Tidal Wetlands Restoration

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1. Introduction

Jamaica Bay (the Bay) is located within the Boroughs of Brooklyn and Queens, New York City, and covers 67.3 square kilometers and opens into the Atlantic Ocean via Rockaway Inlet (Fig. 1). The Bay contains disturbed tidal salt marsh wetlands and upland ecosystems, mud flats, parks, landfills, residential urban communities, commercial and retail facilities, and J. F. Kennedy International Airport. Also present are tidal creeks, navigational channels, and areas of open water. In the early 1900s, Jamaica Bay was an extensive estuarine ecosystem that sustained large expanses of tidal salt marsh. Jamaica Bay was renowned for its abundant and diverse shellfish and ecological importance as a nursery and feeding ground for numerous bird species (JBERRT 2002) and various fish species rely on the Bay for habitat (USFWS 1997). Jamaica Bay is also valuable for various bird species during seasonal migration (NYCDEP 2006). Other wildlife including amphibians and reptiles also rely on these salt marsh wetlands as primary habitat (Tanacredi & Badger 1995).

The Jamaica Bay ecosystem is part of the Gateway National Recreation Area, a unit of the National Park Service, and is connected to the lower bay of New York Harbor by Rockaway Inlet. The Jamaica Bay Federal navigation channel extends from offshore of Rockaway Point, Queens, through Rockaway Inlet and bisects at the southern edge of Floyd Bennett Field (Barren Island), Brooklyn, with one branch extending north into the upper part of Jamaica and a second branch extending east into lower Jamaica Bay (Fig. 1). The dominant littoral drift is to the west along the south shore of Long Island (Kana 1995) and has almost doubled the length of the Rockaway spit since the early 19th century (Englebright 1975). Along the northern New Jersey shoreline, the dominant littoral drift is to the north which causes the elongation of Sandy Hook. These shoreline patterns are attributed to the effect of Long Island in shielding the area from waves from north and northeast. Since the 1930s the Rockaway inlet has been stabilized by jetties. Urbanization of the Rockaway Beach barrier island during the 20th century has effectively halted the delivery of sand to Jamaica Bay via overwash during periods of storm surge. An increase in water depth, such as that caused by dredging of navigation channels, modifies the hydrodynamics and generally leads to an increase in tidal range. Within the Bay alteration to the tidal range also changes the marsh hydroperiod, e.g., plants at the same elevation are inundated for a longer portion of the tidal cycle than at that same elevation prior to dredging of the channels in Jamaica Bay. This may further enhance tidal currents and exacerbate erosion. Mean tidal range within Jamaica Bay varies between 1.5 m and 1.6 m.

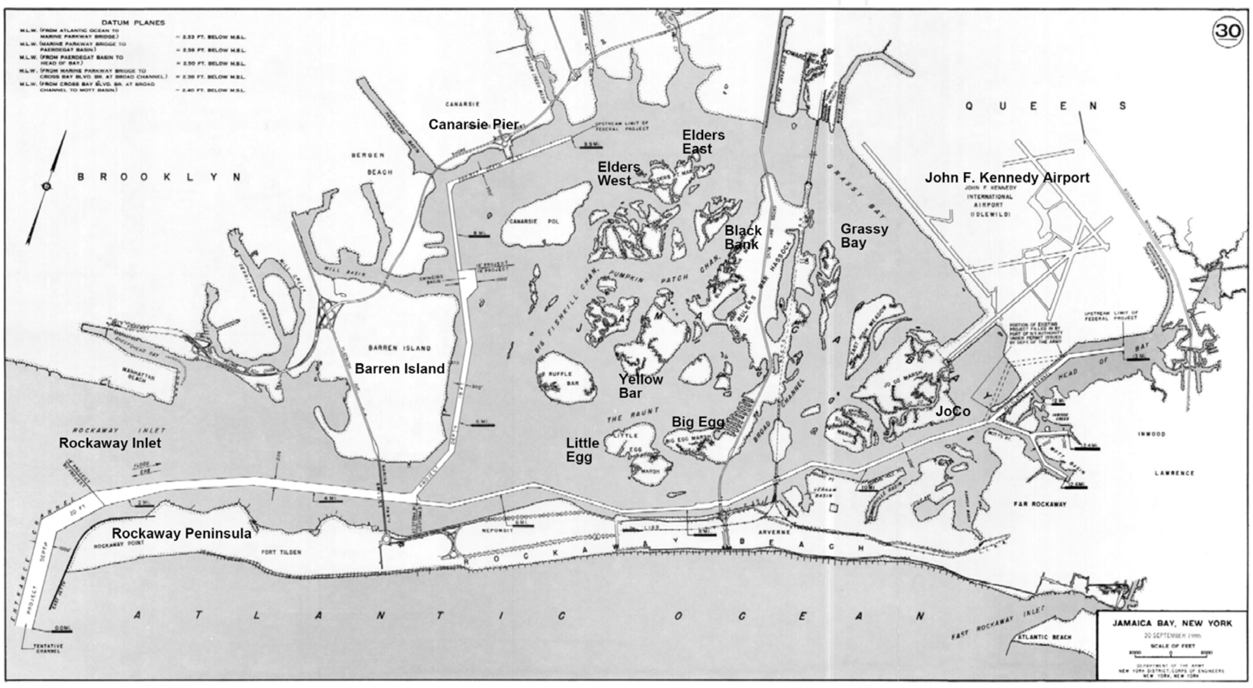

Fig. 1. Jamaica Bay, located within the Boroughs of Brooklyn and Queens, New York City, opens into the Atlantic Ocean via Rockaway Inlet.

The undertaking of tidal salt marsh restoration projects on the order of magnitude presented herein, lead by the U. S. Army Corps of Engineers, will be a unique opportunity to measure and assess the success of such large scale efforts. To prevent continued loss of wetlends decisive action must be taken by placing emphasis on improving compliance and maintaining a true baseline (Race & Fonseca 1996). Race & Fonseca (1996) further noted that past mitigation projects nationwide indicate that the success rate remains low overall. Elders Point East and Elders Point West will establish baselines for future restoration/mitigation efforts in Jamaica Bay and elsewhere. Roberts (1993) reported that the sober reality regarding marsh losses is likely to be that mitigation projects have a high degree of failure. Reporting results of tidal salt marsh restoration projects in Jamaica Bay may be pivotal for establishing baselines and achieving success for future efforts.

