APPENDIX B

History of Managing Marshes for Coastal Resilience

Craig Tobias, Ph.D.
Department of Marine Sciences
University of Connecticut

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1 Why Use Marshes?

Given the drawbacks and expense of shoreline stabilization, coastal municipalities are increasingly turning to natural, or nature-based, shoreline protection as a cost-effective and multifunctional solution (Sutton-Grier et al. 2015). Rising sea levels and large storm events such as Superstorm Sandy emphasized the value of salt marsh as both valuable habitat and a means to attenuate waves and buffer uplands from adjacent waters (Bridges et al. 2015). In the aftermath of Superstorm Sandy, federal, state, and local governments as well as non-governmental organizations emphasized increasing coastal resilience – defined as the ability of a coastal community to prepare for, resist, and recover from disturbances such as storms – as part of storm recovery planning. Salt marsh management is increasingly being incorporated into a 'natural infrastructure' approach to coastal resiliency; in terms of sustaining the marsh ecosystem services described above and for protecting adjacent built infrastructure (Gedan et al. 2011, Sutton-Grier et al. 2015).

Coastal marshes are resilient to storms and sea level rise and can effectively decrease damages associated with coastal storms (Narayan et al. 2017). In addition to serving as a buffer against sea level rise (SLR), storm surges, and extreme weather events, salt marshes are one of the most productive ecosystems in the world, and provide critical ecological functions and services. These include a variety of ecosystem services such as improving water quality via excess nutrient removal and sediment trapping, providing nursery grounds for juvenile fin- and shellfish, habitat for birds and wildlife including threatened and endangered species, and support of food webs locally and in adjacent waters (Minello et al. 2003, Mitsch and Gosselink 2000, Tobias and Neubauer 2009). More recently, the ability of salt marshes to sequester carbon dioxide (CO_2) in their sediment for hundreds to thousands of years has resulted in national and international efforts to protect and conserve these habitats as a means to reduce atmospheric greenhouse gases (GHG) and mitigate the impacts of climate change (Nellemann et al. 2009). The high plant production rates found in marsh habitats, coupled with their ability to increase sediment volume over time, results in higher carbon burial rates per area in salt marshes than any terrestrial ecosystem, including tropical rainforests (McLeod et al. 2009, Hopkinson et al. 2012). This burial of atmospheric carbon in marshes, mangroves, and seagrasses is termed 'blue carbon'. The loss of sediment carbon alone in existing marshes, has been estimated to be 0.02 – 0.24 Pg CO_2 yr^{-1} globally, representing an economic cost of 0.7 to 10 billion US \$ yr^{-1} (Pendleton et al. 2012). The importance of marshes as a 'blue carbon' sink, is matched by the ability of marshes to retain excess nutrients' both nitrogen and phosphorous through the same mechanism of marsh accretion (Craft 2007, Tobias and Neubauer 2009). These functions are contingent on the ability of marshes to vertically accrete at a rate that keeps pace with the local rate of sea level rise.

Traditional approaches to protect wetland coast lines often involve shoreline hardening, which have adverse impacts on coastal ecosystems and may leave them more vulnerable to coastal storms than natural habitats. Recent research has demonstrated that conventional hardened structures (sea walls, bulkheads and riprap revetments) to protect coastal infrastructure often provide less protection against coastal storms and flooding than coastal marshes, while simultaneously compromising ecosystem function (Gittman et al. 2014). The function of coastal marshes, however, is reliant on the marshes' ability to accrete sediment. There is disruption of sediment availability by man-made barriers, shoreline armoring, and disposal of dredged sediments in deep water (Slocum 2005, Croft et al. 2006, Weston 2014). This results in reduced sediment supply leading to marsh submergence, shoreline retreat/erosion, fragmentation, and ultimately loss of function (Kirwan et al. 2010). As traditional approaches to shoreline protection underperform and sediment supplies are constrained, the use of dredged sediment has proven beneficial for managing coastal marsh elevation and function.

