Rhode Island Coastal Wetland Restoration Strategy

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Acronyms

EPA	U.S. Environmental Protection Agency
CRMC	Rhode Island Coastal Resources Management Council
DEM	Rhode Island Department of Environmental Management
NBNERR	Narragansett Bay National Estuarine Research Reserve
NOAA	National Oceanic and Atmospheric Administration
NRCS	U.S. Natural Resources Conservation Service
RINHS	Rhode Island Natural History Survey
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service

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Cover photo of Nag Marsh on Prudence Island provided by the Narragansett Bay National Estuarine Research Reserve

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Executive Summary

Coastal wetlands are valuable to people and wildlife for the important ***ecosystem services and functions*** they provide, which include protection of property and structures from storm waves and erosion; filtration of sediments and pollutants; uptake and storage of nutrients and carbon; and critical forage, breeding, and cover habitat for numerous fishes, birds, mammals, and invertebrates, including commercially and recreationally-important species. Yet, Rhode Island's coastal wetlands have been impacted by people since colonial times, causing ***substantial loss*** and ***widespread degradation***, diminishing the ecosystem services and functions they have historically provided. Historic and ongoing anthropogenic stressors, such as filling, impoundment, ditching, and nutrient enrichment have recently been overshadowed by clearly visible impacts from ***accelerating sea-level rise***, which is expected to reach 0.3 to 2.5 meters above current levels by the end of this century, causing further, widespread marsh loss.

Ecosystem restoration has historically focused on restoring or improving prior environmental conditions at the site scale. A more recent approach spatially and conceptually expands ecosystem restoration to include beneficial ***interventions*** such as buffer restoration, land conservation, and policy changes that restore ecosystem functions and services. Because many coastal wetlands are unlikely to be sustainably restored to prior conditions in the face of accelerating sea-level rise and other stressors, a broader intervention approach needs to be taken that identifies and prioritizes restoration of the ecosystem functions and services provided by coastal wetlands on a statewide, rather than a strictly site-specific scale.

The ***vision, goals, and objectives*** of coastal wetland restoration in Rhode Island presented in this Strategy are:

Vision

- Coastal wetlands retain the critical functions and ecosystem services they have provided historically.

Goals

- Wetland loss is minimized through restoration, conservation, and other interventions;
- Management leads to no net loss of critical functions and ecosystem services across broad systems.

Objectives

- Develop restoration and intervention prioritization tools based on the criteria outlined in this Strategy;
- Prioritize coastal wetlands for restoration and migration facilitation;
- Systematically maintain or restore the ecosystem functions and services of coastal wetlands based on priorities outlined in this Strategy;
- Systematically evaluate restoration outcomes;

- Identify, evaluate, adapt, and implement the most effective and efficient management practices.

Reaching stated goals will be best served through the continued development of a centralized ***state coastal wetlands program***, which will act as a clearinghouse for information and promote long-term planning for and adaptive management of coastal wetlands, statewide. While funding is available for program development, ***long-term implementation funding has not been identified***.

This Strategy identifies ***criteria for prioritizing coastal wetlands*** for restoration, conservation, and intervention. Prioritization should consider highly-valued ecosystem functions and services, vulnerability to sea-level rise, feasibility and sustainability of the restoration, landward migration potential of coastal wetlands, ecological condition, and social and cost benefits. The CRMC has developed a restoration project prioritization protocol for Rhode Island's Coastal and Estuary Habitat Restoration Program and Trust Fund that considers these criteria and can be adapted to other projects.

Restoration activities that have been implemented in the state include removing fill, restoring tidal flow to impounded wetlands, controlling invasive species, and elevating the marsh surface with sediments to delay marsh drowning. Broader ***ecological interventions*** have included conserving and managing adjacent properties to allow coastal wetlands to migrate inland as sea level rises; reducing nutrient inputs from groundwater, storm water, and contributing surface waters; restoring buffer vegetation; drainage enhancement; and wetland creation. Carefully monitoring restoration projects and outcomes will reveal the most effective and efficient methods.

Monitoring and assessment plays a critical role in coastal wetland restoration for assessing condition and vulnerability trends, prioritizing restoration projects, and evaluating restoration and intervention outcomes. There are a number of monitoring tools available for coastal wetland managers, including statewide marsh migration and vulnerability models; remote, rapid, and intensive assessment methods; and wildlife data. Further development of purpose-specific tools is needed, however. And, while much is known about coastal wetland ecology and restoration, questions remain that could be answered through long-term ecosystem monitoring and research.

Coastal wetland restoration in Rhode Island has been conducted though ***collaborations*** among state, federal, municipal, NGO, and academic coastal wetland scientists and resource managers. Organizing partners through a centralized coastal wetlands program and integrating coastal wetland restoration into the state regulatory framework according to this Strategy will improve effectiveness and efficiency of coastal wetland restoration in the state.

1. Introduction

Coastal wetlands are valuable for the many important ecosystem services they provide; yet coastal wetlands are at increased risk of degradation and loss due to various historic and ongoing stressors caused by human activities. Accelerating relative sea-level rise, a result of global climate change and geological processes, poses an imminent threat to coastal wetlands as it is predicted to displace or destroy the majority of Rhode Island's existing coastal wetlands by the end of this century (CRMC 2015). Human stressors may work individually or interactively to threaten the functions, services, and sustainability of these important natural systems for the future (Gedan et al. 2011, Wigand et al. 2014, Roman 2017, Watson et al. 2017a), underscoring the need for coastal wetland restoration.

This Rhode Island Coastal Wetland Restoration Strategy (hereafter, Strategy) provides a strategic framework to guide the management of coastal wetlands facing increasing stress in the coming decades. This Strategy was developed considering up-to-date research and science-based restoration information, with input from state, federal, and academic researchers, state regulators, and state and NGO managers, to provide a rigorous and vetted tool for planning and prioritizing restoration, conservation, and other management actions aimed at preserving these critical resources. Specifically, this Strategy outlines the ecological functions and services of coastal wetlands in Rhode Island and the stressors acting upon them; establishes coastal wetland restoration goals and priorities; identifies available restoration, management, and monitoring tools as well as information and resource needs; and presents a rationale for developing a long-term centralized state coastal wetland restoration program.

2. Coastal Wetlands of Rhode Island

Description

For the purposes of this Strategy, ***coastal wetlands*** refers to mostly-vegetated, tidal, saline (>0.5 ppt salinity) wetlands; namely brackish and salt marshes. ***Brackish marshes*** are a narrowly-distributed plant community type in Rhode Island, generally occurring as transitional areas between freshwater and saltwater dominated systems. Brackish marshes often occur at the landward edge of salt marsh vegetation where fresh water (overland flow, groundwater) from uplands or freshwater wetlands enters a salt marsh system, or where freshwaters are intermittently exposed to salt storm overwash or salt spray (Enser et al. 2011). Brackish marshes tolerate a relatively narrow range of physical and chemical conditions but can support diverse vegetation, including locally uncommon and valued plants, such as rose mallow (*Hibiscus moscheutos*) and Eastern gamagrass (*Tripsacum dactyloides*).

Coggeshall marsh on Prudence Island. Photo provided by NBNERR.

Salt marsh is by far the most common coastal wetland type in Rhode Island and is considered one of the most productive ecosystems on Earth (Nixon and Oviatt 1973, Kirby and Gosselink 1976). New England salt marshes occupy a unique niche in which the frequency and duration of tidal flooding with salt water largely control physical, chemical, and biological processes, making elevation of the marsh surface relative to the tidal frame critical (Mitsch and Gosselink 2000). Salt marshes are dominated by a small number of halophytic (salt-tolerant) plants, but range widely in size, age, and complexity. Larger salt marshes are typically located along the lower tidal reaches of streams and rivers and within back-barrier systems, where sediments and nutrients from the landscape contribute to marsh platform growth, but they can also be found as narrow fringing bands along estuarine shorelines.

A well-developed New England salt marsh can be thousands of years old and may contain a number of habitat community types and land forms (Redfield 1972, Nixon and Oviatt 1973, Roman 2000). The high marsh platform is typically a nearly level peatland, which is flooded only on spring high tides and is dominated by native plant species, including salt hay (*Spartina patens*), spike grass (*Distichlis spicata*), black grass (*Juncus gerardii*), and short-form cordgrass (*Spartina alterniflora*) (Niering and Warren 1980). The low marsh zone is generally located at the seaward edges of a marsh and along creeks and pools, is flooded by nearly all tides, twice daily, and is dominated by tall-form cordgrass. The marsh shrub zone is typically a transitional zone to upland dominated by high tide bush (*Iva frutescens*) and/or groundsel (*Baccharis halimifolia*) and is only flooded on the highest spring tides and surges. A well-developed natural marsh platform also typically contains tidal creeks, pools, and natural pannes (shallow depressions) interspersed across the platform. Less-developed salt marshes can simply be monotypic stands of cordgrass as fringes along lower-energy estuarine shorelines (McKinney and Wigand 2006).

Salt marshes provide opportunities for recreation and education. Photos provided by NBNERR.

Functions and Ecosystem Services

Coastal wetlands provide a host of valuable ecosystem services and functions that benefit people, animals, and the environment (Gedan et al. 2009, Barbier et al. 2011). Large coastal wetlands can ***enhance coastal resilience*** by mitigating the impacts of coastal storms on adjacent properties through wave attenuation and shoreline stabilization (Shepard et al. 2011). Costanza et al. (2008) estimated that, per hectare, salt marshes provide $8,240 worth of protection from coastal storms annually, totaling $23.4 billion per year in protection from storms in the United States (unadjusted for inflation). Coastal wetlands ***support recreational activities***, such as bird-watching, fishing, shellfishing, and hunting, and provide ***scenic vistas***. They act as ***natural filters*** that can prevent sediments and pollutants coming off the landscape from contaminating surface waters (Bertness 1999) and, as they grow, can ***sequester carbon*** from the atmosphere in soil (Chmura et al. 2003, McLeod et al. 2011) and remove nutrients from surface waters through plant growth and by converting dissolved nitrogen to nitrogen gas through ***denitrification*** (Caffrey et al. 2007).

Coastal wetlands are ***highly productive*** and provide critical ***forage, breeding, and cover habitat*** for numerous fishes, birds, mammals, and invertebrates, including commercially and recreationally-important species. Salt marshes are critical nesting and foraging habitats for regionally at-risk salt marsh and seaside sparrows (*Ammodramus* spp.). They provide nesting and foraging habitat for many songbirds (order: *Passeriformes*), wading birds, shorebirds, gulls, and terns (order: *Charadriiformes*) (Brawley et al. 1998, Shriver et al. 2004, McKinney and Wigand 2006), and critical foraging, cover, and overwintering habitat for several small fish, crab, and shrimp species (i.e., nekton), including marsh specialists such as killifish (*Fundulus* spp.) and grass shrimp (*Palaemontetes pugio*), and commercially important summer and winter flounders (order: *pleuronectiformes*), blue crabs (*Callinectes sapidus*), and American eels (*Anguilla rostrata*) (Raposa and Roman 2001, Raposa 2003). As such, coastal wetlands are important to property, economy, quality of life, and the coastal environment in Rhode Island.

Salt Marsh Development

New England salt marshes have developed within the last 3,000 to 4,000 years, as sea-level rise from the most recent glaciation slowed and stabilized (Redfield 1972, Niering and Warren 1980). Salt marsh platforms increase in elevation and are maintained relative to the tide frame through accretion of organic matter and mineral sediments (Stumpf 1983, Roman et al. 1997). Sediments carried in from upstream sources and by wave energy settle from suspension to the marsh platform when the water movement is slowed by the marsh vegetation. Additionally, as marsh plants grow and die, growth of belowground biomass and deposition of plant matter onto the platform contribute to peat formation; this latter process is thought to be responsible for the bulk of marsh accretion in Rhode Island, as mineral sediment inputs are generally low (Turner et al. 2000, Carey et al. 2017, Watson 2017a), although past land use practices, such as farming, may have temporarily increased sediment loads during the 19th and early to mid 20th centuries (Kirwan et al. 2011). For many centuries, accretion rates have kept pace with sea-level rise (Bricker-Urso et al. 1989), and this process has allowed salt marshes to sustain and grow. However, in recent years sea-level rise has outpaced marsh elevation increase in Rhode Island (Raposa et al. 2017b), and many salt marshes now exhibit signs of plant stress and die-off, vegetation community shifts, marsh platform and edge erosion, ponding, and drowning (Warren et al. 1993, Donnelly and Bertness 2001, Raposa et al. 2017a, Watson et al. 2017a).

