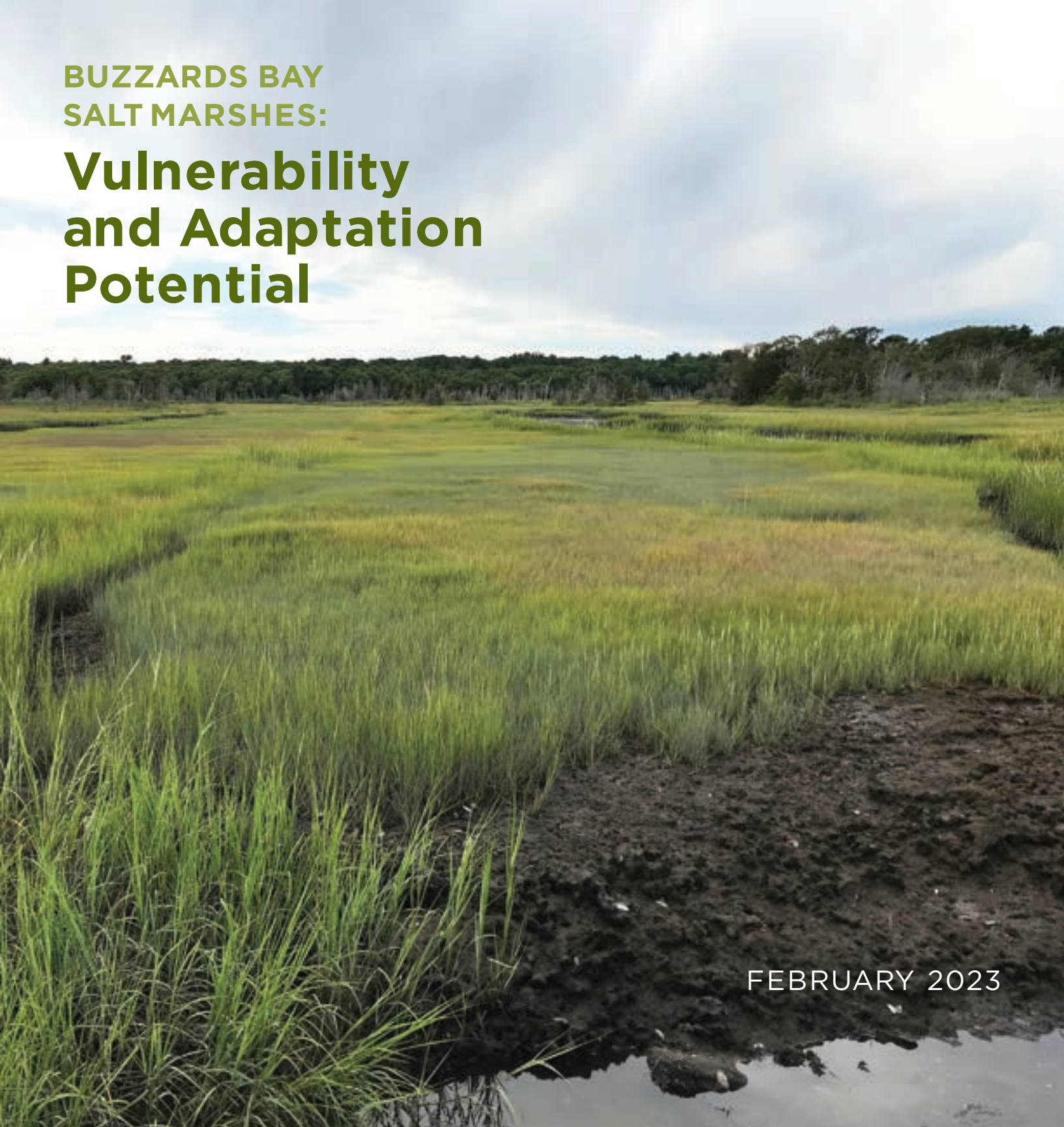


BUZZARDS BAY
SALT MARSHES:

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.

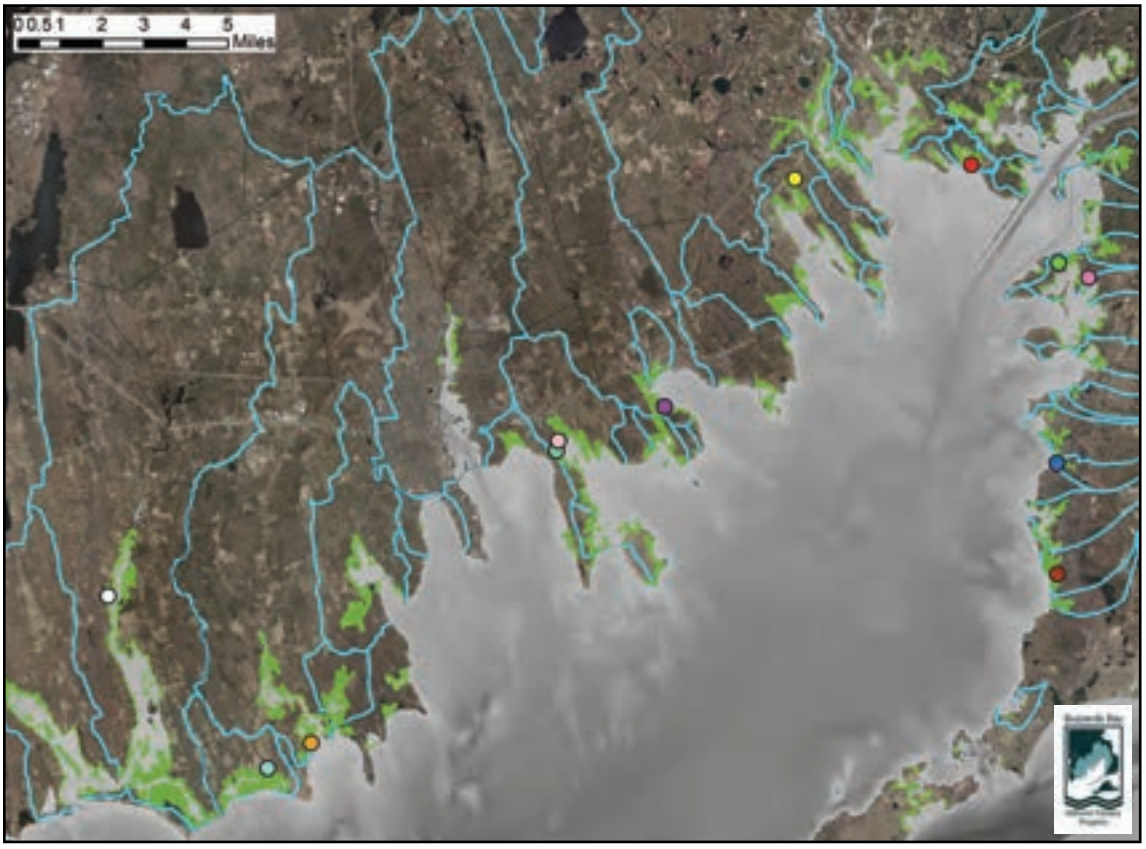
Photo credit for all photographs: Buzzards Bay Coalition

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.