2 Why Do Marshes Need to be Adaptively Managed?

Coastal salt marshes occupy the intertidal zone, approximately between mean sea level and mean high water. Positive feedbacks between tidal inundation, marsh plant production, and sediment trapping, have resulted in the current intertidal distribution of salt marsh habitat (Morris et al. 2002). Multiple factors control the distribution and condition of marsh systems (Silvestri et al. 2005, Morris et al. 2002, among others). Hydroperiod, sediment supply, and peat production via plant growth interact to govern wetland sustainability and function. Marshes are typically considered either minerogenic, they build elevation by trapping sediment, or peat forming, they build elevation by making below ground biomass. Connecticut marshes are a mix of both and rely on both high rates of plant productivity and sediment availability. There are physical limits on accretion rates provided through net growth (Morris et al. 2016). In many coastal areas, and under current and predicted future conditions, suspended sediment concentrations are insufficient to balance the downward repositioning of the marsh platform within the tidal frame (Weston 2014). Experimental studies in the field and laboratory demonstrate that there is a 'tipping point', or marsh position within the tidal frame, where local conditions of Sea Level Rise (SLR) and sediment supply are such that marshes can no longer keep up with SLR and drown (Morris et al. 2002, Kirwan et al. 2010, Schile et al 2014; Figure 1). With the drowning of marshes, so goes the shoreline protection and ecological benefits they provide. Thus, it is critical that some marshes are managed to prevent them from reaching this 'tipping point'.

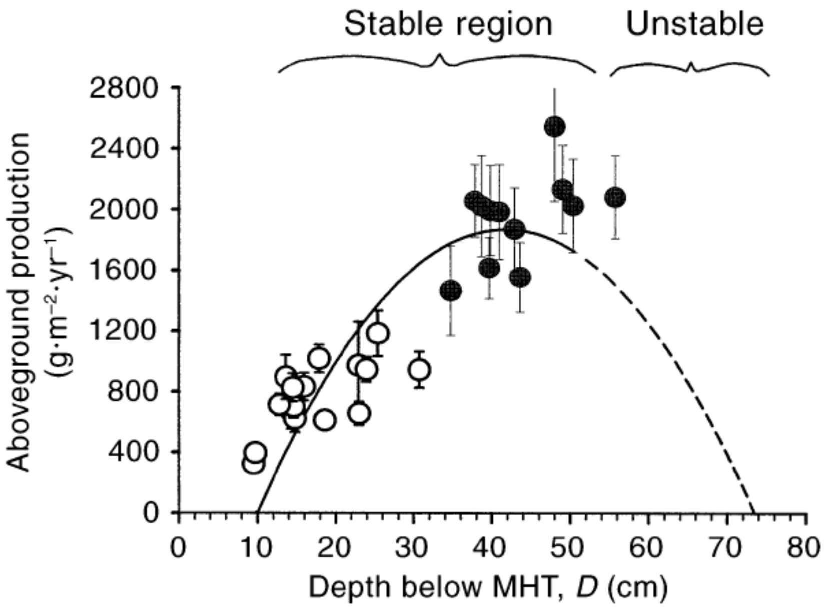

Figure 1. Relationship between elevation and marsh stability, as measured by plant production. MHT = mean high tide. Modified from Morris et al. 2002.

Salt marshes have the ability to increase their surface elevation via sediment trapping and belowground biomass production. However, in many areas, sediment movement has been disrupted by man-made barriers. Suspended sediment concentrations are often insufficient to support necessary accretion rates to maintain marsh elevation, and there are physical limits on the accretion rates via net growth. Regardless of the cause, lack of sediment can affect marsh's resilience to SLR and its ability to provide ecosystem services, including infrastructure protection. One technology that can be used to provide sediment to maintain or increase marsh elevation is by repurposing dredged sediment.

3 How Can Dredged Sediment Help?

With sufficient sediment, coastal marshes have the ability to increase their surface elevation, enabling them to keep pace with SLR over millennia (Morris 2002). This resiliency provides a low maintenance and self-sustaining natural infrastructure that protects coastlines and associated built and natural infrastructure. Using dredged material to enhance or create coastal marshes also presents an opportunity for the beneficial use (BU) of that sediment. The disposal of uncontaminated sediment onto uplands, spoil islands, or open water as a byproduct of dredging is increasingly being recognized as misappropriation of a resource in environments where marsh sustainability relies on sediment supply in already constrained sediment environments (Childs 2015, ASCE 2017). There is a need to find alternate uses of sediment as disposal sites are costly to maintain and have limited capacity. The American Society of Civil Engineers recognizes sediment as a resource and endorses its BU for coastal areas to ensure ecosystem and development sustainability. Beneficial use of dredged sediment is also a priority for the USACE (Childs 2015). Thus, there is a confluence of the need for protection of coastal assets, awareness of the efficacy of 'natural infrastructure's ability to provide a host of services, the adoption of BU as a natural infrastructure alternative to manage deteriorated marshes and marshes vulnerable to SLR, and the need for reuse of an important sediment resource. While a full spectrum of engineered responses will be required to address the scale of coastal shoreline threats and loss of essential habitat in CT, adaptively managing natural coastal marshes can be a pivotal part of that strategy. If given adequate sediment supply, coastal marshes can be a self-sustaining natural infrastructure that protects coastlines and built infrastructure (Gedan et al. 2011, Arkema et al. 2013, Temmerman et al. 2013, Bridges et al. 2015, Sutton-Grier et al. 2015).

