



September 26, 2023

Members of the Falmouth Water Quality
Management Committee
59 Town Hall Square
Falmouth, MA 02540

Re: Request for Committee's Support of Article 6 Amendment

Dear Members of the Falmouth Water Quality Management Committee:

Over the past two weeks, the Coalition made three separate requests to be placed on the Water Quality Management Committee's agenda for September 27 to discuss Article 6 on the upcoming Fall Town Meeting Warrant. We are sorry that those requests were not granted. This letter and attachments are provided to summarize what we had hoped to discuss with the Committee.

The Town does not need to expand discharge to sites 14 and 15

There is a way forward at this upcoming Town Meeting that does not slow down town progress towards sewerage Maravista/Teaticket and avoids adding new loads of nitrogen and phosphorus to Crocker Pond and Herring Brook. **The reality is that the timeline for permitting and construction of an ocean outfall is nearly the same as the permitting, construction and discharge to beds 14 and 15.**

Attached to this letter is a timeline (derived from the Town's Comprehensive Wastewater Management Plan and our knowledge of the state discharge permitting process) which illustrates the time it will take to permit an expanded groundwater discharge at sites 14 and 15 that will add pollution to Crocker Pond and Herring Brook, and compares that to the permitting and construction of an ocean outfall that solves the pollution problem town-wide. This timeline suggests that an **ocean outfall is possible within the same time, or even shorter, time period as an expanded groundwater discharge**. It makes no sense to pursue a groundwater discharge that will harm coastal resources when the outfall is a timely and comprehensive alternative.

The Coalition urges you to support a change in the Article 6 language, as shown below, which would allow the town to move forward with sewer design in Maravista and Teaticket without spending limited resources on unnecessarily permitting a discharge to sites 14 and 15.

Proposed Amendment to Article 6:

"To see if the Town will vote to appropriate a sum of money to fund the engineering **and** design **and** ~~permitting~~ of the wastewater collection system for the northeastern part of the Maravista peninsula and the Teaticket Path peninsula, the booster pump station and force main to convey the wastewater to the

Town's Main Wastewater Treatment Facility, and ~~the expansion of the Town's existing northernmost open sand beds for discharge of treated wastewater, and~~, to the extent any funds remain unexpended for such projects, such unexpended funds may be applied to the payment of a portion of the costs of construction of the designed projects, including without limitation, all costs incidental or related thereto, and to determine how the same shall be raised and by whom expended. Or do or take any other action on the matter."

By eliminating the phrases, "the expansion of the Town's existing northernmost open sand beds for discharge of treated wastewater", Falmouth can move forward with engineering for the expanded collection system in Maravista and Teaticket neighborhoods and avoid degrading Herring Brook, Crocker Pond, and Buzzards Bay.

Herring Brook Saltmarsh

This amendment is needed to protect one of the town's most precious, and already endangered, salt marshes at Herring Brook.

- In 2023, a Buzzards Bay-wide assessment of 12 salt marshes performed by researchers including the US Geological Survey, Woodwell Climate Research Center, and the Buzzards Bay National Estuary Program, found that the **Herring Brook saltmarsh lost 18% of the marsh between 2009 and 2019** and is one of the most rapidly degrading salt marshes on all of Buzzards Bay.¹ (attached)
- Most recently, Dr. Craig Tobias at the University of Connecticut Avery Point found that the Herring Brook saltmarsh is not healthy and concluded that **additional nitrogen discharge will likely exacerbate further degradation of the marsh**. Adding nitrogen to this already impaired marsh makes no sense and does not need to happen. (attached)

We urge the Town to Move Forward with the Outfall and the Design and Construction of the TASA Sewer Project.

The town MUST move forward with the permitting and construction of the outfall at the same time as it is designing and constructing the TASA project. The town of Falmouth has the capacity to pursue the permitting and construction of an ocean outfall at the same time as it is designing a sewer collection system. If the town moves in parallel, the town achieves the long term discharge needed at the same time expanding sewers and protecting sensitive coastal resources.

Conclusion

The Coalition requests that the Water Quality Management Committee support an amendment to Article 6 and pursue the design of the sewer collection system without the discharge to sites 14 and 15.

¹ Jakuba, R.W., Besterman, A., Hoffart, L., Costa, J.E., Ganju, N., Deegan, L.(2023) Buzzards Bay Salt Marshes: Vulnerability and Adaptation Potential.

The Coalition is a membership-supported nonprofit organization dedicated to the restoration, protection, and sustainable use and enjoyment of our irreplaceable Bay and its watershed. We are supported by approximately 1,000 members in Falmouth.

Sincerely,

A handwritten signature in blue ink, appearing to read "Korrin N. Petersen".

Korrin N. Petersen, Esq.
Vice President Clean Water Advocacy
petersen@savebuzzardsbay.org

Cc: Senator Susan Moran
Falmouth Select Board
Falmouth Department of Public Works

Attached:
Timeline
Buzzards Bay Salt Marshes: Vulnerability and Adaptation Potential
Dr. Craig Tobias Review

Timeline Comparison: Discharge TASA to Herring Brook v. Discharge all to Ocean Outfall

Discharge Teaticket (TASA) to Herring Brook

2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Town Meeting authorizes \$4.5M for design and permitting for TASA Phase 1	<ul style="list-style-type: none"> Town Applies to amend Groundwater Discharge Permit to discharge to Herring Brook beds 14 & 15. GWDP appeal process begins Town Meeting asked to vote \$50M for construction costs. 	<ul style="list-style-type: none"> Planned TASA Phase I construction start delayed due to DEP Adjudicatory process on GWDP appeal. Town Meeting asked to vote \$4M for TASA Phase II Design and permitting 	<ul style="list-style-type: none"> Planned TASA Phase I construction delay continues due to GWDP appeal. GWDP appeal decision by DEP. If approved, decision may be appealed to Superior Court. Town meeting to vote construction of TASA Phase II 	Planned TASA Phase I & II construction start delay continues due to GWDP appeal.	Planned TASA Phase I & II construction start delay continues due to GWDP appeal.	<ul style="list-style-type: none"> If GWDP appeal is rejected, TASA Phase I & II may proceed. Costs increased due to delay. Bidding and contractor selection 	TASA Phase I & II construction is underway. Planned TASA Phase I & II construction start delay continues to due to GWDP appeal.	TASA Phase I & II construction is underway.	TASA Phase I & II construction is complete. Discharge to WWTP commences.

*See Towns initial TASA timeline from Comprehensive Wastewater Management Plan below

Discharge Everything to Ocean Outfall

2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
<ul style="list-style-type: none"> WQMC unanimously endorses Outfall. Fall Town Meeting votes \$1.4M to complete the science. 	Town Meeting to vote \$6M for Design & Permitting	Design and Permitting underway	Design and Permitting underway	Town Meeting to vote construction costs for outfall	Outfall receives permit approvals (After 5 year process)	Outfall drilling and construction	Outfall is operational. All discharges to WWTP groundwater beds to WF Harbor and Herring Brook cease.	Even if the outfall takes 2 yrs longer than expected, it is still no slower than TASA.	

Table 5.7. Great Pond TWMP Implementation Schedule

Activity	2022	2023	2024	2025	2026	2027	2028
Falmouth WWTF TASA Improvements Project Construction							
Town Meeting – Vote to Establish TASA Betterment Percentage							
TASA Collection System (Phases 1 & 2) and Recharge Facilities Design Appropriation and Ballot Vote							
TASA Collection System and Recharge Facilities Construction Appropriation and Ballot Vote							
TASA Collection System and Recharge Facilities Construction							

Falmouth Comprehensive Wastewater Management Plan predicted 7 year timeline to complete TASA project, with no allowance for GWD permit appeals.

BUZZARDS BAY
SALT MARSHES:

Vulnerability and Adaptation Potential

FEBRUARY 2023

PROJECT PARTNERS



Buzzards Bay Coalition



Buzzards Bay National
Estuary Program



Woodwell Climate
Research Center



U.S. Geological Survey

SUMMARY CONCLUSIONS

- **Current conditions** – Marsh area at all our study sites was lost between 2001 and 2019, indicating that the stressors are overwhelming the marsh's natural resilience. The total loss varied, ranging from about 1% to around 20% depending on the site.
- **Marsh stressors** – Two of the most important stressors that are impacting Buzzards Bay salt marshes are low marsh surface elevations that make them susceptible to drowning with sea level rise and structures that obstruct natural tidal flow to the marshes.
- **Potential to adapt** – To adapt to sea level rise, marshes will need to migrate landward. Eight of our 12 marsh sites are free from hardened barriers that would prevent the marsh migrating landward. At nine of the 12 sites, over 50% of the marsh area is located at an elevation that is expected to remain marsh until at least 2100.



