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A climate change adaptation strategy for management of coastal marsh systems

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Abstract

Sea level rise is causing shoreline erosion, increased coastal flooding, and marsh vulnerability to the impact of storms. Coastal marshes provide flood abatement, carbon and nutrient sequestration, water quality maintenance, and habitat for fish, shellfish, and wildlife, including species of concern, such as the saltmarsh sparrow (*Ammodramus caudacutus*). We present a climate change adaptation strategy (CCAS) adopted by scientific, management, and policy stakeholders for managing coastal marshes and enhancing system resiliency. A common adaptive management approach previously used for restoration projects was modified to identify climate-related vulnerabilities and plan climate change adaptive actions. As an example of implementation of the CCAS, we describe the stakeholder plans and management actions the US Fish and Wildlife Service and partners developed to build coastal resiliency in the Narrow River Estuary, RI in the aftermath of Superstorm Sandy. When possible an experimental BACI (Before-After, Control-Impact) design, described as pre- and post-sampling at the impact site and one or more control sites, was incorporated into the climate change adaptation and implementation plans. Specific climate change adaptive actions and monitoring plans are described, and include shoreline stabilization, restoring marsh drainage, increasing marsh elevation, and enabling upland marsh migration. The CCAS provides a framework and methodology for successfully managing coastal systems faced with deteriorating habitat, accelerated sea level rise, and changes in precipitation and storm patterns.

Keywords

salt marsh; resiliency; sea level rise; storms; adaptive management; restoration; climate change; living shoreline; thin-layer sediment application

Introduction

While climate mitigation efforts focus on reduction of greenhouse gas (GHG) emissions and related strategies, such as the development of carbon sequestration capacity, climate change adaptation focuses on preparing for, coping with, and responding to the impacts of current and future climate change (Stein et al. 2013). It has become increasingly clear that regardless of how aggressively GHG emissions are reduced, major shifts in climate will occur over at least the next century, requiring effective adaptations in addition to climate mitigation (NRC 2010; IPCC 2013). For all anticipated rates of GHG emissions, sea level rise (SLR) is predicted to continue accelerating throughout the Northeast USA causing increased coastal flooding, increased vulnerability to the impact of storms, and the loss of coastal marsh area (Ashton et al. 2007). Public resources and infrastructure in low lying areas, such as roads, public access points, sewer and water mains, would be especially susceptible to increased flooding due to accelerated SLR and the forecasted increase in the frequency and severity of storms in the Northeast (IPCC 2013).

Coastal marshes provide flood abatement, carbon and nutrient sequestration, water quality maintenance, and habitat for fish, shellfish, and wildlife, including obligate species such as the saltmarsh sparrow (*Ammodramus caudacutus*), whose nesting success and future survival is inversely correlated with increased inundation (Bayard and Elphick 2011). Over 40 million people currently live in coastal shoreline counties in the Northeast USA, with substantial increases in population density and new home construction occurring between 1970 and 2010 (NOAA 2013a). Such high population figures emphasize the importance of the flood abatement services provided by coastal marshes. In addition to wildlife-based ecosystem benefits, the presence of vegetated coastal marsh protects shore communities through wave attenuation by diminishing near-bed shear stresses via the drag and baffling effects of high stem densities (Leonard and Luther 1995; Feagin et al. 2015). Plant roots present in coastal marshes also reduce shoreline erosion directly by stabilizing soil profiles and indirectly by creating shore bathymetric profiles that dissipate wave energy (Gedan et al. 2011).

The vulnerability of coastal communities in the Northeast to storm induced flooding was highlighted most recently by Hurricane Sandy, the deadliest and costliest storm of the 2012 Atlantic hurricane season, with damages exceeding $50 billion (NOAA 2013b). An unusually large (1800 km diameter), although not extraordinarily intense tropical storm (category 3 at peak intensity, category 1 at landfall), Superstorm Sandy formed as the alignment of a tropical storm with an extratropical depression, an incipient nor'easter. Also, a function of Sandy's size, associated storm surges persisted over several tidal cycles, and occurred during spring tides, which exacerbated coastal flooding to almost unanticipated levels in coastal New York, USA (Greene et al. 2013).