Painting depicting salt marsh hay harvesting and grazing by Martin Johnson-Heade c. 1865

3. Rationale: Why Restoration is Necessary

Coastal wetlands are naturally-resilient systems, but historic and ongoing human exploitation has caused ***widespread and substantial wetland loss and degradation***, threatening the functionality and sustainability of these important resources (Gedan et al. 2009, 2011, Watson et al. 2016b). Coastal development, sea-level rise, invasive species, and water pollution, including anthropogenic nutrients, have been identified as worldwide stressors to coastal wetlands (Greenberg et al. 2006); these same ***anthropogenic stressors*** also threaten coastal wetland health in Rhode Island (Table 1). Recognizing and understanding the individual, cumulative, and interactive effects of stressors on Rhode Island's coastal wetlands is necessary for effective resource management, conservation, and restoration (Wigand et al. 2014, Watson et al. 2017a, Roman 2017).

Table 1. Anthropogenic stressors to coastal wetlands in Rhode Island, their principal impacts, and facilitating or synergistic interactions

Stressor	**Code**	**Wetland Impacts**	**Potential Interactions**
Filling	FIL	Loss, *Phragmites* facilitation	PHR, SLH, SLR
Impoundment and tidal restriction	ITR	*Phragmites* facilitation, subsidence, vegetation and nekton community shifts, loss	NUT, PHR, DSS, SLH, SLR
Ditching	DIT	Altered hydrology, vegetation community shifts, ponding, dieoff, edge erosion	NUT, BCR, DSS, SLR
Nutrient enrichment	NUT	Reduced root growth, soil degradation, subsidence, ponding, N_2O emission	ITR, PHR, SLR
Phragmites	PHR	Vegetation community shifts, reduced habitat function	FIL, ITR, NUT, SLR
Burrowing crabs	BCR	Vegetation dieback, accelerated erosion	DIT, SLR
Decreased sediment supply	DSS	Accretion deficit, vegetation change, ponding, dieoff	ITR, DIT, SLH, SLR
Shoreline hardening	SLH	Impoundment, migration impediment	FIL, ITR, DSS, SLR
Watershed development	WSD	Nutrient enrichment, scouring, toxin inputs, invasive species facilitation	Causes or contributes to all above
Sea level rise	SLR	Increased inundation, ponding, vegetation community shifts, dieoff, loss	Interacts with all above

Filling

Historically, the ecosystem services of wetlands were not well understood, and coastal wetlands were generally considered low-value lands suitable for refuse disposal, filling for conversion to upland for development, and draining for salt hay production and livestock grazing (Gedan et al. 2009). Historic losses of salt marshes in Rhode Island from direct filling are estimated to be more than 50% and are highly correlated with urbanization (Bromberg and Bertness 2005). Regulations imposed in the 1970s have greatly reduced further filling of coastal wetlands, but coastal wetland area continues to be lost to other factors. Filling may introduce seeds or viable fragments of the invasive species *Phragmites australis* (subsp. *australis*) and can facilitate its colonization and growth through smothering native vegetation that might otherwise suppress its establishment (Chambers et al. 1999). Steep or hardened fill edges prohibit marsh vegetation from migrating inland as sea levels rise.

Impoundment and Tidal Restriction

Beyond direct filling (resulting in wetland loss), perhaps the most influential widespread anthropogenic stressors directly affecting coastal wetland function have been salt marsh impoundment and tidal restriction. Impoundment and tidal restriction are most often the unintended consequences of road, railroad, berm, and stone wall building. Impounding structures interfere with natural hydrology and can cause reduction or elimination of tidal flushing, entrapment of freshwater runoff and watershed nutrients, lowering of salinity, ponding with fresh or brackish water, and platform submergence and subsidence (Roman et al. 2000). These changes can result in stagnant, eutrophic, brackish systems with substantially altered plant and animal community assemblages, prone to invasion by non-native species, particularly *Phragmites* (Roman et al. 1984, Raposa 2002, Roman et al. 2002, Dibble et al. 2013, Dibble and Meyerson 2016). Additionally, lowered salinity associated with impoundment results in emission of CH_4 (Poffenbarger et al., 2011), which offsets a portion of the carbon stored in marsh soil.

Ditching

Ditching has been another widespread stressor affecting salt marshes in Rhode Island. From colonial times into this past century, salt marshes were ditched and drained by farmers to increase production of salt hay and for grazing cattle on the high marsh platform (Mitsch and Gosselink 2000). Additionally, in the early 1900s, public works projects ditched salt marshes extensively to drain natural ponds and creeks and hasten tidal drainage in an attempt to control salt marsh mosquito breeding. Ditching spoils were usually cast nearby resulting in raised levees bordering the ditches (Miller and Egler 1950). Dense parallel rows or grids of ditches and levees across the majority of high marsh platforms throughout New England have impacted the normal hydrology of these systems broadly. Many of these historic ditches have since clogged, impeding, rather than increasing drainage (Watson et al. 2017b). Ditching makes salt marshes more vulnerable to ponding and marsh drowning within the networks of raised levees (Smith and Niles 2016, Watson et al. 2017b), and ditches may act as sediment sinks, exacerbating marsh accretion deficits in relation to sea-level rise (Corman et al. 2012).

Ditching may diminish the suitability of salt marsh habitats to support shorebirds, wading birds, waterfowl, and other wildlife (Clark et al. 1984, Roman et al. 2000). Marsh pools are important habitat features for fish and wildlife, but it is reported that ditched salt marshes throughout New England have 70% fewer pools than unditched marshes (Adamowicz and Roman 2005).

Aerial image of Quonochontaug Pond marshes showing extensive man-made ditches.

Nutrient Enrichment

Nutrient enrichment is another widespread historic and ongoing stressor to coastal wetlands. Nutrients are introduced through groundwater (largely from onsite wastewater treatment systems), storm water runoff, rivers and streams, and ambient estuarine water, and are primarily the byproducts of human waste and urban runoff (Nixon et al. 1995, Nixon and Buckley 2007). Nutrient enrichment in salt marshes increases above-ground plant biomass, decreases below-ground biomass and peat production, and increases microbial decomposition, leading to destabilization of the peat soil, decreased accretion rate, platform subsidence and ponding, edge erosion, and marsh loss (Wigand et al. 2003, Darby and Turner 2008, Turner et al. 2009, Deegan et al. 2012, Watson et al. 2014). Nutrient enrichment facilitates the establishment and proliferation of invasive *Phragmites* (Meyerson et al. 2000, Windham and Meyerson 2003, Silliman and Bertness 2004, Mozdzer and Megonigal 2011), contributes to dissolved oxygen depletion in marsh pools, and may cause changes in the capacity of salt marshes to provide cover habitat for fish and other nekton (Deegan 2002). Nutrient enrichment has also been demonstrated to stimulate emission of nitrous oxide (N_2O) from salt marshes (Moseman-Valtierra et al. 2011, Martin and Moseman-Valtierra 2017). This potent greenhouse gas has 300 times the global warming potential as CO_2, and its emission therefore may offset some benefit of carbon stored in salt marsh soils.

Phragmites

Coastal wetlands are susceptible to invasion by the ubiquitous non-native genotype of the common reed, *Phragmites*. *Phragmites* is a fast-growing clonal grass species that is tolerant to brackish waters and can reach 5m in height. It can out-compete native wetland species for light and space resources and can dominate brackish coastal wetlands and salt marsh edges (Chambers et al. 1999). *Phragmites* can encroach onto tidal salt marsh platforms by sending fresh water from less saline to more saline parts of the marsh through a network of connected rhizomes (Amsberry et al. 2000, Vasquez et al. 2005) and can encroach into open water, completely covering coastal freshwater and brackish wetlands and ponds.

Phragmites australis is commonly found in RI salt marshes, especially in areas of disturbance. Photo provided by Dr. Laura Meyerson, URI.

Phragmites domination lowers plant species richness, changes soil composition, diminishes habitat value for some salt marsh dependent species (e.g. salt marsh and seaside sparrows), reduces open-water refugia for migrating and wintering waterfowl, and impedes landward migration of marsh vegetation (Benoit and Askins 1999, Farnsworth and Meyerson 1999, Meyerson et al. 2000, Smith 2013), in addition to blocking valuable vistas. *Phragmites* is not entirely devoid of ecological value, however.

For example, the rigorous growth and litter of *Phragmites* support higher soil accretion rates than other salt marsh plants (Rooth et al. 2003) and has been associated with higher net greenhouse gas uptake than native-vegetation marshes (Martin and Moseman-Valtierra 2015). *Phragmites* also provides nutrient uptake and pollution filtration, cover, and nesting habitat for a variety of birds, and foraging and cover habitat for small fishes (Meyerson et al. 2000, Meyerson et al. 2009).

Extensive crab burrowing along a marsh creek bank. Photo provided by NBNERR.

Burrowing Marsh Crabs

A recent proliferation of burrowing marsh crabs has contributed to marsh dieback (denuding of marsh vegetation), reduced plant biomass, marsh edge and creek-bank erosion, and marsh loss in southern New England (Alber et al. 2008, Holdredge at al. 2009, Smith and Tyrrell 2012). Altieri et al. (2012) theorize that predatory release of the purple marsh crab (*Sesarma reticulatum*) has resulted in its rigorous grazing and denuding of *S. alterniflora* and extensive burrowing in certain marsh systems. Burrowing and grazing by *S. reticulatum* has been shown to reduce plant biomass and increase marsh and creek edge erosion (Vu et al. 2016). Proliferation of another burrowing crab, the mud fiddler crab (*Uca pugnax*), may also contribute to low plant survivorship and marsh edge degradation (Smith and Tyrrell 2012, Luk and Zajac 2013). Dieback and edge erosion caused by burrowing crabs can release sequestered carbon from centuries-old salt marsh peat and contribute to platform edge erosion (Coverdale et al. 2014). Crotty et al. (2017) demonstrate that marsh peat softening due to increased levels of tidal inundation increases marsh vulnerability to consumer-driven die-off, and that the interaction between sea level rise and crab overgrazing has the potential to exacerbate marsh loss.

Decreased Sediment Supply
Reduction of sediment loads from damming of upstream rivers and watershed development threatens salt marsh accretion (Watson et al 2014, Weston 2014). Sediment supplies from farm soil erosion artificially spurred marsh growth in the Plum Island Estuary (northern Massachusetts) until the mid-1900s (Kirwan et al. 2011). It is unknown whether some Rhode Island salt marshes experienced similar increased growth during this period. Reforestation and development of farmlands in this past century would reduce similar anthropogenic sediment supplies that may have sustained marsh development in the Narragansett Bay watershed, and study is needed to determine whether or to what extent this has occurred.

Shoreline Hardening
More than 50% of the shoreline of Narragansett Bay has been hardened with rip-rap, bulkheads, and other shoreline protection structures (derived from RIGIS 2006, available at www.rigis.org). Shoreline hardening landward of coastal wetlands can prohibit the landward migration of marsh vegetation and its establishment in the intertidal zone. Shoreline hardening seaward of coastal wetlands can cause impoundment; prohibit natural processes such as tidal flow, storm overwash, and coastal erosion, which are sources of suspended sediments necessary for salt marsh accretion and function; and may prevent salt marsh predators from accessing adjacent benthic food sources (Gerber-Williams 2017).