Photo credit for all photographs: Buzzards Bay Coalition

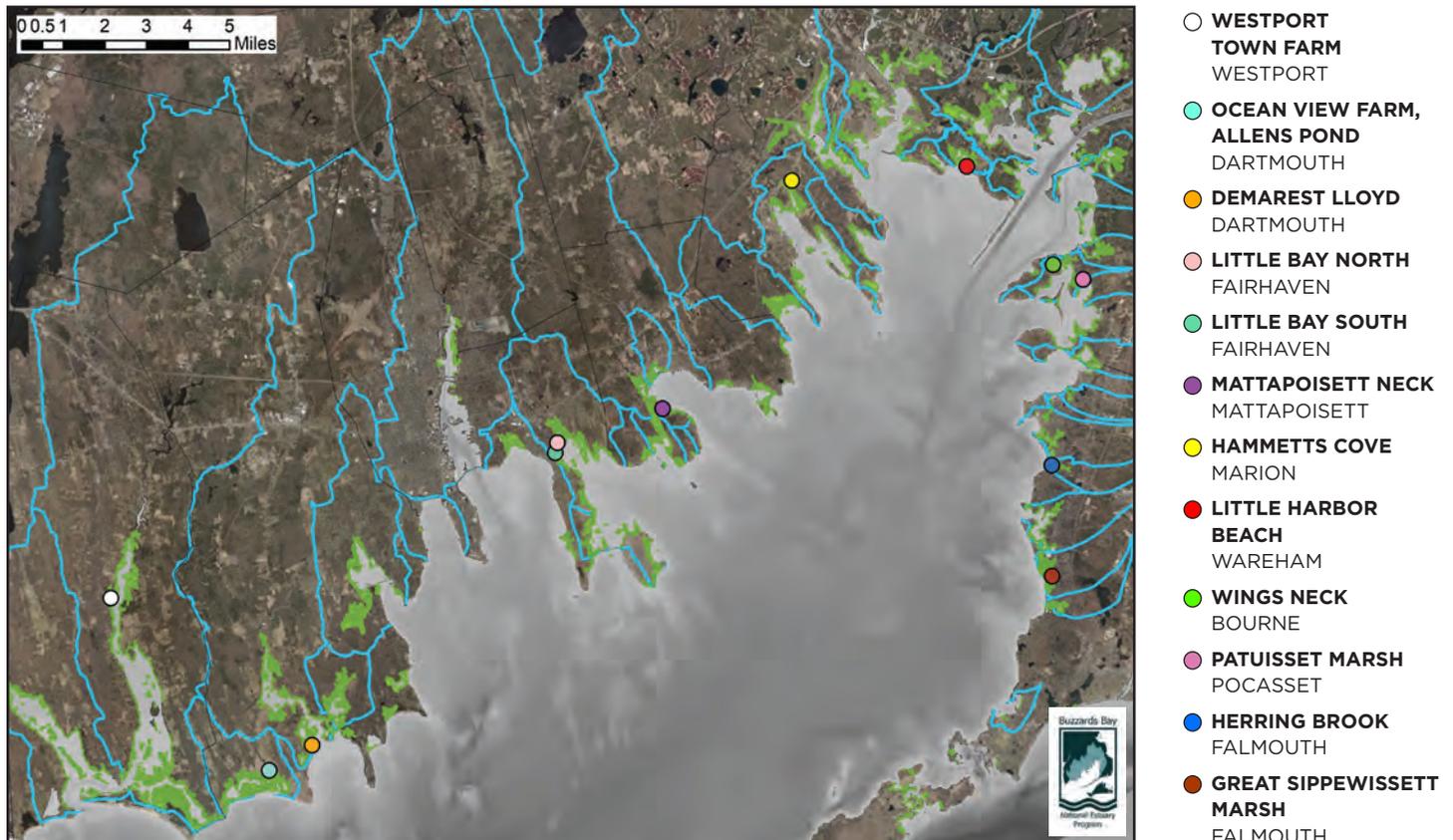
ABOUT THIS REPORT:

Salt marshes with lush grass meadows teeming with shorebirds are iconic features of the Buzzards Bay coast and provide important environmental benefits as well as opportunities for recreation and aesthetic enjoyment. These productive coastal wetlands are important because they protect properties from storm surges, remove nutrients from the water and carbon from the atmosphere, and provide critical habitats for fish, shellfish, and birds.

Found where the land meets the sea, salt marshes are naturally dynamic features that change with rising seas, waves, ice, and storms. In the past, humans purposely altered salt marshes by filling them to create buildable land or digging drainage ditches. These major alterations harmed marsh structure and health. In recent decades, however, marshes are degrading because of more diffuse

and complex pressures such as nutrient pollution, sea level rise, major storms, and crab overgrazing. As a result, at many places along the East Coast, marshes have crumbling banks and large areas where the plants have died, leaving behind mudflats.

The Buzzards Bay Coalition and the Buzzards Bay National Estuary Program began field monitoring of salt marshes around Buzzards Bay in 2019 to document changes (map below shows sites). We partnered with the U.S. Geological Survey and the Woodwell Climate Research Center to use aerial tools to investigate how different characteristics of the long-term marsh sites and their watersheds affect the marsh's current health and likely future. This report brings together the results of on the ground monitoring with data from aerial imagery to look at marsh status at 12 long-term monitoring sites based on existing stressors, current marsh conditions, and potential for adaptation.



Map shows salt marsh area shaded in green, watershed boundaries in blue, and long-term monitoring sites as colored dots. Source: Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services and Buzzards Bay National Estuary Program.

What impacts marsh condition and future trajectory?

Marshes have an amazing natural capacity to adapt to changing environmental conditions. But all things have limits. With many factors — both historical and current — stressing marshes, marshes are degrading across the northeastern United States. These **stressors** not only impact a salt marsh's **current condition**, but also its capacity to **adapt** to changing environmental conditions. There are many ways to describe aspects of marshes and their surrounding environment. For this report, we selected a set of metrics that describe stress, condition, and potential for adaptation, and that integrate information about multiple factors. While not exhaustive, the metrics described below help us to understand the status of a marsh and how it will persist into the future.

Stressors on Salt Marshes

Changing environmental conditions and human activity at both small and large scales can stress marsh plants and soils, altering how these ecosystems “work”.

Sea Level Rise - Due to climate change, sea levels have been rising over the past century faster than they would naturally. To persist, salt marshes must build up surface elevation faster than sea level rises. Marshes increase surface elevation by: 1) plants producing dense root mats that build up over time, and 2) stems of marsh plants trapping sediment particles from flooding tides that deposit on the marsh surface. If sea level rises faster than a marsh can increase its elevation, the marsh will begin to drown. The surface elevation of a marsh determines how vulnerable it is to drowning from rising sea levels.

➡ ***Salt marshes with more area sitting at low elevations are more vulnerable to loss from rapidly rising seas.***

Nitrogen pollution - Excess nitrogen can increase the amount of marsh grass (like over-fertilizing your lawn), but it can also cause the underground root network to become sparse and weak. This destabilizes the marsh and can lead to marsh banks crumbling into the water. Excess nitrogen also increases the activity of microorganisms that break down organic material, which can result in the marsh losing elevation.

➡ ***Salt marshes exposed to high nitrogen concentrations (e.g., from nearby septic systems) are more vulnerable to marsh loss.***

Tidal Restrictions - Many salt marshes are crossed by highways, roads, and railroads that often have culverts (pipes or openings) installed to allow tidal water to pass beneath them. In many cases, these culverts are too small to allow enough tidal water to pass through to maintain natural salt marsh conditions.

➡ ***Tidal restrictions can make marshes more vulnerable to loss.***

Current Conditions

The current health of the marsh reflects how well it is handling existing pressures.

Vegetated and Unvegetated Areas - Healthy marshes are covered with dense vegetation that builds up the soil elevation by creating root mats and peat and by trapping sediment from flooding tides. When the plant community becomes stressed by current conditions, vegetation dies and converts to unvegetated, bare area. Bare areas are also more susceptible to erosion.

➡ ***Salt marshes with larger amounts of unvegetated, bare areas indicate the marsh's susceptibility to existing stressors and make the marsh more vulnerable to marsh loss.***

Marsh Loss - Loss of marsh area happens when the edge of a marsh crumbles into the water, tidal creeks and ditches expand outward creating mudflats, and interior areas convert from vegetated marsh to bare mudflats with standing water.

➡ ***The amount of marsh area lost over the past few decades demonstrates the effect of existing stressors on the marsh. Marshes showing high amounts of loss are generally more vulnerable to future losses.***

Potential for Adaptation

Salt marsh ecosystems are adapted to thrive in areas that are periodically flooded by the tides. Within the marsh, different vegetation “zones” are adapted to tolerate different amounts of time under water and levels of saltiness. Each zone has distinct plant species. As sea level rises and the tides reach further inland, flood-tolerant grasses and marsh plants will colonize these places where there is currently forest or fields or other undeveloped land. If a salt marsh can migrate landward, the total marsh area may remain the same even if vegetation is lost at the seaward edge.

Coastal squeeze – Sea walls, roads, or other development landward of a marsh limit the ability of marsh plants to colonize new areas. Even where landward areas are undeveloped, a steep slope may prevent marsh plants from colonizing the undeveloped area.

➡ ***Salt marshes with developed areas or steep slopes on their landward edge have limited potential for adaptation making them more vulnerable to marsh loss.***

Plant community – If a marsh is covered primarily by plants that tolerate only a moderate level of seawater flooding, then as the marsh is flooded more often, the plant community can transition to plants that tolerate higher levels of flooding and keep the marsh vegetated. When a marsh is already dominated by flood-tolerant species, as sea level rises, there is no additional capacity for the plant community to adapt. Once flooding exceeds a threshold, the flood-tolerant plants will die and the marsh will convert to bare mud flats.

➡ ***Salt marshes that are already predominantly covered with very flood-tolerant species have limited potential for adaptation making them more vulnerable to marsh loss.***

Elevation – While the amount of low elevation areas in a marsh tells us about its vulnerability to loss from current stressors, the amount of high elevation areas tells us about its ability to adapt to rising seas. These higher elevation areas will persist for longer, and have a better chance of increasing surface elevation faster than sea level rises.

➡ ***Salt marshes with a smaller percentage of higher elevation areas have limited potential for adaptation making them more vulnerable to marsh loss.***

Other Factors

As illustrated above, marshes are complicated. The exposure to stressors, current conditions of a marsh, and capacity to adapt to a changing environment are all dependent on many factors. In addition to those described above, other factors include the intensity of mosquito ditching, exposure to wind-driven wave erosion, and possible impacts from crabs, among others. Intensive mosquito ditching alters water flow, soils, and vegetation in marshes, and makes them more vulnerable to loss. Wind-driven waves can stress the edges of marshes, causing them to destabilize and erode. And some marsh crab species eat plants. When crab populations are too high, plants can be consumed or stressed from herbivory. Intense burrowing from multiple crab species may also be a stressor for marshes. Some of these factors are challenging to quantify and our understanding of their importance is still developing.

