Inventory of Cape Cod Salt Marshes with the Best Migration Potential

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1. Summary

This final report categorizes potential salt marsh restoration projects that have the ability to migrate into upland areas as sea levels rise. Sea levels are rising globally because of melting glaciers, ice sheets and the thermal expansion of ocean water that are linked to a warming climate. Sea-level rise is expected to have a significant impact on coastal communities by influencing coastal erosion, coastal wetlands, changes in freshwater hydrology, and changes in habitats that effect birds, fish, and plants.

Some Cape Cod towns are preparing for sea-level rise by drafting coastal resilience plans that aim to build natural infrastructure and artificial structures that mitigate future climate change and allows communities to survive changing coastal conditions. One way towns are preparing for sea-level rise is by building "green infrastructure", which are naturally occurring ecosystems that provide better protection from the impacts of climate change.

Restoring salt marshes is one way to build "green infrastructure" as they provide both human and ecosystem services. Salt marshes provide habitat for wildlife, act as nurseries for valuable commercial fisheries, protect coastal towns from erosion and storm surges, filter pollutants and contaminants from water, and provide organic materials necessary to support coastal food webs. Restoring salt marshes will not only help coastal towns be prepared for natural disasters but also address water quality standards and help commercial fishing concerns.

Salt marshes will be able to survive sea-level rise by being able to grow vertically through the process of peat formation (accretion) and by their ability to migrate into upland areas that have open space. Upland migration will be limited by barriers like roads, houses, invasive species, undersized culverts, and steep elevations adjacent to the marsh. An inventory of salt marshes that need to be tidally restored that have the best potential for migration with limited barriers has not been completed and is important for resource managers to effectively prepare for higher sea levels.

2. Introduction

Salt marshes are valuable coastal wetlands that form transition zones between land and sea. Healthy salt marshes have a high amount of biodiversity, good tidal flow from the ocean needed for proper sedimentation, low amounts of invasive species, and high amounts of primary productivity that help build peat. On Cape Cod, 38% of salt marshes have already

been lost or degraded by human development. Historically, salt marshes were impaired because railroads and roads were built through them which cut off the salt water inundation that is necessary to maintain these ecosystems. Often, undersized culverts were used to allow some tidal flow into marshes; however the resulting insufficient tidal flow often caused upland areas to become dominated by freshwater species. Such tidally-restricted brackish wetlands particularly favor the growth of invasive plants like *Phragmites australis* (Common reed) and *Lythrum salicaria* (Purple loosestrife) that outcompete native salt marsh plants and reduce biodiversity. Salt marshes can be restored by enlarging the undersized culverts to improve tidal flow and help invasive species die back.

Coastal resilience is the ability of a community to "bounce back" after a hazardous event like a hurricane, coastal storm, or severe flooding event. Communities that are informed and prepared for natural disasters will have a greater possibility of rebounding quickly from severe weather events and be able to adapt to sea-level rise. Cape Cod towns are preparing for climate change and sea-level rise by drafting coastal resilience plans in order to survive as coastal communities. Healthy salt marshes provide natural vegetative communities that aide in helping coastal communities adapt to changing coastal conditions by being able to absorb flood waters, diminish wave energy, and reduce storm surges.

Unfortunately, salt marshes are particularly vulnerable to higher and more frequent coastal flooding associated with sea-level rise. As a result, salt marsh plants that are adapted to grow in the middle to high marsh will die back with higher levels of flooding and begin growing closer to upland areas of the marsh. High marsh vegetation composed of *Spartina patens* and *Distichlis spicata* will typically grow between the mean high water (MHW) line and the highest astronomical tide (HAT) line (Nielson et al., 2014). These marsh plants will shift their growing pattern and migrate to survive higher rates of flooding. This type of plant migration often takes place over a longer timeframe than animal migration.

In order for salt marshes to survive sea-level rise, they must be able to migrate into open space and form new salt marsh as older salt marsh becomes flooded. Salt marsh plants will die if sea-level rise occurs faster than marsh accretion and migration rates. High marsh communities near the marsh border are especially vulnerable because they have to cope with natural barriers like changes in salinity, steep gradients, and competition with Phragmites which often grows near the edges of marshes. Also, as more human development occurs near the coastal zone, salt marsh migration is blocked by artificial structures like houses, berms, seawalls, and roads. High marsh vegetation that is not able to migrate upland will also have to compete with native species like *Spartina alterniflora* migrating from the low marsh.

Cape Cod lacks an inventory of salt marshes which have the highest potential to migrate and keep pace with sea-level rise. This inventory is needed to help state government agencies and resource planners prioritize projects that will be most beneficial in preparing for future natural disasters. Most salt marsh restoration projects will also help towns address other resource management needs like restoring fish runs / shell fish beds, reducing nutrients and contaminants, and protecting critical facilities in the face of sea-level rise. Ultimately, the information in this report will be used by resource managers to pro-actively

identify areas adjacent to salt marshes located in low-lying areas that need conservation and identify risks to infrastructures that may be affected by restoration efforts and future sea-level rise scenarios.

3. Goals and Objectives

The program goals are to protect and restore coastal wetlands; protect human health and ecosystem integrity; and encourage resource managers to prepare for sea-level rise.

The program objectives are to: (1) identify and inventory salt marshes to find the best candidates for restoration and protection based on landward migration ability; (2) identify barriers to marsh migration; (3) take into account low-lying properties at 2 feet of sea-level rise; (4) provide information to towns and regional entities to assist in planning for climate change and coastal resiliency planning.

4. Tasks

Task 1. Collect information about priority salt marsh restoration projects that were identified by each town. The initial inventory of potential salt marsh restoration projects was compiled from 2014-2015 by Dr. Jo Ann Muramoto (APCC senior scientist and Mass Bays Program Regional Coordinator for Cape Cod bay) and Rick DeVergilio (Cape Cod Conservation District) during meetings with municipal staff and representatives from each of the 15 towns on Cape Cod. Trish Vosburg (APCC summer intern 2015) compiled additional information for each site using the Cape Cod Atlas of Tidally Restricted Marshes and the Buzzards Bay Atlas of Tidally Restricted Marshes. She helped organize information in the Priority Restoration Projects spreadsheet which summarizes information about storm water sites, fish/shellfish, water quality (i.e., Total Maximum Daily Loads or TMDL status for nutrients and pathogens), and salt marsh restoration projects throughout Cape Cod. This inventory was originally created to help the APCC and the Cape Cod Conservation District update the Cape Cod Water Resources Restoration Project (CCWRRP), but will also be used to identify restoration projects appropriate for the newly formed Cape Cod Restoration Coordination Center (RCC).

The updated information from the spreadsheet will be used to help categorize salt marsh sites that have the potential for migration. A separate marsh migration Excel spreadsheet will be created and will include general information for each salt marsh site including creek name / road, unique identifier, total affected area, fish/shellfish habitat, TMDL status, and approximate mean tidal range. The data from this spreadsheet will be used to help categorize salt marsh restoration projects.

Task 2: Analyze each salt marsh site using the Cape Cod Commission's Sea Level Rise (CCC SLR) viewer. Each salt marsh that was identified as a priority project from town staff members will be analyzed for potential migration. There are other salt marshes listed in the restoration atlases; however, the sites that are analyzed in this report will come from the recommendations from each town. Each recommended salt marsh restoration project will be analyzed using the CCC's SLR viewer to determine the migration potential

at 2 feet, 4 feet, and 6 feet of sea-level rise. Notes about each salt marshes ability to migrate into unimpeded open space and the barriers will also be documented in the marsh migration Excel spreadsheet. Nearby culverts and properties inundated at 2 feet of sea-level rise will be noted as potential barriers in additional columns and used to prioritize each salt marsh restoration project.

Task 3: Categorize each salt marsh as high, medium, or low priority. Each salt marsh will be categorized based on the available open space for potential migration, the number and types of barriers, and the amount of low-lying culverts and houses that will be flooded at 2 feet of sea-level rise. If there is time, a short summary for each salt marsh restoration project will be written.

Task 4: Conduct site visits to evaluate potential restoration projects. Conducting site visits is crucial in evaluating restoration projects that have the potential for marsh migration. Sites will be chosen based on their accessibility, feasibility for restoration, and marsh migration potential using the CCC's SLR viewer. Information to be collected during site visits will include photographing *Phragmites australis*, culverts, barriers, and adjacent open space. Site visits will also help verify information collected from the atlases of tidally restricted marshes, phone interviews, and the CCC's SLR viewer computer models.

Task 5. Recommendations, outreach and reporting. The findings from this report will be used to help identify potential restoration projects and open space that help with coastal resiliency planning. The recommendations at the end of the report will guide further research and planning in inventorying and monitoring salt marsh restoration projects that will benefit town and resource managers in preparing for sea-level rise. It will also be used for public outreach to raise awareness on the need for coastal resiliency planning.