- **WESTPORT TOWN FARM** WESTPORT
- **OCEAN VIEW FARM, ALLENS POND** DARTMOUTH
- **DEMAREST LLOYD** DARTMOUTH
- **LITTLE BAY NORTH** FAIRHAVEN
- **LITTLE BAY SOUTH** FAIRHAVEN
- **MATTAPOISETT NECK** MATTAPOISETT
- **HAMMETTS COVE** MARION
- **LITTLE HARBOR BEACH** WAREHAM
- **WINGS NECK** BOURNE
- **PATUISSET MARSH** POCASSET
- **HERRING BROOK** FALMOUTH
- **GREAT SIPPEWISSETT MARSH** FALMOUTH

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.

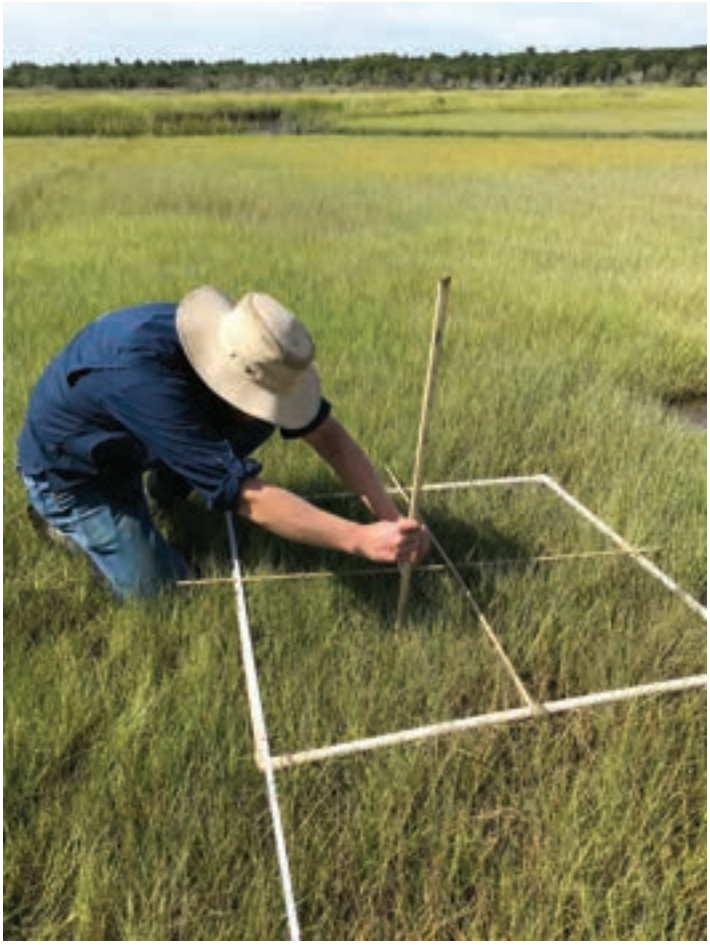
In this report we present a set of metrics describing a marsh's stressors, current condition, and potential for adaptation and apply them to selected sites. These sites represent about 40 acres of the 5,000 acres of salt marsh that exists around Buzzards Bay. However, these marshes represent the diversity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


