State of Narragansett Bay and Its Watershed
2017 Technical Report

Bay Ecosystem Condition Indicators

CHAPTER 11: SEAGRASSES

NARRAGANSETT BAY ESTUARY PROGRAM

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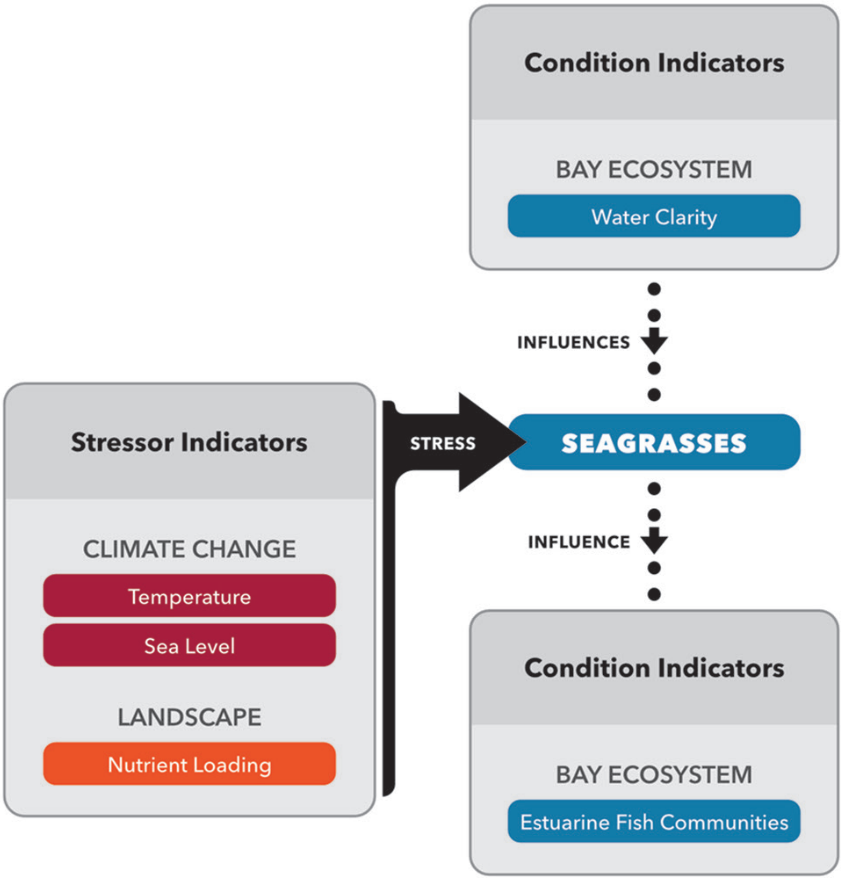
Overview



BACKGROUND

- Seagrasses are aquatic vascular flowering plants that stabilize sediments and provide vital habitat and nursery grounds for fish and shellfish. Because they require good water quality to thrive, seagrasses serve as good indicators of ecosystem health. Temperature, sea level, and nutrient loading are important stressors, and water clarity is an important influence on seagrass condition.

KEY FINDINGS

- ***Status:*** A survey in 2012 mapped 513 acres of seagrass in Narragansett Bay. Of that total acreage, 29 acres were found in Greenwich Bay, where seagrass had not been documented since the 1990s. A survey conducted in 2016 mapped 479 acres of seagrass in Narragansett Bay, according to initial analysis of the data.

- ***Trends:*** Prior to the 1930s, seagrasses were prevalent throughout Narragansett Bay, including the Providence River Estuary and Mount Hope Bay. A marked decline related to increased nutrient loading, disease, and physical removal or disturbance occurred, and now seagrasses are found predominantly in the Lower Bay. Between 2006 and 2012, seagrass increased by 37 percent (132 acres) in areas of Narragansett Bay that were mapped in both years. Seagrass acreage decreased by seven percent from 2012 to 2016, but the acreage in 2016 (479 acres) was still greater than the 2006 acreage (357 acres). Under climate change, warmer temperatures and sea level rise may become increasingly important stressors that impair seagrass growth and survival.

