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Author manuscript

Estuaries Coast. Author manuscript; available in PMC 2018 September 28.

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Published in final edited form as:

Estuaries Coast. 2017 May 1; 40(3): 617–625. doi:10.1007/s12237-016-0166-1.

Anthropocene survival of southern New England's salt marshes

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Abstract

In southern New England, salt marshes are exceptionally vulnerable to the impacts of accelerated sea level rise. Regional rates of sea level rise have been as much as 50% greater than the global average over past decades: a more than four-fold increase over late-Holocene background values. In addition, coastal development blocks many potential marsh migration routes, and compensatory mechanisms relying on positive feedbacks between inundation and sediment deposition are insufficient to counter inundation increases in extreme low turbidity tidal waters. Accordingly, multiple lines of evidence suggest marsh submergence is occurring in southern New England. A combination of monitoring data, field re-surveys, radiometric dating, and analysis of peat composition have established that, beginning in the early and mid-twentieth century, the dominant low marsh plant, *Spartina alterniflora*, has encroached upwards in tidal marshes, and typical high marsh plants, including *Juncus gerardii* and *Spartina patens* have declined, providing strong evidence that vegetation changes are being driven, at least in part, by higher water levels. Additionally, aerial and satellite imagery show shoreline retreat, widening and headward extension of channels, and new and expanded interior depressions. Papers in this special section highlight changes in marsh-building processes, patterns of vegetation loss, and shifts in species composition. The final papers turn to strategies for minimizing and coping with marsh loss by managing adaptively and planning for landward marsh migration. It is hoped that this collection offers lessons that will be of use to researchers and managers on coasts where relative sea level is not yet rising as fast as in southern New England.

Keywords

climate change; sea level rise; anthropogenic impacts; wetlands; storms; *Spartina alterniflora*; *Spartina patens*; elevation capital; coastal adaptation; Superstorm Sandy; vegetation loss; submergence

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Introduction

The genesis of this *Estuaries and Coasts* special section was a workshop held in April 2014 in Providence, RI, entitled “The Effects of Sea Level Rise on Rhode Island’s Salt Marshes” organized by the Narragansett Bay National Estuarine Research Reserve, Save The Bay, the Rhode Island Coastal Resources Management Council, and the U.S. Environmental Protection Agency (West 2014). Attendees included almost 100 members of state agencies, the academic community, land trusts, non-profit conservation organizations, and representatives of federal agencies. At the workshop, new research on the condition of the region’s salt marshes was shared, and potential adaptation and monitoring strategies related to relative sea level rise (SLR) were discussed.

This introductory article is intended to provide additional context and synthesis on the vulnerability of tidal marshes in southern New England to SLR and address the question of what can be done to lengthen their lifespan given high rates of drowning. We also provide a description of the papers incorporated in this focus issue, which range from short-term to multi-decadal studies of vegetation change, inundation-productivity feedbacks, and marsh vertical accretion, to management-focused assessment and adaptation strategies. By publishing this set of manuscripts jointly, we show how a range of historically focused studies and experiments point to SLR as a key driver of pervasive marsh changes occurring over recent decades. In addition, we report on a vulnerability assessment that may allow managers faced with similar SLR threats to target interventions and an adaptive management approach that is the best course of action while approaches are being tested and assessed.

