SALT MARSH

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1. OVERVIEW

Salt marshes are critical resources as they provide numerous benefits to Narragansett Bay including nursery grounds and other habitat for fish and wildlife, protection from storms and flooding, and filtration of pollutants in the Bay. Using National Wetlands Inventory data, the Narragansett Bay Estuary Program mapped 3,320 acres of salt and brackish marsh throughout Narragansett Bay. In Little Narragansett Bay, 582 acres were mapped, and 946 acres were mapped in the Southwest Coastal Ponds.

The majority of Narragansett Bay's salt marshes were lost between the 1800s and the 1970s due to development, nutrient pollution, sea level rise, and other stressors. However, as global temperatures and sea levels rise more dramatically, it is estimated that 13 to 87 percent of existing salt marsh will be converted to open waters under 1- and 5-foot sea level rise scenarios.

2. INTRODUCTION

Salt marshes are intertidal ecosystems located between land and open salt or brackish water, occurring along protected shorelines and embayments. In this report, the term salt marsh is frequently used as a general term encompassing both salt and brackish marshes. New England salt marshes are characterized by distinct vegetation zonation, related primarily to the tolerance of plants to the frequency and duration of tidal flooding (e.g., Niering and Warren 1980, Bertness 1991, Mann 2000). The low marsh is flooded by daily tides (i.e., regularly flooded) and is dominated by tall-form smooth cordgrass (*Spartina alterniflora*) often occurring as a narrow band along creek banks, ditches, and bayfront margins. The high marsh is flooded by high tides less frequently (i.e., irregularly flooded) and is generally dominated by a mosaic of vegetation, including salt hay (*S. patens*), black rush (*Juncus gerardii*), spike grass (*Distichlis spicata*), and short-form smooth cordgrass, among others. The high marsh can also contain sparsely vegetated shallow depressions, or pannes. At the border, flooded by the highest of tides and storm tides, high tide bush (*Iva frutescens*) and common reed (*Phragmites australis*) are often encountered. These plants facilitate sediment accretion (where possible) through decreasing the current velocity of water. As they grow, die, and partly decay, they add organic matter to the sediments, forming an organic soil known as peat, which helps stabilize the marsh substrate. In addition to marsh vegetation, other features such as tidal creeks, ditches, and pools define the marsh landscape and provide important habitat for fish species, most notably common mummichog (*Fundulus heteroclitus*), sticklebacks (*Gasterosteus aculeatus, Apeltes quadracus*), and silversides (*Menidia menidia*) (e.g., Raposa 2008).

It is important to mention the relationship of salt marshes to sea level rise (Reed 1995). Southern New England salt marshes form as smooth cordgrass colonizes intertidal flats. The vegetation facilitates the trapping of sediment, while roots and rhizomes grow below the marsh surface. These processes—sediment accumulation on the wetland surface and the build-up of peat (belowground live and decaying plant material and sediment)—contribute to the vertical growth or increase in marsh elevation, ultimately resulting in conversion of low marsh areas to high marsh (those marsh areas of higher elevation). However, the increase in salt marsh elevation must keep pace the continuous rise in sea level, or the marshes will become submerged and too wet to support marsh plants. Redfield (1972), in a classic study of a Cape Cod salt marsh, described the process of salt marsh establishment and vertical growth in response to sea level rise. Salt marshes in southern New England have been growing and responding to sea level rise, some for three or four centuries (e.g., Redfield 1972, Orson et al. 1987). However, there is recent evidence that some Narragansett Bay salt marshes are getting wetter, with high marsh vegetation being replaced by the more flood-tolerant smooth cordgrass and open water (Donnelly and Bertness 2001, Raposa et al. 2015a). The marshes may not be keeping pace with rates of sea level rise that appear to have accelerated in recent decades and are anticipated to increase even more dramatically as global temperatures rise (see "Sea Level" chapter).

Salt marshes have been recognized for multiple benefits: shoreline stabilization, flood mitigation, filtering nutrients and pollutants, carbon sequestration, nursery grounds for commercially and recreationally important species, and habitat for fish and wildlife (Roman et al. 2000, Valiela and Cole 2002, Gedan et al. 2011, Mcleod et al. 2011). At the time of first European contact, salt marshes were used for pasture and hay production, and as marine access points (Gedan et al. 2009). With industrialization, salt marshes were filled in for development, landfills, or disposal sites for dredge material; hardened; tidally restricted with dams or road crossings; polluted by runoff; and ditched for mosquito control (Gedan et al. 2009). Alterations to the landscape of salt marshes through human activity led to their decline, with the loss of approximately half of the salt marshes in Rhode Island and Massachusetts, and larger losses in the upper Narragansett Bay region (Bromberg and Bertness 2005, Cicchetti in prep).