2. Historical marsh loss in Jamaica Bay

2.1 Trends

Jamaica Bay was historically more land than open water (Fig. 2), however, vegetated emergent marsh islands in the Bay are being lost at an alarming rate (Hartig *et al.* 2001, GATE & JBWPAC 2007). In 1907, 3430 hectares (ha) of the Bay was shallow water and 6549 ha consisted of marsh islands (Hartig *et al.* 2002). Most of the wetland loss in Jamaica Bay prior to early 1970s can be attributed to human activity such as dredging or filling (Black 1981). When direct anthropogenic sources of loss are removed, a pattern of consistent marsh island loss persists. Excluding areas affected directly by dredging and filling, of the 950 ha of

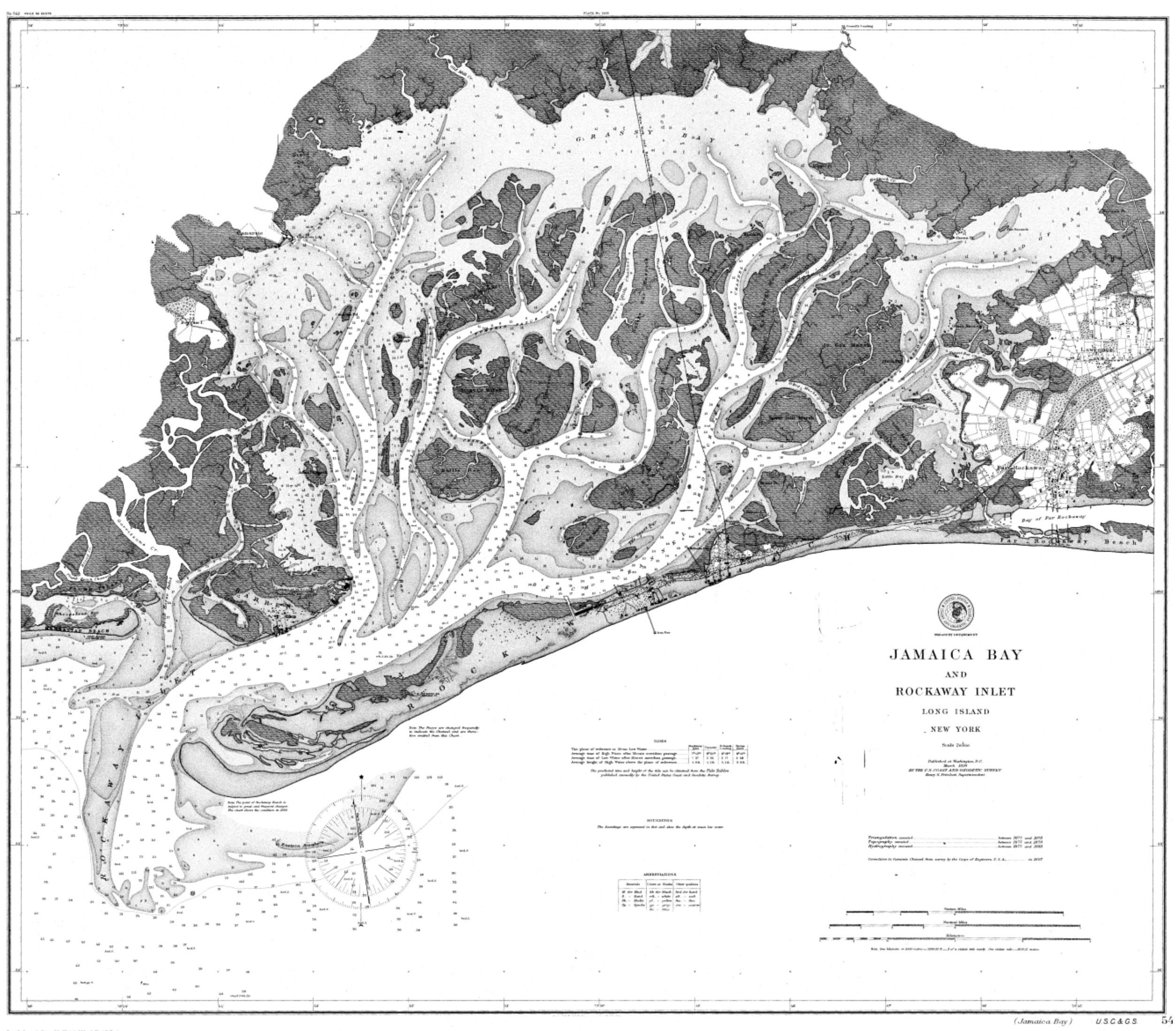

Fig. 2. Jamaica Bay and Rockaway Inlet 1899.

vegetated marsh island in the Bay in 1951, only 355 ha remained as of 2003. During that 49 year period, 63% of the Bay's salt marsh islands were converted from emergent vegetated habitat to submerged and intertidal habitat (Table 1). The calculated average rate of marsh loss increased throughout that time period from 6.9 ha y^{-1} from 1951-1974 to 13.4 ha $y^{-1}$from 1989-2003 (Table 2) (GATE & JBWPAC 2007). Recent analysis (2003-2008) indicates that the rate of loss may be decreasing to 7.7 ha y^{-1}(Christiano 2010).

	Time Period			
	1951*	1974	1989	2003
Vegetated Marsh (hectares)	950	652	539	355

* From 1951 to 1974, 23 ha of marsh island were calculated as lost due to the construction of West Pond and 115 ha lost as a result of the Broad Creek and Goose Pond marsh impoundments. Other factors accounted for the loss of the remaining 161 ha.

Table 1. Total area of vegetated marsh islands in Jamaica Bay (from GATE & JBWPAC 2007).

	Time Period		
	1951-1974	1974-1989	1989-2003
Average Rate of Loss (hectares /year)	6.9	7.3	13.4

Table 2. Rate of marsh loss of vegetated marsh islands in Jamaica Bay (from GATE & JBWPAC 2007).

Based on aerial photography interpretation, the New York State Department of Conservation (NYSDEC 2001) estimated that approximately 567 hectares (ha) of tidal salt marsh island within Jamaica Bay have been lost since 1924, with the rate of loss rapidly increasing in recent years. Elders Point is currently comprised of two separate islands, Elders Point East (Elders East) and Elders Point West (Elders West) that together total about 4.9 ha prior to the restoration project led by the U. S. Army Corps of Engineers (USACE), NY District in 2005 (Fig. 3). Elders Point was historically one island, comprising approximately 53.4 ha but over the last more than 80 years, marsh loss in the center of the island severed the connection creating two distinct islands separated by mud flat. At Elders Point, between 1994 and 1999, an estimated 89 ha of salt marsh was lost at a rate of 17.8 ha per year (USNPS 2001). Hartig *et al.* (2002) reported marsh loss for Elders Point from 1924 through 1999 with an increasing rate of loss from 0.5% (1924 – 1974) to 8.5% (1994 – 1999). It is estimated that if these trends continue, all remaining salt marsh within the Bay will be lost over the next three decades. Steinberg *et al.* (2004) have speculated that by 2024 all of the interior tidal marsh islands will be lost based on the current rate of deterioration.