In addition to anthropogenically-linked climatic forcing, human activities in the Northeast have disrupted sediment inputs and organic matter accumulation, key sustaining processes for coastal marshes. During the 18th and 19th centuries, erosion related to deforestation allowed marshes in the U.S. Northeast to aggrade vertically and horizontally (Kirwan et al. 2011). However, as watershed erosion has declined with reforestation and urbanization, and as dam emplacement captures upstream sediments, coastal sediment inputs have become diminished, threatening the capacity of coastal wetlands to aggrade with accelerated rates of SLR (Weston 2014). Organic matter accumulation via vegetation production is often the major contributor to growth in New England marshes (Allen 1990). Increasing nutrient loads associated with high human populations in the Northeast USA have increased coastal eutrophication (Roman et al. 2000), which may have adverse effects on marsh belowground production, organic matter accumulation, and soil strength (Turner et al. 2009; Turner 2011; Deegan et al. 2012; Wigand et al. 2014). Decreased ability for sustaining processes reduce the resistance of coastal marshes to SLR in the Northeast, which is a hot spot for an increase in the frequency of storms, more frequent and intense rain events, and accelerated SLR (Wehner 2004; Frumhoff et al. 2007; Sallenger et al. 2012). The recent expansion of dieback areas in salt marshes in the Northeast have been attributed to increased tidal flooding associated with accelerated SLR (Warren and Niering 1993; Hartig et al. 2002; Smith 2009; Raposa et al., this issue). Continuing land subsidence in the region (Donnelly 1998) and the relatively low quantities of sediment currently available to coastal marshes in the Northeast make these systems highly susceptible to accelerated SLR (Kirwan et al. 2010; Fagherazzi et al. 2012; Weston 2014).

Increased inundation of coastal marsh soils is associated with an increase in phytotoxic sulfides (King et al. 1982; Kolker 2005; Watson et al. 2014a) and peat waterlogging that reduce the capacity of marshes to resist storm erosion (DeLaune et al. 1983; Wigand et al. 2014). Narragansett Bay marsh soils appear unable to keep up with recent accelerated SLR and are becoming waterlogged, fully saturated and not draining even on the ebb tide (Carey et al., this issue). Although it is relatively clear that accelerated SLR and changes in the frequency and intensity of storms will result in areal losses of coastal marsh systems in the Northeast, it is difficult to predict specific shoreline changes due to the complexity of coastal systems and the influence of stochastically unpredictable future storm events (Ashton et al. 2007). These complexities may constrain coastal managers’ ability to make quantitative predictions of future system behaviors, and therefore emphasize the importance of a flexible and adaptive management strategy (West et al. 2009; Glick et al. 2011b; Stein et al. 2013).

Managers are challenged with developing appropriate methods to identify climate-related vulnerabilities and adaptation actions to build system resistance and resiliency, and to enable desirable transformations (Millar et al. 2007; West et al. 2009; Glick et al. 2011a). Climate adaptive actions implemented to promote *resistance* (e.g., shoreline stabilization) would increase coastal marsh persistence and maintenance of current conditions, while actions to promote and enhance system *resilience* (e.g., thin-layer application of sediment) would improve the capacity of a coastal marsh to return to desired conditions and associated species assemblages or to at least maintain some level of functionality in an altered state. *Transformation* (e.g., upland migration) refers to climate adaptive efforts that enable or facilitate the transition of the system to a new functional state (e.g., woodlands transform to salt marsh). Climate change adaptive actions relative to coastal marsh system survival and sustainability encompass actions that inclusively increase resistance, increase resilience, and facilitate desired transformations.

The Narrow River Estuary Climate-Adaptation Project

Successfully adapting to a rapidly changing climate, while sustaining habitat and wildlife, is challenging for natural resource managers, and an area of applied science that has only recently received attention by restoration scientists and ecologists (Bierbaum et. al. 2013). One example of a community project in which local stakeholders, state, and federal partners joined together to develop a plan and actions to build coastal resiliency in the aftermath of Superstorm Sandy is the Narrow River Estuary (NRE) climate-adaptation project. The Narrow River is approximately 9.5 km long, composed of a tidal inlet and back bay, an estuary, and two fjord-like ponds in southern Rhode Island (Gaines 1975). The US Fish and Wildlife Service (USFWS), the lead organization of the NRE climate-adaptation project, initiated stakeholder meetings to plan and implement a habitat restoration strategy for coastal marsh and estuarine habitat in the NRE. The coastal marsh restoration component of the project is part of a larger effort to restore ecosystem resilience, system functions, and the provision of ecosystem services to the entire mosaic of estuarine habitats in the NRE. Much of the NRE is located within the John H. Chafee National Wildlife Refuge (NWR). National Wildlife Refuges are required to administer lands and waters for the conservation, management, and where appropriate, restoration of the biological integrity, diversity, and environmental health of the refuge as described by The National Wildlife Refuge System Improvement Act of 1997. The climate change adaptation plans recommended by the workgroup were aligned with the missions of the USFWS and the John H. Chafee NWR.

The NRE restoration project was financed under the Disaster Relief Appropriations Act of 2013 (Public Law 113–2). The USFWS organized various federal, state, and local stakeholders (Table 1) to partner in developing a climate change adaptation strategy for managing and restoring the tidal marshes of the NRE, part of the larger Narragansett Bay Estuary, RI. The NRE restoration project is intended to enhance marsh condition to better withstand predicted climatic shifts, in particular with respect to increased inundation resulting from SLR and future storm events. The USFWS used a planning horizon of 35 years for the project. In an effort to advance the strategy, we share the approach and methodology developed to manage coastal marshes in the NRE. We hope to facilitate the dissemination of best practices and lessons learned from the NRE climate change adaptation plans, and in the future, share the implementation and post implementation monitoring results of selected adaptation actions.