Background on Study Area

Based on studies of basal peat depth and age, existing coastal and estuarine marshes of southern New England formed over the past four millennia (Redfield and Rubin 1962; Keene 1971; Orson et al. 1987; Kelley et al. 1988). Necessary for the development of persistent marsh was a reduction in the rate of post-glacial SLR to a pace where peat and sediment aggradation were sufficient to fill the accommodation space (Mudge 1858; Roman et al. 2000). Barrier spit progradation and the associated development of lagoon marshes also dates to this time period (4-2.5k y B.P.), as the moderation in SLR rates promoted the formation and expansion of coastal barriers (Redfield 1972; Kelley et al. 1988). Studies of tidal marsh peat depth and sediment chronology throughout the U.S. Northeast show that an additional pulse of marsh establishment resulted from watershed erosion dating to post-European settlement land clearing (Kelley et al. 1988; Pasternack et al. 2001; Kirwan et al. 2011). However, sediment inputs are now diminishing in the region due to upstream sediment retention by dams and declines in agriculture (Weston 2014). In combination with coastal development and accelerated SLR rates (Church and White 2006; Boon 2012; Sallenger et al. 2012; Calafat and Chambers 2013; Torio and Chmura 2013), these sediment reductions place limits on the adaptive response of tidal marshes (Watson et al. 2014; Passeri et al. 2015).

Southern New England is characterized by salt marshes that are generally small in spatial extent and often exist as narrow estuarine fringe marshes (Niering and Warren 1974;

Jacobson et al. 1997; Roman et al. 2000; Trocki 2003), and rely on the aggradation of organic matter to build vertically (Chapman 1960; Roman et al. 2000; Carey, Moran, et al. this volume; Watson et al. this volume). These coastal wetlands are typically found fringing coves and tidal ponds, along tidal rivers, and behind barrier spits (Roman et al. 2000). Marshes in the region typically have a tidal range of 1 m, although tides range from <0.20 m in Rhode Island's coastal ponds (Boothroyd et al. 1985) to nearly 2.0 m in upper Narragansett Bay (Deacutis et al. 2006) and western Long Island Sound (Steever et al. 1976). As in most Atlantic tidal salt marshes, *Spartina alterniflora* dominates the low marsh as a monoculture, growing as a tall growth form along tidal channels and shore edges; and is common as a short growth form on the high marsh platform (Miller and Egler 1950; Niering and Warren 1980; Nixon 1982). Also common in the high marsh are the species *Spartina patens*, *Distichlis spicata*, and *Juncus gerardii* (Niering and Warren 1980).

Sea Level Rise: the Future Has Arrived

Tide gauge and satellite measures of water level document that global SLR acceleration is occurring (Church and White 2006; Spada et al. 2015; Kopp et al. 2016; Mengel et al. 2016), and that the Atlantic coast between Boston and Cape Hatteras is a “hotspot” (Sallenger et al. 2012; Boon 2012). While relative sea level has been rising since the Last Glacial Maximum (19k y B.P.) (Fairbanks 1989), rates of SLR for the U.S. Northeast and Mid-Atlantic region are accelerating significantly faster than rates for the U.S. Pacific and Gulf Coasts (Sallenger et al. 2012; Boon 2012). Linear regression of monthly averages of mean sea level (MSL), mean high water (MHW), and extreme high water (EHW) against time for the last 19 years for southern New England tide gauges (New London, CT; Newport, RI; Providence, RI) yield rise rates of 3–4 mm yr⁻¹ for MSL and MHW and 4–6 mm yr⁻¹ rise rates for EHW (NOAA 2015). These rates are almost double that of the historic average (~2.5 mm yr⁻¹; NOAA 2015) and are several times that of Late Holocene rates (0.5–1.0 mm yr⁻¹; Donnelly et al. 2004; Donnelly 2006). This pattern is apparent throughout the region (Kemp et al. 2011; Sweet and Zervas 2011; Boon 2012; Sallenger et al. 2012; Goddard et al. 2015) and is thought to be a consequence of dynamic ocean circulation patterns (e.g., Yin et al. 2009; Ezer 2015) rather than geologic factors such as subsidence or forebulge collapse (Doran 2010; Sallenger et al. 2012).

