Pleasant Bay Living Shorelines

Nature-based Approaches for Shoreline and Salt Marsh Restoration at Jack Knife Beach, Chatham, MA

Applied Coastal

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Technical Report

Prepared in partnership with Massachusetts Coastal Zone Management Coastal Resilience Grant Program FY21

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1. Project Overview

Identifying nature-based solutions to address the loss of salt marsh began with FY20 CZM Coastal Resiliency Grant which identified Jack Knife Beach as a plausible site where restoration of the salt marsh could be successful implemented while balancing complementary and competing interests of public access, broad variety of recreation usages, multiple wetland resource areas, and environmental regulatory restrictions on what measures can be undertaken within the sensitive wetland environment and ACEC designation. To accomplish this balance during the development and design of alternatives the Project Team; Pleasant Bay Alliance, Town of Chatham, Massachusetts Coastal Zone Management, and project consultants Wilkinson Ecological Design (Wilkinson) and Applied Coastal Research and Engineering (Applied Coastal) collaboratively worked to:

- Characterize and examine the factors influencing salt marsh loss within the project area.
- Develop and evaluate the potential implementation of various nature-based stabilization solutions, traditional stabilization solutions, and potential hybrid solutions for stabilizing and restoring the eroding salt marsh along the tidal channel.
- Recommend public and traffic management practices relative to the restoration goals.
- Development and design of the preferred alternative for salt marsh stabilization and restoration.
- Develop a technical discussion on how the preferred alternative will function and anticipated dynamics with the marsh and tidal system.
- Development of a preliminary permitting plan showing the alternative.
- Engagement with Local, State, and Federal regulators to discuss the preferred stabilization and restoration approach represented by the preferred alternative.
- Engage with the local community and users of Jack Knife Beach.

The salt marsh that boarders the tidal channel into Muddy Creek and Jack Knife Beach, have been evolving for decades based on climate and estuarine processes, as well as anthropogenic changes to the system. The constantly evolving conditions and active recreational uses have stressed sections of the salt marsh leading to ongoing loss of marsh vegetation. The loss of salt marsh can be attributed to a number of factors; erosion and cleaving of the marsh bank along the tidal channel, trampling of salt marsh vegetation by recreational users seeking to utilize the beach, recreational kayakers/boaters accessing the water and storing boats on the marsh, shell fishermen accessing the channel and outer ebb shoal, as well as, movement of vehicles along the public accessway which is spatially limited due to the salt marsh bordering seaward edge and steep coastal bank on the landward boundary.

2. History of Jack Knife Beach

Muddy Creek is a tidal river that discharges into the main basin of Pleasant Bay and serves as boundary between the Towns of Harwich and Chatham (Figure 1.1). Jack Knife Beach is located east of Route 28 and serves as the outlet of Muddy Creek into Pleasant Bay and public beach recreational area. Muddy Creek and the areas adjacent to creek have been significantly altered over past centuries by human activities. In the late 1800's a roadway bridge was installed at the mouth of Muddy Creek. Historic records indicate that the bridge spanned a majority of the marsh with the roadway supported on piles, which likely did not significantly affect tidal flows into Muddy Creek. The bridge was replaced with earthen fill embankment to support the roadway which separated Pleasant Bay from Muddy Creek around 1899. Initially, the upper basin was separated from Pleasant Bay allowing the upper system to change from a brackish estuary to a freshwater system. The embankment was breached, likely by the Hurricane of 1938, allowing brackish conditions to return to Muddy Creek. The upper estuarine system was hydraulically connected to Pleasant Bay through a pair of stone box culverts, which were approximately 2.5-feet wide, 3.75-feet in height, and 100-feet in length. Resulting in a significant tidal restriction between Muddy Creek and Pleasant Bay. The small and restrictive hydraulic connection was shown to have a direct effect on water quality and wetland health upstream of Route 28 (MDEP, 2007). In 2016, the Towns of Chatham and Harwich replaced the box culverts with a single span bridge to restore the upper estuarine system and improve the water quality to abate nitrogen loading from upland watershed septic systems as part of a wider Comprehensive Wastewater Management Plan. The tidal channel beneath the new bridge is trapezoidal, with a 22-foot wide base with side slopes opening up on 1.7:1 (horizontal to vertical) slope (Fuss & O'Neill, 2012). Increasing the hydraulic opening from Pleasant Bay to Muddy Creek intensified tidal flow in and out of Muddy Creek due to the resulting increase in tidal prism upstream of Route 28. Water quality monitoring conducted after opening of bridge indicated improvements to water quality within the upstream estuarine system. The marsh system upstream has also responded with increased productivity of salt marsh vegetation and species along with reductions of invasive and fresh water species which previously encroached on the salt marsh communities due to the limited tidal exchange and variably salinity in the upper system (Pleasant Bay Alliance 2017). Downstream along Jack Knife Beach the Muddy Creek tidal channel has undergone morphological changes in response to the increased tidal flow and widen channel beneath the Route 28 bridge. Human activities have also impacted the salt marsh, ranging from damage along the parking areas to trampling vegetation along pathways to the beach and water.

Figure 1.1 Location of Jack Knife Beach.

Tidal hydrodynamics in Pleasant Bay have been rapidly evolving since the breaching of Nauset Beach during a nor'easter on January 2, 1987, which in turn affect the tidal hydrodynamics along Muddy Creek. Breaching of the barrier beach initiated a period of cyclic evolution and inlet transition for Pleasant

Bay (Giese 2019). The January 1987 breach rapidly deepened and developed into the dominant inlet, which became known at the South Inlet. The eventual dominance of the South Inlet resulted in a transition phase where the inner tidal channels within the Bay morphological responded to the formation of shoals and changes in tidal exchange between the inlets. In 2007, a breach of the norther barrier beach occurred opposite Minister's Point, which is known as the North Inlet. North Beach Island, which formed as a result of the breaching of North Inlet, continually grew and migrated south and west, reducing the width of South Inlet. During the April Fools storm of 2017, the connection from the Chatham mainland to South Beach was breached creating Fool's Inlet. The resulting changes in Pleasant Bay led to the North Inlet becoming the dominate inlet to Pleasant Bay (Giese 2019). The changing inlets and shoal dynamics over the past decades have influenced the evolution of Jack Knife Beach and Muddy Creek, through continual changes in tidal elevations and range, as well as associated flow patterns. Variations in inlet position, number, and dominance have also influenced the natural response to storm conditions within Pleasant Bay. All of which can have a significant impact on the salt marsh along the backside of Jack Knife Beach due to the narrow range in elevation across the marsh surface and inability of the marsh to migrate landward in response to trends in tidal elevations and sea level driven by inlet dynamics of Pleasant Bay and large-scale changes in sea level and storm intensity.

3. Condition Assessment of Salt Marsh at Jack Knife Beach

The initial identification and assessment of Jack Knife Beach as part of the FY20 CZM Coastal Resilience Grant Program identified a number of concerns relative to the degradation of salt marsh adjacent to the upland areas, losses of salt marsh along the tidal inlet channel to Muddy Creek, and decreasing salt marsh vegetation east of the bridge opening on the northside of the channel. Before evaluating measures and methods for stabilizing and preventing further loss of salt marsh, a field survey was conducted by Applied Coastal and Wilkinson. The field survey delineated existing salt marsh boundaries, characterized the low coastal dunes and accompanying wetland resource areas, documented the site and marsh conditions through photography, and collected additional topographic and bathymetric data.

3.1 Salt Marsh Delineation

Edge of the salt marsh was delineated and flagged across the entire Jack Knife Beach complex east of Route 28 on November 7, 2020 by Wilkinson. The low coastal dunes adjacent to the salt marsh were located and flagged. Flagging was then surveyed by Applied Coastal using a Leica Viva GS08 GNSS receiver RTK network rover coupled with a Leica Viva CS15 3.5G Data Collector system. The survey data was collected in Massachusetts State Plane Coordinates Horizontal Datum and North American Vertical Datum of 1988 (NAVD88). The delineated salt marsh boundary is shown in Figure 3.1, along with the project area being considered for solutions to restore and minimize losses to the salt marsh.

The seaward crest of the salt marsh was surveyed along the tidal channel during the November 2020 field evaluation. A series of four bank surveys were conducted in 2016 (Applied Coastal 2017) as part of the Route 28 bridge construction monitoring program conducted by the Pleasant Bay Alliance and once in 2015 prior to construction by Massachusetts Division of Ecological Restoration. The addition of updated bank survey, provides the ability to identify areas of movement in the channel and examine if there has been sustained migration or movement in the channel over the past 4 years. The results from the comparison of bank surveys are shown in Figure 3.2 which shows the bank crest positions between 2015 and 2021. Changes in shoreline position have been presented in Figure 3.3 through graphical representation of calculated annal erosion/accretion rates between the 2016 and 2020 surveys. The rates of change are calculated along shore perpendicular transects illustrated in the figure. The northern shoreline of the channel has experienced erosion range from 0.5 to 1.5 feet per year, the erosion of the salt marsh along the shoreline is attributable to intensification in ebb tide currents associated with increases in tidal prism upstream of Route 28. Additionally, the marsh surface was also noted in 2016 as being lower in elevation than the adjoining marsh. The low elevation relative to the surrounding marsh increases the likelihood of prolonged inundation and drowning of the vegetation and loss of root systems to help stabilize the peat soils. The southern side of the tidal channel shows that the channel immediately after the bridge has remained stable with minimal change in shoreline position. The survey data does not illustrate the undercutting of the bank that is occurring along this stretch of salt marsh. Undercutting was measured from the bank face and ranged from 0.5 - 1.6 feet, as shown in Figures 3.4 and 3.5. At the time of the November 2020 survey, a fissure in marsh peat surface was observed running parallel to the tidal channel. Over the next two-months the undercutting continued and gravity caused the peat surface to collapsed into the tidal channel as shown in Figures 3.6 and 3.7. The calculated erosion rates in Figure 3.3, do not illustrate or predict the episodic erosion resulting from the undercutting due to the relative short time interval between surveys relative to the episodic erosion occurrences. Shoreline change data shows a significant amount of erosion occurring around the first 90-degree bend downstream from the Route 28 bridge. Analysis of erosion rates range from 0.5 to 1.75 feet/year. Erosion was observed in this area during the 2016 monitoring program. The marsh plain in the bend was noted to be lower in elevation than the surrounding marsh, making the salt marsh vegetation more susceptible to prolonged inundation and erosion. The edge of the marsh activity retreated during the 2016 6-month monitoring period, so it is foreseeable that erosion has continued resulting in the loss of salt marsh on the outside bend of the tidal channel.

Figure 3.1 Salt Marsh and regulatory resource areas along Jack Knife Beach.

Figure 3.2 Measured bank position in 2015 (blue markers) and 2021 (red markers).