Watershed Development
Watershed development causes or exacerbates many of the stressors listed above. Development bordering coastal wetlands is directly responsible for filling and marsh loss, shoreline hardening, impoundment, nutrient enrichment from individual septic systems, lawn fertilizers, and yard waste, and water pollution from runoff. Coastal development is also a direct impediment to marsh landward migration. Additionally, watershed development often reduces or destroys protective vegetated buffers and causes flashy and often polluted stormwater runoff, which can contribute to the proliferation of invasive *Phragmites* (Bertness et al. 2002).

Sea-level Rise
Multiple lines of recent evidence point to sea-level rise as a key driver of recent degradation of many New England coastal wetlands, as the rate of increase in relative sea-level rise in southern New England is significantly higher than the global average, nearly doubling over the last two decades (Watson et al. 2017a). Raposa et al. (2017a) found that from 1999 to 2015, high-marsh elevation change rates at Rhode Island salt marshes averaged 1.40 mm per year while the rate of sea-level rise in Newport, RI averaged 5.26 mm per year, indicating that salt marshes are losing elevation relative to the tide frame. In a nation-wide study, salt marshes from southern New England ranked among the most vulnerable to sea-level rise in the U.S. (Raposa et al. 2016c). Earlier studies have suggested that changes in marsh vegetation proportions favoring the more salt-tolerant *S. alterniflora* over high marsh species may be a result of increased

inundation associated with sea-level rise (Warren and Niering 1993, Donnelly and Bertness 2001). These vegetation changes, as well as salt marsh ponding, dieoff, and drowning, have more recently been documented throughout Narragansett Bay and coastal Rhode Island, indicating a widespread accretion deficit (Raposa et al. 2017a, 2017b, Watson et al. 2017a, Cole Ekberg et al. 2017), and the growth of the majority of southern New England salt marshes is now thought to be limited by inundation (Watson et al. 2014). In addition, a recent study in Virginia has indicated that back-barrier salt marshes are being lost to accelerating landward migration of barrier islands due to increased coastal storms associated with climate change (Deaton et al. 2016). This phenomenon may warrant consideration by coastal wetland managers for the numerous back-barrier systems along Rhode Island's south coast, where barrier Islands have also been shown to be migrating landward with rising sea levels (Dillon 1970, Boothroyd et al. 1985).

Sea Level Affecting Marshes Model (SLAMM) data from a recent mapping project predict that 52 - 87% of existing coastal wetland area in Rhode Island will be lost to inundation by the end of this century considering a scenario of 0.9 - 1.5 m of sea-level rise (CRMC 2015). SLAMM further predicts a net gain in marsh area if marshes are allowed to migrate and establish onto low-lying coastal land, although investigators in that modeling project caution that the model likely underestimates marsh losses and overestimates migration potential in several ways (CRMC 2015). Contrary to SLAMM predictions of net gain, a recent retrospective study found a net loss in salt marsh area of 17.3% in Rhode Island over the last 40 years, indicating continuing ***widespread marsh loss*** with sea level rise due to interactive effects of sea-level rise with biological, physical, and human-caused factors (Watson 2017a).

Sea-level rise may work additively or synergistically with other stressors to degrade marsh structure and function (Warren and Niering 1993, Watson 2017a). Coverdale et al. (2013) suggest that increased inundation associated with sea-level rise may interact with historic ditches to exacerbate marsh edge die-off and erosion. Smith and Niles (2016) found that ditched marshes are more prone to ponding and marsh drowning with increasing sea-level rise. Subsidence and soil degradation from nutrient enrichment may also facilitate ponding and plant die-off from increased inundation (Wigand et al. 2003). Kirwan et al. (2016) found that marsh accretion deficits in relation to accelerating sea-level rise are occurring mostly in estuaries with nutrient enrichment and altered sedimentation regimes. Increased soil saturation associated with sea-level rise may facilitate belowground grazing of marsh vegetation by burrowing marsh crabs by softening peat deposits (Crotty et al. 2017). Recent evidence indicates that in Southern New England, landward migration will be necessary for coastal wetlands to persist in the face of sea level rise (CRMC 2015, Watson et al. 2017b), yet shoreline hardening in response to rising seas and increasing coastal storms associated with climate change will act as barriers to migration (Watson et al. 2017a), and *Phragmites* may impede the landward migration of native marsh species, even as it may facilitate higher accretion rates in the face of rapid sea-level rise (Smith 2013). Marshes have been migrating landward for millennia, when proper conditions prevail, but the ability of marshes to migrate under a regime of accelerated sea level rise remains a topic for research. Although additive and synergistic effects of sea-level rise with other human stressors can be difficult to identify and predict, it is becoming evident that widespread, rapidly-occurring changes now threaten the functionality and sustainability of coastal wetlands in Rhode Island and the ecosystem services they provide, highlighting the need for restoration.

4. Coastal Wetland Restoration: Historic and Current Approaches

Ecological restoration has historically involved working to return degraded ecosystems to their original states. More recently, many restoration ecologists have recognized the need for a broader approach that expands the concept of restoration to include ecological interventions that preserve or enhance ecosystem functions and services in cases where returning the system to an original state is not possible. This broader approach is particularly relevant to coastal wetlands under the threat of accelerating sea-level rise, as original conditions may not be possible to maintain or recreate.

Ecosystem Restoration Approach

The Merriam-Webster Dictionary's primary definition of restoration is "an act of [ ] bringing back to a former position or condition." The classic approach to ecosystem restoration conforms to this definition as it generally aims to return discrete ecosystems back to original or improved functional conditions. The Society for Ecological Restoration International (SER) defines ecological restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Clewell et al. 2004 and at www.ser.org accessed Jan, 2017), a definition that implies the return to a former or improved condition. To clarify that definition, SER presents a list of attributes of restored ecosystems, including that the species, structure, and function of a restored system should be characteristic of a natural reference, stressors leading to the degradation of the system should be reduced or eliminated, and the restored ecosystem should be resilient and self-sustaining (Clewell et al. 2004). This intuitive approach of restoring individual systems to original or improved functional condition has been practiced widely in coastal wetlands in Rhode Island and throughout the region. The majority of coastal wetland restoration projects conducted over the last two decades have focused on restoring tidal flow to impounded systems, controlling the spread of *Phragmites*, and fill removal (Neckles et al. 2002, Roman and Burdick 2012, CRMC, unpublished data).

Hydrologic Restoration

Tidal flow restoration projects typically have involved installation or widening of culverts through impounding structures. As many impounded marshes were dominated by invasive *Phragmites*, a main goal of restoration was often the re-establishment of native flora and habitat types, and a common evaluation measure has been the percent cover of *Phragmites* versus native plant species. Studies have indicated that restoration of regular tidal inundation generally reduces *Phragmites* dominance and vigor, but seldom eliminates the plant or results in full recovery of native vegetation (Farnsworth and Meyerson 1999, Roman et al. 2002, Buchsbaum et al. 2006, Raposa 2008, Raposa et al. 2017). Benefits of tidal restoration have included improved tidal flushing and platform drainage, partial re-establishment of native marsh vegetation, increased bird use, more characteristic nekton assemblages, restoration of nekton fitness, and likely substantial reduction of CH_4 emissions (Burdick et al. 1996, Sinicrope et al. 2000, Raposa 2002, Roman et al. 2002, Raposa 2008, Dibble and Meyerson 2016, Kroeger et al. 2017). Full benefits of coastal wetland restoration may take two decades or longer to be realized (Warren et al. 2002); this has been indicated particularly in tidal flow restorations, wherein vegetation recovery typically lags behind hydrologic process recovery (Raposa et al. 2017 and citations therein). Negative consequences of tidal restorations have also been documented, such as marsh-wide soil decomposition, subsidence, and loss; failure to re-vegetate; and at least temporary loss of marsh sparrow breeding success (DiQuinzio et al. 2002, M. Cole and W. Ferguson, unpublished data, J. Turek and M. Cogliando, unpublished data), highlighting the need for careful consideration of tidal restoration projects.

Self-regulating tide gates have been used to limit upper tidal amplitude as part of a tidal flow salt marsh restoration in Galilee (Myshrall et al. 2000). The gates were installed to protect existing homes adjacent to the restoration site from flooding during elevated tides and surges. It is unknown whether tide gates could be successfully used to limit increased inundation associated with accelerating sea-level rise at other salt marsh sites with narrow or restricted tidewater inflows.

Fill Removal

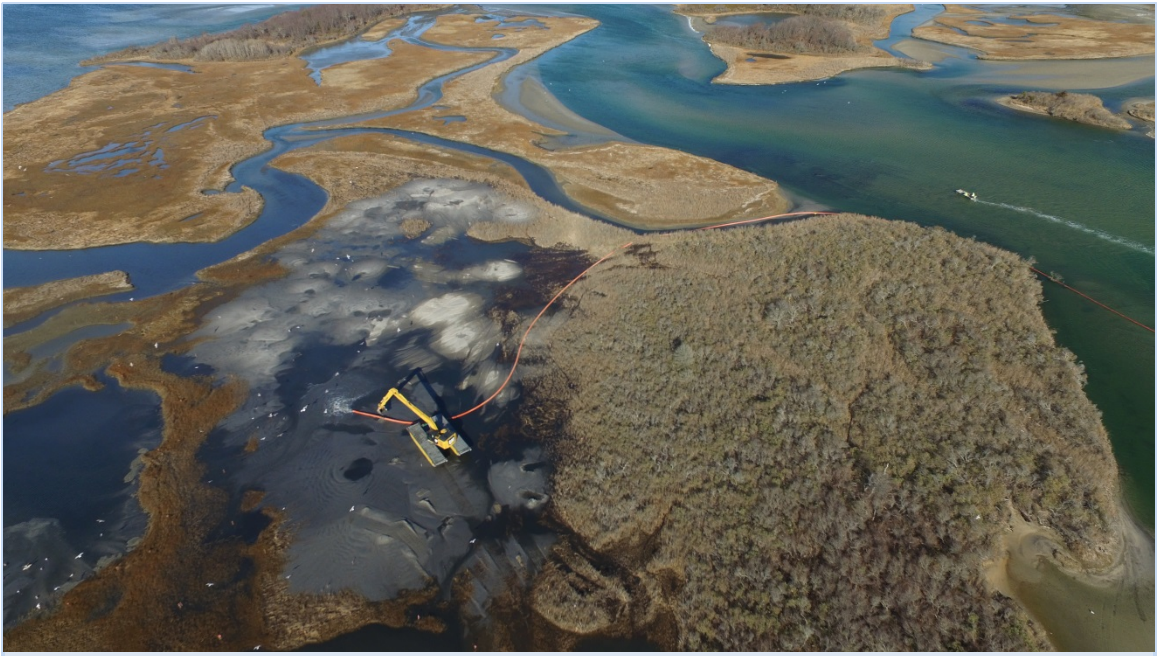
Restoration projects aimed specifically at ***fill removal*** from coastal wetlands have also been conducted in the region. These projects have typically entailed removing fill to an elevation known to support high or low marsh vegetation. Projects at Allen Harbor, Town Pond, and Galilee Marsh in Rhode Island have successfully restored native low marsh vegetation to part or all of the project area, but in all cases high marsh platform structure and vegetation did not reestablish at expected levels, leaving some functionality, such as marsh sparrow use, unimproved (DiQuinzio et al. 2002, CRMC unpublished data). Reassessment of those sites now could reveal whether functionality has returned with time as predicted by Warren et al. (2002), but recent predictions of continued marsh platform drowning due to accelerated sea-level rise may hinder the recovery process, particularly for high marsh vegetation (Raposa 2015, 2017a, Watson 2017a).