Northeastern coastal wetlands are clearly being impacted independently, and synergistically, by a wide range of anthropogenic stressors, including cultural eutrophication, altered hydrology, increased storm intensity, declining sediment inputs, and crab herbivory (Watson et al. this volume). These factors have been associated with enhanced rates of edge erosion and declines in macrophyte productivity, in addition to alterations in their capacity to aggrade vertically (Kennish 2001; Deegan et al. 2012; Smith et al. 2012; Watson et al. 2014; Weston 2014). Nevertheless, several lines of evidence suggest that SLR is impacting the structure and function of southern New England's coastal wetlands. Evidence is accruing that neither tidal sediment accretion nor subsurface accumulation of refractory peat material are allowing wetlands to grow vertically at rates approaching that of SLR in this region. Analysis of a network of surface elevation tables installed in Rhode Island wetlands shows a mean elevation gain of 1.40 mm yr⁻¹, far below the rates of inundation increases (Raposa et al. in press). Similarly, analyses of sediment accretion also show rates lower than that of

SLR, further suggesting that marsh sediments are becoming more porous over time (Carey, Moran et al., this volume). Collectively, these data show that flooding increases resulting from SLR far exceed elevation gains and elevation deficits are developing. Because marshes across Rhode Island and southern New England are also sitting low relative to their potential growth range (Watson et al. 2014; Watson et al. this volume) and thus lack elevation capital (Cahoon and Guntenspergen 2010), marshes in this region have little resilience in the face of accumulation deficits.

Field and remote sensing studies show that changes in plant distribution patterns are occurring in association with flooding increases and elevation deficits. The flood tolerant *S. alterniflora* is shifting landward, replacing high marsh taxa such as *S. patens* and *J. gerardii* (Warren and Niering 1993; Cameron Engineering & Associates 2015; Smith 2015; Watson et al. 2015; Raposa et al. this volume) (Fig. 1). High marsh plants are prevented from transgressing into uplands by coastal development (Torio and Chmura 2013), steep slopes, and ecological barriers such as forest edges (Field et al. 2016) and invasive stands of *Phragmites australis* (Smith 2013) which can delay or prevent migration of marsh taxa into coastal forests. Patterns of outright marsh vegetation loss are also occurring via tidal channel network expansion, shore erosion, and the development of interior ponds and dieback areas (Fig. 2). While patterns of widespread loss among U.S. Northeast wetlands were first reported for Jamaica Bay, New York City and Delaware Bay (Hartig et al. 2002; Kearney et al. 2002), recent work focused on Cape Cod, MA, Rhode Island, and Long Island, NY has revealed regionally widespread reductions in tidal marsh acreage over past decades. Studies appraising rates and patterns of tidal marsh drowning in the Long Island and southern New England region show that tidal wetland vegetation loss rates over the past three to four decades average 0.40-0.44% yr⁻¹ (Smith 2009; Berry et al. 2015; Cameron Engineering and Associates 2015; Watson et al. this volume), matching or exceeding rates in the Mississippi Delta region (Britsch and Dunbar 1993; Barras et al. 2003). Also of concern is the homogeneity of the response. Of the several hundred (500+) marsh units analyzed in Long Island, 85% experienced vegetation loss between 1972 and the mid-2000s (Cameron Engineering & Associates 2015), and of the several dozen units analyzed in Rhode Island, all but one experienced loss over past decades (Berry et al. 2015; Watson et al. this volume). On Cape Cod, all marshes were found to have experienced 20th century reductions in vegetated area (Smith 2009). And while observational data do not implicate the process responsible, recent studies, including several in this volume, show that lower elevation marsh platforms are experiencing both more rapid loss of high marsh habitat (Warren and Niering 1993; Donnelly and Bertness 2001; Watson et al. 2016; Raposa et al. this volume) and more vegetation losses (Wigand et al. 2014; Watson et al. 2014; Watson et al. this volume), suggesting that inundation is a key driver of these habitat changes.

In summary, rates of SLR are accelerating significantly in the southern New England region, and this acceleration is associated with global climate change and related shifts in ocean circulation, suggesting an uncertain future for some coastal wetlands in the Anthropocene. A growing body of evidence suggests that this SLR is driving significant coastal habitat changes, which include declines in high marsh taxa, marsh retreat, and marsh drowning.