The ecological and aesthetic values of salt marshes are well documented (see reviews: Geden et al. 2009, Weinstein and Kreeger 2000), and thus the declining area of marshes has been widely researched and discussed among the scientific, advocate, and policy-maker communities. Researchers have attempted to establish loss rates for Narragansett Bay. Bromberg and Bertness (2005) estimated that Rhode Island lost 53 percent of salt marsh area between 1832 and 1988, while Massachusetts lost 41 percent of salt marshes between 1832 and 1999. Loss was most significant in the early portion of this period, due to urbanization and the Industrial Revolution. Another wave of loss occurred during the late 1940s to 1950s with suburbanization of Greenwich Bay and the upper East and West Passages. After the 1950s, acreage loss slowed but did not come to a halt.

Throughout Narragansett Bay from the 1950s to 1990s roughly 10 percent of coastal marsh has been lost (net loss of 306 acres of estuarine marsh; Table 1), with these losses attributed mostly to filling and changes from herbaceous marsh vegetation to shrub or forested wetland in response to tidal restriction and ditching (Tiner et al. 2004). From a recent analysis of aerial photographs dating from 1972 to 2011, investigators studied 36 salt marshes throughout Narragansett Bay, Little Narragansett Bay, and the Southwest Coastal Ponds and report a 17 percent loss of vegetated salt marsh (Watson et al. 2016). This loss of vegetated marsh was related to erosion of marsh shorelines, expansion of creeks, and conversion of vegetated marsh to ponds or unvegetated wet areas on the marsh surface. Similar findings are reported for other areas of southern New England (Smith 2009). Multiple drivers and stressors, all with complex interactions and feedbacks, have been implicated in this loss of vegetated marsh, including sea level rise, temperature increase, nutrient enrichment (Deegan et al. 2012), and crab herbivory on *Spartina*, among others (Deegan et al. 2012, Bertness et al. 2014, Geden et al. 2011, Roman 2016).

Recent estimates of salt marsh area throughout Narragansett Bay and the southern shore of Rhode Island all range from 2,600 to 4,000 acres regardless of sampling year (Table 1). This variability is likely due to differences in the resolution of the aerial images, differences in salt marsh classification, and variability among the photointerpreters. Some of this variability was reduced in the Tiner et al (2004) comparison of 1950s and 1990s aerial photographs as the same classification and photointerpretation methods were employed. Documenting temporal changes in the area of salt and brackish marshes represents an important assessment to pursue as an indicator of marsh status throughout the watershed.

Table 1. Salt marsh acreage throughout Narragansett Bay, Little Narragansett Bay, and the Southwest Coastal Ponds.

Year	Study Areas	Area (acres)[1]	Source
1951/2	Narragansett Bay	2,966	Tiner et al. 2004
1974	Rhode Island	3,668	Halvorson and Gardiner 1976
1988	Narragansett Bay	4,000	Bromberg and Bertness 2005
1996	Narragansett Bay	2,660	Tiner et al. 2004
1996	Little Narragansett Bay, Southwest Coastal Ponds, and Block Island[1]	1,625	Huber 2003
2010	Narragansett Bay	3,776	Tiner et al. 2014
2010	Narragansett Bay, Little Narragansett Bay, Southwest Coastal Ponds, and Block Island[1]	4,172	RI CRMC 2015

[1] These reports include areas that are outside of our study areas. Due to the presentation of the data, we cannot extract those areas. Therefore, the acreage estimates above may overestimate the true extent of salt marsh within study areas.

