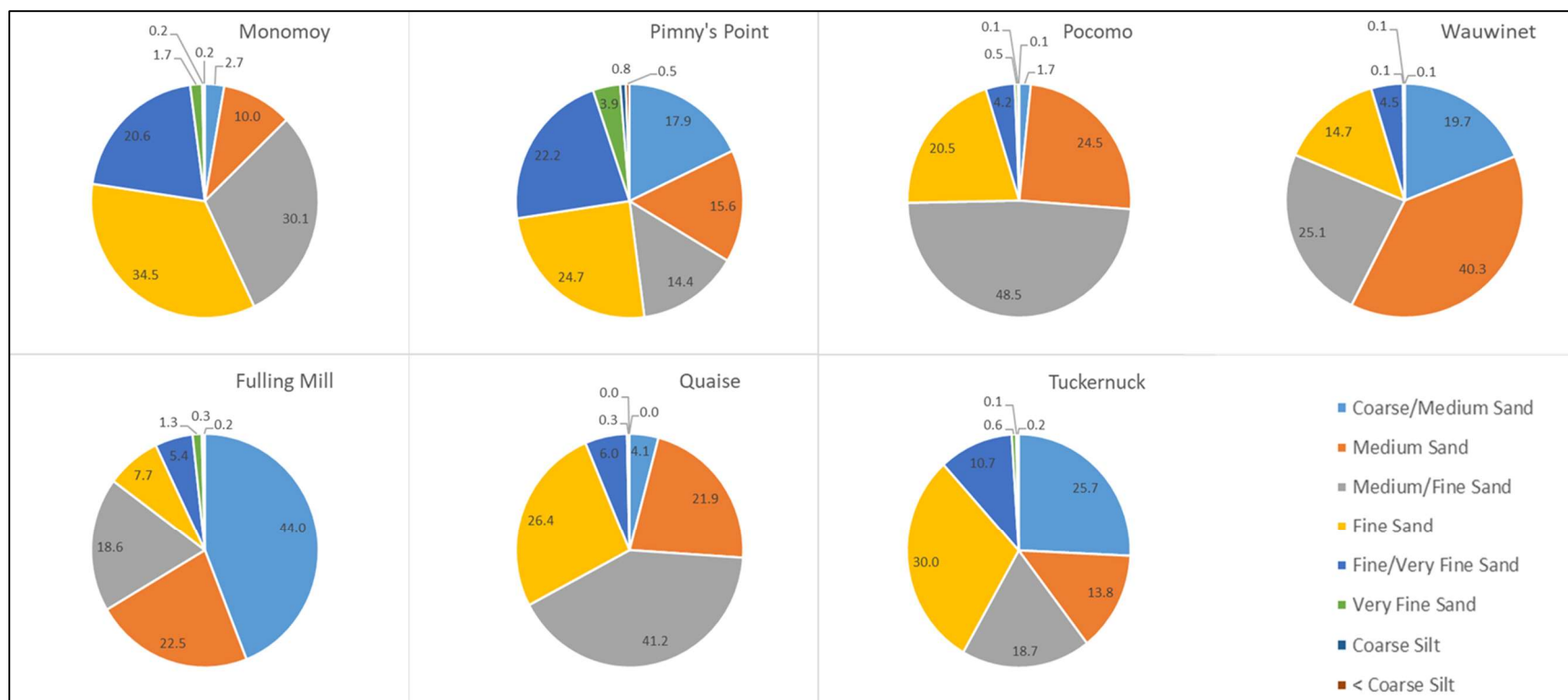
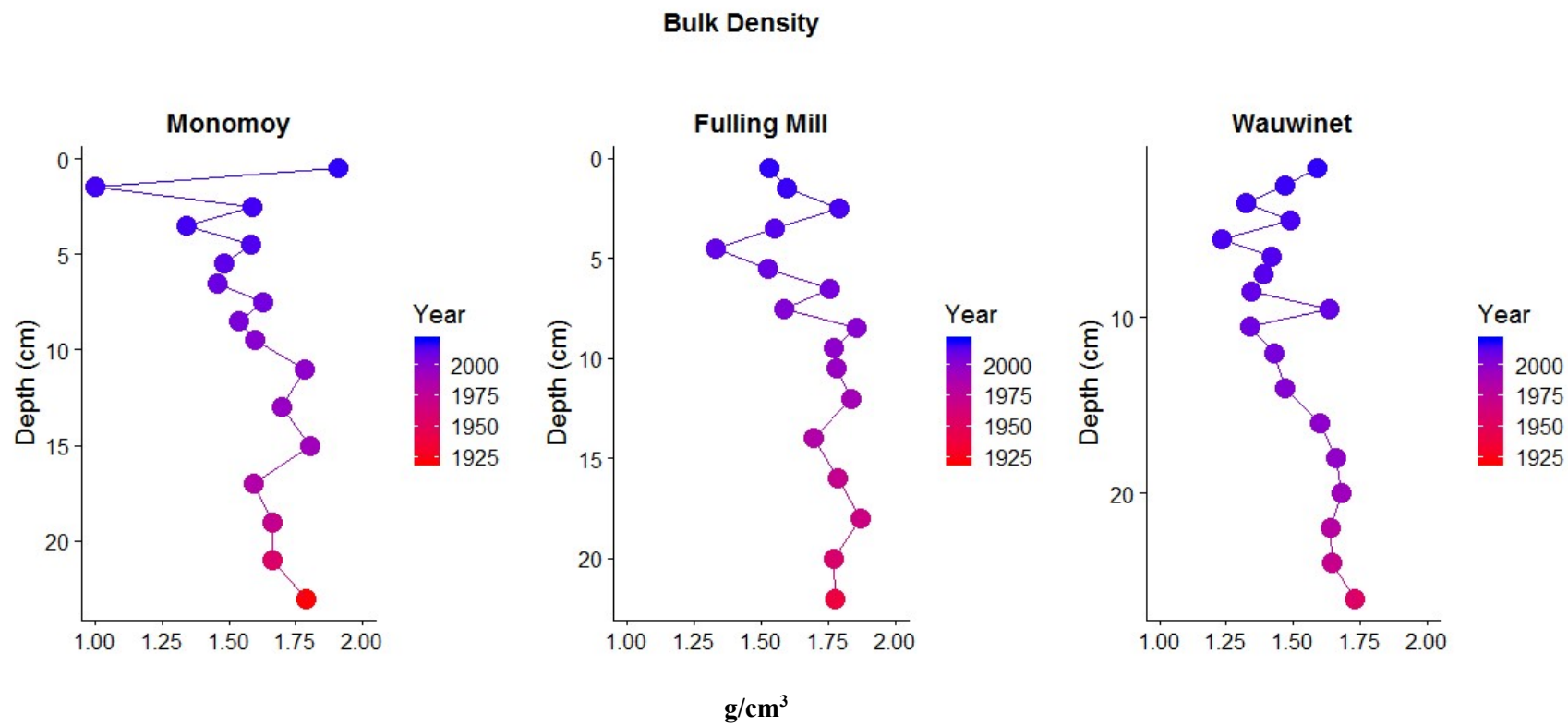
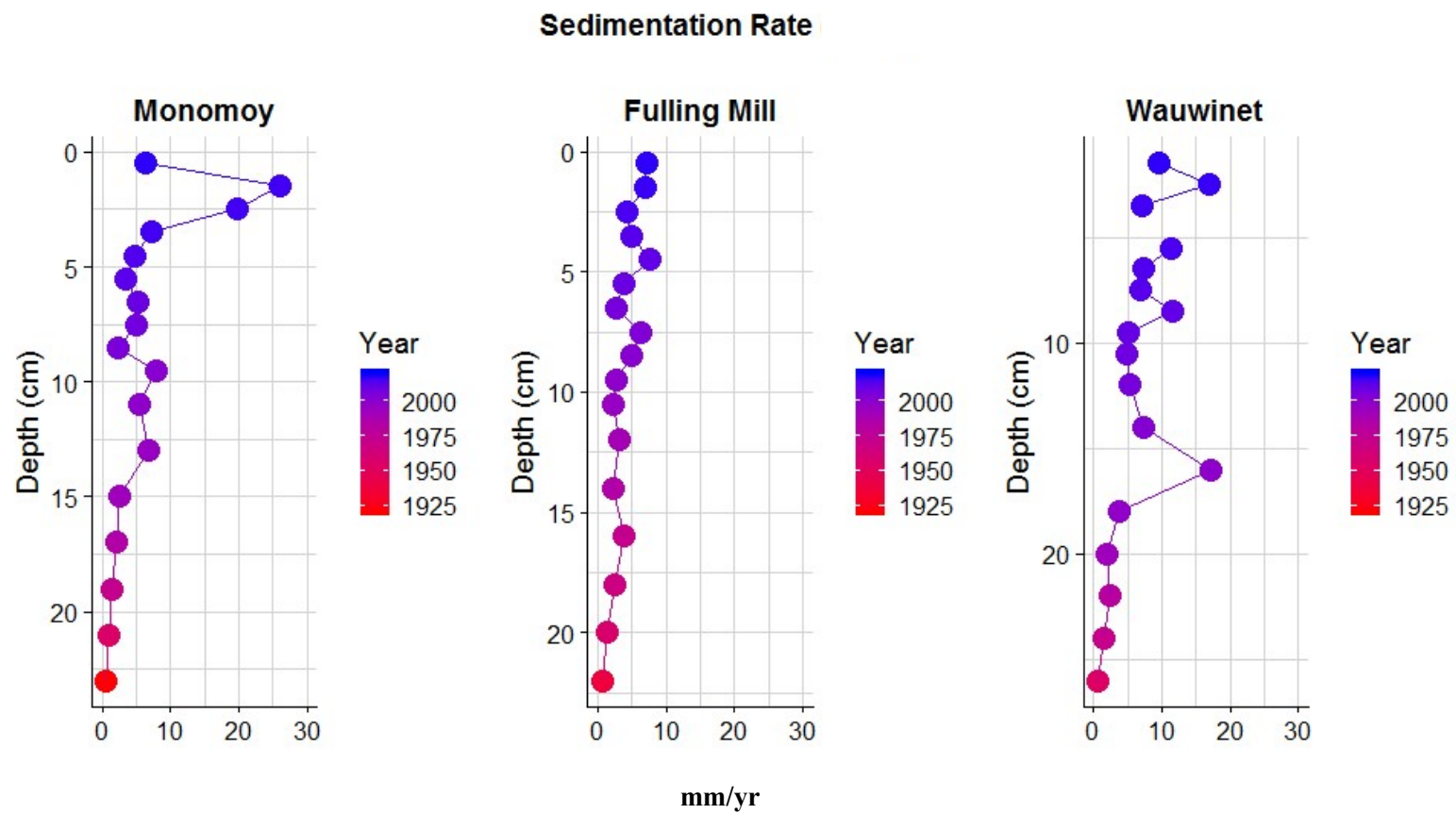
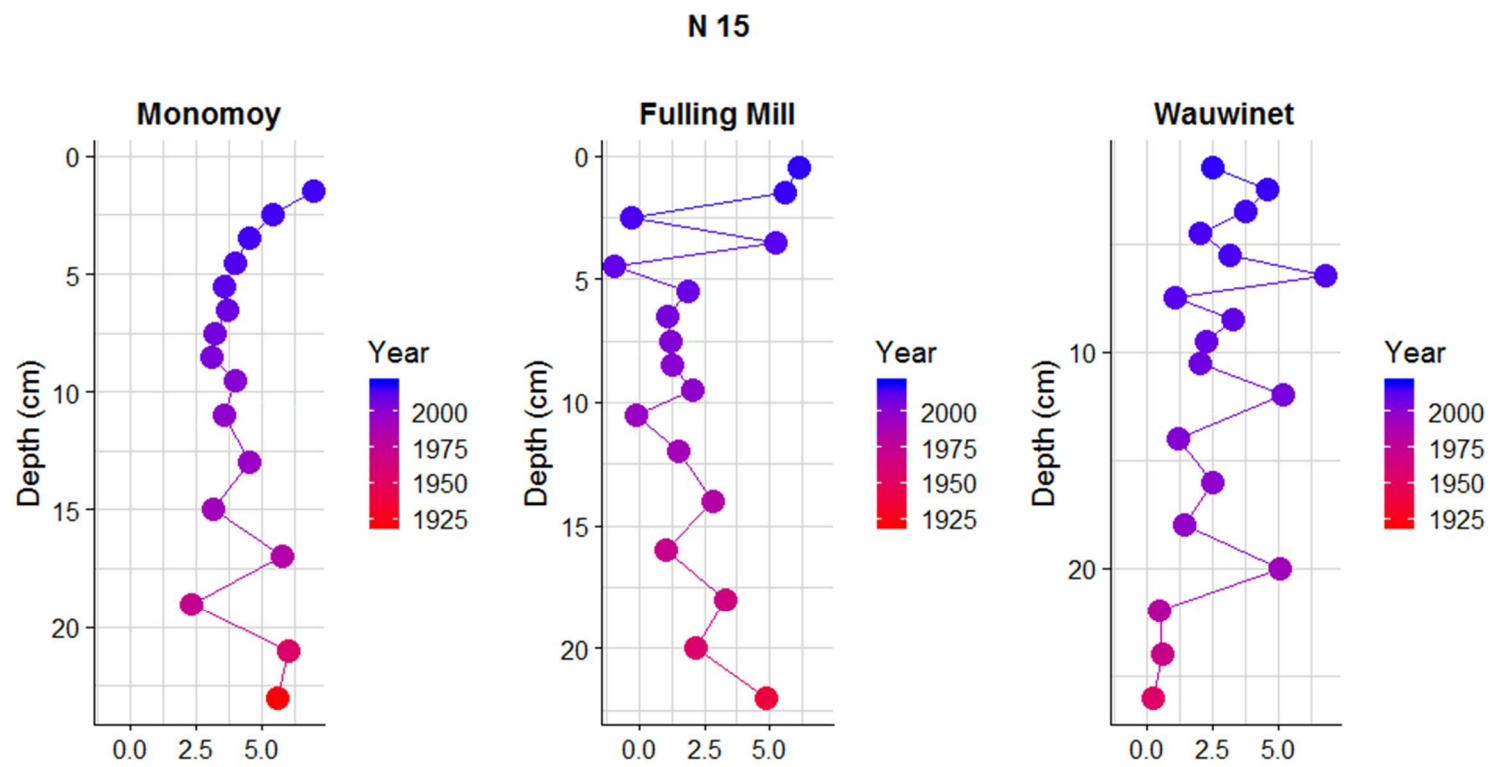