5. Methods

APCC staff have been developing a Cape-wide inventory of potential restoration projects, including potential salt marsh restoration projects. Specific information about each salt marsh was collected and put into a spreadsheet by APCC staff using personal interviews with the Cape Cod Commission and town / state officials, information from the Cape Cod Atlas of Tidally Restricted Salt Marshes (Cape Cod Commission, 2001), and the Atlas of Tidally Restricted Marshes in the Buzzards Bay Watershed (Buzzards Bay Project National Estuary Program, 2002). General information for each salt marsh was compiled into an Excel file.

Using the list of potential salt marsh restoration projects as a springboard, we prioritized 35 salt marsh restoration projects according to their ability to migrate with sea-level rise. As a first step, for each potential salt marsh restoration site, the Cape Cod Commission's SLR viewer was used to determine the extent of sea level flooding. This computer model was created using Digital Elevation Model (DEM) data that was collected from Light Detection and Ranging (LiDAR) in 2011 by the U.S. Geological Survey. The data is accurate to +/-18 cm at a 95% confidence level with 1 meter resolution. This is a static "bathtub" inundation model that shows changes in elevation with regards to sea-level rise but does not account

for changes in hydrology, sedimentation, erosion, productivity of plants, or wave action associated with sea-level rise (Retrieved from http://www.capecodcommission.org/sealevelrise/ on July 27th, 2015). The migration potential for each salt marsh was analyzed using 2 feet, 4 feet, and 6 feet of inundation so that this study coincides with an APCC project being conducted in collaboration with the U.S. Geological Survey to evaluate the effects of sea-level rise on the mid-Cape's groundwater system. Each salt marsh was categorized using the following information collected from the Cape Cod Commission's SLR viewer:

1. The available open space in low-lying areas adjacent to salt marshes that have room to migrate with 2, 4, and 6 feet of sea-level rise.

2. The number and types of barriers (low-lying houses, roads, elevation, and abundance of *Phragmites australis*) that would potentially limit migration.

3. Estimated number of developments flooded at 2 feet of sea-level rise using the CCC SLR viewer.

4. Roads that had culverts which were flooded at 2 feet of sea-level rise. The Cape Cod Commission's SLR viewer used the 2013 Navteq road dataset to determine which roads would be disconnected during each increment in sea-level rise (Retrieved from http://www.capecodcommission.org/sealevelrise/ on August 4, 2015).

Each salt marsh was analyzed separately and categorized as high, medium, and low for migration potential. Salt marshes that had open space to migrate, very few barriers, and less than 5 properties inundated at 2 feet of sea-level rise were categorized as high priority. In this project there was not sufficient time to collaborate with the Cape Cod Commission to quantify the exact area each marsh had for migration potential. As a result, a more qualitative approach was used and each marsh was compared to each other for migration potential. Salt marshes that were categorized as high priority showed continuous migration potential up to 6 feet of sea-level rise. Salt marshes that were categorized as medium priority had relatively less open space for migration, more barriers to migration (roads, developments, or elevation), and/or had culverts and more than 5 housing developments inundated at 2 feet of SLR. Marshes were categorized as low because they had relatively little upland area to migrate and with a significant number of barriers.

Site visits were conducted to three salt marshes to evaluate the possibility of marsh migration potential if they are restored. These sites were chosen because they appeared to have enough open space for long term migration according to the CCC's SLR viewer. The three sites included Little Buttermilk Bay in Bourne, MA (BN-39), Stage Harbor / Chaplain Creek in Chatham, MA (CH-5), and Park Avenue marsh in Yarmouth, MA (YA-6). The site visits were crucial for understanding and evaluating the topography, nearby open space, barriers, and size of culverts. Information about each site included photo documentation of *Phragmites australis*, culverts, barriers, upland plant communities, and areas for potential migration.

6. Results

The ability of a salt marsh to migrate with sea-level rise is dependent on sedimentation rates and the amount of available open space located in the watershed the marsh. An Excel file with specific information related to marsh migration for each salt marsh site was collected using the CCC SLR viewer, interviews, site visits, Google Maps, and Cape Cod atlases of tidally restricted marshes (Table 1). Barriers to marsh migration were identified and documented using the CCC SLR viewer. Most barriers to migration included roads, low-lying developments, and/or changes in elevation. The presence of Phragmites was also noted as a barrier to migration. The number of housing developments that were flooded at 2 feet of inundation were documented and recorded for each salt marsh in the data table. Also, roads that acted as tidal restrictions that were inundated at 2 feet appeared red and were identified because they may need to be re-evaluated for restoration (Figure 1). Figures 2a and 2b compares the inundation models at Mary Chase Salt Marsh, Eastham at the current mean higher high water (MHHW) line with 2 feet of inundation to determine if housing developments, roads, or steep elevation gradients acted as barriers to migration.

At the time this study was done, the CCC's SLR viewer treated roads with culverts as complete barriers to tidal inundation, causing wetlands upgradient of the culvert to often appear as low-lying "green" areas on the map corresponding to areas that may be influenced by flooding (personal communication, Cape Cod Commission staff) (Figure 3). To evaluate the actual extent of area that could be flooded as sea-level rises, I used the topographic maps on the Town of Sandwich GIS website to compare with "green" low-lying areas to determine if there was a relationship between elevation and the CCC SLR viewer designation of "low-lying areas". We chose to compare low-lying areas in the Cow River marsh system (the subject of a restoration feasibility study by the NRCS) and the Stony Brook marsh system for which there is already significant information from the restoration project. Unfortunately, there was not a consistent pattern between the low-lying "green" areas shown on the CCC SLR viewer and contour lines on topographic maps. While the Cow River / Ploughneck Road marsh coincided with the 2-4 feet contour line, inundation at Stony Brook was more closely linked with the 8 foot contour line. More data on the elevation of each culvert will need to be collected and incorporated into the CCC SLR viewer to effectively map tidal inundation levels for salt marshes that appear as "green" low-lying areas on the restricted sides of the marshes.

7. Discussion

The ability of a salt marsh to migrate both vertically and horizontally is determined by many variables including rates of sedimentation, productivity of salt marsh plants, nutrient inputs, sea-level rise rates, available open space, elevation gradients, competition with invasive species, herbivory, and salinity. While outside the scope of this project, vertical accretion rates are important in determining if salt marshes will be able to keep pace with sea-level rise. Vertical accretion in a salt marsh is a complicated process that includes organic matter and sediment accumulation that are necessary for building peat (Dudley et al., 2011). Historically, in New England the vertical accretion rates in salt marshes have kept pace with past rates of sea-level rise (0.6 to 2.5 mm / year) (Nielson et al., 2014);

however, sea levels are expected to continue rising and may reach 8.4 mm / year in the next century (Frumhoff et al., 2007). Knowing the direction of longshore sediment deposition is important in knowing how coastal erosion will deprive or enhance the accretion rates within salt marshes (Berman, 2011). Changes in plant species composition at Nauset Marsh within the Cape Cod National Seashore indicate that it is gradually being submerged, although historic sedimentation rates suggest that it is keeping pace with the current rate of sea-level rise (Roman et al., 1997; Goodman et al., 2007).

Vertical accretion rates can also be accompanied by horizontal migration into open areas adjacent to marshes; however barriers may prevent salt marshes from upland movement. Human made structures such as roads, dikes, low-lying developments, and seawalls can act as barriers to salt marsh migration because they block colonization of salt marsh vegetation into upland areas and also occupy land that might be available for salt marsh formation. Additionally, these artificial structures may alter sedimentation rates that are necessary for marshes to migrate vertically with rising sea levels. While some artificial structures like culverts allow tidal flow into marshes, they may need to be re-evaluated to allow proper tidal inundation and sedimentation necessary for migration into upland areas.

The goal of this study was to identify and inventory salt marshes that have the greatest potential for horizontal migration into upland areas of the watershed. The following categories prioritize salt marshes on their ability to migrate with sea-level rise while also considering the potential barriers to migration. It is important to note that there is a strong correlation between tidal range and accretion rates in salt marshes (Morris, 2007). Cape Cod is surrounded by different bodies of sea water that have different tidal ranges. Therefore, the geographic location of the salt marsh on Cape Cod is important to consider because it may provide better sedimentation rates necessary for accretion. For instance, 4 out of 5 salt marshes that were categorized as high are located on Cape Cod Bay which has the highest mean tidal range of 9.73 feet (Retrieved from http://tidesandcurrents.noaa.gov/ on August 10th). The tidal ranges on Cape Cod Bay may provide better sedimentation rates necessary for faster salt marsh accretion compared with salt marshes located in Buzzards Bay and Nantucket Sound. Also, artificial structures like sea walls and jetties can influence higher accretion / erosion rates near salt marshes because they change coastal sedimentation budgets (Berman, 2011).