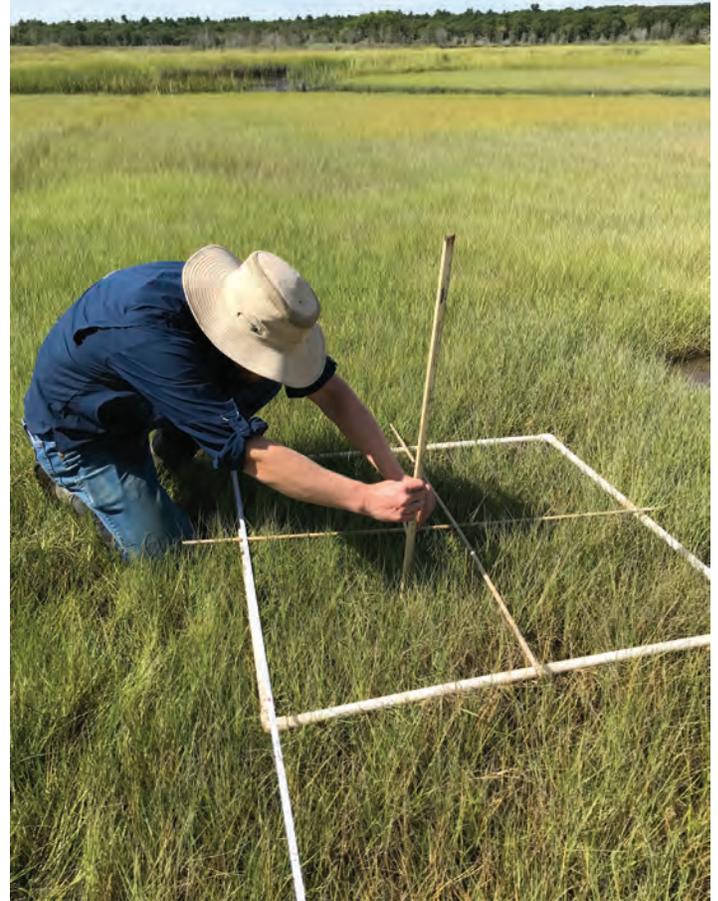
In this report we present a set of metrics describing a marsh’s stressors, current condition, and potential for adaptation and apply them to selected sites. These sites represent about 40 acres of the 5,000 acres of salt marsh that exists around Buzzards Bay. However, these marshes represent the diversity of salt marsh ecosystem types and conditions found throughout the watershed.

Methods

In this report we present stressors, current conditions, and potential for adaptation for 12 marshes around Buzzards Bay. The data presented pertain to our study sites, so metrics on size and distances describe our study areas rather than the entirety of the marsh. At each marsh we provide an overview of the marsh setting as well as information on the marsh's **resilience** against and **vulnerability** to future losses. We define resilience as a marsh's ability to persist as a marsh ecosystem while undergoing stress. We define vulnerability as a marsh's risk of converting into open water or bare mudflat. This information is presented in a short paragraph, a table of metrics, and in figures and maps for each site.

The information presented in this report was collected at several different scales. On the ground measures were made at the smallest scale (one-square meter plots). Aerial and satellite measurements were made at larger scales (1-10 acres). Collecting information at multiple scales helps to put the results in context and maximize the available information.

Marsh-Specific Metrics: At each long-term site, we established transect lines along which to collect data. The transects go from a tidal creek or ditch up to where the vegetation transitions from marsh to woody plants. The transects are representative of what is happening across the marsh, but measurements are made at a limited number of points. At most sites, this resulted in 20 quadrats per site. Three sites were part of a pilot test for a restoration technique ("runnels"). At these runnel test sites, sample areas targeted potential restoration areas where the marsh showed signs of stress. As a result, the metrics used to quantify current conditions may look worse than if the sample areas were selected to target general marsh condition (as they were at other sites) rather than potential restoration areas. The data are indicated for runnel test sites with an asterisk.



Summer field technician Ryan Kappel measures stem height at a monitoring quadrat at the Mattapoisett Neck site.

Bay-Wide Metrics: Airplanes and satellites are able to collect data and photographs across a large marsh area at once (collectively referred to as remotely-sensed data). This information provides an integrated look with many data points across the marsh. We used metrics calculated for each marsh site by analyzing aerial images and remotely-sensed data. Site values were aggregated, and we present bay-wide estimates based on our 12 marsh sites. These metrics quantify recent marsh loss, current vegetation condition, and elevation of all our marsh sites around Buzzards Bay.

	METRIC AND METHOD	WHERE TO FIND IN REPORT	RANGE*
Stressors on Salt Marshes	Percent Low-Lying – At each site, survey equipment was used to measure marsh surface elevation along each transect. The percent low-lying was calculated as the percentage of transect elevations below a point roughly equivalent to the height of low marsh. Data from 2019-2021 were used. These areas are more vulnerable to loss with sea level rise. This part of the marsh may be lost within decades.	This metric is presented on each site page in the “Marsh-Specific Metrics” tables, and as the area shaded orange in the figures titled “Vulnerability to Sea Level Rise.”	2% to 21%
	Nitrogen – The concentration of total nitrogen was measured in water samples collected near the marsh sites. The samples were collected through the Buzzards Bay Coalition’s Baywatchers Program. Data from 2016–2020 were averaged. Lower levels of nitrogen in the water (-0.5 mg/L or less) make marshes more resilient.	This metric is presented on each site page in the “Marsh-Specific Metric” tables.	0.4 to 0.9 mg/L
	Tidal restrictions – Buzzards Bay National Estuary Program (BBNEP) gathered information on the location and status of tidal restrictions around Buzzards Bay in 2002 and 2009. We used the BBNEP atlas of tidal restrictions to determine when restrictions were present at a site.	This metric is presented on each site page in the descriptive text.	None to restricted by a culvert
Current Conditions	Percent Unvegetated – At about 20 locations per site, the area of a one-square meter plot that was either bare or covered with plants was measured. The percent unvegetated is the percentage of the plots that were bare without any plants. Data from 2020 and 2021 were averaged.	This metric is presented on each site page in the “Marsh-Specific Metric” tables, and as the brown shaded area in figures titled “Current Conditions.”	1% to 19%
	Unvegetated to Vegetated Ratio (UVVR) – The U.S. Geological Survey used computer software to analyze 2018 aerial images from the National Agricultural Imagery Program to classify marsh areas as vegetated with plants or as bare surface or water. The unvegetated to vegetated ratio (UVVR) is a measure of how much of the overall marsh is covered by bare areas (including water-filled channels, ponds, and bare mudflats) versus the amount covered with marsh plants. Larger values indicate more open water, bare areas, and less vegetation. Values above 0.15 indicate higher marsh loss vulnerability. Values below 0.15 indicate greater stability.	This metric is presented using the data from all sites combined in the “Results and Conclusions” section.	0.02 to 0.69
	Marsh loss – Vegetated marsh areas were measured using GIS tools and aerial images from 2001, 2009, 2014, and 2019. Marsh loss was calculated by dividing the slope of the linear regression of the marsh area at the four timepoints with the marsh area in 2001 and multiplying by 18 for the study period.	This metric is presented in the map legend of each site page and in the “Results and Conclusions” section using the data from all sites combined.	1% to 23%
Potential for Adaptation	Plant community – We identified marsh plants in the one-square meter plots and measured their abundance. Plants were classified as low marsh species (flood-tolerant) or high marsh species (low flood-tolerance). Marshes that are already predominantly covered with very flood-tolerant species have less capacity to adapt as sea levels get even higher and are susceptible to converting to bare mudflats.	This metric is presented on each site page in the “Marsh-Specific Metric” tables, and as the pie-chart with high marsh species in blue and low marsh species in orange in figures titled “Potential for Adaptation.”	13 to 63% High Marsh 37 to 87% Low Marsh
	Percent Above Mean High Water – At each site, survey equipment was used to measure marsh surface elevation along each transect. The percent of transect elevations above mean high water (MHW) were calculated. Areas above MHW are more likely to “keep up” with sea level rise, and persist until at least 2100.	This metric is presented on each site page in the “Marsh-Specific Metric” tables, and as the area shaded green in the figures titled “Vulnerability to Sea Level Rise.”	36% to 93%
	Percent Resilient – The National Ocean Service and U.S. Geologic Survey use laser instruments (LiDAR) on airplanes to measure ground elevation. Data are from 2013-2014. Percent Resilient was measured as the percentage of vegetated marsh sitting equal to or above the mean high water (MHW) datum. Areas above MHW are more likely to “keep up” with sea level and persist until at least 2100.	This metric is presented using the data from all sites combined in the “Results and Conclusions” section.	19% to 92%

* Range indicates the highest and lowest value measured from the 12 marshes in this report.

Marsh Vegetation

Within a salt marsh, different plant species are adapted to tolerate certain levels of flooding by seawater with the tides. The areas of marsh that are flooded daily by the tides are known as the low marsh. The primary low marsh plant adapted to this frequent flooding is *Spartina alterniflora* (smooth cordgrass). High marsh areas are only flooded when the tides are particularly high — such as the highest high tides each month or from storm surge. Plants that occur in the high marsh include *Spartina patens* (salt marsh hay), *Juncus gerardii* (saltmarsh rush), *Distichlis spicata* (saltgrass), and *Iva frutescens* (high tide bush), which is the least tolerant of flooding. The images to the right show examples of the most common species observed at our marsh sites.

LOW MARSH SPECIES

Spartina alterniflora (FIGURE A)

HIGH MARSH SPECIES

Spartina patens (FIGURE B)

High Tide Bush (FIGURE C)

Saltmarsh rush (FIGURE D)

Saltgrass (FIGURE E)

LOW MARSH

HIGH MARSH

UPLAND





WESTPORT TOWN FARM

WESTPORT

830 Drift Rd. Westport, MA 02790

Owner: Town of Westport

The Westport Town Farm site is a large marsh and is located on the upper part of the East Branch of the Westport River. There are no restrictions to the flow of seawater to the marsh. Behind the marsh are large hayfields and conservation land. Over 90% of the study area sits at a relatively high elevation, there is a large proportion of high marsh species, and the current vegetation coverage is 99%. These characteristics will help the marsh's **resilience** to current and future stressors. A factor that contributes to the marsh's **vulnerability** is that the marsh is flooded by water with some of the highest nitrogen concentrations across our study sites. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	2%
Nitrogen Pollution	0.8 mg/L estuary

Current Conditions

Percent Unvegetated	1%
---------------------	----

Potential For Adaptation

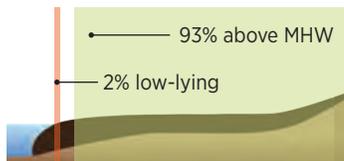
Plant Community	50% High Marsh 50% Low Marsh
Percent Above MHW	93%



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

2% Low-Lying



CURRENT CONDITIONS

1% Unvegetated



POTENTIAL FOR ADAPTATION

50% High Marsh





2001



2009



2014



2019

STUDY AREA:

4.5 ACRES

LOST FROM 2001-2019:

1%

Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.