Adaptation Strategies

A slowing of tidal marsh loss for southern New England would likely require a cessation of global SLR acceleration, a phenomenon not yet on the horizon. However, a number of adaptation strategies designed to build coastal ecosystem resistance and resilience are currently being explored and implemented in Rhode Island and elsewhere in the U.S. Northeast. Such experimental strategies include informed coastal planning and interventions such as sediment subsidies, reductions in edge losses using biomaterials ('living shorelines'), hydrologic remediation, restoration of sediment supplies through dam removal, and facilitated marsh-upland migration (Wigand et al. this volume). While adaptation plans remain in the early phases of implementation, and robust and holistic monitoring is required to ensure that desired targets and outcomes are achieved, the development and application of such demonstration projects provide hope for the future survival of some tidal marshes in the region.

The goals of these adaptation actions are to build ecosystem resistance and resilience, and to enable desired transformations (Wigand et al. this volume). Raising marsh elevations through thin layer addition of dredged sediment is intended to add elevation capital to marshes. The goal of living shoreline installations, as implemented in Rhode Island, is to stabilize eroding marsh edges using nature-based infrastructure. Improving drainage to recently formed shallow pools is designed to reduce marsh groundwater to levels that can support the marsh macrophytes. Dam removal can increase water column suspended sediment concentrations, and therefore, promote enhanced rates of sediment accretion. Facilitating marsh-upland migration through barrier or *Phragmites* removal, or grading, is intended to enable marsh vegetation to move upslope.

Elsewhere in the U.S., interventions to counteract marsh drowning have been implemented where losses have been significant, in locations such as Jamaica Bay, New York City (JB) (Hartig et al. 2002); Blackwater Wildlife Refuge, MD (BW) (Stevenson et al. 1985), Elkhorn Slough, CA (ES) (Van Dyke and Wasson 2005), and in the Mississippi River Delta (MRD) (Barras et al. 2003). Multiple stressors are thought to be affecting these wetlands, in addition to SLR, including changes to sediment supply, altered hydrology, nutrient over-enrichment, subsidence linked to natural gas and groundwater exploitation, and invasive species establishment. However, because the separate and synergistic roles of these stressors are difficult to isolate, projects to restore coastal wetlands have proceeded accepting uncertainty about the relative importance of primary and ancillary drivers (Turner 2009; Wasson et al. 2015). Intervention actions conducted to date, or underway, have included rebuilding drowning marsh with dredge sediments (JB, BW, MRD, ES), removing nutria (BW), re-grading marsh-upland boundaries to promote inland migration (ES), and installing living shorelines to reduce edge erosion (BW, MRD). Also common in the MRD are sediment diversions, and installation of earthen barriers (terraces) to reduce fetch and edge erosion in drowning marshes. Although many commonalities exist between previous restoration efforts and those being conducted in southern New England, it is likely that approaches will need to be tailored to the tidal range and soil types found in Rhode Island. For instance, living shoreline installations need to be tailored to the low turbidity waters by using sand in-fills instead of relying on natural sediment deposition. With respect to thin layer projects, it is

unclear if thick sand depositions are likely to compact very low-density marsh peats, leading to little net benefits for marsh elevation capital.

Additionally, managers are struggling with balancing the expense of interventions against pervasive patterns of marsh loss. Given limited resources and the complete suite of ecosystem stressors, deciding where and how to intervene is challenging (Kreeger et al. 2015). Strong collaboration between the scientific and management communities is needed to help determine which techniques are most effective at preserving valued coastal ecosystem functions, including aesthetic and cultural benefits.