High priorities for restoration due to marsh migration potential:

Salt marshes that were categorized as high priority restoration projects include:

1. WE-6; Herring River, Wellfleet, MA
2. WE-5; Mayo Creek, Wellfleet, MA
3. TR-3, TR-4; Pamet River, Truro, MA
4. YA-9; Parkers River, Yarmouth, MA
5. SA-9; Cow River, Sandwich, MA

WE-6: Herring River, Wellfleet MA

The Herring River has been a top priority salt marsh restoration project for the Cape Cod National Seashore, the Town of Wellfleet, APCC and many partner agencies and organizations. In terms of marsh migration, there are large areas of undeveloped land in the upland areas of the watershed. There are a few low -lying houses and a golf course that may be inundated with restoration. The major barriers to future migration will be tidal restrictions on Hopkins Drive, Pole Dike Road, and Bound Brook Island Road. There are some steep elevations adjacent to the marsh that would also limit migration into these areas.

WE-5: Mayo Creek, Wellfleet, MA

Mayo Creek is a top priority salt marsh restoration project because of the potential upland area that is undeveloped which would allow the marsh to migrate over time. Hydrological information still needs to be collected by the town to determine if septic systems will be affected by the restoration project. The RV Park and 14 abutting properties and their septic systems may be affected by tidal restoration and future sea-level rise (Figure 4). The unrestricted side of this marsh is dominated by *Phragmites australis* and may limit the migration of halophytes if tidal inundation does not control its growth. There is also open space on the opposite side of Chequesett Neck Road that would allow for longer term migration potential with 6 feet of SLR estimates (Figure 5). This project may also benefit fish / shell fish / nutrient loading issues in nearby coastal waters.

TR-3 and TR-4: Pamet River, Truro, MA

More hydrological modeling needs to be completed on the Pamet River restoration project to understand potential impacts of increased tidal flow on public water supply and abutting properties. There is potentially 158 acres of open space in the headwaters of the Pamet River watershed where marsh migration could occur which may help to alleviate flooding during storms and erosion.

YA-9: Parkers River, Yarmouth, MA

The Parkers River restoration project would restore 35.18 acres of salt marsh, diadromous fish runs, shellfish beds, and will improve water quality (TMDL) levels in Swan Pond. The 18' bridge would be replaced with a larger opening of 30''. Low-lying houses will be impounded at 6 feet of SLR. This marsh may potentially migrate into upland low-lying areas opposite Winslow Gray Road to the west. This is the only salt marsh project located on Nantucket Sound and so sedimentation rates may not be as high because of a lower tidal range (Morris, 2007). Sedimentation rates may also be affected by a jetty at the mouth of the salt marsh. This restoration project is underway and construction is expected to commence within the next two years.

SA-9: Cow River, Sandwich, MA (aka Ploughed Neck Road)

During Phase 1 of the Cape Cod Water Resources Restoration Project (CCWRRP), a restoration feasibility study was conducted for the Massachusetts Department of Ecological Restoration. Low-lying properties were identified as a major concern for this project. The undersized culvert restricts tidal flow to 160 acres of potential salt marsh. This marsh has potential to migrate into upland cranberry bogs and into a large, low-lying undeveloped area south of the tidal creek (Figure 6).

Medium priorities for restoration due to marsh migration potential:

Salt marshes that were categorized as medium priority restoration projects include twelve sites:

1. BA-19: Ocean Street / Snows Creek
2. BN-39: Earthen bog dike on Little Buttermilk Bay
3. CH-1, HA-8: Deep Hole Road / Red River
4. CH-5: Stage Harbor / Champlain Creek
5. CH-6: Frost Fish Creek
6. CH-7, HA-9: Route 28 / Muddy River (this project is underway)
7. DE-5: Lower County Road / Weir Creek
8. EA-6, EA-7, and EA-8: Mary Chase Road, Governor Prence Road, Route 6A / Abelino's Creek
9. TR-1: Old County Road / Eagle Neck Creek
10. YA-1, YA-2, BA-8: Keveney Lane / Mill Lane restriction
11. YA-3: Thatcher Road
12. YA-6: Park Avenue Restriction on unnamed creek

I chose to focus on researching and studying four salt marshes from the list above, highlighted in yellow, that have potential for migration. These marshes appeared to have more upland space for migration when analyzed using the Cape Cod Commission's SLR viewer. Overall, salt marsh restoration projects that were categorized as medium priorities had the fewest houses inundated at 2 feet of sea-level rise.

BN-39: Earthen bog dike on Little Buttermilk Bay

The earthen bog dike on Little Buttermilk Bay in Bourne, MA (BN-39) has a metal corrugated culvert that is submerged during most of the tidal cycle and restricts tidal flow into an abandoned cranberry bog (Barros Bog) that is approximately 14 acres (Photo 1). Historically, there was a direct connection between BN-39 and Little Buttermilk Bay before this area was converted to a cranberry bog (Taber, 2013). The tidal flow into Barros Bog was significantly altered when a 9-11 foot dike was constructed to prevent saltwater tidal flow into the bog to allow cranberry production (Taber, 2013). After the bog was abandoned 30 years ago, Phragmites started to take over and is still expanding into the upper parts of the bog. The Bourne Conservation Commission owns 24 acres of this property and the Bourne Open Space owns the dike and adjacent areas. A wetland

restoration and management plan was completed by the USDA Natural Resources Conservation Service (NRCS) in 2013.

This marsh has enough upland open space to allow for long term salt marsh migration. The upland areas for migration include the three sections of Barros Bog, Queen Sewell's Pond, and an unused / abandoned cranberry bog north of Queen Sewell's pond (Figure 7). One major barrier to potential marsh migration will be the abundance of Phragmites that may outcompete native salt marsh plant communities if the restoration project moves forward (Photo 2). There is a community of halophytes present in the middle of the first section of the Barros Bog system (*Spartina patens, Juncus gerardii,* and *Salicornia depressa*) that may be able to expand into upland areas if competition with Phragmites does not pose a barrier to growth. There are also upland and freshwater tolerant plant species growing in section 2 of the bog (*Clethra alnifolia, Scirpus americanus, Toxicodendron radicans, and Eleocharis* spp.) suggesting less salt water tidal flow into this section. Increasing tidal flow into this system should cause the Phragmites to die back and allow native salt marsh plants to become re-established. There are remnants of an unused concrete culvert and a metal culvert between section 2 and section 3 of Barros Bog that is filling with sediment (Photo 3). Both section 3 of Barros Bog and the abandoned cranberry bog upland of Queen Sewell's Pond are showing signs of filling in with later successional species (Photo 4 and Photo 5). There is a second blockage between section 3 of Barros Bog and Queen Sewell Pond (Photo 6), and a third barrier between Queen Sewell's Pond and the abandoned cranberry bog (Photo 7). The Bourne Conservation Commission and the NRCS are in the process of planning for the restoration of the first three sections of Barros Bog and possibly creating a tidal connection with Queen Sewell's Pond. Removing Phragmites is a top priority in restoring this marsh.

Historic town records and interviews with local residents have indicated that this area was a herring run (Taber, 2013). According to the NRCS wetland management report, the Bourne Conservation Commission has expressed a desire to re-establish the herring connection from Little Buttermilk Bay to Queen Sewell Pond (Taber, 2013). More information will need to be collected from the Division of Marine Fisheries to determine if re-establishing a herring run into this system will be possible. The Barros Bog marsh system also has Eastern Box Turtles and Diamondback Terrapins and falls within the Natural Endangered Species Program (Taber, 2013).

In 2006, the Cape Cod Water Resources Restoration Project (CCWRRP) conducted an EIS and estimated it would cost $263,000 to restore this marsh (USDA NRCS, 2006). This estimate may need to be re-evaluated in the future if additional restoration projects are considered as marsh migration progresses. NRCS Wetland Restoration Program will fund construction, but funding for additional design and permitting would be needed (BB Atlas).

CH-5: Stage Harbor / Champlain Creek

CH-5 is a tidally restricted salt marsh located on Stage Harbor Road of Champlain Creek in Chatham, MA. The primary concerns over this salt marsh restoration project are the impacts it will have on the harbor master facility and nearby low lying private residences.

There is a 20" metal pipe running under Stage Harbor Road (Photo 8) and the seaward opening is buried under a pile of rocks (Photo 9). Restriction indicators include major scouring, significant erosion on both sides of the pipe, vegetation dieback, and Phragmites, cattails (*Typha angustifolia*) and purple loosestrife (*Lythrum salicaria*). This has salt marsh has the potential to migrate into adjacent upland areas if the elevation is conducive to migration and freshwater inputs from upstream do not favor invasive plant growth (Figure 8). According to the CCC SLR viewer, future migration potential in this marsh will eventually be blocked by Honey Suckle Lane to the north. Currently, there is a small metal pipe under Honey Suckle Lane that allows freshwater to drain the upland watershed (Photo 10). This marsh may eventually migrate into conservation areas and a white cedar swamp owned by the Town of Chatham (Figure 9).