Climate Change Adaptation Strategy (CCAS)

A common adaptive management approach previously used for successful restoration management (e.g., Teal and Weishar 2005; Buchsbaum and Wigand 2012; Williams and Brown 2012) was modified to identify climate-related vulnerabilities and propose climate change adaptation actions and monitoring schemes (Fig. 1). We describe the organization and planning of the NRE adaptation project as an example of the implementation of the CCAS. The USFWS convened a series of facilitated meetings with stakeholders to define the goals of the project, compile the available scientific and ecological information about the marsh ecosystem, assess climate-related coastal vulnerabilities, and discuss potential climate change adaptive actions. Other anthropogenic stressors (i.e., eutrophication) that might co-occur with climate-related ones (e.g., accelerated sea level rise; changes in storm frequency) were considered in the climate-adaptation plans to help ensure the provision of water quality maintenance, in addition to flood abatement and habitat for fish, shellfish, avifauna, and other wildlife. Collaborative and consensus oriented decision-making were employed throughout the planning process (Feurt 2008; Hartnett 2010).

Stakeholders recommended that a BACI (Before-After, Control-Impact) sampling design (Stewart-Oaten et al. 1986; Stewart-Oaten et al. 1992; Underwood 1992; Stewart-Oaten 2003) be employed when possible to help measure the success of the adaptation or restoration actions. Because control or reference sites with identical conditions to the impact (restored) site typically are rare, one or more reference sites near the impact site, but not directly part of the area being restored served as unaltered controls. Before and after sampling would help determine how actions alter the site through time, and the controls and impact sampling would allow the effects of the adaptation actions to be discerned from natural variability, stochastic events, and underlying trends in the larger marsh system.

Stakeholders defined performance metrics and targets of actions taken to restore the marsh system or adapt to climate change. It was acknowledged that an appropriate monitoring program with a timeline would be necessary: first, assess system responses to actions; then, evaluate actions; and finally, determine if different or additional actions would be warranted. The CCAS recommends an iterative process to evaluate targets and performance metrics as prescribed by the agreed upon timeline. The iterative approach allows for flexibility in options so that mid-course adjustments and corrections are possible. It is important to be able to revise actions and share information and lessons learned. Uncertainty about future climate and human activities can interrupt or alter expected outcomes of climate adaptation actions. Additionally, the sharing of best practices and lessons learned is crucial in advancing understanding and transfer of climate adaptation and restoration actions.

Implementation of the CCAS

Identification of the problem and selection of management areas in the NRE—

Stakeholders defined the problems and goals during a series of facilitated meetings. The threats to marsh persistence primarily attributed to the increase in frequency and intensity of storms as well as accelerated SLR on the NRE coastal marshes were identified. Stakeholders were concerned about the loss of coastal marsh area and the services that marshes provide such as habitat for fish and wildlife, flood abatement, and water quality maintenance, among others. More specific and local problems included the loss of nesting habitat for the saltmarsh sparrow (Fig. 3), an obligate saltmarsh species. The saltmarsh sparrow is listed as “Vulnerable” on the International Union for Conservation Nature Red List of Threatened Species (IUCN 2014), as a species of highest conservation concern for the New England/ Mid-Atlantic Bird Conservation Region (USFWS 2008), and as a species of continental importance (Rich et al. 2008). The nesting habitat for the saltmarsh sparrow is in the high marsh vegetation *Spartina patens* (salt meadow hay) and *Juncus gerardii* (black rush), which are impacted by accelerated SLR, experiencing increased frequency of inundation (Smith et al. 2014; Raposa et al. this issue).

The physical boundaries of coastal marsh areas in the NRE to be considered for climate adaptive actions were organized by river reach to facilitate stakeholder discussions (Fig. 2).

River reach areas were defined by landscape features, including bridges and large channels, and contained current salt marsh, associated tidal brackish wetlands, shrub wetlands, and pools and pannes. The stakeholder initial discussions focused on assessing the vulnerability of coastal marsh areas, developing management plans, and prioritizing locations for adaptive actions.

Key scientists, managers, and experts presented information to the stakeholders to provide best available knowledge and science on the NRE to assess vulnerabilities and decide upon climate change adaptive and restorative actions for coastal marshes. The NRE coastal marshes were modeled with the Sea Level Affecting Marshes Model (SLAMM version 6.1, 2009). The SLAMM model uses recent vegetation, accretion, and elevation data and different sea level scenarios (0.3 – 1.5 m by 2100) to map which marsh areas are likely to become permanently inundated and disappear in future decades, and which upland areas have the potential to become tidal wetlands.