Invasive Species Management

Management of invasive species is another common coastal wetland restoration practice that has been under some scrutiny in recent years. The most common invasive species management practice targets *Phragmites* via tidal restoration (see above) and/or herbicide treatment, which typically involves spraying the foliage with herbicide on a multi-year schedule; yet few projects have eliminated *Phragmites* without continued maintenance (Warren et al. 2002, Moore et al. 2012). Under high nutrient loading or lowered salinity regimes, which are both widespread in Rhode Island, *Phragmites* has a competitive advantage over native species, particularly on disturbed marsh soils (Chambers et al. 1999, Bertness et al. 2002, Meyerson et al. 2009). In addition, *Phragmites* distribution is widespread throughout the state, resulting in high propagule pressure. This suggests that unless both tidal restriction (alternately stormwater inputs) and nutrients are reduced to thresholds giving native species an advantage, *Phragmites* domination may be the only achievable stable state in some areas, limiting the effectiveness of herbicide-only management. While reintroduction of saline tidal water is a common restoration activity, reduction of nutrients is more difficult to target. More research is needed to identify the suite of factors that determine *Phragmites* versus native species domination (Moore et al. 2012) so that managers can decide whether, or in what cases, management will be beneficial.

Drainage Enhancement

Drainage enhancement of ponded or waterlogged high marsh surface habitats has recently been reconceived as a potentially beneficial management action. Widespread marsh platform ponding and drowning have prompted salt marsh managers to use shallow drainage channels (referred to as runnels) to break the feedback loop of flooding, ponding, plant growth suppression, soil decomposition, subsidence, further ponding, and so on that ensues following prolonged and frequent inundation (Raposa et al. 2017a, Watson et al. 2017b). In contrast to ditches historically used to drain marsh peat, runnels are intended to drain only ponded water from the surface of the marsh platform. Although this technique was developed as a low-impact management practice for reduction of mosquito breeding (Dale et al. 1993), preliminary data indicate that runnels may also stimulate marsh platform re-vegetation and reduction of filamentous algal mats on the marsh surface (W. Ferguson, unpublished data). Drainage enhancement has been used in Rhode Island to remove ponded water from the salt marsh platform in preparing restoration sites for elevation enhancement and is currently being evaluated as a standalone restoration practice. Rapid marsh platform subsidence, a threat to marsh stability, has recently been documented following a marsh drainage enhancement project using 0.5-m deep drainage channels on Prudence Island (K. Raposa, unpublished data); this highlights the need to determine and document the potential benefits and detriments of drainage enhancement, as well as factors contributing to its effects on marsh hydrology, soil structure, elevation, and vegetation, before its large-scale implementation.



Aerial view of an elevation enhancement project in Ninigret Pond .

Elevation Enhancement

Elevation enhancement is a method used to artificially raise coastal wetland substrate heights relative to the tide frame. Elevation enhancement (sometimes referred to as *thin-layer placement; TLP*) involves spreading a thin layer (typically less than 0.3 m) of sand, silt, or mud onto the surface of a marsh that shows signs of subsidence, ponding, or drowning. The goal is to restore or establish marsh platform heights that provide elevation capitol (Cahoon and Guntensperhen 2010) and enhance soil drainage, root growth, and marsh resilience. Elevation enhancement can use material dredged from nearby waterways or upland sediments mined from quarries. Elevation enhancement done in conjunction with navigational dredging projects (often referred to as beneficial reuse) can help to offset costs associated with dredged material disposal. Marsh elevation enhancement projects have been generally successful in other regions, with many reporting restoration of viable vegetated marsh habitat (Mendelssohn and Kuhn 2003, Langlois 2011, Wigand et al. 2016).

Smith and Niles (2016) caution that ponding on the marsh platform may be part of a natural and ecologically beneficial cycle of pool formation and vegetative re-growth, particularly in undisturbed systems. They suggest that because elevation enhancement is a potentially harmful activity, managers should carefully consider the potential for removing other marsh stressors that may be contributing to marsh ponding and drowning, such as historic ditching, before using elevation enhancement. Elevation enhancement is considered experimental in Rhode Island, thus marsh elevation projects underway include rigorous monitoring and assessment components to evaluate outcomes. Managers considering elevation enhancement must also consider the sustainability of this method in light of predicted accelerated sea-level rise. According to current predictions, 0.3 to 2.5 m of sea-level rise could be realized by the end of this century (CRMC available at www.crmc.ri.gov). While studies have indicated that marsh platforms are more likely to accrete sediments faster at an ideal position in the tidal frame (Watson et al. 2017a), it is uncertain whether elevation enhancement can produce conditions in which marsh plant community condition and platform accretion are sustainable under predicted sea-level rise rates (Wigand et al. 2016).

Integrated Marsh Management

Pool and creek restoration, often referred to as integrated marsh management, is another ecosystem restoration method that has been considered in the state. This method aims to undo the harm caused by historic ditching and filling of pools by excavating filled pools and creeks and filling manmade ditches to recreate original natural drainage and hydrologic patterns, and restore ecological function and services. Recent findings suggest that restoration of natural hydrology on the marsh platform may relieve excessive marsh ponding and drowning and improve accretion rates relative to sea-level rise (Smith and Niles 2016). More study is needed to determine whether this approach would be beneficial locally, as it is uncertain whether accelerating sea-level rise and low sediment inputs would limit the effectiveness of pool and creek restorations in Rhode Island.

Intervention Continuum Approach

Hobbs et al. (1996, 2011) argued that ecological restoration cannot effectively be carried out by simply improving ecological conditions on a site by site basis, but that ecological interventions should be pursued on broader physical and conceptual scales, particularly in the face of global climate change. The concept asserts that there is a continuum of possible management practices (i.e. ***ecological interventions***) that can help to improve ecosystem function and services, ranging from discrete ecosystem restorations (as discussed above), to broader management practices (for example, upstream nutrient reduction), to policy, regulatory, and even political actions (for example, improved buffer regulations). This approach recognizes that habitats and species assemblages will be changing with a changing climate and thus restoration to historic conditions will not always be feasible. And, it assumes that novel systems may provide many of the functions and services provided by natural systems. The ecological intervention concept is particularly relevant to coastal wetlands facing continually accelerating sea-level rise, as coastal wetlands will theoretically drown in place unless they can migrate into low-lying uplands or are artificially enhanced in elevation; restoration to prior conditions will not likely be possible. The intervention continuum approach broadens the concept of restoration to include interventions or adaptations that enhance resilience and maintain ecosystem functions and services without restoring prior conditions.

Table 2. Ecosystem restoration and intervention methods and their typical applications; Type ER conforms to the Ecosystem Restoration Approach and Type IC follows the Intervention Continuum Approach (discussed below); C indicates methods that target reducing or eliminating one or more causes of stress, whereas S indicates methods addressing the symptom only

Method	Type	Applications	C/S	Notes
Tidal Flow Restoration	ER	Impoundment, tidal restriction	C	Practiced throughout the Northeast
Fill Removal	ER	Historically filled areas	C	Typically reverts to low marsh vegetation
Invasive Species Management	ER	Phragmites domination	S	Typically requires continued maintenance, could cause harm
Drainage Enhancement	ER	Ponded areas	S	Inexpensive, short-term solution, more study is needed to assess benefits and risks
Elevation Enhancement	ER	Clearly vulnerable marsh with available sediments	S	Expensive, association with adjacent dredging makes feasible
Pool and Creek Restoration	ER	Ditched marsh, filled marsh	C	Slightly to moderately degraded marshes may recover
Migration Facilitation	IC	Vulnerable marsh with appropriate adjacent land	C	Perhaps most sustainable practice, requires migration potential
Buffer Management	IC	Buffers compromised by development	C	Physical and potential regulatory intervention
Nutrient Management	IC	Nutrient source identified	C	Ranges from storm water treatment at the site to regulatory change
Living Shoreline	IC	Developed shorelines	S	Typically applied to improve ecological function of protective structures
Floating Wetlands	IC	Low energy eutrophic systems	S	Provide habitat, largely untested

Planning for Marsh Migration

Marsh migration facilitation is an illustrative example of an ecological intervention that does not necessarily restore prior conditions but helps a marsh to retain and sustain form, function, and ecosystem services on adjacent lands. Coastal wetlands need low-lying land without impediments in order to migrate landward. Impediments to migration include steep adjacent topography; hardened structures; coastal development; human activities such as mowing; certain vegetation communities, such as forests and *Phragmites*-dominated landscapes (Field et al. 2016, Smith 2016); and certain boundary conditions, such as groundwater upwelling. Management activities that can facilitate the landward migration of coastal wetlands include conservation of low-lying uplands or shallow freshwater wetlands adjacent to existing coastal wetland habitats, shoreline and landscape grading, removal of structures and infrastructure, drainage enhancement, and vegetation management. Scientists are presently gaining knowledge on how these management practices will affect migration rate and success. Additional study is needed to predict marsh migration processes under forecasted accelerating rates of sea-level rise.

In the face of predicted accelerating sea-level rise, facilitation of marsh migration through ***conservation of adjacent lands*** will be a critical management practice for preserving coastal wetland functions and services moving forward (Donnelly and Bertness 2001, CRMC 2015, Watson et al. 2017b). But, because coastal land is highly valued for development and is a key source of tax income for coastal communities, it is expensive and challenging to conserve. Coastal managers will need to make a strong case extolling the ecosystem functions and services of coastal wetlands or create other incentives to persuade land owners and municipal and state officials to conserve or modify coastal properties for marsh migration. Ownership, conservation status, threat of future development, property value, and hazard risk will thus be key considerations for prioritizing coastal parcels for conservation. Additionally, land attributes such as slope, soils, aspect, land cover, and land use will need to be considered.

Vegetated Buffer Zones

Buffer management is an indirect ecological intervention that may reduce some of the causes of degraded conditions in coastal wetlands. Vegetated buffers provide sediment and toxin filtration, uptake and denitrification of nutrients, roosting, resting, and cover habitat for wildlife, improved protection from coastal storms, and a physical barrier to direct human impact (Castelle et al. 1994). As such, buffers protect and enhance the functions and services of coastal wetlands in many ways. Similar to conservation of adjacent lands, maintaining buffers that are wide enough to be effective can come into conflict with economic and social interests. Since 1971, the CRMC has had authority over regulating coastal buffers for new construction and substantial infrastructure improvements. Vegetated buffers ranging from 25 to 200 feet are required between developed property and coastal natural features, including coastal wetlands (CRMC 2012). Buffer requirements are applied to new development and redevelopment projects that increase the structural lot coverage by more than 50%. Lowering the redevelopment threshold for coastal buffer requirements has been suggested, particularly in areas representing potential wetland migration corridors. Regulatory ecological interventions such as this could help decouple synergistic stresses degrading coastal wetland condition.

Nutrient Management

Another promising ecological intervention is ***nutrient management***. Studies indicate that soil structure degradation associated with excessive nutrient loading may be a contributing factor in salt marsh drowning (Wigand et al. 2003, Kirwan et al. 2016). Nutrient loadings to coastal systems could be decreased through both physical and regulatory actions, depending on the source. Nutrient loadings to Narragansett Bay have been reduced by over 50% since 2003 through actions mandated by state regulations, largely through reductions in allowable nutrient concentrations in wastewater treatment facility effluent discharges (Schmidt 2017), but many areas of excessive enrichment remain from individual septic systems and other non-point sources. Storm water management via infiltration, buffer management, or storm water infrastructure can reduce nutrient loadings, indirectly restoring ecological function by removing a known cause of degradation.

Wetland Creation

Wetland creation is an option for coastal areas where vegetated coastal wetlands do not already exist (typically in unvegetated intertidal habitats) to restore wetland function and services that have been lost. Coastal wetlands that are created specifically to stabilize shorelines or protect coastal properties are a common type of ***living shoreline***. Living shorelines typically use a low-lying stone, bagged shell, or bundled natural-fiber sill, extended into the intertidal zone, to contain elevated wetland soils. The sill is intended to reduce wave energy and erosion of the manmade wetland while theoretically promoting sedimentation and accretion by trapping sediments on the wetland surface. Living shorelines can mitigate some of the detrimental effects of shoreline hardening for coastal property protection, such as loss of intertidal ecological function, yet they can impede lateral access for people along the shore (a constitutional right in Rhode Island), fill intertidal areas, and disrupt natural beach nourishment that occurs through bluff erosion and long-shore drift.