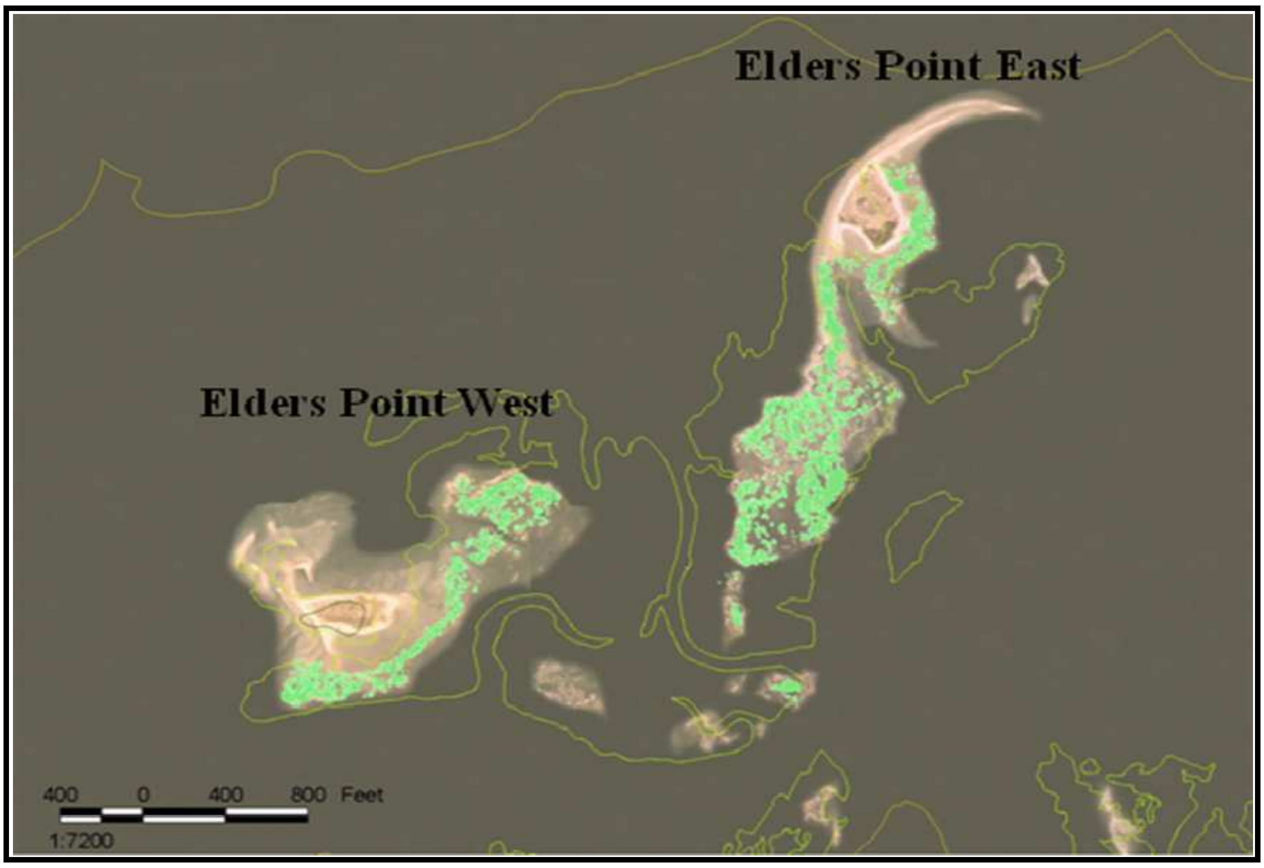

Fig. 3. Aerial view of Elders Point (East and West), Jamaica Bay preconstruction conditions (2005) where green represents *Spartina alterniflora* hummocks, opaque tan areas indicate mud flats, remainder is open water .

2.2 Possible causes

Regional sea level rise has been identified as a contributing factor in Jamaica Bay salt marsh loss (Swanson & Wilson 2008). Within the Bay the low marsh has accreted at 0.8 cm yr^{-1} and high marsh at 0.5 cm yr^{-1}. Prior to 1974 when the New York State Department of Environmental Conservation (NYSDEC) gained regulatory authority over intertidal wetlands, marsh losses have been caused by urbanization and associated land development activities, such as dredging and filling. The historic rate of sea level rise within Jamaica Bay is approximately 2.7 mm yr^{-1} (Gornitz *et al.* 2001) in comparison to the mean eustatic sea level rise of 1.2 mm yr^{-1} (NRC 1987) to 1.5 mm yr^{-1} (Gornitz 1995) during the past century and predicted 1.7 mm yr^{-1} in the next 100 years (IPCC 2007). The difference between the eustatic (global) and the New York (regional) sea level trend has been attributed to local subsidence resulting from crustal readjustments to the removal of ice following the retreat of the last glacial period (Dean *et al.* 1987). The south shore of Long Island, New York is the extent of the leading edge of the Wisconsinan glaciation ice sheet (ca. 20,000 years ago). The area to the south was upwarped while land to the north was depressed beneath the weight of the ice sheet. Much of the Atlantic coast has subsided while the land that was under the ice has rebounded. Marsh losses over the past century do not appear to be related to sea level rise (Kolker 2005); however, sea level rise is likely to be a cause of marsh loss in the future (Hartig *et al.* 2002). Based on ^{210}Pb chronology data Jamaica Bay marsh islands have accreted at rates in excess of the long-term rate of sea level rise at the Battery, NY (0.28 cm y^{-1}) (Kolker 2005). Analysis by Hartig *et al.* (2002) indicates that over the next 80 years, current rates of accretion would only be adequate to maintain Jamaica Bay marsh islands under the most conservative predictions for future sea level rise.

Marsh loss occurs through the undercutting and collapse of peat along the perimeter of marsh islands, widening of tidal creeks, and the development and expansion of pools within the marsh interior (Hartig *et al.* 2002, GATE & JBWPAC 2007). While the causes of marsh loss are poorly understood or not known, Hartig *et al.* (2002) suggest that water logging is contributing to the loss of marsh islands in the Jamaica Bay through the development and growth of interior pools and the subsequent collapse of the root system. Belowground biomass contributes to marsh elevation (Valiela *et al.* 1976, DeLaune *et al.* 1994, Morris & Bradley 1999). Diminished root production can also lead to a loss in marsh elevation. Without sufficient accumulation of belowground organic matter (peat), a marsh that exhibits high aboveground biomass could quickly convert to mudflat or open water if aboveground vegetation dies off (Mendelssohn *et al.* 1981, DeLaune *et al.* 1994). In addition, roots bind sediments and slow sediment compaction (Redfield 1972, DeLaune *et al.* 1994, Rybczyk & Cahoon 2002, Cahoon *et al.* 2002, 2003). Subsidence has been found to be lower in a vegetated marsh compared to adjacent unvegetated pools (Erwin *et al.* 2006). The hydrology of a tidal marsh can be defined as the frequency (how often) and duration (how long) that a marsh is flooded. Mechanisms that will alter hydrology, and thus increase water logging, include increased sea level rise, changes in tidal range, changes in the rate of accretion, and subsidence. Eutrophication and goose grazing have also been identified as possible causes of wetland loss in Jamaica Bay.