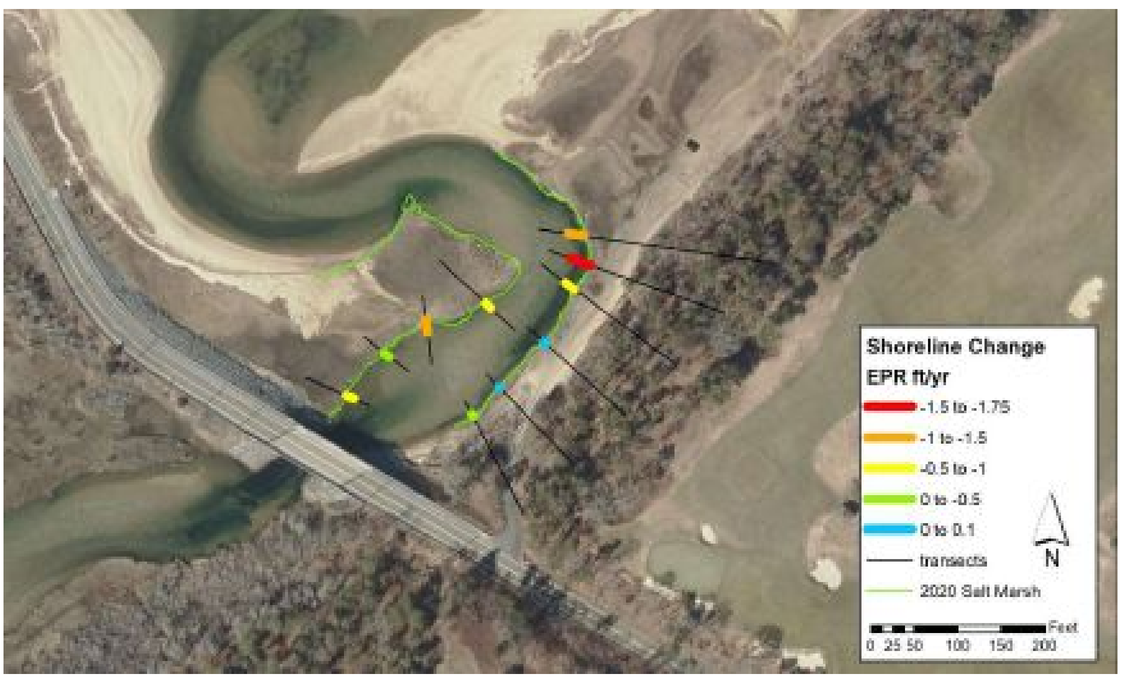

Figure 3.3 Shoreline erosion rates along the inlet channel to Muddy Creek between 2016 and 2020.

Figure 3.4 Detailed perspective of the peat bank undercutting along the tidal channel channel on November 10, 2020.

Figure 3.5 Detailed perspective of the peat bank undercutting along the tidal channel on November 10, 2020.

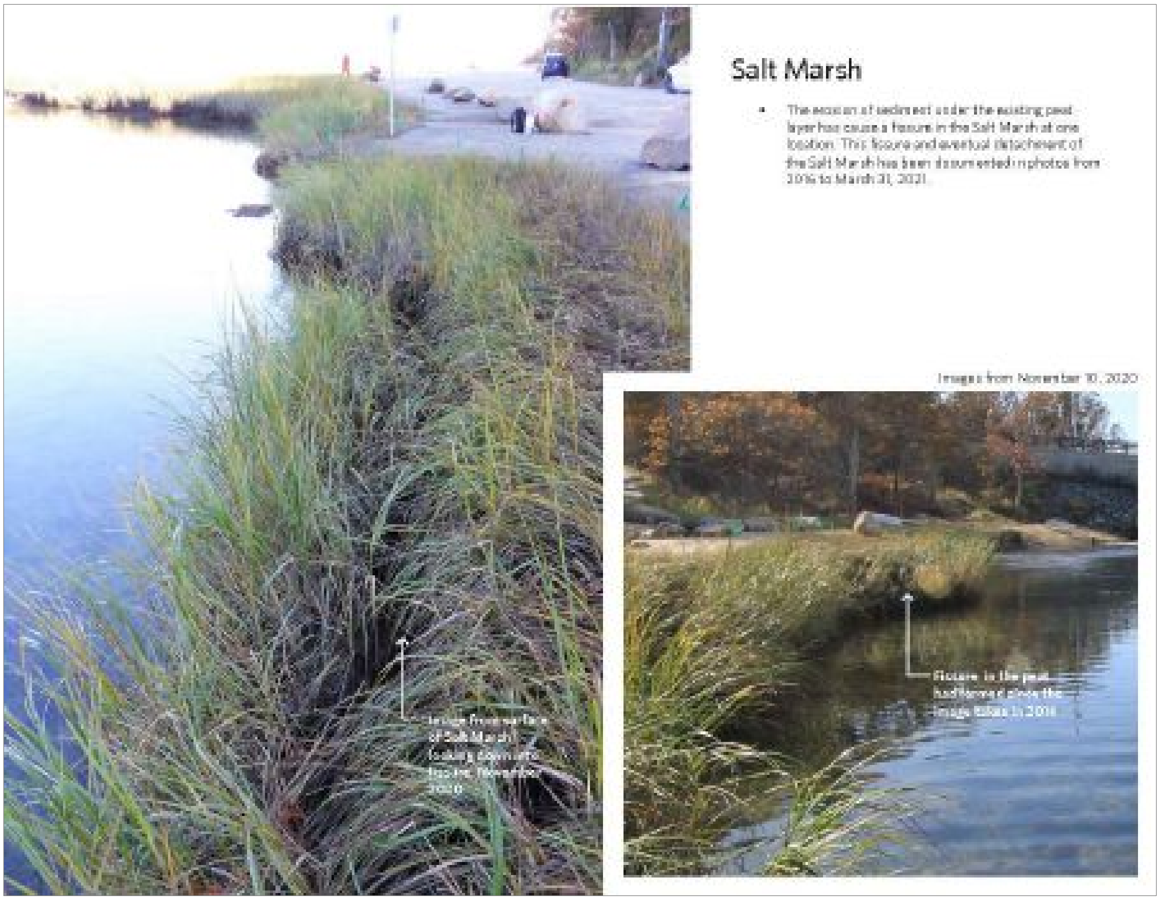

Figure 3.6 Photographs of a fissure developing in the salt marsh peat surface along the inlet tidal channel on November 10, 2020.

Figure 3.7 Photographs of the collapse of salt marsh bank between November 10, 2020 to March 31, 2021

3.2 Observed Conditions with the Salt Marsh

During two site visits to Jack Knife Beach in November 2020 and March 2021 a number of different areas of concern were noted which need to be addressed as part of the restoration process to prevent continued degradation and loss of salt marsh. These factors are related to the usage of Jack Knife beach and are related to vehicle passage and parking, foot traffic and trampling of marsh vegetation, and launching of paddle craft over the salt marsh. Vehicle passage and parking along the backside of Jack Knife Beach has resulted in damage to the landward salt marsh edge and will be important to address during the development of alternatives. The Town of Chatham has taken steps to minimize the damage by setting large stones to prevent vehicles from crossing into the salt marsh, however additional measures need to be considered to provide more prominent visual barriers to protect the marsh edge. Visual barriers could also be effective in minimizing the public from straying from access pathways onto the vegetated marsh. Signage could also provide educational information and directions on ways to minimize damage, for example a signed and marked area for the launching and recovery of paddle craft could minimize the usage of marsh surface by recreational users looking to minimize the distance from their vehicles and the water. These concerns are further illustrated in the following series of photographs of unintended recreational impacts to the salt marsh.

Figure 3.8 A unvegetated areas of highly impacted salt marsh adjacent to the parking area. The areas have been depressed by tires and collect water during high tides and rainfall events resulting in the loss of salt marsh vegetation.

Figure 3.9 Photograph representing the heavy public usage of the Jack Knife recreational area during the summer. The lack of boundaries between the salt marsh and parking areas has resulted in unintended parking and passage on vegetated salt marsh surface. A unvegetated area of highly impacted salt marsh adjacent to the parking area has been depressed by tires is holding standing water on the left side of the photograph.

Figure 3.10 Illustration of the heavy public usage of the Jack Knife recreational area during the summer. Boats have been left on fringing areas of salt marsh vegetation. The lack of designated boat racks and boundaries between the salt marsh and the public recreational spaces has resulted in unintended damage to the salt marsh surface.

3.3 Topographic and Bathymetric Survey

A topographic and bathymetry survey of the entire Jack Knife Beach complex was conducted to support the development, design, and permitting of alternatives. The survey was conduct by Coastal Engineering Company for the Town of Chatham. Coastal Engineering Company has been collecting monitoring data for years along this shoreline on behalf of Eastward Ho. Eastward Ho agreed to allow the Town of Chatham and Pleasant Bay Alliance to utilize the past monitoring data as a basis for the existing conditions survey. The wetland flagging data was sharing with Coastal Engineering Company along with the locations the channel transects which had been part of the 2016 monitoring. The surveyors were able to located the transect positions and measure an updated set of profiles. The survey was completed in February of 2021 and then utilized by the Project Team as part of the alternative development.

3.4 Evaluation of Cross-Channel Geometry

Cross-channel bathymetry sections were established and surveyed upstream and downstream of Route 28 beginning in 2015 by Massachusetts Division of Ecological Restoration prior to the construction of the bridge over Muddy Creek. The transect end-points are permanently marked with PVC pipe set vertically into the marsh. Two additional transects were added to the post-construction monitoring conducted in 2016. The additional transects were added to the outer channel, in the vicinity of the Jack

Knife Beach access road, due to concerns about erosion and shifting of the channel that potentially could alter the functionality of the access road. During the existing conditions survey the transects downstream of Route 28 were measured to provide an updated view of the changes occurring.

Plots of the cross-channel profile data are presented in Figures 3.12 through 3.18. The transect plots are presented from Pleasant Bay progressing upstream toward the Route 28 bridge. The numerical sequence of the transect order is presented in Figure 3.11. Each cross-section figure shows the data from the Fall of 2015 pre-construction survey and the June, July, September, and November 2016 post-construction surveys (There is no pre-construction survey data for Transects 10 and 11) and the February 2021 updated conditions survey.

Figure 3.11. Locations of the cross-channel monitoring transects.

The focus of examining the transect data is to look for sustained changes in channel geometry which could be attributed to degradation or losses in the marsh. Transect 1 is closest to Pleasant Bay and depending on the stage of the tide and storm surge levels is open to wave energy from a Nor'easter type storm event. The cross-sectional profiles for Transect 1 are shown in Figure 3.12, the data from 2021 shows a significant shift in the channel to the south. This can also be seen in the plan view of the bank data shown in Figure 3.2. A review of historic aerial photographs shows that the inlet to Muddy Creek has historical osculated in position as the ebb shoal and shoreline shifted, likely driven by Nor'easter storm events. Similar shifts in inlet position should be expected to continue into the future. Review of Transect 2 (Figure 3.13) shows that the cross-section has not experienced any significant shifts similar to Transect 1, but it does show a significant retreat of the eastern marsh bank. The eastern edge of the channel has contained the main flow conveyance channel since 2016, the higher magnitude flows in this section of channel can scour weak or damaged sections of marsh along the channel edge causing eventual collapse into the channel as the peat soil is washed away or undercut. A deepening of the channel along the eastern bank is also shown in Transect 3, Figure 3.14, which corresponds to erosion shown in this area which was discussed above and shown in Figure 3.3. Transect 4, 10, 5, and 11 (Figures 3.15 to 3.18 in the order of occurrence) show that channel geometry has remained relatively stable over the past four years. This trend is expected to continue with some minor adjustment as the system continues to respond to the changes in tidal range and winter storms. Erosion of marsh along the northside of the channel, which was discussed previously, can be seen in Transects 4 and 10. The steepening and cutting back of the southern shoreline is observable in Transect 5 and 11, corresponding to the erosion shown in Figure 3.3. At the time of the survey, the bank in this area had yet to cleave away and settle into the channel. The increase in depth on the southern side of the channel has resulted in bank being undercut and loss of salt marsh along the edge of the marsh plain. The slow continual undercutting is expected to continue at the sand/peat interface at the base of the channel, repeating the cycle of salt marsh cleaving away from the remaining marsh over time. This is an area where a designed sacrificial enhancement of the bank face could minimize future erosion.

Overall, the erosional areas are predominately located immediately after armored channel through the bridge and at channel bends where the complex nature of the tidal flows caused by curvature effects generate secondary currents. The secondary currents occur in the plane normal (across channel towards the marsh banks) to the primary flow direction (along channel the axis). The secondary currents appear at bends due to skewing of a portion of the cross-stream vorticity into the along-stream direction. The main, skew-induced secondary cell drives fast, near-surface water outwards at a bend, and carries slow, near-bed water inwards. The high intensity outward flow scours sediment along the face of the channel bank, while the near-bed return flow carries sediment to the inside of the bend where it is deposited as the flow velocities decrease. The changes in channel geometry resulting from the secondary flows can be clearly observed in the historic progression shown in the cross-sectional plots.