The USFWS and US EPA presented results of trend analyses of historic photographs showing that since the 1930s coastal marsh systems in the Narrow River and other Narragansett Bay marshes have exhibited increased shoreline and channel erosion, higher frequency of ponds and pannes in the high marsh, and a widening of tidal creeks (C. Vandemoer, unpublished data; Watson et al. 2014b). Higher loss rates have been found for marshes lower in elevation, pointing to increased inundation related to accelerated SLR as a driver of the marsh loss (Watson et al., this issue). Some pools and pannes in the NRE marsh system however, are historic and were present as far back as the 1930s (Watson et al. 2014b).

Rapid assessment vegetation, soil, and landscape data examining marsh condition and potential vulnerability to SLR at specific marsh areas were presented to the stakeholders by Save the Bay (Cole Ekberg et al., this issue). The rapid assessment included metrics to assess the extent of die-back in the high marsh area, vegetation composition, and soil strength, as well as identification of potential restoration locations. Collectively, the stakeholder discussions of the current marsh condition and vulnerability of the marsh areas to accelerated SLR and increased storm activities allowed for identification of various climate change adaptive actions in specific river reaches. This was then further refined based on the known distribution and relative abundance of nesting and migratory birds, other resources of concern and to adjust for logistical constraints in some cases. Ultimately, climate adaptive actions were assigned to specific river reaches to maximize improvements to marsh health while minimizing any short-term impacts to threatened, endangered, or migratory species at the site.

Climate change adaptive actions in the NRE—Climate change adaptive actions considered for the NRE included: shoreline protection, raising the elevation of the marsh, increasing marsh drainage, facilitating marsh upland migration, and dam removal (Table 3). Because of breeding and nesting behavior of marsh birds and sensitivity of fish to turbidity plumes associated with sediment dredging and thin layer application, some restoration actions require constraints on time of year the action is carried out and location of the action. These constraints will be defined and applied through state and federal permits. The sites selected and the climate adaptive actions recommended by the stakeholders informed USFWS restoration plans and were subject to formal Environmental Assessment (EA) and permitting before implementation. The public was encouraged to provide written comments on the draft EA document that described USFWS proposed climate-adaptation and restoration actions for the coastal marshes in the NRE.

Areas of vegetated shoreline in vulnerable river reaches with low to medium wave activity were selected for placement of living shorelines, which are natural marsh bank stabilization approaches. A living shoreline is a biomaterials-based installment (e.g., plants, oyster shell, organic materials, or other natural materials) created to stabilize and protect the marsh coast from erosion, and therefore builds system resistance (Duhring 2006; Temmerman et al. 2013). Coconut fiber (coir) logs (Fig. 4a) and oyster shell bags (Fig. 4b) were set along about 150 meters of marsh shoreline in the NRE. Oyster shell bags were placed in a sill formation with sufficient reef height to attenuate waves and wakes. Fiber logs were placed in front of marsh banks to enhance sediment deposition and stabilize physically weakened marsh banks. The coir logs and oyster shells are expected to promote sediment deposition, absorb and dissipate wave energy, and promote growth of creek bank vegetation. Stabilizing the salt marsh shoreline with coir logs and oyster shell will help minimize future erosion, and improve habitat diversity and shellfish habitat. Over the next two years, and in future monitoring programs, the condition of the living shoreline and reference site shoreline areas will be monitored and compared by The Nature Conservancy and the University of Rhode Island.

Dredging actions to spray or mechanically place and spread dredged sediment over the marsh surface to raise elevation and build system resiliency (Ford et al. 1999; Mendelssohn and Kuhn 2003; Frame et al. 2006; Ray 2007) was adopted as another climate change adaptive action to implement in the NRE. The project technical team finalized the design for sediment placement, which is recommended to occur in multiple phases. Areas of tidal flat and subtidal bottom will be dredged to depths suitable for eelgrass habitat and the dredged material used to raise elevations in portions of the marsh that have become degraded due to waterlogging and subsidence. The dredged sediments will be characterized (e.g., grain size, organic content, toxicants) prior to application. Permitting for these activities include applications to the RI CRMC for a Federal Consistency Determination, RI Department of Environmental Management for a Section 401 Water Quality Certification, the US Army Corps of Engineers for a Section 404 permit, and an EA to comply with requirements under the National Environmental Policy Act. Permitting concerns include the placement of material within existing wetlands and potential adverse impacts to wetlands, water quality, and essential fish habitat. The stakeholders proposed that follow up actions to the placement of the dredged sediments on the marsh might include planting the altered marsh area when the applied sediment has stabilized. Alternatively, some plants might revegetate from existing rooted plants with thin-layer application of dredged sediments. Revegetation patterns will be monitored to evaluate the relative success and trade-off between elevation gain from application of sediments and time to revegetated condition. The first, “test” phase of material placement will occur within a limited area, and results will inform a second phase the following year that is anticipated to occur on a larger scale. Lessons learned related to equipment, access, mobilization, methods, soil characterization of source material, depth of dispersed material, consolidation of dispersed material, marsh drainage patterns, vegetation survival and regrowth, and impacts to surrounding habitats will be used to improve project design for the second phase.