Coupling salt marsh restoration projects to the management of dredged sediment has increased in frequency and scope over the past 2 decades. Such nature-based shoreline management can take the form of Living Shorelines, Thin Layer Placement (TLP) of sediment on existing marshes and/or construction of new marshes on subtidal habitat.

3.1 Living Shorelines

Living shorelines consist of small scale alternatives to armoring unvegetated shorelines. They are principally implemented as an alternative to bulkheading to stem the rate of shoreline retreat. Typically a few to 10 meters in width, they are composed of usually a rock or shell sill with a narrow strip of salt marsh planted behind it. Because of their relatively small size, their use as a repository for dredge material is limited at best and largely impractical as a disposal alternative. There is a rich body of literature on the successes, failures and lessons learned from 30 years of constructing living shorelines. The reader is referred to CT SeaGrant and NOAA resources, and Currin et al. (2017) for further review of Living Shorelines.: https://oceanservice.noaa.gov/facts/living-shoreline.html, https://seagrant.uconn.edu/focus-areas/healthy-coastal-ecosystems/

Figure 2. Living shoreline. Photo credit – NC Coastal Federation

3.2 Thin Layer Placement (TLP)

By far the most common BU for marshes consists of the placement of a thin-layer (typically<50 cm) of sediment to provide 'elevation capital' to shallow intertidal areas, in order to improve the resiliency of existing coastal wetlands. Thin Layer Placement (TLP) has become a catchall term used to describe augmenting existing marshes with dredged sediment. It is sometimes also applied to small-medium scale marsh creation projects. For existing marsh systems, TLP thicknesses are typically limited to 20 cm or less but greater lifts are utilized in subtidal areas. For marsh new marsh construction on subtidal areas and/or in conjunction with barrier island building, the depth of sediment and thus BU of dredged material is much larger. Sediment can be hydraulically deposited on the marsh or manually applied and graded.

Marshes that are low in the tidal frame and/or accreting at rates slower than sea level rise are good candidates for TLP. The first goal is to raise the marsh surface elevation of each site to the optimal elevation for plant growth to increase the marsh's resilience to SLR (Schile et al. 2014). The second goal is to maintain/enhance core ecosystem functions provided by coastal marshes which include habitat for animals, high rates of ecosystem production, and carbon/nutrient sequestration.

This approach has been used with increasing frequency over the past decade with primary objectives being either enhancement of wetlands or simply a disposal option for dredge material. At present, TLP projects constitute only a small fraction of dredged sediment use. The TLP approach to enhance marsh resilience and associated services has been demonstrated in one-off projects with increasing frequency over the past decades (Stagg and Mendelssohn 2011). Past projects have been conducted in several regions, and at multiple scales from tens to hundreds of thousands of m^3 of sediment (Croft et al. 2016, Stagg and Mendelssohn 2011). The method provides an attractive option for protection of coastal assets against SLR and storm events, and that coastal marsh management can be a part of that protection.

Past and recent projects have served to validate various approaches and offer solutions to some of the technical hurdles that hindered early efforts to implement the technology, although there is currently no robust one-size-fits-all guidance on how to implement a BU project (Bridges et al. 2015). Previous work has shown coastal marshes can respond and adapt to a wide range of sediment additions. Studies from isolated sites going back to the 1980s show a consistent positive marsh response from two to 10 years following TLP (Ray 2007).

4 General History of Beneficial Use (BU) of Dredged Sediment for Marshes

BU has been utilized in some form since the 1970s, following the Tidal Wetlands Act of 1969, but the technology is still gaining maturity. There is limited, but growing, guidance on site suitability and design practices and few studies examine the complete suite of effects on marsh function. Early attempts at BU were done in limited, and under sometimes ad hoc conditions; consisting of only a handful of studies using opportunistic sediment "spills" or small scale additions (DeLaune et al. 1990). These early efforts were done with mixed motivations ranging from convenient nearby options for dredge disposal at small scales in support of canal maintenance, to legitimate attempts to prevent submergence and shoreline retreat. Moreover, the application of the technology had been limited in scope, generally deployed on an experimental basis in areas undergoing significant subsidence or extremely high rates of local sea level rise, such as coastal Louisiana, Texas, and parts of the Chesapeake Bay. Post deposition assessments were not standardized and in some cases the efficacy of some of the earliest projects consisted of revisiting the marsh 5-10 years later and determining if it was 'still there'. Only in the last 5+ years have more projects been started in the mid-Atlantic and Northeast.