DE-5: Lower County Road / Weir Creek

The culvert on Weir Creek (DE-5) is a 2 foot concrete pipe that runs under Lower County Road / South Main Street in Dennis, MA. The opening of the culvert was submerged under water during high tide during a site visit on August 25, 2015 (Photo 11). Weir Creek is part of the Bass River Watershed that drains into Nantucket Sound. The estimated mean tidal range (MHW-MLW) in Nantucket Sound is 4.07 feet. Weir Creek does not support anadromous / diadromous fish runs, but supports historic shellfish resources (CC Atlas). This salt marsh has very little Phragmites growth on the unrestricted side; however, the restricted side has Phragmites growing on the outer edges of the marsh and upland areas away from the culvert (Photo 12). There are 42.16 acres of salt marsh impacted by the undersized culvert on the restricted side of the marsh (CC Atlas). The tidal creek shows bank erosion and scouring on both sides of the culvert suggesting a reduction in tidal flow (CC Atlas).

The CCC's SLR viewer indicates that the Weir Creek salt marsh has good migration potential into undeveloped upland shrub swamp areas of the watershed at 2 feet of SLR (Figures 10a and 10b); however, a few low-lying properties may be affected at 2 feet of SLR. Interviews with town resource managers indicate the major barriers to restoring this marsh are the low-lying properties adjacent to the marsh that may become flooded with restoration. More elevation and hydrological information may need to be collected before this restoration moves forward.

YA-6: Park Avenue Restriction on unnamed creek, Yarmouth

The Park Avenue salt marsh in Yarmouth, MA is categorized as a medium priority project for marsh migration because of the available space in the upland areas of the marsh system at 2 feet and 4 feet of SLR (Figures 11 and 12, respectively). An unnamed tidal creek passes under Park Avenue via 3.5' concrete pipe set in a headwall that is filling with silt and debris (Photo 13). On the restricted side of the marsh, there is a stand of Phragmites located near the culvert and also in the upper parts of the watershed (Photo 14). A healthy community of salt marsh plants are growing between the two stands of Phragmites. The Park Avenue salt marsh is separated from the old Bayview Cranberry Bog by a concrete culvert (Photo 15). The old Bayview Cranberry Bog and nearby wetlands are owned by the

Cape Cod Hospital which have been preserved as freshwater habitats (CC Atlas, 2001). Freshwater coming from the Bayview Cranberry Bog may have influenced the abundant growth of *Scirpus pungens* and *Hibiscus moscheutos* in the headwaters of this marsh (Photo 16). This salt marsh could potentially migrate into the low-lying freshwater cranberry bog as sea-level rises. There are two additional wetlands with culverts located on the Bayview Cranberry Bog watershed that may act as barriers with higher levels of sea-level rise. Low lying houses near the restriction on Park Avenue may need to be evaluated for flooding and a more detailed feasibility study might need to be completed to identify potential mitigation.

Low priorities for restoration due to marsh migration potential:

Salt marshes that were categorized as low priority restoration projects include:

1. BN-08: Gray Gables Upper and Lower Marsh
2. BN-38: Canal Service Road / Dyke's Creek
3. CH-2: Chatharbor Lane / Mill Creek
4. CH-3: Ridgevale Road / Mill Creek
5. DE: Cold Storage Road
6. EA-1, EA-2: Dyer Prince Road
7. FA: Oyster Pond, Shrub Bog, Little Neck Bay
8. FA-10: Woodneck Beach
9. FA-39: Ravenwood Road / Wild Harbor Boat Basin
10. FA: West Falmouth Harbor Watershed
11. OR-2: Hurley Bog on the Cape Cod Rail Trail
12. OR: 16 Ewing Road / Pleasant Bay
13. PR-1: The Breakwater / Long Point Dyke
14. TR: East Harbor Salt Marsh Restoration
15. YA-8: Lewis Bay Road restriction
16. YA-10: South Shore Drive / Bass River Beach
17. YA-11, DE-13: Route 6 restriction of the Bass River

Salt marshes categorized as low priority for migration potential had relatively little upland area to migrate. These marshes should still be considered for restoration because they may be cost effective projects that are feasible to complete that still restore native plant and animal species and have smaller scale influences in preparing for sea-level rise. However, the focus of this report was to prioritize marsh restoration projects based on their migration potential and there was not enough time to analyze each of these salt marshes for their feasibility.

7. Recommendations

The goal of this report was to inventory salt marshes with the highest potential for marsh migration using the Cape Cod Commission's SLR viewer while identifying barriers to future migration. Due to time constraints, it was not possible to address other variables that

may affect marsh migration at these sites. Recommendations include suggestions for follow-up work that will likely be needed for project development and implementation.

The following recommendations should be addressed in subsequent follow-up work:

- Additional information should be collected and analyzed on the total area of potential migration using the CCC SLR viewer. It would be important to know how many square meters of marsh migration potential each marsh has under 2, 4, and 6 feet of sea level rise.

- While outside the scope of this repot, more data will need to be collected and analyzed on marsh sedimentation and accretion rates to understand how these marshes will be able to build vertically to keep pace with SLR. Marker horizons (MH) and a sediment elevation table (SET) might be used to determine the sedimentation rates within marshes. Pre-existing SET tables may be available in salt marshes around Cape Cod. This data should be compared with coastline sediment and shoreline change budgets to determine how coastline accretion and erosion rates are influencing sedimentation rates within salt marshes.

- As a potential coastal resilience measure, it may be useful to identify low lying areas along the coast of Cape Cod that currently do not have salt marshes but might be protected enough to build and sustain salt marsh vegetation in the future. For instance, some of the freshwater streams and rivers on Cape Cod that are not currently salt marshes may become salt marshes as sea level rises. Also, areas that may become barrier beaches as sea-level rises should be analyzed for potential marsh building areas.

- The original scope of this project was going to take into account mapping the plant community boundaries of the salt marshes with the greatest potential for migration, the water quality, and the nekton; however, there was not enough time to complete these projects. It is important to map plant community boundaries in the high / low marsh and upland border using GPS to track the rate of migration in the high/low and border of the marsh. It will also be important to know how plant biodiversity will change with sea level rise. A simple plant monitoring program developed by Elpick et al. (2014) would help keep track of changes in plant communities at the border of marshes that are restored.

- Currently the Massachusetts Office of Coastal Zone Management (MCZM) is utilizing a computer model that predicts marsh migration called the Sea Level Affecting Marshes Model (SLAMM). MCZM will use SLAMM to identify areas along the Massachusetts coast that will be impacted by sea-level rise while taking into account barriers like elevation and housing developments. The results from this study should be compared to the SLAMM model to better understand marsh migration and help with adaptive management plans and policy changes.

- Climate change adaptation science is rapidly evolving, and this area of salt marsh adaptation to sea level rise is likewise rapidly evolving. The results and recommendations from this study should continue to be reviewed and updated as needed to stay abreast of scientific developments as well as

Acknowledgements

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- Lauren Tierney, APCC Geist Intern;
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List of Tables

Table 1. See attachment at the end of the report. A summary of information collected for each salt marsh restoration project includes site name and identifier, number of properties inundated at 2 feet, potential barriers, notes on migration potential, support for fish run/shellfish/TMDL, total affected area, and estimated mean tidal range.

Data Storage

Marsh migration reports and data table

[Report and summary excel file for barriers for marsh migration report]

Server (X) – Programs and Projects – Salt Marsh Migration 2015

Includes:

- Marsh Migration Barriers Summary Spreadsheet
- Marsh Migration Report 2015
- Marsh Migration Figures
- Marsh Migration Photos

Copies of references used for report

Server (X) – Programs and Projects – Salt Marsh Migration 2015 – References

Includes:

- Burdick-marsh elevation and sea level rise.
- CACO-Salt-Marsh-Elevation-Monitoring-Protocol-Final
- Donnelly-Sea Level Rise (Zonation) and accretion rates
- Elphick Field 2014 (marsh transgression monitoring protocol)
- Cape Cod Commission – Estimation of High Ground- Water Levels for Construction and Land Use Planning
- NROC Marsh Migration Doc - Draft 11-15-14-1
- Marsh_Migration_Methods-NOAA-CSC
- HighGroundH20TechBulletin
- Cape Cod Longshore Transport-Berman-2011
- CCC SLR Viewer-questions-AR

Updated matrix of Cape Cod priority projects

Server (X) – Program and Projects – CCWRRP Update-2014-2015-Biology Intern 2015-Priority Projects-June-2014-July-2015-Draft-TV

Sea level rise maps and FEMA flood plain maps

Server (X) – Program and Projects – CCWRRP Update-2014-2015-Biology Intern 2015-Sea Level Rise Maps folder

FIGURES

Abbreviations: SLR Sea level rise

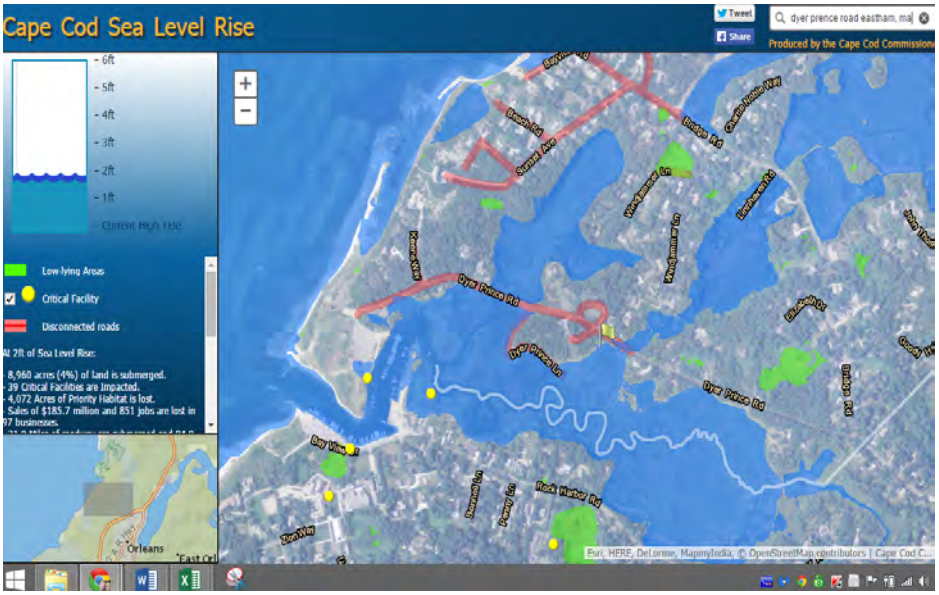


Figure 1. Roads that are flooded at 2 feet of SLR turn red on the Cape Cod Commission's SLR viewer. The Dyer Prence Road (Eastham, MA) culverts would be impacted at 2 feet of SLR.

