NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

SCIENCE ADVISORY BOARD

FINAL REPORT

THE STATUS AND FUTURE OF TIDAL MARSHES IN NEW JERSEY
FACED WITH SEA LEVEL RISE

Prepared for:

Commissioner Catherine R. McCabe

Prepared by:

SAB Work Group

Approved by:

NJDEP SCIENCE ADVISORY BOARD

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Nancy C. Rothman, Ph.D.

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Members of the SAB Work Group:

Judith S. Weis, Chair, Rutgers University
Charles Harman, Wood Environmental Consulting
Beth Ravit, Rutgers University
Elizabeth Watson, Drexel University

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Executive Summary

We gathered data from salt marshes around the state on the trends in horizonal extent of coastal marshes over the years and of recent elevation changes to be compared with the current rate of sea level rise in NJ, which is between 5-6 mm per year.

Horizontal changes:
Meadowlands: Although SLR is undoubtedly affecting the Meadowlands' marshes, estimating losses is difficult due to ongoing development pressures that reduce wetland acreage and ongoing mitigation efforts which have resulted in slightly increased wetland acreage.
Raritan Bay: Evidence suggests that Raritan Bay marshes are not losing acreage. There is no systematic publications on this.
Barnegat Bay: Evidence indicates that 11.9% of the tidal wetlands were lost 1972-2012. A higher resolution analysis completed for three marshes a loss of 9.7% from 1975 -2015.
Delaware Bay: Marsh loss is 1.1-1.9% per decade, less than Barnegat Bay. This low rate is largely due to marsh area being gained through migration upland into low-lying maritime forests.

Elevation Changes
Meadowlands SETs in five *Spartina* marshes found net elevation increases of 3.03-5.0 mm per year. SETs placed in two *Phragmites australis*-dominated marshes found net elevation increases of 8.17 and 11.75 mm per year. Only the latter marshes are keeping up with current SLR.
Raritan Bay Accretion has been measured for only one and one-half years, so data are not necessarily reliable, but twelve sites (*Spartina* and *Phragmites*) show net subsidence rather than increase in elevation during this time.
Barnegat Bay Nine SET sites showed net elevation increases of -1.96 to 5.77 mm per year, with only two sites increasing at a rate of over 5 mm/yr. Many marshes studied by FWS did not include subsidence information and are not considered reliable.
Delaware Bay Twelve SET sites showed net elevation increases between 1.16 - 6.89 mm per year, with five sites accreting at rates greater than 5 mm per year.

We note that there is a need for more study, particularly in the northern part of the state, where, except for the Meadowlands, the NY/NJ Harbor estuary is lacking in data.

Potential Remedies

Migration Pathways: In developed areas, the problem of "coastal squeeze," may be mitigated by developing and maintaining pathways and open areas for the marsh to migrate into. Migration pathways are areas that could convert to wetlands. Creating pathways generally involves local governments working with landowners, using instruments such as rolling easements. Problems that can arise are unfamiliarity with potential pathways, connecting scientific findings to policy and practice, insufficient budget, lack of coordination on land acquisition, lack of guidance on managing lands for coastal habitat advancement, and uncertainty about when and how marshes can move upslope. The role of NJDEP could be working with local governments to provide information about and encouragement to embark on efforts to create migration pathways.

Phragmites management: The invasive common reed, *Phragmites australis,* has been shown to perform many ecosystem services; the most important for this report is enabling marshes to increase elevation more rapidly than native plant communities. Indeed, in this report the marshes that were increasing their elevation at the greatest rates were two *Phragmites* marshes in the Meadowlands. Nevertheless, restoration projects continue to remove the plant. Management could be modified to leave some *Phragmites* in place to enable marshes to keep up with SLR, for example excavation of large shallow pools within *Phragmites* stands.

Sediment Manipulation: Methods for manipulating sediments are being studied to increase resiliency to SLR. In one widely studied technique, dredged material is sprayed on the marsh surface to elevate its height. This "thin-layer placement" has been shown to be a valuable tool for creating, restoring and maintaining coastal marshes. Sediments can also be piled in water adjacent to a marsh where currents can move them onto the marsh; accretion begins as sediments build up on the marsh. Another technique, the installation of runnels across the marsh floor facilitates drainage from ponded areas if there is enough slope for the water to run off. Runnels provide a way to drain water off the marsh and can restore the natural hydrologic cycle.

Living shorelines: Adding harder materials at a marsh edge can reduce erosion and preserve the horizontal extent of the marsh. Options include adding material to raise marsh surfaces or enhance sedimentation, marsh toe protection with coir logs or oyster reefs, placement of large woody debris, and floating wetlands that dampen wave or storm surge energies. Living breakwaters can increase the rate of sediment retention, and thereby combat effects of SLR. Challenges to implementation include site specificity, the lack of data on effectiveness, and obstacles in permitting projects. Installations in NJ are relatively new, and projects are small. The most extensive projects are in Delaware Bay. Other initiatives include oyster castles (Raritan Bay and Delaware Bay), coir logs and toe revetments (Delaware Bay), large woody debris (Pt. Pleasant), and living breakwaters (Cape May).

Regulatory Context

Activities to increase resiliency in the face of rising sea levels can benefit coastal marshes. In evaluating environmental impacts of physical measures to address SLR in marsh systems the regulatory context is important. To implement activities in regulated environments, authorization to proceed requires issuance of permits from USACE and the New Jersey Department of Environmental Protection (NJDEP) regulatory entities. Restoration practitioners have noted that overcoming regulatory hurdles is a significant difficulty in implementing coastal resiliency options. DEP has taken steps to facilitate such projects. Projects undertaken should have continued monitoring and adaptive management to see that they are meeting their objectives and not causing any unintended consequences.

Introduction and Charge Questions

Salt marshes are key coastal ecosystems that provide habitat for valued and protected wildlife, including invertebrates, fishes (including commercial species, some of which use marshes as nursery habitats), and birds. They provide vital ecosystem services to humans such as protection from storm surge and waves, attenuation of flooding, sequestration of pollutants (e.g. "blue carbon"), and nutrient removal via denitrification. Narayan et al (2017) found that the presence of tidal wetlands in the northeast US avoided $625 million in flood damages from Hurricane Sandy (much in New Jersey). They estimated salt marshes reduced annual flood losses by 16%, with greater reductions at lower elevations. With reduced marsh acreage and more intense coastal storms, there will be less protection for coastal communities and greater storm damage.

Reduced extent of marshes, the nursery grounds for important commercial and recreational fish stocks, will likely also lead to reduced fish production.

Key threats to salt marshes are land reclamation, coastal development, dredging, and sea level rise (SLR). While SLR is the major driver of loss, other factors can amplify the vulnerability of tidal wetlands to climate change. Eutrophication can contribute to marsh loss (Deegan et al. 2012). Eutrophication increases above-ground biomass of marsh plants, decreases root biomass, and increases microbial decomposition, resulting in plant instability. Top-heavy plants can fall over or be pulled out by waves, causing creek-bank collapse and marsh conversion to unvegetated mud. Overfishing of some fish has led to increased populations of herbivorous marsh crabs (*Sesarma reticulatum)* whose excessive consumption of marsh grasses caused marsh die-back in some areas (Bertness et al. 2014). Modification of coastal hydrology through tidal restrictions, construction of dams, as well as drainage ditches ('mosquito ditches') and control ponds ('OMWMs') constructed for mosquito management can amplify vulnerability to SLR. Such practices may reduce sediment inputs (Weston 2014; Elsey-Quirk and Adamowicz 2016), contributing to marsh loss through direct habitat conversion (Powell et al. 2020), as well as by enhancing erosion, ponding, or disturbance (Crain et al. 2009). Marshes with small tide range and inadequate sediment supply are most vulnerable to SLR (Fagherazzi et al. 2012). With reduced marshes, there is less productivity for the estuary as a whole and reduced protection for human communities.

SLR is by far the largest climate-related threat to salt marshes. The Intergovernmental Panel on Climate Change (IPCC) predicts with medium confidence a global SLR of 0.26-0.98 m by 2100 (Church et al. 2013). Nicholls et al. (1999) predict that 1 m SLR will eliminate 46% of the world's coastal wetlands. The loss of marshes due to rising sea levels is now an issue for the present time, rather than a future problem. The urgency of addressing this problem is reflected in "the second warning to humanity" focused on threats to wetlands (Finlayson et al. 2018).

The rate of SLR is not identical at all sites, and some marshes are better able than others to keep up with SLR. Crosby et al. (2016) synthesized worldwide data and found many salt marshes did not keep pace with SLR. Marshes in regions experiencing higher local SLR or greater subsidence were less likely to keep pace. Under the most optimistic IPCC emissions pathway, 60% of the marshes they studied will accrete less than the rate of SLR by 2100. The issue of SLR in the Mid-Atlantic is especially acute, as local SLR is significantly greater than observed globally. This heightened vulnerability is due to apparent subsidence effects caused by sediment compaction, glacio-isostatic adjustment, groundwater overdraft, as well as changes in ocean currents and gravitational effects resulting from shifting masses between land and sea ice and ocean water (Sun et al. 1999; Kopp et al. 2019). Over the last century sea level in New Jersey has risen 0.45 m vs. 0.18m globally, 250% the global average (Kopp et al. 2019). Over the next century, rates of SLR in New Jersey are expected to accelerate due to climate change; median predictions for 2000-2100 range from a SLR of 0.85-1.19m with the lower end prediction resulting from a low emissions scenario, and the high end prediction resulting from a high emissions scenario (Kopp et al. 2019). The current rate is 5-6 mm/yr (Kopp, pers. commun June, 2020).

Raposa et al. (2016) applied tidal marsh resilience to sea-level rise (MARS) indices of ten metrics that contribute to overall marsh resilience. They applied MARS indices at 16 marsh sites in the U.S and found Pacific marshes were more resilient than Atlantic marshes, with the least resilient marshes in southern New England (none of the marshes studied were in New Jersey). The scores can inform the management strategy: moderate scores call for enhancing resilience, while low scores suggest seeking opportunities for marsh migration. The indices provide a way to evaluate resilience and inform adaptation strategies in the face of SLR. Hill and Annisfeld (2015) studying Connecticut and New York marshes found that declining relative elevation led to increased tidal flooding, particularly in the high marsh. As flooding increased, organic matter accumulation accelerated at all marshes, but mineral deposition was only observed in areas of short-form *Spartina alterniflora*. Peteet et al. (2018) found that urban development in Jamaica Bay greatly reduced inputs of mineral sediment, but organic matter increase allowed vertical accumulation to outpace sea level for a time. However, reduced mineral content caused structural weakness and edge failure. They concluded that marsh survival will require mineral sediment addition to the marsh surface, subsurface channels and borrow pits. Borchert et al. (2018) concluded that migration corridors are particularly important in urbanized estuaries where low-lying coastal development prevents marshes from moving inland. Migration is also difficult or not feasible in areas with a steep slope where increased elevation quickly exceeds the range of tidal flooding (Brinson and Blum 1995).

Climate change is also expected to increase the frequency and intensity of extreme rainfall events (Hayhoe et al. 2008), including tropical storms, which can have major effects on salt marshes. The physical damage caused by storms includes breaking above-ground tissue, lateral erosion of tidal marshes, and in some cases denudation of vegetation (Hanley et al. 2020). Fragmented or degraded marshes are more vulnerable to disturbance and less resilient to extreme events. However, storms can also deposit new sediments on top of marshes, which may enable them to better keep up with SLR, provided burial does not kill the vegetation (Schuerch et al. 2013). However, large storm surges may deposit sediment upland of tidal marshes and the weight of a storm surge can compress the marsh, negating benefits of added sediments (Cahoon et al. 2019).

Mitigating factors and possible remedies

A meta-analysis by Davidson et al. (2018) found that certain invasive plants that are "ecosystem engineers" such as *Phragmites australis*, increase biomass and carbon storage potential over 100%. The species also stores more nitrogen, reducing eutrophication, and increases marsh elevation. Rooth and Stevenson (2000) found greater rates of both mineral and organic sediment trapping in *P. australis* due to greater litter production.

One possible way of increasing marsh elevation is “thin layer deposition/placement” (TLP) – spraying sediments onto the marsh surface (Ford et al. 1999). Some of the places this has been done in New Jersey include, Middle Township, Avalon, Fortescue, and Maurice River. Its effectiveness and how often the procedure should be done are as yet unknown. Plant recovery rates after deposition have been variable. Dredged material can be placed in the water at the seaward edges of marshes to provide additional sediment via tides and waves. Other techniques have focused on reversing marsh drowning. In Rhode Island for 10 years, the construction of small channels to drain areas of expanding open water have been used to promote drainage and encourage revegetation (Wigand et al. 2017); this was piloted in 2017 in the Cape May Wildlife Refuge at Reeds Beach.

When marshes are eroding at the edge, "living shorelines" (Bilkovic et al. 2017) in the form of oyster reefs, rocks, coir logs, and other materials can be placed at the edge to restore a more gradual vegetated slope and prevent further erosion, for a time. Under low energy conditions, living shorelines can enhance marsh resilience to hurricanes better than either hard edges or natural marshes (Smith et al. 2016). Similarly, there are experimental projects in other states developing floating marshes. For example, experimental floating salt marsh islands were constructed in Maine starting in 2014 to try to create nesting habitat for the Salt Marsh Sparrow that would be free from flooding. A few living shoreline projects have been installed in NJ. Since these are relatively new approaches, their continued effectiveness in the face of SLR remains to be seen.

Charge Questions

Characterizing the Problem

1. What is the status of NJ marshes vis-à-vis sea level rise in different regions of the state including Delaware Bay, Jersey Shore/Barnegat Bay, Hudson/Raritan Estuary, and the NJ Meadowlands?
2. Is there enough evidence to characterize their status? For example, are measured sediment accretion rates available for all relevant parts of NJ? If not, what and where are the gaps?

Characterizing Potential Solutions

3. How well do we understand the characteristics of potential management solutions to help salt marshes respond to sea level rise? What is the current state of knowledge generally, and with regard to the specific solutions listed below?

   3.a. Where are the pathways along which salt marshes could move inland, and what are the characteristics of those locations?

   3.b. What would be the consequences of managing marshes by leaving *Phragmites* in place in some areas to enable marshes to increase their elevation more rapidly?

   3.c. What are the results to date of thin-layer deposition? How can projects at particular sites determine how many inches of new sediment is optimum? How can the science of determining marsh floor target elevations be balanced by construction capabilities? What is the state of the science in construction methods for implementing thin-layer deposition projects? What are the regulatory impediments to TLD projects? What are the appropriate measures for the success of a project?

   3.d. What are the results to date of living shoreline strategies for eroding marshes? What are indicators of success?

Characterizing the Problem: Status of New Jerseys' Marshes

This review considers two indicators of tidal marsh stability and vulnerability relative to sea level rise (SLR): first, **analyses of marsh habitat changes in New Jersey**, and second, **analyses of marsh accretion and elevation trends**. SLR contributes to habitat changes apparent in tidal marshes through several modes: (1) edge erosion, (2) widening and expansion of tidal channels, (3) formation and expansion of interior ponds, (4) habitat changes along upland transition zones, and (5) increased salinity in tidal fresh and brackish marshes. Increased water levels, in concert with increasing storm frequency and intensity, subject marsh edges to attack by waves, in some cases resulting in extreme erosion rates of 5-20 meters per year (Elsey-Quirk et al. 2019). Because the volume of water moving through tidal channels is in equilibrium with the tidal channel volume (D'Alpaos et al. 2010), as SLR occurs, lateral erosion and headward extension of tidal channel networks are observed to accommodate this increased volume (Hughes et al. 2009), which reduces the areal extent of marsh vegetation. Marsh groundwater tables also increase with SLR, and where these water tables are at or above the marsh surface, marsh vegetation is typically not able to survive, and is replaced by bare mud or open water (Andres et al. 2019). Finally, another symptom of habitat change related to SLR in marshes is changes occurring at the marsh-upland transition. Over space and time, maritime forests abutting marsh experience lack of regeneration, tree thinning, and the succumbing of mature trees due to intrusion of salt water or a heightened water table (Fagherazzi et al. 2019), permitting marshes to expand into former-upland areas. In developed areas, such as farms and parks, marsh vegetation may encroach into fields and lawns, and soil salinization may occur. New marshes developing in previously upland areas tend to be dominated by *Phragmites australis* (Smith 2013).

Although changes in areal extents of marsh habitats provide a strong indicator of coastal wetland status relative to SLR, an important indicator of marsh status that has been widely assessed is marsh accretion and elevation change. If SLR exceeds the capacity of the marsh to accrete vertically, the marsh will drown, and if SLR is matched by accretion, the marsh will persist (Orson et al. 1985). Thus, monitoring programs have included installation and monitoring of surface-elevation tables (SETs). SETs provide a non-destructive measure of sediment elevation change in wetlands relative to a fixed sub-surface elevation datum, and typically include the establishment of feldspar marker beds, which measure sediment accretion (Lynch et al. 2015). They measure rates of vertical accretion and elevation change and allow partitioning of elevation change into surface sediment deposition versus the elevation produced through belowground biomass production or lost through subsurface consolidation (Lynch et al. 2015).