Changes in sediment availability, distribution and accumulation may contribute to the loss of marsh islands in Jamaica Bay (Gordon & Houghton 2004, Goodbred *et al.* 2004). Westward growth and stabilization of the Rockaway Inlet, dredging and ocean disposal of sediments from the Rockaway Inlet, development within the watershed, shoreline hardening channelization of runoff through storm sewers and combined sewer overflows, and trapping of sediments within navigation channels and borrow pits (e.g., Grassy Bay) are mechanisms by which sediment availability, distribution, and accumulation may have been altered within the Bay. Inorganic mass of marsh sediments has decreased at Yellow Bar Hassock (Fig. 1) and JoCo marshes (Fig. 1) since European settlement (Peetet *et al.* 2008) while organic matter has increased over the same period (Peetet *et al.* 2004). Kolker (2005), using ^{210}Pb chronology data, determined that accretion rates were higher in the latter half of the twentieth century and lower in the first half. Accretion rates at Big Egg marsh (Fig. 1) were lowest from 1900 to 1920 (0.14 - 0.18 cm y^{-1}) and highest from 1995 to 1999 (0.63 – 0.64 cm y^{-1}). East high marsh accretion rates were lowest from 1900 to 1950 (0.09 – 0.14 cm y^{-1}) and highest from 1950-1980 (0.57 – 0.75 cm y^{-1}). Accretion rates at JoCo were lowest during the 1920s (0.18 cm y^{-1}) and highest during the 1960s (0.59 cm y^{-1}) (Kolker 2005). Accretion rates at the same marshes from 1974 to 2000 were 0.41, 0.35, and 0.46 cm y^{-1}, respectively (Kolker 2005, Cochran *et al.* 2009). Recent short-term accretion rates (2003-2009) measured at Black Bank (Fig. 1) and JoCo marshes are similar (0.48 and 0.44 cm y^{-1}, respectively) (Cahoon 2008). Hydrodynamic modeling indicates that there is little deposition of sediment within navigation channels, however deep pits, such as Grassy Bay (Fig. 1), may serve as sinks for fine sediments (Wilson & Flagg 2008). Additional research is needed to better understand the sources and distribution of sediments within the Bay.

While sediment accretion rates within Jamaica Bay marshes exceed the rate of long-term sea level rise, changes in tidal hydrodynamics have resulted in water level increases within the Bay that exceed regional sea level rise (Swanson & Wilson 2008). Dredging and other development activities have increased the volume of the Bay by 350% (NYDEP 2007) and the mean depth from approximately 1 m to 5 m (Swanson & Wilson 2008). In addition, during the twentieth century, Jamaica Bay experienced an overall increase in tidal range and an amplification of tidal range from west to east as a result of development activities as well as the westward migration and subsequent stabilization of the Rockaway Peninsula. Increases in tidal range have resulted in high tide water levels that are currently 56-78% greater than sea level rise. Prior to 1899, mean tidal range was generally uniform throughout the bay (0.12 m) and tidal height varied from 1.22 m at Plum Beach Channel to 1.28 m at Canarsie (Fig. 1). Combined changes in sea level and increases in sea level rise and tidal range result in tidal height today of 5.0 ft (1.65 m) at Barren Island (modern proxy for Plumb Beach Channel) and 1.58 m at Canarsie Pier (Swanson & Wilson 2008). The rate of marsh loss observed in Jamaica Bay greatly exceeds that which has been observed in other Long Island marshes (Kolker 2005). These marshes have experienced rates of sediment accretion (Kolker 2005) and sea level rise (Kolker 2005, Swanson & Wilson 2008) similar to Jamaica Bay; however, tidal range in these marshes has not changed much (Swanson & Wilson 2008). Thus, increases in the frequency and duration of marsh flooding due to changes in tidal range are likely to contribute to the loss of emergent salt marsh islands within Jamaica Bay (Swanson & Wilson 2008).

Nitrogen loading is frequently indicated to be a factor that may cause or contribute to marsh loss in Jamaica Bay (O'Grady 2001, USNPS 2001, NYCDEP 2007). Nitrogen loading in Jamaica Bay has increased substantially in the past 110 years from an estimated 35.6 kg d^{-1} N, which entered the bay via submarine groundwater discharge, to 15,785 kg d^{-1} that enters the bay via wastewater discharge, subway dewatering, landfill leachate, submarine groundwater discharge, and atmospheric deposition (Benotti *et al.* 2006). High nitrogen levels may result in the reallocation of energy from roots to shoots in *Spartina alterniflora* (Valiela *et al.* 1976, Morris & Bradley 1999, Turner *et al.* 2004). High nitrogen loading may also amplify microbial activity and increase the rate of peat decomposition (Valiela *et al.* 1985). The U.S. Environmental Protection Agency (USEPA) is currently conducting research to evaluate soil respiration, above- and belowground biomass, and root structure at marshes in Jamaica Bay (Wigand *et al.* 2008). In 2009, the USNPS (U.S. National Park Services, P. Rafferty, co-author on this paper) initiated research to evaluate the role of eutrophication on plant function (allocation of resources between above and belowground biomass) at three marshes in Jamaica Bay.

Sulfide toxicity may also contribute to the loss of salt marsh islands in Jamaica Bay. Labile organic carbon resulting from phytoplankton blooms in the eutrophic Bay or direct inputs from water pollution control plants and combined sewer overflows may increase sulfate reduction in marsh sediments and result in elevated pore water sulfide concentrations. Prolonged exposure to high pore water sulfides in greenhouse studies results in stunted growth (>2mM) or death (>4mM) of *S. alterniflora* (Koch & Mendellsohn 1989). *S. alterniflora* seedlings are more sensitive to sulfide exposure than mature plants (Seliskar *et al.* 2004). Reactive iron can serve as a sink for sulfide via the precipitation of iron sulfides (Berner 1980, Goldhaber & Kaplan 1974, as cited in Cochran *et al.* 2009). A 2007 study at JoCo, Elders

East, and Elders West marshes found pore water sulfide concentrations (2-3mM) that are considered to be stressful to *S. alterniflora*. Generally these concentrations were observed at depths of 20 cm or greater and thus are at the lower extent or below the root zone. This study also found that Jamaica Bay marshes have a high degree of pyritization, thus indicating sulfide saturation of the sediment reactive iron pool (Cochran *et al.* 2009). This will result in a decreased capacity of sediment to buffer pore water sulfide levels and may result in the buildup of toxic sulfide levels (Berner 1984, Leventhal & Taylor1990, Raiswell & Canfield 1998, as cited in Cochran *et al.* 2009).

2.3 The sustainability of tidal salt marsh restoration efforts in Jamaica Bay, New York

With the completion of Elders Point East and Elders Point West there is an unprecedented opportunity for monitoring the long term success of such large scale restoration projects. The sustainability of restored/mitigated tidal marsh islands within Jamaica Bay will be critical for incremental environmental improvements in this heavily urbanized ecosystem. The next element for restoration in Jamaica Bay will be Yellow Bar scheduled to begin in 2012 and will be the third large scale restoration project for the Bay. The ongoing multiagency effort to monitor benchmarks for success will be a unique opportunity for lessons learned and improving the sustainability of such restoration efforts in Jamaica Bay in addition to similar tidal salt marsh systems elsewhere.

3. Restoration methods

One of the navigation missions of the U. S. Army Corps of Engineers is to maintain navigable waterways at coastal inlets and may include placement of dredged material to create, restore, or mitigate salt marsh wetlands (Sánchez 2008). The Army Corps of Engineers has been involved with the creation and restoration of wetlands for more than 30 years through the beneficial use of material dredged from navigational channels (Yozzo *et al.* 2004). Restoration at Elders Point East was the first such project led by the Army Corps of Engineers for Jamaica Bay and is part of a multi-phased effort with the first phase successfully constructed on Elders East in 2006. The second phase of these restoration efforts was Elders Point West with construction completed in 2010. Construction of the third restoration element for the Bay is anticipated to begin sometime in 2012.