600 ft



OCEAN VIEW FARM, ALLENS POND

DARTMOUTH

DNRT Ocean View Farm Reserve: Allen Neck Rd. and Barneys Joy Rd. Dartmouth, MA 02748

Owner: Dartmouth Natural Resources Trust (DNRT), conservation restriction held by the Buzzards Bay Coalition

The Ocean View Farm site is located on the northern shores of Allens Pond, which is a salt pond behind a barrier beach. The flow of seawater to the marsh is restricted by the natural tidal inlet of Allens Pond that closes intermittently, though the inlet is managed to prevent closure for more than a few months. The site is adjacent to retired farm fields that are now managed to provide grassland habitat for birds. The large extent of marsh within Allens Pond, and absence of any restrictions to migration support the **resilience** of this marsh. In fact, the Dartmouth Natural Resources Trust is looking to actively facilitate marsh migration into the former farm fields. However, almost 16% of the study area along our transects is bare, and only 47% of the marsh is sitting above mean high water. These factors contribute to the marsh's **vulnerability**. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	5%*
Nitrogen Pollution	0.9 mg/L estuary

Current Conditions

Percent Unvegetated	16%*
---------------------	------

Potential For Adaptation

Plant Community	27% High Marsh 73% Low Marsh*
Percent Above MHW	47%*

*Runnel test site. On the ground measurements were collected using a modified sampling design. See methods for details.

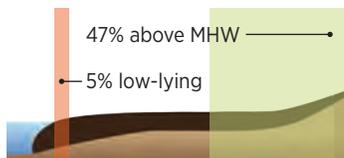


Site map showing transects where on the ground measurements were made. Created with Google Earth.



VULNERABILITY TO SEA LEVEL RISE

5% Low-Lying



CURRENT CONDITIONS

16% Unvegetated



POTENTIAL FOR ADAPTATION

27% High Marsh

Plant Type

High Marsh
Low Marsh





2001

2009

2014

2019

STUDY AREA:

5.7 ACRES

LOST FROM 2001-2019:

6%

Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.

600 ft



DEMAREST LLOYD

DARTMOUTH

115 Barneys Joy Rd. Dartmouth, MA 02748

Owner: Demarest Lloyd State Park

The Demarest Lloyd site is located near the mouth of the Slocums River, along the banks of a tidal creek. Seawater flows to the marsh freely, without any tidal restriction. The marsh is adjacent to a recreational area that includes some forested land, picnic areas, and a large parking lot. A large portion of this site sits at relatively high elevation, and the current vegetation coverage is 99% — these two characteristics increase the marsh's **resilience** to future stressors. Two factors that contribute to the marsh's **vulnerability** are that low marsh species dominate the plant community (65%) and that the marsh is flooded by water with relatively high nitrogen concentrations. As a well-loved public destination, another pressure on this site is a large number of people walking through the marsh. Low marsh plant species are damaged when they are stepped on, increasing their vulnerability to other pressures. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	7%
Nitrogen Pollution	0.6 mg/L estuary

Current Conditions

Percent Unvegetated	1%
---------------------	----

Potential For Adaptation

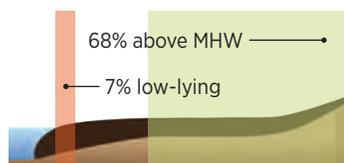
Plant Community	35% High Marsh 65% Low Marsh
Percent Above MHW	68%



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

7% Low-Lying



CURRENT CONDITIONS

1% Unvegetated

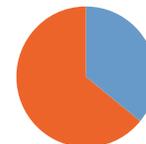


POTENTIAL FOR ADAPTATION

35% High Marsh

Plant Type

High Marsh
Low Marsh





STUDY AREA:
2.2 ACRES

LOST FROM 2001-2019:
1%

Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.



600 ft

LITTLE BAY NORTH

FAIRHAVEN

12 Little Bay Rd. Fairhaven, MA 02719

Owner: Town of Fairhaven

Little Bay North marsh is located where the Nasketucket River opens into the inner part of Little Bay. The marsh is exposed to a large, open embayment, with a protected forest upland found adjacent to the marsh. A paved walking trail provides access to this marsh and a small fishing pier. The flow of seawater to the marsh is unrestricted, and there are no impediments to upland marsh migration. The high elevation at this marsh contributes to its **resilience**. Resilience is further enhanced by the prevalence of high marsh plants. However, the marsh's **vulnerability** is increased by the fact that the marsh is exposed to open water and high wind, increasing the risk of erosion from waves. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	14%*
Nitrogen Pollution	0.6 mg/L estuary

Current Conditions

Percent Unvegetated	9%*
---------------------	-----

Potential For Adaptation

Plant Community	52% High Marsh 48% Low Marsh*
Percent Above MHW	76%*

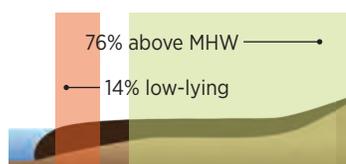
*Runnel test site. On the ground measurements were collected using a modified sampling design. See methods for details.



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

14% Low-Lying



CURRENT CONDITIONS

9% Unvegetated



POTENTIAL FOR ADAPTATION

52% High Marsh

Plant Type

High Marsh
Low Marsh





2001

2009

2014

2019

STUDY AREA:

4.7 ACRES

LOST FROM 2001-2019:

5%

Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.



500 ft



LITTLE BAY SOUTH

FAIRHAVEN

Near 10 Edgewater St. Fairhaven, MA 02719

Owner: Town of Fairhaven

The Little Bay South marsh site is found just south of Little Bay North, open to the inner part of Little Bay and seaward of a small area of undeveloped land and neighboring residential buildings. A paved road bisects this marsh, but does not create a barrier to migration. At this marsh, **resilience** is promoted by an unrestricted flow of seawater, and only a small percentage of low-lying elevation. However, **vulnerability** is increased by a high density of historical ditches which are eroding and expanding today, especially in the areas closest to the water beyond our study area. The marsh is also exposed to wind-driven waves which can contribute to erosion. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	5%*
Nitrogen Pollution	0.6 mg/L estuary

Current Conditions

Percent Unvegetated	11%*
---------------------	------

Potential For Adaptation

Plant Community	37% High Marsh 63% Low Marsh*
Percent Above MHW	76%*

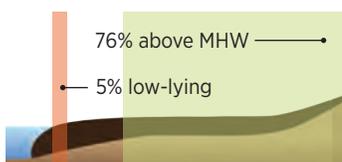
*Runnel test site. On the ground measurements were collected using a modified sampling design. See methods for details.



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

5% Low-Lying



CURRENT CONDITIONS

11% Unvegetated

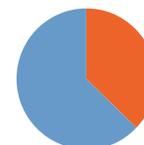


POTENTIAL FOR ADAPTATION

37% High Marsh

Plant Type

High Marsh
Low Marsh





2001

2009

2014

2019

STUDY AREA:

4.8 ACRES

LOST FROM 2001-2019:

1%

Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.



600 ft

MATTAPOISETT NECK

MATTAPOISETT

70 Mattapoissett Neck Rd. Mattapoissett, MA 02739

Owner: Town of Mattapoissett

The Mattapoissett Neck site lies within a large marsh in the upper part of Mattapoissett Harbor, near the mouth of the Mattapoissett River. The flow of seawater to the marsh is restricted by a culvert running beneath a road. There are several houses behind the marsh, limiting space for migration. A factor that supports the **resilience** of this marsh is that 88% of the survey area is covered with vegetation. However, low marsh species make up 87% of the vegetation surveyed which is the greatest amount at any of our sites and contributes to the marsh's vulnerability. A large percentage of the marsh is also found at low-lying elevations, and the ditches have significantly eroded and expanded. These factors contribute to the marsh's **vulnerability**. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	14%
Nitrogen Pollution	0.4 mg/L estuary