Figure 6. Charts showing sediment grain-size distribution at each of the six sites in Nantucket Harbor as well as at the sample site on Tuckernuck Island.







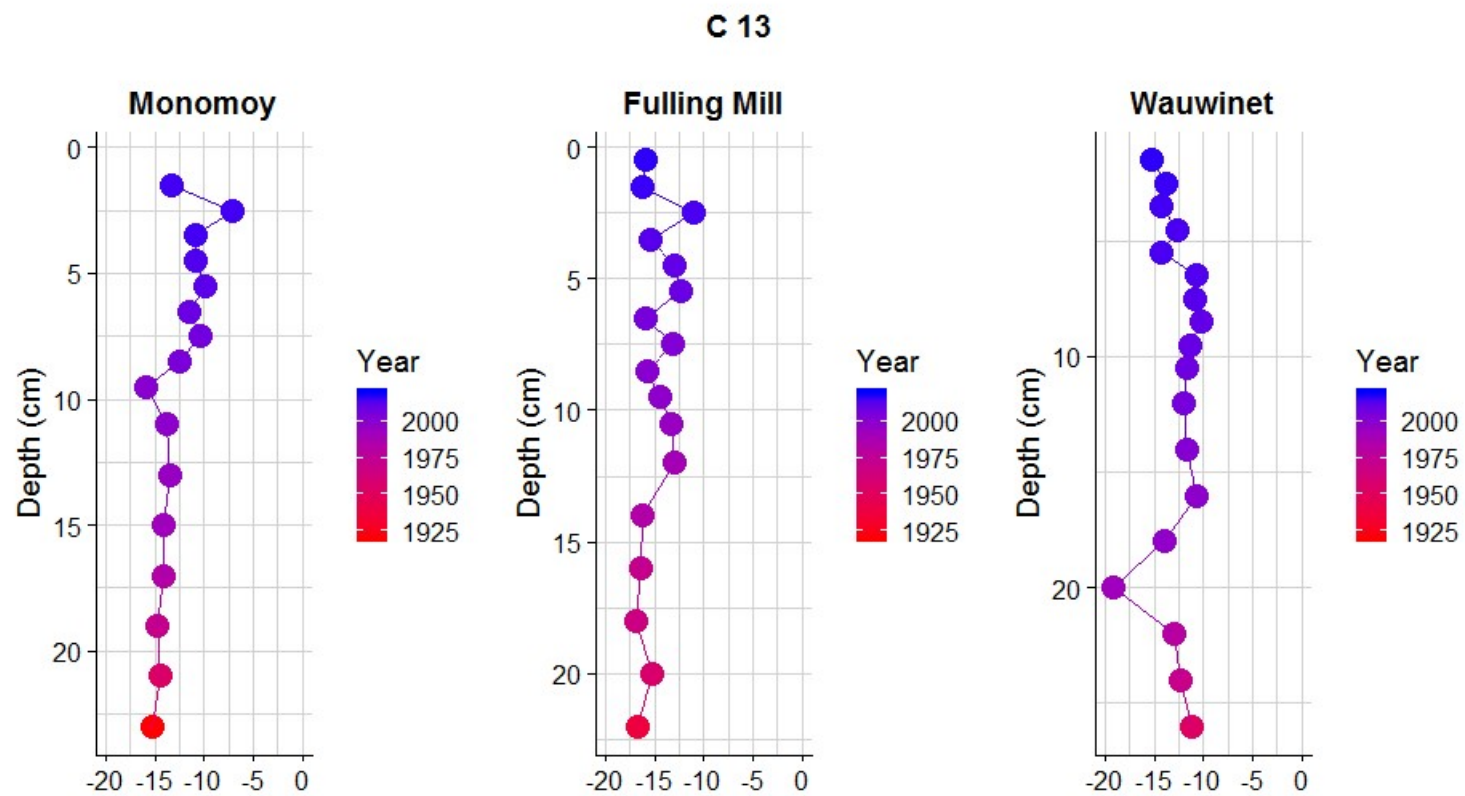


Figure 10. $\delta^{13}\text{C}$ values at Monomoy, Fulling Mill, and Wauwinet. $\delta^{13}\text{C}$ can be used to identify sources of carbon.

MAY

Site	Avg. Intensity	% Surface Irradiance
Monomoy (Top)	3274	23.07
Monomoy (Bottom)	2409	16.97
Pimny's Point (Top)	2705	19.06
Pimny's Point (Bottom)	0	0.00
Fulling Mill (Top)	3615	25.46
Fulling Mill (Bottom)	2115	14.90
Quaise (Top)	3176	22.37
Quaise (Bottom)	1454	10.24
Pocomo (Top)	2825	19.90
Pocomo (Bottom)	1836	12.93
Wauwinet (Top)	2920	20.57
Wauwinet (Bottom)	2259	15.91

June

Site	Avg. Intensity	% Surface Irradiance
Monomoy (Top)	3155	28.76
Monomoy (Bottom)	1632	14.88
Pimny's Point (Top)	3217	29.32
Pimny's Point (Bottom)	2276	20.75
Fulling Mill (Top)	3063	27.92
Fulling Mill (Bottom)		
Quaise (Top)	2772	25.27
Quaise (Bottom)	1788	16.30
Pocomo (Top)		
Pocomo (Bottom)		
Wauwinet (Top)	2082	18.98
Wauwinet (Bottom)	1087	9.91

Figure 11. Average percent of light reaching the top and bottom of the eelgrass canopy between 10:00 and 14:00 for the months of May and June.

July

Site	Avg. Intensity	% Surface Irradiance
Monomoy (Top)	3654	24.46
Monomoy (Bottom)	2498	16.72
Pimny's Point (Top)	4694	31.43
Pimny's Point (Bottom)	1081	7.23
Fulling Mill (Top)	4304	28.81
Fulling Mill (Bottom)	2413	16.15
Quaise (Top)	3676	24.61
Quaise (Bottom)	2311	15.47
Pocomo (Top)	3281	21.96
Pocomo (Bottom)	1288	8.62
Wauwinet (Top)	3180	21.29
Wauwinet (Bottom)	2369	15.86

August

Site	Avg. Intensity	% Surface Irradiance
Monomoy (Top)	2858	26.49
Monomoy (Bottom)	1262	11.70
Pimny's Point (Top)	2299	21.32
Pimny's Point (Bottom)	358	3.32
Fulling Mill (Top)	4878	45.23
Fulling Mill (Bottom)	2514	23.30
Quaise (Top)	3031	28.10
Quaise (Bottom)	1657	15.36
Pocomo (Top)	2442	22.64
Pocomo (Bottom)	1811	16.79
Wauwinet (Top)	3107	28.80
Wauwinet (Bottom)	1939	17.98

Figure 12. Average percent of light reaching the top and bottom of the eelgrass canopy between 10:00 and 14:00 for the months of July and August.

May						June					
Site	MIN (°C)	MAX (°C)	AVG (°C)	% Time > 25 °C	% Time > 28 °C	Site	MIN (°C)	MAX (°C)	AVG (°C)	% Time > 25 °C	% Time > 28 °C
Monomoy (Top)	14.04	28.75	17.74	1.4	0.2	Monomoy (Top)	18.14	29.15	22.19	10.6	0.7
Monomoy (Bottom)	13.94	28.66	17.72	1.3	0.2	Monomoy (Bottom)	18.24	27.86	22.02	9.3	0.0
Pimny's Point (Top)	13.85	28.75	18.19	1.3	0.3	Pimny's Point (Top)	18.33	30.76	22.72	19.4	1.6
Pimny's Point (Bottom)	14.23	28.75	17.89	1.3	0.3	Pimny's Point (Bottom)	18.43	30.05	22.57	15.3	1.1
Fulling Mill (Top)	13.65	29.45	18.73	1.3	0.4	Fulling Mill (Top)	18.90	30.46	23.20	27.2	2.8
Fulling Mill (Bottom)	13.75	29.35	18.66	1.1	0.3	Fulling Mill (Bottom)					
Quaise (Top)	14.52	29.45	18.67	1.2	0.3	Quaise (Top)	18.90	29.35	23.14	25.3	1.6
Quaise (Bottom)	14.52	28.85	18.54	1.2	0.3	Quaise (Bottom)	19.00	29.15	23.06	24.4	1.3
Pocomo (Top)	14.33	28.75	18.94	1.1	0.3	Pocomo (Top)					
Pocomo (Bottom)	14.13	28.56	18.78	1.1	0.3	Pocomo (Bottom)					
Wauwinet (Top)	16.05	29.65	19.11	1.0	0.3	Wauwinet (Top)	19.28	30.56	23.66	24.8	3.7
Wauwinet (Bottom)	15.95	29.75	19.02	0.9	0.2	Wauwinet (Bottom)	19.28	30.15	23.51	22.3	3.2

July						August					
Site	MIN (°C)	MAX (°C)	AVG (°C)	% Time > 25 °C	% Time > 28 °C	Site	MIN (°C)	MAX (°C)	AVG (°C)	% Time > 25 °C	% Time > 28 °C
Monomoy (Top)	21.86	29.65	25.02	52.7	5.1	Monomoy (Top)	21.95	29.55	24.77	41.6	1.5
Monomoy (Bottom)	21.76	29.65	24.90	49.2	4.5	Monomoy (Bottom)	22.05	29.05	24.61	35.2	0.7
Pimny's Point (Top)	21.57	30.56	25.41	58.4	7.3	Pimny's Point (Top)	21.86	29.55	24.92	46.7	1.1
Pimny's Point (Bottom)	21.76	29.65	25.15	54.1	4.3	Pimny's Point (Bottom)	21.76	28.85	24.69	38.8	0.8
Fulling Mill (Top)	21.76	30.66	25.75	64.9	9.9	Fulling Mill (Top)	21.76	30.66	24.98	45.9	3.4
Fulling Mill (Bottom)	21.95	30.36	25.74	65.8	8.2	Fulling Mill (Bottom)	21.66	29.75	24.87	44.0	2.2
Quaise (Top)	20.23	30.17	25.70	65.3	9.5	Quaise (Top)	22.33	29.05	25.03	51.2	1.7
Quaise (Bottom)	20.04	30.95	25.65	64.7	9.0	Quaise (Bottom)	22.43	28.85	25.07	51.1	1.4
Pocomo (Top)	20.33	30.17	26.16	77.6	13.0	Pocomo (Top)	21.86	29.55	25.27	53.1	4.7
Pocomo (Bottom)	19.95	30.44	25.90	73.3	9.3	Pocomo (Bottom)	21.86	29.25	25.26	53.0	3.4
Wauwinet (Top)	20.04	31.94	26.25	77.9	12.3	Wauwinet (Top)	22.91	29.95	25.54	59.9	5.0
Wauwinet (Bottom)	19.57	30.84	26.14	67.0	10.8	Wauwinet (Bottom)	22.91	29.65	25.44	56.5	2.8

Figure 13. Descriptive statistics for temperature between the months of May and August. Continuous water temperature were collected at 15 minute intervals.