Focus Issue

The papers in this focus issue present and integrate new information on SLR impacts on coastal marshes and potential adaptation strategies. Although the focus of the special issue is coastal New England, other regions worldwide face similar climate change stressors, and can draw from the integration of multiple historic analyses and management-scientist collaborations presented here. The first four papers (Carey, Moran, et al. this volume; Carey, Raposa, et al. this volume; Raposa et al. this volume; Watson et al. this volume) present complementary studies illustrating changes in wetland extent and plant species composition linked to increased flooding, and emphasize the lack of a stabilizing organic matter-inundation feedback through field mesocosm experiments and sediment composition analysis. While increased tidal flooding provides an opportunity for minerogenic marshes to aggrade through increased sediment deposition (e.g., Watson 2004), for southern New England organogenic marshes, increased flooding results in reduced organic matter accumulation and reflects greater instability to SLR than previously noted. Two additional papers (Cole Ekberg et al. this volume; Wigand et al. this volume) present an assessment tool designed to identify intervention opportunities, and the presentation of an adaptive management strategy for intervention to prevent marsh drowning. This collection of papers presents impacts of SLR on tidal marshes of the southern New England region and shares lessons learned from the first phase of climate adaptation planning.

Salt marshes respond to SLR through pathways tied to accretion: if SLR exceeds the capacity of the marsh to aggrade vertically, the marsh will drown; if SLR is matched by aggradation the marsh will persist (Orson et al. 1985). Given accelerating rates of SLR found in southern New England, *The Declining Role of Organic Matter in New England Salt Marshes* asks whether and how coastal marsh accretion rates have altered since first measured roughly 30 years ago (Bricker-Urso et al. 1989). Authored by Carey, Moran, Kelly, Kolker, and Fulweiler, the manuscript reports that marsh accretion rates have not increased since the 1980s in response to increases in SLR, and in addition, surface sediment composition is more porous, with less mineral and organic material. Because organic matter accumulation is the primary means by which these marshes maintain their elevation, this finding suggests a widespread shift in sediment structure, as has been reported previously for other drowning marshes (e.g., Hartig et al. 2002; Wigand et al. 2014).

Other papers in the issue consider impacts of SLR on marsh vegetation and persistence. Previous studies have reported large-scale shifts in marsh vegetation occurring in southern

New England, describing the replacement of high marsh species with the more flood tolerant *S. alterniflora*, attributing these shifts to SLR in combination with accumulation deficits (Warren and Niering 1993; Donnelly and Bertness 2001; Smith 2015). In *Vegetation Dynamics in Rhode Island Salt Marshes During a Period of Accelerating Sea Level Rise and Extreme Sea Level Events* (authored by Raposa, Weber, Cole Ekberg, and Ferguson), the authors use yearly vegetation surveys to identify the timing and mode of species composition changes. In addition to uncovering pervasive patterns of high marsh loss, the authors conclude that vegetation shifts are coincident with years of higher than normal flooding. Also, species composition shifts are occurring at sites with greater inundation levels, while at higher elevation plots, high marsh vegetation is stable. This study also reports on both gradual loss of high marsh, as high marsh taxa are gradually replaced by low marsh taxa, and episodic replacements, where large dieback patches form and which are slowly invaded by *Spartina alterniflora*.

Another perspective on long-term vegetation shifts was presented by *Contrasting Decadal-Scale Changes in Elevation and Vegetation in Two Long Island Sound Salt Marshes* (authored by Carey, Raposa, Wigand, and Warren). Here, data on historic elevation and vegetation change was presented for two marshes exhibiting different accretion behavior in eastern Long Island Sound (CT). At the first marsh, shifts from high to low marsh vegetation were linked to elevation deficits, while at the second marsh, high marsh communities were persisting in association with more rapid rates of peat formation. While describing a similar vegetation shift as reported by the preceeding manuscript (Raposa et al. this volume), and by previous studies (Donnelly and Bertness 2001), this paper additionally suggests that marshes found higher in the tidal frame may be more successful at maintaining their elevation in the face of rapid SLR. The higher elevation platform may support higher rates of belowground biomass production, because plants are less flood-stressed, as has been found in inundation experiments conducted with *S. alterniflora* and *S. patens* (Voss et al. 2013; Watson et al. 2014; Kirwan and Guntenspergen 2015; Watson et al. 2016). This study additionally supports the concept of an optimum elevation for marsh accumulation (Morris et al. 2002; Morris et al. 2016), below which marsh accretion will fail to keep up with SLR.