Shallow creeks (or runnels), generally 0.2 m to 0.5 m in depth and 0.15 m to 0.5 m wide, will be excavated to drain some portions of marsh where interior ponding is resulting in apparent marsh die-back (Fig. 5). Improved surface drainage is intended to help restore growing conditions for marsh vegetation. To create these runnels a low ground pressure excavator or hand digging will be utilized to connect areas of impounded water to existing ditches or creeks to increase drainage and build system resiliency. The material excavated will be used to either fill old agricultural ditches that create mosquito-breeding habitat or to create areas for revegetation by placing excavated peat in areas of low elevation where vegetation has died.

While runnels typically target small ponded areas, large sinuous creeks are more appropriate for restoring hydrology to much broader sections of marsh. As applicable, a low ground pressure excavator will dig sinuous creek networks into low elevation areas that currently show signs of degradation from waterlogging. An ongoing marsh adaptation project in the nearby Narragansett Bay National Estuarine Research Reserve excavated new sinuous creeks into waterlogged and ponded areas, which resulted in a rapid and dramatic drop in water table depths and revegetation (Fig. 6; K. Raposa, unpublished data). A successful integrated marsh management project in New York also incorporated new sinuous creeks as part of its holistic restoration design (Rochlin et al. 2012a, b). In general, it is expected that a combination of runnels and larger sinuous creeks can be used to increase drainage, improve hydrology, and reduce waterlogging inundation in target areas of deteriorating coastal marsh systems.

On-the-ground observations in the NRE marsh system and SLAMM (version 6.1, 2009) maps identified high priority marsh units for removal of impediments to migration such as old roads, stone walls, or other human-made features, and conservation easements and land acquisition to protect specific upland migration areas from development. A marsh unit was defined as an area of marsh within a river reach, where a restorative action was planned. Dam removal can sometimes increase sediment loads into coastal marsh systems and contribute to marsh accretion however, the dam upstream of the NRE has very little chance of removal because of its historic status. Therefore, stakeholders did not recommended dam removal as a feasible adaptation action.

Proposed Monitoring for Climate Adaptive Actions in the NRE—Proposed monitoring plans included hydrology, sediment accretion, soil characterization, pond, pool, and panne extent, and vegetation, avian, and elevation surveys (Table 2). A total of 13 surface elevation tables (SETs) and marker layers (Cahoon et.al. 1995, 2002, 2006) will provide for long term monitoring of marsh sediment accretion and elevation change throughout the NRE. When possible, monitoring activities will be conducted before and after, at reference sites and impacted sites where actions will be carried out, as prescribed by the BACI design. For some planned actions where reference sites are not available and the BACI design is not feasible or practically possible, before and after assessments at the impacted sites could be conducted. As crab activities on the marsh landscape are increasingly implicated as a cause for marsh loss (e.g., Coverdale et al. 2012; Luk and Zajac 2013), crab communities might also be monitored. It was noted that large-scale astronomical cycles such as the Metonic cycle and regional and local tidal cycles needed to be considered in the long- and short-term monitoring efforts. The majority of the monitoring will be conducted by the biological staff of the USFWS and project partners (Tables 1, 2). In addition, the Saltmarsh Habitat and Avian Research Program (www.tidalmarshbird.org) was awarded funding to evaluate the resilience of the tidal marsh community to impacts from Hurricane Sandy and marsh restoration activities, and has established monitoring stations at this site as part of the regional analysis. The CCAS specifically suggests flexibility and iteration, so that performance metrics and expected targets can be monitored, and if necessary adjustments and corrective actions can be carried out.

Conclusion

We presented a climate change adaptation strategy, which included a framework and methodology of adaptive management actions that could be employed to build resistance and resiliency in coastal habitats. As an example of the use and implementation of the CCAS, selected climate change adaptive actions to manage and sustain NRE coastal marshes were described. Other climate adaptation actions may also be considered to build coastal marsh resilience and resistance in other systems, depending upon site specific biodiversity, geomorphic, hydrological, and biogeochemical characteristics of the coastal system along with co-occurring anthropogenic stressors.