3. METHODS

The Narragansett Bay Estuary Program compiled salt marsh data using U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) data for Rhode Island, Massachusetts, and Connecticut. These data were selected as the geospatial source for the extent of salt marsh within the study area because the data collection methods used by the U.S. Fish and Wildlife Service were consistent among all three states. The National Wetlands Inventory used imagery from 2008 for Massachusetts (except for the upper Taunton River imagery from 1995) and from 2010 for Rhode Island and Connecticut. The original National Wetlands Inventory data were processed by the Estuary Program using ArcGIS and filtered for two specific categories (salt marsh and brackish marsh). These salt marsh and brackish marsh categories were defined through the land cover codes used in the Sea Level Affecting Marshes Model (RI CRMC 2015). The inventory database maps were produced using U.S. Geological Survey topographic maps, and thus the wetland areas were analyzed at a scale of 1:24,000 or smaller. For segments and sections of Narragansett Bay's estuarine waters, salt marsh and brackish marsh were identified, and areas were calculated for each segment and section by their location.

The National Wetlands Inventory (NWI) survey estimated a total of 4,854 acres of salt marsh across Narragansett Bay, Little Narragansett Bay, and the Southwest Coastal Ponds. This assessment is similar to that of the SLAMM report (Table 1; RICRMC 2015). Even though the same aerial imagery and NWI maps were used, a difference in area was expected due to how the data were analyzed. The SLAMM report used municipal boundaries, while the Estuary Program analysis used watershed boundaries. State-level datasets—including Rhode Island's Ecological Communities assessment (Enser et al. 2011), the Massachusetts Department of Environmental Protection's wetlands dataset, and the Connecticut Department of Energy and Environmental Protection's wetlands dataset—were all more detailed than the NWI dataset and may have captured smaller, fringing marshes that the NWI wetlands inventory did not. However, those datasets are not comparable across state lines, so a cohesive watershed analysis would not be possible. Therefore, even though the wetlands inventory had a coarser resolution, it provided the best geographical coverage for the purposes of this analysis.

4. STATUS

A. Narragansett Bay

Narragansett Bay had 3,320 acres of salt marsh, according to the National Wetlands Inventory data (Figure 1; Table 2). The majority (68 percent) of marsh area was concentrated within the Warren, Palmer, and Barrington Rivers (902 acres), followed by the West Passage (551 acres), the Sakonnet River (441), and the Taunton River estuary (369 acres).