These current restoration efforts involve a multi-agency group led by the U. S. Army Corps of Engineers, NY District to restore the tidal wetlands of Elders Point East and Elders Point West. Critical to these efforts are the partnering agreements with the Port Authority of NY/NJ (for Elders East) and NYDEC and NYDEP (for Elders West) as well as the land owning agency, U.S. National Park Service. The USNPS wrote the monitoring protocol and their in-kind contributions essentially doubled the monitoring budget annually. For Elders Point East federal, state, and local agencies, with diverse missions, worked collaboratively for more than ten years towards the success of this effort. The cooperative funding among the various agencies has also been a success. Elders Point East was initially a CAP (Continuing Authorities Program) project. When funding for the program changed and less CAP money was available, it was pairing of the need for funding for a Restoration Project with the need for a harbor deepening project (i.e., Mitigation Project) that allowed this effort to come to fruition.

Restoration efforts at Elders Point East and West are being extensively monitored to ensure worthwhile ecological goals have been provided and are a long term sustainable benefit to Jamaica Bay. Monitoring parameters include vegetation, nekton, surface elevation (sediment erosion/accretion) benthic marco-invertebrates, goose/waterfowl grazing impacts, and habitat change. Challenges that need to be better understood, resolved, and overcome include compaction and erosion of placed material, and subsidence. The geomorphic sustainability and plant survival will be an ongoing challenge with the existing physical, chemical, and biological stresses that are present in the Bay. With potential for increase in storm surge via climate change, there are physical benefits to tidal salt marsh wetlands that will act as an energy dissipater against wave action (Dean 1978), but at the same time add further stress to this highly urbanized ecosystem. The objectives of this work are to analyze change in elevation (geomorphology) and to evaluate the initial response for vegetation at the restoration site at Elders East and West. At this time vegetation data is not available for Elders West.

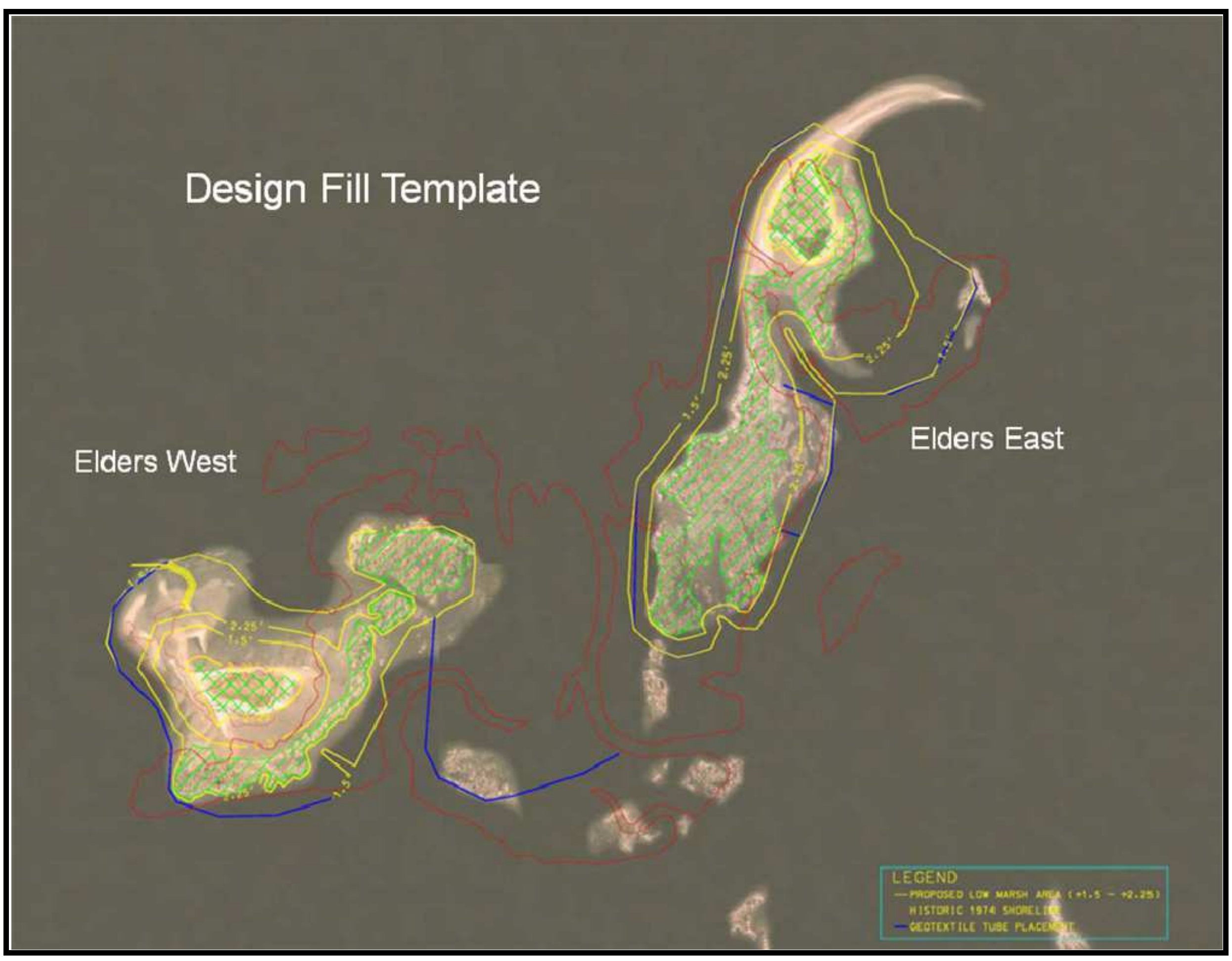

Fig. 4. Design fill template for Elders Point East and Elders Point West based on the 1974 shoreline limits.

3.1 Elders Point East

Elders Point East used material from the maintenance dredging of the Rockaway Inlet navigational channel (120,800m^3/ 158,000 yd^3), Ambrose Channel (35,170 m^3/46,000 yd^3), and purchased from Amboy Aggregate (34,405m^3/45,000 yd^3) totaling 190,374 m^3 (249,000 yd^3) which was composed primarily of sand (98%). The project involved the placement of fill (e.g., sediment from maintenance dredging), regrading the site to appropriate elevations for the target community, and planting with native coastal plant species. This design was based on the approximate extent of the 1974 marsh coverage as reported by NYSDEC. A mixture of *S. alterniflora*, *Spartina patens*, and *Distichlis spicata* was planted since it is representative vegetation throughout the New York Harbor estuary. Figure 4 is the design fill template for Elders Point East and indicates the planting scheme for *S. alterniflora*, tri-plug plantings (combination of all three species), and existing *S. alterniflora* hummock relocation. Approximately 580,000 *S. alterniflora* plugs, 45,876 *S. alterniflora* pots, 33,640 tri-plugs (*S. alterniflora, Distichlis spicata,* and *S. patens*) were planted over a total of 16.2 ha. Most of the project (i.e., > 95%) was planted with *S. alterniflora.* Figure 5 is an aerial view showing the construction of Elders Point East which illustrates the grids created for plantings. The individual grids (cells) included waterfowl fencing to minimize predation by the Canada Goose population.