In this section, we summarize and synthesize what is known about tidal marsh habitat changes and tidal marsh elevation change relative to SLR in New Jersey. Then, recommendations are made for new data that would be useful in developing policy and regulatory responses.

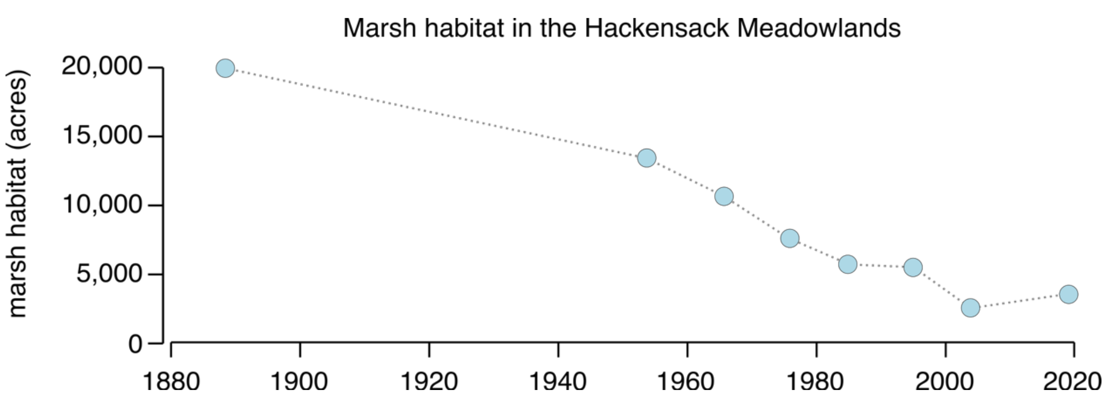
Marsh Habitat Changes Relative to SLR

Pervasive loss of tidal marshes as an indication of SLR in the NY-NJ area was first appreciated in the early 2000s, with the recognition that Jamaica Bay, New York had lost a significant portion of its wetlands and marsh islands (Hartig et al. 2002). In Jamaica Bay, 48% of tidal wetlands were found to have disappeared during the 20th century (1920s-1990s), predominantly due to symptoms of SLR, such as edge slumping, tidal channel widening, expansion and coalescence of tidal marsh pools and bare spots, and general fragmentation (Hartig et al. 2002). An analysis of satellite imagery published that same year also showed a high level of deterioration in tidal marshes in Delaware Bay (Kearney et al. 2002). A spectral un-mixing approach revealed that a large percentage of marshlands on the Delaware bayshore were in deteriorated condition (62% degraded in NJ; 45% in DE), and that this level of deterioration increased between the 1980s and 1990s (Kearney et al. 2002). Similar analyses have subsequently reported widespread deterioration of tidal marshes throughout the Mid-Atlantic and southern New England (Smith 2009; Cameron Engineering & Associates 2015; Watson et al. 2017; Krause et al. 2020).

Systematic analyses of marsh habitat change relative to SLR in New Jersey have focused primarily on marshes in Delaware and Barnegat Bays, including analysis of marsh edge retreat and habitat change. Less well studied are the Back-barrier marshes south of Great Harbor (e.g., Stone Harbor, Ludlam Bay, Great Egg Harbor Bay) on New Jersey's Atlantic Coast and Raritan Bay. Marsh habitat changes have been tracked in the Meadowlands of the New York-New Jersey Harbor, where long-term losses are related to development, while mitigation and restoration efforts have resulted in some habitat increases (Stinette et al. 2018).

The Meadowlands – In 1889, it was documented that there were 20,045 acres of tidal wetlands in the Meadowlands. By the second half of the twentieth century, wetland acreage had declined due to development pressures (Tiner et al. 2002). By 2019, there were about 8,400 wetland acres remaining (Fig. 1) of which 3,544 were conserved (www.njsea.com/master-plan-2020). Although SLR is undoubtedly affecting the Meadowlands' marshes, estimating losses is difficult due to ongoing development pressures that continue to reduce wetland acreage and ongoing restoration efforts which have resulted in increased wetland acreage. New Jersey Sports Exposition Authority (NJSEA) is currently digitizing the wetlands within the Meadowlands District using drone and aerial imagery to establish a baseline to better track future wetland changes.

Figure 1. Meadowlands Habitat Change (1889-2019) Sources: Tiner et al. 2002; NJSEA 2019



New York-New Jersey Harbor Estuary – Four percent of wetlands in the overall NY-NJ harbor estuary were lost between 2002 and 2012. While most losses were forested wetlands, 186 acres of tidal emergent wetland were lost (Stinnette et al. 2018). About 68% of this loss was to urban development, while about 15% reflect conversion to open water, which includes salt marsh conversion to unvegetated underwater areas and freshwater marsh conversion to artificial lakes. Raritan Bay – Between 1986-2015 Raritan Bay, including Staten Island and the kills showed no changes in acreage of tidal marshes (2418 to 2424 acres) (Lathrop, personal communication June 29th, 2020). In just the NJ portion of the bay, from 1977-2010, there was more accretion than erosion (Yepsen, personal communication June 30th, 2020). Published data are lacking. The absence of loss is perplexing since there is little room for the marsh to move inland. This indicates a need for further study.

Delaware Bay – By most indicators of SLR vulnerability, Delaware Bay wetlands would appear to be relatively resilient to climate change (large tidal / growth range, low slope, adequate sediment supply). However, most analyses suggest that Delaware Bay marshes are eroding and converting to open water (Table 1). Collectively it appears that marsh loss rates in the Delaware Bay sum to between 1.1-1.9% per decade, considerably less than the 4.4% found for coastal New York and Rhode Island (Cameron Engineering & Associates 2015; Watson et al. 2017). The difference between these two locations is the significant percentage of marsh area gained through migration into low-lying maritime forests, which was not found to be significant in New York or Southern New England (Smith 2009; Cameron Engineering and Associates et al. 2015; Watson et al. 2017). Position on the Atlantic coastal plain likely confers some adaptive capacity for preserving tidal marshes with SLR, depending on adjacent development land uses (Table 1).

Table 1. Tidal marsh habitat changes in Delaware Bay, 1778-2015.

Study	Time period	Geographic area	Total Loss (acres)	Total Gains (acres)	Net Change	Annualized loss rate
PDE 2017	1996-2010	Delaware Bay	2,700	-	-1.8%	-0.13%
Smith et al. 2017	1931-2015	Delaware Bay, NJ	19,501	6,958	-15%	-0.18%
Carr et al. 2018	1778-1918	Delaware Bay	18,780		-8.2%*	-0.05%
Carr et al. 2018	1918-2011	Delaware Bay	36,572		-17.3%*	-0.19%
Carr et al. 2018	1975-2011	Delaware Bay	12,009		-6.4%*	-0.17%
Watson et al. 2019	1974-2015	NJ MACWA sites	3,108	2,446	-4.4%	-0.11%

*total marsh area in 1778, 1918, and 1975 estimated from Fig. 3; Carr et al. 2018

In addition to marsh loss rates, an analysis of shore erosion rates was completed for Delaware Bay in 1986, which calculated an average erosion rate of 3.2 m yr^{-1} for the entire Delaware Bayshore between 1940 and 1978 (Phillips 1986), with average values ranging between 2-5 m/year along different segments.

Barnegat Bay – Analysis of Barnegat Bay wetland change was reported by Lathrop and Bognar for 1972-1995, using Coastal Change Analysis Program (C-CAP) data and the Barnegat Bay Partnership for 2007-2012 (Table. 2). Wetland change analysis suggests that 11.9% of the tidal wetlands were lost between 1972 and 2012. The highest loss rate was between 1995 and 2007, and the recent wetland loss rate is higher for Barnegat Bay than Delaware Bay, at 2.9% per decade for Barnegat Bay vs. 1.1-1.9% per decade for Delaware Bay. A higher resolution analysis completed for three focus marshes in Barnegat Bay totalled 1094 hectares, (using 0.3m 4-band imagery rather than 30m resolution C-CAP imagery) found a loss rate of 9.7% from 1975 -2015. While these values roughly mirror figures from analysis of C-CAP cover data, this higher resolution analysis showed relatively large gains (11.3%) and losses (18.4%), with internal marsh fragmentation contributing to losses and upland migration contributing to gains (Watson et al. 2019). Shoreline erosion rates have also been determined for Barnegat Bay between 1930 and 2013, digitizing more than 100 km of marsh shorelines, using aerial photographs from 1930, 1995, 2002, 2007, 2010, and 2013. Results found that median shoreline erosion rates were ~0.5 m yr^{-1} and that shoreline erosion has not accelerated over the past decade (Leonardi et al. 2016).

Table 2. Area of marsh habitat change in Barnegat Bay between 1972 and 2012.

Year	Tidal wetlands	Net loss*	Annualized loss rate	Source
1972	25,877 acres	-		Lathrop & Bognar 2001
1984	25,647 acres	-0.88%	1972-1984: 0.07% yr^{-1}	Lathrop & Bognar 2001
1995	24,564 acres	-1.3%	1984-1995: 0.38% yr^{-1}	Lathrop & Bognar 2001
2007	23,033 acres	-11.0%	1995-2007: 0.52% yr^{-1}	BBP 2016
2012	22,795 acres	-11.9%	2007-2012: 0.21% yr^{-1}	BBP 2016

*from 1972

Marsh Elevation and Vertical Accretion Trends

Over the past decade, SETs have been established across New Jersey to determine whether marsh elevation changes have been keeping pace with SLR. In areas where rates of SLR (or high-water level rise) exceed rates of marsh elevation change, elevations relative to sea level decline, and eventually marsh drowning is predicted (Orson et al. 1985). Conversely where rates of vertical elevation change are greater than SLR, then marsh persistence is predicted (Orson et al. 1985). In New Jersey, SET establishment has occurred in association with the Mid-Atlantic Coastal Wetland Assessment (MACWA), a partnership of the National Estuary programs in Delaware and Barnegat Bay, together with the Academy of Natural Sciences[ANS]) and Rutgers University, by the National Wildlife Refuges (Forsythe NWR, Cape May NWR, Sapawna Meadows NWR), the Meadowlands Environmental Research Institute, The National Park Service (Table 3), The Jacques Cousteau National Estuarine Research Reserve, Villanova University, and by the Nature Conservancy, The Wetlands Institute, and New Jersey PSEG as part of wetland restoration projects.

Analysed SET data available for this report include data published as part of a statistical analysis of United States Fish and Wildlife Service (USFWS) SET data from Edwin B. Forsythe NWR (Ladin and Shriver 2017); MACWA data (Haaf et al. 2019), Meadowlands Environmental Research Institute data (Artigas et al. 2020), and sediment accumulation data from the Raritan River collected from buried sediment plates, which can be roughly considered as equivalent to SET data (Quispe, personal communication).

Table 3. Locations of New Jersey SETs considered by this synthesis

	Location	NJ SETs	Source
MERI	Meadowlands	7	Artigas et al. 2020
Rutgers	Raritan	4*	Quispe, personal communication
Edwin B. Forsythe NWR	Barnegat Bay	19	Ladin and Shriver 2017
MACWA	Barnegat Bay	12	Haaf et al. 2019
MACWA	Delaware Bay	12	Haaf et al. 2019
Total	New Jersey	54	

*Four locations of sediment plates

The Meadowlands

SETs and feldspar horizons were set up at seven locations in 2008 across the Meadowlands: Lyndhurst Riverside (LR) high marsh, Riverbend Patens (RBP) high marsh, Riverbend Mixed (RBM) high marsh, Saw Mill (SM) low marsh, Secaucus High School (SHS) low marsh, Walden Swamp (WS) high marsh, and Eight Day Swamp (EDS) high marsh (MERI 2019; Artigas et al 2020). The first five sites showed accretion rates ranging from 3.61 mm yr^{-1} to 7.8 mm yr^{-1} but they all were subsiding at rates ranging from 0.36 to 3.60 mm yr^{-1} (Table 4). The net elevation change ranged from +3.03 (LR) to +5.0 (RBP) mm yr^{-1}. The average subsidence at these sites was 1.5 mm yr^{-1} , the average accretion rate was 5.5 mm yr^{-1}, so that the average elevation change was 4.0 mm yr^{-1}. Low marsh surfaces showed greater accretion rates (6.6 mm yr^{-1}) than high marsh (4.7 mm yr^{-1}), but subsidence rates were higher in the low marsh due to greater decomposition and compaction rates. The latter two sites were dominated by *Phragmites*, and were not subsiding, perhaps due to the thick reed stand and rhizome system. The net accretion rate for Walden Swamp was 11.75 mm yr^{-1} and for Eight Day Swamp was 8.17 mm yr^{-1}. Based on a current SLR rate of about 5-6 mm yr^{-1} only the oligohaline sites that are dominated by *Phragmites,* are keeping pace with SLR. It should be noted that of the first five sites, Lyndhurst and Secaucus had previously been *Phragmites australis* before they were restored and converted to *Spartina alterniflora*.

Table 4. Elevation change, accretion, and subsidence of tidal marshes in the Meadowlands

Location	vegetation	salinity	accretion rate mm yr^{-1}	subsidence rate mm yr^{-1}	elevation change mm yr^{-1}
Lyndhurst	*Spartina patens*	11.5	3.61	0.58	3.03
Riverbed	*S. patens*	11.5	5.36	0.36	5.00
Riverbend	*P. australis* *S. patens*	15.5	5.21	1.11	4.10
Saw Mill	*S. alterniflora*	13.5	7.80	3.60	4.20
Secaucus	*S. alterniflora*	7.5	5.52	1.97	3.56
Walden Swamp	*P. australis*	4.5	5.45	-6.3	11.75
Eight-day swamp	*P. australis*	4.0	6.45	-1.72	8.17

Raritan Bay

Short term accretion change rates in Raritan Bay were measured using sediment plates from May 2018 to November 2019 in four tidal marshes: two *Spartina alterniflora* marshes, and two *Phragmites australis* marshes (Quispe, personal communication). Average accretion in the *P. australis* after 18 months was -3.81 mm yr^{-1}; while average accretion in *S. alterniflora* was -6.53 mm yr^{-1}. Although a few plots were accreting over the first 12 months, none of the sites showed overall accretion after 18 months. Data from the sediment plates installed and monitored along the Raritan River are not directly comparable to data collected from the other sites, but in any case none of the sites appear to be experiencing sediment accretion or elevation gains at rates exceeding those of SLR (6.3 mm yr^{-1} over the past 19 years). SETs were installed in Raritan Bay by Rutgers in 2019, and data will become available over the coming years to reveal marsh elevation trends (Table 5).

Table 5. Change in accretion (mm) at D_{T2} and D_{T3} for marshes along the Raritan River, NJ.

Raritan Site	Marsh Plot	Marsh Vegetation	average total accretion at 12 months (mm)	Average total accretion at 18 months (mm)
1	1	*P. australis*	-0.36	-1.88
	2	*P. australis*	-3.68	-6.44
	3	*P. australis*	-7.92	-8.84
2	4	*P. australis*	2.84	-
	5	*P. australis*	0.56	-
	6	*P. australis*	-	-
3	7	*S. alterniflora*	9.4	-
	8	*S. alterniflora*	-5.28	-13.52
	9	*S. alterniflora*	-17.5	-15.65
4	10	*S. alterniflora*	3.76	-6.36
	11	*S. alterniflora*	-24.36	-14.28
	12	*S. alterniflora*	-5.08	-0.8

Delaware Bay

Marsh elevation trends in Delaware Bay range from a low of 0.7 mm yr^{-1} to a high of 6.9 mm yr^{-1}. High sediment accretion was found in the tidal freshwater site, and other SET stations in the tidal freshwater stations (in Delaware and Philadelphia) also show high sediment accumulation rates. Marshes along the Maurice River and Dennis Creek had high variability in elevation change, while marshes at Crosswicks Creek and Dividing Creek had similar rates of elevation change across sites. There are no strong trends or associations apparent between vegetation and salinity and elevation change rates (Table 6).