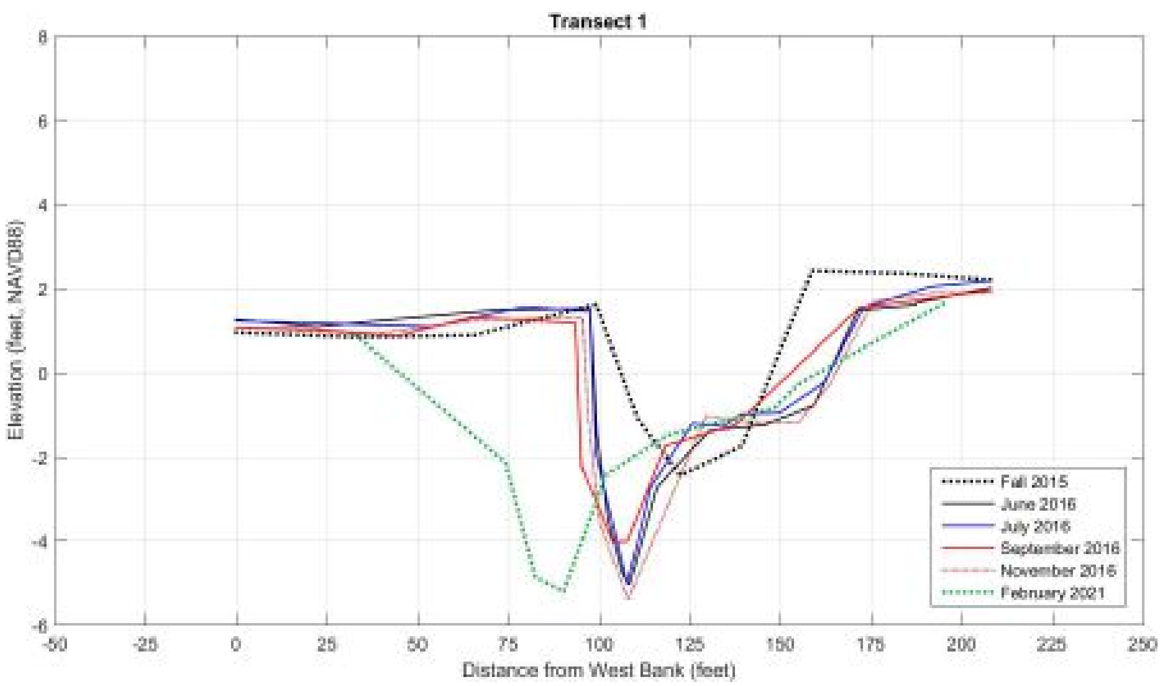

Figure 3.12 Cross-channel monitoring Transect 1. Distance are relative to the West Channel Bank and datum elevations are given relative to NAVD88.

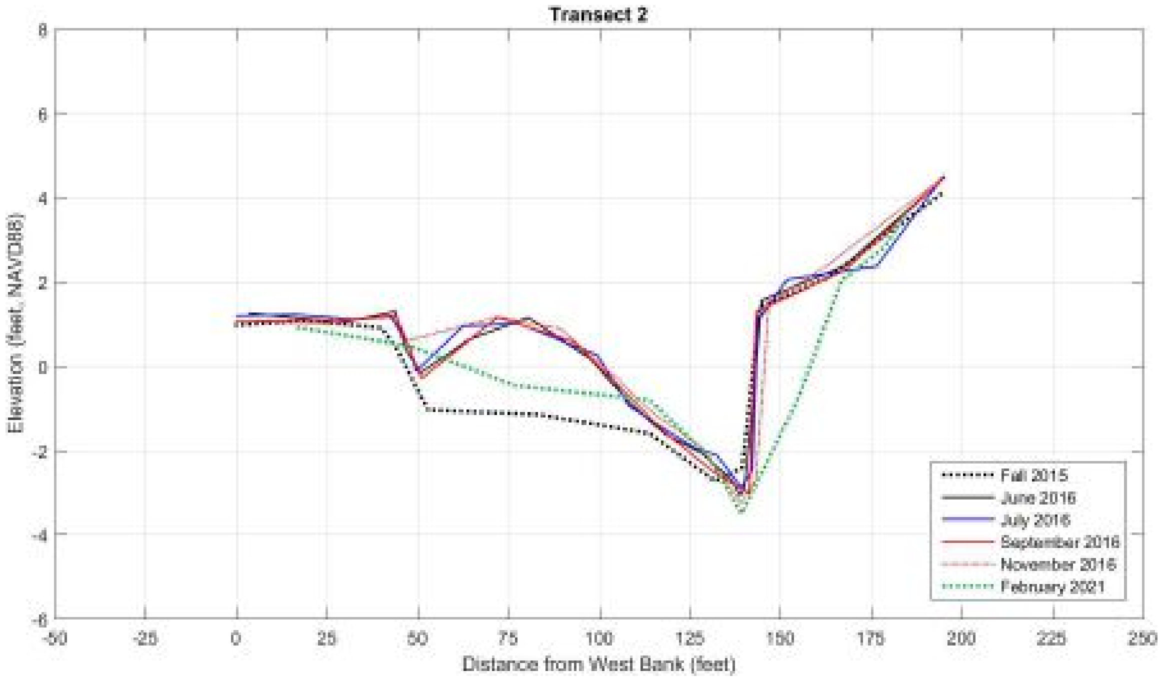

Figure 3.13 Cross-channel monitoring Transect 2. Distance are relative to the West Channel Bank and datum elevations are given relative to NAVD88.

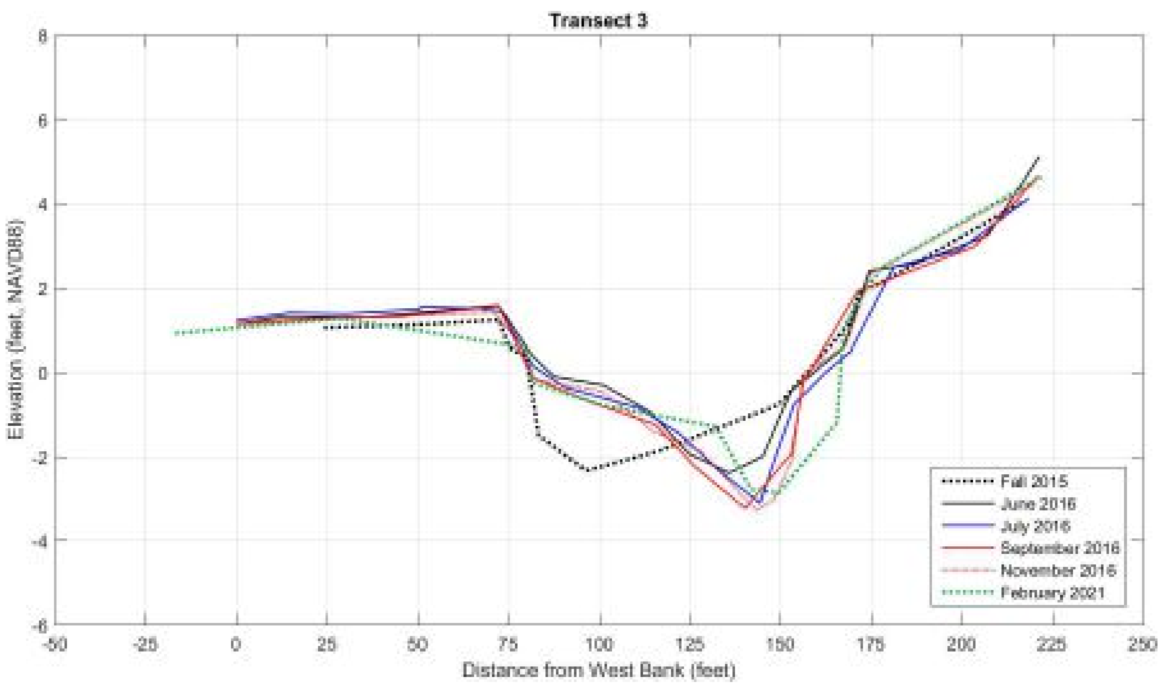

Figure 3.14 Cross-channel monitoring Transect 3. Distance are relative to the West Channel Bank and datum elevations are given relative to NAVD88.

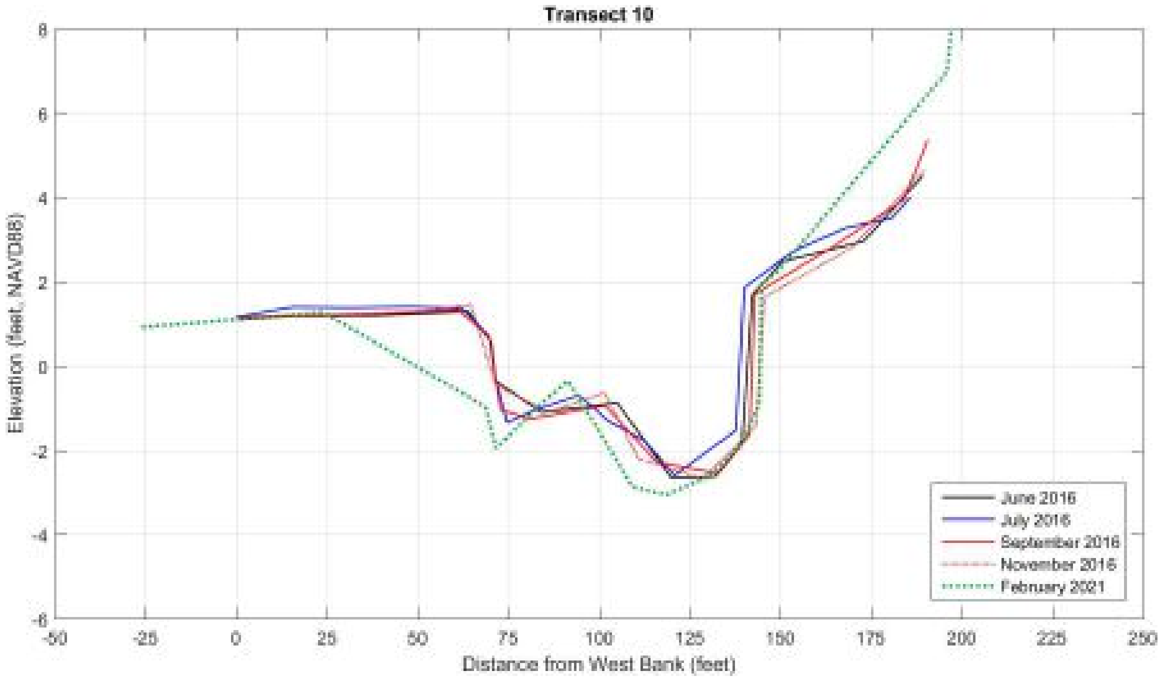

Figure 3.15 Cross-channel monitoring Transect 10. Distance are relative to the West Channel Bank and datum elevations are given relative to NAVD88.