NANTUCKET LAND COUNCIL
ASSESSING EELGRASS HEALTH IN MADAKET HARBOR, NANTUCKET
MASSACHUSETTS

submitted by

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Introduction

Eelgrass (*Zostera marina* L.) is a marine flowering plant that forms extensive meadows in the shallow coastal waters of Massachusetts. The value of eelgrass meadows is well documented and includes stabilizing sediments, improving water quality and clarity, mitigating for CO² emissions, and providing habitat to a number of commercially important and/or endangered species (Orth et al. 1984; Heck et al. 1989; Hughes et al. 2002; Lazarri and Tupper 2002). Nantucket Island, located 30 miles off the coast of Cape Cod, supports over 2,000 acres of eelgrass (Costello 2015) that serve as essential habitat to a number of different species including the last commercially viable “wild” bay scallop fishery in the U.S. The abundance of eelgrass, however, has significantly declined during the last 25 years threatening the future ecology and economy of this island.

Declines in eelgrass in Nantucket over the last decade have been mostly confined to Nantucket and Madaket Harbors, with Madaket Harbor experiencing a 24% loss in aerial coverage (Costello and Kenworthy 2011; Costello 2015). Eelgrass declines in Madaket Harbor have occurred along the deeper edges in the area South of Eel Point and are believed to be due to storm and tidal current action. Declines have also occurred along both sides of the channel and in the upper reaches of the inner portions of the harbor. These losses are believed to be caused by water quality issues as the contributing watershed has experienced increased development (Costello 2015).

Increases in nitrogen loading to Madaket Harbor over the last several decades are primarily from on-site disposal of wastewater. While the Town of Nantucket does have a centralized wastewater treatment facility servicing the downtown area, all the residences in the Madaket Harbor area are serviced by septic systems. These unsewered areas contribute significantly to Madaket Harbor through transport in direct groundwater discharges and through surface water flows from Long Pond to Madaket Ditch and Hither Creek (Howes et al. 2006). In addition to residential septic systems, groundwater is influenced by the

nearby landfill, the runoff from roads and application of agricultural and lawn fertilizers, groundwater discharge of runoff from rooftops and natural areas such as grasslands and wetlands.

Madaket Harbor appears to have reached its nitrogen loading threshold, the level of nitrogen input that a system can tolerate without showing a decline in habitat quality. While large portions of Madaket Harbor still support eelgrass, the decline of eelgrass in specific areas of the Harbor suggests a certain degree of impairment. Consistent with a system at its nitrogen threshold for eelgrass habitat, the bulk of the Harbor is currently supporting healthy benthic animal habitat, critical for supporting the Harbor's and coastal food web (Howes et al., 2006).

Many indicators of seagrass plant health and environmental quality have been identified in previous monitoring studies and workshops. Seagrass cover, above-ground biomass, leaf length and width have been shown to be affected by nutrient loading and shading (Erftemeijer 1994; Lee and Dunton 2000; Burkholder et al. 2007; van Katwijk 2010) along with epiphyte content on blades (Bohrer et al. 1995; Uku and Bjork 2001). Stable isotope analysis is being increasingly used to monitor the health status and nutrient pollution sources of various ecosystems. Although there are other factors that increase N content of plants such as light availability and herbivory, isotopic signatures can identify the source of the elements (Fourqurean 1997). For example, Cole et al. (2006) showed that water derived from sewage on Cape Cod typically has ^{15}N values of +10 to +20 ‰, while water influenced by atmospheric deposition has values of +2 to +8, and water loaded with fertilizer features values between -3 to +3. Thus, using these parameters, stable isotope analysis can be used to detect the presence of sewage-derived or agricultural nitrogen (N) in the tissues of eelgrass that continually uptake nutrients from their environment.

Our study assessed the overall health of eelgrass meadows located at 5 sites within Madaket Harbor (Figure 1) by collecting information on various eelgrass plant parameters. Because the impact of increased nutrient loading on eelgrass is of particular concern in this system we also assessed nutrient status in eelgrass tissues and in sediment samples. To provide a context for potential influences, nutrient data from eelgrass meadows located in Madaket Harbor was compared to nutrient data collected from eelgrass meadows located in Nantucket Harbor, Tuckernuck Island, and Muskeget Island as well as light and temperature data collected from Nantucket Harbor (Figure 1).

Methods

Eelgrass plant health was assessed by collecting information on meadow structure and nutrient content in leaf tissue and sediment.

Eelgrass

Morphology

Plants were collected at 5 sites in Madaket Harbor as well as at sites in Nantucket Harbor, Tuckernuck Island and Muskeget Island for morphological measurements in August 2020 (Figure 1). At each site, five 0.25 m² quadrats were haphazardly tossed and two representative shoots with roots and rhizomes were collected from each quadrat for information on number of leaves, leaf width, above/below-ground weight, and internode length.

Nutrient Content in Leaf Tissue

Eelgrass shoots collected in August were analyzed for nutrient content and to calculate a Nutrient Pollution Indicator (Lee et al., 2004). In the lab, mass was determined on the second and/or third youngest leaves of each shoot. All epiphytes were removed from leaves. Six 10 cm long sections of constant width were then cut from each leaf to obtain samples of mature leaf tissue. The cleaned leaf sections were dried at 60 °C to a constant weight and leaf mass was quantified. Each leaf segment was then assessed for %C and %N content and stable isotopes of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ using an Eurovector CN analyzer (see stable isotope section below).

The Nutrient Pollution Indicator (Lee et al., 2004) was calculated by using the ratio of the leaf nitrogen content (%N) to area normalized leaf mass mg dry weight cm⁻².

$$\text{NPI} = \frac{\text{Leaf nitrogen content (\%N)}}{\text{Area normalized leaf mass (mg dry wt cm}^{-2}\text{)}}$$

Sediment Samples

Sediment cores were taken at 3 sites (2 in Madaket Harbor and 1 on Tuckernuck Island) to assess sediment and nutrient characteristics (Figure 1). The corer (length: 50 cm, diameter: 70 mm) was manually driven to a depth of 25 cm or point of refusal, extracted, capped at both ends under water, and kept in a vertical position during transport to shore. Cores were divided into sections (1 cm sections for

the first 20 cm and 5cm sections for the remaining core) and used to measure dry bulk density, determine age of sediments, and %C, %N, analyze stable isotopes of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (see stable isotope section below).

Dry Bulk Density

Bulk density reflects the size, shape and arrangement of particles and voids (soil structure) and gives a good indication of the suitability for root growth and sediment permeability. Bulk density generally increases with compaction and tends to increase with depth. Sandy substrate is also more prone to high bulk density. Dry bulk density was determined for sediment cores taken at each site using the mass of sediments dried at 60°C for 7 days divided by the volume of the sediment section. Following bulk density measurements, the sample was sub-divided using a sediment splitter to obtain a smaller portion for stable isotope and ^{210}Pb analyses.

Sediment Accumulation and Core Age

Sedimentation rates at the three sites was obtained by analyzing core samples for ^{210}Pb radioisotopes using gamma spectroscopy. Samples were packed in Petri dishes and sealed with electrical tape and paraffin wax 30 days prior to analysis to allow for equilibration between ^{226}Ra and its daughter isotopes (^{214}Pb and ^{214}Bi). Radioisotopic concentrations were determined for all samples along each core using a Canberra GL 2020 low energy germanium detector (Virginia Institute of Marine Science, Gloucester Point, VA). The concentrations of excess ^{210}Pb used to obtain the age models was determined as the difference between total ^{210}Pb and ^{226}Ra (supported ^{210}Pb). The Constant Rate of Supply (CRS) model was used to calculate mean sedimentation rates over the last 100 years at all sites (Appleby and Oldfield, 1978). These rates were calculated using the following formula:

$$A = A(0)e^{-\lambda t}$$

where A is the excess (unsupported) ^{210}Pb inventory below a given core section, A(0) is the excess ^{210}Pb inventory for the entire core profile, and λ is the ^{210}Pb decay constant. The t is the time a now-buried section of core was at the surface.

The formula from Kaste et al. (2011) was used to calculate error for the CRS model:

$$1\sigma = \sqrt{n}/n$$

where n = the number of detected counts.

Carbon, Nitrogen, and Stable Isotope Analyses

Carbon (%C), nitrogen (%N) and stable isotope analyses were performed on plant and sediment samples in a Eurovector CN analyzer. During each sequence run by the mass spectrometer, each sample was flash combusted at 1800°C and the combustion products (CO₂, N₂ and H₂O) were separated chromatographically and introduced into the mass spectrometer, with water removed in a chemical trap. The gases of interest were introduced into the mass spectrometer for isotope analysis and the rest pumped away. The sample isotope ratio was compared to a secondary gas standard, whose isotope ratio has been calibrated to international standards. For ¹³CV-PDB the gas was calibrated against NBS 20 (Solenhofen Limestone), NBS 21 (Spectrographic Graphite), and NBS 22 (Hydrocarbon Oil); for ¹⁵N air the gas was calibrated against atmospheric N₂ and IAEA standards N-1, N-2, and N-3 (all are ammonium sulfate standards). Elemental content of leaf tissue was calculated on a dry weight basis and elemental ratios on a molar basis (QA/QC BU Stable Isotope Lab 2013).

Environmental Conditions

Environmental conditions at each of the eelgrass sampling sites in Madaket Harbor and Nantucket Harbor was also assessed. One Hobo light/temperature sensor (<http://www.onsetcomp.com/sensors>) was deployed at each site for 2-week intervals from mid-May to the beginning of October. One sensor was deployed on land, attached in an unobstructed location to a fence. The sensors recorded temperature and light every 15 minutes. For comparison between sites, a subset of the light data was collected in a 4-hour period around solar noon (11:00 to 15:00) for two weeks each month for analyses.

Statistics

To assess differences among sites in meadow structure, shoot morphology, nutrients, and environmental conditions, one way ANOVAs were performed. To provide a regional context for %N and $\delta^{15}\text{N}$, a one-way ANOVA was performed on samples collected from Madaket to sites located in Nantucket Harbor as well as Tuckernuck and Muskeget Islands. All data was tested for homogeneity of variances using Cochran's test. Tukey's post-hoc tests were used to determine groupings in the analysis of stable isotope data.