Table 6. Trends of surface elevation table (SET) stations within Delaware Bay established as part of MACWA (Haaf et al. 2019).

	vegetation	salinity	accretion rate mm yr^{-1}	subsidence rate mm yr^{-1}	elevation change mm yr^{-1}
Crosswicks Cr 1	*Zizania aquatica,*		13.5	-9.41	4.11
Crosswicks Cr 2	*Peltandra virginica,*	0.10	8.35	-3.83	4.52
Crosswicks Cr 3	*Nuphar advena*		9.98	-6.59	3.40
Dividing Cr 1	*S. alterniflora, S.*		8.16	-3.03	5.13
Dividing Cr 2	*patens, D. spicata*	17	10.1	-3.82	6.28
Dividing Cr 3			6.01	0.89	6.89
Maurice 1	*S. alterniflora, S.*		7.70	-6.54	1.16
Maurice 2	*patens, D. spicata*	11	3.72	0.05	3.77
Maurice 3			6.81	-1.6	5.21
Dennis Cr 1	*S. alterniflora, S.*		6.99	+0.99	5.85
Dennis Cr 2	*patens, D. spicata*	16	3.78	-4.12	0.74
Dennis Cr 3			5.06	-3.40	1.46

Barnegat Bay

Reported marsh elevation change by the USFWS ranged from -20 to +154 mm $yr-^{1}$ (Table 7), while values reported at MACWA sites ranged from -2 to +5.8 mm yr^{-1}. Several values from the Edwin B. Forsythe National Wildlife Refuge appear to be outliers, were identified as such in a USFWS analysis (Ladin and Shriver 2017) and are not credible values relative to those reported in the literature. The anomalous values from Forsythe may reflect anthropogenic disturbance. SETs in the MACWA network that were disturbed by pond construction suggest rapid sediment accretion associated with sediment sidecasts and post-deposition subsidence (Haaf et al. 2019). Barnegat Bay SETs in Island Beach are experiencing no net elevation gains and SETs at Horse Point and Reedy Creek are gaining elevation at rates slightly below SLR rates.

Table 7. Trends of surface elevation table stations within Edwin B. Forsythe National Wildlife Refuge (FWS) and SETs established and monitored as part of MACWA (*) in Barnegat Bay.

	Vegetation	salinity	accretion rate mm yr^{-1}	subsidence rate mm yr^{-1}	elevation change mm yr^{-1}
AT&T 1 (FWS)	-	-	-	-	1.67
AT&T 2 (FWS)	-	-	-	-	3.98
AT&T 3 (FWS)	-	-	-	-	-1.06
AT&T 5 (FWS)	-	-	-	-	88.77
AT&T 6 (FWS)	-	-	-	-	0.57
AT&T 7 (FWS)	-	-	-	-	0.64
AT&T 8 (FWS)	-	-	-	-	75.79
AT&T 9 (FWS)	-	-	-	-	99.50
Mill Cr 1 (FWS)	-	-	-	-	154.85
Mill Cr 2 (FWS)	-	-	-	-	12.31
Mill Cr 3 (FWS)	-	-	-	-	8.03
West Cr 1 (FWS)	-	-	-	-	2.31
West Cr 2 (FWS)	-	-	-	-	5.31
West Cr 3 (FWS)	-	-	-	-	-19.69
LB 1 (FWS)	-	-	-	-	-18.34
LB 2 (FWS)	-	-	-	-	-11.64
Motts (FWS)	-	-	-	-	-0.86
Simpkins (FWS)	-	-	-	-	-6.36
Reedy Creek 1*		20	4.75	0.46	5.21
Reedy Creek 2*	*S. alterniflora*	20	6.72	-0.95	5.77
Reedy Creek 3*		20	4.52	-2.28	2.24
Island Beach 1*		27	2.91	-2.28	0.62
Island Beach 2*	*S. alterniflora*	27	3.63	-5.6	-1.96
Island Beach 3*		27	2.57	-1.24	1.32
Horse Point 1*		26	5.87	-1.95	3.92
Horse Point 2*	*S. alterniflora*	26	5.86	-1.47	4.40
Horse Point 3*		26	5.39	-1.22	4.17

Back-barrier Marshes South of Great Bay

No analysed SET data was available for the back-barrier marshes south of Great Bay along the Atlantic Coast of New Jersey. Data analysis from SETs in the region are planned in 2021 as part of a state wide analysis being conducted by the New Jersey Tidal Wetlands Monitoring Network (NJTWMN). Approximately 9 SETs are located on the Atlantic Coast sections of the Cape May National Wildlife Refuge. As part of pilot TLP projects in the back back-barrier marshes of Avalon and Stone Harbor, SETs were installed by The Nature Conservancy and The Wetlands Institute in 2016. A total of 15 SETs and paired marker horizons were installed (6 in TLP areas, 6 in natural marsh control sites, and 3 in natural marsh reference sites at The Wetlands Institute). Data will become available over the coming years to reveal marsh elevation trends. The installation of 9 SETs in tidal marshes along the Tuckahoe River by ANSDU is planned for 2020.

Characterizing the Problem: Needed Data

Given deterioration in coastal wetlands in surrounding states (Hartig et al. 2002; Cameron Engineering & Associates 2015; Schepers et al. 2017), rapidly accelerating rates of SLR in New Jersey, and SET and accretion data that suggests sediment accumulation deficits are occurring, additional data are needed to plan the States' response to this pressing issue. It is important to determine where coastal marsh loss is most severe, where there is high potential for marsh survival, and where mitigation efforts might be most profitably focused (Kearney and Rogers 2010). To advance such an approach, the following data sources would be valuable:

- Statewide remote sensing analysis of wetland trends analysis to identify areas of marsh deterioration
- A synthesis of consistent and comparable SET and coastal erosion data from across the state to identify emergent patterns and areas of high vulnerability
- Research studies on factors that promote marsh resilience vs. vulnerability to SLR
- Filling gaps in the tide and salinity gauge networks across the state

Ideally, this data would then guide policy and stewardship responses, in concert with other concerns, such as socio-economic vulnerability, conservation status, and other anthropogenic stressors. Basing protection and restoration or intervention actions on strong science will better preserve functioning coastal marsh ecosystems, aid in producing desired results including promoting desired transformations, and will better utilize scare restoration funding.

State-wide Trends Analysis

Geographically extensive analyses of marsh loss in New Jersey to determine effects of SLR are not possible because the data sources available - the National Wetlands Inventory (NWI), NJDEP Land Use Land Cover (LULC), and the Coastal Change Analysis Program (C-CAP) data - do not adequately delineate observed changes (Fig. 2). The National Wetlands Inventory and NJDEP LULC data often does not discriminate between open water and marsh, meaning that changes apparent in NWI do not show the erosion, fragmentation, and interior ponding observed in coastal marshes. Analyses using Landsat satellite imagery data (such as the (C-CAP) data used by the National Estuary Programs) are at a coarse resolution (30 m x 30 m) and cannot detect fragmentation and conversion to open water happening at spatial extents of $<900\ m^2$. To identify marshes that are actively degrading, a new analysis is needed using high resolution aerial photography or satellite imagery, and the analysis needs to be done consistently. Ideally such an analysis would include as a deliverable a spatially explicit analysis of marsh habitat change over the last 1-4 decades, and also an analysis of the drivers of marsh loss. Because each individual pixel could not be classified accurately relative to the driver of change, one approach that could be used would be to distribute a large number of random points (5,000) to areas that experienced habitat change and the driver(s) of change could be classified for these randomly distributed points. Additionally, drone imagery, which often has a resolution of 5-15 cm, is extremely valuable as baseline against which future change can be measured.

The Sea Levels Affecting Marshes Model (SLAMM), available throughout New Jersey, is one data source able to characterize marsh vulnerability to SLR that could predict changes in coastal habitats resulting from SLR. SLAMM has been run for the whole state, and predicted habitat changes between 2000 and 2050 are accessible via the New Jersey Flood Mapper. However, like the currently available landcover data, this approach does not reflect changes that have been observed over past decades. While it is valuable for identifying places where vulnerabilities will occur, it should be supplemented with remote sensing analyses that focus on **current patterns of wetland deterioration**. Policy should focus on observed patterns of marsh deterioration, because due to shortcomings in the SLAMM approach (e.g., lack of localized accretion rates and inaccuracies in LULC maps), predicted changes may or may not materialize. Wetland trends data, and other digital datasets could best be displayed in the NJ Flood Mapper.

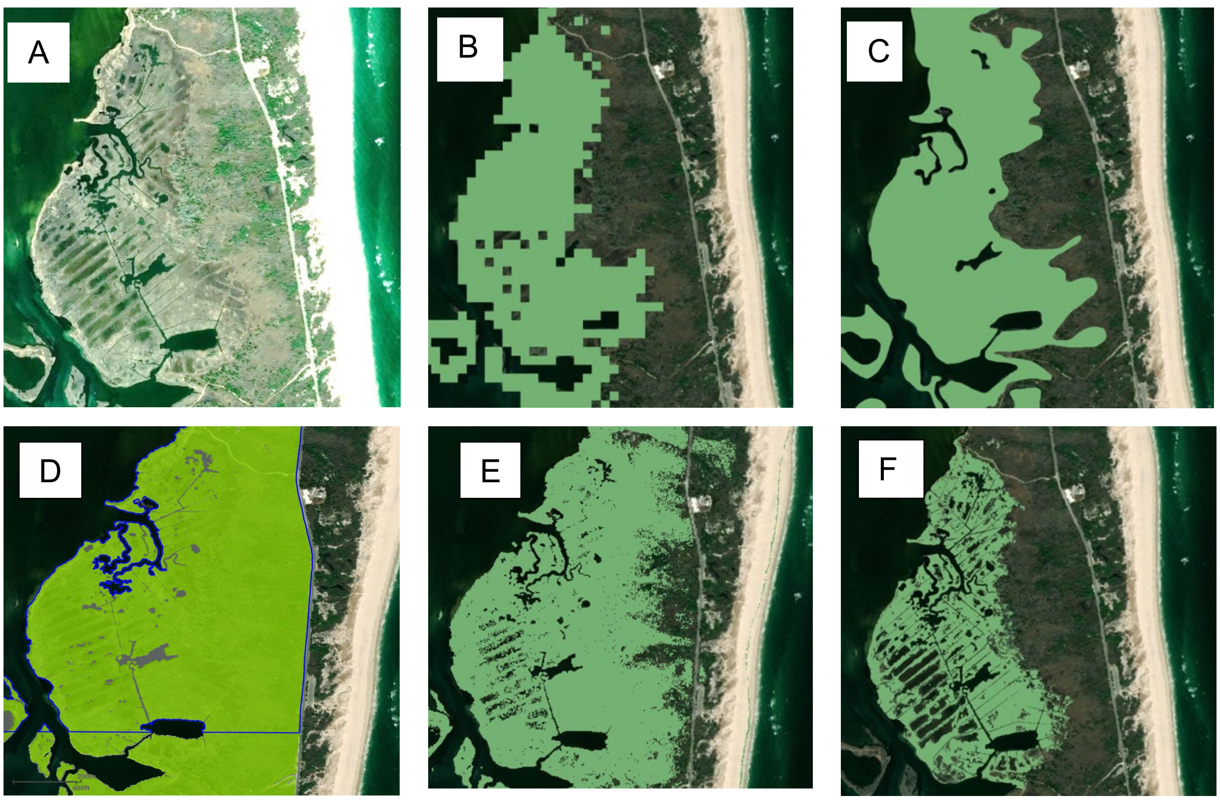


Figure 2. Comparison of tidal marsh extent (in green) from Island Beach State Park, New Jersey, showing aerial digital imagery from the: (A) ESRI basemap; (B) extent of tidal marshes mapped by CCAP data (estuarine emergent wetland landcover category) (NOAA 2020); (C) NWI (estuarine and marine wetlands) (USFWS 2008), (D) TNC salt marsh explorer habitat data; (E) from Correll et al. 2019 and (F) an analysis of 2015 digital 0.3m 4-band digital imagery using modern image classification techniques (object-based image analysis). ESRI Source imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Another data source which has been developed as a vulnerability metric for Mid-Atlantic coastal wetlands is the unvegetated to vegetated ratio (UVVR) (Ganju et al. 2017), which quantifies the area of open water and bare soil within the footprint of a marsh. Marshes with larger areas of water, tidal channels, or bare ground tend to be exporting sediment, and are thus expected to be more vulnerable to SLR (Ganju et al. 2017). This metric is likely to be extremely helpful for ranking wetlands in terms of their SLR vulnerability, although there are shortcomings in this approach relative to a trends analysis. First of all, UVVR does not identify the reasons for the areas of open water. While open water areas might result from marsh fragmentation as a symptom of SLR, areas of open water can result from direct and indirect anthropogenic manipulations of hydrology. For example, over 7,000 ponds were excavated in Barnegat Bay wetlands for mosquito control (Powell et al. 2020) or managed impoundments (Smith et al. 2017). Human constructed open water areas are pervasive and are not likely to reflect SLR vulnerability. Secondly, in areas lacking mosquito ditches areas of open water are often quite extensive, but often are stable or grow and shrink cyclically (Smith and Niles 2016). While a trends analysis would identify such areas as stable, or changing very slowly, simply measuring the area of open water might mistakenly identify such an area as being highly vulnerable to sea level rise. The UVVR is however publicly available for marshes on the Atlantic Coast of New Jersey through The Nature Conservancy's Coastal Resilience Mapper and can be calculated using the Marsh Habitat Zonation Map GIS developed by SHARP in 2017. This information can be used as a vulnerability assessment tool (Defne and Ganju 2016).

Synthesis of statewide SET and lateral marsh loss data

This report considers marsh elevation trends from 52 SETs. However, there are 220 SETs in the state, whose data is still in the early stages of being collected, or the data has not yet been shared and synthesized across agencies. Over the coming decade, regional coordination and synthesis will help identify sites where SLR is far exceeding rates of marsh accretion or elevation change. Comparisons between sites can permit improved understanding of important controls (e.g., tidal range, elevation), and identify locations where more data are needed. This effort ideally will include coordinated data management, a website, and webmapper for examination of spatial and temporal trends. These efforts are being untaken by the New Jersey Tidal Wetlands Monitoring Network[1]. An additional issue related to coordination is the continued support of SET monitoring. Because SETs were generally established with grant funds, continued monitoring requires continued support. Specifically, organizations that applied for Wetland Program Development Grants to support SET installation are now looking for additional sources of funding to support continued monitoring.

In addition to SET data, various analyses of coastal erosion, or shoreline position, have been conducted throughout the state (Phillips 1986; Leonardi et al. 2016; Terrano and Smith 2016; Lathrop 2019), although during different time periods, in different geographies and for different purposes. Rates of erosion are displayed in the Living Shoreline app of TNC's New Jersey

[1] The New Jersey Tidal Wetlands Monitoring Network (NJTWMN) is comprised of federal, state, academic, and non-profit groups conducting long-term monitoring of tidal wetlands in New Jersey. The stated mission of the NJTWMN is to identify current conditions and trends of tidal wetlands in New Jersey to improve resilience of coastal communities and ecosystems by providing data to prioritize restoration efforts and support informed management decisions.

Coastal Resilience Mapping Portal as are acreages of marsh lost due to erosion. Predicted future loss of tidal wetlands to erosion through 2050 are mapped statewide on Rutgers Flood Mapper.

Evaluation of SLR Vulnerability

In addition to a statewide trends analysis, data collection, synthesis and analysis of statewide SET and lateral erosion rates, research is needed on factors that promote or prevent tidal marsh SLR vulnerability in New Jersey. It would be useful to learn what factors contribute to local variation in elevation rates within the same system. The role of such factors as tidal range, salinity, creek morphology, hydrological modifications, dominant vegetation, and sediment availability in SLR vulnerability is not well understood for New Jersey. More research is also needed on the factors that control marsh migration upland: is it easily predicted by slope, or dependent on other factors?

POTENTIAL SOLUTIONS

Wetlands Pathway Protection

Salt marshes can migrate inland as sea levels rise, creating marsh in former upland areas, but it is not feasible unless there is open space landward of the marsh. Otherwise, if there is development, roads, etc. landward of the marsh, the low marsh can move into the high marsh, but the high marsh plants have nowhere to go. This problem, called "coastal squeeze," may be mitigated by developing and maintaining pathways and open areas for the marsh to migrate into. Wetlands pathways are areas that could convert to wetlands. Generally, areas that are both undeveloped and contiguous to existing wetlands are more likely to become pathways than developed areas or areas not adjacent to existing marsh. Pathways can be facilitated by preserving migration spaces, removing berms, resizing bridges and culverts, and adjusting the slope of the land (Maryland Sea Grant 2019). Pathway protection is considered a type of "retreat" (restoration): measures taken to "restore" natural ecosystems (Schectman and Brady, 2013). Their study examined resilience projects in many townships in the northeast and found these were the rarest type of adaptation, representing only 3% of projects.

Issues in Pathway Protection:
Obstacles can include unfamiliarity with potential pathways, connecting scientific findings to policy and practice, limited staff and competing organizational priorities, insufficient budget, lack of coordination on land acquisition, lack of guidance on managing lands for coastal habitat advancement, uncertainty about when and how marshes can move upslope, and lack of public awareness of pathway protection (Blair Environmental Consulting 2018). Local communities play a critical role in wetlands restoration and adaptation. There may be resistance to preserving land that might be seen as developable. For residents to "buy in," community participation is needed. This can be challenging, as managers may face inadequate economic or political resources and run up against cultural norms. An aspect that may be useful is a long-term vision of how coastal communities and wetlands can benefit each other (Regional Planning Association 2018). Education is critical for local communities and politicians (Maryland Sea Grant 2019). Local governments face a "buy-out" dilemma when coastal lands face frequent inundation because if they pay people to leave, it is a loss to their tax base. Non-residential land may be better for buy-out (Maryland Sea Grant 2019).