Manmade ***floating wetlands*** have been proposed for nutrient mitigation in low-energy sections of upper Narragansett Bay (DEM, unpublished manuscript). Floating wetlands rely on floating rafts and artificial growing media for buoyancy and structure. In freshwater systems, they are considered low maintenance and provide habitat and nutrient uptake (Headley and Tanner 2006), but they are largely untested in northeast estuarine systems. Research is needed to test this recent technology in coastal waters in Rhode Island.

5. Vision, Goals, and Objectives of Coastal Wetland Restoration in Rhode Island

Vision

Coastal wetlands perpetually retain the critical functions and ecosystem services they have provided historically.

Goals

1. Wetland area loss is minimized through restoration, conservation, and other interventions;
2. Management minimizes loss of critical functions and ecosystem services across broad systems.

Objectives

1. Develop restoration and intervention prioritization tools based on the criteria outlined in this Strategy;
2. Prioritize coastal wetlands for restoration and migration potential;
3. Systematically maintain or restore the ecosystem functions and services of coastal wetlands based on priorities outlined in this Strategy;
4. Systematically evaluate restoration outcomes;
5. Identify, evaluate, adapt, and implement the most effective and efficient management practices.

Vision

Coastal wetlands perpetually retain the critical functions and ecosystem services they have provided historically.

Under the increasing stress of sea-level rise and other human-caused stressors, managers will need to employ restoration, conservation, and other interventions to sustain the critical functions and ecosystem services provided by coastal wetlands. These functions and services have been documented extensively in scientific literature and are outlined earlier in this Strategy. ***Critical*** functions and ecosystem services are those that are not adequately provided by other natural or manmade systems.

Goals

Wetland area loss is minimized through restoration, conservation, and other interventions.

Uncertainties in sea-level rise models and the effectiveness of various ecological intervention methods confound setting practical quantitative goals for restoration and conservation of coastal wetlands. However, under the assumption that a net loss of coastal wetlands is expected to continue with predicted rates of sea-level rise (Watson et al. 2017b), managers can work to minimize losses through ecosystem interventions and direct restoration activities. Given the uncertainties, the conservation and management of coastal lands to facilitate marsh landward migration will be critical to maintaining coastal wetland area (Donnelly and Bertness 2001, CRMC 2015, Watson 2017b). Direct restorations could also potentially slow or relieve marsh loss. As examples, marsh elevation enhancement could be applied in places where beneficial use of dredge spoils is practical; restoration of natural marsh platform hydrology through pool and creek restorations and drainage enhancement could mitigate ponding and marsh drowning in some marshes (Smith and Niles 2016); and nutrient reductions could decouple interactions leading to marsh subsidence and ponding (Wigand et al. 2003).

Management minimizes loss of critical functions and ecosystem services across broad systems.

Because restoration of coastal wetlands to prior conditions may not be feasible in the face of accelerating sea-level rise, management may need to be considered on regional or system-wide scales, rather than strictly at an individual marsh site basis, to preserve critical coastal wetland functions and ecosystem services. This may be accomplished through a combination of targeted restorations, such as those designed to minimize wetland loss (as discussed directly above) and broader intervention activities, such as coastal property conservation, nutrient management, and reduction of greenhouse gas emissions. A program evaluating these and other methods will be needed to support adaptive management and prioritize management actions based on effectiveness in preserving coastal wetland ecosystem functions and services.

Objectives

Continued development of a permanent ***statewide coastal wetland restoration program*** will facilitate the implementation of the objectives outlined in this Strategy and benefit management efficiency and effectiveness moving forward. A fully developed program will act as a clearinghouse for restoration research, methods, and assessment information, and for tracking restoration and intervention efforts in the state. The program will provide capacity to identify and monitor reference wetlands according to the statewide salt marsh monitoring strategy (Raposa et al. 2016b); archive and analyze pre- and post-restoration monitoring and assessment data from various restoration projects to promote adaptive management; and share lessons learned with practitioners, managers, and decision/policy-makers. Through the development and documentation of standardized protocols, it will provide capacity for projects to be compared directly to each other, to reference systems, and to themselves over time to assess restoration outcomes; provide guidance for reporting restoration outcomes to decision-makers and the public; and promote wide-scale coastal wetland restoration on statewide, regional, and national platforms. Additionally, the program could make available resources and communications developed for educational and outreach activities. A web-based portal to house program information would provide statewide and broader accessibility for scientists, managers, practitioners, and policy-makers.

The following stepwise objectives have been identified as necessary for fulfilling the above vision and goals.

1. ***Develop restoration and intervention prioritization tools based on the criteria outlined in this Strategy.*** Tools should be developed to reflect criteria outlined in Section 7 of this Strategy. Existing tools need testing and validation for applicability and efficiency to meet identified needs, and new tools may need to be developed where needs cannot be met. Tools may include: grant funding scoring worksheets, such as the one developed for the Coastal and Estuary Habitat Restoration Program and Trust Fund (available at http://www.crmc.ri.gov); field and remote sensing tools designed to provide reliable and efficient information on vulnerability, condition, functions, ecosystem services, and other important attributes of coastal wetlands; and other tools as needed (see Section 8 for detail). Prioritization tools should be based on best available science and incorporate viewpoints from diverse stakeholders and experts.

2. ***Prioritize coastal wetlands for restoration and migration potential***. Prioritization of wetlands for restoration and intervention can be done through discrete identification of need, such as through a grant-funding program, or broadly, through a statewide needs assessment using the results of the SLAMM model, other remotely-sensed data, rapid assessment, or other efficient tools. Pursuing both strategies may provide a balance of need and opportunity, as grant applicants have identified both need and opportunity, and statewide information about wetlands attributes will give managers and grant funders information with which to prioritize resource and land management proposals.

3. ***Systematically maintain or restore the ecosystem functions and services of coastal wetlands based on priorities outlined in this Strategy.*** Restorations and other ecological interventions should be pursued systematically. While ad hoc restorations may collectively contribute to overall ecological health and value, and should certainly be pursued, strategically-planned, wide-scale intervention will more efficiently and effectively produce desired outcomes (Hobbs et al. 2011). This objective relies on successfully achieving objectives 1 and 2, and requires identifying critical functions and values at most risk regionally (see Section 7), gathering and analyzing statewide prioritization information, and prioritizing wetlands for restoration based on statewide information and opportunity. Interventions that most efficiently and sustainably protect or restore multiple valued ecosystem functions and services should be targeted.

4. ***Systematically evaluate restoration outcomes****.* The Rhode Island Salt Marsh Monitoring and Assessment Strategy (SMMAS) (Raposa et al. 2016b) details a systematic strategy to develop standardized monitoring and assessment protocols, methods, and metrics to support restoration prioritization and the

evaluation of restoration outcomes. By using a standardized evaluation strategy across marshes, restoration projects can be treated as experimental replicates to increase confidence in evaluation outcomes. The statewide coastal wetland restoration program should work to further develop the SMMAS as it applies to restoration evaluation.

5. ***Identify, evaluate, adapt, and implement the most effective and efficient management practices.*** Effective and efficient management practices should be identified through research and adaptive application and management. This will require tools and protocols to evaluate and compare restoration outcomes in the context of preserving or restoring coastal wetland ecosystem functions and services under the constraints of limited funding. Evaluations should consider all applicable science and be conducted using a collaborative oversight process that aggregates expertise from broadly-relevant sectors, including state, federal, academic, and NGO partners with knowledge in coastal wetland ecology, ecosystem management and restoration, and physical sciences.

6. Monitoring and Evaluation of Resources

Coastal wetland managers need ***science-based tools*** and other resources (Table 3) to provide information for assessing and characterizing current conditions and vulnerability of coastal wetlands, prioritizing allocation of resources and disbursement of funds, and evaluating restoration and intervention outcomes. Several tools have been developed to monitor ecological conditions in coastal wetlands, and many of these have been used for characterization, prioritization, and evaluation. The SMMAS (Raposa et al. 2016b) recommends developing standardized methods and protocols that purpose existing monitoring methods to specifically address these tasks. For example, vegetation monitoring data have been widely used to characterize conditions in coastal wetlands and identify trends over time. Standardized metrics or protocols could be developed to apply these data for other specific purposes, such as ranking the relative vulnerability of coastal wetlands to increased inundation and prioritizing restoration resource allocation. CRMC and DEM have entered into a contractual agreement with RINHS to work with partners on developing coastal wetland evaluation and prioritization methods using these existing and new types of data. Below is a list and brief synopses of existing resources that have either been specifically designed to characterize, prioritize, and evaluate coastal wetlands or have the potential to be used for these purposes.

Table 3: Monitoring and evaluation resources to support coastal wetland restoration and intervention in Rhode Island

Resource	Data Type	Main Applications	Status
Long-term Monitoring	Intensive ground-based monitoring data of physical and biological attributes	High-resolution trends in condition and vulnerability over time	Methods and protocols well-developed, need monitoring site expansion and metric development and testing
Rapid Assessment	Observational data documenting characteristics and ranking stressors and response	Characterize vulnerability and condition across multiple sites, analysis of causes of degradation	Comprehensive method currently being developed based on two existing methods
Functional Assessment	Observational data documenting perceived ecosystem functions and services held by a wetland	Prioritization for restoration	Methods known and used in the state for freshwater wetlands. New regional method under development by USACE and EPA Region 1
Remote-sensed Products	Secondary aerial-imagery-based mapping products that usually quantify ground cover and habitat type	Statewide assessment of vulnerability and response to SLR	Regionally-developed method completed for 2012 data, new data available, needs validation against more accurate data
Predictive Elevation Models	Elevation-based models for assessing marsh resilience and migration potential	Statewide restoration policy and development planning	SLAMM is complete in RI, but thought to underestimate loss and overestimate migration. MEM is untested locally.
Vulnerability Assessment Tools	Intensive research-based models predicting relative impacts of climate change on coastal habitats	Prioritize or characterize sites or systems for management actions	MARS was tested at salt marshes across the U.S., CCVATCH was tested for 14 salt marshes in RI
Wildlife Data	Opportunistic existing monitoring and survey data	Prioritization and justification of restoration projects, addressing permit requirements	Several statewide datasets could be applied to complement other data
Socioeconomic Benefit	Various economic models to estimate monetary or social value of the natural resources	Restoration prioritization and justification	National models available have not yet been tested in RI for salt marshes

Intensive Long-term Monitoring Data

The SMMAS details a strategy to establish a network of eight long-term reference marshes spanning Narragansett Bay and coastal Rhode Island (Raposa et al. 2016a). The reference marshes will be monitored in perpetuity, adapting methods and protocols initially developed for the National Estuarine Research Reserve System (NERRS 2012) to document changes in vegetation, hydrology, elevation, soil condition, wildlife use, and other parameters over time, particularly in response to sea-level rise and inundation. Intensive monitoring data will provide information that can be used for identifying temporal trends in salt marsh integrity and vulnerability to sea-level rise; assessing effectiveness of restoration and intervention management; and in the development and validation of rapid and landscape-level assessment methods. The SMMAS recommends the development of standardized metrics that can apply long-term monitoring data to these other purposes, specifically. Five long-term reference sites are currently providing data at salt marshes at Prudence Island, Ninigret Pond, Block Island, and the Narrow River, and supplemental grant funding is being sought to phase in the full network of sites to represent the diversity of salt marsh types and settings that occur in Rhode Island.

Dr. Kenneth Raposa records SET measurements. Photo provided by Marlo Garnsworthy.