Introduction

Two types of seagrasses are found in Narragansett Bay: eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*). Eelgrass is a predominantly estuarine species, while widgeon grass thrives in lower salinity waters (Kantrud 1994). Eelgrass is taller than widgeon grass, and the two species have been observed intermixing within seagrass beds in Narragansett Bay (Peg Pelletier, USEPA-Atlantic Ecology Division, Narragansett, Rhode Island, personal communication). To date, most seagrass research in Narragansett Bay has focused on eelgrass, and additional research on widgeon grass would be useful for a more comprehensive understanding of seagrass dynamics.

Because seagrasses require abundant light, they are restricted to shallow areas with clear water. The slope of the substrate and the amount of light that can penetrate the water determine the greatest distance that seagrasses can grow from shore (Dennison and Alberte 1985, Mann 2000). Seagrasses in the temperate zones flower between 50 and 70°F (10 and 20°C). They live in areas with low nutrient input, as high nutrient levels tend to favor nuisance macroalgae, phytoplankton, and epiphytic growth that shade seagrasses and reduce their growth (Mann 2000). Seagrasses are perennial plants, but in the shallowest areas (less than approximately 3.3 feet [1 meter] depth), they may be considered functional annuals because the plants are often killed by ice scouring, freezing, and other seasonal stresses (Costa 1988).

Prior to the 1930s, the total extent of seagrass acreage in the estuarine waters of the Bay was vast—encompassing almost all sections of the Bay that were less than 10 to 12 feet deep, including the Providence River Estuary and Mount Hope Bay (Doherty 1995). Seagrasses then declined markedly, and now they are found only in the Lower Bay (Bradley et al. 2007, 2013). The decline was caused by stressors such as nutrient enrichment and physical disturbances (e.g., dredging, removal through boating or other activities, and storms), as well as by a seagrass disease outbreak in the 1930s that caused extensive losses along the Atlantic coast (Costa 1988, Short et al. 1993, Doherty 1995, Kopp et al. 1995).

Seagrass beds are highly productive and help to create complex habitats for a variety of other species that live in, on, or above the seabed, and they help to maintain the physical, chemical, and biological integrity of the ecosystem (e.g., Thayer et al. 1975, Collette and Klein-MacPhee 2002, Liu and Nepf 2016). In southern New England, seagrass beds provide nursery grounds, refuge, and feeding grounds for many commercially important and iconic organisms, such as bay scallops, flounder, striped bass, tautog, and seahorses (e.g., Heck et al. 1989). Additionally, seagrasses bind and stabilize sediment by slowing water currents and causing sediment to drop out of the water column (Liu and Nepf 2016). This provides food for animals that feed on the bottom and creates clearer water, increasing the amount of light reaching the seagrass blades (Orth 1977).

The productivity of seagrass beds makes them potentially valuable candidates for long-term carbon storage to mitigate the impacts of climate change (known as blue carbon). Seagrasses store or sequester carbon through both primary production and accumulation in the sediment (Lavery et al. 2013, Greiner et al. 2013). Data on organic carbon content of living seagrasses and sedimentary accumulation in seagrass meadows worldwide show a significant amount of storage capacity—roughly 4.6 to 9.3 billion tons (4.2 to 8.4 petagrams) of carbon (Fourqurean et al. 2012). The amount of organic carbon stored per unit area of seagrass is similar to that of forests worldwide (Fourqurean et al. 2012). Protection and conservation of seagrass beds enhances global and regional resilience to climate change.

The ecological and societal value of seagrasses makes it critical to adequately monitor trends in the extent and condition of seagrass beds. Seagrasses are considered "coastal canaries" because the loss of seagrass often indicates ecosystem degradation and loss of ecosystem services, which can result in habitat regime shifts (Orth et al. 2006, Costello and Kenworthy 2011).

In this chapter, the Narragansett Bay Estuary Program reports on the extent (in acres) of seagrasses based on mapping data collected in 2006 and 2012. Mapping data were also collected in 2016, and initial results became available in late June 2017. The chapter discusses findings about seagrass acreage in the context of other recent and historical data, and explores how present and future stressors such as nutrient loading, warmer temperatures, and sea level rise may affect seagrasses.