A


B


C


D


E

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%**

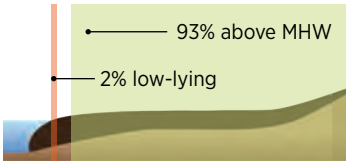
Potential For Adaptation

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

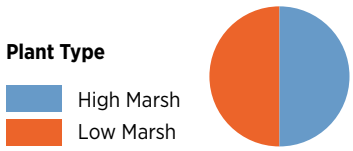


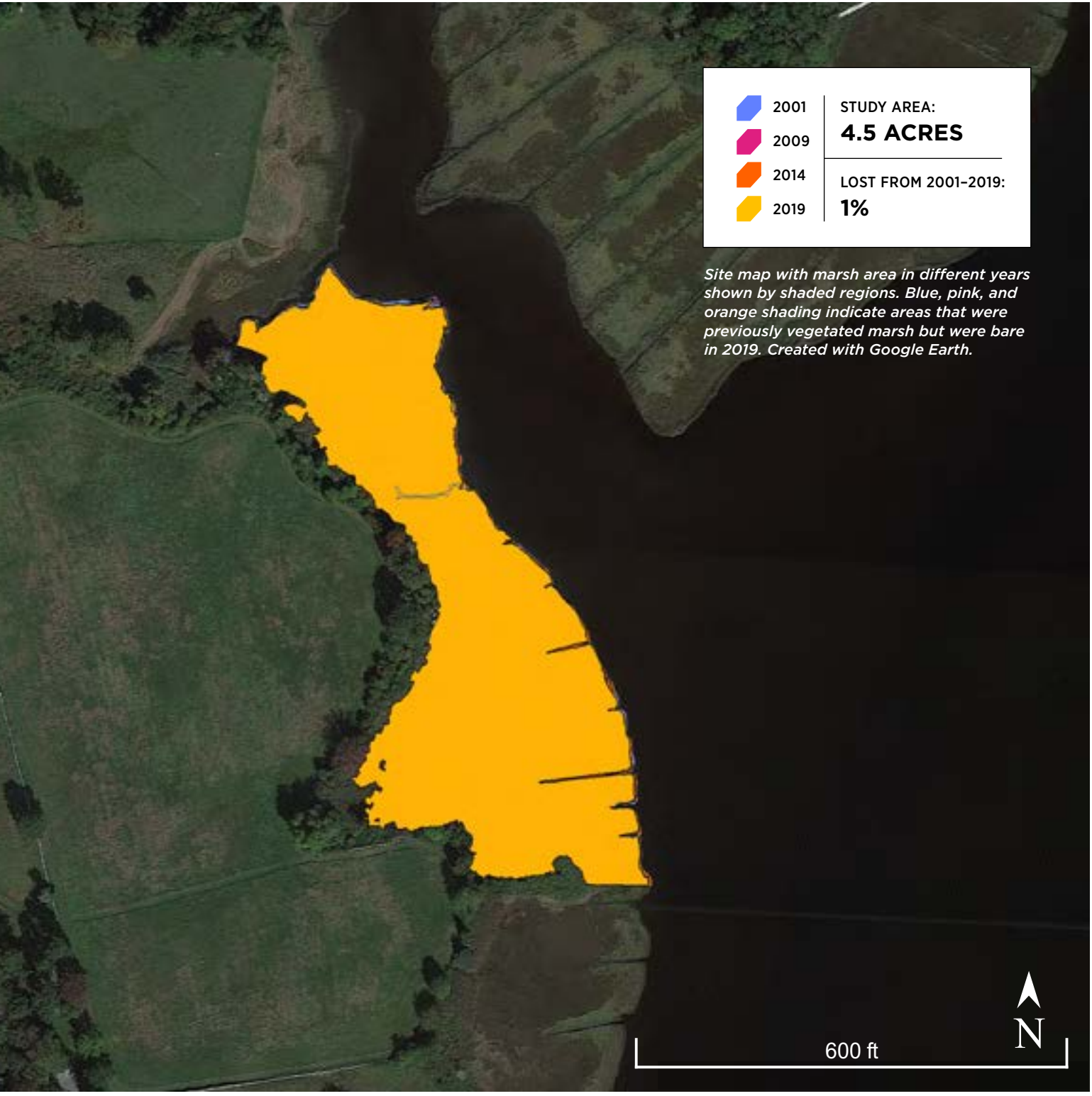
CURRENT CONDITIONS

1% Unvegetated

POTENTIAL FOR ADAPTATION

50% High Marsh





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.

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

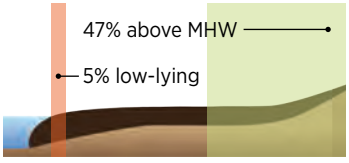
Plant Community	**27%** High Marsh **73%** Low Marsh*
Percent Above MHW	**47%***

*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

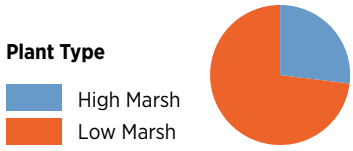


CURRENT CONDITIONS

16% Unvegetated

POTENTIAL FOR ADAPTATION

27% High Marsh



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.

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%**

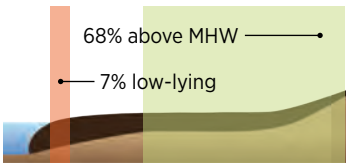
Potential For Adaptation

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

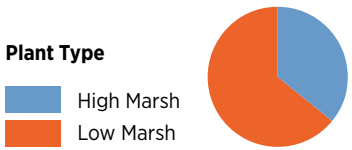


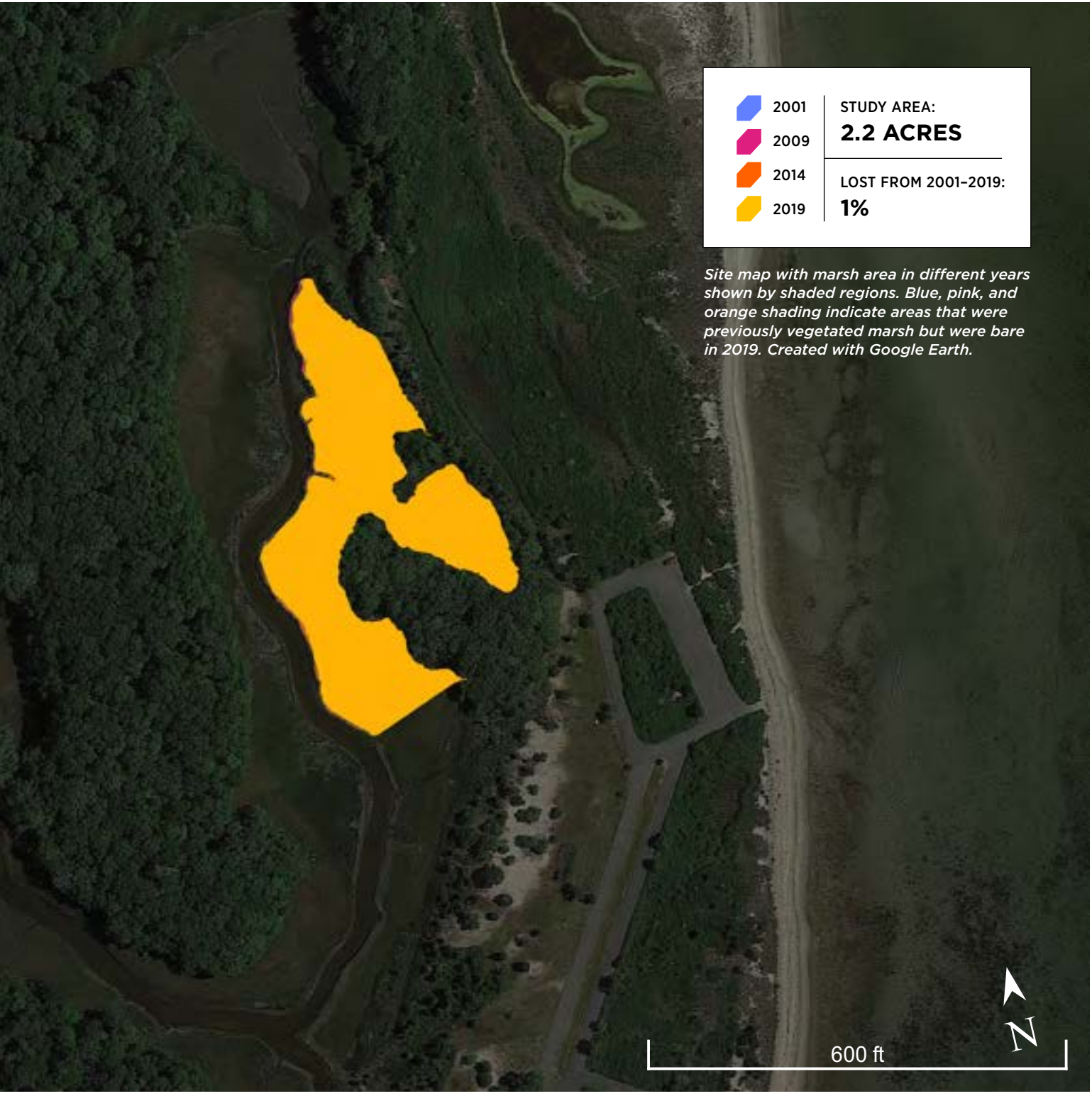
CURRENT CONDITIONS

1% Unvegetated

POTENTIAL FOR ADAPTATION

35% High Marsh





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 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