Rapid Assessment

Rapid assessment provides easily attainable information that is generally applied in wetland assessment to characterize wetland integrity based on observable stressors and response to stress (USEPA 2006). Rapid assessment is unique in that it is designed to accommodate comparison and analysis of stress, response, and environmental context across multiple wetlands and categorize individual wetlands by relative condition or vulnerability; this is not practical with intensive or typical remote-sensed data and is essential for prioritization. The SMMAS (Raposa et al. 2016b) recommends the development of a rapid assessment method for salt marshes that considers previous work. To facilitate analyses of marsh condition, vulnerability, and resilience, a rapid assessment method needs to capture the effects of all stressors, including disturbances, sea-level rise, and others. A rapid assessment can also include easily-attainable, relevant classification information to categorize salt marshes and further facilitate analysis. A rapid assessment method typically takes no longer than a single work day to conduct at a site (Fennessy et al. 2007), making data collection across multiple sites per season possible. In partnership with CRMC and NBNERR, RINHS is currently funded to develop a rapid assessment method for coastal wetlands that aims to capture vulnerability to sea-level rise, marsh migration potential, stressors affecting marsh integrity, and classification information, for use in restoration prioritization and outcome evaluation.

Functional assessment

Functional assessment is another rapid methodology that documents perceived functions and ecosystem services held by a given ecosystem. Methods that assess whether wetlands provide specific functions and ecosystem services such as flood attenuation; sediment, toxicant, and pathogen retention; nutrient removal, retention, and transformation; production export; sediment and shoreline stabilization; fish, shellfish, and wildlife habitat; recreation, educational and scientific value; heritage value; visual quality; and threatened or endangered species habitat, have been used in Rhode Island (e.g. the Highway Methodology, USACE 1993). The USACE and EPA Region 1 are currently developing the New England Functional Assessment to rapidly characterize the ecological functions of wetlands, including coastal wetlands (Minkin and Sachs, unpublished data). The method uses a model that quantifies wetland functions based on their association with readily observable or measurable wetland attributes, reducing subjectivity often associated with functional assessments. Attributes pertaining to wetland soils, vegetation structure, and observable stressors are estimated or measured in the field by appropriate experts to populate the model. Functional assessment may be valuable to identify primary functions held by specific coastal wetlands for use in restoration prioritization.

Remote-sensed Imagery and Data Products

Remote-sensed data products are derived from aerial or satellite surveys of the land. Primary products, such as spectral imagery and LiDAR, can provide images or other visual characterizations of the landscape that can be directly inspected and interpreted for restoration planning. High-resolution primary data products have become widely available through servers such as Google Earth© and the Rhode Island Geographic Information System (RIGIS), which are both clearinghouses for archived and newly-acquired data. Secondary data products are derived from primary data using classification or other analyses to generate more specific information such as vegetation, land cover, and elevation maps, although oftentimes these secondary products require remote-sensed data collected specifically for the purpose. The SMMAS details a remote-sensing project completed by NBNERR and federal partners that used purpose-collected aerial spectral imagery and semi-automated habitat classification to quantify coastal wetland habitats statewide (Raposa et al. 2016b). The project produced high-resolution vegetation-community data intended to be used to detect spatial changes in community composition over time. These data may also be useful for Tier-1 (landscape-level) assessment of coastal wetland condition and vulnerability; for example, simple vegetation community metrics such as the ratio of unvegetated to vegetated area (UVVR) may be useful for wide-scale vulnerability analysis (Ganju et al. 2017). Remote-sensed data products are valuable for restoration assessment and planning, and regional decision-support tools based on remote-sensed data are increasingly available to managers for assessing coastal wetland vulnerability and marsh migration opportunity.

Predictive Elevation Models

Remote-sensed elevation data are used to develop or enhance mechanistic salt marsh resilience models, such as SLAMM and the Marsh Equilibrium Model (MEM). SLAMM is a geospatial model that uses geographic information systems (GIS), elevation, land cover, wetland habitat data, and marsh accretion rates to estimate salt marsh loss and migration potential under various sea-level rise scenarios. SLAMM was used in Rhode Island to estimate losses and gains in coastal wetland area under 0.3, 0.9, and 1.5 meters of sea-level rise (low, moderate, and high predictions according to CRMC 2015) with current cultural structures remaining and removed. SLAMM data are inherently uncertain and the recent application of the model likely underestimates marsh loss and overestimates marsh migration (CRMC 2015). Although the SLAMM model was mainly intended to inform state and municipal coastal planning, it identifies areas of potential marsh loss, migration potential, and migration impediment, and may be useful for salt marsh migration, creation, and restoration planning and prioritization. SLAMM data have already been used in salt marsh restoration planning throughout the state. CRMC (2015) offers specific recommendations for its potential application in policy-based ecosystem intervention, as well. These include using SLAMM data to: inform development and redevelopment projects to allow for marsh migration; develop setbacks and buffers that will protect marsh migration corridors; identify coastal properties where conservation easements based on dynamic natural features could phase out investment; identify areas where the use of hardened shorelines should be strictly discouraged; develop zoning risk overlays; identify parcels of high marsh migration potential for conservation; and identify restoration opportunities.

MEM is a similar mechanistic elevation model that incorporates suspended sediment availability, salinity, and plant productivity to predict salt marsh resilience at varying rates of sea-level rise (Schile et al. 2014). MEM uses remote-sensed elevation data, tide-frame data, and intensive site-level field data, such as above- and below-ground biomass, minimum and maximum elevation of marsh vegetation, rooting depth, root to shoot ratio, etc., and therefore requires significant planning and resources to conduct. MEM may be a useful tool for predicting marsh resilience at long-term monitoring sites where intensive data are already collected, but due to its intensive site-level data requirements, it may not be practical for assessing individual salt marshes for conservation and restoration prioritization.

Vulnerability Assessment Tools

Two vulnerability assessment tools have been tested in Rhode Island. The Tidal Marsh Resilience to Sea Level Rise (MARS) tool uses elevation, tide range and mean, rates of elevation change and accretion, and sea-level rise data to estimate the relative resilience of salt marshes to degradation from sea-level rise and other stressors (Raposa et al. 2016b). Several of the MARS parameters are collected at long-term monitoring sites in Rhode Island and across the National Estuarine Research Reserve System (Raposa et al 2016a). MARS was conducted across 16 NERRS sites across the coastal U.S., including a site in Rhode Island, and was found to indicate relative resilience to sea level rise at national and potentially local scales. Such information at local or regional scales would be useful for marsh management planning (Raposa et al. 2016b).

The Climate Change Vulnerability Assessment Tool for Coastal Habitats (CCVATCH) is a decision-support tool designed to help coastal managers develop restoration, conservation, and intervention plans for coastal habitats. The tool is intended to identify climate change-related stressors and their impacts on specific land parcels, based on consensus of scientific literature and local scientific and site-specific knowledge. CCVATCH considers ecosystem responses to broad a suite of potential stressors associated with climate change and their potential interactions with non-climate stressors. CCVATCH was applied to 14 salt marshes in Rhode Island, and steps were taken to standardize metrics from CCVATCH that are shared among all marshes to reduce assessment times. In this form, CCVATCH may be a useful for indicating relative vulnerability to climate change for targeted coastal wetlands and contribute to restoration and intervention prioritization.

Fish and Wildlife Survey Data

Various sources of fish and wildlife survey data are available for coastal wetlands in Rhode Island. While there are long-standing state monitoring efforts collecting finfish, wading bird, and waterfowl data in Narragansett Bay (DEM, unpublished data), most fish and wildlife data are collected in discrete areas or for discrete projects, and will need to be used opportunistically, when relevant to specific restoration efforts. Wildlife survey data may provide useful information on rare or endangered species, species of conservation or recreational concern, and ecological functionality of coastal wetlands on discrete or statewide levels; such information could be applied to restoration project prioritization and is often needed as part of the restoration permitting process. As an example, the Saltmarsh Habitat and Avian Research Program (SHARP, available at www.tidalmarshbirds.org) collects, archives, and analyzes data on the presence, abundance, and nesting characteristics of salt marsh specialists including saltmarsh, seaside, and Nelson's sparrows (*Ammodramus* spp.), American black duck (*Anas rubripes*), clapper rail (*Rallus crepitans*), and willet (*Tringa semipalmata*). These species are important to monitor as they depend on salt marshes for part of their life cycles and are species of conservation concern statewide and regionally (Wiest et al. 2016).

Socioeconomic Benefit Analysis

Socioeconomic benefit analysis is a methodology that provides a means of assessing the social and economic benefits of wetlands—those benefits related to the health, well-being, and enjoyment of people that are derived from wetland functions. The Rapid Benefits Indicators Approach is one such method developed by EPA in Rhode Island that provides a rapid process for assessing the social benefits of ecosystem restoration (Mazotta et al., 2016). Although developed for assessing freshwater wetland projects, the approach and its associated decision-making tools could be applied to coastal wetland restoration. Various methods to quantify economic benefits, such as Willingness To Pay (WTP) analyses, have been used within the context of wetland restoration (Nadeau, 2016).

7. Criteria for Identifying Priority Coastal Wetlands for Restoration and Intervention

Prioritizing projects for the allocation of limited resources is central to most effectively preserving or restoring critical ecosystem functions and services provided by coastal wetlands. Prioritization should be considered at both landscape and site scales (Hobbs et al. 2011). Prioritization of projects at a ***landscape level*** should target restoration or preservation of ecosystem functions and services that are critical and most at risk across broader systems, such as statewide or regionally. Applying landscape-level objectives to discrete opportunistic site-based restoration, conservation, and intervention projects as detailed in this section will offer greater cost benefit over strictly site-based allocations.

At the ***site level***, priority can be based on vulnerability to stressors, site-level ecosystem functions and services, potential for success, cost benefit, opportunity, and other factors; this requires not only broad ecological knowledge of the interactions of stressors and management practices, but also considerable site-specific information. Tools for the collection of site-specific information are described in Section 6, and continued development of coastal wetland restoration monitoring and assessment programming will advance the development and application of those tools to support prioritization moving forward.

CRMC has developed a grant application ***scoring worksheet*** for its Coastal and Estuary Habitat Restoration Program and Trust Fund (CEHRTF, available at http://www.crmc.ri.gov). The worksheet ranks site-level restoration project proposals based on ecological function; measurability, specificity, and achievability of goals; significance of degradation; economic and public benefit; and expected outcomes, among other factors. This approach uses a team of environmental scientists, managers, and practitioners to analyze and rank restoration proposals through a standardized scoring process, and it considers state and regional restoration priorities. Such an approach could be applied to other funding efforts and to statewide or regional prioritization efforts. Broader criteria that can be used to develop prioritization tools for selecting site-level restoration projects, as well as conservation and intervention actions beyond the scope of the CRMC program, are described below.

Statewide coastal wetland prioritization criteria at a glance

1. Target restoration of high-priority ecosystem functions and services
2. Target marsh migration facilitation interventions
3. Target mitigation of stressors that diminish condition or increase vulnerability
4. Consider vulnerability to sea-level rise
5. Require project sustainability and resiliency
6. Consider project achievability and potential for adverse impacts
7. Evaluate cost benefits
8. Consider social benefits

1. Target restoration of high-priority ecosystem functions and services

Ecosystem functions and services should be considered both at the site scale and on a statewide or regional scale. Restoring, preserving, or improving ecosystem functions and services that are regionally ***critical*** (i.e. are not adequately provided by other ecological or manmade systems), ***vulnerable*** to stressors, and have high ***human and ecological value*** should take priority over those that are non-critical, less valuable, or are generally stable in other coastal wetlands or ecosystems. Based on those factors, ***priority ecosystem functions and services*** were identified as follows, in no particular order:

- **Protection of coastal property from storm waves and erosion**
- **Pollution filtration and nutrient uptake**
- **Support of marsh-dependent animal and plant species**
- **Support of commercial and recreational fish and shellfish**

2. Target marsh migration facilitation interventions

In the face of accelerating sea-level rise, landward migration may be the most effective intervention to sustainably conserve the ecosystem services and functions of coastal wetlands into the future (Donnelly and Bertness 2001, Watson et al. 2017a). The potential for coastal wetlands to migrate inland depends on the size, slope, elevation, soils, vegetation composition, land use of adjacent land, and ability of the migration process to proceed under a regime of accelerated sea level rise. Coastal wetlands adjacent to parcels with high migration potential should be targeted for conservation of adjacent land and mitigation of stressors that may impede landward migration. Parcels with high migration potential that are under the ***threat of development*** should be prioritized over parcels with existing conservation easement or otherwise not likely to be developed. Once a parcel is developed, it is economically less likely to be conserved for marsh migration.