Methods

In the past twenty years, several surveys have mapped seagrasses in Narragansett Bay and nearby waterbodies (Table 1). In 1996, the Narragansett Bay Estuary Program and partners commissioned aerial photography to map seagrass habitat (Huber 1999). The 1996 survey documented approximately 100 acres of seagrass in Narragansett Bay. Starting in 2006, the Rhode Island Eelgrass Task Force (Task Force) continued and refined these efforts by developing a set of mapping and monitoring protocols (Raposa and Bradley 2009). The Task Force is composed of researchers from the University of Rhode Island, state agencies, and non-profit organizations. Seagrass surveys using the Task Force protocols were conducted in 2006 and 2012. Mapping efforts were repeated in 2016.

Technological and methodological differences between the 1990s surveys and the 2000s surveys make statistical comparisons and analysis of change between them problematic (Bradley et al. 2007). For that reason, this report focuses on data from the 2006 and 2012 surveys (Bradley et al. 2007, 2013).

The Task Force developed a three-tiered system (Raposa and Bradley 2009) for monitoring and mapping seagrasses, based on the work of Neckles and colleagues (2012). In Tier 1, mapping is performed based on aerial photography with seagrass signatures digitized by a GIS technician; fieldwork is then conducted to augment and ground-truth the mapping data. The Task Force recommended conducting Tier 1 mapping and ground-truthing every three to five years. The 2006 and 2012 mapping efforts were Tier 1 mapping assessments conducted in Narragansett Bay with the methodology and results summarized by Bradley and colleagues (2007, 2013). While data from the other two tiers in the three-tiered system are not included in this chapter, the methods are important to summarize as background for the Data Gaps and Research Needs section. In Tier 2, a subset of seagrass beds is monitored annually for percent cover and other metrics of eelgrass condition. Currently, Tier 2 monitoring is conducted only at one seagrass bed in Narragansett Bay, at the southern end of Prudence Island. In Tier 3, biomass and other metrics are monitored repeatedly over multiple time scales within individual sites, following the SeagrassNet protocol (Short et al. 2002). Although Tier 3 monitoring occurred at two sites (Fort Getty in Jamestown and T-Wharf on Prudence Island) from 2005 to 2013, it is currently suspended due to lack of funding.

Table 1. Inventory of seagrass surveys using aerial photography in Narragansett Bay since 1996.

Year Photographs Taken	Orthophotograph Resolution	Citation
1996	1:12,000	Huber 1999
2006	1:5,000	Bradley et al. 2007
2012	1:5,000	Bradley et al. 2013
2016[1]	1:5,000	Bradley et al. 2017

[1] Detailed analysis of the 2016 data has not been completed as of this writing (June 2017)

The Estuary Program analyzed seagrass status in the 2006 and 2012 surveys, and assessed persistence of seagrass beds between the two surveys. Mapping was conducted at a 1:1500 scale and ground-truthing focused on new beds or areas of gain/loss (Bradley et al. 2013). Areas of seagrass present in both surveys were considered persistent, while other areas were classified as either gains or losses of seagrass acreage. No formal error analysis has been conducted but is planned for future survey datasets.

Because this report focuses on only two years of data, differences in seagrass coverage are discussed as changes, not as trends.

To examine historical changes that occurred prior to the 2006 survey, the Estuary Program conducted a presence-and-absence analysis of seagrass based on a comprehensive review of historical documents and oral history ranging from 1848 to 1994 (Doherty 1995, Kopp et al. 1995) and a comparison of those

Table 2. Changes in seagrass acreage in Narragansett Bay between 2006 and 2012. Acreage values were rounded to the nearest whole number. Data are reported for sections (bold) and segments (plain) of Narragansett Bay (see Introduction and Appendix for definitions of geographic areas). Persistence is the number of acres that were consistent between the two years of record. N/A means not applicable because 2006 acreage was zero or unknown. N/D means no data were collected. Mapping was conducted at a 1:1500 scale and ground-truthing focused on new beds or areas of gain/loss (Bradley et al. 2013).