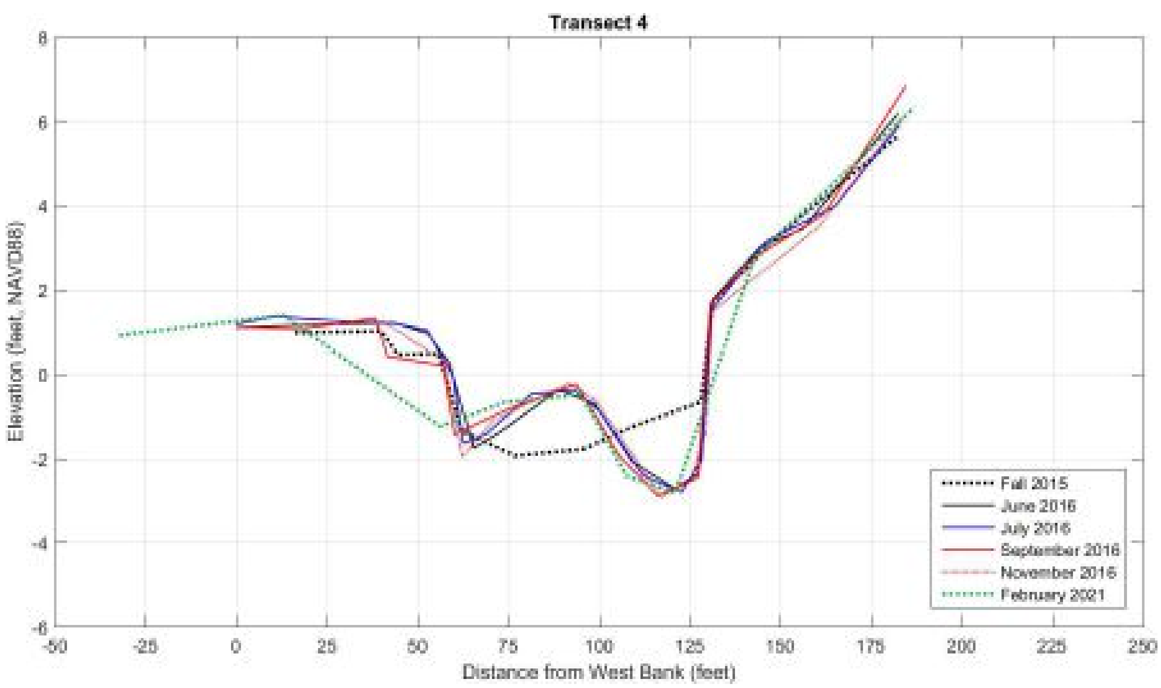

Figure 3.16 Cross-channel monitoring Transect 4. Distance are relative to the West Channel Bank and datum elevations are given relative to NAVD88.

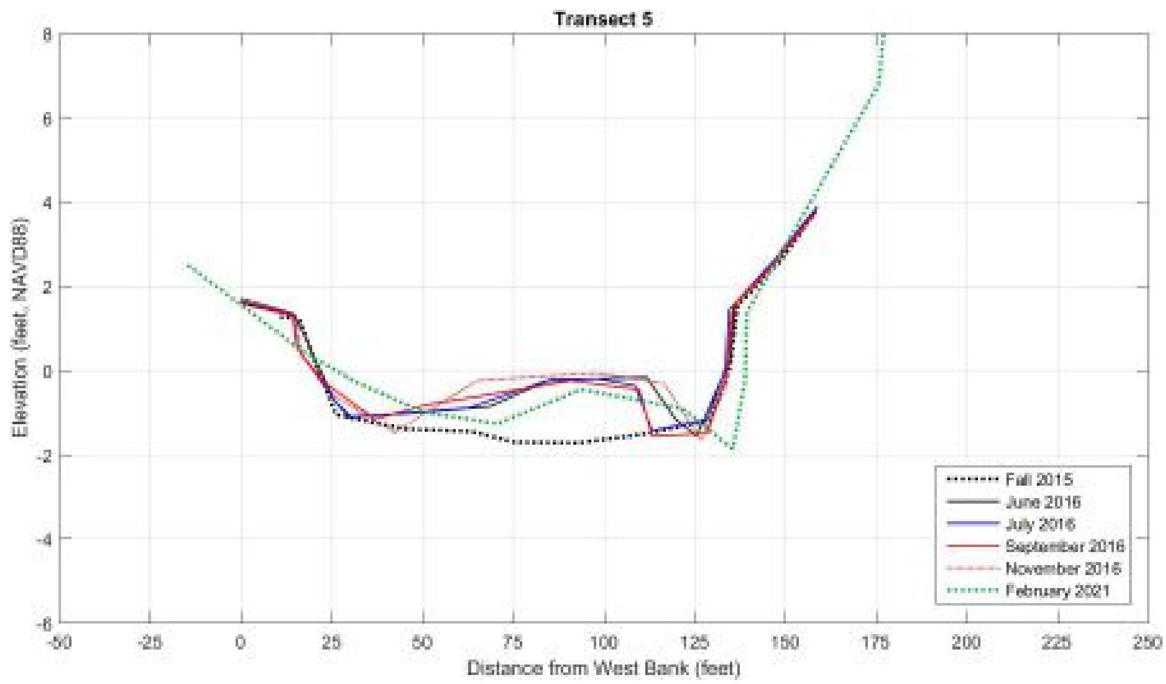

Figure 3.17 Cross-channel monitoring Transect 5. Distance are relative to the West Channel Bank and datum elevations are given relative to NAVD88.

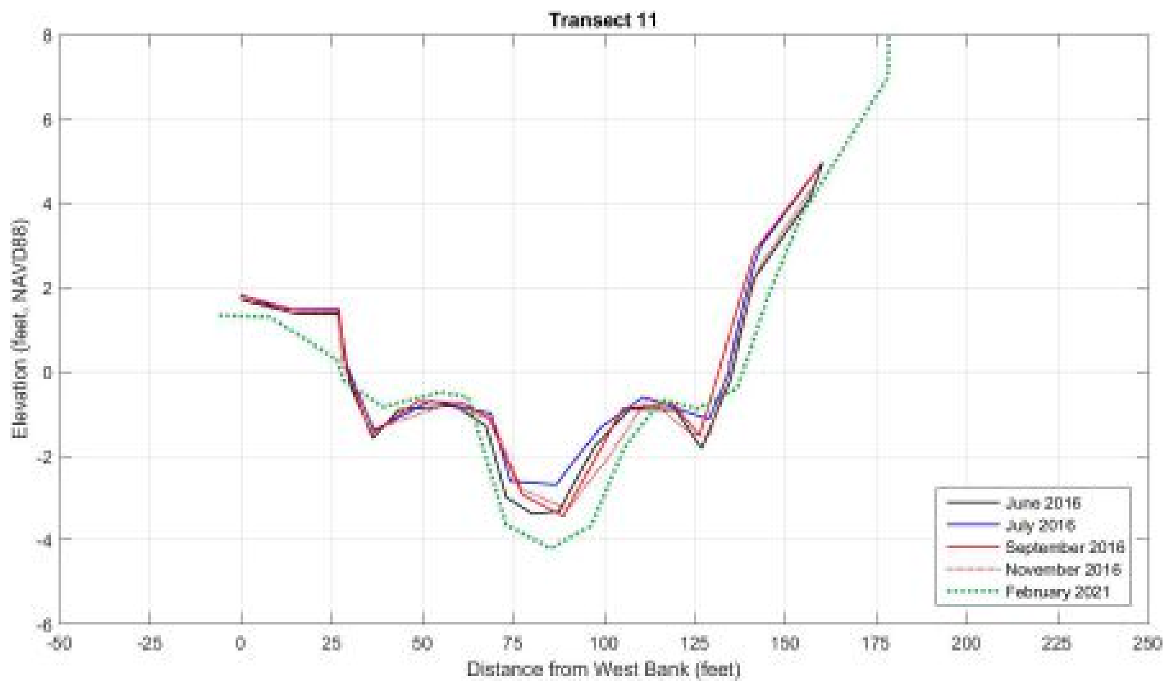

Figure 3.18 Cross-channel monitoring Transect 11. Distance are relative to the West Channel Bank and datum elevations are given relative to NAVD88.

3.5 Shellfish Survey

Town of Chatham DNR Shellfish Division conducted a shellfish survey of Muddy Creek on April 14, 2021. The survey area was limited to Chatham waters within Muddy Creek. The survey did not locate significant abundance of shellfish in the project area. The survey report noted there were no indications of siphon holes which would indicate live soft-shell clams, quahogs (Mercenaria mercenaria) and/or razor clams (Ensis directus) within the project area. The most abundant shellfish resource in Muddy Creek were sub-legal quahogs, in addition to ribbed mussels attached to peat, blue mussels, single sea clam, legal quahog, and oyster (Chatham DNR, 2021). Figure 3.19 shows ribbed mussels attached to the peat bed along Muddy Creek.

Figure 3.19 Ribbed mussels were also observed within the Salt Marsh. Images below were taken within the project area March 11, 2021.

4. Jackknife Beach Area Alternatives Analysis

The Project Team has brought forward and evaluated numerous alternatives to stabilize the salt marsh. A project goal was to utilize 'green' or nature-based solutions to address the losses in salt marsh. However, the Project Team decided to include more traditional approaches for stabilization to ensure that the alternatives analysis was inclusive of all the potential solutions for Jack Knife Beach. A number of these options were deemed as non-viable during the assessment due to environmental impacts, regulatory constrains associated with wetland resources and project being located with an Area of Critical Environmental Concern (ACEC). ACECs are places in Commonwealth that receive special recognition because of the quality, uniqueness and significance of the natural resources. However, the function of how these 'harder' engineered approaches to address stabilization or erosion can be useful to review to determine how similar nature-based approaches can be adapted and modified to produce similar results.

The basis for the screening process of alternatives is the USACE Highway Methodology. The primary emphasis of the alternative selection process is screening, where the process is to identify the most appropriate alternative(s) based upon a series of exclusionary and discretionary criteria. There are no numerical thresholds that identify the best alternative; rather, the screening process is designed to assess a wide range of potential alternatives, and through comparative analysis of various rating criteria, narrow the list of options until only the most appropriate remain. This process ensures that the most appropriate options are carried forward to the conceptual design phase.

Screening criteria are characterized as either exclusionary or discretionary. Exclusionary criteria reflect potential measures that are not technically feasible or are prohibited by local/state/federal regulations. Discretionary criteria are those that determine, when applied as a group, the alternatives which are least or best suited for the stabilization and restoration of salt marsh while preserving public recreational and access viability of Jack Knife Beach. The application of discretionary criteria is the main component of the screening process, and it is the process by which the alternatives are compared amongst themselves, using site-specific information to prioritize alternatives.

4.1 No Action Alternative (Continuation of Existing Practices)

- Erosion protection – Poor, taking no action does not address the active and ongoing erosion and undercutting of base of the channel banks which is leading to loss of salt marsh, nor the on-going encroachment of the public on the marsh surface further impacting the viability of the salt marsh.
- Potential environmental impacts – Minimal to Moderate, the continued loss of salt marsh is likely to continue unabated. Given the proximity of the accessway and parking areas relative to the higher fringing salt marsh, no significant area exists for any considerable landward migration of the marsh over time. Not introducing visual or physical measures to direct foot and vehicle traffic away from the marsh and identifying specific areas for launching and storage of paddle craft is anticipated to result in continued damage and loss of salt marsh.
- With the continued loss of marsh which can naturally abate storm energy coupled with rising sea levels, it is expected that the Jack Knife Beach will see exacerbated nuisance and storm flooding of the upland areas of the upper beach, parking area, and access road down from Route 28. It will be necessary for the Town to increase maintenance to protect the access way and parking area. It is expected that fill will be required to preserve public as water levels increase.

Under the No Action alternative, no measures would be undertaken to stabilize the access way or parking area to minimizing anthropogenic effects or to address the on-going loss of salt marsh vegetation and erosion along the channel bank. Future repairs and maintenance to the access way by the Town would continue until such time that repairs to the way were no longer feasible or “non-permitable” due to regulatory constraints.

As a management tool, it is instructive to evaluate the ‘No Action’ alternative to assess whether proactive measures to stop erosion and loss of the salt marsh are necessary from both a short-term and long-term perspective. For the ‘no-action’ alternative, loss and erosion of the existing salt marsh can be expected to continue at its present or at a higher rate in the near future. In areas which salt marsh is completely lost, erosion rates are apt to increase due to the loss of vegetative root systems and associated peat bed which bind the underlying sediments together and minimize the suspension and movement of sediment. Additionally, the loss of vegetation on the surface will likely expand the areas of public use, further degrading adjacent salt marsh and banks along the tidal channel. Therefore, the ‘no action’ alternative does not provide long-term viability for Jack Knife Beach and will result in loss of salt marsh. This is an important public recreational area for the residents of Chatham and was considered an unacceptable alternative.