3. Target mitigation of stressors that diminish condition or increase vulnerability

Although the effects of sea-level rise dominate the conditions of many coastal wetlands in the state, other stressors that work alone or interactively with sea-level rise should be considered in prioritization. Projects aimed to ***diminish the causes of degradation*** should take precedence over those solely focused on the symptoms, given that such projects are more likely to be sustainable (Clewell et al. 2004). Likewise, projects ***decoupling interactive stressors*** should be prioritized. For example, studies have indicated that altered hydrology and excessive nutrient inputs both contribute to marsh drowning by increasing the potential for pooling on the marsh surface (Wigand et al. 2003, Smith and Niles 2016); projects aiming to both reduce nutrient inputs and restore historic hydrology (i.e., both diminishing causes of degradation and decoupling interactions) could potentially bolster accretion rates and make certain marshes more resilient to sea-level rise (Kirwan et al. 2016, Wigand et al. 2014). Properly monitored, such projects could additionally contribute to our relatively sparse knowledge of stressor interactions.

4. Consider vulnerability to sea-level rise

Accelerating sea-level rise has been identified as an urgent threat to the health and sustainability of coastal wetlands in Rhode Island (Raposa 2017a, Watson et al. 2017a, b). Recent work indicates that vulnerability to sea-level rise may increase with decreasing latitude in Rhode Island (Cole Ekberg et al. 2017). As marshes are being lost due to drowning and erosion associated with sea-level rise and its interactions with other stressors at an increasing rate, vulnerability to sea-level rise has become a critical factor in determining appropriate management actions. For example, because restoration to prior conditions is likely unfeasible, marshes assessed as highly vulnerable should be considered for ecological interventions that rebuild or relocate capacity or function, such as elevation enhancement or migration facilitation; whereas wetlands with lower vulnerability could be targeted for conservation and restoration activities that preserve, enhance, or extend existing conditions and functionality (Raposa et al. 2017b).

5. Require project sustainability and resiliency

Coastal wetlands are historically resilient systems, but accelerating sea-level rise and other chronic stressors threaten their sustainability statewide. Restorations and other interventions aimed at improving ecosystem resiliency and sustainability should be given high priority. Projects focusing on relieving the causes of degradation, rather than solely repairing the symptoms, may result in more sustainable systems (Clewell et al. 2004, Smith and Niles 2016). CRMC predicts 0.3 to 2.5 m of sea-level rise by the end of this century; therefore, priority restoration projects should also consider long-term resilience to rapid sea-level rise. Although accelerating sea-level rise is likely to continue for decades or longer unless aggressive greenhouse gas emissions are realized on a global scale (Nicholls and Cazenave 2010, Cazenave et al. 2016), interventions such as conservation of adjacent low-lying property and elevation enhancement can be targeted to sustain critical ecosystem functions and services.

6. Consider project feasibility and potential for adverse impacts

The probability of success in achieving stated restoration goals must be considered. Under predictions of accelerating sea-level rise, many site-based ecosystem restoration activities could fail or be short-lived without continual maintenance. Additionally, aggressive interventions, such as elevation enhancements, drainage enhancements, and migration facilitation risk doing more harm than good in the event of failure. Only time spent conducting and analyzing the outcomes of various ecological interventions in coastal wetlands at a broad scale will provide information needed for their successful adaptive management. Feasibility must therefore be based on the best available data and professional judgment of a qualified inter-disciplinary team.

7. Evaluate cost benefits

Determining the cost-benefit ratio of a project should be considered in the context of ecosystem economics and in relation to other projects. Economic valuation has been ascribed to particular ecosystem services of coastal wetlands, such as storm protection. When accurately accounted for, the value of the restored ecosystem service can be significant, and provide ample economic justification for the intervention. In addition, ecological interventions generally provide ancillary benefits beyond what can be captured by assessing a single function (Benayas et al. 2009). Most proposals will not be able to provide a complete monetary value to the expected outcomes of intervention, but every effort should be made to identify and explain secondary or ancillary economic benefits. For example, projects in the state have taken the opportunity to beneficially utilize material from nearby dredging operations for marsh elevation enhancement, thus alleviating material disposal costs. Similarly, projects that increase protection of property from coastal storms may positively affect property values.

8. Consider social benefits

Projects often have benefits to people that cannot fully be expressed in monetary terms. These are benefits to the health, well-being, and enjoyment of people that may be related to site aesthetics, sense of place, recreation, community, historical, educational, and other social values (Mazotta et al., 2016), and vary depending upon a project’s geographic location and the actions being proposed. These benefits should be addressed in project design and considered alongside other criteria in prioritizing projects for implementation.

8. Information Gaps and Resource Needs

Information Gaps

As discussed, successful ecological intervention through restoration, conservation, or management requires knowledge of ecosystem processes, functions, and services, and how they react to direct, indirect, cumulative, and interactive stressors, as well as how they will respond to various interventions. While much progress had been made in developing a body of applicable knowledge on the subject for coastal wetlands, questions remain.

Natural and Hydrologic Impediments to Marsh Migration

While manmade hardened structures and land uses impede marsh migration in many clearly-evident ways, recent studies have indicated that landward migration of salt marsh vegetation is also impeded differentially across upland and wetland natural community types. Forested lands may slow the rate of marsh migration (Field et al. 2016), and the presence of *Phragmites* at the wetlands border has been found to impede the landward migration of native vegetation (Smith 2013). Yet, it remains uncertain how landward migration occurs with existing coastal vegetation communities in Rhode Island. An NBNERR proposal to study differential migration response following migration facilitation management in various coastal habitats has recently been funded. This study will provide important information for determining marsh migration potential for conservation of adjacent lands, as well as the effectiveness and cost of select marsh migration facilitation management practices. Intertwined with natural and manmade impediments is an uncertainty in the capacity of salt marshes to migrate landward under further accelerating rates of sea level rise. More research in these areas will help managers make critical decisions regarding restoration and conservation options.

Ecological Functions and Services of Phragmites

Even as several studies have focused on the ecological benefits and stressors associated with *Phragmites* domination in coastal wetlands, questions remain. Foremost is the question of whether *Phragmites* represents a net benefit or detriment in the face of accelerating sea-level rise. *Phragmites* clearly provides some of the benefits of native vegetation (e.g., nitrogen uptake, pollution filtration; Meyerson et al. 2009) and destroys others (e.g., salt marsh sparrow habitat, support of native species; Wiest et al. 2016), but relative benefits remain vague. Additionally, it is uncertain how *Phragmites* will react to accelerating sea-level rise. Although *Phragmites* can build surface elevation faster than native marsh vegetation, it is also less tolerant of salt water (Rooth et al. 2003, Warren et al. 2002). These and other factors, including the potential adverse impacts and health risks of herbicide use, must be taken into consideration when approaching the question of whether, or in what cases, to manage *Phragmites*.

Fate of Ecosystem Services and Functions, Statewide

This Strategy identifies landscape-level priority ecosystem functions and services of coastal wetlands; however, it remains uncertain how they will each fare under accelerating sea-level rise in conjunction with other stressors. Studies indicate that marsh sparrow numbers are declining (Correll et al. 2016), coastal wetland carbon sinks may be decreasing (Chmura 2013, Coverdale et al. 2014), and productivity is declining (Watson et al. 2017a), but the fates of other ecosystem functions and services are less certain. For example, there are signs that nekton and wading bird use may increase in early stages of marsh drowning, but it is unclear whether this would be a short-term result of intermediate disturbance, or if this trend would continue as marsh surfaces completely drown (Rozas and Reed 1993, M. Cole and W. Ferguson, unpublished data). It also remains unclear how marsh-specific and broader nitrogen dynamics will play out under increased atmospheric carbon and subsiding wetland soils (Craft et al. 2009, Wigand et al. 2014), how drowning or drowned marshes will support commercially and recreationally important fish and waterfowl, and how coastal property values may be affected.

Salt Marsh Formation and Stability

Although it has been estimated that more than 53% of historic salt marsh area has been lost in Rhode Island (Bromberg and Bertness 2005, Watson et al. 2017b), the pre-colonial cover and distribution of coastal wetlands statewide remain unclear. Many of the salt marshes in the state have been dated to be thousands of years old, but it is possible that some portion of marshes in Rhode Island developed within the last 300 years as a result of increased sedimentation from widespread farming in the watersheds (E. Watson, personal communication). Kirwan et al. (2011) found that salt marshes expanded by ~50% in the Plum Island Estuary, a Massachusetts estuary with a similar agricultural past to Rhode Island, in response to early colonial land uses; an occurrence also documented in salt marshes on the Pacific coast (Watson et al. 2011). Kirwan et al. (2011) suggest that these anthropogenic marshes are now unsustainable under current sediment regimes. Knowing the extent of historic marsh area in Rhode Island would give state managers insight into marsh stability and provide a more natural baseline with which to assess marsh loss and functionality.

Resource Needs

The need for permanent statewide programming supporting coastal wetland monitoring, assessment, and restoration has been identified (Raposa 2016b, CRMC unpublished report), and program development is now underway, funded by a USEPA Wetland Program Development Grant. While these funds can support multi-year program development, they cannot be used for long-term program implementation. As discussed (Section 5), a cohesive and centralized ***state coastal wetlands program***, focused on monitoring, assessment, and restoration, is needed to carry out the goals and objectives of this Strategy and address the needs identified below.

Prioritization Protocols
CRMC has developed an effective protocol for prioritization of funding coastal restoration projects through its Coastal and Estuary Habitat Restoration Program and Trust Fund (available at http://www.crmc.ri.gov). A review of that protocol, considering the prioritization criteria presented here, is recommended. Additionally, as other funding sources and needs for project prioritization arise, such as statewide prioritization, the CRMC protocol may need to be revised, or others developed, to meet specific needs. Monitoring and assessment data collected according to the SMMAS (Raposa et al. 2016b) and other methods outlined in this Strategy (Section 6) will be needed to support statewide prioritization.

Coastal Wetland Assessment Tools
The SMMAS details a strategy for collecting reference and statewide data for assessing coastal wetland integrity, vulnerability to sea-level rise, and restoration outcomes over time, and identifies the need for developing assessment metrics and tools designed for those tasks, specifically (Raposa et al. 2016b). Remote-sensing and rapid assessment tools (Section 6) are currently being developed to broadly and rapidly evaluate ***vulnerability to sea-level rise*** and ***marsh migration potential***, and intensive long-term monitoring data may reveal vulnerability (e.g., Raposa et al. 2016c, Watson et al 2016b) and migration trends across statewide gradients. Likewise, the development of purpose-specific metrics and protocols will be needed to apply remote, rapid, and intensive data to assessing ***coastal wetland integrity***, identifying ***key stressors*** beyond sea-level rise, and evaluating ***restoration outcomes***. Additionally, a ***functional assessment*** tool may need to be modified or developed to identify and qualify the presence of priority ecological functions and services.

Long-term Datasets on Evaluation Outcomes
Standardized long-term information on project prioritization and outcome evaluation will be needed for adaptive management. Analyzing this information against broader monitoring and assessment data will allow managers to identify success and failure trends associated with identified stressors, specific interventions, coastal wetland types and settings, and restoration outcomes. In turn, this will inform adaptation of restoration methods and objectives, and prioritization of future projects.

Socioeconomic Benefit Information
While applicants are asked to provide project-specific information on community and economic benefits when requesting state restoration funding, there is little information comparing broader-scale socioeconomic benefits of marshes that could be used in statewide project prioritization. Efforts that have attempted this for freshwater wetlands might provide insight into which approaches might be most effective for coastal systems.