Results

Eelgrass morphology

Morphological characteristics of shoots were significantly different among sites in Madaket Harbor in August 2020. Shoots at site M-6 (located in the middle of the harbor) were consistently larger than shoots

located at other sites in Madaket Harbor (Figure 2; one-factor ANOVA: leaves/shoot $F_{4,35} = 9.8106$, $p < 0.0001$; leaf width $F_{4,35} = 15.3067$, $p < 0.0001$; leaf length $F_{4,35} = 41.0478$, $p < 0.0001$; internode length $F_{4,35} = 14.2147$, $p < 0.0001$; total above-below ground weight $F_{4,35} = 37.9421$, $p < 0.0001$; total below ground weight $F_{4,35} = 14.6459$, $p < 0.0001$).

Compared to other eelgrass populations, shoots from Madaket Harbor were morphologically similar to shoots in Nantucket Harbor, but smaller than shoots from Muskeget and Tuckernuck Islands (Figure 3; one-factor ANOVA: leaves/shoot $F_{3,82} = 1.1677$, $p = 0.3272$; leaf width $F_{3,82} = 11.0623$, $p < 0.0001$; leaf length $F_{3,82} = 21.3550$, $p < 0.0001$; internode length $F_{3,82} = 2.7018$, $p < 0.0509$; total above-below ground weight $F_{3,82} = 30.1229$, $p < 0.0001$; total below ground weight $F_{3,82} = 6.8417$, $p < 0.0004$).

Influence of Nitrogen on Leaf Tissue

Analysis of eelgrass leaf N content for samples revealed significant differences in mean leaf %N, C:N, NPI, and $\delta^{15}\text{N}$ among sites. Site M-6 (located in the middle of the harbor) had lower %N, NPI, and a higher C:N ratio (Figure 4; ANOVA: %N $F_{3,34} = 5.1614$, $p = 0.0023$; C:N $F_{4,34} = 4.7147$, $p = 0.0039$; NPI $F_{3,34} = 7.3070$, $p = 0.0002$; $\delta^{15}\text{N}$ $F_{4,34} = 11.8259$, $p < 0.0001$). Leaf N ranged from 1.25 % to 1.6%, C:N ranged from 22 to 29, NPI ranged from 0.24 to 0.41, and $\delta^{15}\text{N}$ values ranged from 3 to 7.

Eelgrass from Madaket Harbor had similar % N values compared to eelgrass from Tuckernuck and Muskeget and the same C:N values as eelgrass from Nantucket Harbor and Tuckernuck. NPI was the same across all sites while $\delta^{15}\text{N}$ values were higher in eelgrass from Madaket compared to Nantucket Harbor and lower than Tuckernuck or Muskeget (Figure 5; ANOVA: %N $F_{3,80} = 3.2936$, $p = 0.0247$; C:N $F_{3,80} = 3.5189$, $p = 0.0188$; NPI $F_{3,80} = 1.9786$, $p = 0.1238$, $\delta^{15}\text{N}$ $F_{3,80} = 48.6287$, $p < 0.0001$). $\delta^{15}\text{N}$ values show a relationship with nutrient source.

Sediment Samples

Bulk Density

The bulk density measurements from Madaket Harbor and Tuckernuck are comparable to other eelgrass meadows in the region (Plaisted, pers. comm.). The density for the two cores taken from Madaket Harbor ranged from 0.9 to 2.4 g/cm³ while the density for the core taken from Tuckernuck ranged from 1.3 to 1.8 g/cm³. The large fluctuation in bulk density values of the Madaket Harbor cores compared to the Tuckernuck core can be attributed to high mobility of substrate (Figure 6).

Sedimentation Rates and Core Age

The three cores that were dated ranged in age from 62 to 83 years. MH3 had a depth integrated sedimentation rate of 3.7 ± 1.2 mm/yr and core age of 62 years in the upper 25 cm. MH5 had a depth integrated sedimentation rate of 6.1 ± 1.5 mm/yr and core age of 77 years in the upper 22 cm. Tukernuck had a depth integrated sedimentation rate of 1.9 ± 0.4 mm/yr and a core age of 83 years in the upper 18 cm (Figure 7). The large variability in sedimentation rates in the upper 5-8 cm of each core can be attributed to high mobility of substrate within the system (e.g., shoaling, turbidity from boats).

Stable isotopes

Sediment core material $\delta^{15}\text{N}$ ranged from 2.0 ‰ to 8.0 ‰ while $\delta^{13}\text{C}$ ranged from -22.6 ‰ to -12.1 ‰ (Figures 8 & 9). Each core showed variability with depth for $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$, with Tukernuck showing the greatest. Cole et al. (2006) showed that water derived from sewage typically has $\delta^{15}\text{N}$ values of +10 to +20 ‰, while water influenced by atmospheric deposition has values of +2 to +8, and water loaded with fertilizer features values between -3 to +3. Phytoplankton and particulate organic matter have $\delta^{13}\text{C}$ ranging from -15 ‰ to -28 ‰ while eelgrass have $\delta^{13}\text{C}$ ranging from -5 ‰ to -10 ‰ (Fry and Wainwright, 1991; Fry, 2006; Novak et al., 2020).

Environmental Conditions

Light

The average daily light available to eelgrass relative to ambient land conditions between May and September ranged from 15.58% measured at the bottom of the canopy located at MH1 up to 49.1% at MH5. Large quantities of algae were consistently found in the eelgrass meadow at all sites (note MH6 was not monitored and no algae was observed at this location). In September, the light sensors at MH2 and MH3 were lost/damaged (Table 1). Note that only light data was collected at MH1 and no morphometric, nutrient or sediment information was collected.

Temperature

The average monthly temperature measured between May and September ranged from $\sim 4.5^\circ\text{C}$ measured at M4 in May and up to $\sim 25^\circ\text{C}$ measured at MH3 in August. During the month of August only MH3 was above 25°C more than 50% of the time and MH3 and MH5 were above 28°C more than 10% of the time (Table 2). Note that only temperature data was collected at MH1 and no morphometric, nutrient or sediment information was collected.

Discussion

Madaket Harbor has experienced a significant loss in aerial coverage of eelgrass in the past few decades (Costello and Kenworthy 2011; Costello 2015). The majority of the losses have been attributed to watershed development and the consequent increase in nutrient loading to the system. In addition to residential septic systems, Madaket Harbor is influenced by groundwater from the nearby landfill, runoff from roads and the application of agricultural and lawn fertilizers, groundwater discharge of runoff from rooftops and natural areas such as grasslands and wetlands. In our study, we assessed the health of eelgrass meadows at five sites in Madaket Harbor by collecting information on various plant and environmental parameters. Our results show that eelgrass meadows located near the shore in Madaket Harbor are exposed to high levels of nutrients, light-limited, and thermally stressed during parts of the peak growing season, suggesting that cultural eutrophication as well as warming waters are contributing to eelgrass losses throughout this system.

Research suggests that eelgrass plants in New England require 58% surface irradiance (SI) and above to grow and expand and are light-limited at 34% SI and below (Ochieng et al. 2010). Kenworthy et al. (2014) further suggested that the threshold for survival is 13.9% based on studies in Nantucket Harbor. In our study, all sites located near the shore in Madaket Harbor (MH1, MH2, MH3, MH4, and MH5) received between 15 and 34% SI from June to August. These results suggest that eelgrass at these sites are receiving enough light to survive, but less light than what is required to maintain a positive carbon balance for growth and expansion. The causes of light-limitation in Madaket Harbor can be attributed to large quantities of drift macro-algae collecting in eelgrass meadows and reducing the light available to eelgrass through shading. Large quantities of algae were especially prevalent at sites MH2, MH3, and MH4 while no algae was observed in the middle of the harbor at site MH6 where it is well flushed. Compared to light data collected from Nantucket Harbor, eelgrass in Madaket Harbor was exposed to slightly higher light levels in 2019 and lower levels in 2020 (Figure 1; Table 1). Eelgrass in Nantucket Harbor is also light limited at many locations.

Temperatures above 25°C have previously been identified as a stress threshold for eelgrass (Greve et al. 2003; Reusch et al. 2005). At 25°C, water temperatures cause rates of respiration to exceed photosynthesis, resulting in a negative carbon balance (Marsh et al. 1986; Moore et al. 1997). At 28°C, large scale declines in eelgrass cover have been observed at the southern range of this species distribution (Shields et al. 2019). During the months of July and August, plants in Madaket Harbor were above 25°C between 13 and 60% of the time period and above 28°C between 0.2% and 13.5%. These temperatures are slightly lower, but similar to what is being experienced in Nantucket Harbor. During the month of July in 2019, all study sites in Nantucket Harbor had an average water temperature above 25°C and were

exposed to temperatures above 28°C for ~13% of the time. Moreover, in August all sites in Nantucket Harbor spent more than 50% of the time above the 25°C and more than 3% of the time above 28 °C (Table 2). Based on the results of this study, it appears as though eelgrass meadows in Madaket Harbor (as well as Nantucket Harbor) are thermally stressed throughout the growing season possibly due to climate change.

C:N, NPI, and % N in leaves have been used as indicators of nutrient enrichment in seagrass meadows. C:N ratios less than 20 in leaves, NPI values greater than 0.3, and/or leaf nitrogen values above 1.6 % have been found in nutrient enriched systems such as Great Bay (NH), Waquoit Bay (MA), and Narragansett Bay (RI; Heminga and Duarte 2000; Lee et al. 2004). In Madaket Harbor, all sites except MH6 (located in the center of the Harbor) had %N and NPI values similar to nutrient enriched systems, confirming that eelgrass is being exposed to high nutrient loads (Figure 4). We also observed similar values in Nantucket Harbor, Tuckernuck and Muskeget with the higher values at Tuckernuck and Muskeget attributed to feces from seal colonies (Figure 5).

Stable isotopes analysis of plant material offers the possibility of detecting the biological role of groundwater flow in the marine environment or the impact of sewage effluent before major ecological changes occur (Mac Clelland et al. 1997; Mac Clelland and Valiela 1998). It is particularly useful in areas where a small nutrient increase could have a significant impact on the ecosystem especially where this nutrient increase is undetectable in the water due to, for example, a low sewage load or rapid dilution in the surrounding environment (Gartner et al. 2002; Yamamuro et al. 2003). As mentioned previously, Cole et al. (2006) showed that water influenced by sewage on Cape Cod typically has ^{15}N values of +10 to +20 ‰, while water influenced by atmospheric deposition has values of +2 to +8, and water loaded with fertilizer features values between -3 to +3. In our study, $\delta^{15}\text{N}$ values ranged from 3.1 to 7.08‰ in Madaket Harbor with sites further in the harbor and near shore (MH2 and MH3) showing lower values, indicating input from fertilizers (Figure 4). Overall, $\delta^{15}\text{N}$ values in eelgrass located in Madaket Harbor eelgrass were higher than Nantucket Harbor and lower than Tuckernuck and Muskeget. The lower values in Nantucket Harbor were expected as the area is more developed and influenced by fertilizer runoff. The exceptionally high $\delta^{15}\text{N}$ values (+12‰) at Tuckernuck and Muskeget, both relatively preserved sites, are believed to be due to seal effluent and the occurrence of denitrification processes. Denitrification can result in the ^{15}N enrichment of the remaining inorganic N pool and, consequently, a ^{15}N enrichment of plants which incorporate inorganic N from the water column (Fourqurean 1997).

Recommendations

Our study provides baseline information on eelgrass health for Madaket Harbor and identifies mechanisms for reported declines. It is apparent that eelgrass in Madaket Harbor is exposed to high nutrient loading from fertilizers and sediments, as well as water temperatures that can inhibit growth and/or survival. As the climate continues to warm, eelgrass in Madaket Harbor will continue to be exposed to increased water temperatures and periods of thermal stress. However, eelgrass can survive if other environmental parameters that promote growth and expansion are optimal. Below are some recommendations for future work, as well as management actions that will improve eelgrass health and facilitate recovery in the harbor.