BU was bolstered in 1990 by passage of The Coastal Wetlands Planning, Protection and Restoration Act, (CWPPRA) whose intent was to "*identify, prepare, and fund construction of coastal wetlands restoration projects*" that engage in or promote: marsh creation and restoration; shoreline protection; hydrologic restoration; beneficial used of dredge material, terracing; sediment trapping; vegetative planting; barrier island restoration; and bank stabilization. Within the last 5 years USACE renewed a push for adoption of BU. The USACE Dredge Manual EM 1110-2-5025 released in 2015 stressed BU, and recognized its utility for facilitating coastal resilience. This document was followed by a joint USACE – NOAA "Engineering with Nature" initiative in 2017 which resulted in the implementation Beneficial Use of Dredge Material Pilot Program in 2018. This program will fund up to 10 pilot BU sites including application of sediment to existing marshes and construction of new ones. As a result there has been a wider recognition of BU across USACE District offices that will likely lead to a less cryptic and more successful permitting process for such projects.

Present day (within the last decade) BU projects typically use a combination of techniques that may include dredged sediment sourced locally or from elsewhere, the latter adding considerable expense to transport of material. In some cases, upland soils are included (Sparks et al. 2013) although there can be geochemical drawbacks to their use. Sediment deposition may or may not be followed by vegetation planting. The terminology and implementation of BU includes application of sediment to existing marsh platform, or filling of fragmented open areas in existing marshes, or wholesale construction of marsh in open water that in most cases, but not all, used to be marsh. Some of the largest restorations are being undertaken in the Louisiana and consist of diverting riverine sediment supplies. River diversion projects such as the Davis Pond, LA project comes with large potential ecological consequences including diverting nutrient loads and altering salinities. Because of extant, and poorly understood potential ecosystem responses to those factors, not to mention cost, wholesale river diversions to enhance sediment supply to marshes is considered only in the Gulf where the rate of wetland loss is nothing short of catastrophic. Such projects are unwarranted and unrealistic for implementation in CT. The more common implementation of BU is that of hydraulic or direct application to the marsh surface or into an impoundment for new marsh creation in what was previously subtidal habitat. The vast majority of BU projects, for marsh restoration in general occur in Louisiana. A compendium of projects can be found through the Louisiana Coastal Protection Resource Authority (http://coastal.la.gov/). Additionally, Restore Americas Estuaries a non-profit conservation organization (https://www.estuaries.org/) is an excellent source of background information for wetland restorations using BU on scales appropriate for the Northeast. Projects in the Northeast of moderate to large scale have been implemented in RI at the John Chafee and Sachuest Point National Wildlife Refuge, RI and a more mature project in Jamaica Bay, NY. Even Jamaica Bay at > 600,000 cubic yards of sediment deposited, represents a small fraction of the amount of dredged material annually. It is important to realize that BU will not replace current methods of dredge disposal but rather provide an opportunity to derive some coastal resilience benefit from some of it. These benefits include the protection of built infrastructure and enhanced ecosystem services that have been diminished by the urbanization of the CT shoreline over the past centuries. Table 1 summarizes a few examples of BU projects of spatial scales suitable for the CT shoreline.

Table 1. Examples of recent BU marsh projects. See https://lacoast.gov/new/Projects/List.aspx for a compendium of numerous restorations in Louisiana. *Includes other smaller resilience efforts. An expanded list of projects and added details are included in Appendix C. The potential for marsh creation in CT is discussed in section 8 - The Future of Beneficial Use in CT Marshes– What's Possible? in the report.

Project	Marsh Restoration Type	Size (acres)	Cost ($M)
Sachuset Point NWR, RI	Augmentation	11	4.2*
Seal Beach, CA	Augmentation	8	2.4
Avalon, Ring Island NJ	Augmentation	45	7.4
Jamaica Bay, NY	Augmentation, Creation	75	16.0
Bayou Dupont, LA	Augmentation, Creation	186	39
Portersville, AL	Marsh Island Creation	50	11.0
Barataria Bay Islands	Island + Marsh Augmentation, Creation	1000+	100
Poplar Island, MD	Island + Marsh Augmentation, Creation	1700	667