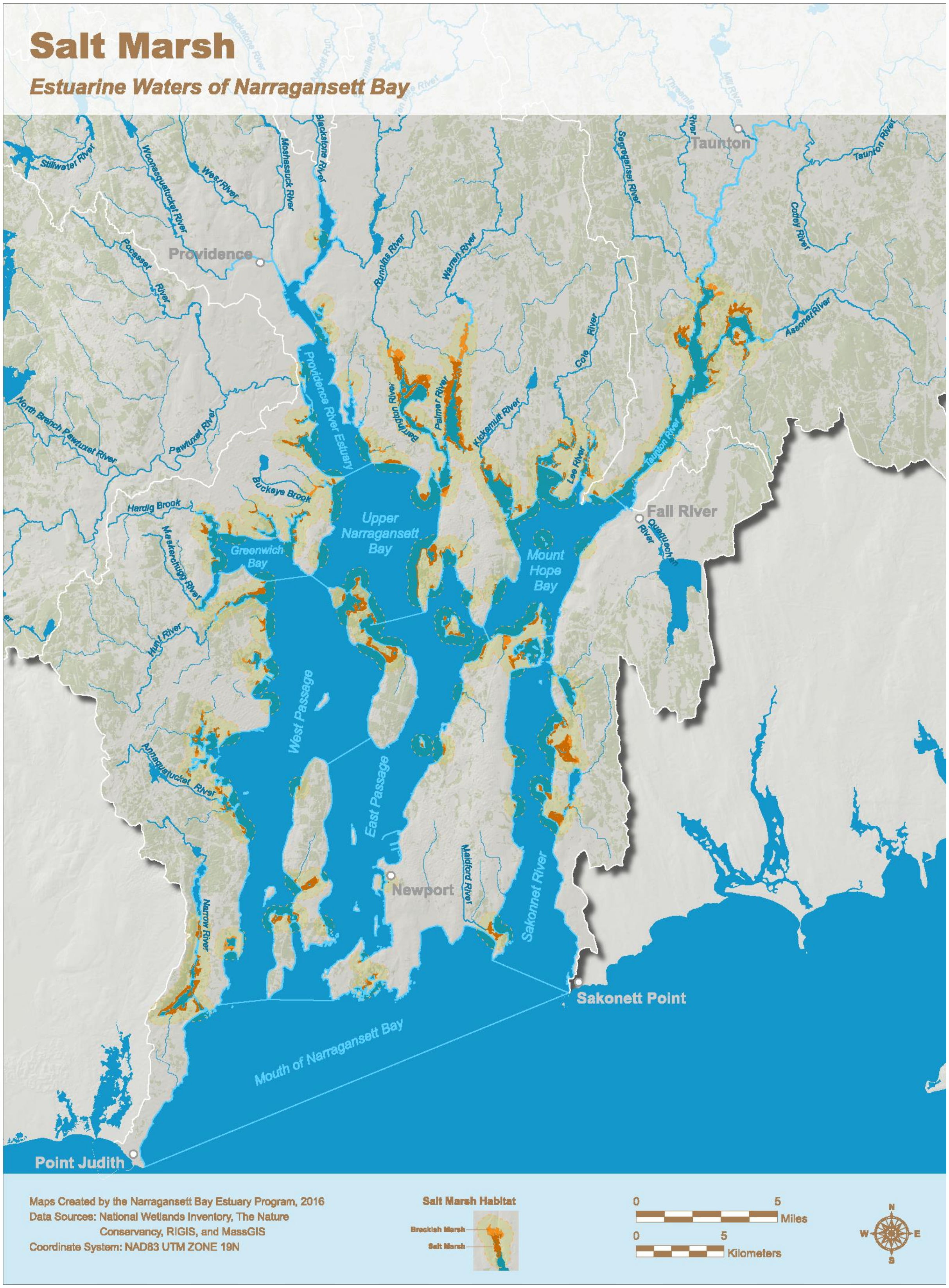

Figure 1. Salt marsh in the estuarine waters of Narragansett Bay.

Table 2. Area (acres) of salt and brackish marshes in Narragansett Bay.

Narragansett Bay Sections	Marsh Area (acres)	
	Salt Marsh	Brackish Marsh
Narragansett Bay	**2,884**	**436**
Providence River Estuary	***72***	***16***
Upper Providence River	1	0
Watchemoket Cove	3	2
Bullocks Cove	3	2
Seekonk River	4	0
Middle Providence River	11	1
Lower Providence River	50	11
Omega Pond	0	0
Pawtuxet River	0	0
Waterplace Park	0	0
Warren, Palmer, & Barrington Rivers	***705***	***197***
Warren River	32	15
Barrington River	300	77
Palmer River	373	105
Taunton River Estuary	***325***	***44***
Assonet River	7	0
Upper Taunton River	31	39
Lower Taunton River	52	5
Broad Cove	83	0
Assonet River & Bay	152	0
Upper Narragansett Bay	***173***	***23***
Buckeye Brook	5	20
Upper Bay	168	3
Mill Gut	0	0
Mount Hope Bay	***225***	***50***
Lower Cole River	16	0
Lee River	28	7
Upper Cole River	44	4
Mount Hope Bay	53	39
Kickemuit River	84	0
Greenwich Bay	***82***	***10***
Greenwich Cove	0	1
East Greenwich Bay	2	0
Buttonwoods Cove	15	2
Warwick Cove	21	1

Narragansett Bay Sections	Marsh Area (acres)	
	Salt Marsh	Brackish Marsh
West Greenwich Bay	21	5
Apponaug Cove	23	1
Greenwich Cove	0	1
West Passage	***503***	***46***
Wesquage Pond	4	21
Bissel Cove	11	0
Quonset Harbor	14	6
Potowomut River	58	1
Wickford Harbor	66	7
Dutch Harbor	115	4
Upper West Passage	117	4
Middle West Passage	120	3
Lower West Passage	0	0
East Passage	***144***	***11***
Lower East Passage	1	0
Newport Harbor	2	0
Middle East Passage	13	4
Potter's Cove	19	0
Bristol Harbor	21	7
Nag Pond	38	0
Upper East Passage	50	0
Sakonnet River	***406***	***35***
Nannakuaket Pond	6	0
The Cove	45	4
Lower Sakonnet River	52	0
Almy's Creek	75	5
Upper Sakonnet River	228	26
Narrow River	***232***	***1***
Mouth of Narragansett Bay	***15***	***3***
Gooseberry Bay	15	3
Easton Bay	0	0
Mouth of Narragansett Bay	0	0
Sachuest Bay	0	0
TOTAL	**3,320**	

B. Little Narragansett Bay

Little Narragansett Bay had 582 acres of salt marsh, according to the wetlands inventory data (Table 3). The majority of the salt marsh area was concentrated within Little Narragansett Bay proper (368 acres), followed by the Lower Pawcatuck River (79 acres) and Wequetequock Cove (65 acres).