As climatic factors continue to impact natural systems in future decades they are expected to cause realignments and alterations in both spatial and temporal patterns of biodiversity including the reshuffling of community composition and the emergence of “novel ecosystems” (Hobbs et al. 2006; Williams and Jackson 2007). Such shifts and realignments will make protecting some species and ecosystems and the services these provide in their current locations and conditions difficult, and in some cases impossible (West et al. 2009). As future coastal impacts of climate change may be difficult to predict, it is important to be prepared to move from a management model of preserving the current condition or designing restoration to historic conditions to a model of managing sustainable systems that may differ in composition, structure, and sometimes function than historic states (West et al. 2009; Cole and Yung 2010). However, historical knowledge of specific ecosystems, associated habitats and species, and system functions can guide restoration and climate adaptation actions, not necessarily to recreate historic conditions, but when possible to best manage for continuity of ecological processes and patterns over time (Higgs et al. 2014). Some emphasis on historical knowledge may provide the benefit of curbing potentially destructive actions that emphasize human interests at the expense of ecosystems (Higgs et al. 2014).

Both bottom-up community planning and top-down national strategies will be needed to help regions deal with the impacts of climate change, and these efforts will require federal, state, and local agencies to coordinate as they incorporate climate adaptation planning into their programs (Bierbaum et al. 2013). There has been recent attention at the USA federal level to develop climate adaptation plans and actions; for example, the 2009 Presidential Executive Order 13514 (whitehouse.gov/assets/documents/2009fedleader_eo_rel.pdf; viewed 3 Nov. 2014) requiring federal agencies to develop recommendations for strengthening policies and programs to adapt to the impacts of climate change. State and federal resource management plans now incorporate climate adaptation actions; for example, the 2012 US National Fish, Wildlife, and Plants Climate Adaptation Strategy (www.wildlifeadaptationstrategy.gov). Also, the State of RI Coastal Resources Management Program (RICRMP) recognizes a projected rate of 0.3–1.5 m of SLR by 2100 for planning purposes (RICRMP 1983; Section 145). These types of strategies and others (e.g., freeboard requirements in building codes) can help reduce climate change vulnerabilities. However, a lack of coordination at the federal, state, private, and nongovernmental levels, and the proliferation of often duplicative and sometimes contradictory adaptation approaches can hinder implementation of timely adaptive actions (Bierbaum et al. 2013).

In general, barriers to climate adaptation activities include lack of funding, policy and institutional constraints, and difficulty in anticipating climate shifts given the current state of information on climate changes (West et al. 2009; Bierbaum et al. 2013). In particular, the lack of resources and sustained multi-year funding impedes resource managers' ability to advance climate adaptation planning, implementation, and monitoring. Fragmentation of jurisdictional control is also a critical barrier to building the resilience of systems that cross-jurisdictional boundaries (Bierbaum et al. 2013). To work successfully at broader landscape scales, it will be necessary to develop governance structures and collaborative approaches to facilitate planning and implementation across multiple jurisdictions, administrative units, and land ownerships (Pressey and Bottrill 2009).

Using a CCAS that allows for a continuum of approaches, including restoring resistance, building resilience, and facilitating system transformation, we address short term (e.g., protecting shorelines; restoring marsh sparrow habitat) and long-term (e.g., enabling upland marsh migration) climate adaptation goals. Collaborative decision-making and stakeholder engagement at the onset and throughout the term of the project are key to assessing the vulnerability of the resource, defining goals, developing management plans, and implementing the climate adaptation actions. We provide the CCAS as guidance for successful management of other coastal marsh systems faced with stressors associated with climate change.

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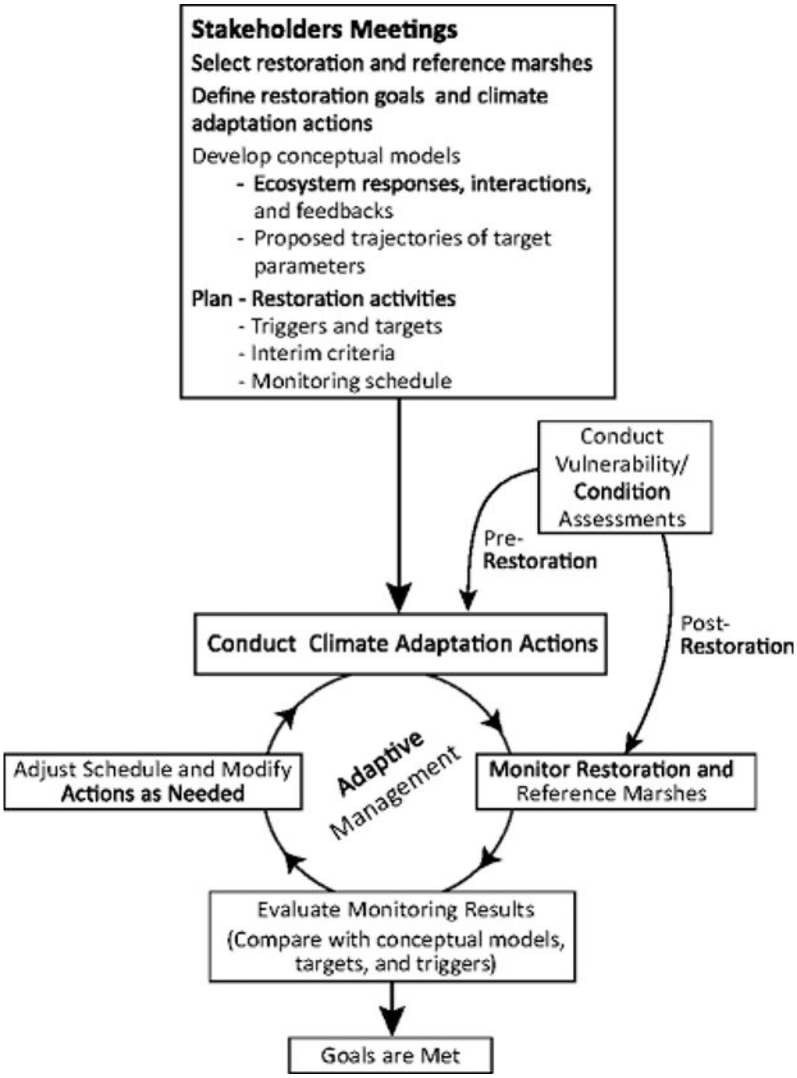