First and foremost, water quality within the harbor needs to be improved by reducing land-based pollution and decreasing nutrient and sediment run-off, reducing or eliminating the use of fertilizers and persistent pesticides and increasing filtration of effluent. The reduction in nutrients within the system will lead to a reduction in nuisance algae which limit the amount of light available to eelgrass for growth. Moreover, if plants are no longer light-stressed they will be able to tolerate longer periods of thermal stress caused by climate change. To achieve this objective, we recommend implementing/continuing public education programs that identify actions that individuals can take to improve water quality and reduce stresses on eelgrass in this system as well as Nantucket Harbor. For example, individuals can help reduce threats to water quality by preventing pollutants (e.g. fertilizers, paint, gasoline, solvents and garden chemicals) from entering storm-water drains. To reduce sediment and nutrient run-off into waterways, individuals can maintain vegetation on creek banks and shorelines adjacent to the harbor, create retention ponds or ditches to reduce high-discharge flows or plant a buffer strip of plants in these areas. In addition, homeowners could upgrade septic systems by retrofitting septic tanks with advanced pre-treatment, recirculating aerobic treatment units, or replacing traditional septic tanks with upgraded nutrient-reducing technology.

In addition to improving water quality in Madaket Harbor, we also recommend monitoring existing eelgrass meadows in the harbor using a hierarchical framework to detect and predict changes so that appropriate management strategies can be developed. The monitoring approach would include three tiers that are integrated across spatial scales and sampling intensities (see Neckles et al. 2012). Tier 1 monitoring would involve mapping eelgrass in Madaket Harbor every three-five years to provide large-scale information on seagrass distribution and meadow size. Costello (2015) has already developed an appropriate mapping process for this system that involves the acquisition of high-resolution digital imagery captured within strict environmental conditions. Tier 2 monitoring would involve bay-wide, quadrat-based assessments of eelgrass percent cover and canopy height at permanent sampling stations

following a spatially distributed random design. The National Park Service on Cape Cod has a design that is used to monitor Pleasant Bay that could be adapted to this system. Tier 3 monitoring would involve high-resolution measurements of seagrass condition (percent cover, canopy height, total and reproductive shoot density, biomass, and seagrass depth limit) at a representative index site in the system. SeagrassNet is an example of a program that collects more detailed Tier 3 data and could be easily implemented in the harbor (<http://www.seagrassnet.org/>). If a hierarchical approach to monitoring is not feasible for Madaket Harbor at this time, light and temperature data, as well as percent cover of algae and eelgrass should be monitored at multiple sites within the system.

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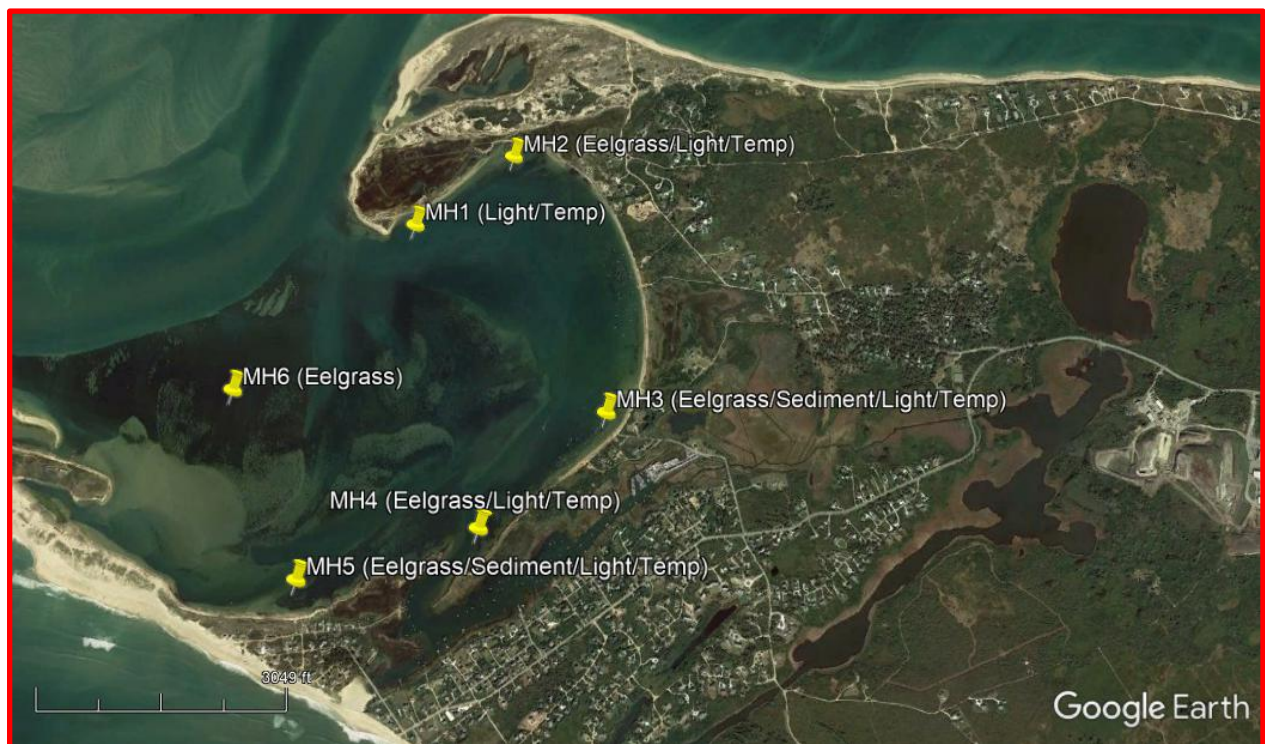
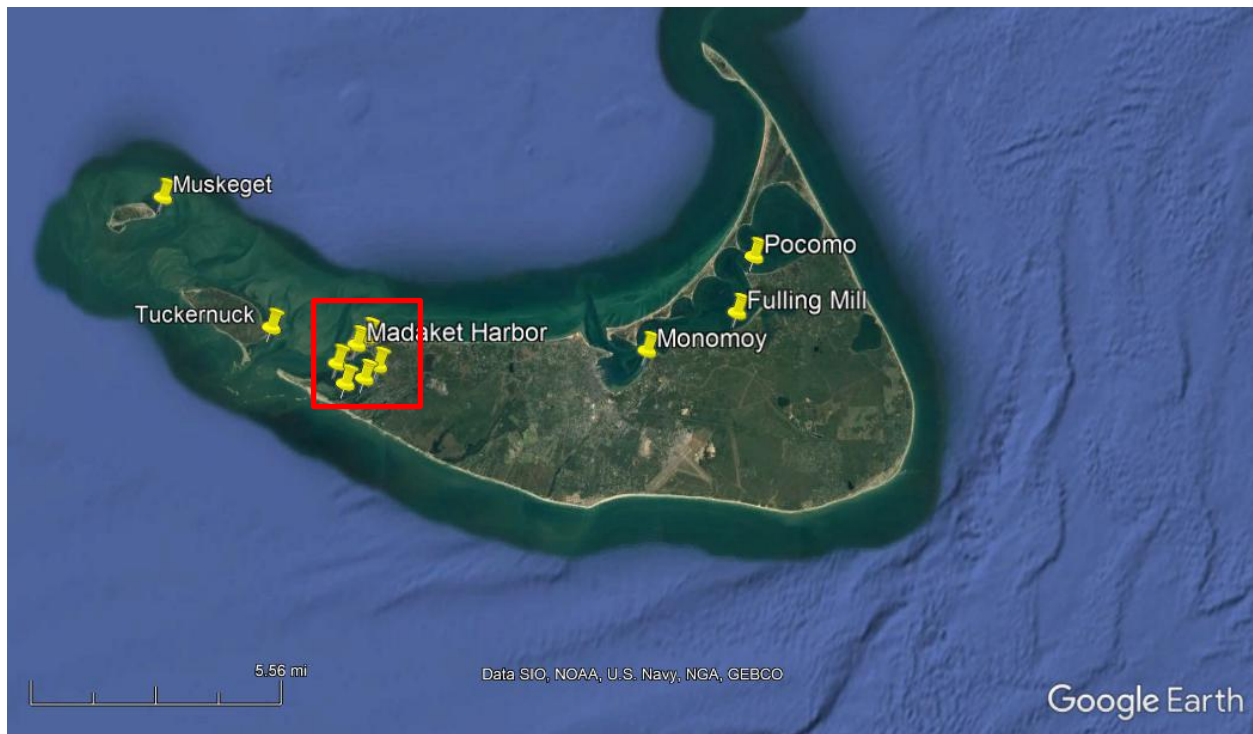


Figure 1. Maps showing eelgrass, nutrient, sediment, and light/temperature sampling sites.

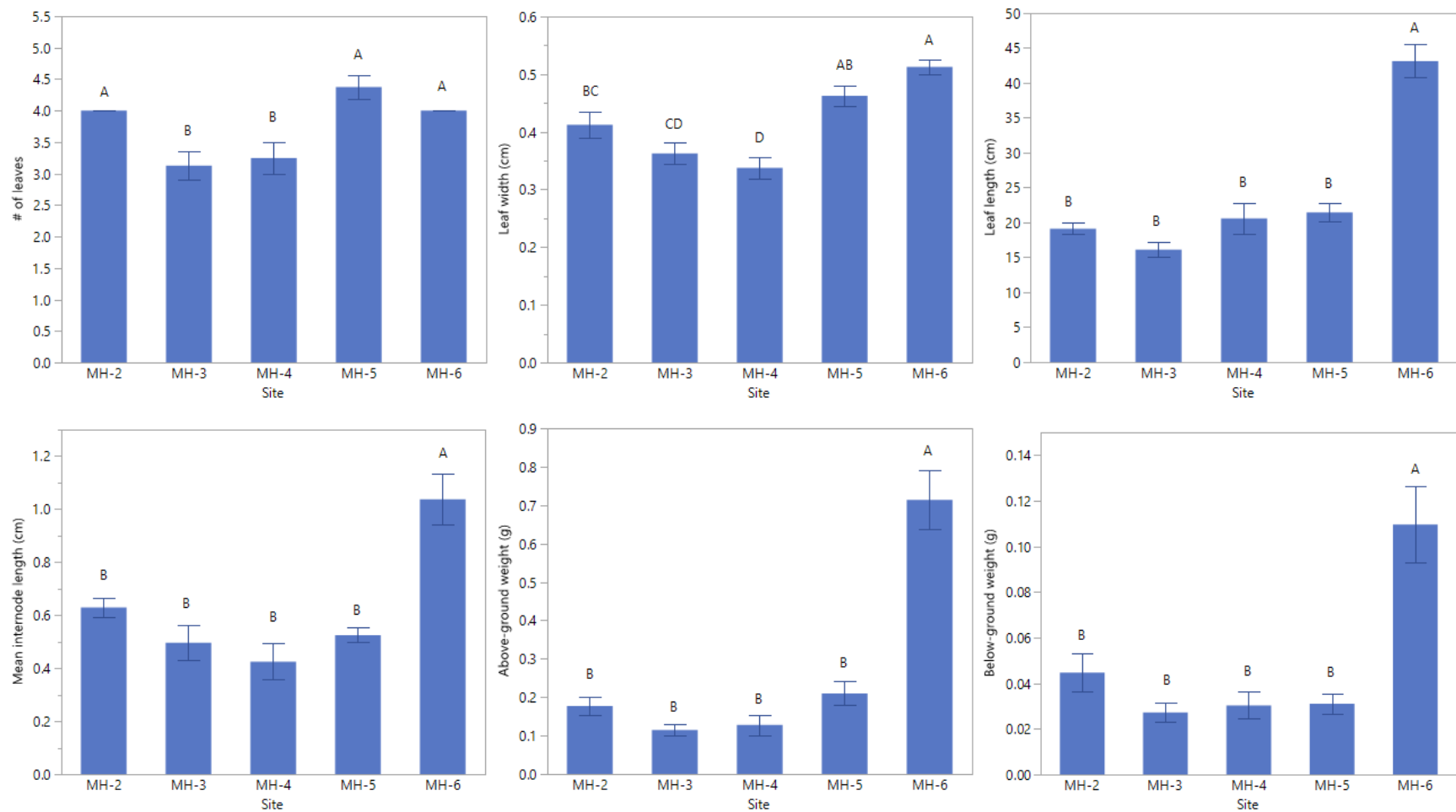


Figure 2. Morphological characteristics of shoots collected from five sites in Madaket Harbor.