4.2 Natural Fiber Roll Array and Envelopes

- Erosion protection – Good in short-term - soft alternatives such as fiber rolls or sand/growing medium filled envelopes are generally not designed to withstand the daily tidal inundations or the associated tidal currents. Use of fiber rolls in Muddy Creek would likely experience considerable degradation within two years, which would limit the time for a halophytic plant community to become established. A sand/growing medium filled envelope would be more suspectable to large or catastrophic deflation due to the loss of sediment as the natural fibers degrade, thus shortening the design life to approximately 12-18 months.

- Potential environmental impacts – Minor, it is expected biodegradable debris from fiber roll would be dispersed into Pleasant Bay or Muddy Creek and continue to naturally decompose.
- Constructability - Constructing a solution with fiber rolls or envelopes would be straight-forward, with appropriate light construction equipment to drive any required anchors, excavate, and place material along the salt marsh and beach area.
- The natural fiber would likely require monitoring and potential maintenance or reconstruction after storms if the integrity of the rolls or envelopes were damaged by floating debris or increase scour associated with storm events.
- A solution constructed strictly with natural fiber rolls and envelopes is not expected to prevent the medium and long-term continued loss of salt marsh or prevent future damage to the public access way to Jack Knife Beach. It is anticipated the roadway could be non-functional in a period of 10 years, depending on storm severity and the rate of sea level rise.

Soft natural fiber alternatives can involve several different components (i.e. coir envelopes, fiber rolls, erosion control mats, etc.), which are often combined to build a shore protection system to address erosion and stabilize beach faces, dunes, or coastal banks. The materials comprising a majority of these shore protection systems are generally biodegradable materials such as jute, coconut (coir) fibers, untreated timber, and sediments as opposed to rock, concrete, steel, and geotextiles which will not degrade as rapidly in the marine environment. Therefore, these natural fiber systems are considered 'soft' by local, state, and federal regulations and looked on more favorably. The use of biodegradable material also makes the structures temporary in nature. For this application, the goal of the fiber rolls is to reduce and minimize the loss of the peat and natural sediments from the base of the channel bank. This would ensure a stabile substrate, allowing for additional stabilization and restoration of the salt marsh vegetation above. The natural degradation of jute and coir fibers which are regular submerged, would not provide sufficient time for a halophytic plant community to become fully established. A sand or growing medium filled envelope would likely degrade and deflate in approximately 12-18 months with the intertidal characteristics of Muddy Creek.

Options for enhancing the performance of natural fiber system could include the use of naturally rounded river stone (characteristic of the material found in the tidal channel) as an additional component included within the growing medium. The increased weight would limit the ability of the current to transport the material away, allowing it to naturally settle along the base of the channel bank protecting from future scour. Increasing layering of natural fibers could also provide additional structural strength to the system, the doubling of fibers as the fabric approaches the end of the natural design life would provide an additional safety factor for the halophytic plant community to become fully established.

4.3 Open Weave Synthetic Fiber Rolls and Envelops

- Erosion protection – Good - synthetic fiber rolls and envelops are similar to natural fiber alternatives above in function and use. However, various forms of synthetic material are utilized to increase the design life of the material. This is advantageous when utilized in higher current or wave environments where the natural fibers break down before the vegetation can fully mature and establish roots systems. In some applications the synthetic fiber is blended with natural fabrics to enhance longevity, and example is shown in Figure 4.1.
- Synthetic alternatives such as rolls or filled envelopes can be designed to withstand the daily tidal inundations and address the scour of the peat bank. The use of synthetic alternatives is more prevalent in fresh water stream and riverine settings. The increased design life over a standalone natural fiber alternative would provide the increased time for a halophytic plant community to become established and greater ability to withstand storm energy.

- Potential environmental impacts – Minor, the synthetic rolls and envelops are designed to be open weave and are developed to blend into the natural environment. However, if removal were required in the future, the fiber could be cut along the surface but covered sections would remain and eventually be released into the environment when erosion occurs.
- Constructability - Constructing the with synthetic fibers would be similar to construct with natural fiber solutions and would be straight-forward. Construction would require appropriate light construction equipment to drive any required anchors, excavate, and place material along the salt marsh and beach area.
- Regular monitoring and adaptive management will be required to ensure the halophytic plant community takes hold and natural sediments are not lost initially after construction. Periodic maintenance should be anticipated after moderate to severe storms. Use of synthetic fibers could potentially extend the design life 5 to 10 years over the natural fiber solutions.

Utilization of synthetic fibers or adaptive utilization of synthetic fibers in conjunction with natural fibers can involve several different components, just like solutions using natural fibers (i.e. rolls, envelopes, erosion control mats, etc.). The individual components are often combined to build shore or bank protection systems to address erosion and stabilize channel banks, coastal banks, and other areas that experience erosion from water flow. The synthetic fabrics used in these products are designed to prevent the structural fabric from degrading as rapidly in the marine environment. It is important to consider how UV degradation will affect the material. A number of the synthetic products on the market require a covering of sediment to protect from UV exposure, which weakens and breaks down the material. A protective cover layer of sediment would not be possible along the marsh bank due to the constant tidal flow which would wash sediment cover away. A key distinction which should be mentioned is these fabrics are different in design from closed weaved geotextiles which are meant to serve as barrier to sediment movement and not intended to serve as foundation for vegetation. The fibers being consider are open weaved to allow for vegetation to grow through the fabric and thus will allow for some sediment movement through the surface.

Figure 4.1. Coconut fiber log with synthetic reinforcement (Photo Credit: An-Wil Inc.)

The use of synthetic rolls and envelopes are widely used in fresh water settings to restore and stabilize channels and banks from storm water and highwater flows. The use in tidal channels is emerging in different areas of the country as the technology evolves and gains acceptance with local, state, and federal regulators. Use of hybrid synthetic and natural fiber solutions have been previously approved within the Commonwealth along steep eroding coastal banks, however there are no known approvals within a salt marsh or tidal creek. With the added requirements associated with the project site being located within an ACEC, it is unlikely a solution incorporating synthetic materials would receive regulatory approval while natural fiber materials exist and can be design to provide similar levels of protection and function.

4.4 Rock Sills, Stone Revetments or Sheet Pile Seawalls (Coastal Engineering Structures)

- Erosion Protection – Moderate, coastal engineering structures of the types listed can protect an area landward of the structure. However, these types of structures can accelerate and redirect tidal flows causing increased erosion at the ends of the structure. Scour at the toe of the structures is also likely, the elevation of the intertidal tidal area fronting the structure could be maintained with the use of additional rock scour protections. These types of structures are not often used in sensitive eco-systems unless required as part of the design of critical infrastructure. A similar but smaller scale approach could be the use of low elevation flow redirecting sills. A properly designed sill would disrupt the tidal flow along the marsh bank and could offer increased longevity of the salt marsh due to the erosional force reductions. The materials utilized could also be varied to increase the sensitivity to the environment.
- Potential Environmental Impacts – Significant, both during construction and in the long-term. Tidal scour would be expected to be amplified by a hardened structure along the salt marsh bank. End scour should be anticipated at the terminus of the structure and the location and characteristics of the adjacent channel would be expected to change in response to the reflection and concentration of tidal energy. The environmental impacts related to a natural rounded rock or potentially shell sill in the tidal channel would be less than the more traditional coastal engineering structures. The material would be characteristic of the natural materials found in the channel sediments and vertical relief of the sill within the water column could redirect tidal energy. Depending on the material composition, a sill could provide habitat for aquatic organisms like algae, shellfish, and fin fish. Sediment could be added behind a sill and planted with native marsh vegetation. The top of the flow redirecting sill usually extends just above the mean high-water elevation.
- Constructability - straight-forward with the appropriate heavy equipment to place the stone or seawall sheets. Close consideration should be given to the adjacent salt marsh to prevent any negative impacts to this coastal resource area, which may prove challenging due to the size of equipment. A sill utilizing naturally round rock or shells could be potentially be constructed by hand with appropriate light construction equipment to lift and place shell and rounded stone within the channel just beyond the salt marsh.
- Limited maintenance would be required for traditional coastal engineering structure. The size and choice of material utilized for a sill would dictate the frequency and magnitude of maintenance.
- Protection of Jack Knife Beach – Mixed, the redirection of tidal energy could result in scour on adjoining areas of unprotected marsh and coastal resources in the vicinity of the project. Depending on the magnitude and location of scour, the introduction of a coastal engineering structure could ultimately threaten the larger salt marsh system, access way, and parking area.

A hardened shore protection alternative could be located along the eroding channel banks to prevent further erosion of the salt marsh. Regulatory limitations for this type of structural intervention would be prohibitive due to the ACEC designation in which the project is located and the wetland resources areas in which the structure would be constructed. Revetments and seawalls are considered Coastal Engineering Structures under the Massachusetts and Federal Wetlands Protection Act (WPA) Regulations. Coastal Engineering Structures are generally not allowed to protect salt marshes, coastal beaches, coastal dunes, or coastal banks, unless such a coastal bank supports a structure which predates the promulgation of the Wetlands Protection Act in 1978. No such structure exists along Jack Knife Beach. Therefore, a variance from the WPA and ACEC Regulations would be required. For a variance to be issued under the WPA, there must be a compelling public interest such as public safety. Access to a recreational beach area would not be sufficient to satisfy a variance from the WPA.

A flow redirecting sill constructed utilizing naturally rounded stone and/or shell would be viewed more favorably by the regulatory agencies. However, as a standalone structure designed to redirect tidal flow, the design would have to meet the same regulatory standards as a traditional Coastal Engineering Structure and therefore not able to receive regulatory approval. Examples of low elevation rock sills along a salt marsh are shown in Figures 4.2 and 4.3. Note that angular stone was utilized in these designs, as opposed to round rock. Neither example is located within a tidal channel similar to the setting found in Muddy Creek.

Figure 4.2 A low rock sill fronting a salt marsh restoration constructed along the eastern shore of Maryland using NOAA grant funding (Photo Credit: Chesapeake Bay Trust and NOAA).

Figure 4.3 Installation of living shoreline in Delaware Bay with rock sill and core logs with the addition of oyster shells along seaward edge. Restoration site 1-Year after installation. (Photo Credit: Delaware Department of Natural Resources)

4.5 Living Shoreline – Cobble Reinforced Marsh

- Erosion Protection – Mixed. Due to regulatory requirements, a typical living shoreline approach would need to be located just landward of the existing fringing marsh community. Therefore, ongoing erosion of the peat bank, which underlays the fringing marsh would continue unabated. A cobble reinforced marsh (CRM) community located just landward of the existing fringing salt marsh would resist the regular scour forces better than sandy sediment which presently exists along the base the marsh. The CRM is expected to ultimately become undermined and suffer the same fate as the existing fringing salt marsh.
- Potential Environmental Impacts – Minor. As the installation of a CRM would be located landward of the salt marsh and constructed with natural materials, both installation and long-term concerns are mitigated. All biodegradable components of a CRM would be expected to be full biodegraded by the time erosion may threaten a CRM intervention. Therefore, the only consideration would be for the cobble stone components, which would enter the inlet channel if the intervention was undermined by erosion. The CRM cobble is similar to the cobble located amongst the sediments naturally found within the tidal channel and there not a significant concern relative to environmental impacts.
- Constructability is straight-forward with the appropriate compact equipment to prepare the coastal beach area for placement of CRM components.
- Limited maintenance required, though regular monitoring and adaptive management is recommended.
- Protection of Jack Knife Beach – Moderate, the tidal scour forces which are undermining the marsh bank would decrease after the marsh erodes further and widens the tidal channel slowing the rate of scour at the toe of the CRM. The alternative represents a delay of the erosion of the Jack Knife Beach more so than a long-term alternative for the restoration of the salt marsh and preservation of this public recreational resource.