Fig. 1.

Climate change adaptation strategy (CCAS) for management of coastal marshes

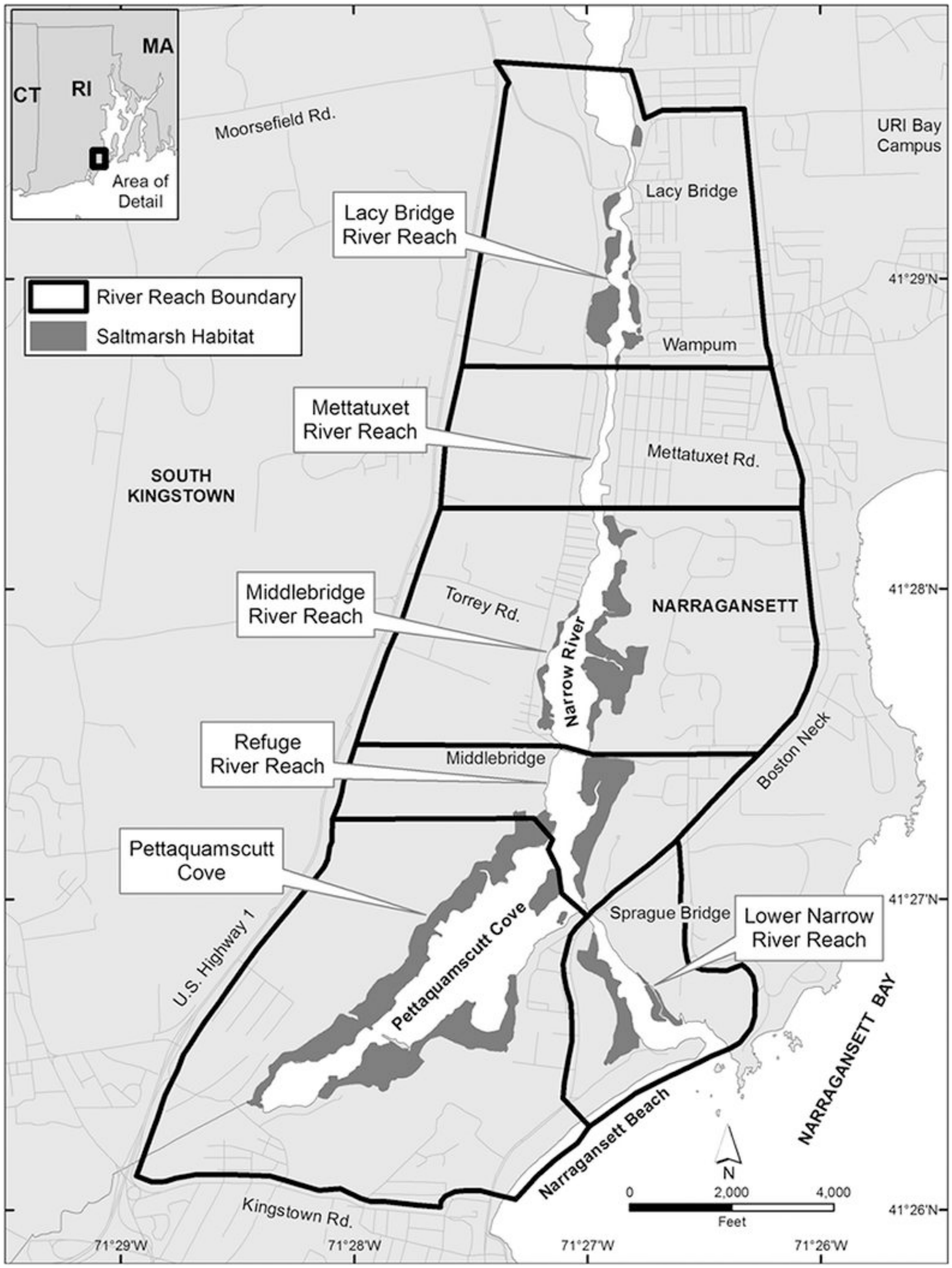

Fig. 2.