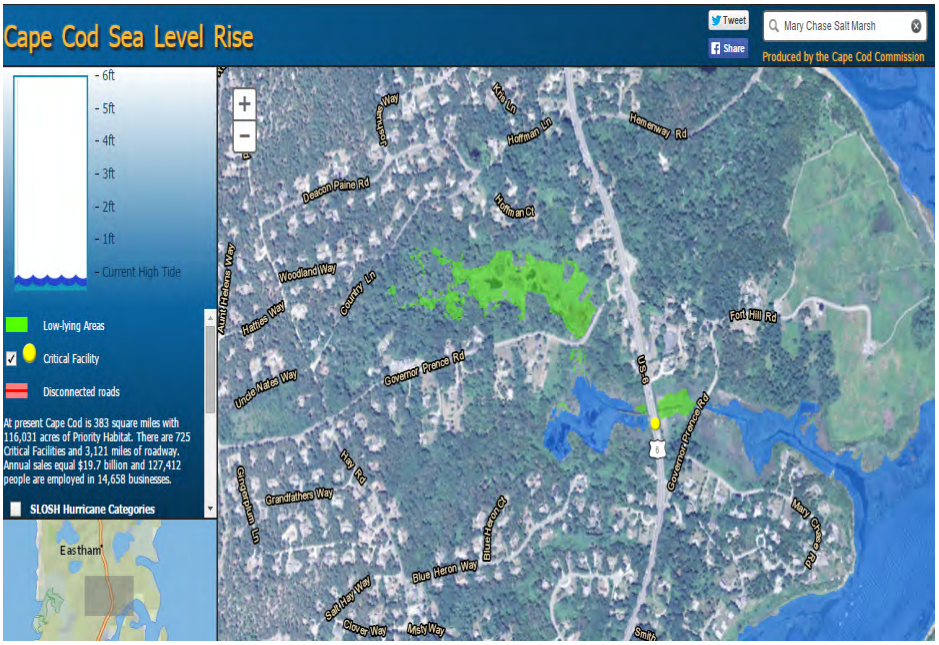


Figure 2a. Comparing SLR inundation models at Mary Chase Salt Marsh, Eastham, MA. The image shows current inundation levels at the Mean Higher High Water (MHHW) line.

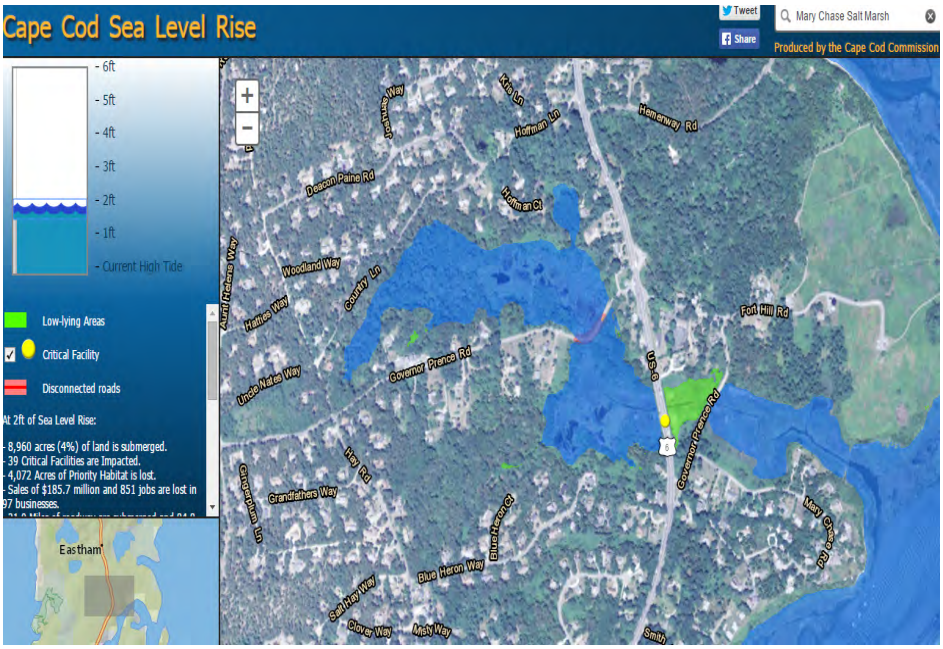


Figure 2b. Comparing SLR inundation models at Mary Chase Salt Marsh, Eastham, MA. The image shows inundation levels at 2 feet of SLR.

Figure 3. Green areas indicate low lying areas / wetlands that are located at 0 feet of elevation (Personal Communication with the Cape Cod Commission). Also an example of housing developments inundated with 2 feet of SLR on Dyke's Creek in Bourne, MA on the Canal Service Road.

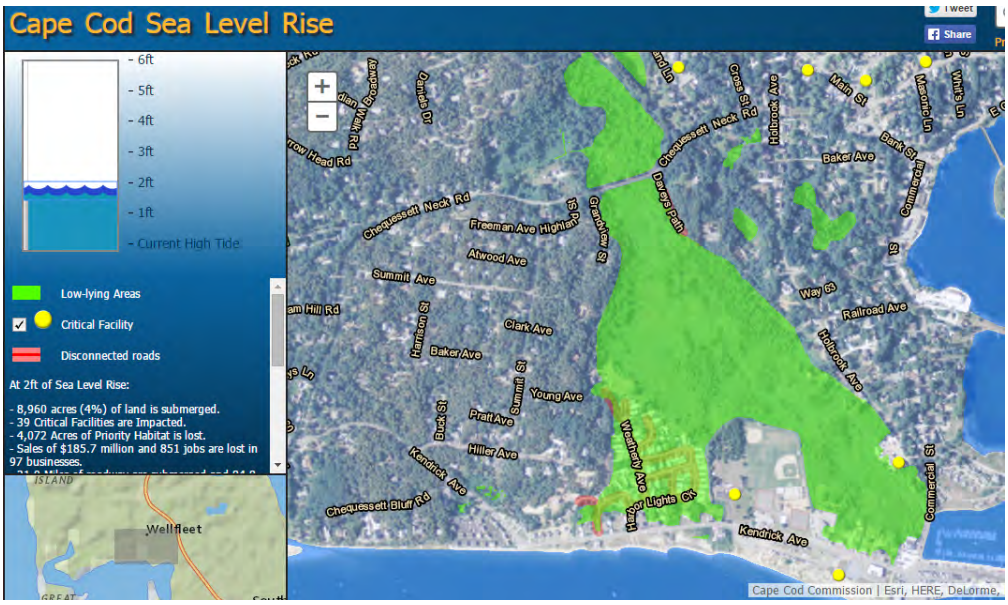


Figure 4. Mayo Creek (Wellfleet, MA) inundation scenario at 2 feet of SLR.