Fig. 5. Aerial photograph taken near high tide during construction of Elders Point East October 2006.

3.1.1 Methods for morphological monitoring (survey) Elders Point East

Plantings on Elders Point East were completed in spring 2007, and the baseline monitoring data were collected in July 2007 using real time kinetic global positioning system (RTK-GPS) survey equipment. The first set of follow-on monitoring data was taken in May 2009, again using RTK-GPS technology. The July 2007 data points were collected most densely throughout the southern portion of the island and were regularly spaced approximately 20 feet on-center. Data points were the least dense within the south-central portion of the island, where the muddy conditions can be very difficult to transverse. In the northern half of the island, data were collected along transect lines spaced approximately 100 feet apart. The May 2009 and July 2010 data points were collected along profile lines spaced approximately 100 feet apart, each beginning toward the center of the island and moving radially outward toward the shoreline. The average distance between points along the profile lines was approximately 30 feet and prominent features such as the vegetation line and the centerlines of the tidal creeks were also captured. Data collection was focused along the perimeter of the island where it was anticipated that sediment transport would be the most active. The collected data were post-processed using the National Geodetic Survey's Online Positioning User Service (OPUS) and were plotted with ESRI™ ArcMap® version 9.3. Both data sets were overlaid on top of one another and the areas that did not have a high coincidence of points between the data sets were blocked or "masked," from being used to create a 3-dimensional surface. These areas were blocked because their inclusion would have resulted in a greater degree of interpolation between the two data sets. By only capturing those areas with a higher coincidence of points between the two data sets, the resultant surface is more reliable. A resultant surface between the two data sets was created using ArcMap®'s Spatial Analyst extension. From this surface, areas of sediment erosion, deposition and of no sediment transport were determined.

3.2 Elders Point West

Elders Point West, with construction initiated in late 2009 and completed in mid-2010, involved beneficial reuse of dredge material from Anchorage Channel, the main navigational channel for New York Harbor. The total quantity of placed material was 230,877 m^3 (301,976 yd^3) composed primarily of sand with some silt which created 23.4 ha of new tidal marsh area. The project involved the placement of fill, regrading the site to appropriate elevations for the target community. The planting scheme for Elders West was different from that at Elders East and may allow for a better understanding of species success once that vegetation data becomes available. For this planting scheme no *S. alterniflora* plugs or pots were included. All the low marsh plants were relocated *S. alterniflora* hummocks from the project site which covered approximately 7.0 ha. Of the 23.4 ha of tidal marsh created, 1.62 ha was high marsh transition zone, 0.49 ha upland seeded area, 1.62 ha of no planting acting as a planting control area. A total of 0.61 ha was low marsh hummock relocation, replanted so that they were evenly spaced throughout the designated transplant area. There was also 1.62 ha of no planting zone with a 6.1 m low marsh planted perimeter, 0.65 ha of upland planting and seeding, 7.65 ha of low marsh vegetation, and 0.41 ha of seeded area planted by National Resources Conservation Service. The planted areas included 85,580 high marsh transition plants with a variety of tidal marsh wetland vegetation, 240 shrubs, and 60 wetland trees covering approximately 1.6 ha. Figure 6 is an aerial view of Elders Point West showing the grids that include waterfowl fencing similar to Elders East.

Fig. 6. Construction of Elders Point West July 2010.

3.2.1 Methods for morphological monitoring (survey) Elders Point West

Plantings on Elders Point West were completed in spring 2010, and final as-built survey data were collected in September 2010. A second survey was conducted in May 2011, near the end of the maintenance period of the construction contract for Elders West. On each occasion, survey data were collected with sufficient density to generate 0.5 foot contour lines for the entire project site. An elevation surface for each survey was generated using the ArcGIS Spatial Analyst extension and a third surface was generated by differencing the 2010 and 2011 elevation surfaces. From this surface areas of sediment erosion, deposition, and of no sediment transport were determined.

4. Results and discussion

Perhaps an important outcome of this project is that federal, state, and local agencies, with diverse missions, worked collaboratively for more than nine years towards the success of this effort. The cooperative funding among the various agencies has also been a success. Elders Point East was initially a CAP (Continuing Authorities Program) project and when funding for the program changed and less CAP money was available, it was the pairing of the need for funding for a Restoration Project with the need for a harbor deepening project (i.e., Mitigation Project) that allowed this effort to come to fruition. The construction of Elders East and West did not occur at the same time as a result of funding availability. Figure 7 is an aerial view from 2009 showing the completion of Elders East and preconstruction conditions of Elders West. Figure 7 illustrates the vegetation has become well established through the third growing season (2009).

Fig. 7. Aerial view of Elders Point 2009, inset with arrow indicating location at Elders Point East.

4.1 Elders Point East

Patterns of morphological change (erosion and deposition) from July 2007 to May 2010 at Elders Point East are illustrated in Fig. 8. There is a range in elevation change from approximately – 0.8 m (loss, erosion) to + 0.6 m (gain, deposition) during this time. The GIS methodology used did not permit an overall assessment determining a net change (loss/gain) in volume at Elders Point East. It is apparent however that there is some loss (as much as 0.8 m) along the southwest side of the marsh and an overall gain (up to 0.6 m) on the northeast portion. The elevation in the central portion of Elders East is not included in Figure 8 since this is the interior of the island and not subjected to the same current velocities and sediment transport. Not shown in Figure 8 is the sand spit that extends from the northwest tip of Elders East which has been a well established natural feature of the sediment transport in this area of Jamaica Bay. This spit was not planted with vegetation, remains in relative equilibrium, and is not part of this current tidal marsh restoration effort.

Sediment elevation change from 2007 to 2009 provides a point-in-time measurement of elevation change and is indicative of the tidal energy that is acting upon the restored marsh platform. Anecdotal evidence, particularly in the no planting treatment on the southwest side of the island at Elders Point East, suggested that the variation in plant response may be related to sediment movement. Linear models of individual vegetative metrics for 2009 and the sediment elevation change from 2007 to 2009 were not significant. It is possible that vegetative response is related to other elevation metrics (i.e., initial constructed elevation, 2009 elevation, elevation change from 2008 to 2009). In addition, coordinates for vegetative plots were collected with a Garmin rino 530 GPS unit; thus providing low accuracy for vegetative plot locations. The accuracy of the plot location and the size of the plot buffer both affect pixel selection for GIS computation of a mean elevation change for each plot.