Current Conditions

Percent Unvegetated	12%
---------------------	-----

Potential For Adaptation

Plant Community	13% High Marsh 87% Low Marsh
Percent Above MHW	44%



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

14% Low-Lying



CURRENT CONDITIONS

12% Unvegetated

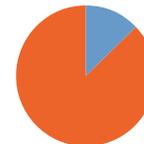


POTENTIAL FOR ADAPTATION

13% High Marsh

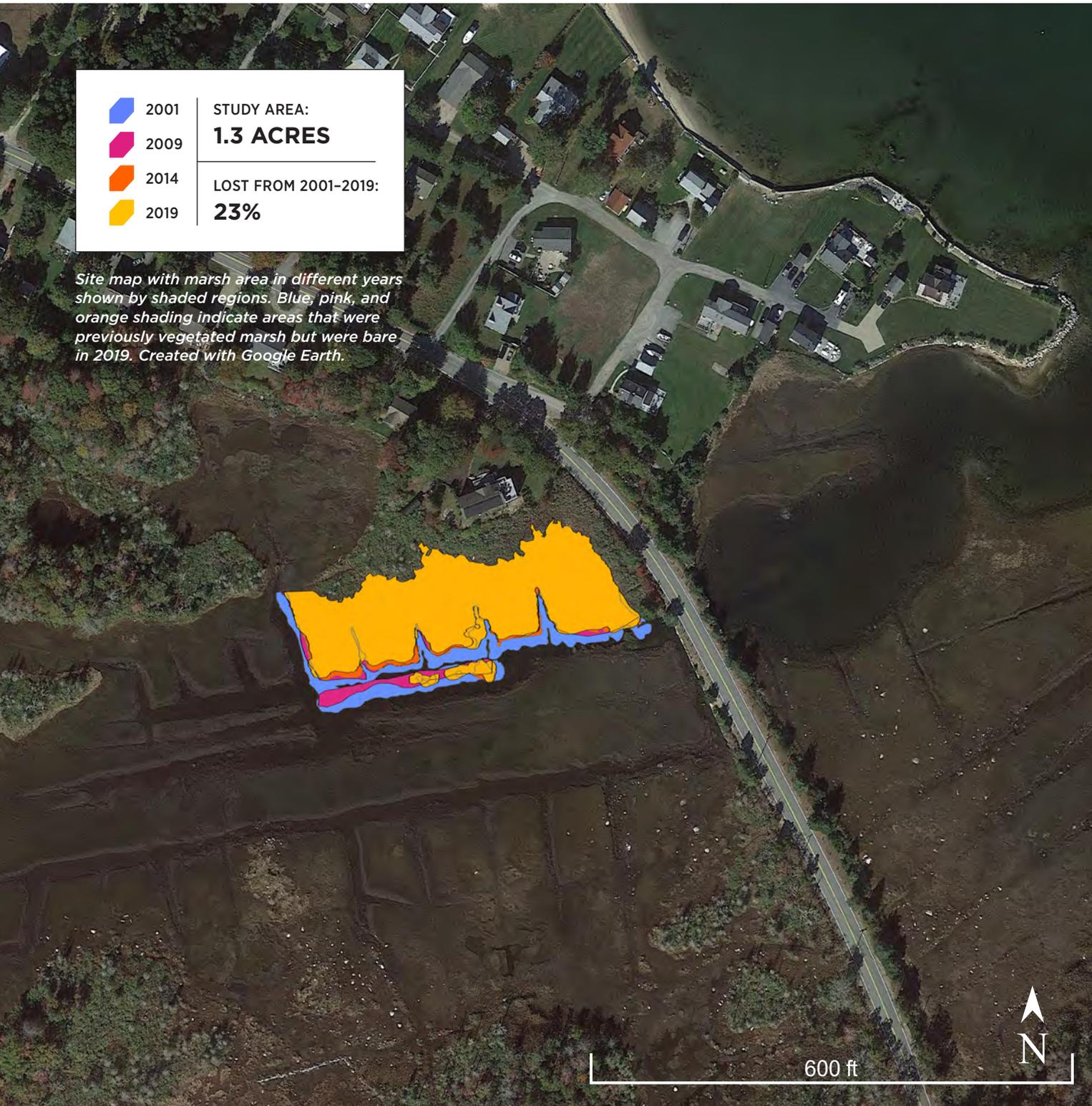
Plant Type

High Marsh
Low Marsh





Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.



HAMMETT COVE

MARION

18 Creek Rd. Marion, MA 02738

Owner: Town of Marion

The Hammett Cove site is open to the upper part of Hammett Cove. The site is small, and lies just seaward of a small undeveloped upland area. Hammett Cove is found in an open embayment, where the flow of seawater to the marsh is unrestricted. This site's **resilience** is enhanced by the plant community, with the highest proportion of high marsh species of any of our sites. A factor contributing to this marsh's **vulnerability** is that it is relatively narrow, extending only about 30 yards from upland boundary to open water. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	6%
Nitrogen Pollution	0.6 mg/L estuary

Current Conditions

Percent Unvegetated	11%
---------------------	-----

Potential For Adaptation

Plant Community	63% High Marsh 37% Low Marsh
Percent Above MHW	89%



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

6% Low-Lying



CURRENT CONDITIONS

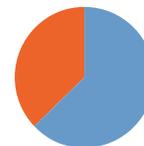
11% Unvegetated



POTENTIAL FOR ADAPTATION

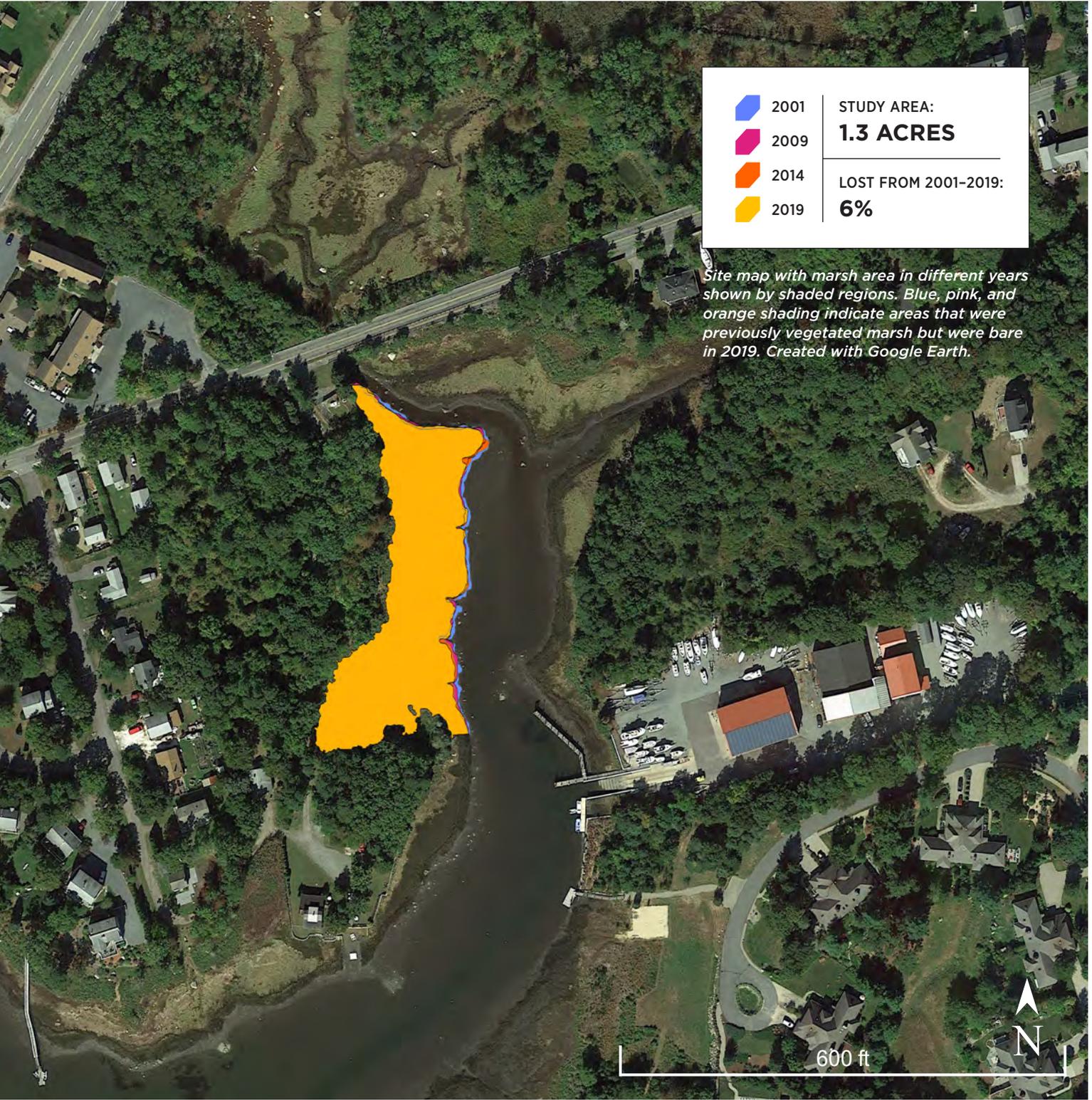
63% High Marsh

Plant Type



	2001	STUDY AREA: 1.3 ACRES
	2009	
	2014	LOST FROM 2001-2019: 6%
	2019	

Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.



LITTLE HARBOR BEACH

WAREHAM

32 Little Harbor Rd. Wareham, MA 02571

Owner: Town of Wareham

The Little Harbor Beach site is located on the back side of a barrier beach. Directly behind the marsh is a large parking lot for the beach, which is very popular. The flow of seawater to the marsh is unrestricted. Two factors that support the **resilience** of this marsh are that it sits at a high elevation and a high percentage (93%) of the survey area is vegetated. The beach parking lot built next to the marsh limits the potential for this marsh to migrate with rising sea level — this contributes to the marsh's **vulnerability**. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	5%
Nitrogen Pollution	0.6 mg/L estuary

Current Conditions

Percent Unvegetated	7%
---------------------	----

Potential For Adaptation

Plant Community	43% High Marsh 57% Low Marsh
Percent Above MHW	80%



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

5% Low-Lying



CURRENT CONDITIONS

7% Unvegetated

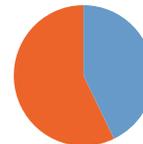


POTENTIAL FOR ADAPTATION

43% High Marsh

Plant Type

High Marsh
Low Marsh

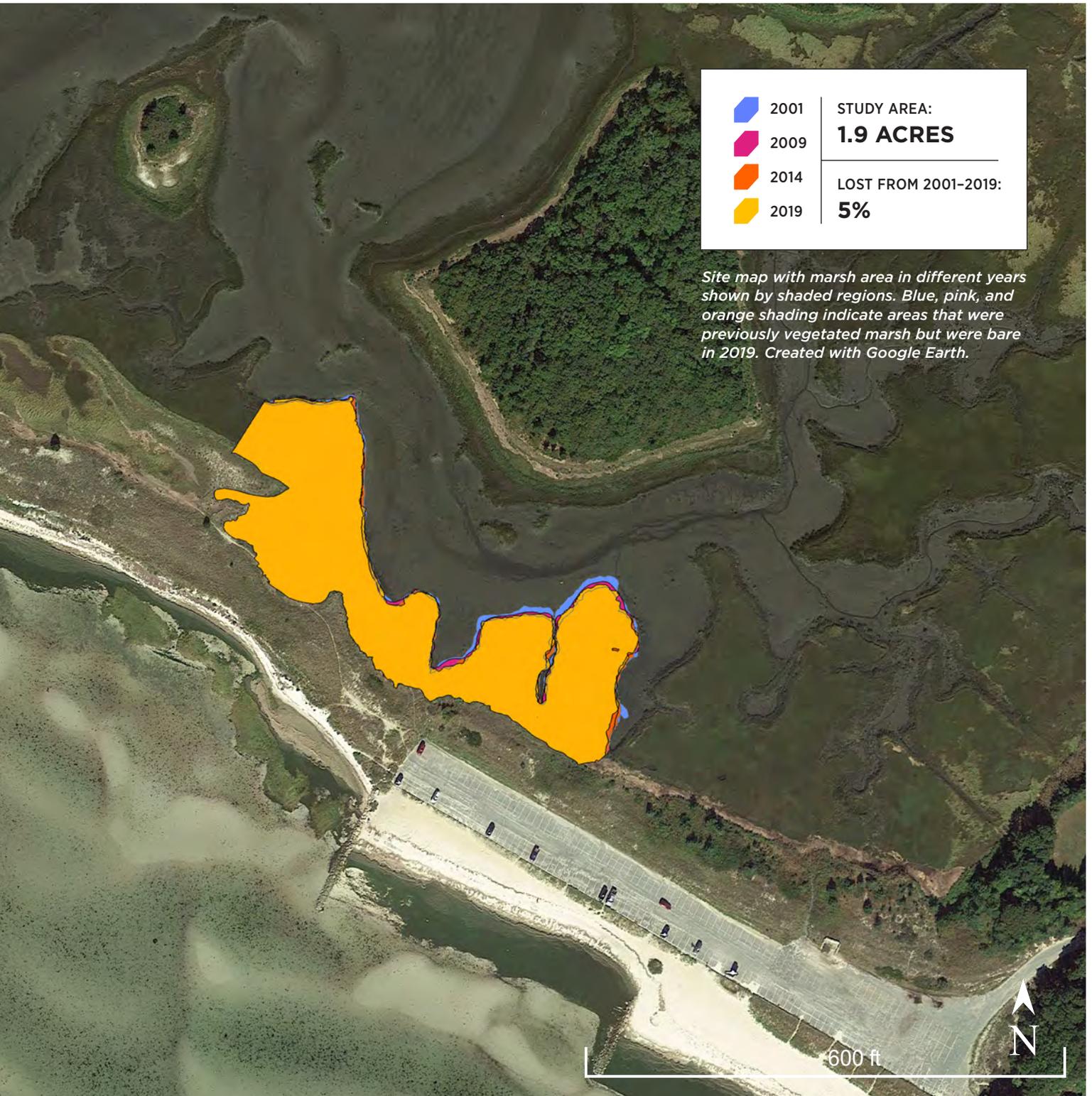




STUDY AREA:
1.9 ACRES

LOST FROM 2001-2019:
5%

Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.