Living shorelines incorporate a variety of shoreline stabilization approaches to attempt to incorporate and mimic features of the natural environment and reduce erosion. The use of these systems has increased in recent years along stream and river banks, bays and estuaries with fringing wetlands and salt marshes where living shorelines projects can be effectively designed to stabilize the shoreline and create or enhance habitat or wetland resources. Living shoreline projects can take on a number of different forms from shellfish reefs; structures incorporating various forms of vegetation, bio-degradable materials, and habitat recreations; harden elements designed to recruit aquatic vegetation and/or shellfish, offshore living reefs, as well as more typical coastal engineering solutions which attempt to incorporate ecological principles into engineering design.

For living shoreline projects to be effective at providing erosion protection and enhancing the habitat or environmental resources after construction, it is critical that the environmental forces which are causing the erosion are accurately assessed and understood. The information and data regarding the natural processes can then be utilized to develop appropriate design parameters required for an effective living shoreline solution. The critical design parameters for design of a living shoreline system along Muddy Creek are;

- Tidal range is a critical factor in the design of most living shorelines projects not only for energy dissipation but tidal range is also critically important for any "living" portion of a project. Mussels, oysters and other shellfish cannot be exposed to air for long periods of time, and long-term viability also requires that exposure to freezing temperatures be minimized. For living shorelines that incorporate salt marsh vegetation, the elevation of the plants within the appropriate portion of the tide range is critical, often limiting the use of vegetation as shore protection along more exposed shorelines.
- Elevation of the salt marsh relative to beach and dune elevations and the elevation of the tidal flat to ensure the salt marsh is not buried as a result of the changes in littoral processes due to the measures taken.
- Soil bearing capacity of the sediment in the bottom of the channel relative to weight of the living shoreline feature and the forces tidal and wave induced currents will place upon the structure elements.
- Height of the living shoreline solution can be designed relative to tide or surge water levels to provide effective erosion protection to the backing salt marsh and public resource areas.

CRM are typical located just landward of the existing fringing marsh community to avoid impacting existing salt marsh. The design profile of a CRM matches the elevation of the boarding marsh and then gradually increases in height to provide a transition as water level increase and then gradually slopes downward to meet existing grades. The CRM is encased with two layers of coir and single layer of jute-burlap along the seaward edge. The coir envelope is filled with a mix of sediments tailored to the site conditions, but a typical sediment composition would include 50-percent by volume of 8-to-10-inch rounded cobble, 25-percent by volume coir fiber and compost, and 25-percent beach or marsh compatible sediments characteristic of the placement site. The surface of the CRM is planted with marsh species on 12-inch centers. Resulting in a stable low relief extension of the salt marsh landward of existing marsh boundary as illustrated in Figure 4.4. A CRM is very effective and restoring or increasing the overall extent of salt marsh, however additional solutions would be required to address the undercutting and loss of salt marsh along the channel edge at Jack Knife Beach. Numerous options exist, a few selected examples will be reviewed in conjunction with the use of a cobble reinforced marsh.

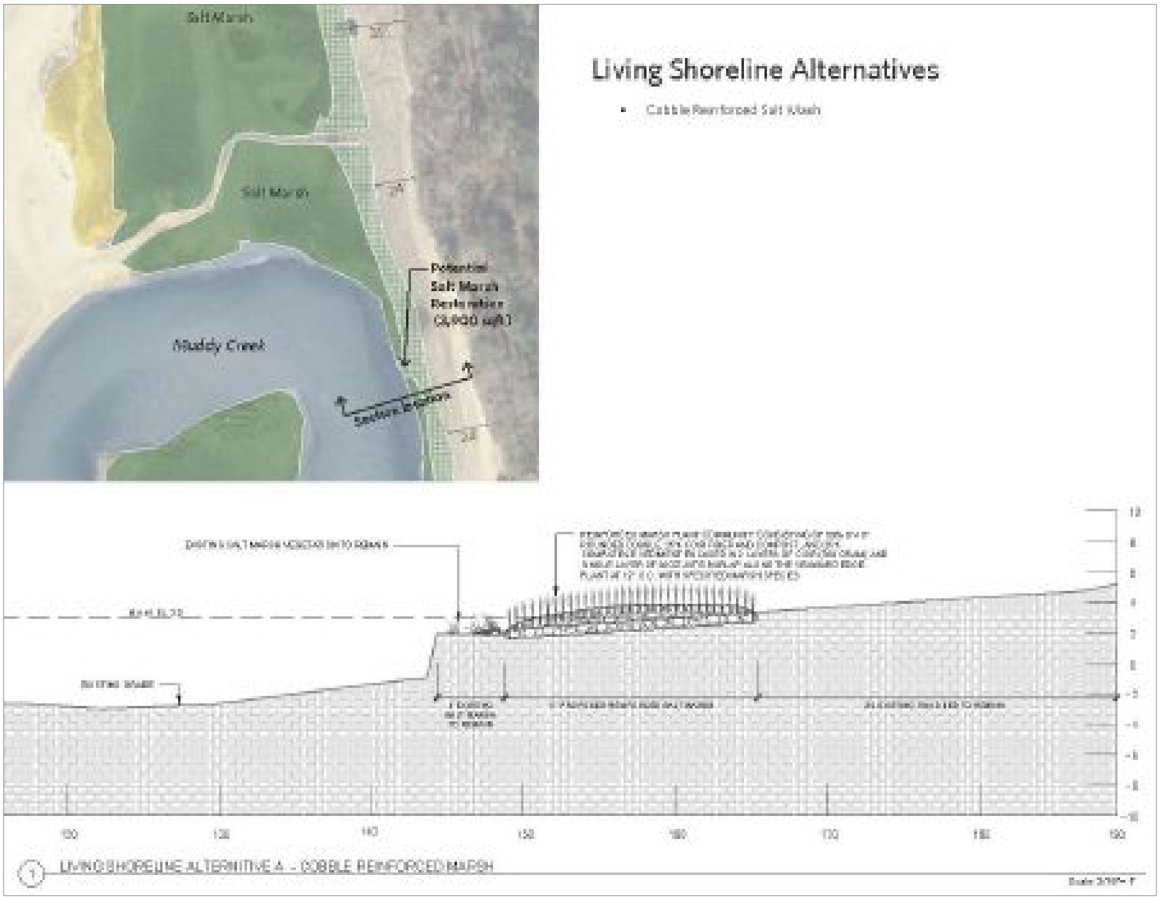

Figure 4.4. Typical cross-section of a Cobble Reinforced Marsh which could be utilized along the backside of the salt marsh at Jack Knife Beach.

4.6 Living Shoreline – Cobble Reinforced Marsh with Large Woody Debris

- Erosion Protection – Good. Due to regulatory requirements, a typical living shoreline approach such as CRM would need to be located just landward of the existing fringing marsh community. Large Wood Debris (LWD) could be carefully installed either in an existing peat bed where no salt marsh presently exists or LWD could be installed under the salt marsh surface within the peat beds which support existing fringing salt marsh. A large tree with the lower trunk and root crown preserved could be installed "trunk first" into the existing peat bank and anchored in place using low-profile earth anchors. The root crown would serve to create turbulence in the tidal currents and likely dissipate tidal energy and trigger the attenuation of sediment out of the water column. The installation of a cobble reinforced marsh (CRM) would increase the overall area of salt marsh community and provide a gradual increase in elevations along the landward edge to allow a natural response in the marsh vegetation to sea level rise.
- Potential Environmental Impacts – Minor to Moderate. The LWD would be placed either extending from the channel bank or anchored immediately adjacent to the bank. Excavating in areas which are in close proximity to salt marsh increase the potential for unintended impacts and thus would require close oversite during placement and anchoring of LWD. All the components of LWD and CRM are biodegradable and found within the surrounding marsh along Muddy Creek.

- Constructability is straight-forward. Appropriate compact equipment would be required to prepare the coastal beach area for placement of CRM components. Medium sized equipment would be likely required for the place of LWD. But the size and weight of the LWD selected, would determine the lifting capacity and hence size of the equipment required.
- Limited maintenance required, though regular monitoring and adaptive management is recommended. If LWD were to break free of its anchor cables during a severe storm, it could potentially damage adjacent resource areas, though this risk could be satisfactorily mitigated with regular monitoring. It should be noted that a naturally occurring LWD is presently located in the central reach of Muddy Creek in the vicinity of the project area. No impacts, other than the accretion of sand, have been observed with the naturally occurring LWD in Muddy Creek.
- Protection of Jack Knife Beach – Good, the inclusion of LWD to create turbulence in the tidal currents and dissipate tidal energy would help minimize the scour forces which are undermining the existing fringing marsh. This would enhance the viability of the existing marsh and newly created area of CRM.

The incorporation of natural wood logs along the channel banks to stabilize and reduce the tidal and wave energy mimics features of the natural environment and can be used to reduce erosion. The use of LWD has increased in recent years along stream and tidal banks in marsh and estuary restorations with remarkable success. The logs are installed anchored into the banks extending into the channel to create turbulence as the current moves around the logs, which dissipates energy and flow velocities. The reduction in erosive forces can aid reestablished of banks and minimize the straighten of tidal channels that can occur over time. A few examples of the use of LWD are shown below in Figures 4.5 and 4.6. A number of the restoration projects incorporating logs have been implemented by NOAA and USFWS. The use of LWD by these agencies has increased the awareness and acceptance among regional and state agencies. Thus, the approval for the use of LWD has been gaining acceptance as a restoration tool.

Figure 4.5 Tidmarsh Farms River & Wetland Restoration. The restoration utilized approximately 3,000 pieces of large woody debris into the stream restoration (Photo Credit: Mass Audubon).

Figure 4.6 Bandon's Ni-les'tun Marsh restored 400 acres of diked and drained pasture into a vibrant tidal marsh. The project created over 5 miles of new tidal channels and doubled the acreage of tidal marsh habitat in the estuary (*Photo Credit:* Roy Lowe, USFWS).

For restoration projects to effectively incorporate LWD into the design for erosion protection and enhancement of the diversity of habitat, it is critical that the environmental forces which are causing the erosion are accurately assessed and understood. Based on the tidal and environmental forces occurring along Muddy Creek, the size and magnitude of large woody debris shown in the restoration examples above are well beyond what would be required. Logs could be incorporated in two locations along the channel to dissipate energy and minimize the undercutting of the bank. Due to the heavy public usage of Jack Knife Beach by families, concerns about tidal currents carrying people along the channel and into the logs was considered. While unlikely, it was decided that open root systems may not be appropriate for this site. Without the enhanced turbulence generated as flow passes by the submerged root system, additional logs would be required to generate the same level of scour reduction. The use of LWD with a CRM is illustrated in Figure 4.7. The volume of logs added as part of the restoration was limited relative to the quantities shown photographs above, to not adverse impact the existing recreational uses of the channel for shell fishing, paddle boating, and swimming and wading along the tidal channel.