9. Capacity and Strategic Approach

The CRMC has endeavored to fulfill a leadership role in the restoration and management of coastal wetlands that is derived from a statutory mandate and regulatory authority to "to preserve, protect, develop, and where possible, restore the coastal resources of the state for this and succeeding generations…" (RICRMP). However, the complex and important work of monitoring, evaluating, conserving and restoring these systems in Rhode Island is shared by a number of local, state, federal and non-governmental entities that play a variety of roles.

Project Funding

At the state level, the CRMC administers the RI Coastal and Estuarine Habitat Restoration Trust Fund (CEHRTF, RIGL 46-23.1), which is a legislatively-established source of habitat restoration funding allocated on an annual basis from the state's Oil Spill Prevention and Response (OSPAR) fund (RIGL46-12.7). This funding is awarded on a competitive basis through an RFP process overseen by a Technical Advisory Committee (TAC). The TAC is comprised of representatives from state, federal and non-governmental resource management organizations. Typical applicants include municipalities, non-profit organizations, and state agencies. Awards do not carry a specific match or cost share requirement; however, CEHRTF funds are typically used to leverage federal awards or are matched by local funding or in-kind service contributions.

Federal funding for coastal wetland restoration is typically found in the form of agency programs related to proactive habitat restoration. Some programs, such as the US Army Corps of Engineer's program for Aquatic Ecosystem Restoration Projects (Section 206), operate on a continual basis in response to project requests from local sponsor groups. Others, such as the NOAA's Community-Based Restoration and Coastal Resiliency Program, operate on a highly competitive basis, nationwide. These federal programs are subject to funding appropriations in a given fiscal year and typically require some level of non-federal cost-share or match. The RI CEHRTF frequently provides non-federal match for projects funded under these types of federal programs.

Both state and federal restoration funding sources are generally aimed at the implementation of "on-the-ground" habitat restoration projects. This focus is apparent in the relatively short award periods (typically 2 to 3 years for most programs) and project performance metrics, which are often related to physical outputs such as "acres restored." In contrast, there are fewer funding sources—state or federal—dedicated to long-term monitoring and assessment programs.

Project Identification and Management

Previous efforts to identify potential coastal wetland restoration projects include the application of the Narragansett Bay Method developed in 1996 by Save The Bay. This protocol was used by restoration professionals and volunteers to identify and restore over 200 acres of degraded coastal wetlands. The majority of the sites identified through the Narragansett Bay Method had site-specific hydrologic impacts. There has since evolved a need for a project identification and prioritization method that takes into consideration the widespread impacts of additional climate change-driven stressors.

At the state level, projects are currently identified through the annual RFP process for the CEHRTF administered by the CRMC. This is largely a “bottom up” process of project identification where local sponsors initiate the majority of proposals with limited consultation from the TAC. Projects are then prioritized for funding using an established set of criteria. The development of a more comprehensive state restoration strategy will allow for a more proactive identification and strategic prioritization of restoration efforts and provide additional funding justification for individual projects.

Thirteen years of habitat restoration funding through the CEHRTF have shown that the involvement of a local group that can provide long-term project stewardship is a key element to project success. This stewardship is often driven by strong ties to a sense of place or history of the project site. Many of the projects proposed for funding through the CEHRTF originate from a local sponsor, such as a watershed organization or municipality. While these groups are motivated project proponents, they sometimes lack the capacity to carry out the various stages of project management (funding, design, permitting, construction, monitoring and reporting). For this and other reasons, local project sponsors often partner with non-governmental organizations such as Save The Bay. Save The Bay has been involved in the majority of coastal wetland restoration efforts conducted throughout Rhode Island, assisting local groups with project identification, design, funding applications, permitting, monitoring services, and volunteers for project implementation. Non-governmental organizations such as Save The Bay and The Nature Conservancy have also played important partner roles in larger state and federal restoration efforts. They have provided vital services such as ecological monitoring, volunteer mobilization for planting efforts, contract management, and public outreach.

In recent years, the CRMC has taken on a coastal wetland restoration project management role on an ad-hoc basis when federal funding has become available for restoration efforts that require state-level coordination. The CRMC has developed proposals in coordination with project partners, applied for and administered funding for project planning and construction, and provided construction oversight and overall project management. Though these state-led restoration efforts tend to be larger in geographic scope and scale, engagement and buy-in of local stakeholders and other project partners is still vital to project success.

DEM has been a frequent partner in coastal wetland restoration projects, particularly those carried out on state lands. Coastal public lands often represent an opportunity to demonstrate coastal wetland restoration or migration facilitation strategies. Of note, the largest marsh migration facilitation project in the state to-date is a DEM-led effort at Sapowet Point in Tiverton. Similarly, USFWS manages public coastal lands as National Wildlife Refuges, and has engaged state, NGO, and academic partners in implementing recent coastal wetland restoration and monitoring projects across the state.

Recommendations

A successful approach to coastal wetland restoration would use the proposed state coastal wetlands restoration program and the criteria detailed in this Strategy to prioritize restoration efforts throughout the state, while improving the capacity of local sponsors to implement individual projects. Assistance to local sponsors could be improved by building upon the framework of the CEHRTF's Technical Advisory Committee, which currently provides some technical assistance to project applicants in the form of proposal development and feedback.

Support for assessment and monitoring both of established long-term sites and of restoration project sites is needed in order to evaluate the relative success of different intervention techniques and adjust the statewide restoration strategy accordingly. Additionally, key to building sustained support for a state restoration program will be the development of a broad public outreach and education campaign that goes beyond individual projects and highlights the functions and values of coastal wetlands and the stressors that impact them.

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Appendix A. Tasks to Operationalize the Rhode Island Coastal Wetlands Restoration Strategy

1. **Objective: Continue to develop and formalize a coastal wetland monitoring, assessment, and restoration program for RI** (anticipated completion dates in parentheses, **>>** = currently in progress, **$** = funding currently available)		
Action	**Potential Funding Source**	**Lead Organization(s)**
1.1 Retain FTE wetland scientist to manage and work on program development ($ >>)	EPA Wetland Program Development Grant (secured thru 2020)	DEM,CRMC, RINHS
1.2 Further formalize technical advisory/working group(s), program lead, and organizational structure		CRMC, Partners
1.3 Develop and maintain a coastal wetlands monitoring, assessment, and restoration website and/or data platform to house information on protocols, methods, metrics, restoration actions, restoration outcomes, and all other aspects of coastal wetland management	NBEP capacity-building grants	CRMC, Partners

2. **Objective: Develop restoration and intervention prioritization tools based on the criteria outlined in this Strategy**		
Action	**Potential Funding Source**	**Lead Organization(s)**
2.1 Finalize and update existing Tier 1 vegetation community mapping and assessment methods	CEHRTF	NBNERR
2.1.1 Test accuracy versus field data and work to improve accuracy as needed (>>)	CEHRTF	NBNERR
2.1.2 Run classification on 2016 aerial imagery		NBNERR
2.1.3 Develop metrics for vegetation community: UVVR, MarshRAM coefficients, SLAMM, or other metrics	EPA WPDG	NBNERR, RINHS
2.1.4 Validate against Tier 2 or other available data (e.g. B. Watson loss data)		NBNERR, RINHS
2.1.5 Research other available Tier 1 prioritization tools ($) (2020)	EPA WPDG	RINHS, URI-EDC, USGS
2.2 Identify critical unknown information, and carry out research and monitoring needed to fill gaps in knowledge		URI, NBNERR, EPA
2.2.1 Collect tide-frame data in sub-estuaries and large marsh systems ($) (2018)	EPA WPDG	URI-EDC
2.2.2 Evaluate marsh migration potential in various habitats, soils, slopes, and SLR rates ($ >>)		NBNERR
2.2.3 Monitor *Phragmites* long-term response to accelerating SLR		URI, NBNERR

2.2.4 Assess *Phragmites* long-term effects on marsh migration		URI, NBNERR
2.2.5 Quantify gains and losses in coastal wetland functions and services under accelerated SLR	NERRS	
2.2.6 Establish baseline historic marsh area and age ($)		URI GSO
2.3 Validate Tier 2 Marsh RAM against existing data, such as B. Watson loss data, Tier 1 metrics, RISMA, Tier 3 data ($ >>) (2019)	EPA WPDG	RINHS
2.4 Develop a probabilistic condition/vulnerability reference gradient using Tier 2 data, against which individual sites can be compared for prioritization or restoration evaluation ($ >>)	EPA WPDG	RINHS
2.5 Expand Tier 3 monitoring site network (>>)	EPA WPDG, CEHRTF	RINHS, NBNERR
2.6 Develop Tier-3 metrics or models to predict region-level resiliency and marsh migration potential, such as MEM, refined SLAMM, MARS, etc.		NBNERR, CRMC, URI-EDC
2.7 Develop funding mechanisms and/or partnerships to ensure collection of long-term, standardized data for Tiers 1, 2 and 3		CRMC, NBEP
3. Objective: Prioritize coastal wetlands for restoration and migration potential (anticipated completion dates in parentheses, **>>** = currently in progress, **$** = funding currently available)		
Action	**Potential Funding Source**	**Lead Organization(s)**
3.1 Develop a protocol for prioritizing coastal wetland sites, statewide, for restoration, intervention, and conservation ($) (2020)	EPA WPDG	CRMC, RINHS
3.1.1 Identify and quantify, if possible, collective functions and services held by coastal wetlands in RI		RINHS, CRMC
3.1.2 Assess which tools and information will best inform statewide prioritization	EPA WPDG	RINHS, CRMC
3.1.3 Apply criteria for statewide prioritization (outlined in this report) to develop classes and ranks for restoration, intervention, and conservation/migration	EPA WPDG	RINHS, CRMC
3.1.4 Develop scoring sheet based on CEHRTF	EPA WPDG	CRMC, RINHS, Partners
3.1.5 Develop spreadsheet-based model that categorizes individual wetlands based on the scoring sheet	EPA WPDG	RINHS, CRMC
3.2 Collect data statewide to populate the prioritization model (>>)	EPA WPDG, Others	RINHS, NBNERR, Partners
3.3 Use prioritization model and protocol to categorize and rank coastal wetlands for restoration, intervention, or conservation		CRMC

4. Objective: Systematically maintain or restore the ecosystem functions and services of coastal wetlands based on priorities outlined in this Strategy (anticipated completion dates in parentheses, **>>** = currently in progress, **$** = funding currently available)		
Action	**Potential Funding Source**	**Lead Organization(s)**
4.1 Pursue funding and resources to restore, intervene, or conserve coastal wetlands based on statewide priority and opportunity	RIDEM Open Space grants, CEHRTF, Federal Programs	CRMC, Partners
4.2 Work with partners to evaluate proposed restoration projects according to established protocol (Objective 3)		CRMC
4.3 Quantify or otherwise document functions and services restored or conserved		Practitioners

5. Objective: Systematically evaluate restoration outcomes		
Action	**Potential Funding Source**	**Lead Organization(s)**
5.1 Develop specific monitoring and assessment protocols and metrics for particular intervention types through consensus of coastal wetlands monitoring and assessment group	EPA WPDG	RINHS, NBNERR, Partners
5.1.1 Test metrics, as needed, to validate utility		NBNERR, RINHS
5.1.2 Publish monitoring and assessment protocols and make them available through coastal wetland restoration program website	EPA WPDG	RINHS, CRMC, Partners
5.2 Analyze restoration outcomes on short-term and long-term scales		
5.2.1 Short-term analysis of metrics versus reference gradient using various levels of monitoring data		Partners
5.2.2 Long-term analysis of matured (> 10 yr) restorations using original monitoring data versus new data, and rapid assessment versus established condition/ vulnerability reference gradient ($) (2020)	EPA WPDG	NBNERR, RINHS
5.3 Identify, evaluate, adapt, and implement the most effective and efficient restoration and intervention practices		
5.3.1 Use monitoring results to evaluate outcomes and effectiveness of specific interventions		
5.3.2 Use field experiments, as needed, to test various methods or method variants/modifications to promote effectiveness and efficiency		
5.3.3 Modify prioritization protocols/models and monitoring/assessment protocols as needed		