WINGS NECK

BOURNE

3 Harbor Dr. Pocasset, MA 02559

Owner: Town of Bourne

The Wings Neck site is found along the inner part of Pocasset Harbor. A road was built over the marsh so the flow of seawater to the northern half of the site is restricted by the road and culvert. The marsh is surrounded by residential areas. A factor that supports the **resilience** of this marsh is that 91% of the study area is covered with vegetation. However, a large proportion of the marsh is low-lying, and the marsh is surrounded by homes which contribute nitrogen to the marsh system via septic fields. These factors contribute to the marsh's **vulnerability**. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	12%
Nitrogen Pollution	0.4 mg/L estuary

Current Conditions

Percent Unvegetated	9%
---------------------	----

Potential For Adaptation

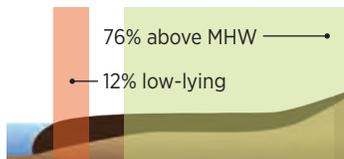
Plant Community	38% High Marsh 62% Low Marsh
Percent Above MHW	76%



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

12% Low-Lying



CURRENT CONDITIONS

9% Unvegetated

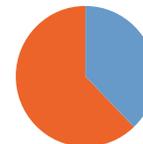


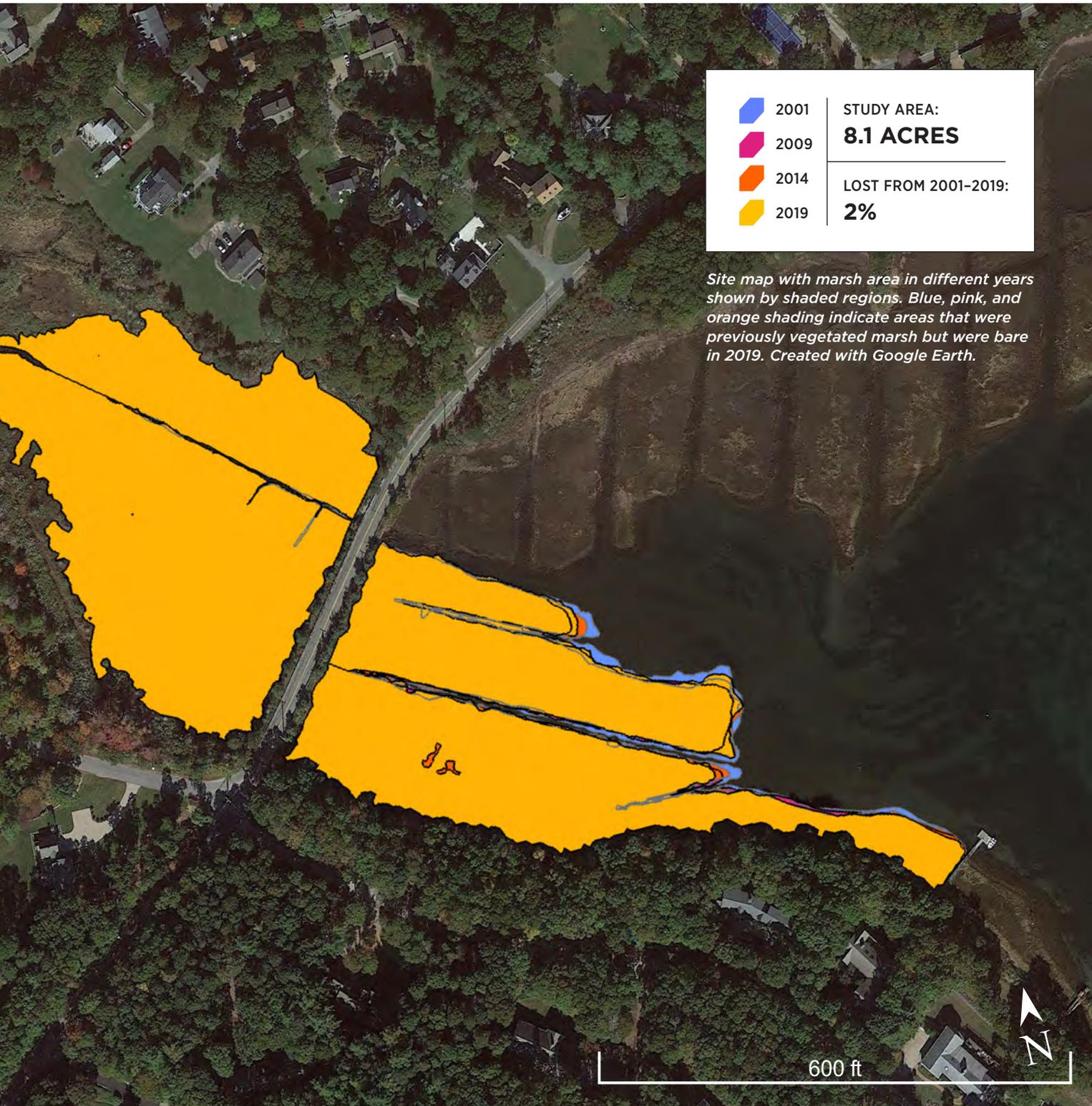
POTENTIAL FOR ADAPTATION

38% High Marsh

Plant Type

High Marsh
Low Marsh





PATUISSET MARSH

POCASSET

176 Circuit Ave. Pocasset, MA 02559

Owner: Town of Bourne

The Patuisset Marsh site is located behind a barrier beach and upland areas in upper Pocasset Harbor. The flow of seawater to the marsh is partially restricted by a road culvert on the northwest side. Directly behind the marsh is a small conservation area that is ringed by residential buildings. A factor that supports the **resilience** of this marsh is that 94% of the transects are covered with vegetation. However, the high density of residential buildings with septic fields surrounding the marsh adds nitrogen to the system, and the marsh beyond our transect area shows substantial degradation and loss — these factors contribute to the marsh’s **vulnerability**. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	4%
Nitrogen Pollution	0.4 mg/L estuary

Current Conditions

Percent Unvegetated	6%
---------------------	----

Potential For Adaptation

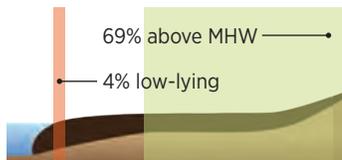
Plant Community	32% High Marsh 68% Low Marsh
Percent Above MHW	69%



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

4% Low-Lying



CURRENT CONDITIONS

6% Unvegetated



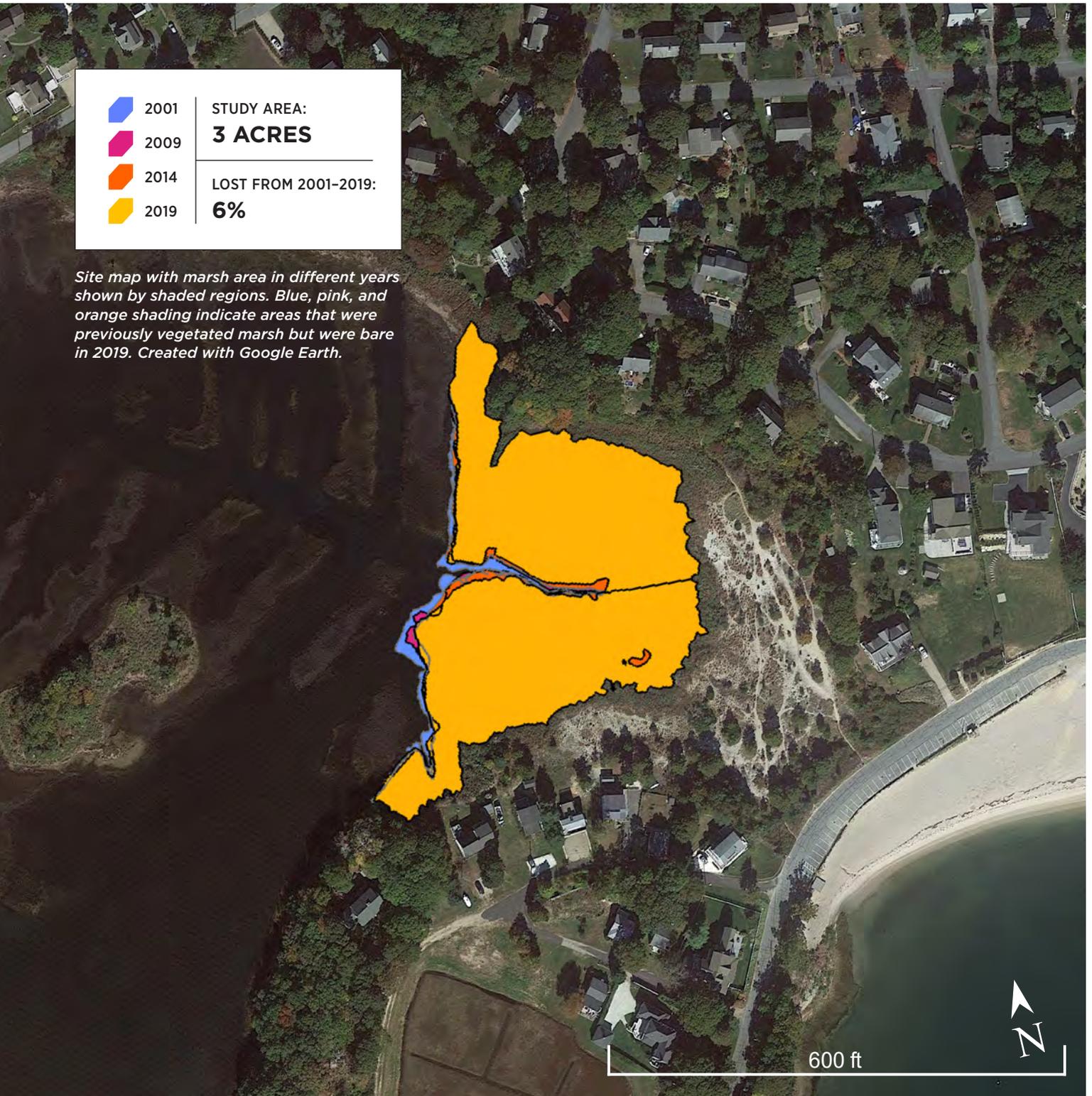
POTENTIAL FOR ADAPTATION

32% High Marsh





Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.