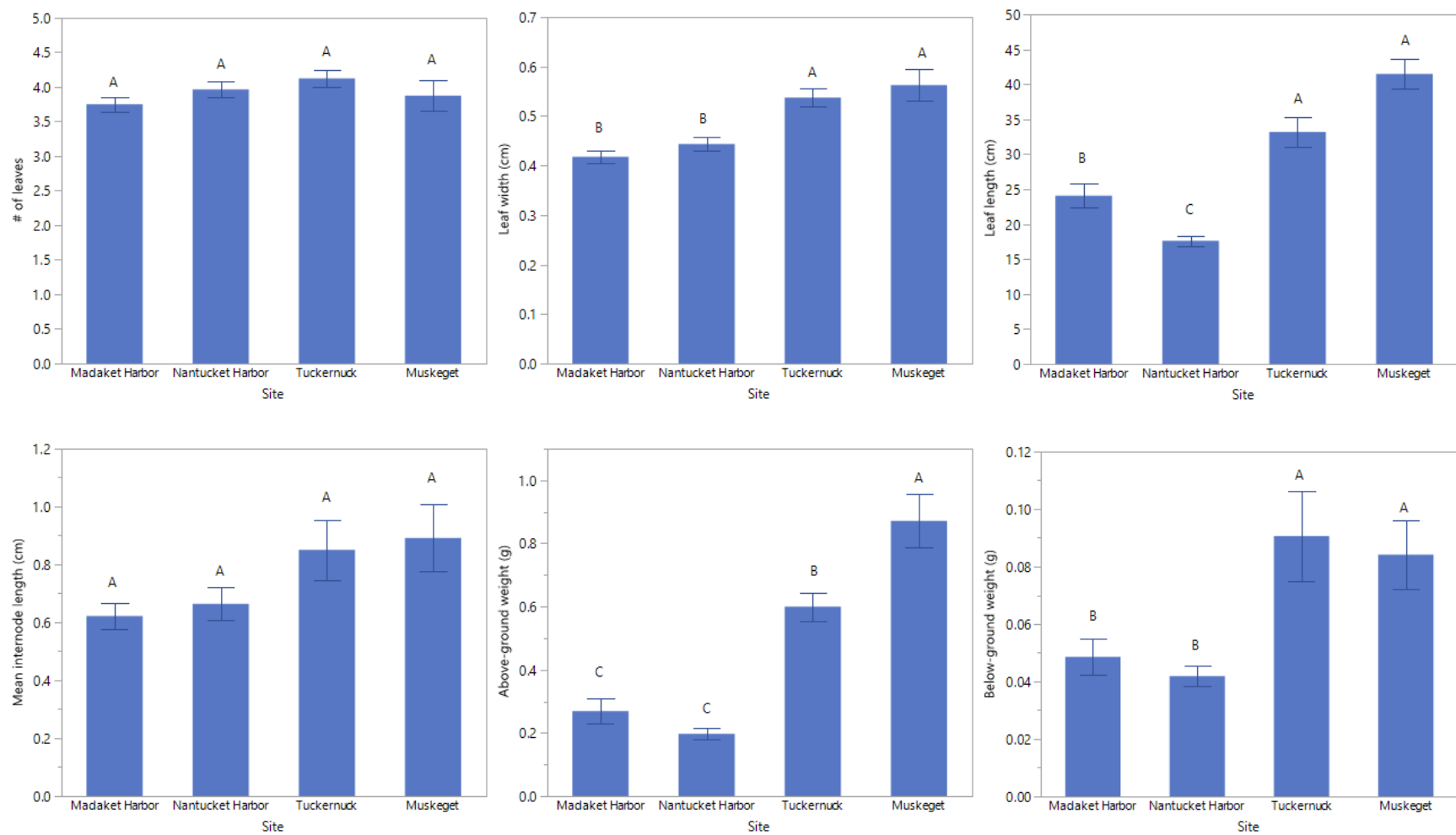


Figure 3. A comparison of morphological characteristics of shoots collected from Madaket Harbor, Nantucket Harbor, Tuckernuck, and Muskeget.

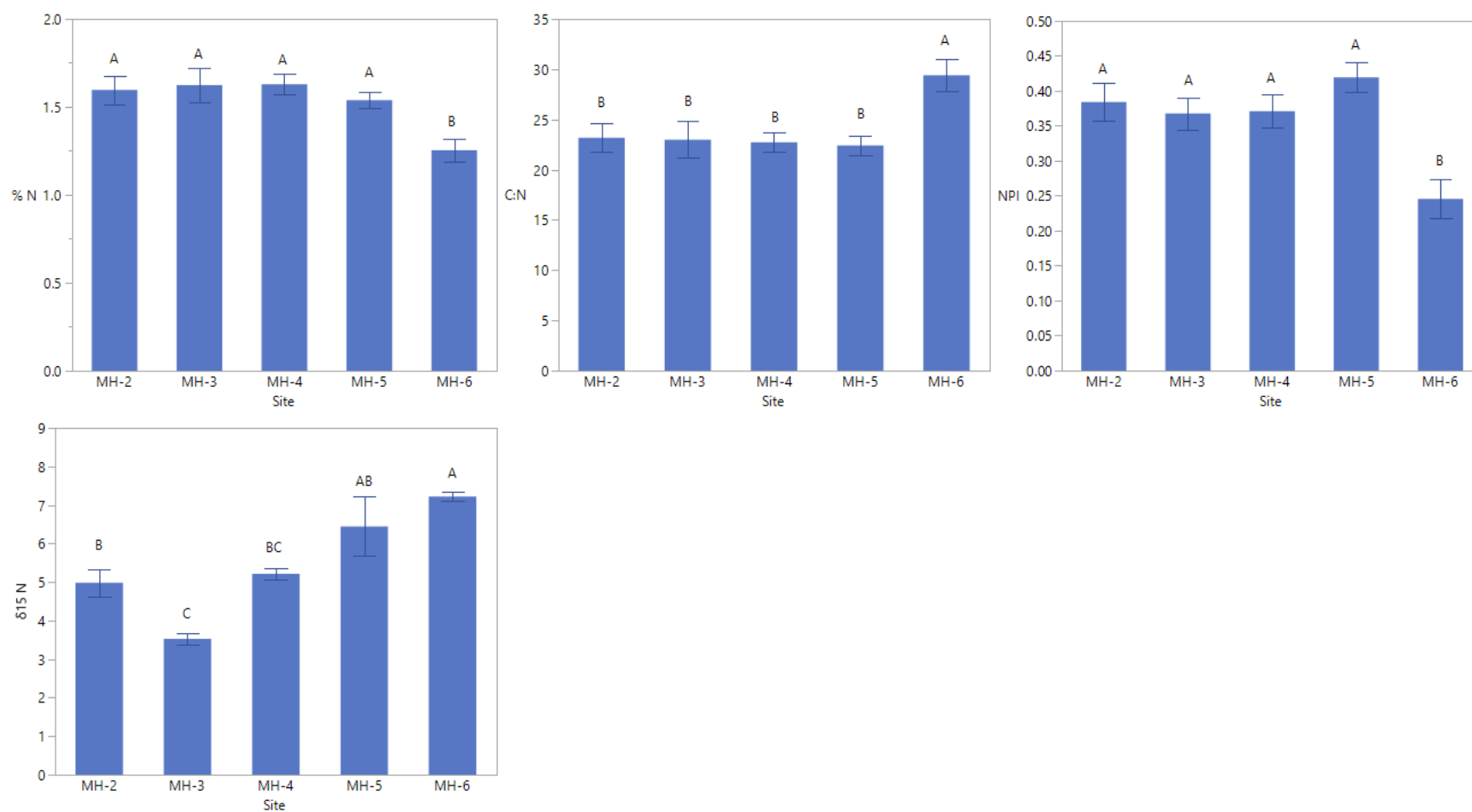


Figure 4. Nutrient content of eelgrass leaf tissue collected from five sites in Madaket Harbor.

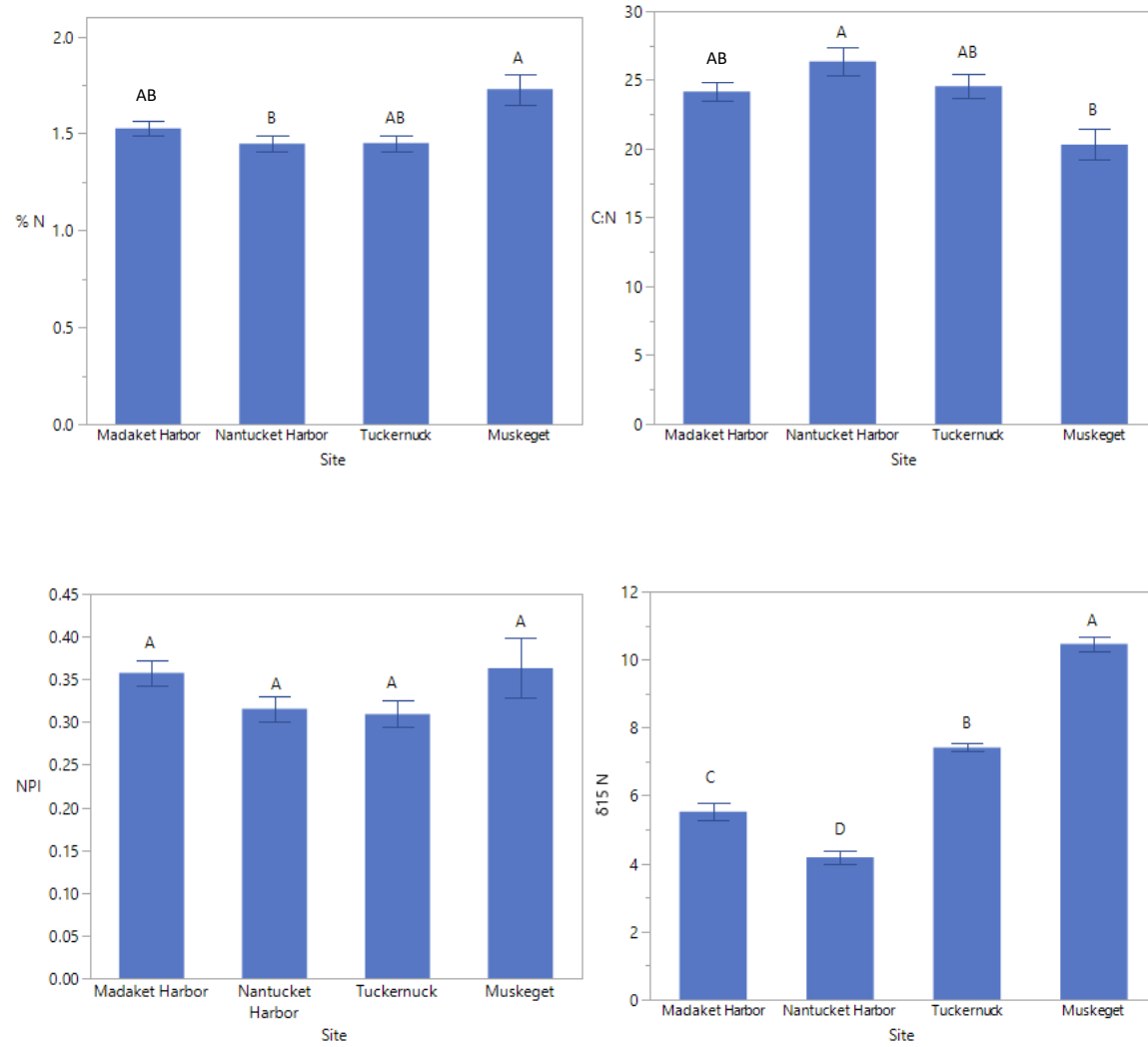


Figure 5. A comparison of nutrient content in leaf tissue from Madaket Harbor, Nantucket Harbor, Tuckernuck, and Muskeget.