Narragansett Bay Sections	Total Acreage 2006	Total Acreage 2012	Persistence (acres)
Providence River Estuary	**0**	**0**	**N/A**
Warren, Palmer, and Barrington Rivers	**0**	**0**	**N/A**
Taunton River	**0**	**0**	**N/A**
Upper Narragansett Bay	**0**	**0**	**N/A**
Mount Hope Bay	**0**	**0**	**N/A**
Greenwich Bay(1)	**0**	**29**	**N/A**
Apponaug Cove	0	1	N/A
East Greenwich Bay	0	3	N/A
West Greenwich Bay	0	25	N/A
West Passage	**55**	**91**	**44**
Upper West Passage	3	2	1
Wickford Harbor	5	7	5
Middle West Passage	15	29	12
Lower West Passage	32	53	25
East Passage	**210**	**258**	**183**
Middle East Passage	89	112	77
Newport Harbor (Brenton Cove)	4	6	3
Lower East Passage	118	140	103
Sakonnet River	**31**	**52**	**26**
Lower Sakonnet River	31	52	26
Narrow River (Pettaquamscutt River)	**N/D**	**24**	**N/A**
Mouth of Narragansett Bay	**61**	**59**	**48**
Gooseberry (Island) Bay	35	21	28
Mouth of Narragansett Bay	26	38	20
TOTAL	**357**	**513**	**301**

(1) Widgeon grass was mapped in Greenwich Bay in 2012; no eelgrass or widgeon grass was documented in Greenwich Bay in the 2006 mapping survey.

Table 3: Comparison of historical presence of seagrass (1840 to 1994) to recent presence (2006 and 2012). Data are reported for sections (bold) and segments (plain) of Narragansett Bay. Green cells indicate presence of seagrass documented in Doherty (1995), Kopp et al. (1995), Bradley et al. (2007), or Bradley et al. (2013). Light blue cells preceding green cells indicate likely presence of seagrass based on Doherty (1995) and Kopp and colleagues (1995). "Unknown" indicates no evidence of seagrass presence; this does not imply absence, just no evidence of presence. For the 2006 and 2012 data, a blank cell indicates no seagrass found, and the numbers inside the green cells correspond to acreage in Table 2. Thick vertical line indicates the separation between historical data and the recent data. Information from Huber (1999) was not included because that report only calculated Bay-wide acreage, not acreage in specific areas of the Bay.

Narragansett Bay Sections	1840–1899	1900–1939	1940–1979	1980–1994	2006	2012
Providence River Estuary						
Upper Providence River			*Unknown*	*Unknown*		
Bullock Cove				*Unknown*		
Middle Providence River						
Lower Providence River						
Warren, Palmer, and Barrington Rivers						
Warren River			*Unknown*	*Unknown*		
Barrington River	*Unknown*			*Unknown*		
Palmer River						
Taunton River						
Taunton River (all segments)	*Unknown*	*Unknown*	*Unknown*	*Unknown*		
Upper Narragansett Bay						
Upper Bay						
Mount Hope Bay						
Lower Cole River			*Unknown*	*Unknown*		
Lee River			*Unknown*	*Unknown*		
Upper Cole River			*Unknown*	*Unknown*		
Mount Hope Bay	*Unknown*			*Unknown*		
Kickemuit River				*Unknown*		
Greenwich Bay						
Greenwich Cove			*Unknown*	*Unknown*		
East Greenwich Bay						3
Buttonwoods Cove			*Unknown*	*Unknown*		
Warwick Cove			*Unknown*	*Unknown*		
West Greenwich Bay						25
Apponaug Cove			*Unknown*	*Unknown*		1
West Passage						
Potowomut River						
Wickford Harbor					5	7
Middle West Passage					15	29
Bissel Cove				*Unknown*		
Dutch Harbor			*Unknown*	*Unknown*		
Quonset (Allen) Harbor						
Upper West Passage					3	2
Lower West Passage					32	53

Table 3 continued.