For the first six months after the initial fill occurred (2006) much of the settlement would have taken place and therefore that data would not reflect a meaningful trend for change of elevation. The observed areas of loss (south west side of the marsh) and gain (north east side) are consistent with observed historic sediment transport in this area of Jamaica Bay. There is an existing sand spit that extends from the North West tip of Elders Point East and curves north east for more than 200 m and is visible at mean low water (MLW). This observed pattern of deposition is consistent with observed losses along the south west side of the island that are seen from this data (Fig. 8). Overall there was no appreciable change in elevation of placed material that would have lead to adverse conditions for the vegetation. For example, exposed roots were not observed in areas on Elders East where elevation change was measured to be on the order of 0.7 meters.

Vegetation monitoring at the Elders East and reference marsh (JoCo) seeks to evaluate the response of vegetation to restoration and to determine if vegetation communities at the two marshes are converging. Following two full growing seasons, the vegetation communities in the restored and reference marsh have converged with respect to total canopy cover, *S. alterniflora* stem density, total standing aboveground biomass and annual net belowground production. Total vegetative canopy cover and bare ground canopy cover on the restored and reference marsh are equivalent. Messaros *et al.* (2010) determined that vegetative cover and *S. alterniflora* stem density were greater in the fertilized treatment; no differences were detected between treatments for total standing above- and belowground biomass as well as annual net belowground production. These results suggest that fertilization may affect vegetation form (i.e., the morphology of the aboveground portions of the plant) but not above- or belowground production. The complete discussion for Elders East four year post-construction vegetation monitoring results is available in Messaros *et al.* (2010).

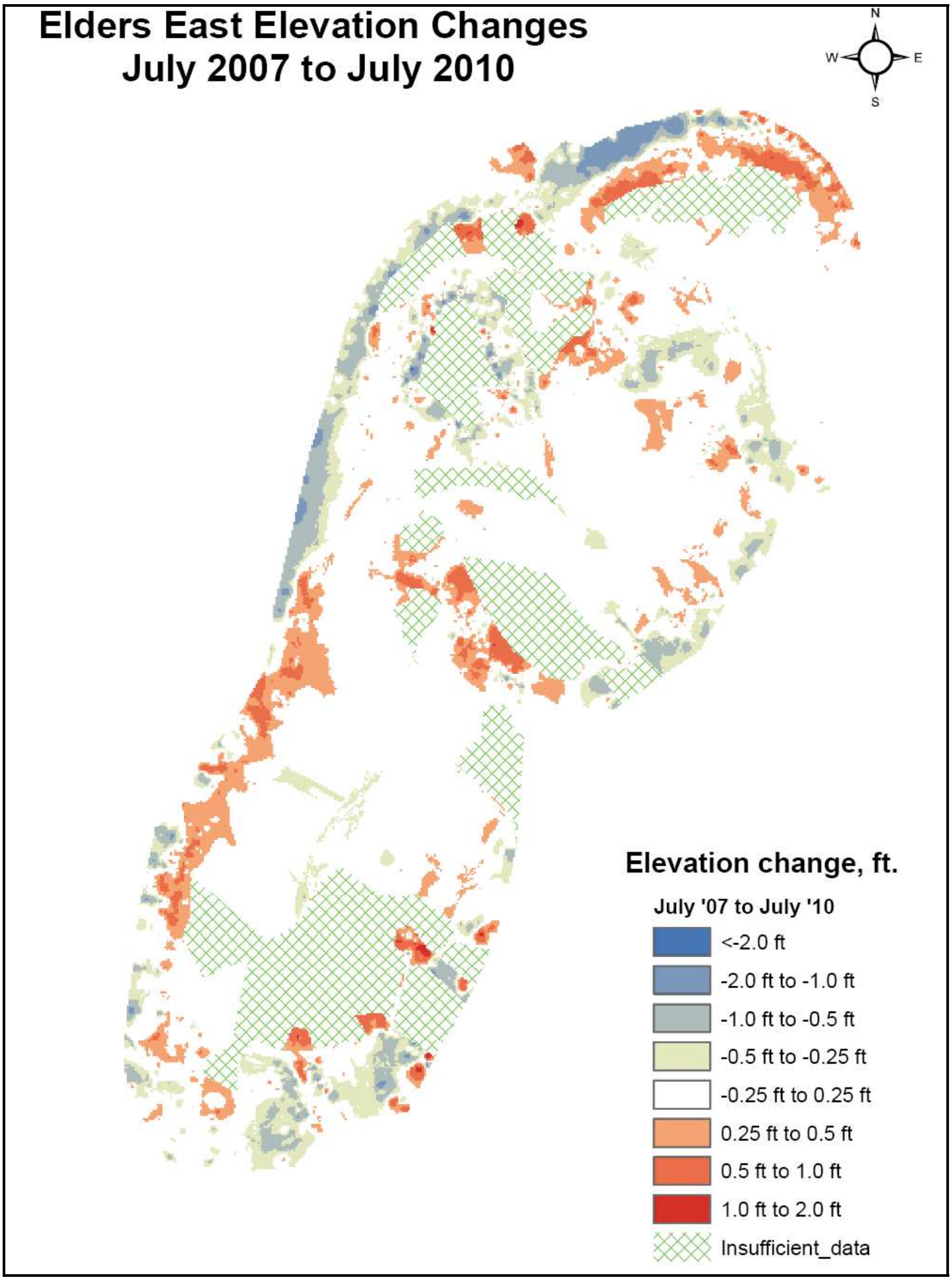

Fig. 8. Elders Point East elevation changes during the monitoring period of July 2007 to July 2010.

Messaros *et al.* (2010) concluded that no significant difference (p=0.6) was detected in total vegetative cover between the reference (JoCo) and restored (Elders East) marshes. Average densities (number of stems $0.25m^{-2}$) for vegetation (within $0.25m^2$ plots) indicate no significant difference was detected in stem density of *S. alterniflora* between JoCo and Elders East (p=0.1). Stem density of *S. alterniflora* was significantly greater in the fertilizer treatment than in the no fertilizer treatment (p=0.002). No difference in stem density of *S. maritima* was detected between the fertilizer treatments (p=0.3). Two hummock relocation areas have been monitored. In 2008, stem counts and height of *S. alterniflora* were also evaluated. All vegetative metrics differed significantly between the two hummock relocation areas. Canopy cover, stem density, and height of *S. alterniflora* were all greater within Relocation Area I. The relocation areas differ with respect to when hummocks were transplanted (June vs. October 2006); however, there may be other confounding factors. For example, canopy cover of *S. maritima* is also significantly greater at Relocation Area I. Recruitment of *S. maritima* at the end of the second full growing season would not be related to the timing of hummock transplant. Relocation Area I is noticeably wetter than Relocation Area II and a small tidal creek has developed adjacent to Relocation Area I, thus suggesting differences in hydrology. There are many possible explanations for partial success for restoration projects including poor hydrology (Race & Fonseca 1996). Relocation area II is bordered by a sand ridge that prevents flooding except during the highest tides. Future analysis of elevation surveys should be conducted to determine if differences in elevation are affecting localized hydrology and vegetative response within these treatments. The densities of both *S. alterniflora* ($p<0.001$) and *S. maritima* (p=0.0008) stems were significantly greater in hummock Relocation Area I as compared to Relocation Area II.