HERRING BROOK

FALMOUTH

301 Quaker Rd. North Falmouth, MA 02556

Owner: Town of Falmouth

Herring Brook Marsh is our smallest marsh site. It is located on a tidal creek behind a recreational beach, parking lot, road, and bridge. The flow of seawater to the marsh is partially restricted by a bridge and man-made channel. It is our only site with no historical ditching. The lack of ditching contributes to its **resilience**. However, multiple factors contribute to this site's **vulnerability**. This marsh has the lowest vegetation cover of all of the marshes and a high percentage of low-lying area. Tidal restrictions and development adjacent to the marsh limit its capacity to adapt to future sea level rise. It experienced consistent edge loss over time and lost the second highest percentage of marsh area of any of our sites. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	21%
Nitrogen Pollution	0.7 mg/L estuary

Current Conditions

Percent Unvegetated	19%
---------------------	-----

Potential For Adaptation

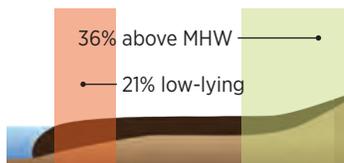
Plant Community	31% High Marsh 69% Low Marsh
Percent Above MHW	36%



Site map showing transects where on the ground measurements were made. Created with Google Earth.

VULNERABILITY TO SEA LEVEL RISE

21% Low-Lying



CURRENT CONDITIONS

19% Unvegetated



POTENTIAL FOR ADAPTATION

31% High Marsh

Plant Type

High Marsh
Low Marsh





GREAT SIPPEWISSETT MARSH

FALMOUTH

Near 410 W. Falmouth Hwy. Falmouth, MA 02540

Owner: Salt Pond Areas Bird Sanctuaries, Inc.

The Great Sippewissett Marsh is a large marsh. It sits in a protected location behind a barrier beach and is bordered by wooded areas and a raised bike path. The flow of seawater to the marsh is unrestricted, and a creek adds freshwater to the system. This marsh is one of our most highly vegetated sites with 99% cover of vegetation. It also sits at a high elevation. These characteristics contribute to this marsh's **resilience**. However, the nearby raised bike path would restrict marsh expansion and adaptation to sea level rise, adding to its **vulnerability**. Despite a relatively high proportion of high marsh species, the marsh study area is still dominated by low marsh species, contributing to this site's vulnerability to future sea level rise. For details on the metrics presented below, see the Methods section (pages 4-5).

MARSH-SPECIFIC METRICS

Stressors

Percent Low-Lying	2%
Nitrogen Pollution	0.5* mg/L estuary

Current Conditions

Percent Unvegetated	1%
---------------------	----

Potential For Adaptation

Plant Community	41% High Marsh 59% Low Marsh
Percent Above MHW	89%

*Nitrogen value from nearby Little Sippewissett Marsh because no data available for Great Sippewissett Marsh.

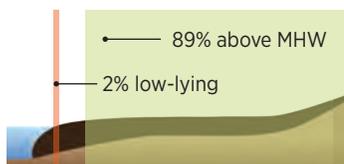


Site map showing transects where on the ground measurements were made. Created with Google Earth.



VULNERABILITY TO SEA LEVEL RISE

2% Low-Lying



CURRENT CONDITIONS

1% Unvegetated

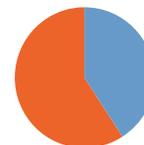


POTENTIAL FOR ADAPTATION

41% High Marsh

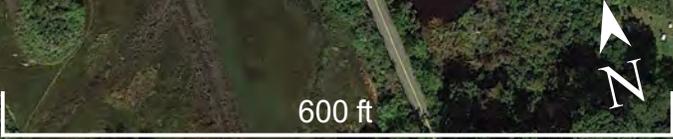
Plant Type

High Marsh
Low Marsh



	2001	STUDY AREA: 5.1 ACRES
	2009	
	2014	LOST FROM 2001-2019: 5%
	2019	

Site map with marsh area in different years shown by shaded regions. Blue, pink, and orange shading indicate areas that were previously vegetated marsh but were bare in 2019. Created with Google Earth.



RESULTS AND CONCLUSIONS:

All marshes around Buzzards Bay are vulnerable to loss due to accelerated sea level rise, and other factors such as tidal restrictions exacerbate the problem. Large losses have already occurred in some places including our Herring Brook and Mattapoisett Neck study sites.

How are marshes doing around Buzzards Bay?

- ➔ **Around the bay about 9% of surveyed areas within marsh complexes were bare, while about 91% were covered with marsh plants. The bare areas represent expanding ditches and creeks, patches of bare and shallow water areas on the marsh, and unvegetated banks at the water's edge. Of our sites, Herring Brook and Ocean View Farm had the largest percentage of unvegetated areas, whereas Westport Town Farm, Demarest Lloyd, and Great Sippewissett had the lowest percentages of unvegetated areas.**
- ➔ **Between 2001 and 2019, our marsh sites lost area where vegetation died leaving behind bare soil and open water, where pieces of the marsh-edge broke off into creeks and embayments, and where ditches expanded. Around Buzzards Bay our marsh sites lost about 7% of their area on average, but there was a wide range across sites. Two sites (Demarest Lloyd and Little Bay South) were quite stable with about 1% loss between 2001 and 2019, but two sites had losses of about 20% each (Herring Brook and Mattapoisett Neck). Though our study area at Little Bay South was stable, just outside the area there has been visibly dramatic loss. Across all our sites, a total of about 2 acres of marsh loss was observed. If we scale these observations to all the marshes in Buzzards Bay, it suggests a possible loss of around 200 acres bay wide.**
- ➔ **The ratio of unvegetated to vegetated areas within marsh sites provides an indicator for marsh resilience to change. Values of -0.15 represent a tipping point, above which marsh resilience to sea level rise decreases sharply. Around Buzzards Bay, the average UVVR was 0.17. This value suggests Buzzards Bay marshes are near this tipping point.**
- ➔ **Around Buzzards Bay, 68% of our marsh areas are sitting at a resilient elevation based on analysis of aerial imagery and remotely sensed elevation data. These areas are likely to survive until at least 2100.**

What factors lead to the different patterns of loss and vegetation we see in Buzzards Bay?

- ➔ **There is a large range of conditions observed at the different study sites around Buzzards Bay. This reflects the fact that marshes are complex with many factors affecting their vulnerability to stressors and resilience against loss.**
- ➔ **A variety of stressors can impact marsh health. Of the factors we examined, marsh surface elevation and tidal restrictions were the two factors most closely linked to marsh health.**
- ➔ **Elevation: Surface elevations appear to be the most important factor for marshes.**
 - Marshes with high percentages of elevations above mean high water had lower amounts of bare area and a higher proportion of high marsh species. Our sites with the highest percentages above mean high water are Great Sippewissett, Hammetts Cove, and Westport Town Farm.
 - Low-lying elevations are vulnerable to loss in the next few decades. The amount of these low-lying elevations at each marsh indicates how much will likely be lost soon. Of our sites, those with the highest percentages of low-lying area are Herring Brook, Little Bay North, Mattapoisett Neck, and Wings Neck.
- ➔ **Tidal Restrictions: Marshes with tidal restrictions, even partial tidal restrictions, appear more degraded on average than marshes without restrictions. Sites with tidal restrictions have both higher UVVR values in aerial imagery analysis, and higher percent bare area measured on the ground.**

Are there some silver linings for marshes in poor condition today?

Marshes with low elevations, high rates of recent loss, and poor vegetation condition today are likely to experience greater marsh loss, but may persist if they are able to migrate landward. One example is Ocean View Farm. Ocean View Farm shows many signs of stress and vulnerability, but has significant protected areas to migrate into. Land protection of areas adjacent to marshes is one of the most promising methods to help conserve marshes into the next century. We have observed evidence of marshes expanding landward at some locations. We did not quantify landward expansion as a part of this report, but based on our observations it appears to be occurring at a slower rate than marsh loss.



ACKNOWLEDGEMENTS

We greatly appreciate the support of landowners who provided access for collecting on the ground information. Support for this project was provided by a Southeast New England Program (SNEP) Watershed Grant funded by the U.S. Environmental Protection Agency (EPA), by EPA Cooperative Agreements to the Massachusetts Executive Office of Energy and Environmental Affairs, Buzzards Bay National Estuary Program, and by the Rose Family and Fleetwing Foundations. This research was also funded by the U.S. Geological Survey (USGS) Northeast Climate Adaptation Science Center (NE CASC). The contents do not necessarily reflect the views and policies of EPA.

Suggested Citation

Jakuba, R. W., Besterman, A., Hoffart, L., Costa, J. E., Ganju, N., Deegan, L. (2023)
Buzzards Bay Salt Marshes: Vulnerability and Adaptation Potential. 32pp.