Narragansett Bay Sections	1840–1899	1900–1939	1940–1979	1980–1994	2006	2012
East Passage						
Upper East Passage						
Lower East Passage					118	140
Newport Harbor (Brenton Cove)					4	6
Middle East Passage					89	112
Potter Cove				*Unknown*		
Bristol Harbor						
Sakonnet River						
Nannaquaket Pond				*Unknown*		
The Cove						
Lower Sakonnet River	*Unknown*				31	52
Upper Sakonnet River	*Unknown*					
Narrow River (Pettaquamscutt River)						
Narrow River (all segments)	*Unknown*	*Unknown*	*Unknown*	*Unknown*	*Unknown*	24
Mouth of Narragansett Bay						
Gooseberry (Island) Bay	*Unknown*				35	21
Mouth of Narragansett Bay					26	38
Sections of Narragansett Bay with Known Presence of Seagrass	9	9	9	8	4	6

findings with more recent Task Force assessments (Bradley et al. 2007, 2013). The U.S. Coast and Geodetic Survey performed extensive surveys from 1832 to 1948 that noted seagrass locations. Other records relating to seagrass distributions were found in archives, herbariums, and reports. Oral interviews were also conducted to obtain information on past or present eelgrass locations. The Estuary Program performed a geospatial analysis of the historical data and developed a presence/absence analysis for sections of the Bay (Doherty 1995). The historical analysis did not attempt to quantify seagrass acreage, only presence or absence.

Status and Trends

In 2012, 513 acres of seagrass were mapped in Narragansett Bay, compared to 357 acres in 2006 (Table 2). In Greenwich Bay, where no seagrass (widgeon grass or eelgrass) had been mapped in 2006, 29 acres of widgeon grass were mapped in 2012. The Narrow River (Pettaquamscutt River), which was not covered in the 2006 survey, had 24 acres of seagrass when it was mapped in 2012. Excluding Greenwich Bay and the Narrow River (Pettaquamscutt River), the 2012 survey found that the other previously mapped areas of Narragansett Bay gained 103 acres of seagrass between 2006 and 2012 for an increase of 29 percent. This increase occurred primarily in the Sakonnet River (21-acre gain), the East Passage (48-acre gain), and the West Passage (36-acre gain) (Table 2). When the 29 acres of widgeon grass in Greenwich Bay are included, the areas of Narragansett Bay that were mapped in both 2006 and 2012 (i.e., not including the Narrow River [Pettaquamscutt River]) gained 132 acres of seagrass for an increase of 37 percent.

The seagrass beds in Narragansett Bay showed strong persistence between 2006 and 2012 (Table 2). Almost 85 percent of the seagrass beds mapped in 2006–301 of the total 357 acres–were also mapped in 2012, indicating that the center of the beds was seemingly stable in the six years between surveys.

The historical analysis of seagrass coverage in Narragansett Bay showed that seagrasses were widespread throughout the Bay until the middle of the twentieth century and then gradually disappeared from the Upper Bay (Table 3). In the twentieth century, seagrass was consistently documented as present in eight or nine sections of the Bay. In the surveys conducted in 2006 and 2012, however, it was present in only four and six sections, respectively–all in the Lower Bay.

Discussion

Seagrass was more prevalent throughout Narragansett Bay before the 1940s, particularly in the northern sections of the Bay including Fox Point in the Upper Providence River, Mount Hope Bay, Hundred Acre Cove in the Barrington River, Potter Cove on Prudence Island, Greenwich Bay, and other locations in the northern reaches of the Bay (Doherty 1995, Kopp et al. 1995, Barrett et al. 2006, Nixon et al. 2008, Pesch et al. 2012, Chintala et al. 2015; Table 3). From 1840 to 1940, seagrass was noted in many sections of the Bay currently devoid of seagrass. Cicchetti (in prep.) concluded that almost 90 percent of seagrass acreage in the Providence River Estuary and Upper Narragansett Bay has been lost since the 1900s. The losses occurred in pulses associated with multiple factors, such as nutrient enrichment and physical removal during dredging and filling activities. From the 1930s through the 1960s, dramatic declines in seagrass acreage were reported (Doherty 1995, Kopp et al. 1995, Short et al. 1996). These declines were most likely due to increased nutrient input from a burgeoning population, punctuated by severe losses from an epidemic of seagrass wasting disease in the 1930s and two major hurricanes in 1938 and 1954 (Costa 1988, Short et al. 1993, Doherty 1995, Kopp et al. 1995; see "Wastewater Infrastructure" and "Nutrient Loading" chapters).