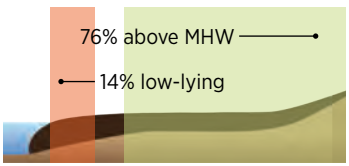
Plant Community	**52%** High Marsh **48%** Low Marsh*
Percent Above MHW	**76%***

*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

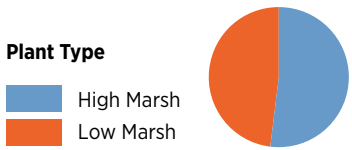


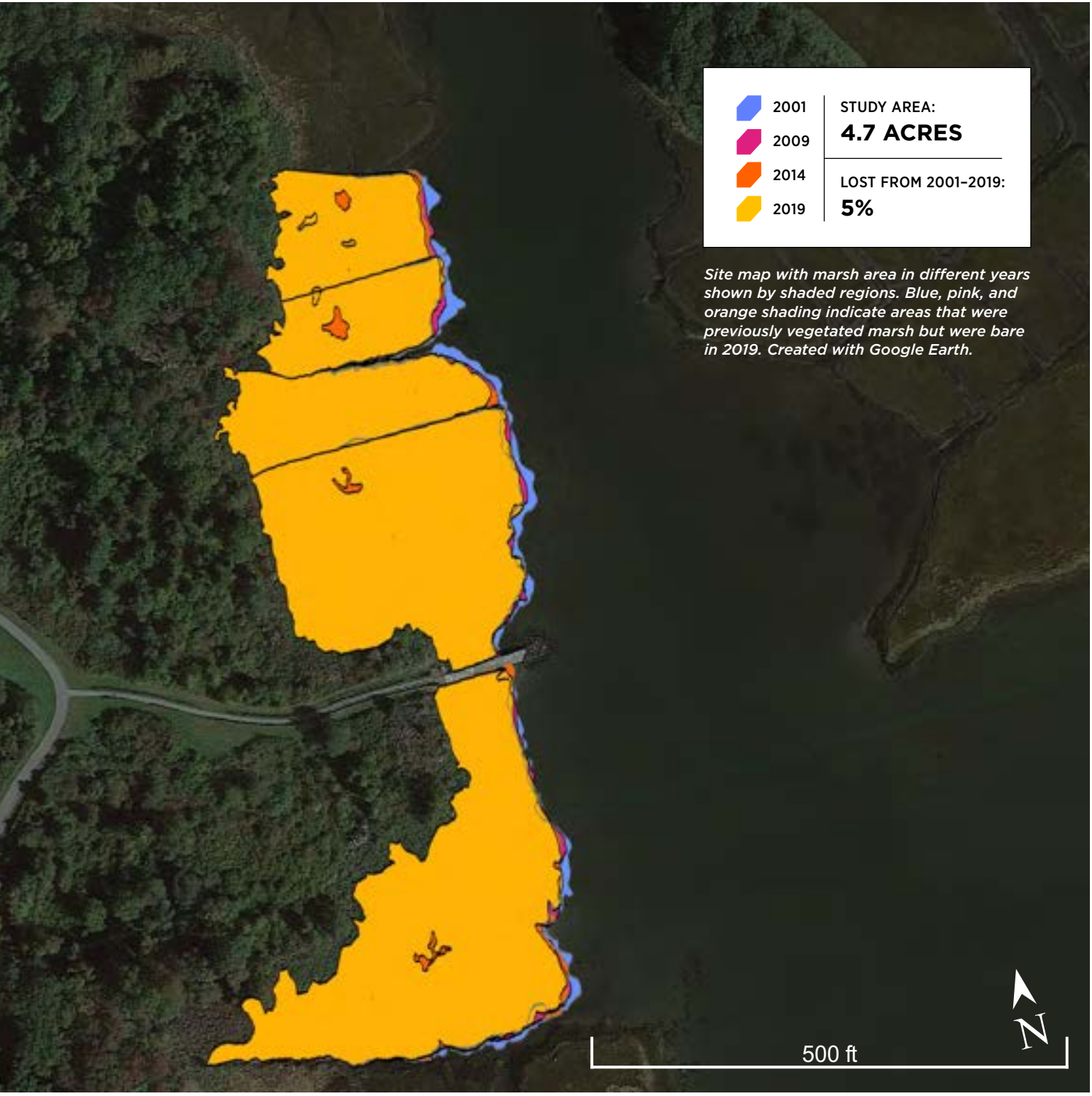
CURRENT CONDITIONS

9% Unvegetated

POTENTIAL FOR ADAPTATION

52% High Marsh





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 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

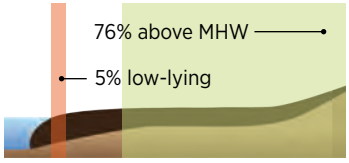
Plant Community	**37%** High Marsh **63%** Low Marsh*
Percent Above MHW	**76%***