Prioritization will depend on ecological and geophysical issues, but also on political and social factors. In identifying which communities are appropriate for pilot projects, there are arguments for whether planners should focus on communities with more resources or those with fewer. Planners should provide resources and capacity building to local institutions and community groups to plan and implement projects. Most existing policy tools are targeted at homeowners, but in parts of the region renters are the majority. Plans for wetland migration should be developed to ensure that benefits and costs are distributed equitably (Blair Environmental Consulting 2018). Since it is important to get the community to support the efforts, engagement is most successful when planners use existing organizations like community or home-owner meetings and Facebook groups. Planners, ecologists, engineers, etc. must be open to learning from the community and adapting the project accordingly. Building trust with communities is important for success (Regional Planning Association 2018; Maryland Sea Grant, 2019).

Policy, Regulation and Planning

What incentives might exist for private landowners to promote conservation of pathways? Are there opportunities to use existing rules and regulations to effect pathway protection, for instance through Section 401 of Clean Water Act and state regulations and coastal management programs? What policies might be applied or created to foster protection? What planning vehicles might be used to broaden and institutionalize pathway protection, such as county master plans, the Coastal Zone Management Program, the New Jersey Coastal Resilience Plan, reduction in greenhouse gas initiatives like The 2050 Energy Master Plan, local waterfront revitalization programs, or organizational strategic plans. If restoring spaces for wetland function were included in county hazard mitigation plans, they would be eligible for Federal Emergency Management Agency (FEMA) funding (Regional Planning Association 2018).

Legal Framework

Rolling Easements

Whether as regulations that prohibit shore protection or property rights to ensure that wetlands move inland, rolling easements decrease or end continued use of coastal properties as sea level rises. The "Building Ecological Solutions to Coastal Community Hazards" report for New Jersey advanced the idea of using rolling easements in designated zones to allow for marsh migration.

Examples of rolling easements include:

- Local zoning or state regulations that prohibit building shoreline protection structures;
- Permit conditions that require public access along dry beach in return for building permits;
- Affirmative easements that allow for continued public access as a beach migrates;
- Conservation easements that prohibit shore protection structures, e.g. bulkheads, and sea walls;
- Restrictive covenants wherein owners are mutually bound to avoid shore protection;
- Future interests that transfer ownership as sea level rises to some predetermined level;
- Migrating property lines, which move as the shore erodes, with coastal parcels migrating inland
- Transferable development rights granting upland land to owners who yield land to sea level rise.

Theoretically, rolling easements appeal to property owners because they allow them to maintain their land for as long as they find it cost-effective—getting more use from the land than they would otherwise. The high value of waterfront property induces owners to maintain their property until the threat of inundation is imminent, even as termination payments can be minimal. These efforts cost money. Gardner and Johnston (2020) have developed a hedonic property value model to predict cost and explore price patterns associated with purchases of undeveloped land suitable for salt marsh migration under SLR. Attention is paid to factors that determine marsh migration potential such as coastal distance, elevation and connectivity.

Status of New Jersey efforts
New Jersey Adapt (http://www.njadapt.org/) is an online tool which (among other things) identifies areas where salt marsh migration is impeded or unimpeded based on sea level rise scenarios for 2050. There is also a new Nature Conservancy (TNC) tool that can also be utilized: The Conservation Blueprint. https://www.njmap2.com/blueprint/

The New Jersey Blue Acres Program buys out lands and manages vegetation; restoration areas are designed to embrace rather than resist encroachment of wetland species as sea-level rises. Until now, this program has only bought flood damaged properties, but there is opportunity for them to look preemptively for buy outs in migration pathways (Blair Environmental Consulting, 2018).

It has been suggested that "eminent domain" be used to buy out vulnerable properties, since the process of acquisition and demolition is too slow to keep up with SLR (Hurdle, 2020). Eminent domain is already part of the buyout policy at the U.S. Army Corps of Engineers, which builds up dunes and beaches, and is looking into ways to defend New Jersey's back bays and other areas. The Corps said in 2015 that it would only participate in programs to acquire, relocate and permanently evacuate people from coastal properties if the programs include the option to use eminent domain (Hurdle, 2020). It is very controversial to remove residents from flood-prone properties.

The Community Rating System (CRS) helps communities become eligible and certified as CRS communities by the Federal Emergency Management Agency (FEMA), resulting in homeowner savings and benefits. Communities accrue points for flood reduction measures, including acquisitions of vulnerable lands, some of which may be wetland migration pathways.
Some existing projects could be augmented to include pathway protection:
(1) A planning effort by NJDEP - New Jersey Fostering Regional Adaptation through Municipal Economic Scenarios (FRAMES) in the Shrewsbury and Navesink River basins in Monmouth County to address vulnerabilities to severe weather and repetitive flooding.
(2) The City of New Brunswick's draft land conservation plan which extends from the Raritan to the mouth of Lawrence Brook, and includes some lands already under conservation easement.
Stinnette (2019) analyzed information developed by Rutgers University, based on the Sea Level Affecting Marshes Model (SLAMM) to predict pathways for marshes in northern NJ. The projection is for 2050 assuming a moderate level of sediment accretion (4mm/year) and 3 ft of SLR (NPCC, 2015). She found 570 acres available for migration pathways and 590 marsh acres that will likely become open water. One-third of the pathways were larger than one acre. Almost half the pathways are in priority habitat areas for native species, including endangered and threatened species (NJDFW, 2019). Of privately owned parcels, 42% are vacant; 21% are within 100 meters of a known contaminated site or groundwater well restriction area. The small size of the pathways indicates that protection should include multiple sites. Most of the pathways are already publicly owned but not necessarily protected from development. Education of, and partnership with public agencies is critical. About half of the pathways are wetlands, which may be protected from development. Many may be protected by the Blue Acres flood mitigation buyout program. Research is needed to determine the protection status of potential pathways.

Most of the current land use in the pathways is forested. The conversion from forest to tidal wetlands may cause loss of carbon storage from trees (although this could be offset by the carbon sequestration of wetland vegetation), biodiversity loss along the salinity gradient (Odum, 1988), which plants the migration involves and what wetland functionalities migrate first (Anisfeld et al. 2017). The predicted area of drowned wetlands in addition to the loss of ~30 acres/year to development (Stinnette et al. 2018) make protecting these pathways critical.

The future of tidal salt marshes will be influenced by adjacent landowners whose decisions could promote or block marsh migration. Researchers found that conservation easements are unlikely to be sufficient to mitigate losses from sea level rise, but some other strategies like restrictive covenants and future interest agreements appear more likely to be adopted by landowners. However, these are unproven in practice and are likely to be more expensive. Failure to factor human behavior into conservation planning can lead to an overly optimistic view of success in marsh migration. Strategies to increase participation in conservation agreements — such as increasing understanding of climate change and increasing awareness of the ecosystem services provided by marshes — had weak effects on landowner attitudes. Landowners with stronger beliefs about increased flooding or marsh migration indicated a greater inclination to build seawalls, potentially leading to greater loss of natural coastline habitats. Overall, 22% of landowners said they were likely to harden their shoreline within 20 years (Balcom, 2020).

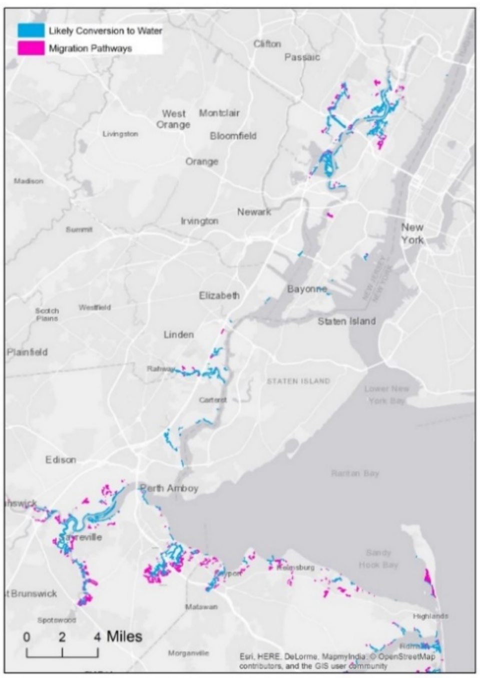


Figure 3. Wetland Migration Pathways in Northern New Jersey. Map created by Isabelle Stinnette from data from NJ Adapt.

Recommended Potential Locations for Marsh Migration are provided in Appendix 1.

Technical Guidance is Needed (Blair Environmental Consulting 2018)
1. Guidance is needed on how to manage land for marsh migration after it is bought by municipalities, counties, or states. FEMA funding is only available for removal of buildings and there is little guidance on what to do after. Guidance is needed on restoration, stabilization, and management to buffer nearby lands from storms, hold storm surge and flood waters, and develop productive habitat.
2. Guidance is needed for regulators who can protect wetland migration corridors. At the local level, model ordinances related to coastal habitats and pathway protection would be helpful.
3. Guidance to inform prospective buyers of foreclosed properties: Municipalities need guidance on how to inform people who are considering purchases of properties foreclosed due to storm damage; there may need to be changes to state law to increase transparency and full disclosure.

Managing *Phragmites australis*

The common reed, *Phragmites australis*, is a native wetland plant in North America, however its expansion has been linked to the cryptic invasion of a non-native genotype (Saltonstall 2002). *Phragmites australis* is invasive in New Jersey tidal marshes and has been viewed to reduce plant and avian diversity (Chambers et al. 1999). It is one of the most aggressively managed plants in the United States (Rogalski and Skelly 2012) and is frequently removed with herbicides and replaced with native *Spartina alterniflora* during restoration projects, which may also lower the marsh surface after removing the reeds. Many restoration practitioners dislike *Phragmites* and want it removed, and millions of dollars are spent on herbicide control. Nevertheless, *Phragmites* does many beneficial ecosystem services that are generally unappreciated and may provide important benefits in the context of SLR acceleration.

Use as Habitat and food
Although *P. australis* has been traditionally viewed to negatively impact wildlife, empirical studies predominantly highlight species tradeoffs. Many studies indicate that fish and invertebrates in tidal creeks of *Phragmites* marshes were about as abundant and diverse as those in *Spartina* marshes (Hanson et al. 2002; Posey et al. 2003; Fell et al. 1998; Meyer et al 2001; Yuhas et al. 2005). Some have found fish assemblages are less diverse and dense in *Phragmites*. The killifish, *Fundulus heteroclitus,* which plays an important role trophic role in coastal areas, is clearly reduced in *Phragmites* marshes (Able and Hagan, 2003). Marsh plant detritus is food for many animals, and detritus from *Spartina* and *Phragmites* provides equivalent nutrition to detritus feeders (Weis et al. 2002). *Phragmites* detritus that is consumed gets into estuarine food webs to support larger fishes (Wainright et al. 2000). Bird use of *Phragmites* varies depending on the species, location, *Phragmites* density, and other available plant species. Some birds do not prefer *Phragmites* habitat, but conversely, some prefer *Phragmites*. Studies comparing the density of individuals or the numbers of species in reeds versus alternate plants show variable results (Benoit and Askins 1999). *Phragmites* also provides habitat for many other terrestrial organisms (Rogalski and Skelly 2012; Kiviat 2013).

Ecosystem Services
Some of the ecosystem services *Phragmites* provides have become much more important with anthropogenic contamination and the urgency of climate change and sea level rise. *Phragmites* is better at sequestering pollutants including nitrogen than *Spartina spp.* (Windham and Ehrenfeld

2003, Windham and Meyerson 2003). Nitrogen immobilization was 300% higher in *Phragmites* litter than *Spartina patens*, and the *Phragmites* removes Nitrogen from surface waters and soil (Windham and Ehrenfeld 2003). Furthermore, biofilms on its senescent stems perform denitrification during the growing season and winter (Soana et al 2018). *Phragmites* is also better at sequestering carbon dioxide than *Spartina alterniflora* (Duman and Schafer 2018; Davidson et al. 2018). In Duman and Schafer (2018) study, a restored wetland in which *Phragmites* were replaced by *Spartina* alterniflora increased its emissions of carbon dioxide (CO_2). The nitrogen *Phragmites* removes is not available to promote algal blooms and eutrophication and the CO_2 that it sequesters is "blue carbon" which cannot contribute to climate change and ocean acidification. Although tidal *Phragmites* habitats also release methane, a potent greenhouse gas (Mozdzer and Megonigal 2013), some studies suggest that *Phragmites* acts as a net greenhouse gas sink due to high CO_2 assimilation (van den Bergh et al. 2016).

In terms of metal contaminants in the sediments, both *Phragmites* and *Spartina alterniflora* take up equivalent amount of metals into the roots, but *Spartina* sends more toxic metals such as mercury, chromium, and lead aboveground into the stems and leaves, which excrete the metals, along with salts, back into the ecosystem. Senescent leaves that fall to the ground are higher in metals that can be transferred to detritus feeders (Windham et al. 2001 a, b; 2003).

Ecosystem Services: Resilience

Phragmites creates more litter on the marsh surface, grows more roots, and traps more sediments thereby enabling a marsh to elevate more rapidly than *Spartina spp.* (Rooth and Stevenson 2000). *Phragmites* builds and stabilizes marsh soils and protects tidal marshes from erosion associated with sea-level rise. In our analysis of New Jersey marshes, among the few that were keeping up with SLR were two *Phragmites*-dominated marshes in the Meadowlands, which had the highest elevation change of all marshes in our data. Two other Meadowlands marshes that had been restored from *Phragmites* to *Spartina* were not keeping up. Furthermore, *Phragmites'* height and dense growth provide better protection from the effects of storm surge and wind.

Management

The Marsh Resilience Summit (Maryland Sea Grant 2019) considered questions of whether alternate stable states (e.g. *Phragmites*-dominated ecosystems) are a viable option to meet management and policy objectives related to ecosystem resilience and of how to prioritize restoration and conservation efforts.

Management practices should consider the vital ecosystem services of *Phragmites*. Martin and Blossey (2013) assessed management of *Phragmites* through a cross-institutional economic survey of 285 land managers from US public and private conservation organizations. The analysis of the expenses and results of restoration projects during 2005 -2009 found that organizations spent >$4.6 million per year on management of *Phragmites*, 94% used herbicides on ~80,000 ha. Despite the high expenditures, few accomplished their objectives and there was no relationship between resources invested and success. Kiviat (2010) noted that areas with *Phragmites* interspersed with small and large shallow pools are excellent for marsh and water birds, and that excavating such pools in *Phragmites* stands is a management technique used in the UK. This requires an approach tailored to individual areas and site-specific management goals.

Twenty years ago, Rooth and Stevenson wrote: “Thus *P. australis* may provide resource managers with a strategy of combating sea-level rise, and current control measures fail to take this into consideration.” This statement is still true. A shift from attempted eradication everywhere to modification of *Phragmites* stands to create habitat for desired species would retain its other important ecosystem services, especially marsh elevation.

Sediment Manipulation in Coastal Marshes

There are physical methods for manipulating sediments to increase marsh resilience that are being studied (Wigand et al. 2017). This section presents an overview of some of the approaches implemented to restore, or extend the lifespan, of coastal marshes that are compromised by SLR.

Thin-Layer Deposition

Salt marshes can increase their elevation via sediment trapping and belowground biomass production. However, in many areas, sediment movement has been disrupted by man-made barriers. Suspended sediments often cannot support accretion rates to maintain marsh elevation relative to sea level rise, and there are physical limits on the accretion rates via growth. Regardless of the cause, lack of sediment can affect marsh’s resilience to SLR. One useful approach to maintain or increase marsh platform elevation, is by the repurposing of dredged material/sediment (Ganju et al. 2019).

Background

Dredged material has been used to create wetlands in other parts of the United States since at least 1969, but unplanned creation of marshes with dredged material has occurred for a longer period (Turner and Streever 2000). Additional sediment can elevate coastal marshes, enabling them to keep pace with SLR (Morris 2002). Beneficial reuse of dredge sediments may slow or reverse losses of salt marsh (Woodhouse et al. 1972) and increase resiliency of systems that have been degraded by anthropogenic impacts such as grid-ditching and salt hay farming (Smith et al. 2018).

Dredged material may consist of rock, gravel and sand, consolidated clay, silt and soft clay, or mixtures. These types of sediments form the majority of material dredged material. Other materials, e.g., rock and consolidated clays, can be used for wave protection during restoration projects; gravel and sand can form the subsoil of wetlands, partially filling shallow areas on which finer grained sediments can be placed (National Research Council (NRC), 1994). The most common source of dredge material is from maintenance projects associated with waterways, harbors, and marinas that are dredged for safe navigation of vessels.

Not all dredged material is compatible with wetland projects. Mathies (1994) discusses factors that limit its use: logistics (proximity of wetland site to dredged location (Reed 2004)), physical and chemical characteristics of the sediments (e.g., contaminated sediments cannot be used), channel dynamics and navigation safety (dictate the type of dredge used), and policy limitations. The Code of Federal Regulations (33 CFR Part 335.4) requires the USACE to select the least-cost, environmentally acceptable alternative, which becomes the “Federal Standard” for the project. Beneficial reuse projects such as wetland creation are not usually the least-cost alternative, and therefore are not consistent with the Federal Standard.