From 2006 to 2012, Narragansett Bay showed substantial gains in seagrass acreage, although the gains do not reflect a recovery to pre-1940s condition (Table 3). While a direct comparison with data from the 1996 survey (Huber 1999) is not possible because of methodological differences, there does seem to have been a substantial increase between 1996 and 2012. The 1996 survey found approximately 100 acres, compared to 513 acres in the 2012 survey. The difference is so great that it probably outweighs any methodological differences between the two datasets, leading researchers to believe that seagrass extent in Narragansett Bay did, in fact, increase over that time period, even if the magnitude of the increase is unclear (Mike Bradley, University of Rhode Island, personal communication). This view is supported by the observation that some seagrass study sites (e.g., Fort Getty and T-Wharf) did have increases in seagrass extent during the same time period (Bradley et al. 2007).

The sudden appearance of widgeon grass in Greenwich Bay in 2012 is noteworthy. Available information from 1996 and 2006 indicates that widgeon grass and eelgrass were not present in Greenwich Bay in those years, or else any seagrass was not visible in the aerial photographs and/or any seagrass beds were too small to be mapped. However, the historical analysis showed that seagrass had been present previously in East and West Greenwich Bay through 1994 (Table 3). Widgeon grass can tolerate fresher and warmer water than eelgrass (Kantrud 1994) and is prevalent in the Southwest Coastal Ponds and Briggs Marsh (located on the southeast side of the Sakonnet River, just outside the Narragansett Bay Watershed). It is unknown why seagrass apparently disappeared from Greenwich Bay for decades, although it is suspected that high nitrogen loading in Greenwich Bay from septic systems and a wastewater treatment facility–coupled with macroalgal and phytoplankton blooms (reducing water clarity), and poor circulation–may have contributed to the dramatic seagrass declines (Deacutis 2008).

While many factors affect seagrasses–such as disease, storms, ice scouring, and dredging–three key stressors are especially important with respect to present-day and future status and trends: nutrient loading, temperature, and sea level rise.

In the past, degradation of water quality appears to have been the main cause of seagrass loss (Costa 1988, Valiela et al. 1992, Hauxwell et al. 2003). Increased phytoplankton productivity, epiphyte growth, and turbidity (due to nutrient enrichment) are often invoked as the reasons for light limitation leading to seagrass decline (Kemp et al. 1983, Duarte 1995, Taylor et al. 1999, Pryor et al. 2007, Chintala et al. 2015). The recent gains in seagrass acreage in Narragansett Bay likely stemmed from improved water quality. A reduction in nutrient loading from local wastewater treatment facilities (see "Nutrient Loading" chapter) likely reduced epiphyte coverage on seagrass leaves, phytoplankton blooms, and macroalgae growth, improving water clarity (see "Water Clarity" chapter). Improved water clarity allows light to penetrate to greater depths, allowing seagrass beds to flourish and expand into deeper waters.

Second, warming waters can affect the spread of seagrass diseases, stress the plants, and influence how they reproduce. As waters warm, diseases such as wasting disease may spread more quickly. A combination of other climate impacts and anthropogenic factors can also exacerbate wasting disease outbreaks (Short et al. 1993, Doherty 1995). To date, wasting disease has not been observed since the early 1930s, even though temperature is warming in Narragansett Bay (Fulweiler et al. 2015; see "Temperature" chapter).

In the temperate zone, seagrasses can reproduce in two ways: by extending new shoots and rhizomes, or through seed propagation. Warming waters may promote seed propagation instead of rhizome and shoot growth, particularly at high temperatures near or above 77 to 86°F (25 to 30°C) (Phillips et al. 1983, Short and Neckles 1999, Bintz et al. 2003). While seed germination can promote expansion of seagrass beds into new areas, if conditions are such that seed germination is restricted or a seed bank cannot be established (Harwell and Orth 2002), then seagrass may suffer and decline. Surface waters in the main channel of Narragansett Bay (Fox Island, West Passage) did not have sustained temperatures above 77 to 86°F (25 to 30°C) during the summer months (June, July, August, September), and seagrass acreage increased as temperatures increased (Figure 1). Many interacting factors will influence the future status of seagrass, with temperature an important factor. Seagrass may reach a tipping point and start to decline when sustained summer water temperatures are above 77 to 86°F (25 to 30°C). Estuarine water temperatures have risen approximately 3.6°F (2°C) over the last 50 years (see "Temperature" chapter), and if the trend continues water temperatures will reach that tipping point.