*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

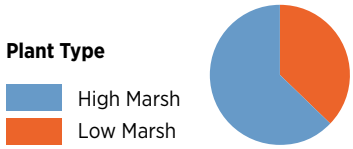


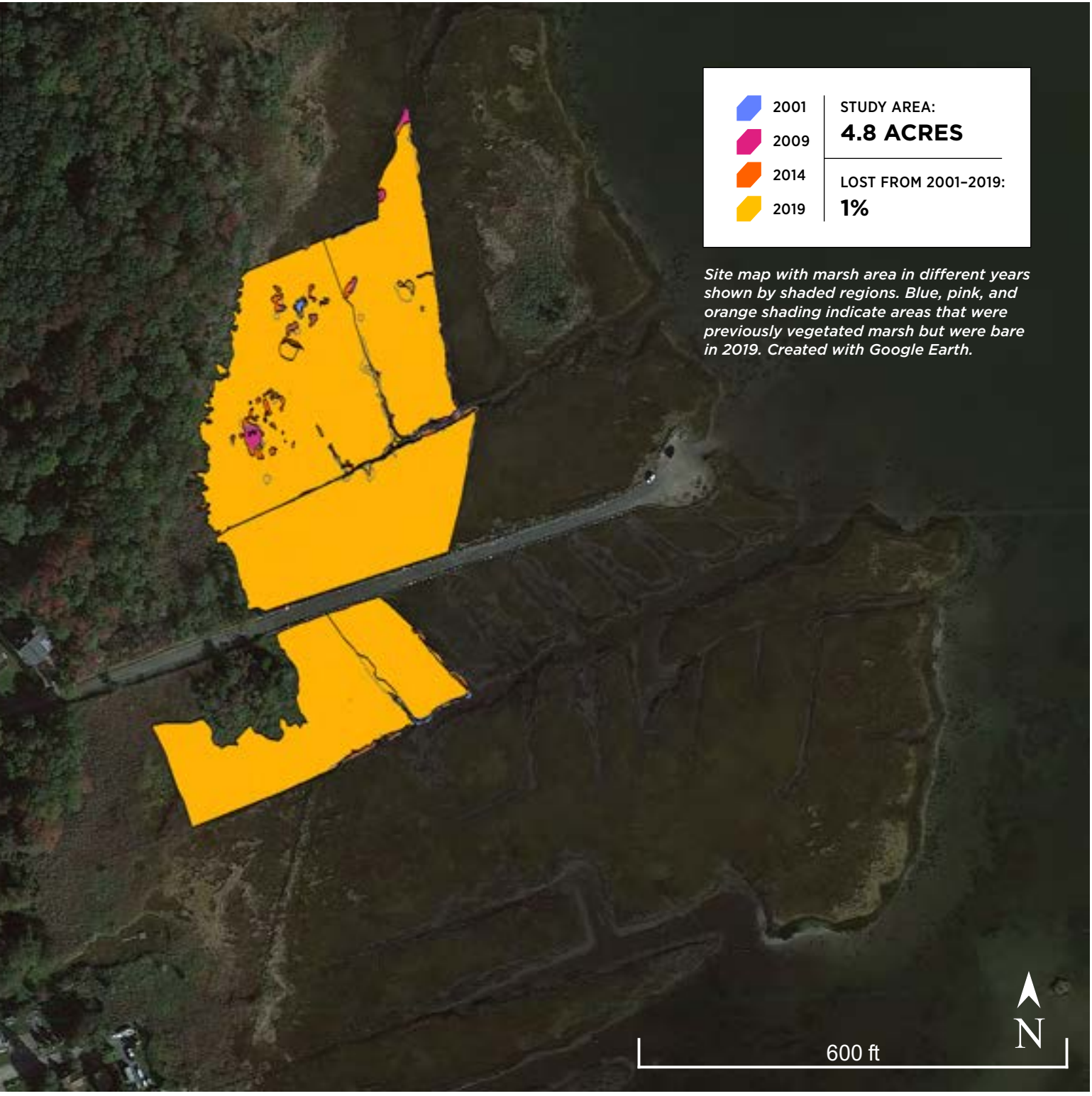
CURRENT CONDITIONS

11% Unvegetated

POTENTIAL FOR ADAPTATION

37% High Marsh





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.

MATTAPOISETT NECK

MATTAPOISETT

70 Mattapoisett Neck Rd. Mattapoisett, MA 02739
Owner: Town of Mattapoisett

The Mattapoisett Neck site lies within a large marsh in the upper part of Mattapoisett Harbor, near the mouth of the Mattapoisett 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%**