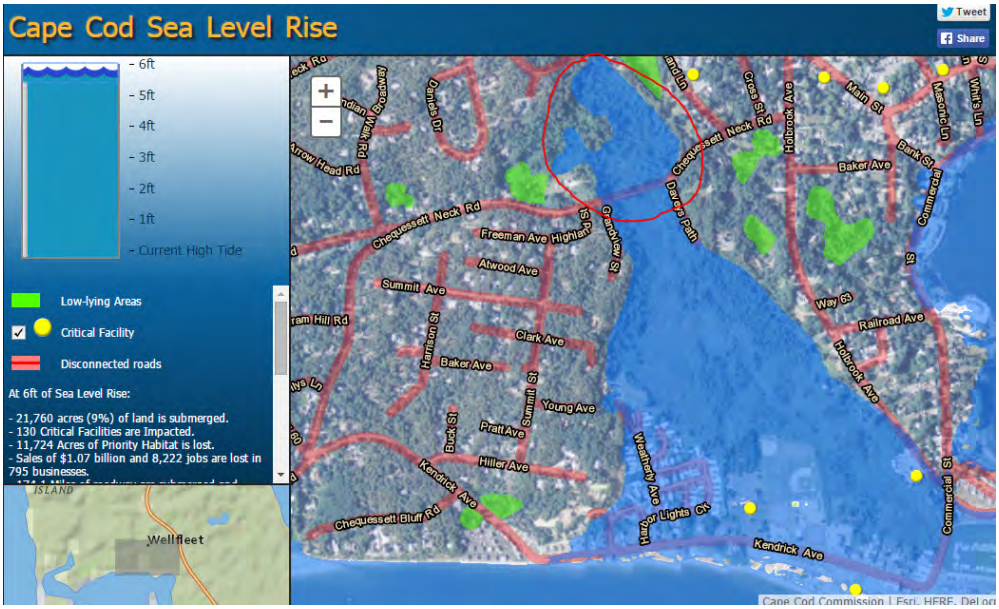


Figure 5. Mayo Creek inundation scenario at 6 feet of SLR. The area north of Chequessett Neck Road has open space where the marsh may potentially migrate.

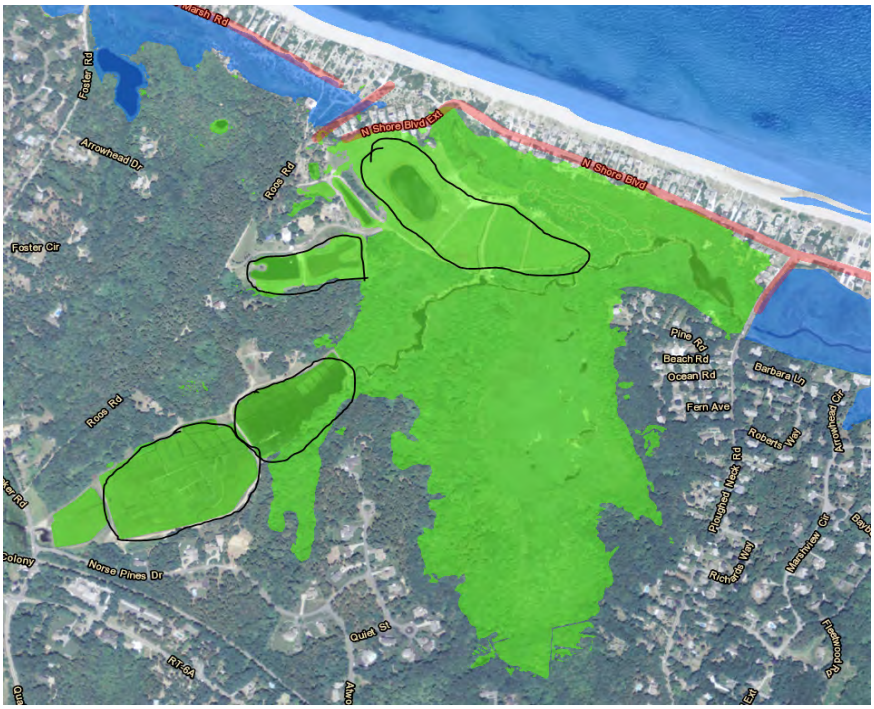


Figure 6. Cow River / Ploughneck Road marsh system in Sandwich, MA showing migration potential into cranberry bogs at 2 feet of SLR.

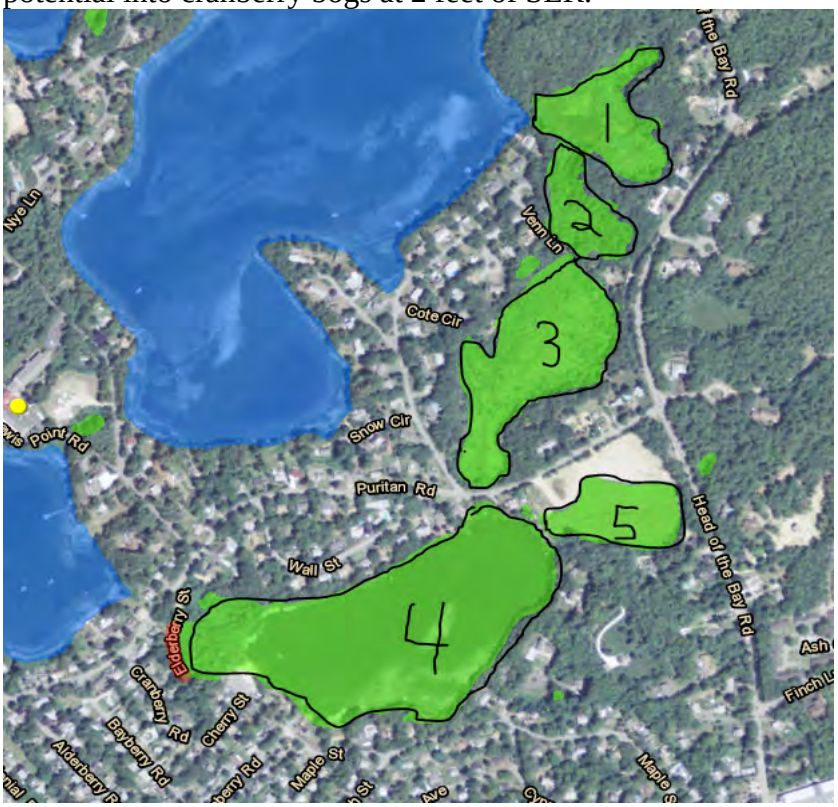
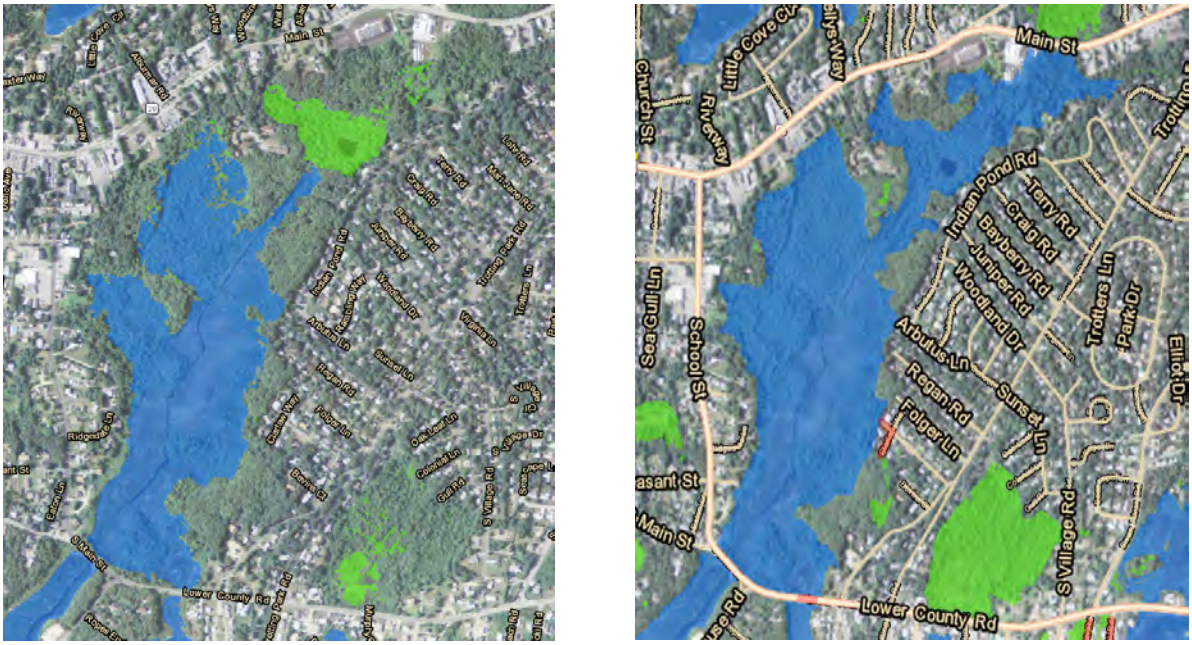


Figure 7. Little Buttermilk Bay salt marsh (BN-39) at 4 feet of SLR. The green low-lying areas that are circled include the three sections of Barro's Bog (#'s 1-3), Queen Sewell's Pond (#4), and an unused cranberry bog (#5). These areas may allow future marsh migration.

Figure 8. Stage Harbor / Champlain Creek salt marsh (Chatham, MA) at 2 feet of SLR. Honeysuckle Lane to the north presents an obvious barrier to future migration potential.

Figure 9. A topographic map showing 2 foot contour lines at Stage Harbor / Champlain Creek in Chatham, MA. Higher models of SLR indicate a possible connection between the salt marsh and the cedar swamp / conservation area located to the northwest of the marsh system. These conservation areas may provide open space for future marsh migration.



A. Current flooding levels at MHHW. B. Flooding levels at 2 feet of sea-level rise.

Figures 10A and 10B. Potential marsh migration into open upland areas at Weir Creek salt marsh in Dennis, MA.