Finally, sea level rise is expected to change the tidal regime and water depth of Narragansett Bay, affecting the distribution of seagrasses (Short and Neckles 1999, Saunders et al. 2013, USEPA 2016). Increased tidal range would increase water depth, depending on local geomorphology. With increased water depth, light penetration may become limiting in places where seagrass currently grows, leading to decreases in seagrass productivity and changes in seagrass condition. Short and Neckles (1999) estimated that a 19.7-inch (50-centimeter) increase in water depth would reduce seagrass growth by 30 to 40 percent, and Saunders and colleagues (2013) predicted seagrass habitat in Moreton Bay, Australia, would decline 17 percent by 2100 if sea level rises

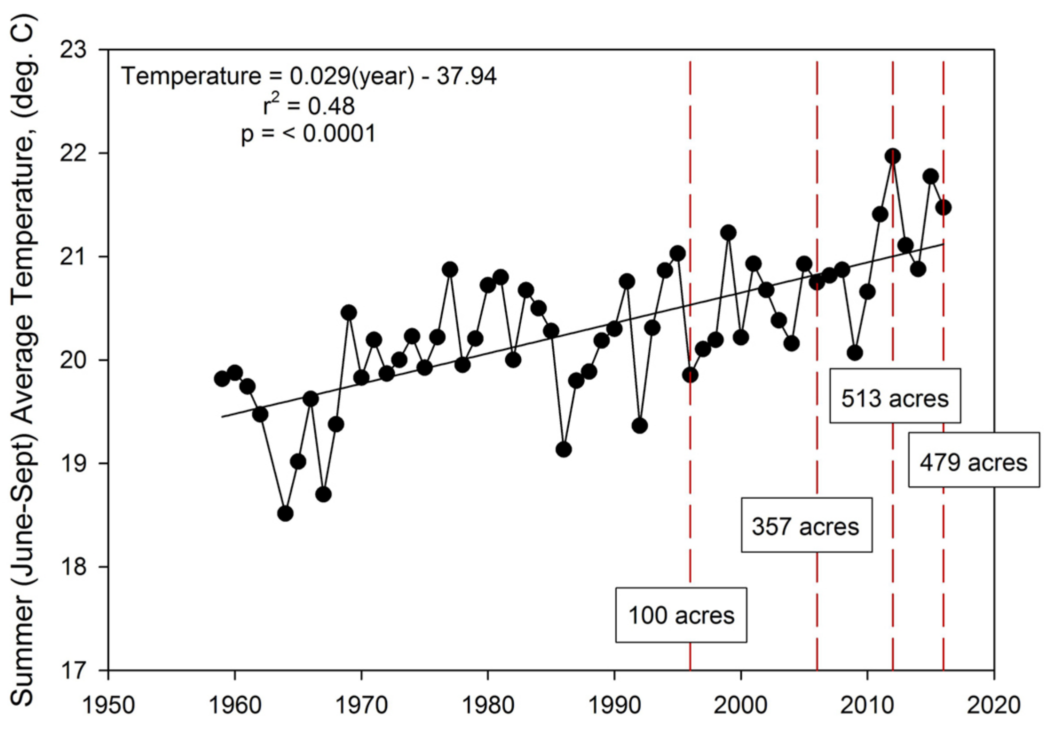


Figure 1. Summer (June, July, August, September) average water temperature from 1959 to 2016. Data are from the GSO Fish Trawl Survey at Fox Island, located in the West Passage of Narragansett Bay. Red vertical dotted lines show the years (1996, 2006, 2012, 2016) of the most recent seagrass mapping efforts with the total number of seagrass acres mapped.