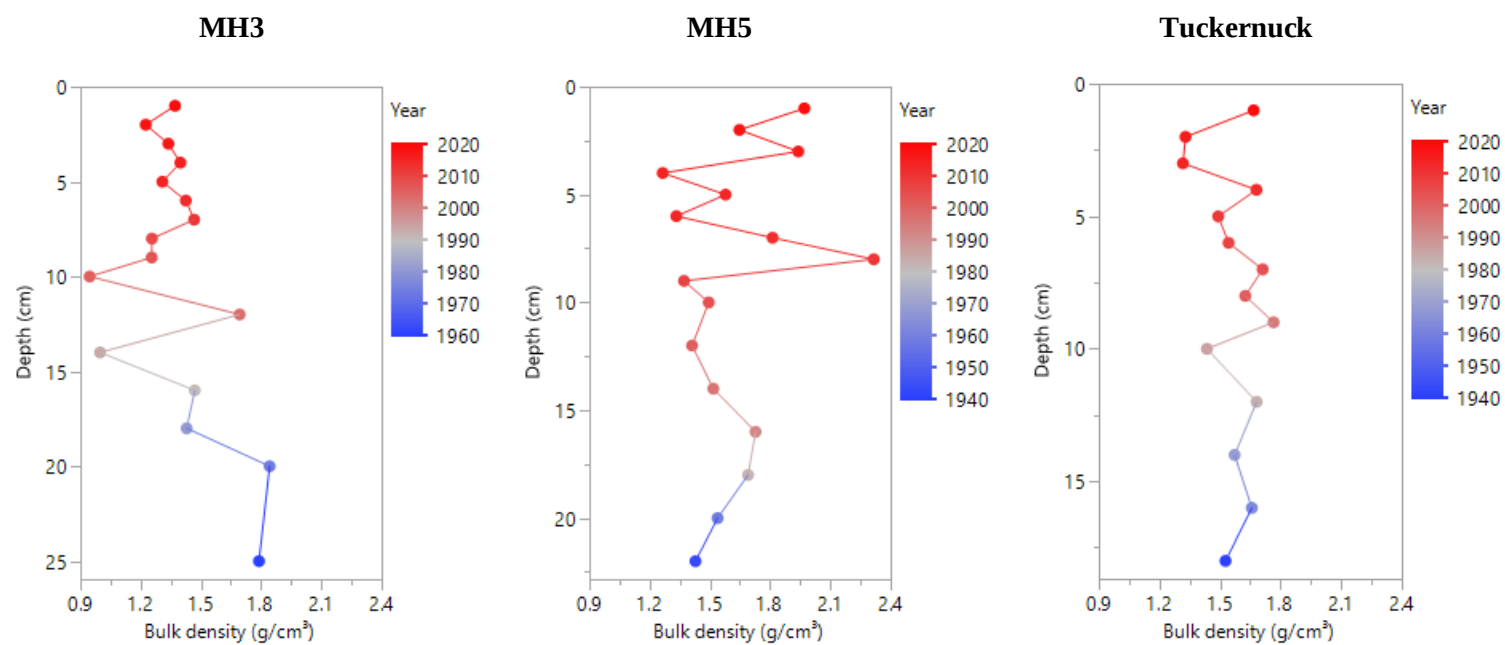


Figure 6. Bulk density (g/cm³) of sediment cores collected from MH3, MH5 and Tuckernuck.

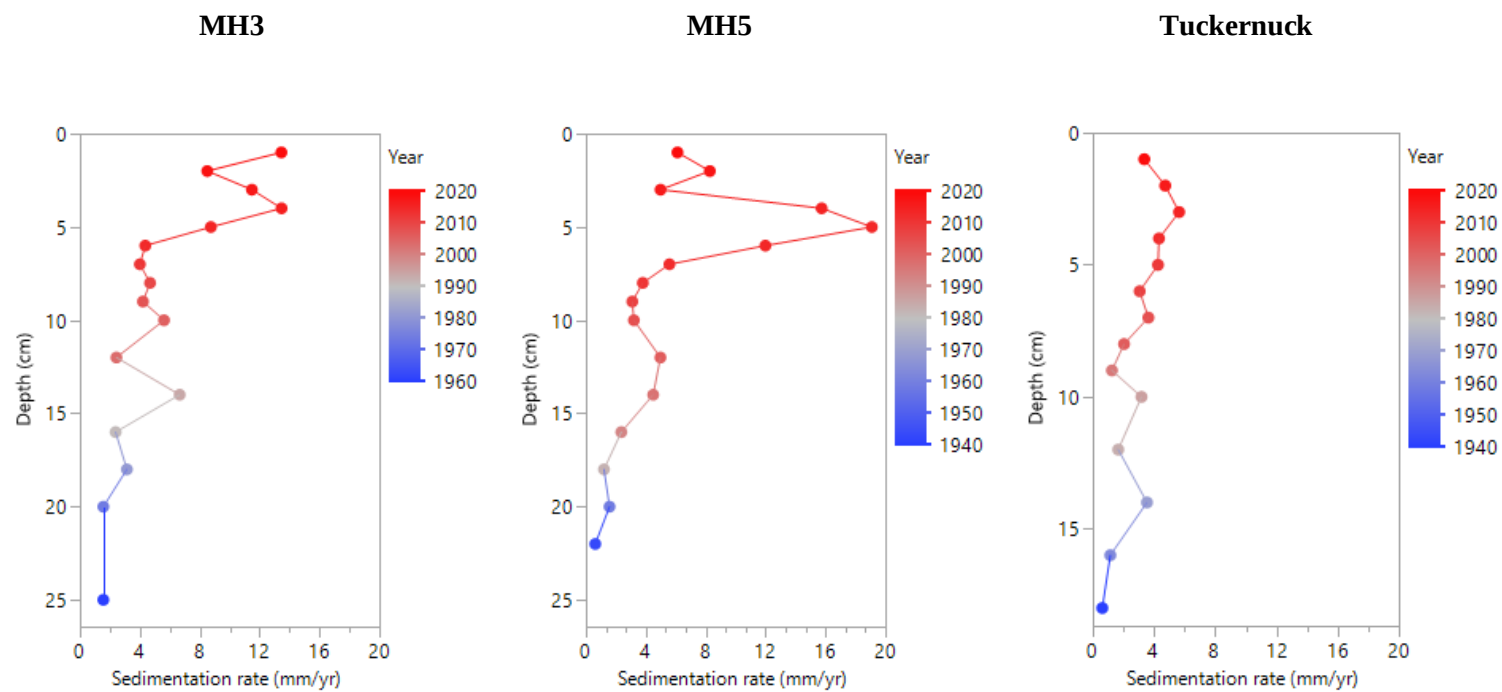


Figure 7. Sedimentation rate (mm/yr) and age of sediment cores collected from MH3, MH5 and Tuckernuck.

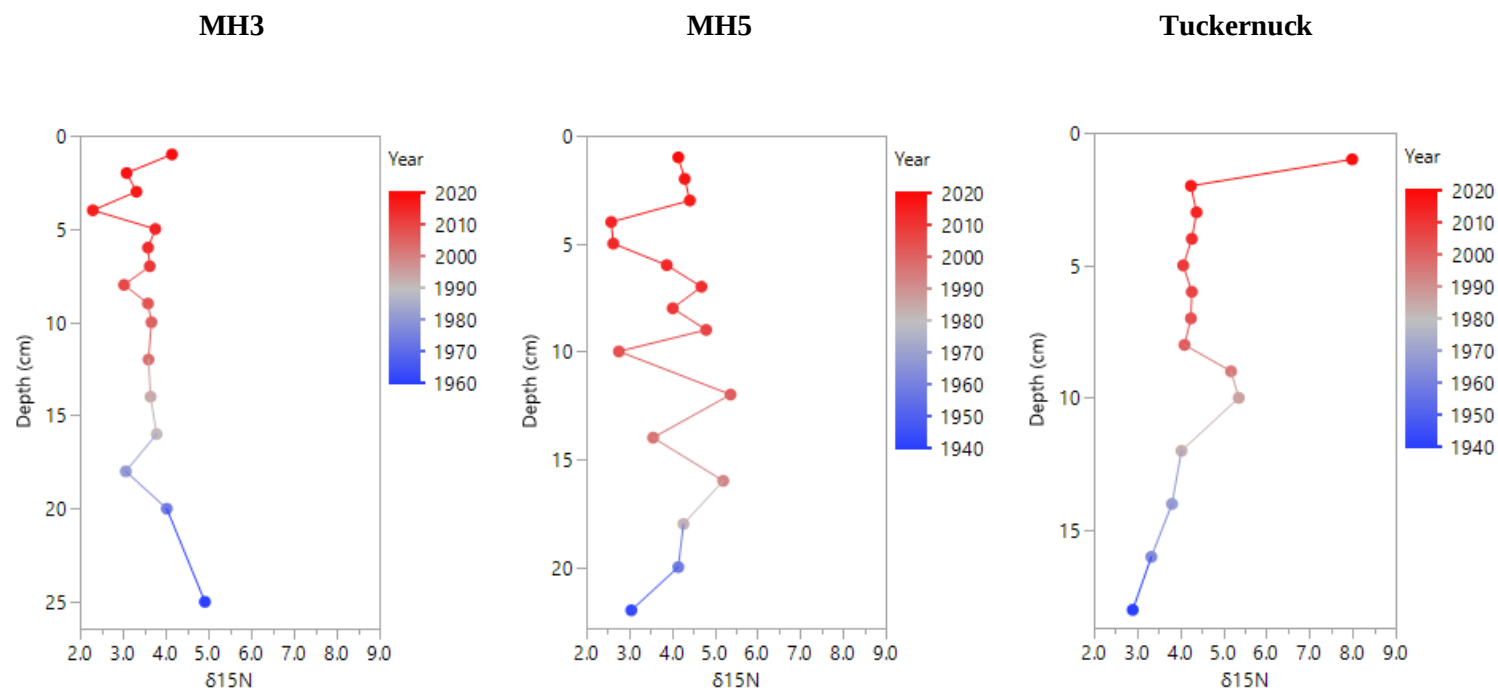


Figure 8. $\delta^{15}\text{N}$ values values at MH3, MH5, and Tuckernuck. $\delta^{15}\text{N}$ can be used to identify nutrient pollution sources.