According to Berkowitz et al. (2019), the best way to place dredged sediment on coastal marshes is to place the material in layers no more than 30 centimeters thick to provide ‘elevation capital’ to shallow intertidal areas. This has been called thin-layer deposition (Ford et al. 1999), thin-layer placement (TLP) (USACE 2019), or sediment enrichment (Slocum et al. 2005). Studies going back to the 1980s show a consistent positive marsh response from two to 10 years following thin-layer placement (Ray, 2007). Wilber (1992) concluded that the best definition of thin layer placement is the placement of a thickness of dredged material that does not transform the receiving habitat’s ecological functions. Another term, marsh nourishment, is the new restoration strategy that can refer to either the direct placement of a thin-layer of sediment through spray or hydraulic dredging or from the “spilling” of a thin-layer of sediment over marsh that is adjacent to an uncontained restoration project (LaPeyre et al. 2006).

Marshes that are low in the tidal frame and/or accreting at rates slower than SLR are good candidates for TLP. The primary goal is to raise the marsh elevation of each site to the optimal elevation for plant growth to increase the marsh’s resilience to SLR (Schile et al. 2014).

Engineering Approach
The process begins with the calculation of how much material is needed across the marsh. The appropriate thickness of material is a function of the habitat type (Ray 2007). Calculating the appropriate thickness requires an understanding not only of the desired or target elevations but also the nature of materials to be pumped, the nature of the sediments in the areas receiving the sediment, and the extent of dewatering and subsequent compression (Ray 2007).

Sediment placement in these projects is less than 30 cm thick so that plants and invertebrates can readily grow or migrate up through the material. Deposits greater than that could smother and kill existing vegetation, requiring revegetation with new plant material (Ford et al. 1999). However, Cahoon and Cowan (1987, 1988) reported that recolonization by typical salt marsh plant species was underway 14 months after high-pressure application of up to 40 cm of dredged sediment. Within four years, the sites were no longer distinguishable or were very similar to reference areas, except for some species variance (Ray 2007). On the contrary, placement of dredged sediment in thicknesses over 6 cm in NJ’s three pilot TLP projects reduced plant cover to under 20% regardless of the texture of the sediment (Metthea Yepsen, personal communication September 2nd, 2020). As these pilot projects matured the relationship between plant cover and thickness of sediment was lost. Placement of less than about 8 cm may not be cost-effective.

Estimation of the amount of dredge material needed to raise the platform elevation begins with accurate determination of the topographic elevations of the proposed project site. Once known, a site-specific target elevation above mean sea level and close to mean high water can be calculated (Barone et al. 2014). These site-specific elevations, called biological target elevations (BTEs) are based on site-specific vegetation, elevation, hydrologic, and orthoimagery data (Mohan et al. 2016). The BTEs are elevations within the range at which healthy high salt marsh is currently growing but is at the lowest end of the range at which the invasive species

Phragmites is currently growing. For low salt marsh habitat, target elevations are above mean low water (USGS 2016) and within the range of currently healthy low marsh.

In preparing the marsh, the area is usually divided into cells to contain the dredged material, which will be filled to varying thicknesses depending upon their baseline elevations. These cells are maintained by containment structures (e.g., hay bales, rock, geotextile tubes). Creeks within or adjacent to the cells are generally protected from the dredged material with erosion controls such as coir fiber logs or other materials. These protective measures are placed at some distance from the edge of the water to provide a buffer for additional protection (Mohan et al. 2016). There will be variation in the material distributed within each cell due to local topographic features, the stability of the marsh surface, and, more importantly, variability in settling as material moves away from the discharge pipe. Coarser sediments will fall out of suspension quickly and tending to pile up, while fine grained sediment will run farther and create a more even topography. The containment structure should be removed after the water has drained and the sediments have consolidated. Allen and Shirley (1988) did report that the containment structures could be left to provide short-term (hay bales), medium-term (until seedlings have become established), or long-term protection from wave activity. Containment was removed from the NJ Pilot Projects out of concern that it was blocking proper tidal flow to and from the restored areas (Metthea, personal communication September 2, 2020).

Regarding the reestablishment of vegetation, approaches include direct plantings, mixing seed in with dredge material as it is being sprayed, aerial seeding, and allowing the area to vegetate naturally (Mohan et al. 2016). Welp (2019) recommends that natural recruitment be allowed to reestablish the vegetation and that long-term restoration may take from three to five years. In New Jersey, most TLP projects consider a 3 to 10-year monitoring period.

Construction Approaches

Dredged material may be deposited using a variety of methods depending on the distance of the placement site from the dredging operation, conditions at the placement site (existing substrate conditions, adjacent depths, wave, wind, and current conditions), type of material being placed, and goals (e.g., create new wetland vs. increase elevation in an existing wetland).

Traditional hydraulic pipeline placement is a method in which dredged material is pumped directly on site. The goal generally is to create marsh from open water or increase the density and health of native plant communities by reducing inundation times. This includes using sandy sediment to restore marshes behind living shorelines. To lower costs, the sediment concentration in the pipeline is maximized; water content can be varied to facilitate spreading of the material.

Spray-dredge placement, thin-layer placement, and rainbow placement all refer to placing sediments via high-pressure spraying. This is the most commonly used method (Fig. 4). In this instance, a nozzle is attached to the pipeline carrying the fluidized dredge sediment and the material is sprayed up to 150 to 200 feet across the marsh surface. Workers manipulate the spray nozzle to allow for preferential deposition of the sediment. The longer the nozzle sprays over a given location, the thicker the deposited material is. Cahoon and Cowan (1988) report that sediment can be sprayed onto living plants without long-term detrimental effects if the sediment thickness is less than 15 cm, this differs from previously noted recommendations as maximum thickness may be influenced by sediment type, method of application, target elevations, and the length of the growing season.

Fig. 4. Dredge sediment placement via a spray nozzle. *Image courtesy NJDEP.*

Slurry placement with hydraulic pipeline placement is a relatively new approach. Sediment can flow onto existing marsh with a high fluid to sediment ratio, which facilitates the sediments flowing over long distances (Mendelssohn and Kuhn 2003), and avoiding excessive sediment deposition on top of existing plants (Leonard et al. 2002). It is most cost-effectively applied in enhancing wetlands that are excessively inundated due to SLR (Mendelssohn and Kuhn 2003).

A final category of dredging placement methods involves placing material from a land-based operation or direct placement during channel dredging into the nearshore. Dredged sediments that have been stockpiled onshore or created in dredged material "islands" adjacent to a navigation channel are sometimes moved to create wetlands using a backhoe or "scrape down" methods. The material is then reworked in the nearshore to obtain the elevation and aerial extent required for a functional wetland.

Monitoring

Mohan et al. (2016) note that monitoring a TLP project is critical to success. Detailed and regularly scheduled monitoring can identify environmental changes in and around the project area and determine if issues detrimental to success can be corrected. The decision to correct should be addressed through adaptive management, which is a structured, iterative process of decision making aimed at reducing uncertainty over time. Monitoring activities are implemented and results evaluated to permit the logical implementation of activities (e.g., increasing drainage, implementing supplemental planting, or installing wildlife enhancement structures).

The Nature Conservancy (2015) details the following attributes for a monitoring program:

- Topography: The primary objective of the placement of dredged material on a salt marsh is to increase marsh surface elevation (Nature Conservancy 2015).
- SETs: Surface elevation is determined by physical processes including sea level rise, erosion, accretion, root growth, compaction and subsidence. Elevation, in turn, is the

primary determinant of many important marsh ecosystem features. Since the placement of dredged material will necessarily change elevation, it is critical to get high resolution measures of surface elevation (TNC 2015).

- Surface Water Elevation/Tide Range: Surface elevation and marsh topography determine a site's depth and duration of tidal flooding, which determines what vegetation grows in different areas of the marsh. Hydroperiod, or depth and duration of inundation, should be calculated using tide range data collected for each project and control site (TNC 2015).
- Vegetation: Elevation and tidal flooding are important determinants of vegetation, and placement will be accompanied by immediate increases in marsh elevation and changes to depth and duration of flooding. Metrics include species richness, percent cover by species, average stem height of dominant plant species, above-ground biomass and below-ground biomass (TNC 2015).
- Wave Energy Modeling: The purpose of the wave energy modeling effort is two-fold: Guide optimization of proposed design of edge restoration and dredged material placement to maximize benefits of wave energy reduction across a range of storm events, as feasible. And, evaluate benefits in terms of wave height/energy and potential flood damage reduction of constructed restoration, utilizing as-built surveys (TNC 2015).
- Epifaunal Macroinvertebrates: Epifaunal macroinvertebrates (EMI) provide important trophic linkages within salt marshes. Determination of success is based on a comparison of the number of species and numbers of specimens within each taxa to conditions for adjacent natural marshes (TNC 2015).
- Benthic Infauna: Benthic infauna are prey for fish and macroinvertebrates and play a key role in organic matter cycling in salt marshes. Determination of success is based on a comparison of the number of observed species and numbers of specimens within each taxa to conditions in adjacent natural marshes (TNC 2015).
- Nekton: Nekton are motile macroinvertebrates and fish. Their movements and use of the marsh plain and adjacent surroundings are controlled by the movement of water through tidal channels and onto and off the marsh plain (TNC 2015).
- Avian: Placement of dredged material on a marsh plain will likely result in a stepwise shift in the composition of the avian community and the utilization of the placement areas after placement. Measures of success are based on observation of species use and frequency of the area compared to baseline conditions (TNC 2015).

The monitored site should be compared with an appropriate background site. Whether that may be an undisturbed location in more remote locations (reference site), to sites with similar conditions (control site), but for the presence of the TLP, or in areas that have suffered from similar historic anthropogenic pressures.

New Jersey Case Studies

TLP projects have been successfully implemented across the country in a variety of settings (Gary, 2007; Welp 2015, and Mohan et al. 2016). In New Jersey, the USACE, NJDOT, NJDEP, and the Natural Fish and Wildlife Foundation (NFWF) completed three pilot/demonstration projects. The objectives for the pilot projects were to (1) increase and maintain the optimal tidal elevation (hydroperiod) for native salt marsh species, (2) increase the cover and health of native salt marsh vegetation, and (3) return all other metrics to baseline conditions unless they were expected to change due to habitat conversion. These projects are summarized in a Project

Summary and Lessons Learned from Implementation document due out in the fall of 2020 from the NJDEP and The Nature Conservancy.

The Ring Island project, in Middle Township, was completed in 2014. Sand dredged from the New Jersey Intercostal waterway was placed on vegetated, short form *Spartina alterniflora* salt marsh to create a one-acre black skimmer habitat and a two one-acre pilot TLP project. Sand was sprayed from a 14-inch pipe onto the marsh as it was hydraulically dredged from the channel. Since the sand fell out of solution quickly, it did not spread across the marsh and piled up unevenly.

During the winter of 2014 and again in winter 2015 marsh enhancement pilots were attempted at Avalon using primarily fine-grained sediments that were hydraulically dredged from the New Jersey Intercostal Waterway. The first was a seven-acre test to explore pumping into expanding pools and the second was a 50-acre project. The sediment was pumped up to a mile from the channel and would spread far into the marsh until it hit containment. Water in the dredged slurry was contained within a fill ring of coconut coir logs and pumping had to stop while the site dewatered. Finer grained sediment led to more even placement, but sediment placed in pools consolidated more than sediment placed on marsh platforms. In winter of 2015, approximately 6-acres of vegetated salt marsh with high and low marsh, received a mix of sandy and fine-grained sediment from the Fortescue Creek navigation channel.

The average depth of placement at Ring Island was 15 cm (SD = 7 cm). At Avalon, the average depth of placement was 30 cm (SD = 27 cm) for monitoring plots that started as marsh platform, and >62 cm (SD = 37 cm) for plots that started as a pool. At Fortescue, the average depth of placement was 17 cm (SD = 15 cm). By 2017, the placement sites had consolidated and lost some of the initial elevation. Mean elevations at Avalon and Ring Island were comparable to the Mean Higher High Water line and mean elevations at Fortescue were comparable to the Mean High Water line.

Vegetative cover at all sites decreased by 40- 60 percent after placement. By 2019, little recovery was observed at Ring Island; cover is increasing at Avalon, but is still well below baseline conditions, and cover at Fortescue has returned to baseline conditions. As of 2018, vegetative cover had no significant correlation with placement depth. *Phragmites australis* has not been an issue in any of the marsh enhancement sites. Monitoring of the pilot projects is ongoing.

Enlarging Marsh Islands

USACE has initiated Island marsh restoration projects as a beneficial reuse for dredge material. Three Mid-Atlantic restoration projects (Elders Island, Jamaica Bay, NY; Poplar Island, Chesapeake Bay, MD; and Mordecai Island in Beach Haven, NJ) have expanded eroded marsh footprints through reuse of dredge material.

The USACE began the Poplar Island project in 1996 by installing dikes on the island boundaries and placing dredge sediment on the dikes. The project was expanded in 2012 with a goal of 1,715 acres, including 735 acres of wetlands and 140 acres of embayment (USACE 2019).

Fig. 5. USACE projects that expand existing island saltmarshes: Elders Island, Jamaica Bay, NY (bottom panel) *Image courtesy USACE.*

Originally one island, erosion and marsh loss disconnected Elders Island in Jamaica Bay into two separate landforms. Application of 200,000 yds^3 of dredge sediment restored 40 acres of marshland replanted with *Spartina alterniflora* (cord grass) (USEPA, USACE. 2007) (Fig. 5).

Mordecai Island in Beach Haven, New Jersey is owned and managed by the Mortdecai Land Trust. The marsh island acts as buffer to storms and waves for residents and proves habitat birds. Over the past 100 years the island has lost more than half of its area. In 2015, the USACE used dredge sediment to rebuild the marsh island. The project is being monitored by NOAA and results are expected by the end of 2020.

Other Beneficial Use Techniques

Recently, the USACE has placed dredged sediment in open water at locations which permit natural forces to transport sediment toward and onto marshes (Fig.6). The practice, known as "strategic placement or "mud motor" (Baptist et al. 2019), is sustainable because 1) placement in open water is well-studied and risks can be managed; 2) additional sediment can be placed during subsequent dredging cycles because the placement site is dispersive; and 3) the practice is cost-effective. Therefore, this practice can be performed in perpetuity and its effectiveness has been demonstrated for enhancing beach volumes (Brutsché, Wang, Beck, et al. 2014; Brutsché, Wang, Rosati, et al. 2014). However, most of the sediment dredged by USACE is mixed sand/silt/clay – often described as "muddy". Perceived risks associated with muddy sediments, coupled with poor understanding of their fate in vegetated and wetting/drying environments has not permitted strategic placement of muddy sediments near marshes to date. The following processes require further quantitative field data collection and analysis before submerged sill placement of dredged material can be regularly incorporated into actual project plans for marsh restoration:

1) Turbulence, flocculation and settling velocity in marshes
2) Effects of wetting/drying and benthic activity on resuspension from mudflats
3) Deposition processes on mudflats during dewatering
4) Deposition in vegetated environments
5) Effects of root mass and stems on erosion in marshes
6) Influence of stem density on trapping of suspended sediments

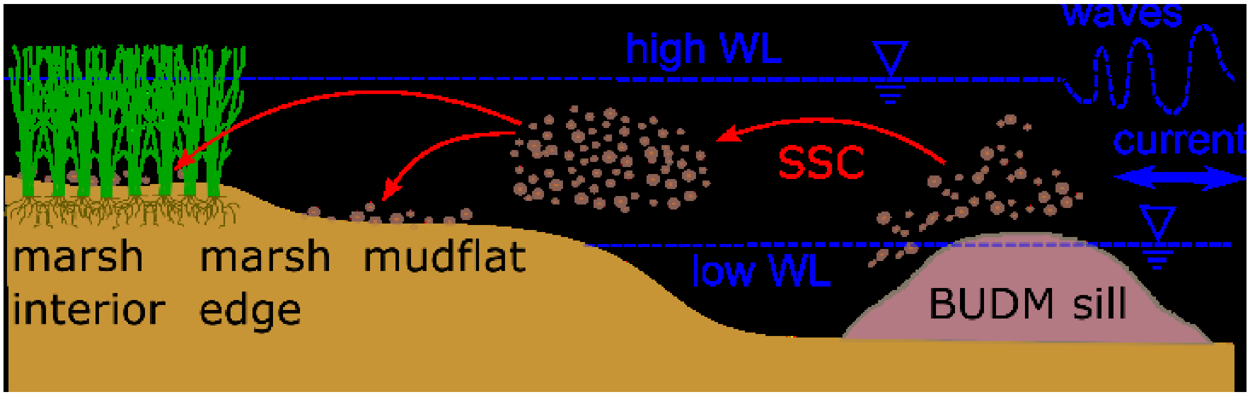


Figure 6. Beneficial Use of Dredged Material

Lessons Learned

While TLP has proven useful, the wide variety of application methods and project objectives complicate defining the TLP concept. Additionally, the ability to obtain a specific TLP thickness or target elevation remains limited by placement technique, equipment, project objectives, and other factors. Specifically, the thickness of material placed is a function of the type of equipment being used, how it is being operated, placement site conditions, and dredged material physical characteristics (e.g., dispersion or consolidation potential; Berkowitz et al. 2019).