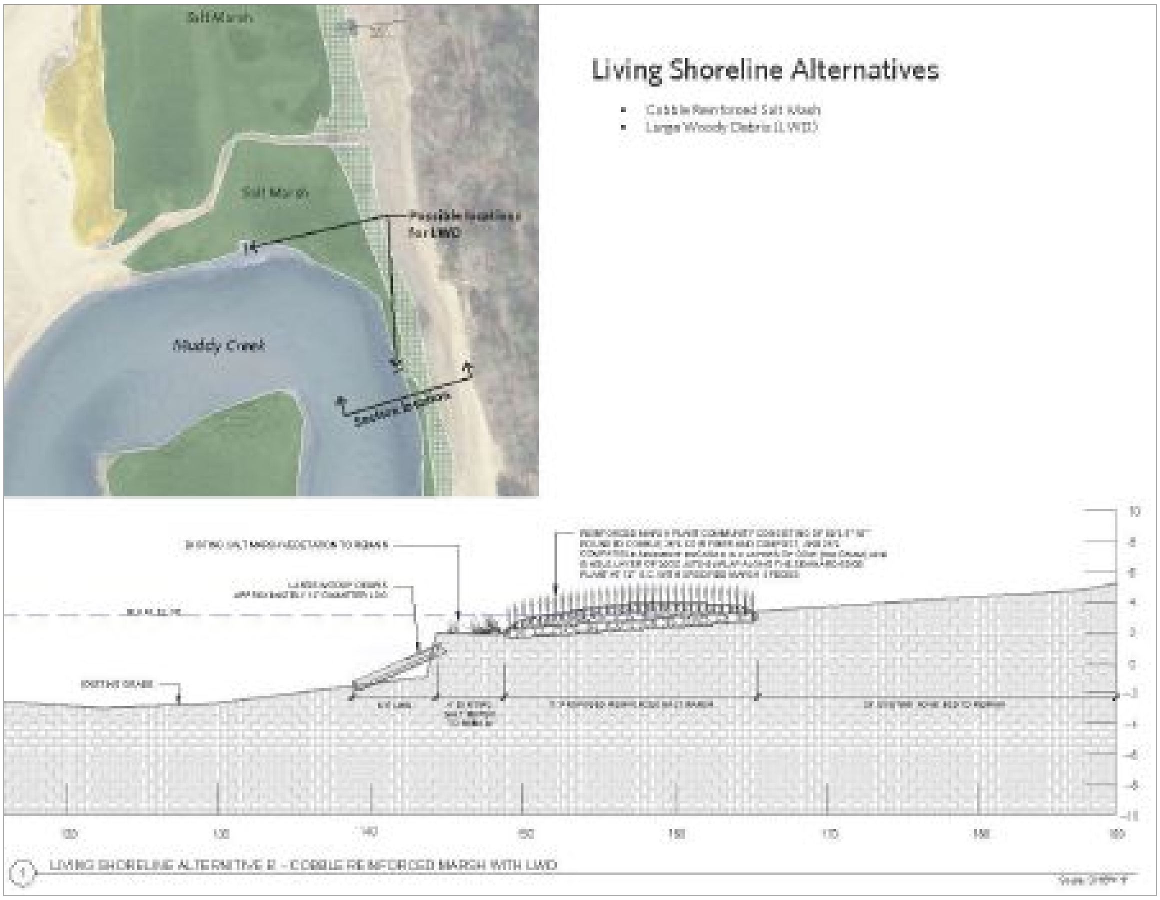

Figure 4.7 Typical cross-section of a Cobble Reinforced Marsh with Large Woody Debris.

4.7 Living Shoreline Alternative – Cobble Reinforced Marsh with Ribbed Mussel Reef

- Erosion Protection – Good. A ribbed mussel reef could be carefully installed just seaward of the existing peat shelf, within the intertidal area to protect the base of the channel from undercutting and scour. CRM would be located just landward of the existing fringing marsh community as discussed above. The ribbed mussels would initially be naturally anchored to natural coir fabric and stabilized with rounded cobble inside of the fabric roll. The cobble would serve as both ballast and a long-term anchor medium for the mussels after the coir fabric naturally biodegrades. The mussel reef would serve to both protect the eroding peat shelf from further erosion and create turbulence in the regular tidal currents and likely dissipate tidal energy and trigger a moderate attenuation of sediment out of the water column. The mussel reef alternative would likely provide the best protection to the existing fringing salt marsh as mussel reefs are incorporated with the seaward edge of the fringing marshes in the immediate vicinity of the project area where the marsh appears particularly stable and healthy.
- Potential Environmental Impacts – Minor. The environmental impacts associated with the installation of a CRM have been discussed above. The addition of a ribbed mussel reef constructed will natural materials would result in no environmental impact if the mussel reef component were ultimately unsuccessful. Ribbed mussels are found throughout the Muddy Creek estuary, coir fabric will naturally bio-degrade, and cobble stones which would remain are compatible with the sediment found in the channel.

- Constructability is straight-forward. The ribbed mussels would either have to be grown offsite or purchased and then allowed to anchor to the coir fabric in a controlled setting. The ribbed mussel-colonized coir fabric could be assembled into a roll and ballasted with cobble by hand. A mini excavator would be placed landward of the existing fringing salt marsh to convey the cobble stones over the fringing salt marsh to prevent any impacts to the marsh.
- Limited maintenance required, though regular monitoring and adaptive management is recommended. The coir is suspectable to damage and should be monitored after storm events.
- Protection of Jack Knife Bach – Good, the combination of a CRM to provide longer-term protection of the public infrastructure combined with the incorporation of a ribbed mussel reef to manage the immediate erosion of the salt marsh bank, which represents the first line of defense from erosion in this sensitive and important area for the Town of Chatham.

The use of ribbed muscles is similar to the use of oysters to improve habitat and overall water quality. Paired with the cobble reinforced marsh, the restoration components will help to ensure sustainability and longevity of the eroding marsh bank. The use of ribbed mussels needs to consider the influence of the tides and effects of prolonged exposure to air and freezing temperatures so the use of muscles would occur between the mean low water (MLW) or the bottom of the channel and mean high water (MHW). Muddy Creek has adequate salinity and dissolved oxygen for growing conditions, and ribbed muscles are found within the system upstream of Route 28. The concept of anchoring of the ribbed mussels to coir fabric has already been proven in preliminary tests. In informal test that Wilkinson conducted with the Massachusetts Maritime Academy aquaculture laboratory, mussels were found to readily and effectively colonize natural coir fabric within an aquaculture tank environment. The byssal threads of the ribbed mussel was found to readily colonize coir fabric. 8-10” cobble stones could be used to form an 12-18” rock roll where the mussel colonized coir fabric could be wrapped around the cobble stones, which would serve as both ballast and a long-term anchor medium for the mussels after the coir fabric naturally biodegrades.

The mussel reef would serve to both protect the eroding peat shelf from further erosion and create turbulence in the regular tidal currents and likely dissipate tidal energy and trigger a moderate attenuation of sediment out of the water column. The mussel reef alternative would likely provide the best protection to the existing fringing salt marsh as mussel reefs are incorporated with the seaward edge of the fringing marshes in the immediate vicinity of the project area where the marsh appears particularly stable and healthy. The design of cobble reinforced marsh with ribbed mussel reef is shown in Figure 4.8.

4.8 Additional Measures for Stabilizing and Enhancing Jack Knife Beach

The decline of the salt marsh adjacent to Jack Knife Beach and the outer channel of Muddy Creek is partially a result of environmental factors, however there is a human component to the decline of the salt marsh that needs to be addressed to ensure that any restoration project maximizes the probability of success. A number of different ideas have been discussed through the scoping, field work, and design phases of this restoration project. For the project to succeed the following idea were evaluated and incorporated into the preferred design.

- Offset the travel and parking areas along Jack Knife Beach further from the salt marsh in areas where room allows for increased spacing.
- Examine and layout symbolic fencing corridors to minimize the intrusion of vehicles and people onto the vegetated salt marsh. Figure 4.9 illustrates how visual barriers can be incorporated in the restoration design.

- Establish a kayak, canoe, paddle board launching area towards the Route 28 bridge where no salt marsh exists as illustrated in Figure 4.10. In addition, recommended locations for boat racks to minimize the storage of boats on the salt marsh surface.
- Evaluate the areas of coastal bank which are showing signs of erosion and determine is those areas could be nourished to provide a continued source of sediment for the long-term adaptation of the marsh to rising sea levels. A similar approach could be incorporated into the low dune areas along the shore line to stabilize the dune and naturally feed material onto the surface of the marsh during over topping events.

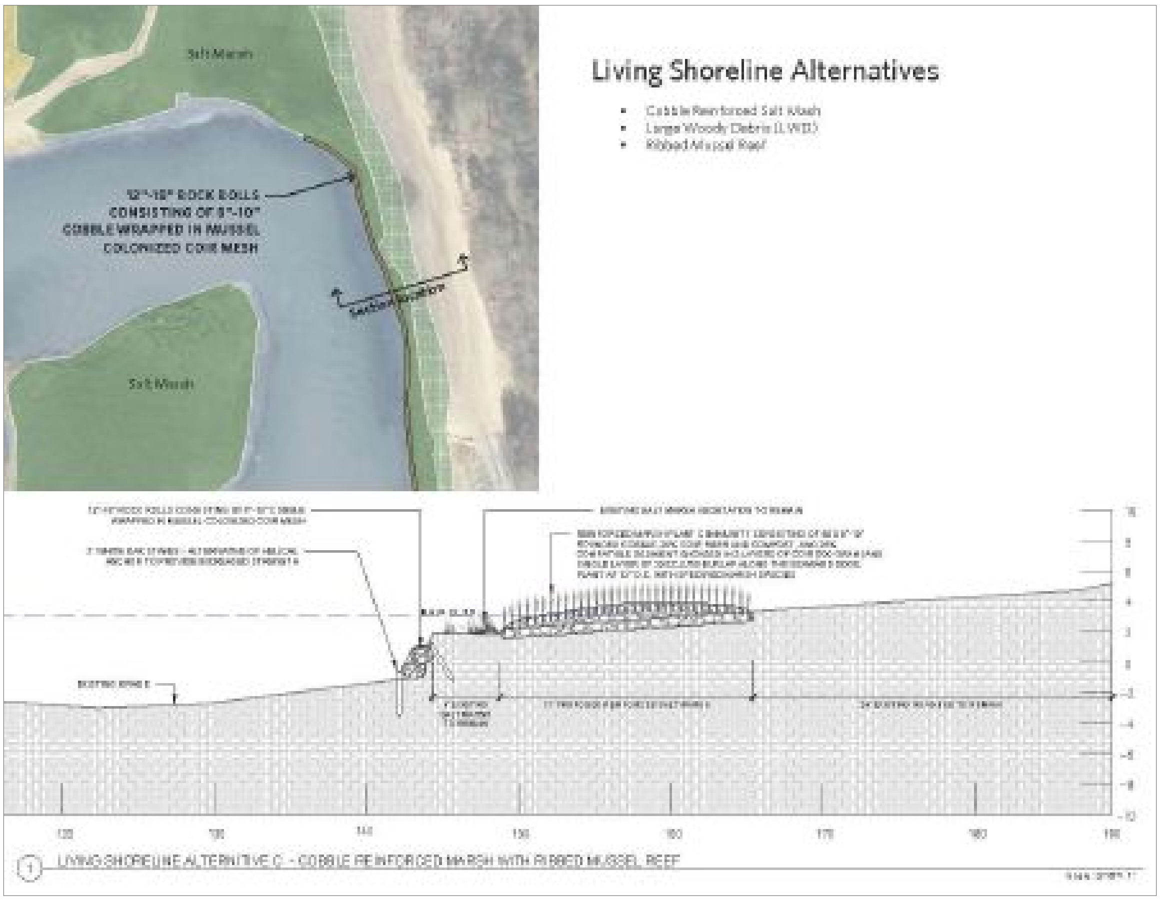

Figure 4.8 Typical cross-section of a Cobble Reinforced Marsh with ribbed mussel reef.