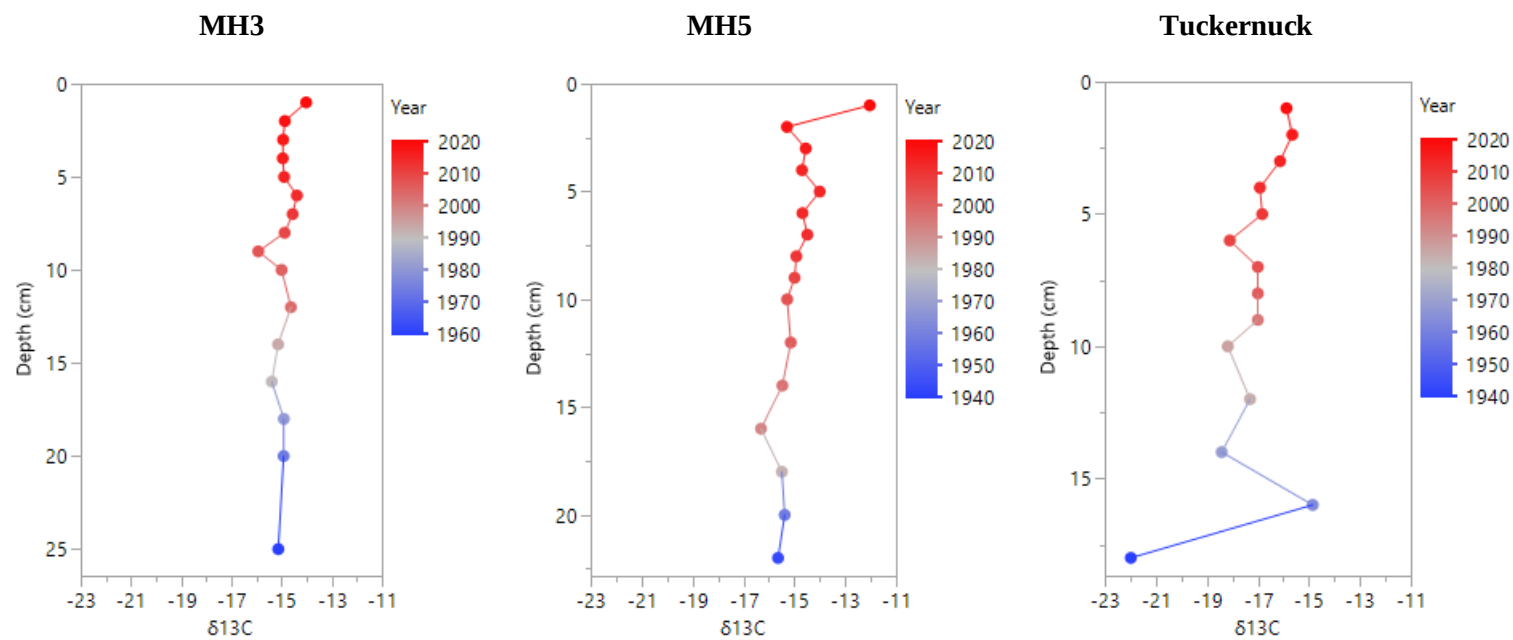


Figure 9. $\delta^{13}\text{C}$ values values at MH3, MH5, and Tuckernuck. $\delta^{13}\text{C}$ can be used to identify sources of carbon.

Table 1. Average light intensity and percent bottom irradiance at multiple sites in Madaket and Nantucket Harbors from May to September.

MAY

Site	2020 Average Intensity (lum/ft ²)	2019 Average Intensity (lum/ft ²)	2020 Avg. % Bottom Irradiance	2019 Avg. % Bottom Irradiance
Nantucket Harbor				
Pocomo		1836		12.93%
Fulling Mill		2115		14.90%
Monomoy		2409		16.97%
Madaket Harbor				
MH1	4721		37.97%	
MH2	4216		31.28%	
MH3	5490		39.87%	
MH4	5942		45.36%	
MH5	6551		49.10%	

JUNE

Site	2020 Average Intensity (lum/ft ²)	2019 Average Intensity (lum/ft ²)	2020 Avg. % Bottom Irradiance	2019 Avg. % Bottom Irradiance
Nantucket Harbor				
Pocomo				
Fulling Mill	5142		45.36%	
Monomoy	4328	1632	40.28%	14.88%
Madaket Harbor				
MH1	4030		32.28%	
MH2	4280		33.11%	
MH3	3834		29.74%	
MH4	4161		32.13%	
MH5	4144		33.22%	

JULY

Site	2020 Average Intensity (lum/ft ²)	2019 Average Intensity (lum/ft ²)	2020 Avg. % Bottom Irradiance	2019 Avg. % Bottom Irradiance
Nantucket Harbor				
Pocomo		1288		8.62%
Fulling Mill	3773	2413	35.83%	16.15%
Monomoy	3512	2498	32.96%	16.72%
Madaket Harbor				
MH1	3164		27.04%	
MH2	3373		28.30%	
MH3	2654		22.89%	
MH4	3436		28.60%	
MH5	3676		29.17%	

AUGUST

Site	2020 Average Intensity (lum/ft ²)	2019 Average Intensity (lum/ft ²)	2020 Avg. % Bottom Irradiance	2019 Avg. % Bottom Irradiance
Nantucket Harbor				
Pocomo	2721	1811	36.82%	16.79%
Fulling Mill	2673	2514	28.74%	23.30%
Monomoy	4088	1262	35.50%	11.70%
Madaket Harbor				
MH1	1849		15.58%	
MH2	3271		28.60%	
MH3	3218		27.27%	
MH4	3262		29.81%	
MH5	3575		28.63%	

SEPTEMBER

Site	2020 Average Intensity (lum/ft ²)	2019 Average Intensity (lum/ft ²)	2020 Avg. % Bottom Irradiance	2019 Avg. % Bottom Irradiance
Nantucket Harbor				
Pocomo				
Fulling Mill				
Monomoy				
Madaket Harbor				
MH1	2545		25.95%	
MH2				
MH3				
MH4	3110		31.36%	
MH5	2638		29.27%	

Table 2. Temperature information collected from Madaket and Nantucket Harbors from May to September.

MAY

Site	2020 % time > 25°C	2019 % time > 25°C	2020 % time > 28°C	2019 % time > 28°C	2020 Min. (°C)	2019 Min. (°C)	2020 Max. (°C)	2019 Max. (°C)	2020 Avg. (°C)	2019 Avg. (°C)
Nantucket Harbor										
Pocomo		1.1%		0.3%		14.13		28.56		18.78
Fulling Mill		1.1%		0.3%		13.75		28.35		18.66
Monomoy		1.3%		0.2%		13.94		28.66		17.72
Madaket Harbor										
MH1	0.0%		0.0%		10.26		23.10		13.97	
MH2	0.0%		0.0%		11.04		23.20		14.93	
MH3	0.0%		0.0%		11.92		23.77		15.52	
MH4	0.1%		0.0%		4.83		25.03		16.18	
MH5	0.2%		0.0%		6.17		27.57		15.70	

JUNE

Site	2020 % time > 25°C	2019 % time > 25°C	2020 % time > 28°C	2019 % time > 28°C	2020 Min. (°C)	2019 Min. (°C)	2020 Max. (°C)	2019 Max. (°C)	2020 Avg. (°C)	2019 Avg. (°C)
Nantucket Harbor										
Pocomo										
Fulling Mill	15.9%		0.4%		20.62		28.66		23.51	
Monomoy	11.1%	9.3%	0.0%	0.0%	19.95	18.24	27.96	27.86	22.82	22.02
Madaket Harbor										
MH1	0.1%		0.0%		12.50		26.49		18.64	
MH2	2.0%		0.0%		12.59		28.36		20.07	
MH3	3.1%		0.0%		13.56		31.37		20.41	
MH4	5.7%		0.1%		13.56		31.27		20.83	
MH5	2.9%		0.0%		12.98		29.05		20.30	

JULY

Site	2020 % time > 25°C	2019 % time > 25°C	2020 % time > 28°C	2019 % time > 28°C	2020 Min. (°C)	2019 Min. (°C)	2020 Max. (°C)	2019 Max. (°C)	2020 Avg. (°C)	2019 Avg. (°C)
Nantucket Harbor										
Pocomo		73.3%		9.3%		19.95		30.44		25.90
Fulling Mill	55.1%	65.8%	7.4%	8.2%	20.52	21.95	33.01	30.36	25.23	25.74
Monomoy	40.7%	49.2%	5.3%	4.5%	20.14	21.76	31.06	29.65	24.64	24.90
Madaket Harbor										
MH1	13.4%		0.2%		19.19		29.15		22.93	
MH2	39.8%		2.4%		19.19		29.15		24.16	
MH3	44.1%		4.2%		20.90		30.66		24.63	
MH4	49.9%		5.8%		20.23		32.39		24.99	
MH5	22.1%		0.1%		19.00		28.56		23.66	

AUGUST

Site	2020 % time > 25°C	2019 % time > 25°C	2020 % time > 28°C	2019 % time > 28°C	2020 Min. (°C)	2019 Min. (°C)	2020 Max. (°C)	2019 Max. (°C)	2020 Avg. (°C)	2019 Avg. (°C)
Nantucket Harbor										
Pocomo	27.2%	53.0%	4.1%	3.4%	19.57	21.86	30.86	29.25	24.15	25.26
Fulling Mill	51.6%	44.0%	8.1%	2.2%	20.33	21.66	30.66	29.75	25.08	24.87
Monomoy	86.8%	35.2%	14.9%	0.7%	20.23	22.05	30.26	29.05	26.42	24.61
Madaket Harbor										
MH1	20.8%		0.2%		20.14		31.97		23.50	
MH2	50.4%		7.4%		19.95		29.85		24.87	
MH3	63.5%		11.2%		20.33		31.57		25.40	
MH4	50.2%		7.6%		19.76		30.66		24.89	
MH5	44.9%		13.5%		17.00		31.34		24.78	

SEPTEMBER

Site	2020 % time > 25°C	2019 % time > 25°C	2020 % time > 28°C	2019 % time > 28°C	2020 Min. (°C)	2019 Min. (°C)	2020 Max. (°C)	2019 Max. (°C)	2020 Avg. (°C)	2019 Avg. (°C)
Nantucket Harbor										
Pocomo	0.7%		0.0%		11.63		25.61		20.52	
Fulling Mill										
Monomoy										
Madaket Harbor										
MH1	0.0%		0.0%		13.27		24.55		20.13	
MH2										
MH3										
MH4	1.7%		0.0%		12.01		25.90		20.17	
MH5	13.3%		7.1%		11.24		35.76		21.45	

OCTOBER

Site	2020 % time > 25°C	2019 % time > 25°C	2020 % time > 28°C	2019 % time > 28°C	2020 Min. (°C)	2019 Min. (°C)	2020 Max. (°C)	2019 Max. (°C)	2020 Avg. (°C)	2019 Avg. (°C)
Nantucket Harbor										
Pocomo	0.0%		0.0%		11.14		21.95		16.16	
Fulling Mill										
Monomoy										
Madaket Harbor										
MH1	0.0%		0.0%		11.53		21.09		15.75	
MH2										
MH3										
MH4	0.0%		0.0%		10.65		21.86		15.77	
MH5	0.0%		0.0%		16.14		23.00		19.54	

Marianne Stanton, Editor
The Inquirer and Mirror
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Dear Editor Stanton:

I am writing about the well-intentioned but incomplete article on fertilizer regulations in the January 27th edition of the I&M. I was secretary to the Article 68 Work Group that developed a “Best Management Practices, BMP,” for fertilizer application on Nantucket and, as well, assisted in the development of Department of Health Regulations, Local Regulation 75, to control such applications. The Work Group had a well-balanced membership of landscapers, shell fishers, water-quality experts, interested citizens, and was led well by Peter Boyce and Lucinda Young. It received substantial input from experts from the University of Massachusetts Extension Service, turf specialists from the University of Connecticut, and our own Harbor and Shellfish Advisory Board. The BMP can be found under “Water Quality” on the web page for the Department of Natural Resources, <https://nantucket-ma.gov/130/Natural-Resources>, and the regulations are on the web page for the Department of Health, <https://nantucket-ma.gov/229/Regulations>. Licensing of commercial applicators and enforcement of the regulations have continued apace since the regulations were promulgated.

In a nutshell, the rules are simple: feed the plants what they need but no more and do not feed when the plants cannot absorb the nutrients. The application regulations are designed to keep the nutrients available to the plants: lawn, vegetables, and plantings, but not in such excess that they would be carried to the groundwater.

The Fertilizer Work Group continues to advise the Health Department. What, in my opinion, should happen next? Explore the conversion of Health Department Regulations into a Town Bylaw; enhance the Health Department’s efforts to enforce existing regulations; expand fertilizer educational efforts; and renew the ten-year-old BMP.

Yours sincerely, Lee W. Saperstein, D.Phil, P.E.