3.6 feet (1.1 meters). In a process potentially offsetting some losses caused by deeper water, seagrass beds can expand landward with sea level rise, if they are not blocked by coastal development or hardening. Saunders and colleagues (2013) predicted that if impervious surfaces could be removed from newly inundated areas of land, loss of seagrass in Moreton Bay could be reduced to 5 percent. The predicted effect of sea level rise on seagrass in Narragansett Bay has not been modeled in a similar fashion. The outcome would depend on many factors, such as site-specific differences in the slope and sediment characteristics of the Bay's seabed, as well as the amount and locations of shoreline hardening around the Bay and the resulting scope for landward expansion of seagrass. Current sea level rise predictions for Narragansett Bay range up to a maximum of 11 feet (3.4 meters) by 2100 (see "Sea Level" chapter). That amount of sea level rise could be detrimental to seagrass beds in Narragansett Bay based on the findings from other parts of the world.

These stressors and others will affect not only the extent but also the condition of seagrass beds. If the extent shrinks or the condition deteriorates, seagrass habitats and the larger ecosystem they support will also deteriorate. The capacity for seagrass beds to store blue carbon would also decrease, and stored organic carbon could even be released as sediments destabilize. However, between 2006 and 2012 seagrass acreage increased by 37 percent in areas of Narragansett Bay that were mapped in both years, primarily in the Sakonnet River and in the East and West Passages (Table 2). In addition, in 2012 there was a newly mapped 29-acre bed of widgeon grass in Greenwich Bay, an area where seagrass had not been documented since the 1990s.

In June 2017, as this chapter was being finalized, Bradley and colleagues (2017) released a report on the 2016 seagrass mapping effort. Using the same methodology described above, they mapped 479 acres of seagrass in Narragansett Bay, with the majority located in the East Passage (Table 4). While that represents a slight decline (7 percent) since 2012, when 513 acres were mapped, the acreage in 2016 was still greater than in 1996 and 2006 (Figure 1), pointing to a potential recovery of seagrass habitat, happening at a time of major nutrient reductions (see "Nutrient Loading" chapter).

Data Gaps and Research Needs

- The Rhode Island Eelgrass Task Force's recommendations for a three-tiered approach to seagrass mapping and monitoring (Raposa and Bradley 2009) need to be implemented in order to conduct seagrass analysis more

Table 4. Seagrass acreage for sections of Narragansett Bay (see Introduction and Appendix for definitions of geographic areas). Acreage values were rounded to the nearest whole number. N/D means no data were collected.

Narragansett Bay Sections	Total Acreage 2006	Total Acreage 2012	Total Acreage 2016
Providence River Estuary	0	0	0
Warren, Palmer, and Barrington Rivers	0	0	0
Taunton River	0	0	0
Upper Narragansett Bay	0	0	0
Mount Hope Bay	0	0	0
Greenwich Bay[(1)]	0	29	25
West Passage	55	91	65
East Passage	210	258	237
Sakonnet River	31	52	44
Narrow River (Pettaquamscutt River)	N/D	24	44
Mouth of Narragansett Bay	61	59	64
TOTAL	357	513	479

(1) Widgeon grass was mapped in Greenwich Bay in 2012; no eelgrass or widgeon grass was documented in Greenwich Bay in the 2006 mapping survey.

systematically, including more refined methods to examine extent and condition.

- Warming temperatures, changes in precipitation patterns, and sea level rise can all affect how seagrass beds survive from year to year. Research is needed to fully understand how Narragansett Bay's seagrass beds will respond.
- A better understanding is needed of the life history traits of eelgrass and widgeon grass in Narragansett Bay. More knowledge of the life history traits will aid in conservation and restoration of seagrass beds to maintain or increase acreage or condition of the beds. Of particular interest is widgeon grass, as it is far less studied than eelgrass. Extensive mesocosm experiments on the response of eelgrass to nutrients, temperature, and other interactive factors have been conducted in Rhode Island (e.g., Bintz et al. 2003, Taylor et al. 1999). These types of studies should be pursued for widgeon grass, as well as for seagrass communities composed of both eelgrass and widgeon grass.

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