Mohan (2016) outlines the following considerations in terms of ensuring a successful TLP project:

- Conduct detailed baseline surveys (bathymetry, topography, water/tidal ranges, rainfall data, vegetative community data) to ensure a successful outcome;
- Incorrect or incomplete characterization of wetland hydraulics can lead to tidal choking;
- Incorporate living shoreline elements to lower impacts from future storm surges;
- Consider habitat diversity as part of restoration design;
- Utilize public outreach to adjacent property owners to discuss project benefits;
- Utilize an experienced design/construction team to avoid delays in execution;
- Be mindful of funding sources to avoid potential project disruptions;
- Incorporate adaptive management to facilitate continuous improvement of the process;
- Allow for natural processes to facilitate continued development; and
- Incorporate monitoring for as long as possible (up to 20 years) to evaluate the project. Based on regulatory requirements, a minimum period of five years would be expected, but a longer time is prudent to judge the progression of wetlands development.

Runnels

Drainage patterns vary depending on location within a tidal marsh, with channel edges seeing better drained conditions, and the marsh interior experiencing prolonged soil saturation (Montalto et al. 2006). While marsh plants can tolerate some waterlogging, excessive saturation causes soil oxygen deficiency, which impacts plant growth and functions (Tiner 1999). As SLR alters inundation patterns, vegetation die-back and reduction of accretion results in conversion of the marsh to pannes or mudflat and ultimately, open water (Watson et al. 2017). Peat collapse was noted by DeLaunne et al (1994). The Nature Conservancy (2018) notes that loss of vegetation alone can cause a loss of 8- 20 cm of biomass and elevation. This is prevalent in salt marshes that have been the subject of historic anthropogenic modifications such as deposition of spoils from mosquito ditching and creation of dikes or levees to facilitate salt hay farming. An approach to resolving this issue is the installation of runnels or shallow ditches to facilitate drainage from these ponded areas (see Figure 7). The objective is to mimic the natural tidal flux across the marsh and restore the natural hydrologic cycle.

Figure 7. Runnel installation at Cape May NWR. *Image courtesy Wood.*

The design of a runnel installation program begins with a detailed determination of the topography of the marsh face. Nature Conservancy (2018) and Wigand et al. (2017) note that in order to maximize efficiency, runnels should be deep enough to drain water off the marsh, should lead to some drainage feature, should avoid ditching through high elevations on the marsh surface, and work with preexisting natural drainages or historic agricultural drainage systems.

In 2017, approximately 9000 linear feet of runnels were installed at the Reeds Beach Unit of the Cape May National Wildlife Refuge in Cape May, New Jersey. Post construction monitoring by the USFWS) indicated that the runnels were working well and were draining water from developing pannes. However, long-term monitoring of the runnels will be required, as there is a tendency for runnels to collect sediment from the movement of water across the marsh. If enough sediment be accumulated to prevent drainage, then the runnels will no longer serve their purpose and water saturation in pannes will return. It is likely that long-term maintenance will be required to ensure the functional capabilities of the runnels.

LIVING SHORELINES

Introduction

The use of living shorelines was designated a ***high priority*** in the New Jersey Coastal Management Program Section 309 Assessment & Strategy (2016-2020). Living shorelines can *"increase the vertical accretion of sediment on shorelines so that wetlands can keep pace with SLR [sea level rise]… use [of] living shorelines to build elevation and stabilize eroding shorelines"* (Whalen et al, 2012). An advantage of living shoreline techniques is the ability to offset previous or current and future coastal habitat loss – a paradigm shift of working with, rather than against, natural processes (Bilkovic & Mitchell 2017).

Many definitions currently describe living shoreline techniques, and there is no universally accepted definition (Living Shorelines in New England: State of the Practice. 2017). The New Jersey's Coastal Zone Management Rules (N.J.A.C. 7:7-1.5 CZM) define a living shoreline as "a shoreline management practice that addresses the loss of vegetated shorelines, beaches, and habitat in the littoral zone by providing for the protection, restoration or enhancement of these habitats." As explained in the CZM Rules, this is accomplished through the strategic placement of plants, stone, sand, or other structural and organic materials. There are three types of living shorelines: natural, hybrid, and structural. There is a range of design options (Pilkey et al. 2012). Erosion control and use of living or natural materials are included in the definitions of living shorelines. NOAA defines living shoreline as "*A shoreline management practice that provides erosion control benefits; protects, restores or enhances natural shoreline habitat; and maintains coastal processes through the strategic placement of plants, stone, sand fill, and other structural organic materials (e.g., biologs, oyster reefs, etc.)"* (https://shoreline.noaa.gov/data/datasheets/index.html). The definition is important because permitting policies, rules, and regulations derive from how a living shoreline is defined.
Living shoreline marsh designs include features that could enhance the ability of marshes to keep up with SLR (Fig. 8). Since 1998, the NOAA Restoration Center has supported implementation of more than 140 living shorelines projects around the country, although to date, these projects have been primarily in Chesapeake Bay and the Gulf of Mexico (https://www.fisheries.noaa.gov/feature-story/north-carolina-living-shoreline-projects-help-protect-habitat-and-communities?utm_medium=email&utm_source=govdelivery). Installation of living shorelines along the edges of marshes could potentially increase New Jersey's current salt marsh inventory. The addition of protective features to existing marshes could mitigate erosive forces negatively affecting existing marshes. These options include the addition of material to raise marsh surface elevations, toe protection with natural or manmade materials, or the addition of breakwaters (natural or manmade). There could also be the inclusion of a non-natural structure to provide stability for the living elements, although not the primary living shoreline intention. Other options could include placement of large woody debris, floating wetlands, or islands that can dampen wave or storm surge energies. Features that stabilize living shorelines could potentially help maintain existing marsh elevations by increasing sedimentation rates (O'Donnell 2016).
Bilkovic & Mitchell (2017) suggest living shorelines are ***"****Engineered shorelines, designed specifically to break wave energy and reduce shoreline erosion, while minimizing the adverse effects typically associated with hardened shorelines and therefore require balance between the*

ecological and engineering design criteria." Natural features may need to be combined with hardened non-natural structures (NOAA 2015), prioritizing protection, rather than restoration.

Challenges Implementing Living Shorelines

Some living shoreline techniques are similar to traditional engineering approaches (Fig 9), such as planted revetments or breakwaters, while others such as living reefs and Reef Balls are more unique (NJDEP 2015). Several researchers note that there are a number of current challenges that must be addressed when implementing living shorelines, including:

➢ Site Specificity – each living shoreline project has different parameters and goals:

- Every design must be site-specific (Hardaway et al. 2013). "Site specific conditions of wave energy, tidal currents and amplitude, elevation and underlying geomorphology will determine the specific design of a living shoreline installation" (Currin et al. 2017).
- Harsh weather conditions (e.g. ice, climate change impacts such as sea-level rise, increased storm intensity and increased temperature variability), herbivory, and large tidal ranges affect the viability and resilience of living shoreline designs (Living Shorelines in New England: State of the Practice. 2017).
- There is a shortage of successful demonstration projects in the NY-NJ region and out of state projects may not resonate with local engineers, regulators, or landowners (Rella et al. 2017).

➢ Lack of quality data related to living shoreline effectiveness meeting project objectives:

- Relatively few studies have quantified the value of natural ecosystems for storm and erosion protection and to our knowledge, **no one has assessed the value of hybrid approaches to date in the peer-reviewed literature** (Sutton-Grier et al. 2015). [There is a] lack of peer-reviewed literature on quantitative monitoring and evaluation of implemented living shorelines (Currin 2010).

- Grant periods that fund living shorelines are rarely long enough for more than a year or two of monitoring, meaning that little is known about long-term effectiveness and maintenance costs.

- Design components that require multiple seasons to establish must be protected by other design elements during living shoreline development (Living Shorelines in New England: State of the Practice. 2017)

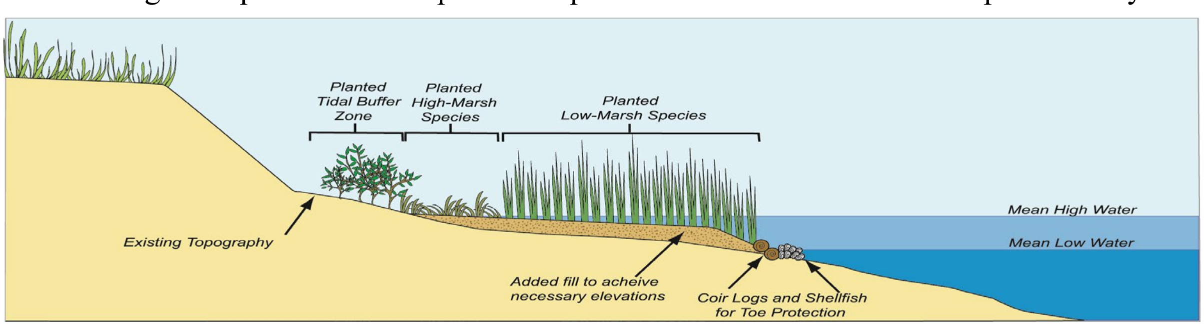


Fig. 8. Example of a living shoreline that includes low and high marsh, an upland tidal buffer zone, coir log and shellfish marsh toe protection against erosion of fill material added to increase marsh surface elevation. *Image courtesy of Living Shorelines Conservation*

- Specific actions to minimize potentially negative site-specific impacts are not required in current regulations (Living Shorelines in New England: State of the Practice. 2017).

➢ Permitting obstacles

- "Current permitting systems provide a reactive approach to address erosion along sheltered coasts." National Research Council of the National Academies (2007).

Research has documented ecological benefits of living shorelines (Sutton-Grier et al. 2015; Gittman et al. 2016; Sharma et al. 2016; Smee, 2019); however, there is limited data that calculates actual protective effectiveness of living shoreline projects. There are numerous publications from NOAA and various states that have installed or are initiating living shorelines, but these reports seldom include long-term monitoring data that evaluates the various techniques. A 2016 literature review describes peer-reviewed research findings that address current living shoreline techniques and benefits. While these were predominately southern projects, options are described that could be applicable along the New Jersey coast (O'Donnell 2016). This is the only review of living shorelines identified in a Web of Science search.

Restore America's Estuaries (RAE) notes that Federal and state permitting of hardened shoreline stabilization structures generally does not adequately consider the state of current science about the cumulative, long-term negative impacts of these structures and the relative benefits of softer

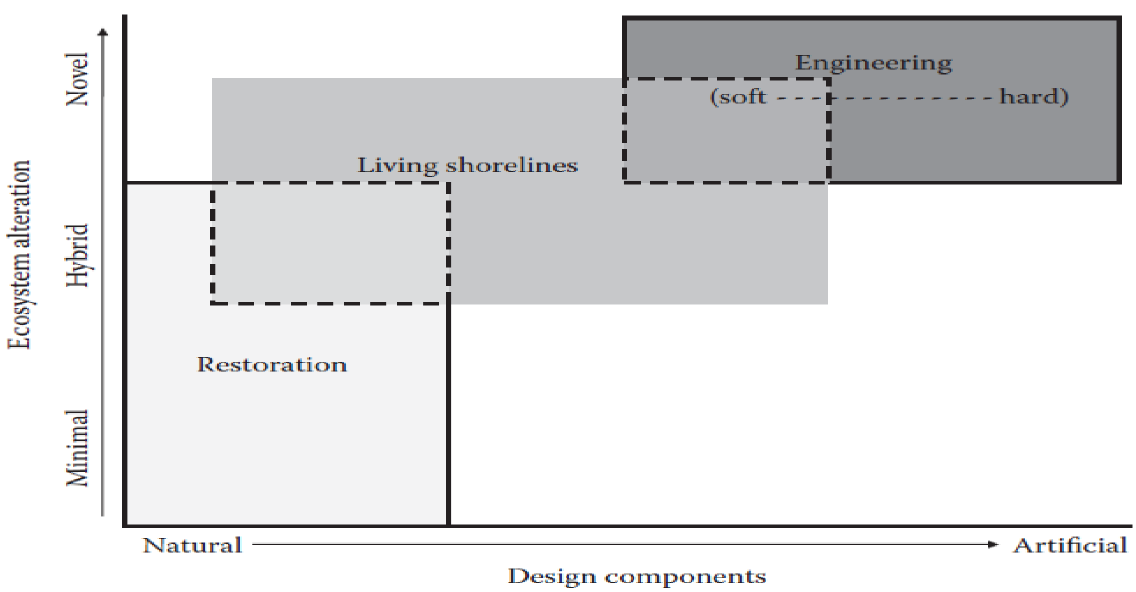


Fig. 9. Project goals for Living Shorelines may differ or overlap with marsh restoration goals. *Image courtesy of Toft et al. (2017).*

structures (Restore America's Estuaries 2015). A living shoreline is site specific and must take into account how the local ecosystem will impact and be impacted by proposed stabilization methods, making the permitting of these projects more complicated. RAE recommends regulatory changes that include reduction in traditional “cookie cutter” solutions, and a program that coordinates Federal, State, and local regulations to evaluate impacts beyond the project site.

New Jersey Living Shoreline Projects

The states with the most mature living shoreline programs include Maryland (first to use the term “living shoreline” in 1981), Virginia, and North Carolina. Numerous projects have been completed in Chesapeake Bay and the Gulf of Mexico. Virginia Institute of Marine Sciences (VIMS) Center for Coastal Resources developed digital tools to determine site appropriateness for a living shoreline installation. The VIMS Management Shoreline Assessment Mapper (http://139.70.26.131:8008/ShorelineAssessmentMapper/) provides assistance in evaluating living shoreline options. It considers data on bank conditions, existing structures, marine resources, and bathymetric contours. The online data can pre-evaluate a site, but a site visit is necessary to confirm parameters needed for project design. An appropriate design (and cost) will depend on local wind and wave energies, erosion rates, and water depths.

Living shoreline rules in New Jersey were adopted in 2013. In 2015 NJDEP and Stevens Institute of Technology released Living Shorelines Engineering Guidelines (Miller et al. 2015), which was developed for engineers, regulators and property owners, and describes the design, permitting, and construction of living shorelines based on current data. Design considerations include site erosion history, tidal range, and SLR. Ecological, hydrodynamic, and terrestrial parameters are also considered. Based on site specific conditions, appropriate options are recommended. Assessment tools include a NJ interactive website, that suggests options for municipalities based on local factors (https://maps.coastalresilience.org/newjersey). The Waterfront Alliance in NYC has recently launched Waterfront Edge Design Guidelines (WEDG®) modeled on the LEED® green building program and provides a certification system for improving coastal resilience and ecology in urban ecosystems based on earned credits (Waterfront Edge Design Guidelines 2019).

Descriptions and locations of NJDEP-permitted living shoreline projects are available (*https://www.arcgis.com/apps/MapJournal/index.html?appid=049f4937cbdd437bb496a7aea94acd35*). These projects are relatively small, although the Spring Lake pilot project is connected to a larger planned installation (Table 8). The monitoring time frame for these installations is only 1-2 years, much shorter than the timeframe commonly used to determine the trajectory of marsh restoration projects. The most extensive living shoreline research and data collection in New Jersey, led by the Partnership for the Delaware Estuary (PDE), is taking place in Delaware Bay. PDE launched the Delaware Estuary Living Shoreline Initiative (DELSI) in partnership with Rutgers University. The DELSI (Fig 10) includes the use of ribbed mussels, coir logs, bagged oysters, and *Spartina alterniflora* (cord grass) to mimic natural features in low energy areas. Long-term monitoring data has contributed to understanding the success and challenges related to Delaware Bay installations. Conclusions drawn include the finding that, by themselves, coir fiber mats were ineffective in protecting coir logs and shell bags in this location. Oyster shell bags in front of the coir logs increased coir log stability.