The paper *Wetland Loss Patterns and Inundation-Productivity Relationships Prognosticate Widespread Salt Marsh Loss for Southern New England* (authored by Watson, Wigand, Davey, Andrews, Bishop, and Raposa) demonstrates that most marshes in Rhode Island are found low within their potential growth range, lack elevation capital, and therefore will not be stable against future SLR. The results of an inundation experiment conducted in several different wetlands using *S. alterniflora* were used to estimate the optimum marsh height for belowground production given the specific soil composition and tidal range found in southern New England. Elevation surveys at several dozen marshes were then used to determine that most marsh elevations fell well below this growth optimum, suggesting the marshes will not be stable in the face of future SLR increases. Additionally, this manuscript also reported on changes in vegetated marsh area over time on both historic (post-1860s) and recent (1972-2011) time scales. In accordance with other recent studies (Kearney et al. 2002; Smith 2009; Cameron Engineering & Associates 2015), rates of average marsh vegetation loss were found to be on the order of 0.4% year, with most marshes losing areal extent

Additionally, a strong negative correlation was found between elevation and loss rate, suggesting that inundation is likely an important driver of these vegetation losses.

The first four manuscripts illustrate the impacts of accelerated SLR on sediment accumulation, plant communities, and landscape changes found in southern New England's tidal wetlands. The integration of research results generated through this number of historically focused and complementary approaches reveal that many southern New England salt marshes show evidence of rapid change and degradation of sustaining processes and ecosystem functions.

The last two papers in this series address management issues related to changes in coastal marsh habitats resulting from SLR. Several dozen projects designed for recovery and to increase the resilience of northeastern coastal areas to storms have been funded in the wake of Superstorm Sandy. Many of these projects include components designed to lengthen the lifespan of coastal wetlands in order to preserve the wildlife habitat and flood mitigation potential that coastal wetlands provide. *Development of a Climate-Change Adaptation Strategy for Management of Coastal Marsh Systems in Southern New England, USA* (authored by Wigand, Ardito, Chaffee, Ferguson, Paton, Raposa, Vandemoer, and Watson) describes the variety of adaptation actions being performed to lengthen the lifespan of drowning wetlands specifically on the Chafee National Wildlife Refuge, in Rhode Island. These techniques include living shoreline installations to reduce edge erosion, thin-layer sediment deposition to build marsh elevations, channel construction to improve drainage in drowning marshes, and marsh migration facilitation. This article also describes the stakeholder-engagement process that was used to collaboratively gather data and design appropriate interventions, and to design monitoring plans in order to adaptively manage intervention projects.

A final article, entitled *Development and Application of an Assessment Method to Identify Salt Marsh Vulnerability to Sea Level Rise* (authored by Cole Ekberg, Raposa, Ferguson, Ruddock, and Watson) considers when and where to intervene with drowning marshes at a broader spatial scale. Large-scale projects, such as the rebuilding of drowning marsh islands in New York City (Frame et al. 2006), are associated with price tags far upwards of tens of millions of dollars. Clearly, funding will not be available to restore and rebuild all drowning coastal marshes, and therefore resources should be focused strategically. This article addresses, and tests the reliability of, tools available to assess coastal wetland vulnerability to SLR, including measurements made as part of traditional rapid condition assessments (e.g., vegetation communities, soil strength), field and remote sensing based measurements of elevation, and VDatum and SLAMM model outputs. This paper presents a transferable vulnerability assessment approach, and articulates the paradigm shift that is occurring in the coastal wetland management community as the impacts of SLR on coastal wetlands in the Northeast are becoming apparent.