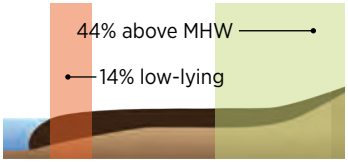
Potential For Adaptation

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

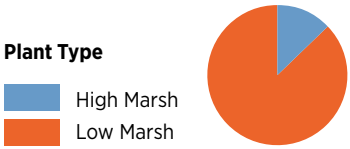


CURRENT CONDITIONS

12% Unvegetated

POTENTIAL FOR ADAPTATION

13% High Marsh



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%**

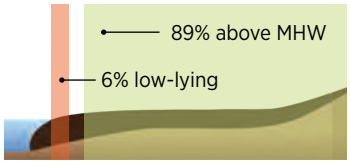
Potential For Adaptation

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

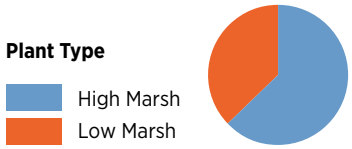


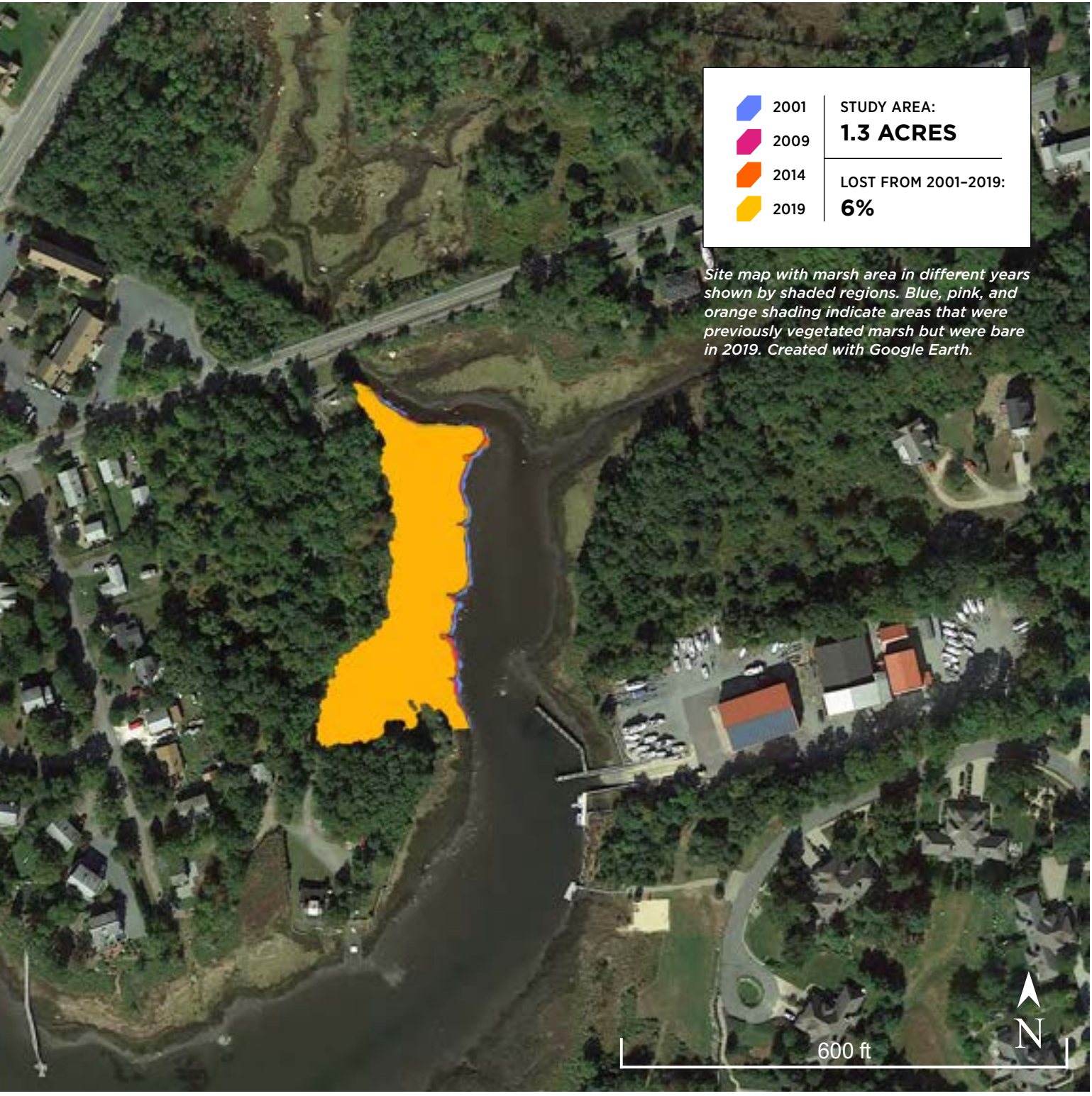
CURRENT CONDITIONS

11% Unvegetated

POTENTIAL FOR ADAPTATION

63% High Marsh





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%**

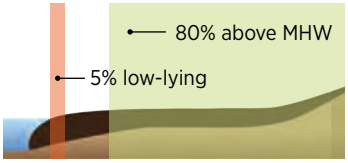
Potential For Adaptation

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

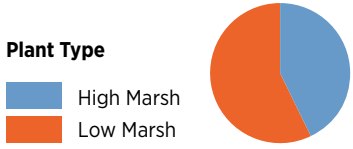


CURRENT CONDITIONS

7% Unvegetated

POTENTIAL FOR ADAPTATION

43% High Marsh



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%**

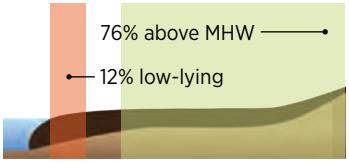
Potential For Adaptation

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

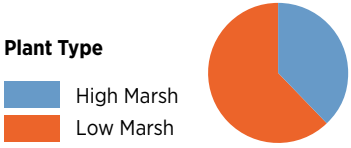


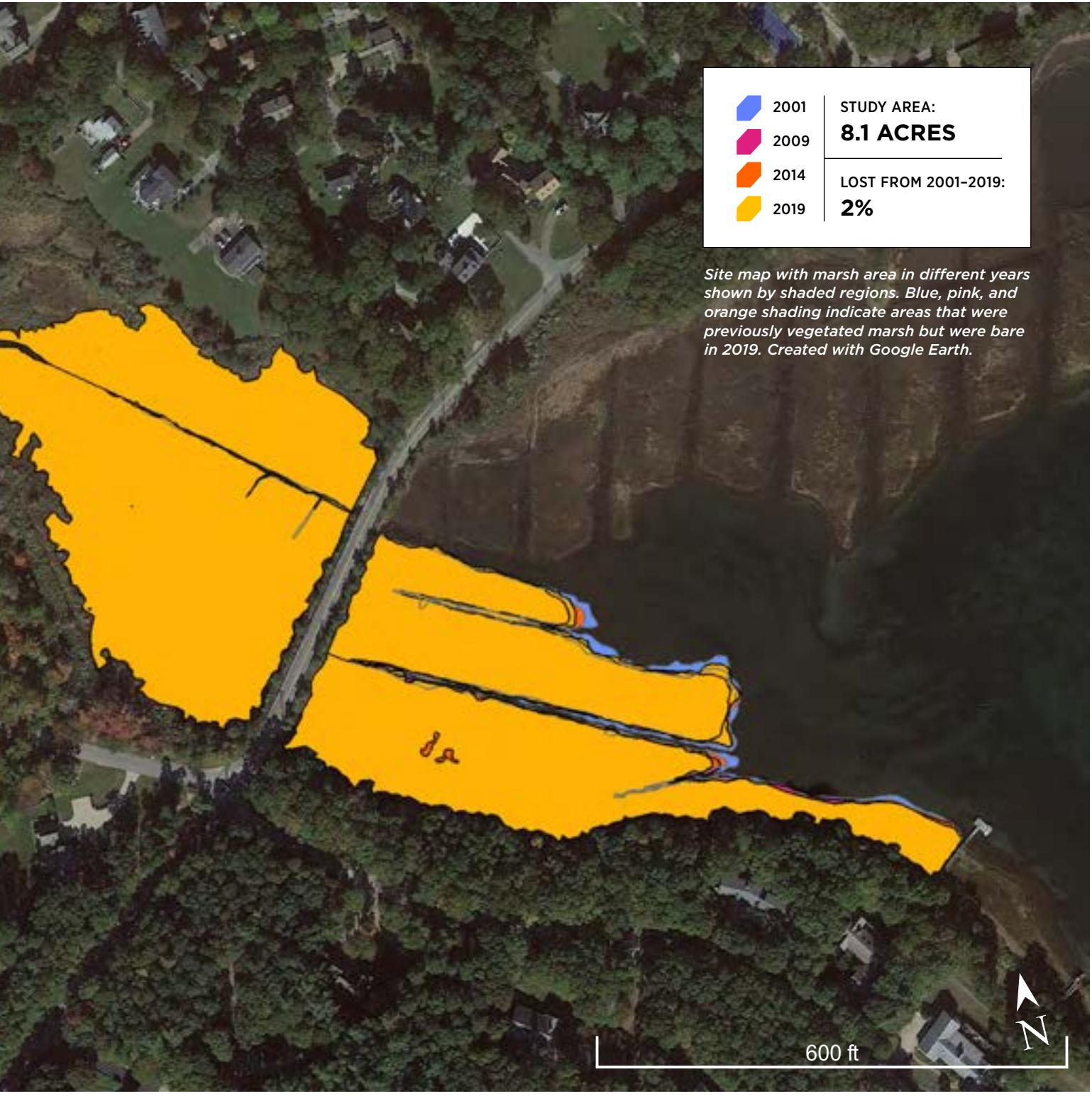
CURRENT CONDITIONS

9% Unvegetated

POTENTIAL FOR ADAPTATION

38% High Marsh





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.