TABLE 8. NJDEP Highlighted NJDEP Living Shoreline Projects
https://www.state.nj.us/dep/opi/living-shorelines.html

Location	Goals	Project	Value	Monitoring/ Assoc. Projects
Atlantic City	Habitat creation/ enhancement Shoreline stabilization Flood mitigation Public education	Stone wall 10’ x 90’ and upland wall 8’ x 35’ Fill & plantings to create low & high marsh and vegetated embankment	Provide protection for 10-acre commercial center and park	1 Year post-implementation No associated projects
Brigantine	Habitat creation/ enhancement Shoreline stabilization Stormwater management	4 dead end streets – shoreline stabilization 5500 ft^2, 5500 ft^2, 8800 ft^2, 4500 ft^2	Fill in gaps in bulk-headed shorelines	1 Year post-implementation Coordinates with ordinance requiring bulkheads designed to Elevation Nine
Secaucus	Habitat creation/ enhancement Shoreline stabilization Stormwater management Tidal flood mitigation	Restore 3 tidal drainage ditches by clearing debris, inappropriate vegetation and soils to restore proper flow levels	Improve runoff water quality and enhance stormwater management systems	1 Year post-implementation Dredging of dock areas and restoration of the Public Safety Marina
Spring Lake	Habitat creation/ enhancement Shoreline stabilization Stormwater management Tidal flood mitigation Public education	Create 900’ of low and high marsh shoreline and vegetated embankment along Wreck Pond shoreline Site - currently mowed turf	Pilot project for design and implementation of living shorelines for remainder of pond perimeter	1 Year post-Implementation New outfall structure and living shorelines for remainder of the perimeter of Wreck Pond
Upper Township	Habitat creation/ enhancement Tidal flood mitigation Public education	Project area <1 acre below mean high water east and west of public boat ramp to enhance marine habitat for crabs, ribbed mussels, sessile organisms	Removal of debris and creating new vegetated habitat for species	2 years post-Implementation Reconstruction and improvement of boat ramp

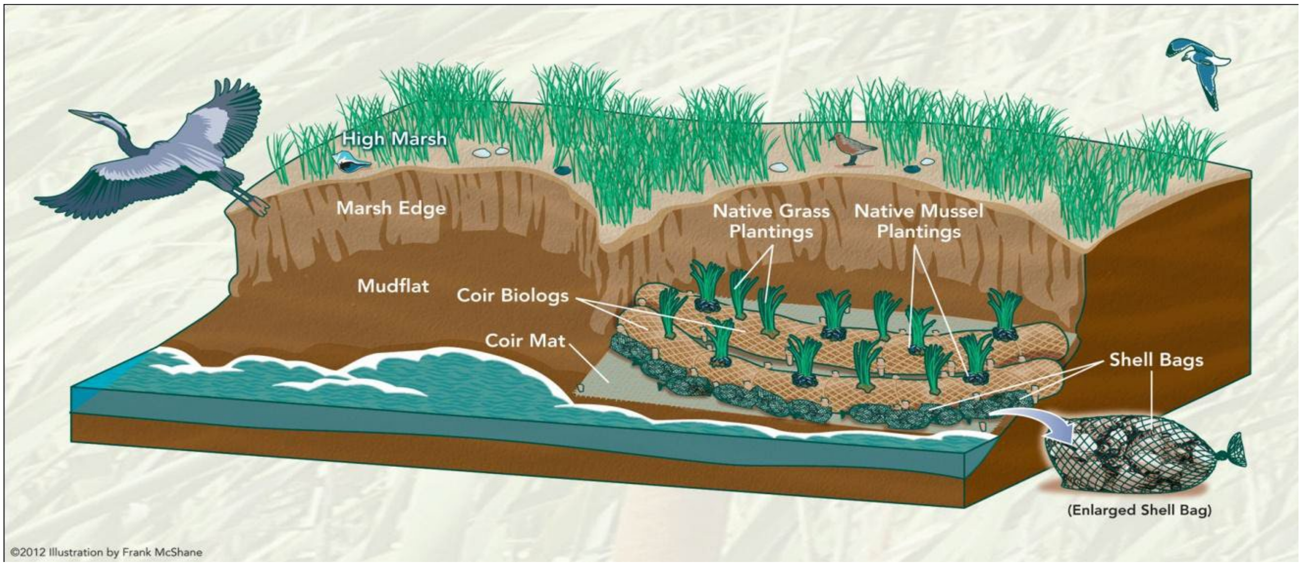


Fig. 10. Project goals for Living Shorelines may complement marsh restoration goals. *Image courtesy of Partnership for the Delaware Estuary. 2013.*

Coir logs were most successful when they spanned eroding areas of 50-100 feet of shoreline (Figure 11). The planting of mussel seed and plant plugs in the early spring, accelerated marsh establishment. Marsh clumps from eroded banks were an effective backfill adding local plants and mussels. The faster that sediment filled in behind the treatments the better the chances for success. To achieve the optimal sediment elevation to support native vegetation, backfilling should be employed if the natural sediment supply is low and marsh accretion too slow.

Fig. 11. Living shoreline installation in Delaware Bay, NJ. Initial installation (left panel) stabilized by coir logs and rock sill (middle panel) leading to subsequent revegetation with *Spartina alternaflora* (cord grass) (right panel). *Image courtesy of Living Shorelines in the Delaware Estuary 2012.*

Fig. 12. Example of marsh creation with coir log toe protection. *Image courtesy of Living Shorelines in New England: State of the Practice. 2017.*

Living Shoreline Approaches Potentially Supporting Saltmarsh Resiliency

In addition to creating new saltmarsh acreage, elements utilized in living shoreline installations should be evaluated to determine their potential to stabilize saltmarshes and support marsh accretion. NY-NJ Baykeeper has been working in Raritan Bay since 2016. At Naval Weapons Station Earle (NWSE) they have installed 600 oyster castles set with oyster spat at the mouth of Ware Creek, where the *Spartina* marsh is eroding. The objective is to measure oyster castle effectiveness in reducing erosive forces currently destroying a remnant salt marsh. Using sediment traps, the rate of deposition is being monitored on the shoreward side of the installation. Shoreline monitoring and sediment deposition data collection continues in 2020 (*personal communication,* M. Comi, NY-NJ Oyster Program Director).



Fig. 13. Oyster spat set on concrete Reef Ball (left panel); oyster spat set on concrete Oyster Castle® and marine fouling organisms (middle panel); Oyster Castles® can be connected to create multiple widths and heights depending on site needs (right panel). *Images courtesy of Dr. B. Ravit.*

Coir Logs, Toe Revetments, Marsh Sills

Where marsh is being lost to erosive forces, the installation of coir logs, toe revetments, or marsh sills should be considered. These are approaches used to stabilize living shorelines that may be effective in reducing the erosion of current marsh edges and surfaces (Figure 12).

Oyster Castles, ReefBalls®

Subtidal installation of Oyster Castles® or Reef Balls (Fig.13) could reduce tidal energies that contribute to erosion. This type of "Living Breakwater" has been used in Gandy's Beach New Jersey by the Nature Conservancy. In 2015, 3,000 feet of oyster castles and coir logs were installed at the site in the Delaware Bay to protect eroding habitat. Preliminary studies suggested that the breakwaters reduced wave height by 50% (Conrad and Katkowski 2017). These methods have also been proposed for the federally funded ReBuild by Design project scheduled for installation on the Staten Island, NY shoreline of Raritan Bay.

Large Woody Debris
The Louisiana Department of Natural Resources installed woody debris in the form of Christmas Tree Erosion-Control Sediment Capture Fences in 1991. Factors determining the effectiveness of this approach included the shoreline configuration, energy regime, sediment supply, water depths, and bottom sediment type (Steller 1992). Approximately 80,000 trees were placed in 7,000 meters of fence to slow shoreline erosion and increase sediment accretion. In low energy locations the trees were simply tied to a network of stakes. In moderate and high energy locations the trees were enclosed in wire cages held in place by posts. These "fences" were oriented to the direction of the prevailing winds and tides to trap sediments. Feldspar marker horizons measured sediment accretion. Installations in shallow water (less than 1 m) low energy locations accreted the most sediment.
A test of a Christmas tree Living Shoreline is now in progress (2019) in Point Pleasant, NJ. The shoreline of the 13-acre tidal wetland and swamp has eroded 300 feet since 1930 and all low marsh has been lost. The American Littoral Society oversaw installation of 300 wooden pilings (Fig.14) that hold the discarded Christmas trees that will form a living breakwater (https://www.littoralsociety.org/blog/recycled-christmas-trees-will-help-restore-local-shoreline.)


Fig. 14. Installation of wooden pilings to hold recycled Christmas trees. *Image courtesy of American Littoral Society.*

Floating Wetlands
Floating wetlands are being tested as shoreline protection devices. Depending on local site characteristics, these structures could contribute to wave attenuation and act as a sediment buffer to support re-establishment of coastal vegetation. Mechanisms to anchor a floating wetland are designed based on specific site energy and water flow conditions. Native marsh plantings can provide habitat benefits such as water filtration and flood resistant platforms for marsh nesting birds like the salt marsh sparrow. The marsh mats are supported by a fiber matrix woven from recycled plastic bottles. However, as with other living shorelines, long-term data are needed to quantify the effectiveness of floating wetlands.

Urban Living Shorelines
Urban waterfronts face different challenges than their suburban and rural counterparts. Urban considerations include contaminant mobility and stabilization, water quality improvements. In 2018 the USACE issued a document titled *"Engineering with Nature"* (Bridges et al. 2018) which describes projects that align natural and engineering processes to sustainably achieve economic, environmental, and social goals. Projects include living shoreline installations, both in the U.S. and Europe. However, there is a lack of data on installation or success of living shorelines under urban conditions.

Recommendations
Living shoreline methods do not yet have a long track record of proven effectiveness in New Jersey. Effectiveness of living shorelines to attenuate wave energy vary under different tidal and

bathymetric conditions, even within a project area, and so post-installation data collection is needed. Zhu et al. (2020) demonstrated an oyster castle installation could increase erosive energies depending on tidal heights and bottom conditions, inadvertently having a negative effect on marsh sustainability. Living shoreline installations need to be adaptively managed and possibly augmented frequently. Therefore, long-term monitoring is recommended for all projects (*Living Shorelines in the Delaware Estuary: 2008-2012)*. Guidance on what to monitor based on project goas was developed in 2016 by a panel of wetland practitioners and scientists in New Jersey (A Framework for Developing Monitoring Plans for Coastal Wetland Restoration and Living Shoreline Projects in New Jersey; (https://www.conservationgateway.org/ConservationPractices/Marine/crr/library/Documents/Framework-Coastal-Wetland-Shoreline-Projects-New-Jersey.pdf).

Based on their research, Toft et al. (2017) have synthesized lessons learned, long-term perspectives and future needs (Table 9).
It is very important for all project partners (practitioners, regulators, funders) agree on project goals (Living Shorelines in New England: State of the Practice. 2017). Project requirements are not always intuitive and may be constrained by existing regulations, policies, and management goals of different agencies. Critical questions to be considered include:

- What candidate sites and tactics exist to address the project's goals?
- What data exist to characterize conditions at prospective sites (energy, distance to opposite bank [fetch], slope, vegetation, soil type, soil firmness, boating activity)?
- Which types of living shorelines would be successful at the site (soft, hard or hybrid)?
- If the installation is successful, how many acres of tidal wetlands would be protected by the installation?
- Is there a time of year for installation to minimize risks or maximize biological stability?
- Are there potential downsides or habitat tradeoff issues to address?
- Standard monitoring protocols and monitoring time period needed to assess trajectory?

Vertical structure can be placed where the accretion area begins to try to reduce water action against the marsh edge, allowing sediment to drop out and build up behind the breakwater. Living breakwaters can be built of different of materials depending upon project objectives and cost. It can be hard, like concrete reef balls or rock piles, or softer such as oyster bags. The major difference is in longevity. Soil could potentially be used, but it would be a short-term, as waves and storms would scour the soil. That would be beneficial if the soil were pushed onto the marsh, but its ability to elevate the marsh depends on where it ended up.

While there is recent research on living breakwaters, there are not many examples of it being used in New Jersey. At the Cape May NWS Supawna Meadows unit, the USFWS developed a living breakwater in 2018 by manipulating the elevations of a historic breakwater constructed as part of salt marsh hay farming in the early 1900's Fig. 15). While the construction project was successful in terms meeting objectives, we could not find data as to the effects of the project at this time.

TABLE 9. Living Shorelines Lessons Learned (Toft et al. 2017).

Focal Area	Top 3 Perspectives
Lessons learned	Understanding the environmental setting helps fit project design to local conditions (e.g., wave energy, sediment processes, tidal regime, predator and competitor habitat suitability). Develop interdisciplinary approaches to encourage project success by collaborating with managers, engineers, and landowners. Natural components (oyster reefs, fringing marshes, sediment nourishment) be considered **first** over artificial components such as stone sills.
Longevity and stability	Coastal squeeze will have higher impact on small projects that may not have space and ability to adapt to climate change; small projects proven to be effective in the short term. Potential for landward migration or tidal elevation shift of vegetation will facilitate adaptation. Natural components (oyster reefs, marsh vegetation) have ability to expand and become self-sustaining and responsive to sea level rise. Engineered components may need maintenance. Living shorelines resilient to wind and waves but may not be at spatial scale to address storm surge even though that is a prime consideration.
Path forward	Broad perspective and adaptive management strategies at multiple scales Long-term quantitative monitoring of living shoreline projects Improve the process for permitting living shorelines to encourage nature based approaches

REGULATORY REQUIREMENTS

In evaluating the environmental impacts of measures to address SLR in coastal marshes the regulatory context is important. To implement activities, authorization is required via the issuance of permits from USACE and NJDEP regulatory entities. Restoration practitioners have noted that regulatory hurdles are a major difficulty in implementing coastal resiliency options (NRC 2007; Restore America's Estuaries 2015; Pace & Morgan 2017; Rella et al. 2017).

The Federal government and the State of New Jersey regulate environmental impacts via conditions in permits. Policy must both protect natural resources that could be impacted by resiliency actions, while being translatable into requirements that the regulated community can understand and meet. These permitting systems were established over decades to prevent destruction of coastal wetland resources caused by inappropriate development (e.g., fill) activities. Resiliency/restoration activities, occurring in sensitive environments protected by Federal and State regulations, are also governed under these regulations because projects do have the

potential to cause a short-term disruption. The permits most relevant to these actions are:

Federal Permits

At the Federal level, potential impacts to coastal marshes are permitted under Section 404 of the Clean Water Act, which regulates the discharge of dredged material or fill into Waters of the United States, including wetlands. Activities related to placement of dredged material or fill into coastal marshes fall under the jurisdictional authority of the USACE. In New Jersey both the USACE and the State of New Jersey permitting requirements must be met, although the USACE would be the lead Federal Agency and the NJDEP being the lead State agency. New Jersey is also responsible for the issuance of the Water Quality Certificate, issued as part of New Jersey's permit. The USACE permit will not be valid until the Water Quality Certificate is issued by New Jersey. USACE has jurisdiction over all construction activities in tidal and/or navigable waters, including adjacent wetlands, shoreward to the mean high-water line. New Jersey has jurisdiction under the N.J.A.C. 7:7, Coastal Zone Management Rules, N.J.A.C. 7:7A, Freshwater Wetlands Protection Act Rules, and N.J.A.C. 7:13, Flood Hazard Area Control Act Rules. The northern part of the state is governed by the New York District office (e.g. NY/NJ Harbor area, including Raritan Bay, Raritan River, the Hackensack and Passaic Rivers and their watersheds, Newark Bay, Arthur Kill, etc.), while the southern marshes are regulated by the Philadelphia District office (Delaware River, coastal areas of southern NJ).

From a regulatory standpoint, different activities proposed to address SLR may have different permit requirements. For TLP, an Individual permit is required to place dredged material or fill in a wetland, and requires evaluation of individual, project-specific applications. After an application is received, a USACE project manager prepares a public notice, evaluates the impacts of the project and all comments received, negotiates necessary modifications of the project, and prepares documentation to support a recommended permit decision. The permit decision is based on the public interest review and, where applicable, a Section 404(b)(1) of the Clean Water Act guidelines analysis or an analysis of ocean dumping criteria. The public interest review involves analysis and evaluation of benefits and detriments of foreseeable impacts of project on public interest factors, such as navigation, general environmental concerns, wetlands, economics, fish and wildlife values, land use, floodplain values, and the needs and welfare of the people. No permit is authorized if the proposed project is found to be contrary to the public interest.

The permit decision includes a discussion of environmental impacts of the project, the findings of the public interest review, and any special evaluation required by the type of activity, such as determining compliance with the Section 404(b)(1) guidelines or ocean dumping. If the proposed work involves discharges of dredged or fill material into waters of the United States, no permit is authorized if the activity is found to be contrary to the Section 404(b)(1) guidelines. A fundamental principle of these guidelines is that dredged or fill material should not be discharged into wetlands and other waters, unless the discharge will not have unacceptable adverse impacts on those waters. The Section 404(b)(1) guidelines require the following determinations: (1) the project is the least environmentally damaging practicable alternative; (2) the project will not cause or contribute to the violation of applicable state or Federal laws, such as water quality standards or the Endangered Species Act; (3) the project will not result in significant degradation of waters of the United States; and (4) any appropriate and practicable steps have been taken to minimize the adverse impacts of the project on wetlands and other waters.

For Living Shoreline activities, a Nationwide Permit is likely to be the permitting mechanism. This is a Permit that authorizes activities on a nationwide basis, unless specifically limited through regional conditions or revoked by division or district engineers. Division engineers can add regional conditions to restrict their use to ensure activities result in minimal adverse environmental effects. Nationwide Permit 54 (Living Shorelines) allows for the construction and maintenance of living shorelines for shoreline stabilization in coastal waters. Among other conditions, a project must be primarily composed of natural, soft structures and should maintain the natural continuity of the land-water interface. Nationwide Permit 27 (Aquatic Habitat Restoration, Enhancement, and Establishment Activities) allows activities in waters of the United States associated with restoration, enhancement, and establishment of tidal and non-tidal wetlands and riparian areas, and the rehabilitation or enhancement of tidal streams, wetlands, and tidal open waters, provided the activities result in net increases in aquatic resource functions and services.
Activities that require USACE permits may also require permits or approvals from other Federal, Tribal, state, or local agencies, such as in New Jersey, where State permit are required. Some of the more prominent Federal interactions are associated with the following regulatory requirements.