Table 3. Area (acres) of salt and brackish marshes in Little Narragansett Bay.

	Marsh Area (acres)	
	Salt Marsh	**Brackish Marsh**
Little Narragansett Bay	**561**	**21**
Upper Pawcatuck River	*5*	*11*
Wequetequock River	*54*	*0*
Wequetequock Cove	*65*	*0*
Lower Pawcatuck River	*76*	*3*
Little Narragansett Bay	*361*	*7*
TOTAL	**582**	

C. Southwest Coastal Ponds

The Southwest Coastal Ponds had 946 acres of salt marsh according to the wetlands inventory data (Table 3). The majority of the marsh area was concentrated within Point Judith Pond (314 acres), followed by Winnapaug Pond (191 acres) and Ninigret Pond (188 acres) (Table 4).

Table 4. Area (acres) of salt and brackish marshes in the Southwest Coastal Ponds.

	Marsh Area (acres)	
	Salt Marsh	**Brackish Marsh**
Southwest Coastal Ponds	**820**	**126**
Cards Pond	*0*	*10*
Green Hill Pond	*16*	*21*
Little Maschaug Pond	*0*	*0*
Maschaug Pond	*0*	*0*
Ninigret Pond	*168*	*20*
Point Judith Pond	*271*	*43*
Potter Pond	*49*	*10*
Quonochontaug Pond	*141*	*6*
Trustom Pond	*0*	*0*
Winnapaug Pond	*175*	*16*
TOTAL	**946**	

5. DISCUSSION

Climate change is a major cause of changes in salt marsh form and function, and these changes may have interactive effects with stressors commonly associated with anthropogenic impacts (Gedan et al. 2011, Crain et al. 2008 and 2009, Oczkowski et al. 2015, USEPA 2016, Roman 2016). In the past, marshes have accreted sediment and peat on pace with sea level rise, but that has changed for Narragansett Bay salt marshes in the last 30 years (Carey et al. 2015), as increases in marsh surface elevation are lagging behind relative sea level rise. As previously noted, the marshes are getting wetter as evidenced by conversion of high marsh vegetation to the more flood-tolerant salt marsh cordgrass and by the increase in open water on marsh platforms. Moreover, although the build-up of marsh peat is an important process contributing to the vertical growth of marshes, peat is decomposing at a greater rate than in the past, which is assumed to be related to increasing temperature (Carey et al. 2015).

In order to quantify how salt marsh extent will change with rising seas, both Rhode Island and Massachusetts have applied the Sea Level Affecting Marshes Model (SLAMM). Findings from this model have been published for Rhode Island (RI CRMC 2015) and are forthcoming for Massachusetts. It is estimated that Rhode Island will lose 13 to 87 percent of its existing coastal wetlands under 1- and 5-foot sea level rise scenarios, respectively, with marshes converting to open water (see "Sea Level" chapter). SLAMM also indicates locations where marshes can migrate landward in response to sea level rise, but in urban/suburban watersheds that are common to the Narragansett Bay watershed, landward migration corridors are often blocked by development (e.g., seawalls, bulkheads, roads). Moreover, relatively steep topographic upland slopes will impede landward marsh migration. Preservation of upland areas that could serve as suitable migration corridors for tidal marshes represents an important strategy to mitigate expected marsh loss from sea level rise.