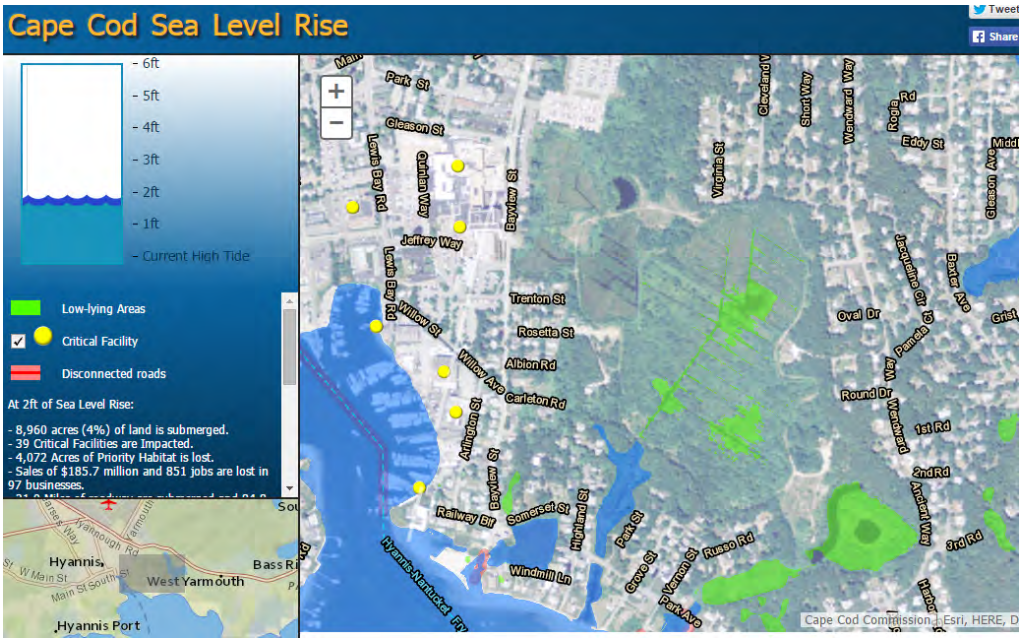


Figure 11. Park Avenue salt marsh in Yarmouth, MA at 2 feet of SLR. The tidal flow into this marsh is not accurate at 2 feet because the height of the culvert and hydrological flow rates have not been collected and implemented in the Cape Cod Commission's SLR model.

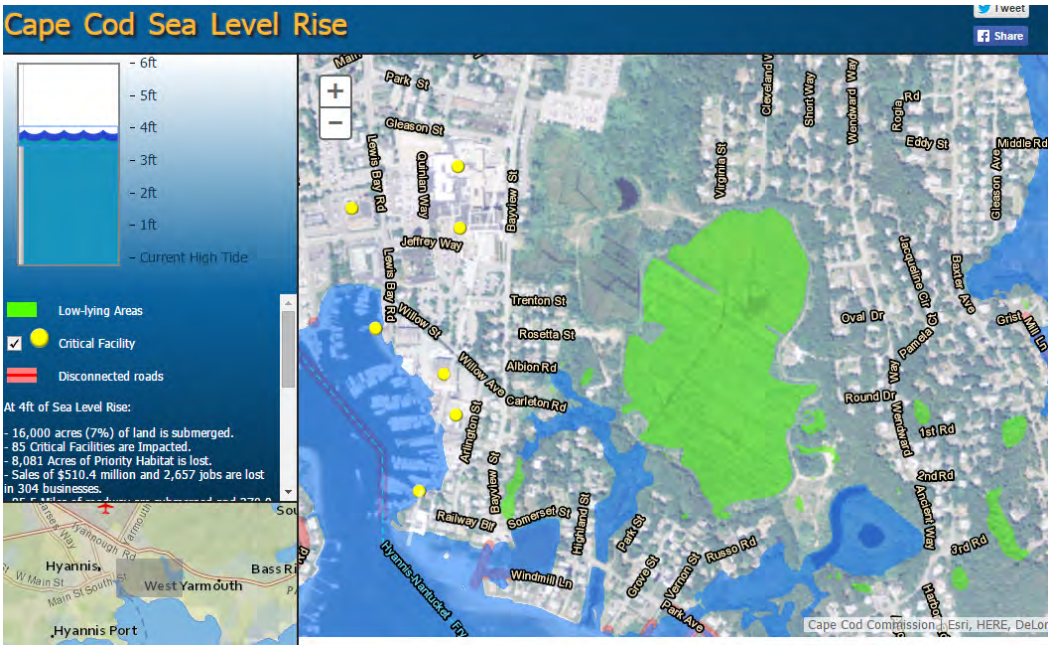


Figure 12. Park Avenue restriction in Yarmouth, MA at 4 feet of SLR showing a better representation of possible tidal inundation at higher rates of sea level rise.

PHOTOGRAPHS

All photographs were taken by Carl Depuy in 2015 unless otherwise indicated.

Photo 1. Culvert that is limiting tidal flow into an unnamed salt marsh (BN-39) on Little Buttermilk Bay in Bourne, MA. This image is taken from the restricted side of the marsh and the metal culvert appears to be covered with slumping earth and rotting boards.

Photo 2. This image shows that most of BN-39 is dominated by thick stands of Phragmites.

Photo 3. Small culvert filling with sediment between located between BN-39 salt marsh and Barrows Bog (Bourne, MA).

Photo 4. Barrows Bog is located adjacent to the Little Buttermilk Bay salt marsh (BN-39). This abandoned bog may provide open space for future marsh migration.

Photo 5. Abandoned bog west of Queen Sewell's Pond which may provide low-lying open space for higher levels of sea-level rise.

Photo 6. Rock pile located between Barrows Bog and Queen Sewell Pond that will act as a barrier to future migration potential.

Photo 7. Blockage between Queen Sewell Pond and upland abandoned cranberry bog.

Photo 8. Restricted culvert running under Stage Harbor Road, Chatham, MA. This image was taken on the restricted side of the salt marsh.

Photo 9. The impaired Stage Harbor Road culvert (Chatham, MA) is buried under a pile of rocks on the seaward side of the marsh.

Photo 10. Small culvert running under Honey Suckle Lane in Chatham, MA that drains freshwater from the upper part of the watershed.

Photo 11. Flooded culvert at Weir Creek salt marsh during high tide.

Photo 12. Phragmites growth is abundant on the outer edges of the Weir Creek salt marsh.

Photo 13. Park Avenue culvert on the seaward side of the marsh which is set in a concrete headwall (Yarmouth, MA).

Photo 14. *Phragmites australis* are located in the upland areas of Park Avenue marsh (Yarmouth, MA). *Spartina patens and Spartina alterniflora* are present in the foreground.

Photo 15. Photograph was taken from above the concrete passageway between the unnamed Park Avenue salt marsh and Bayview bog (Yarmouth, MA).

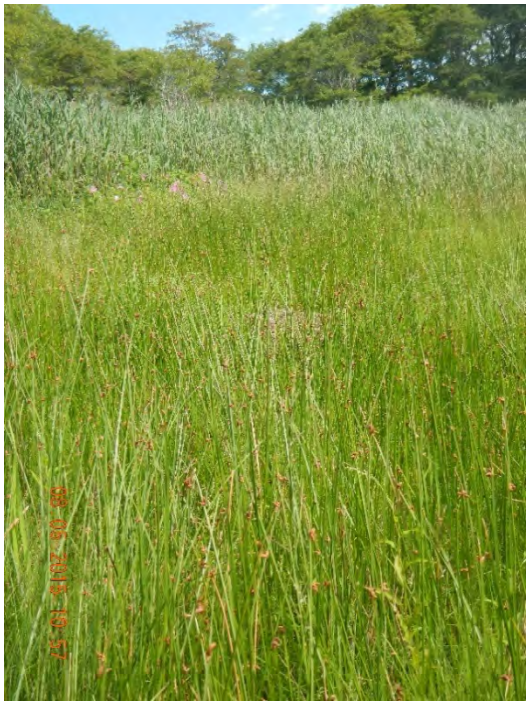


Photo 16. *Scirpus pungens* and *Phragmites australis* located in the upland areas of the Park Avenue marsh (Yarmouth, MA) indicating less tidal flow and more freshwater influence.