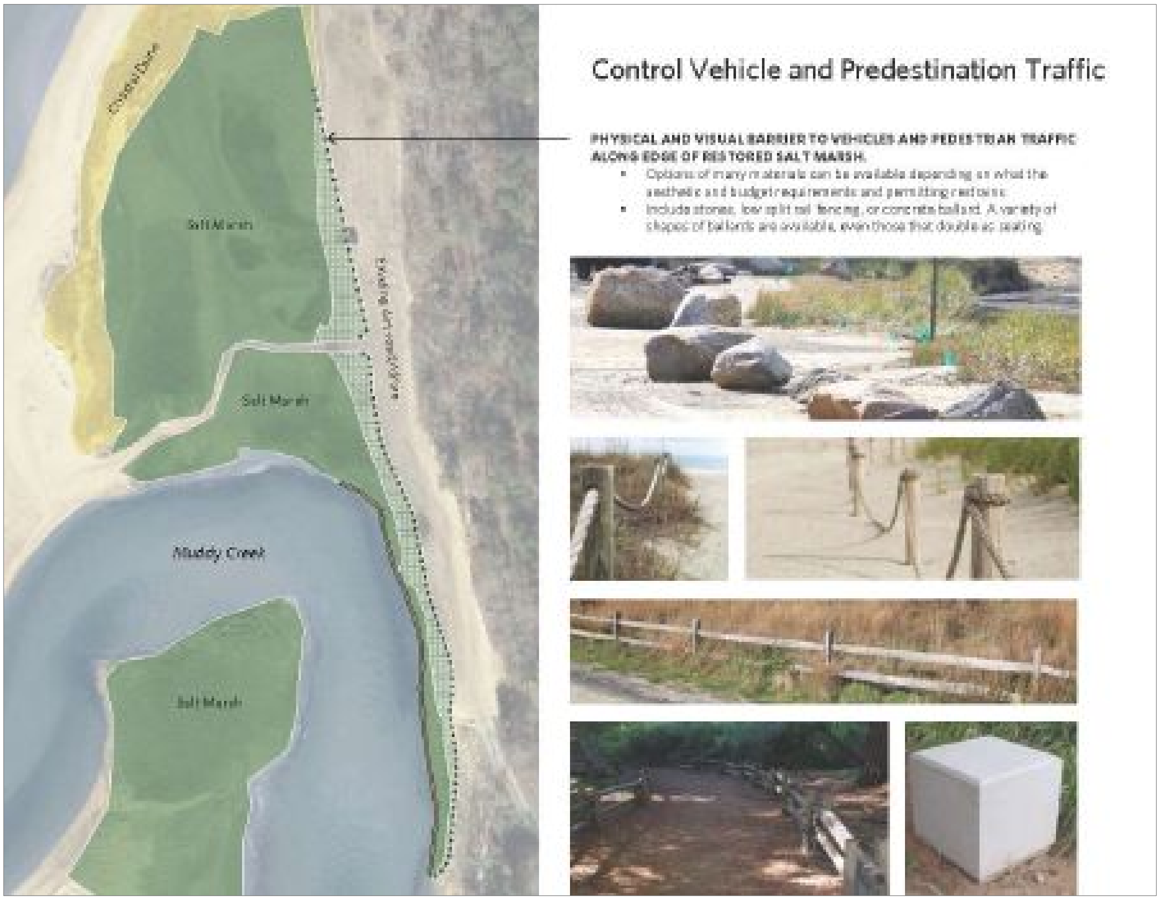

Figure 4.9 The use of physical and visual barrier to prevent unintended impacts to salt marsh and other wetland resource areas.

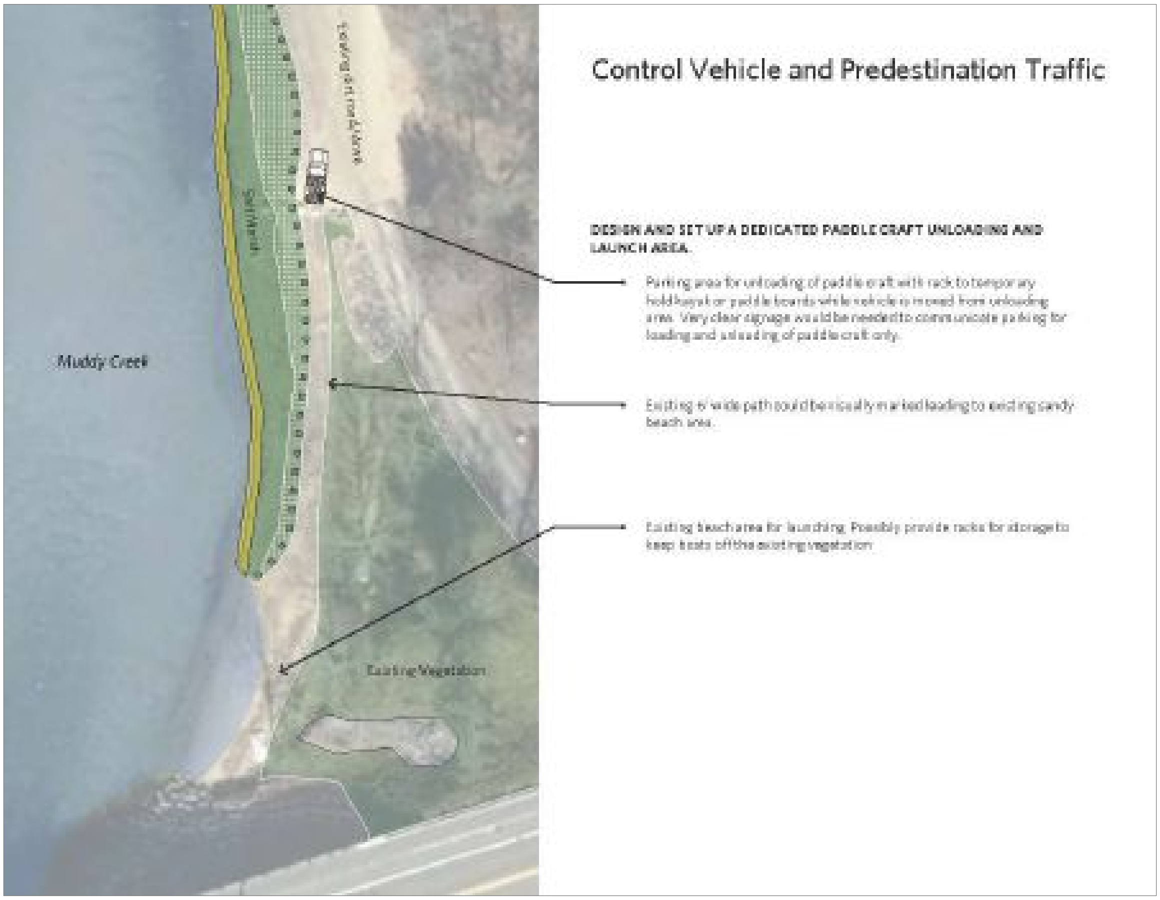

Figure 4.10 Creation to a dedicated paddle craft launching area to prevent damage to the vegetated surface of the marsh and channel bank when access to the water is sought for recreational boating.

5. Summary of Preferred Alternative

During the development of alternatives for the project, the Project Team presented working alternatives and invited comments and feedback from Adrienne Pappal who is a Habitat and Water Quality Program Manager with MCZM and expert on salt marshes, regulatory agencies (DEP, DMF, MEPA, and MCZM), and Town of Chatham Conservation Agent and Parks & Recreation Commission. The discussion and feedback help refine the alternatives and consider different approaches to maximize the potential of the restoration project. The Preferred Alternative brought together during that process and is illustrated below in Figure 5.1.

The design incorporates 6,400 square feet of cobble reinforced marsh along the landward edge of the fringing salt marsh adjoining the public accessway and parking area. Along the channel bank 12- to 18-inch coir rolls colonized with ribbed mussel will be used to stop the undercutting and erosion of the bank. The coir rolls will be support on bio-degradable coir envelop filled with marsh sediments to fill any areas of undercutting and restore portions of the bank which have been lost. The cobble reinforced marsh will be vegetated with appropriate salt marsh vegetation along with areas within the fringing marsh where vegetation has been lost. Physical and visual barriers will be incorporated along the public accessway and parking areas to prevent future damage to the marsh.

The preferred alternative will address all the key issues by recreating bank along the channel through nature-based stabilization methods which incorporate salt marsh substrate, the mussel colonized coir rolls will slow and redirect tidal currents off the bank, the addition of shellfish will strengthen and stabilize the existing and new marsh bank. High marsh along the public access way and parking area will be restored utilizing a cobble reinforced marsh techniques which help the marsh adapt to climate change and sea level rise while feeding sediment onto the adjoining marsh plane to allow for natural adaptation of marsh surface. Finally public access corridor's will be established to prevent the recreational users for unknowingly damaging the salt marsh.

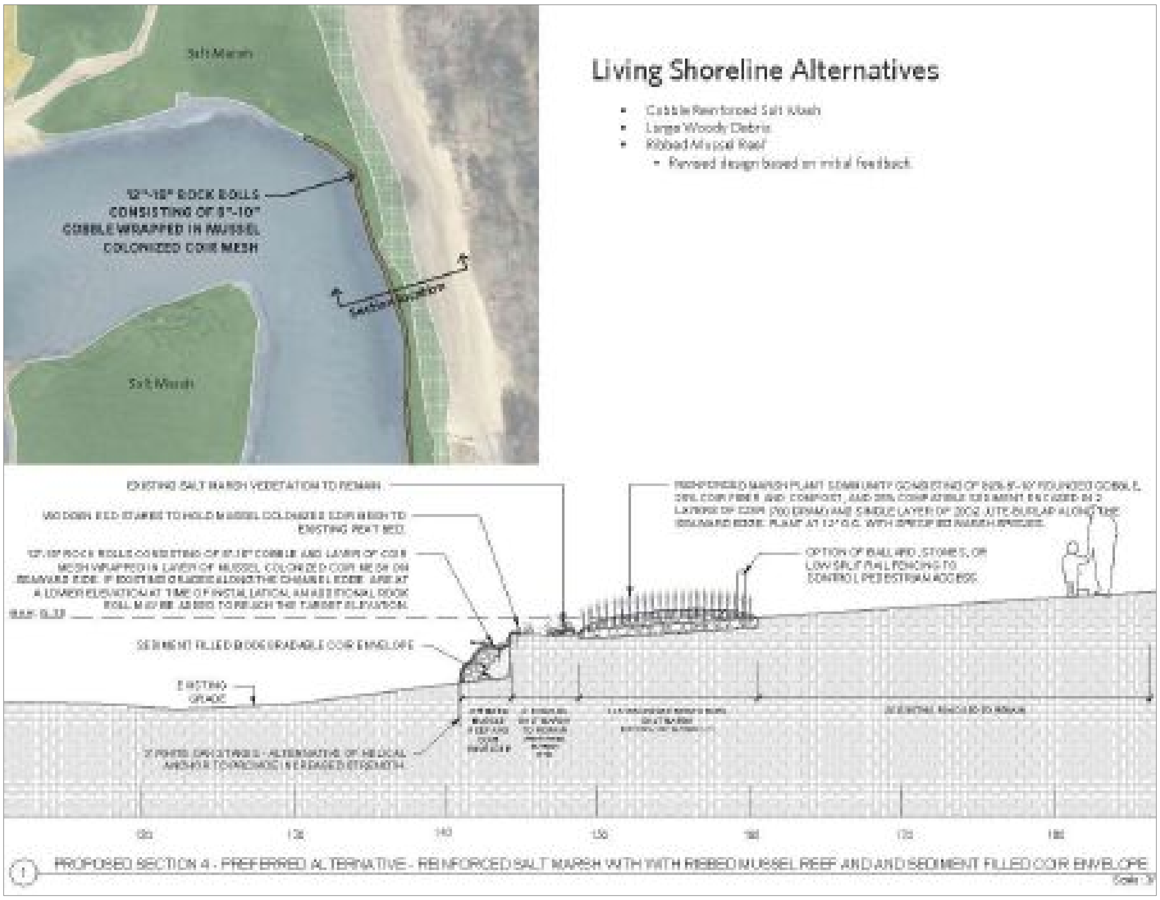

Figure 5.1 The preferred nature-based alternative to address salt marsh erosion along Jack Knife Beach and Muddy Creek.

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