Map of the Narrow River and locations of the river reaches and marsh areas

Fig. 3.

a The saltmarsh sparrow (*Ammodramus caudacutus*) has been ranked as a bird of conservation concern in the US (Rosenberg et al. 2014); here, perched in bayberry (*Myrica gale* L.), located at the upper edge of the salt marsh. Photo taken by P. Paton

b A saltmarsh sparrow nest located in the high marsh of the Narrow River Estuary. Photos provided by RI NWR. Photo taken by R. Smith

Fig. 4.

a Coir logs set along the Narrow River shoreline

b Bags of oyster shell set along the NRE shoreline Photos taken by C. Vandemoer

Fig. 5.

Example of a hand dug runnel (0.15–0.2 m wide by 0.2 m deep) to drain the high marsh. Photo taken by W. Ferguson

Fig. 6.

Example of a newly excavated sinuous creek (1 m wide by 0.6m deep) that was created to increase high marsh drainage as part of an ongoing climate change adaptation project in the Narragansett Bay National Estuarine Research Reserve, RI. Photo taken by K. Raposa

Table 1.

Partners, stakeholders, and decision-makers and their respective roles in the Narrow River project.

Stakeholders	Roles of Partners
US Fish and Wildlife Service Lead organization	Provide oversight of the project and responsible for planning and implementation of the overall project.
RI Dept. Environmental Management	Performing water quality tests. Expertise in marine fisheries.
RI Coastal Resource Management Council	Permitting & legal responsibility. Expertise in living shoreline enhancements and dredging actions.
Army Corp Engineers	Provide technical expertise on marsh restoration actions and design and implementation of dredging actions.
US EPA	Provide technical support on multiple stressor impacts, marsh ecology, and marsh monitoring.
The Nature Conservancy	Conduct and monitor living shoreline work. Provide Narrow River results of scenario testing with the Sea Level Affecting Marshes Model (SLAMM version 6.1, 2009).
Narragansett Bay Estuarine Reserve	Monitoring, habitat restoration expertise.
University of Rhode Island	Assist in developing monitoring and evaluation of techniques.
Save The Bay	Runnel development, monitoring salt marsh conditions.
Audubon Society of Rhode Island	Monitoring, habitat restoration expertise.
NOAA and Ducks Unlimited	Water control structure(s) design.
Local Towns	General assistance, equipment use, permits.
Center for Ecosystem Restoration	Facilitator and organizer of stakeholder meetings.

Table 2.

Pre- and post-monitoring plans for adaptation actions in the Narrow River Estuary project.

Stakeholder	Activities
[1]National Wildlife Refuge-Salt Marsh Integrity Project; Salt Marsh Habitat and Avian Research Project	– Marsh bird surveys (10 points) – Nekton sampling (60 points) – Vegetation surveys (~400 transects, including analysis of historic transects) – Surface elevation tables (13) – Water level loggers (3) – Marsh drainage patterns
[2]Save The Bay	– Assess upland corridors for migration – Plant communities (43 transects) – Bearing capacity (23 transects) – Marsh elevation data – Porewater salinity – Water levels
[3]US EPA Pettaquamscutt Cove	– Plant inundation – Vegetation cover over time – Soil characterization – Marsh water levels – Elevation data – Pore water salinity

[1] Method details reported in Neckles et al. 2013.

[2] Method details reported in Cole Ekberg et al., this issue.

[3] Method details reported in Watson et al. 2014b; Watson et al., this issue.

Table 3.

Climate adaptive actions and proposed restoration methods for Narrow River marshes.

Potential Actions	Proposed Methods	Proposed Monitoring Targets or Performance Metrics	Climate Adaptive Approach
Shoreline protection	Installation of living shoreline: Coir logs and bags of oyster shells	Increase in vegetated shoreline area; increase in flood abatement; increase in sediment deposition	Improve resistance
Raise high marsh elevation	Thin layer application of dredged sediments	Increase in high marsh elevation and habitat for saltmarsh sparrow	Increase resiliency
Restore marsh drainage	Create small, sinuous creeks and runnels to drain newly-formed interior ponds and promote tidal exchange	Lower percentage of flooded saltmarsh sparrow nests; higher percentage of chicks fledged	Increase resiliency
Facilitate marsh upland migration	Remove barriers to migration such as culverts and stone walls; conserve land parcels for marsh migration	Migration of salt marsh plant species into upland land parcels	Enable transition
Restore sediment delivery	Remove inland dams	Increase in suspended sediment loads in creeks emptying into the marsh system	Increase resiliency