Coastal Zone Management Consistency Determination
Section 307(c)(1) of the Coastal Zone Management Act (CZMA) requires the USACE to provide States the opportunity to conduct a consistency determination and determine if the issuance or expansion of activities authorized by a Nationwide Permit are consistent with the State's approved Coastal Management Program. This agreement is required when activities will affect land or water uses or natural resources of the state's coastal zone. New Jersey has an approved Coastal Zone Management Program.

Endangered Species- Section 7 of the Endangered Species Act (ESA)
No activity is authorized by any Nationwide Permit that is likely to jeopardize the continued existence of a listed, or proposed for listing, threatened or endangered species or to destroy or adversely modify its critical habitat under. Permittees must notify the USACE if any Federally listed (or proposed for listing) endangered or threatened species or critical habitat might be affected or is in the vicinity of the project. From a regulatory perspective this is interesting because New Jersey has its own list of threatened and endangered species, which USACE is not obligated to consider. The focus of the federal permit is exclusively on federally listed species.

Magnuson Stevens Fishery Conservation and Management Act (MSA)
The NOAA National Marine Fisheries Service (NMFS) under the MSA requires federal agencies such as the USACE to consult with NMFS on projects that may adversely affect Essential Fish Habitat (EFH). Any proposed activity (for which a Nationwide permit is being applied) proposed within 50 feet of submerged aquatic vegetation (SAV) beds, mapped SAV habitat and/or within sandbar shark (*Carcharhinidae plumbeus*) Habitat Areas of Particular Concern (HAPC) depicted by the Essential Fish Habitat Mapper must file a pre-construction notification.

- Federal Acts permit requirements:
    - The Federal Water Pollution Control Act (Clean Water Act; 33 U.S.C. 1251 *et seq.*).
    - The Rivers and Harbors Act of 1899 (33 U.S.C. 407).
    - The Endangered Species Act of 1973 (ESA; 16 U.S.C. 1531-1544).
    - The National Wildlife System Improvement Act of 1997 (Public Law 105-57).
    - The Migratory Bird Treaty Act of 1918 (MBTA) (16 U.S.C. 703–712).
    - The Bald and Golden Eagle Protection Act (BGEPA) (16 U.S.C. 668-668c).
    - NEPA (83 Stat. 852; 42 U.S.C. 4321 *et seq*.) and the CEQ's NEPA regulations 40 CFR, Parts 1500-1508).
        - Tribal consultation in accordance with both Section 106 NHPA and Section 40 CFR 1501.2(d)(2) of the CEQ's NEPA regulations.
    - The Coastal Zone Management Act of 1972 (16 U.S.C. 1451-1466)
    - National Historic Preservation Act of 1966 (NHPA; 16 U.S.C. 470).
        - If archeological relics or sites are discovered during a project, actions will be taken to be consistent and compliant with additional Federal laws:
            - The Antiquities Act of 1906 (16 U.S.C. 433).
            - The Archeological Resources Protection Act of 1979 (16 U.S.C. 470aa-47011).
            - The Archeological and Historic Preservation Act of 1960 (16 U.S.C. 469-469C).
            - The Historic Sites, Buildings and Antiquities Act of 1935 (Historic Sites Act) (16 U.S.C. 461-462, 464-467).

State of New Jersey Permits

The State of New Jersey regulates coastal wetlands through a permit program administered by NJDEP. In order to conduct a regulated activity within coastal wetlands the project must obtain a permit, issued pursuant to the Coastal Zone Management Rules (N.J.A.C. 7:7), from the Department. The Department must consider the effect of the proposed activity on public health and welfare, marine fisheries, shellfisheries, wildlife, the protection of life and property from flood, hurricane and other natural disasters, and the public policy of the Wetlands Act of 1970. For both TLP and Living Shoreline projects, the NJDEP has General Permit 24 that allows activities within coastal wetlands for the purposes of habitat creation, restoration, enhancement, and Living Shoreline activities. This General Permit authorizes habitat creation, restoration, enhancement, and living shoreline activities necessary to implement a plan for the restoration, creation, enhancement, or protection of the habitat, water quality functions, and values of wetlands, wetland buffers, and open water areas.

- State level:
    - Waterfront Development Act (New Jersey Statutes Annotated (N.J.S.A.) 12:5-3).
    - Wetlands Act of 1970 (N.J.S.A. 13:9A).
    - Tidelands Act (N.J.S.A. 12:3).
    - Coastal Area Facility Review Act (CAFRA) (N.J.S.A. 13:19).
    - Surface Water Quality Standards (SWQS) (New Jersey Administrative Code (N.J.A.C.) 7:9B).

- The New Jersey Flood Hazard Area Control Act (N.J.S.A. 58:16A-50 *et seq*.) and its implementing rules (N.J.A.C. 7:13).
- Coastal Zone Management Rules (N.J.A.C. 7:7)

Regulatory Issues

Historic coastal protection emphasized prevention of fill activities and engineering (bulkhead, seawall, armored protection) solutions, so these activities have a long history of meeting regulatory permit requirements. Because green infrastructure (TLP, Living Shorelines) options are site-specific and may involve fill, the designs require much more pre-construction activity and data collection that can add significant additional costs to the projects. As the description of various entities involved in approving permits illustrates, the amount of baseline detail needed to complete a green infrastructure permit application could be daunting. Frequently cited issues encountered in the permitting process include coordination of Federal, State, and if applicable, local permit requirements (Pace & Morgan 2017). Although the recently approved USACE Nationwide Permit indicates a new approach at the national level (Pace & Morgan 2017), coordinating the multiple Federal and State regulations can be challenging. In addition, restrictions on when work can be completed may be stated in the permit to protect state and federal regulated species. For some TLP projects, this may leave only a few months in the late fall and early winter when a project can be constructed.

In 2015 New Jersey amended General Permit 24 to authorize Living Shorelines designed to protect, restore, or enhance habitat at N.J.A.C. 7:7-6.24. There are specific criteria that must be satisfied, including improving local ecosystem functions and values, disturbing a minimum amount of NJDEP-defined special areas, and a project limit in size of 1 acre or less, unless the applicant is a federal or state agency that can demonstrate the need for a larger project (Rella et al. 2017). Due to the relatively low number of such projects, there is a lack of New Jersey data on the success or effectiveness of these approaches, making it challenging for agencies to determine permit requirements protective of the environment at the project site and adjacent areas, as well as the difficulty in determining monitoring requirements and timeframes. New Jersey regulators also have the challenge of coordinating with two different USACE District offices, which may have different criteria for approving projects in southern versus northern New Jersey.

SUMMARY AND CONCLUSIONS

Status of NJ Coastal Marshes

Horizontal losses

Meadowlands: Although SLR is undoubtedly affecting the Meadowlands' marshes, estimating losses is difficult due to ongoing development pressures that continue to reduce wetland acreage and ongoing restoration efforts which have resulted in slightly increased wetland acreage.
Raritan Bay: Evidence suggests that Raritan Bay marshes are not losing acreage.
Barnegat Bay: Wetland change analysis suggests that 11.9% of the tidal wetlands were lost between 1972 and 2012. A higher resolution analysis completed for three focus marshes in Barnegat Bay totalled 1094 hectares, a loss rate of 9.7% from 1975 -2015.
Delaware Bay: Marsh loss rates in the Delaware Bay are between 1.1-1.9% per decade, considerably less than Barnegat Bay. This low rate is largely due to marsh area being gained through migration upland into low-lying maritime forests.

Elevation Changes

Meadowlands: SETs placed at five *Spartina* marshes found net elevation increases of 3.03-5.0 mm per year. SETs placed in two *Phragmites*-dominated marshes for net elevation increases of 8.17 and 11.75 mm per year. Given the estimated current SLR of 5-6 mm per year, only the latter marshes are keeping up.
Raritan Bay: Accretion has been measured for only one and one-half years, so data are not necessarily reliable, but all of the twelve marsh sites (*Spartina* and *Phragmites*) show net subsidence rather than increase in elevation during this short time.
Barnegat Bay: Nine SET sites showed net elevation increases of -1.96 to 5.77 mm per year, with two sites increasing at a rate of over 5 mm/yr. Many marshes studied by USFWS did not include subsidence information and are not considered reliable.
Delaware Bay: Twelve SET sites showed net elevation increases between 1.16 - 6.89 mm per year, with five sites accreting at rates greater than 5 mm per year.

Potential Remedies

Migration Pathways

In developed areas, the problem of "coastal squeeze," may be mitigated by developing and maintaining pathways and open areas for the marsh to migrate into. Wetlands migration pathways are areas that could convert to wetlands. Creating pathways generally involves local governments working with landowners, using instruments such as rolling easements. Issues that can be encountered are unfamiliarity with potential pathways, connecting scientific findings to policy and practice, insufficient budget, lack of coordination on land acquisition, lack of guidance on managing lands for coastal habitat advancement, and uncertainty about when and how marshes can move upslope. At the state level, the role of NJDEP could be working with local governments to provide information about and encouragement to embark on efforts to create migration pathways.

Phragmites management

The invasive common reed, *Phragmites australis,* has been shown to perform many important ecosystem services; the most important for this report is that it can enable marshes to increase their elevation more rapidly than native plant communities. Indeed, in this report the marshes that were increasing their elevation at the greatest rates were two *Phragmites* marshes in the

Meadowlands. Nevertheless, projects around the state continue to remove the plants. Management could be modified to leave some *Phragmites* in place to better enable a marsh to keep up with SLR, for example excavation of large shallow pools within *Phragmites* stands.

Sediment Manipulation

Physical methods for manipulating sediments in marshes are being studied to increase resiliency to SLR. These techniques aim to modify the relationship between the marsh surface and the level of tidal flow over the marsh. In one widely studied technique, dredged material (rock, gravel, sand, consolidated clay, silt, clay, or mixtures) is placed on the marsh floor to elevate its height. This technique, thin-layer placement, has been proven to be a valuable tool for creating, restoring and maintaining coastal marshes. Sediments can also be piled at the edge of a marsh where currents can move them onto the marsh; accretion begins as sediments build up on the marsh. Another technique, the installation of runnels across the marsh floor facilitates drainage from ponded areas and pannes. Runnels provide a way to drain water off the marsh and can mimic the natural tidal flux and restore the natural hydrologic cycle.

Living Shorelines

Living shorelines can reduce erosion at the edge and preserve the horizontal extent of the marsh, potentially increasing New Jersey's salt marsh inventory. Options include adding material to restore vegetated marsh surfaces or enhance sedimentation, marsh toe protection, placement of large woody debris, floating wetlands, or islands that dampen wave or storm surge energies. Living breakwaters, offshore rock, concrete, or shell bag structures that provide habitat to shellfish and finfish, can decrease wave energy and increase the rate of sediment retention, and thereby combat effects of SLR. Challenges to implementation include site specificity, the lack of data on effectiveness, and obstacles in permitting projects. Regulatory decisions must consider local impacts of these installations, making the permitting of these projects complicated. Design and cost depend on wind and wave energies, erosion rates, and water depths. Digital tools to determine appropriateness for a living shoreline have been developed. Installations in New Jersey are relatively new, and projects are small. The most extensive project is in Delaware Bay. Other initiatives include oyster castles (Raritan Bay, Delaware Bay), coir logs and toe revetments (Delaware Bay), large woody debris (Pt. Pleasant), and living breakwaters (Cape May). NJDEP and Stevens Institute of Technology released Living Shorelines Engineering Guidelines, which describes design, permitting, and construction of living shorelines. Living shoreline installations need to be adaptively managed and possibly augmented frequently, requiring long-term monitoring.

Regulatory Context

Activities to increase resiliency in the face of rising sea levels can benefit coastal marshes. In evaluating environmental impacts of physical measures to address SLR in marsh systems the regulatory context is important. To implement activities in regulated environments, authorization to proceed requires issuance of permits from USACE and NJDEP. Restoration practitioners have noted that overcoming regulatory hurdles is a significant difficulty in implementing coastal resiliency options. NJDEP is currently undertaking a comprehensive review to address climate change within the regulations. Specifically, the New Jersey Protecting Against Climate Change (NJPACT) will usher in systemic change, modernizing air quality and environmental land use regulations, that will enable governments, businesses and residents to effectively respond to current climate threats and reduce future climate damages.

Any projects undertaken should have ongoing monitoring and adaptive management to see if they are accomplishing their objectives and not causing some unintended consequences.

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Appendix Recommended Potential Locations for Migration Pathways

The marshes in the around Delaware Bay have considerably more open space upland than marshes in the more developed northern part of the state. As much as 75% of earlier wetland loss in Delaware has been compensated by increases in new wetland area (Smith 2013, Watson 2019), much of which is *Phragmites australis*. In Barnegat Bay. *Phragmites* occupies the ecotone between salt marsh and forest and expands from this edge into forest dieback areas. Wetlands associated with barrier islands have little room to move because of development (Lathrop and Love 2007). In the more developed Raritan Bay, developing migration pathways is more urgent. Fig. 1 shows potential migration pathways and areas likely to become open water. Potential locations around Raritan Bay Identified by Blair Environ. Consulting (2018):

The South River and Lower Raritan Watershed
Neighborhood buyouts following storms in Woodbridge and Sayreville resulted in acquisition of hundreds of residences that were razed and returned to open space. Some may be suitable for wetland pathway protection. However, formerly industrial or contaminated sites complicate the situation. Contamination should be cleaned up before the site is submerged.
There are planning, stewardship, scientific, and education and outreach activities in the municipalities and counties, state and federal partners, universities, and non-profits, who are working together. These include NOAA training about green infrastructure for coastal resilience hosted by the Lower Raritan Watershed Partnership (LRWP), as well as mapping, monitoring, scientific, and stewardship activities for the Raritan River watershed, including floodplain designs developed for buyout lands. Pathway design could be linked to Middlesex County's master planning process, state and local planning for emergency response, and floodplain management activities that help qualify communities for discounted flood insurance rates under FEMA's National Flood Insurance Community Rating System.

Keyport is on Raritan Bay about three miles from Cheesequake State Park. It participated with the Monmouth County Office of Emergency Management in the 2009 Multi-jurisdictional Natural Hazard Mitigation Plan (HMP) and its 2014 update (Roberts et al. 2014). Low-lying areas are vulnerable to tidal surge, flooding, wave action, and winds which produced unprecedented damage during Sandy. The 2014 HMP update listed land use and development trends and pressures, including continued residential development 50 yards from waterfront, condominium units along a creek, and development pressure for approvals for waterfront multi-family units. The report stated that the jurisdiction continues to regulate development by application and enforcement of CAFRA (NJ Coastal Area Facility Review Act) regulations and floodplain management best practices along Raritan Bay and creeks. There are additional opportunities in areas adjacent to the nearby Cheesequake Park.

The Hackensack Meadowlands: The Meadowlands Environmental Research Institute (MERI) collected detailed hydrology and elevation data for wetland sites that exist amidst industrial sites, residential areas, and legacy landfills. Based on this, Francisco Artigas, Director of MERI, concluded the Meadowlands has few, if any, opportunities for wetland migration.
Schechtman and Brady (2013) evaluated resilience and policies in other NJ communities.

Little Silver has a Coastal Wetlands Ordinance, which prevented development on vulnerable coastal wetlands that are protective barriers for storm surge. Regulated activities include erection of structures, driving pilings, changing tidal flow, constructing dams or water control structures, constructing driveways or roads over tidal wetlands, depositing materials or wastes, and the removal, digging, or dredging of material. The Borough passed a levy for open space and approved an open space plan in 2003, which prioritizes floodplain management. It maintains a wetlands mitigation bank, which restores degraded tidal wetlands and is a protective buffer. The history of the Borough suggests they might be amenable to protecting migration pathways.

Greenwich Township is a low-lying community surrounded by coastal wetlands and Delaware Bay. Coastal hazards threaten agriculture, historic properties, tidal wetlands, and the safety of residents. It is experiencing coastal erosion along the bay, saltwater intrusion, transition from freshwater to salt marshes, and coastal flooding in low-lying areas. Since their marshes protected them from Hurricane Sandy (Schechtman and Brady 2013), they might be amenable to protecting migration pathways to preserve their tidal marshes.

Sea Isle City was the landfall for Hurricane Sandy. It is on a barrier island and is particularly vulnerable to coastal storms. Its comprehensive plan stresses the need to preserve vulnerable land. Goals are to acquire privately owned parcels in flood prone areas and to preserve and acquire open space. It works with NJDEP to secure funding to acquire these lands. Additional funds are available through the Green Acres and Blue Acres programs. This should make it amenable to pathway protection efforts.