Table 1. List of Salt Marshes with Potential to Migrate as Sea Level Rises 9/2/15

Association to Preserve Cape Cod and MassBays Program

Note: These are impaired salt marshes which are potential salt marsh restoration projects

Salt Marsh ID	Town	Project Name	Is restoration site on a state highway?	Is culvert and roadway inundated at 2 feet of SLR?	Estimated number of properties flooded at 2 feet of SLR	Barriers to marsh migration	Marsh migration potential	Fish/Shellfish Habitat/TMDL	Total Affected Area	Approximate Mean Tidal Range (MHW-MLW)
BA - 19	Barnstable	Ocean Street / Snows Creek tidal restriction	No		6	Gosnold Avenue blocks connection with BA-18 marsh system/Old Colony Road/Low lying housing developments	Ability to migrate into open space; however Old Colony Road and Gosnold Road may limit migration with 4-6 feet of SLR. There are also low lying properties.	None	7	4.07
BN - 08 (lower marsh), BN - 43 (upper marsh)	Bourne	Gray Gables Upper and Lower Marsh	No	X	0	Road/Low lying housing developments	Sedimentation from Cape Cod Canal at the mouth adds to the restriction.	None	13	4.07
BN - 38	Bourne	Canal Service Road / Dyke's Creek	No		9	Road/Low lying housing developments	Marsh migration will also be hindered by Bridge Creek Rd restriction and nearby developments. Bourne Pond is the source of the freshwater creek.	Fish Passage	Not in Atlas	3.42
BN - 39	Bourne	Earthen bog dike on Little Buttermilk Bay	No		0	Road/Housing Developments/Phragmites	Migration into Burrows Bog at 2 feet. Marsh migration potential into Queen Sewell's Pond and adjacent cranberry bog at 6 feet of SLR.	None	Not in Atlas	4.07
CH -1 / HA - 8	Chatham	South Chatham Rd. and Deep Hole Road / Red River tidal restriction	No	X	0	Elevation on sides of creek in upper watershed/low lying housing developments/Phragmites	Migration into upland forest / watershed from 2 - 6 feet of SLR. Marsh migration will be restricted by elevation on the creek bank and houses on each side of Red River Creek. Jetty at the mouth of the tidal creek may impact sedimentation into the marsh.	Anadromous fish/Shellfish/Nitrogen	3	4.07
CH - 2	Chatham	Chatharbor Lane / Mill Creek tidal restriction	No		0	Low lying housing developments/Roads	Marsh is abutted with houses, Chatharbor Lane Rd and Nantucket Sound. Very little open space for migration.	None	3.24	4.07
CH - 3	Chatham	Ridgevale Rd. restriction between Cockle Cove / Bucks Creek	No		0	Phragmites dominated marsh.	Marsh is dominated by Phragmites. SLR models indicate tidal flow may be reaching the marsh from Cockle Cove Creek. This restoration may reduce phragmites but will migrate into Cockle Cove salt marsh.	Shellfish	Not in Atlas	4.07
CH - 5	Chatham	Stage Harbor Road Restriction on Champlain Creek	No		1	Roads/Low lying housing development	Honeysuckle Ln. will eventually be a barrier to migration to the North. There is a large low lying parcel of land to the North that is composed of cedar swamp that may become salt marsh.	Shellfish in Stage Harbor	4.87	4
CH - 6	Chatham	Frost Fish Creek	Route 28		2	Roads/Low lying housing development	SLR model shows floodplain extends into the forested area opposite Crowell Rd. May be potential migration into this forested area if the elevation is not significant.SLR models from 2-4 feet show little migration potential.	Fish Passage and TMDL	18.07	9.73
CH - 7 / HA - 9	Chatham / Harwich	Muddy River / Route 28	Route 28		0	Roads/Low lying housing development	Migration into upland forest and into Mill Pond. Old Queen Ann Road acts as a barrier to future migration potential.	Fish Passage and TMDL	34.58	4.07
DE	Dennis	Cold Storage Road Tidal Restriction	No		0	Roads/Low lying housing development	Little potential for migration	Possibly Shell fish	Not in Atlas	9.73
DE - 5	Dennis	Weir Creek/Lower County Road Restriction	No		5	Roads/Low lying housing development	Potential for migration into forested areas near Weir Creek.	Historically a shellfishing site	42.16	4.07
EA - 1, EA - 2	Eastham	Dyer Prence Road	No	X	0	Roads/Low lying housing development	EA - 2 has some room to migrate into nearby forested area but is restricted by Bridge Rd. and other housing developments.	Shellfish/TMDL	18	9.73
EA - 6, EA - 7, EA - 8	Eastham	Abelino's Creek / Mary Chase Road	US 6		0	Roads/Low lying housing development	Potential for migration into upper part of watershed. Low lying houses and 3 culverts are the major restrictions.	Shellfish	31	3.03
FA	Falmouth	Oyster Pond, Shrub Bog, Little Neck Bay	No	X	0	Roads/Low lying housing development	Little Neck Bars Road poses a barier to migration.	Nutrient Loading		4.07
FA -10	Falmouth	Woodneck Beach	No		1	Phragmites/Low lying housing developments	Potential migration into areas dominated by phragmites depending on salinity and freshwater input.	None	6.06	4.07
FA - 39	Falmouth	Wild Harbor Boat Basin / Ravenwood Road	No		4	Low Lying Housing Developments/Wild Harbor Road to the North	Low Lying houses that abut the marsh provide little room for migration potential.	Shellfish	11.4	4.07

FA	Falmouth	West Falmouth Harbor Watershed	No		Unknown				Not in Atlas	4.07
OR - 2	Orleans	Hurley Bog on the Cape Cod Rail Trail	No		0	Elevation/Phragmites/Roads /Developments	Elevation may pose a barrier to migration. Also, adjourning roads and buildings may become barriers as sea level rises.	Shellfish / Rare Species	0.96	9.73
OR: 16 Ewing Road	Orleans	16 Ewing Road / Pleasant Bay	No		0	Elevation	A marsh system West of the Ewing restriction may already be inundating the marsh.	None	Not in Atlas	3.03
PR - 1(?)	Provincetown	The Breakwater / Long Point Dike restoration	US 6 / Province Lands Road		0	Elevation	SLR mapping reveals that sea level rise at 6 feet will not overflow into the forested areas on the Northern side of the marsh. Improving tidal flow may change the hydrology of the marsh and change the bank erosion dynamics that are currently happening on the unrestricted side of the marsh.		5.22	9.29
SA - 9	Sandwich	Ploughed Neck Road / Cow River/Long Creek	None	X (Partially)	10	Cranberry Bogs/Potentially Low Housing Developments	Potentially a good restoration project based on the ability to migrate into open areas; however, there may be flooding of cranberry bogs located upstream of the culvert.	None listed in atlas	79.71	8.74
TR - 1	Truro	Old County Road / Eagle Neck Creek	No		0	Eleveation on sides of tidal creek channel.	Large areas for migration if phragmites does not impede upper marsh migration.	Shellfish/TMDL	16.19	9.29
TR - 2	Truro	Mill Pond Restriction	No		0	Elevation/Houses	The restricted side of the marsh is composed of a brackish pond with phragmites on the edges.	Shellfish and Water Quality	13.13	9.29
TR - 3, TR - 4	Truro	Pamet River Restoration	US 6		2	Some low lying developments	Large areas for migration with potential.	Shellfish / Coastal Resiliency	152.38	9.29 / 3.03
TR	Truro	East Harbor Salt Marsh Restoration	US 6		8			None		9.29
WE - 5	Wellfleet	Mayo Creek	No		14 and RV park	Phragmites/Low lying housing developments	Potential for migration into restricted side of marsh.	Fish/Shellfish/ Water Quality	19.33	9.29
WE - 6	Wellfleet	Herring River Salt Marsh Restoration	No		Numerous depending on delineation of watershed boundary	Low lying properties	Potential for migration into the Herring river waterhsed.	Fish/Shellfish/ Water Quality	1,000	9.29
YA - 1, YA - 2, BA - 8	Yarmouth / Barnstable	Keveney Lane/Mill Lane Restrictions (2)	No	X (YA -1/BA-8)	0	Low Lying Properties/Culvert YA - 2/Possible restriction on Wharf Ln. with 6 feet of SLR.		Shellfish	25.28	9.73
YA - 3	Yarmouth	Thatcher Shore Road	No		0	Elevation/Low lying housing developments	SLR maps reveal that the steep elevation in the marsh would impede migration into the wooded area to the south of the marsh. Instead there is potential for migration up the Short Wharf Creek Watershed and past Thatcher road again into another wooded area.	Shellfish beds that are seasonally closed	3.92	9.73
YA - 6	Yarmouth	Park Avenue Restriction	No		0	Elevation / Low lying housing developments near the culvert.	Potential for migration into the 34.21 acres of shrub swamp. 3 additional culverts located on the perimeter of the shrub swam will be barriers to tidal inundation if this marsh is restored.	Shellfish beds and Water Quality	1.38	4.07
YA - 8	Yarmouth	Lewis Bay Road restriction	No		0	Low lying houses.	Very little room to migrate.	TMDL	1.06	4.07
YA - 9	Yarmouth	Route 28 Parkers River restriction	Route 28		4	Low lying houses.	Low lying houses will impede upstream migration potential.	Fish/Shellfish/ Water Quality	35.18	4.07
YA - 10	Yarmouth	South Shore Dr ./ Bass River Beach restriction	No		8	Low lying properties		TMDL	23.01	4.07
YA - 11, DE - 13	Yarmouth	Route 6 restriction of the Bass River	US 6		21	Low lying houses.	Upper parts of this watershed has some potential for forest migration.	Fish/Shellfish/TMDL	31.71	4.07