In addition to sea level rise, nutrient loading has an influence on salt marsh elevation and may be a contributing factor to the observed trend toward wetter or drowning marshes throughout Rhode Island (Watson et al. 2014, Deegan et al. 2012). With nutrient enrichment, marsh peat can decompose at a high rate and collapse, no longer serving the important role of maintaining marsh elevation. Further, under high nutrient regimes, marsh plants tend to allocate more biomass to the aboveground portion of the plant than belowground, resulting in decreased peat formation (e.g., Wigan et al. 2014). There is also evidence that the purple marsh crab (*Sesarma reticulatum*) is increasing in Rhode Island salt marshes and grazing on cordgrass along creek banks, an important factor contributing to vegetation dieback and marsh loss (Bertness et al. 2014). In response to sea level rise, high nutrient loads and increasing temperatures leading to peat decomposition and collapse, low sediment supply (a natural characteristic of New England watersheds, Roman et al. 2000), increasing herbivory on marsh plants, and other interacting factors, salt marshes are drowning, and the outlook for long-term sustainability is grim given projections of increased sea level rise and global temperatures. A positive factor to consider is that nutrient loading to Narragansett Bay from wastewater treatment facilities is declining (RIDEM 2005, see "Nutrient Loading" chapter), thus reducing this stressor on marshes.

6. DATA GAPS AND RESEARCH NEEDS

A multi-parameter monitoring protocol is necessary to document trends in salt marsh extent in Narragansett Bay and associated coastal areas, changes in marsh cover types (i.e., plant species, marsh features such as ponds, pannes, wet areas), and an assessment of sea level rise and other stressors affecting the long-term sustainability of marshes. Regarding marsh extent and changes in marsh physiographic features (e.g., creeks, ponds, shallow pannes), Watson et al. (2016) provide an excellent approach to be pursued into the future. Their data, mapping 36 marsh sites throughout the Bay watershed and southern coast of Rhode Island, provide insight into vegetation changes and factors responsible for loss of vegetated marsh, including erosion of marsh shorelines and creeks and interior ponding.

Another related and valuable approach to pursue throughout the study area is the Rhode Island Salt Marsh Monitoring Strategy (Raposa et al. 2015b). This approach is in the early stages of implementation (Ekberg et al. 2014, Save the Bay 2014). It includes a three-tiered approach including monitoring of salt marsh extent (similar to Watson et al. 2016), rapid assessment (i.e., characterization of soil properties to understand peat stability), and detailed data collection at a select number of sites. Further, this monitoring strategy evaluates trends in sea level rise and marsh migration opportunities. These approaches (Watson et al. 2016, Raposa et al. 2015b) provide repeatable data collection methods and quantitative data analysis methods in order to detect trends with a high degree of certainty. In addition, perhaps aspects of a biotic integrity index approach for Massachusetts salt marshes could be incorporated into a watershed-wide monitoring protocol (McGarigal et al. 2013).

The Narragansett Bay National Estuarine Research Reserve worked with the National Oceanic Atmospheric Administration to use e-cognition software to identify and map 16 different salt marsh cover types (e.g., low marsh high marsh, pools, pannes) using color orthophotography. The intention was to monitor the extent of salt marsh (similar to Watson et al. 2016, but in a more automated manner) and to monitor marsh condition, such as identifying changes from vegetated marsh to open water habitat. These results, when completed, will provide a more detailed assessment of salt marsh in Narragansett Bay.

Researchers know of many methods to help salt marshes gain ground against sea level rise: resiliency techniques of deposition of a thin layer of sediment, for example, or restoration of marshes to resist sea level rise using shoreline stabilization techniques, or preservation of upland to give marshes places to migrate (Wigand et al. 2015). However, comparisons of those methods to find the best fit for the Narragansett Bay area have yet to occur. A cost-benefit analysis coupled with multi-year monitoring could help determine the best methods, and if those methods will help the salt marshes gain elevation in the long run. Other topics that should be addressed through future research include defining what habitats are likely to replace salt marsh after sea level rise, the difference in functions and values of these different habitats, and socioeconomic gains or losses associated with these changes. Answering questions like these may lead to a better understanding and prioritization of restoration efforts.

Landward migration of salt marshes in response to sea level rise is an important process that should be facilitated. The existing SLAMM maps identify areas where marshes could migrate landward, but incorporating additional information, such as soils data and high-resolution elevation or topographic data of possible migration corridors, will enhance our ability to identify migration corridors with increased confidence. Also, expanded efforts to preserve migration corridors from future development, through conservation easements, acquisition, and other methods, should be pursued.

As noted, sea level rise is a major factor contributing to the recent trend of Narragansett Bay's marshes tending toward submergence, but there are also many other factors interacting with sea level rise (e.g., nutrients, grazing, sediment supply, increasing temperature, increasing CO_2). Additional empirical research and modeling is required to understand the complexity of these interactions so that effective adaptation strategies can be implemented.

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