114 Front Street • New Bedford, Massachusetts 02740

(508) 999-6363

info@savebuzzardsbay.org

www.savebuzzardsbay.org



August 23, 2023

Please find enclosed my review of the *Final Draft for Linked Watershed Marsh Assessment and Modeling to Determine Critical Nitrogen Thresholds and Loading for the Herring Brook Estuarine System (Eichner et al. 2023)*

The enclosed document was generated after review of Eichner et al. (2023), review of additional primary literature as cited Section 3.0 of this document, and with twenty-four years of experience conducting research in salt marshes.

If I can answer any remaining questions, please don't hesitate to send me an email or give me a call.

Best Regards,



Craig R. Tobias, PhD
Professor, Marine Sciences
craig.tobias@uconn.edu
(508) 274-9471

1.0 Overview of the Assessment

The aforementioned assessment combines observations and modeling to predict changes in total nitrogen (TN) concentrations in Herring Brook based on future land use and wastewater treatment build-out scenarios. The document also proposes a threshold TN concentration for Herring Brook marsh / estuary ecosystem below which no negative ecological effects would be realized. The assessment asserts that the Herring Brook marsh/estuary ecosystem is currently 'healthy' and proposes 1.0 mg L^{-1} TN concentration as the threshold. This threshold concentration was determined using similar metrics applied by the authors in other marsh creek assessments which included initial consideration of eelgrass, dissolved oxygen, chlorophyll a, macroalgae, and infaunal communities. Some of these estuarine metrics were considered appropriate. Some were not. Ultimately according to the authors, *"Determination of the critical nitrogen threshold for maintaining high quality habitat within the Herring Brook estuarine system was based primarily upon: 1) the systems structure and function as a salt marsh, 2) macroalgal distribution, 3) current benthic community indicators and 4) nitrogen levels"*. In short – based on measurements at Herring Brook and comparison to 20+ other marsh creeks, if TN concentrations in other marsh creeks were low enough to be flushed by tidal exchange, and macroalgae did not accumulate, then benthic infauna was unimpacted and the system was deemed "healthy". Based upon that criterion and cross-site comparison, the assessment set the threshold in Herring Brook at 1.0 mg L^{-1} .

A hydrodynamic water quality model parameterized by watershed nitrogen loading estimates from hydrogeologic simulations and land use models was created and then validated with salinity and TN concentrations measured in Herring Brook. Model simulation scenarios were run that consisted of: 1) no anthropogenic loads; 2) existing land use and wastewater loads via groundwater; 3) future development based on current zoning; 4) increased wastewater inputs of 0.76 mg d^{-1} at 3.0 mg L^{-1} TN to infiltration beds in the Herring Creek watershed. All model results for all scenarios yielded Herring Brook TN concentrations less than the proposed 1.0 mg L^{-1} threshold, with a maximum modeled TN of 0.857 and 0.518 mg L^{-1} at upper and mid Herring Brook respectively. These concentrations are 9% above currently observed values. Of note is that current concentrations in Herring Brook are 10-fold higher in upper Herring Brook and 2.5 fold higher in mid Herring Brook than the no anthropogenic load scenario.

2.0 Review of Assessment

2.1 Modeling and Scenario Testing

The methodology for the hydrodynamic modeling and scenario testing is largely sound. Hydrogeologic partitioning of subsurface flow has good precedent in the region and land use nitrogen load budgeting has also been used extensively and is widely accepted in various forms. There are two aspects worthy of consideration that could lead to model underestimates of nitrogen loads. The first is a parameterization assumption that the passage of groundwater through ponds upgradient of Herring Brook attenuates 50% of the nitrogen load. Stoliker et al. (2016) showed that downgradient recharge of nitrate rich surface waters in a nearby on Cape Cod pond (Ashumet) provides a source of nitrogen back to the shallow aquifer. Furthermore, this nitrate delivery to the aquifer was linked to the organic matter mineralization in sediments. By extension, as ponds fed by N rich groundwater trend towards nitrogen saturation, the organic matter load to sediments will increase and any attenuation of groundwater nitrogen transiting the pond prior to recharge back to the aquifer would decrease over time. In other

words, the amount of net N removal by the ponds is likely to decrease over time. The second model consideration is that the TN data used for validation was collected in the summer when TN concentrations are typically at a minimum due to biological uptake. Hayn et al. (2014) clearly showed that groundwater N loads to W. Falmouth harbor show their best fidelity to water column concentrations in the winter. The same is likely true for Herring Brook. Therefore, if the loading, transport, and attenuation parameters in the model are tuned to generate model output that matches summertime TN concentrations that are low because of biological uptake, then the model is underestimating the true nitrogen load. Concentrations, threshold or otherwise are net measurements, and as I will elaborate on in the next section, attenuation can have an ecological cost.

2.2 Setting the Threshold

While the modeling might have some parameterization and validation issues leading to an underestimate of nitrogen loads, the criteria for setting the TN threshold is more problematic. The metrics used are largely estuary metrics. Some consideration was made to extrapolate to a marsh setting (e.g., discounting eelgrass), but the core criteria used to set the threshold concentration was whether or not there will be enough nitrogen to grow enough macroalgae, given tidal flushing, to impact benthic fauna. This metric remains a modified application of past approaches in other systems that completely misses the fundamental question of marsh sustainability. Here I define marsh sustainability as the perpetuation of vegetated intertidal habitat and all ecological services extant to that habitat. If the marsh goes away, all other traditionally accepted water quality and/or biotic integrity criteria used to assess ecosystem health are irrelevant. The assessment for Herring Brook asserts that the Herring Brook marsh is 'healthy'. It is not.

Marsh sustainability hinges on building elevation at a rate commensurate with local sea level rise, and by either maintaining edge at the marsh-water interface, or migrating into the upland as sea level rises. Marshes failing to achieve these necessities are in a state of decline and their geomorphology changes. The ratio of unvegetated to vegetated area increases, as does the marsh edge to area ratio (i.e., marsh fragments), and area-weighted elevation declines (Ganju et al. 2017; Ganju 2020; Kirwan and Megonigal 2013). Herring Brook marsh is fragmented with a high unvegetated to vegetated ratio, and it has a highest loss rate of vegetated area of any Buzzards Bay marsh over the past 20 years (Jakuba et al. 2023). The geomorphology of Herring Brook is typical of a marsh in decline. Shoreward topography and land use prevents marsh migration at Herring Brook so long term marsh sustainability hinges on its ability to accrete vertically and to resist erosion at the marsh-water interface.

Marshes build elevation by either trapping sediment or building below ground biomass. The capacity to build elevation capital by trapping sediment is limited in Herring Brook, even when above ground vegetation densities are high, because of typically low total suspended solids concentrations in Buzzards Bay. Sediment trapping is further hampered by tidal restrictions at the creek mouth. Therefore, vertical accretion would almost solely occur by building below ground biomass. It is likely that existing nitrogen loading has contributed to the current decline of the Herring Brook marsh by diminishing that mechanism. The striking result from the simulation scenarios presented in the assessment was how much higher the TN concentration is presently relative to the no anthropogenic effect scenario (~ 0.08 vs 0.8 mgL^{-1} - upper creek). The high degree of marsh fragmentation at Herring Brook is consistent with edge deterioration resulting from chronic nitrogen enrichments in marsh creeks described by Deegan et al. (2012). In that study 0.98 to 1.4 mg L^{-1} N was added to a marsh creek for nine years resulting in

enhancement of above ground growth at the expense of below ground biomass. The decrease in below ground biomass destabilized the marsh edge, increased slumping, erosion, and localized fragmentation. Similar changes in geomorphology were measured in Jamaica Bay, NY marshes following decades of nitrogen enrichment with water column concentrations of 1.1 mg L^{-1} (Hartig et al. 2002). Both of these studies show clear negative effects on marsh sustainability at nitrogen concentrations similar to the threshold concentration of 1.0 mg L^{-1} proposed in the assessment. It is certainly conceivable that negative effects begin at lower concentrations.

2.3 Conclusions

The Herring Brook marsh is not healthy. It is not unreasonable to infer that the declining state of the Herring Brook marsh reflects a contribution from increased nitrogen loading to present day and that increasing future nitrogen loads to the system will accelerate marsh deterioration. Given this likelihood, a recommendation to increase the nitrogen load via higher wastewater input on the basis that it is only a nominal increase from present conditions, fails to acknowledge the severity of the present situation and the almost certain negative consequences of adding yet more nitrogen. Furthermore, it ignores close to two decades of work on marsh sustainability and potential linkages to nutrient loading. For Herring Brook, or any other marsh ecosystem, the criteria for determining a nitrogen threshold should not be based on the typical suite of water quality or biotic integrity metrics routinely applied. It should be based on whether current or future nutrient loads will negatively affect the very sustainability of that marsh.

3.0 References

- Deegan, L.A., Johnson, D.S. Warren, R.S., Peterson, B.J., Fleeger, J.W., Fagherazzi, S., Wollheim, W. 2012. Coastal eutrophication as a driver of salt marsh loss. *Nature*. doi:10.1038/nature11533
- Ganju, N.K., Defne, Z., Kirwan, M.L., Fagherazzi, S., D'Alpaos, A., Carniello, L., 2017. Spatially integrative metrics reveal hidden vulnerability of microtidal salt marshes. *Nature*. doi: 10.1038/ncomms14156
- Ganju, N.K., Defne, Z., Kirwan, M.L., Fagherazzi, S. 2020. Are Elevation and Open-Water Conversion of Salt Marshes Connected? *Geophysical Research Letters*. 10.1029/2019GL086703
- Hayn, M., Howarth, R.W., Marino, R., Ganju, N., Berg, P., Foreman, K., Giblin, A., McGlathery, K. 2014. Exchange of nitrogen and phosphorous between a shallow lagoon and coastal waters. *Estuaries and Coasts*, 37: DOI 10.1007/s12237-013-9699-8.
- Jakuba, R. W., Besterman, A., Hoffart, L., Costa, J. E., Ganju, N., Deegan, L. 2023. Buzzards Bay Salt Marshes: Vulnerability and Adaptation Potential. 32pp.
- Hartig, E. K., Gornitz, V., Kolker, A., Mushacke, F., Fallon, D. 2002. Anthropogenic and climate-change impacts on salt marshes of Jamaica Bay, New York City. *Wetlands* 22, 71–89
- Stoliker, D. and others. 2016. Hydrologic Controls on Nitrogen Cycling Processes and Functional Gene Abundance in Sediments of a Groundwater Flow-Through Lake. *Environ. Sci. Technol.* 50: 3649–3657