Collectively, these contributions highlight the vulnerability of coastal wetlands in southern New England to accelerated SLR, and illustrate current strategies being tested to help facilitate tidal marsh survival. Together these articles emphasize the importance of a long-term perspective based on multiple lines of evidence (sedimentary archives, historical

imagery and maps, contemporary plant distribution surveys) in determining changes in coastal wetland habitats. These approaches provide an integrated account of changes occurring over time, and represent a significant improvement over referencing National Wetlands Inventory Data, which is not recommended for trend analysis due to changes in mapping methods over time (Tiner et al. 2014). In addition to highlighting the need for a long-term perspective in assessing changes in marsh landscapes and sustaining processes, these articles also point to the need for strong collaboration between wetland scientists and managers. If coastal climate adaptation actions are not well considered, nor cast within a framework of experimentation and adaptive management, it will be difficult to learn which techniques are most successful at building ecosystem resistance and resilience. Given limited resources, investments should be strategic, should be conducted in locations where marsh condition is well matched to the intervention applied, and should receive a high level of monitoring. It is hoped that this focus issue proves timely and informative for coastal managers in a region where sea-level rise is already damaging tidal marshes, and where the coastal management community is fully embracing adaptation and planning for marsh migration as vital to tidal marsh survival.

Acknowledgements

Special section authors gratefully acknowledge *Estuaries and Coasts* editorial staff for helping us get the word out on such an important and timely global – and local – issue. We appreciate the cooperation of The Narragansett Bay National Estuarine Research Reserve (NBNERR), Save The Bay, the Rhode Island Coastal Resources Management Council, and the U.S. Environmental Protection Agency as the inter-Agency partnership that organized the workshop. In addition, we thank C. Chaffee, M. Cole Ekberg, and W. Ferguson for contributing the observations that helped spawn these research activities, and J. West, W. Berry, and the staff of the NBNERR for facilitating the workshop that resulted in this set of manuscripts being published as a joint work. This report, ORD Tracking Number ORD-016293, has been reviewed technically by the U.S. EPA's Office of Research and Development, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, RI, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. EPA.

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Figure 1.

Depiction of marsh landscape changes detailed in this theme section, including the study of Carey, Moran, et al. depicting increased porosity of marsh peat; the studies of Raposa et al. and Carey, Raposa, et al. depicting changes in dominant species composition; and the study of Watson et al. depicting conversion of marshlands to unvegetated peat and mudflats, in addition to other reports in the literature. The combination of these four studies on coastal marsh dynamics in southern New England considered in concert with other recent reports (e.g., Smith 2009; Bertness et al. 2014; Cameron Engineering and Associates 2015; Smith 2015) suggests that significant changes in marsh habitats have occurred over past decades. Tidal datum abbreviations are indicated at left: extreme high water (EHW), mean high water (MHW), and mean sea level (MSL).

Figure 2.

Landscape and mechanistic views of marsh vegetation loss patterns apparent in Narragansett Bay and coastal salt pond tidal wetlands, including shoreline straightening and retreat (S), interior pond development and expansion (P), and widening and headward expansion of tidal channel networks (C). Also apparent at many marshes is fragmentation and hummocks. Mussel mortality and crab burrowing also appear to have expanded over recent years, weakening channel edges. Marsh landscape view is Seapowet Marsh, Tiverton, RI, which is thought to be the largest area of contiguous coastal marsh in Rhode Island. Inset photos are of Hundred Acre Cove (Barrington, RI), Mary Donovan Marsh (Little Compton, RI),

Narrow River Estuary (Narragansett, RI), Mary's Creek (Warwick, RI). Additional aerial photograph of a "waffle" marsh at Winnapaug Pond (Westerly, RI).