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%**

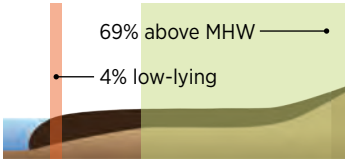
Potential For Adaptation

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

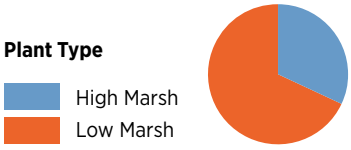


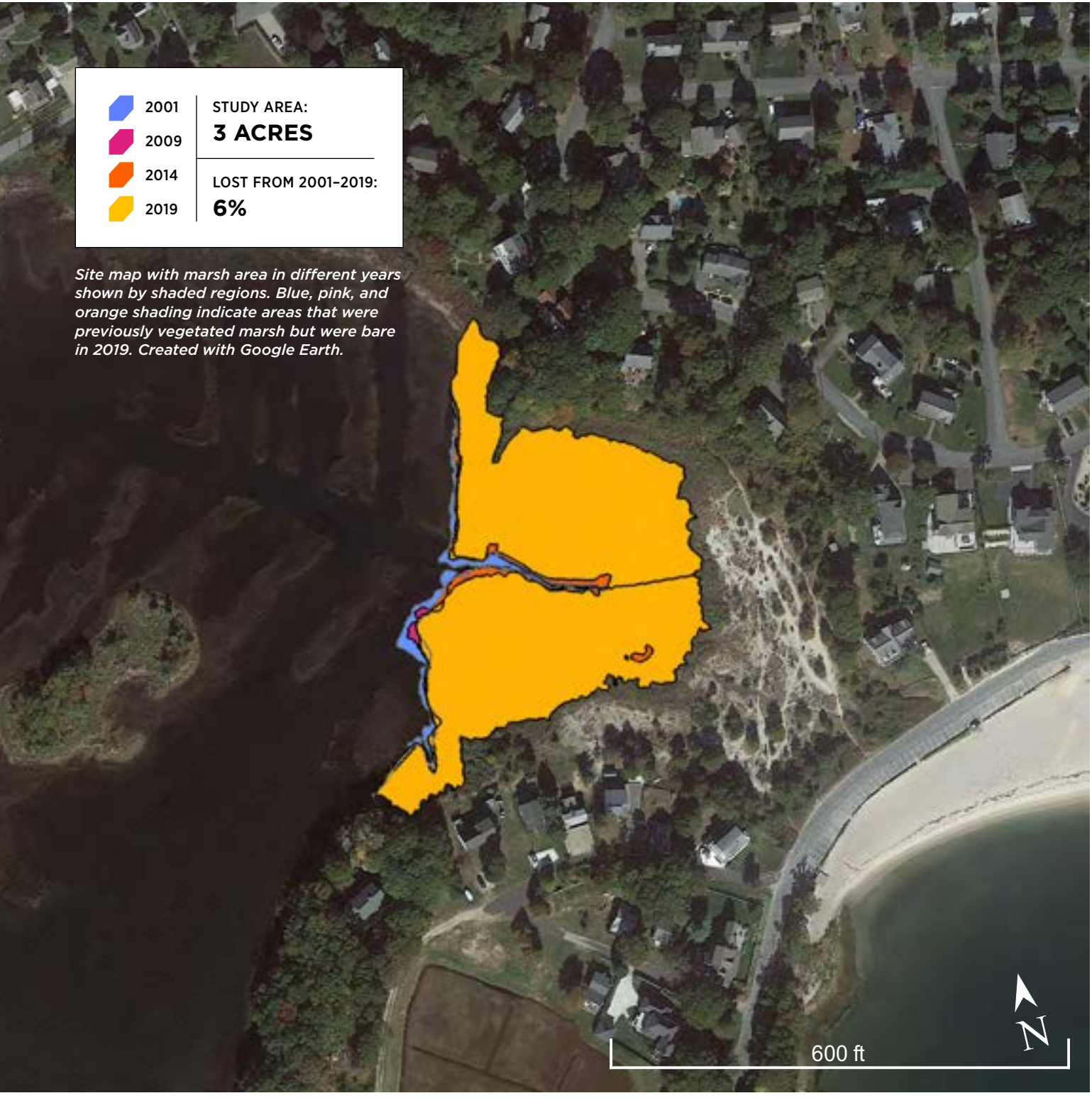
CURRENT CONDITIONS

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%**

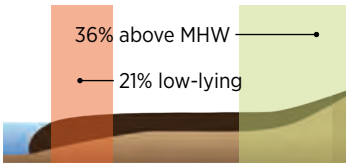
Potential For Adaptation

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

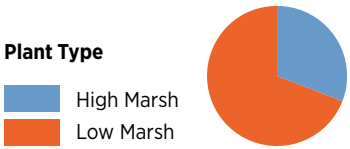


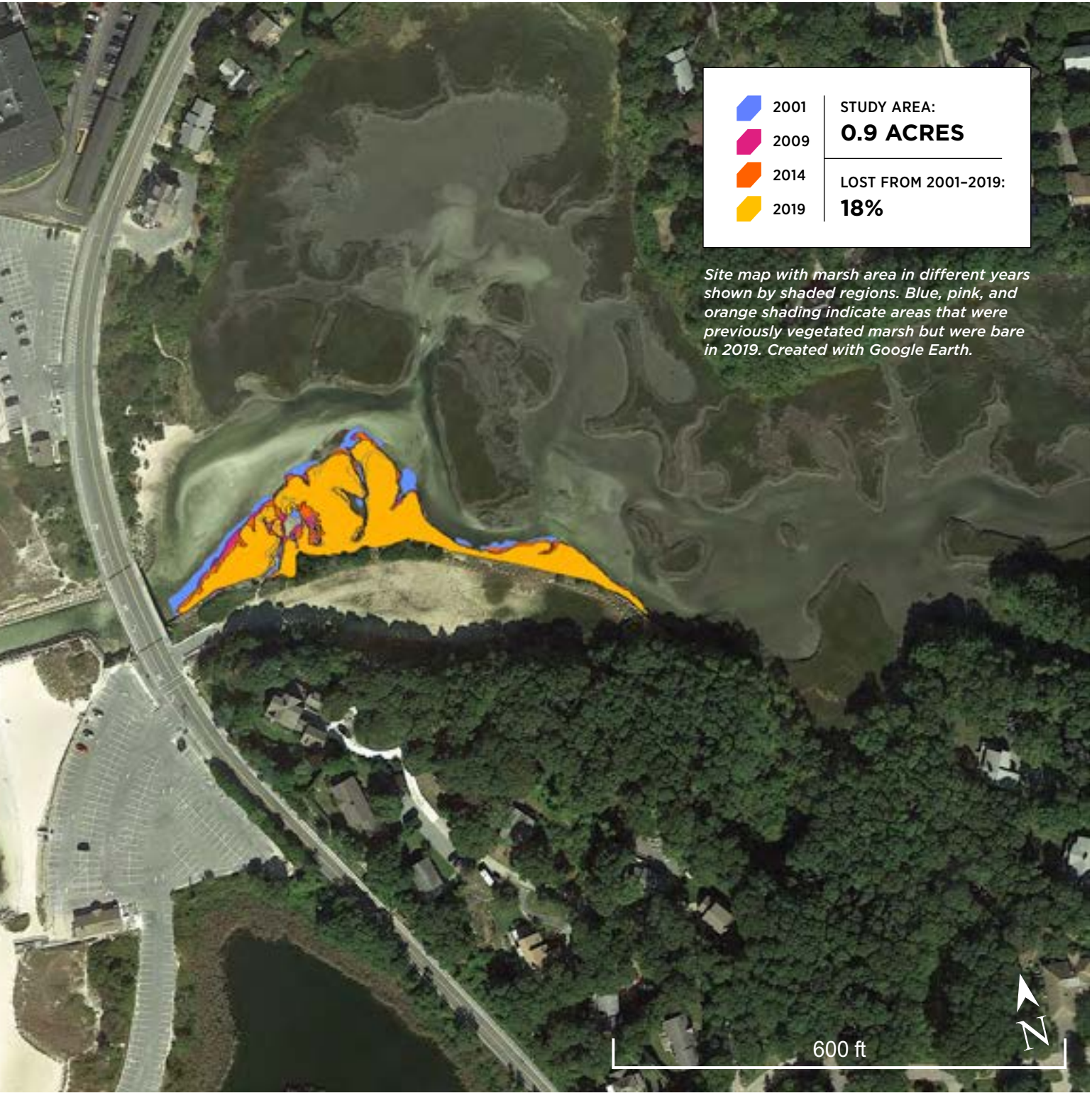
CURRENT CONDITIONS

19% Unvegetated