5 Past Marsh Restorations in CT and Role of Dredged Sediment

The preservation and adaptive management of marshes in CT is rooted in the Tidal Wetlands Act (TWA) of 1969. The TWA identified a suite of wetland benefits, acknowledged the high rate of wetland losses in CT, and declared it to be "*the public policy of this state to preserve the wetlands and to prevent their despoliation and destruction*". The TWA was designed to halt marsh loss in CT. The CT Coastal Management Act (CCMA) of 1980 laid further groundwork for marsh restoration, specifically including the consideration of dredge spoil for habitat restoration among other factors. The CCMA encouraged "*rehabilitation and restoration of degraded tidal wetlands and where feasible and environmentally acceptable, to encourage the creation of wetlands for the purposes of shellfish and finfish management, habitat creation and dredge spoil disposal.*" State and coastal municipalities were charged the management of said policies and currently the Department of Energy and Environmental Protection (DEEP) is tasked with authorization for wetlands restoration and enhancement projects. These include but are not limited to, open water marsh management and coastal culvert and tide gate management provided they are consistent with preservation, protection and restoration of tidal wetland values. CT DEEP formed a dedicated Wetlands Restoration Unit 1994. The entirety of the relevant sections in the TWA and CCMA, respectively, can be found in General Statutes of CT-2017, Chapt. 440, Sec. 22a-28 and Sec, 22a-35, and in Chapt. 444, Sec. 22a-92.

Since the passage of the TWA and CCMA over 1,700 acres of tidal wetlands in CT at approximately 40 sites from Greenwich to Stonington including Long Cove, Guilford; Hammock River, Clinton; Mumford Cove, Groton; and, Barn Island, Stonington have been ‘restored’. Historically, the term ‘restoration’ in CT has been used to describe either re-establishment of tidal flow to marshes, creation of open water ponds for waterfowl, control of invasive plant species, or removal of historical dredge spoil piles that smothered marshes (USFW 2013, Warren et al. 2002). An excellent summary of marsh restorations of this type prior to the mid 1990s is presented in “Tidal Wetlands of Long Island Sound; Ecology History and Restoration” (Rosza 1995). None of these restoration sites involved the application of dredged sediment to enhance marsh elevation or create new marshes.

The use of dredged sediment for augmenting elevation in drowning marshes, or for creating new marshes from subtidal habitat has been almost non-existent in CT. According to the 2003 Long Island Sound Study report on Long Island Sound (LIS) Habitat Restoration Initiative, Beneficial Use of dredged sediment has “*never been used*” in Long Island Sound and cites potential transport cost constraints as a limiting factor (LISS 2033). Since 2003, there are instances where dredged material has been used for beach replenishment but only two very small scale examples of dredged sediment used for marsh enhancement in CT. The first consists of ongoing/planned efforts to divert locally dredged material for deposition on a marsh shoreline in Stratford whose seaward edge is also wave buffered by an engineered intertidal reef (Reefballs®). The second is Bride Brook marsh near Rocky Neck State Park where, in 2016, select low elevation spots in the marsh were augmented with dredged sediment for the purpose of building high marsh (salt hay) habitat.

Because marshes in CT had been historically used as sites for dredge disposal that buried/killed wetland vegetation, and previous marsh restorations consisted of removing those spoil piles, the idea of applying dredged sediment to enhance marsh sustainability represents a shift in the relationship between dredging and coastal marshes in CT. According to the LIS Dredge Material Management Plan (DMMP), Upland, Beneficial Use, and Sediment De-watering Site Inventory Final Report, 2009, and the Final DMMP, 2015 several wetland habitat restoration sites were identified as candidates for BU in NY. None were identified in CT although marsh creation sites were proposed in CT in the Final DMMP for Long Island Sound in 2015. Those are described in Section 4.2 - Technical Challenges for Implementing Beneficial Use in CT Marshes of the report.

The potential benefit for BU in marshes in CT is large, varied and untapped. Supplying sediment in adjacent shallow subtidal has the potential to offset marsh area lost to past dredge dumping in the marsh, particularly in central LIS shoreline (USACE DMMP, 2015). It has a potential use in conjunction with restorations that re-establish tidal flow in marshes. Tidal restrictions often led to a drop in marsh elevation and conversion to open water (e.g. Great Harbor marsh). The removal of tidal restrictions typically results in partial recolonization of open water as low marsh instead of the original high marsh habitat. BU could be used to build high marsh and/or to accelerate general marsh recovery after removal of the tidal restriction. The Long Island Sound Study (LISS 2003) cites more generally that the “*accelerated rate of sea level rise may be causing changes in marsh vegetation, as in the conversion of high marsh to Spartina alterniflora-dominated low marsh, and may be responsible for significant losses of tidal wetland acreage. In southwestern Connecticut and Westchester County, New York, there are numerous accounts of the conversion of low marsh to unvegetated tidal flats*.”

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