POTENTIAL FOR ADAPTATION

31% High Marsh





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.

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

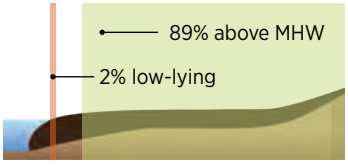
Plant Community	**41%** High Marsh **59%** Low Marsh
Percent Above MHW	**89%**

*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

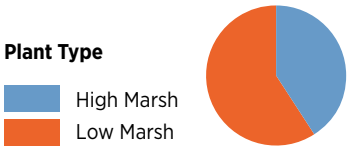


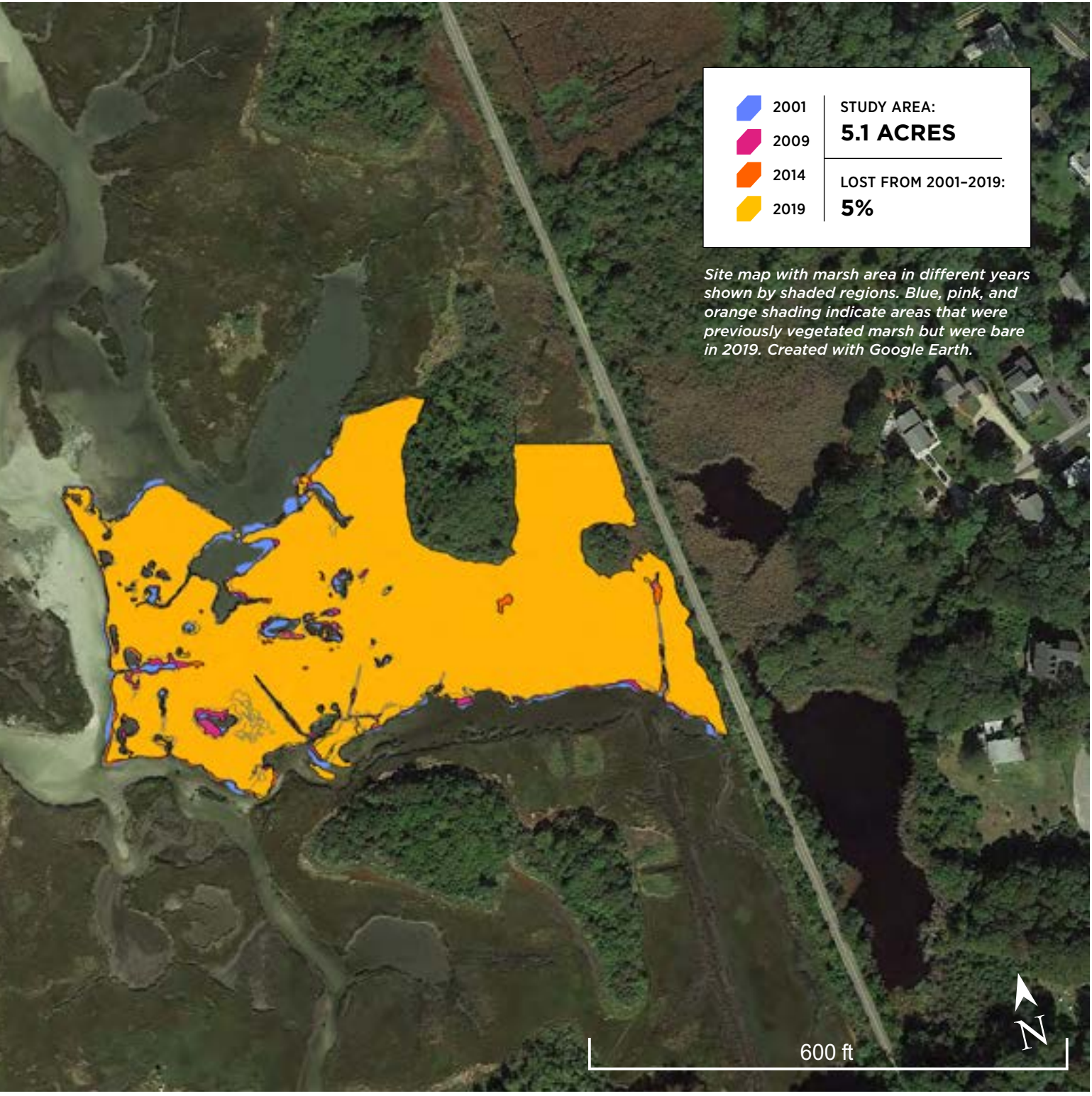
CURRENT CONDITIONS

1% Unvegetated

POTENTIAL FOR ADAPTATION

41% High Marsh





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.

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