4.2 Elders Point West

Patterns of morphological change (erosion and deposition) from September 2010 to May 2011 at Elders Point West are illustrated in Fig. 9. There is a range in elevation change from approximately – 0.6 m (loss, erosion) to + 0.6 m (gain, deposition) during this time. The interior portions of the island appear unchanged with some deposition occurring on the southern shore. There are areas of loss on the east and west side of Elders West. It is likely that some of this observed elevation change is the placed material achieving equilibrium given the local currents, tides, and wind.

The first year vegetation monitoring data was not available at the time this publication went to press. Since there is stability in the fill material, the critical substrate for plant growth, it may be speculated that there will be very similar trends in the plant community with Elders West as reported with Elders East. Critical to long term goals is the sustainability of the placed fill and subsequent plant growth. Once vegetation becomes established it will stabilize the fill and thereby lend itself to a successful plant community. While the results for Elders Point West are limited to the one year time point much of the fill placement achieves equilibrium in a relatively short time. This is based on observations noted from the four year monitoring of the fill placement at Elders Point East.

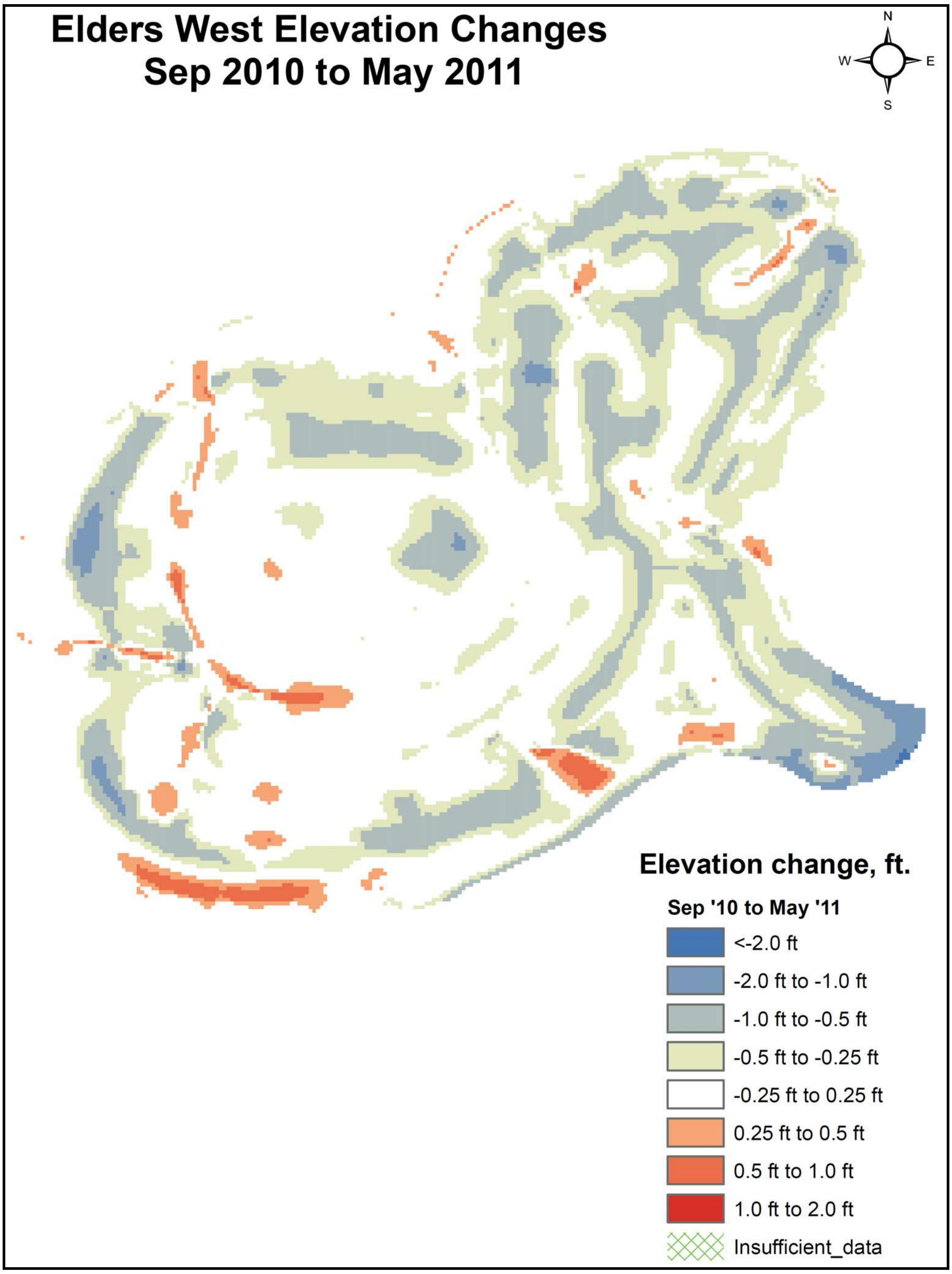

Fig. 9. Elders Point West elevation changes during the monitoring period of September 2010 to May 2011.

5. Conclusion

Based on the survey monitoring to date, no appreciable sediment transport (loss or gain) has occurred and the material has remained in place since the construction of the project in 2006 at Elders Point East and Elders Point West in 2010. On the west side of the Elders East there is some decrease in elevation and likely a result of the historic patterns of sediment transport occurring in a northerly direction of the accreting sand spit at Elders East. Without conducting a sediment transport study the authors reserve a final conclusion but this pattern is consistent with historic observation.

For the *S. alterniflora* plugs (representing >95% of the planted vegetation) the plant communities in the restored (Elders East) and reference marsh (JoCo) have converged with respect to total canopy cover, stem density, total standing aboveground biomass, and annual net belowground production. This occurred after two full growing seasons. In 2008, by the end of the second growing season, the restored marsh achieved 50% vegetative cover, with *S. alterniflora* the dominant species. No significant difference was observed in total vegetative cover and stem density between Elders Point East and JoCo marshes for *S. alterniflora*. It appears that the vegetation for this project is achieving the desired outcome and providing the anticipated ecological benefits. Total vegetative cover was significantly greater in the fertilizer treatment as compared to the no fertilizer treatment. There also appears to be a benefit of increased stem density in *S. alterniflora* when fertilizer is used. However no benefit was detected for total standing above- and belowground biomass as well as annual net belowground production with the use of fertilizer. This project was successful in preventing the return of invasive species such as *Phargmities australis* and also showed no impact from predation as a result of the installation of waterfowl fencing.

Perhaps the most significant conclusion is that there appears to be morphologic stability with the placed material at both Elders Point East and Elders Point West. During the post construction monitoring period the majority of the material has remained unchanged. This may have far reaching implications for future sustainability for restoration/mitigation efforts in Jamaica Bay. Further monitoring is scheduled and subsequent analyses will be essential to develop a more complete understanding of the sediment and plant community dynamics and stability. The need to continue the monitoring programs at Elders Point East and West does not diminish the important observations that have been reported herein as additional efforts are planned in the near future (i.e., restoration of Yellow Bar). Large scale tidal salt marsh restoration efforts in Jamaica Bay may serve as a benchmark for similar projects elsewhere.

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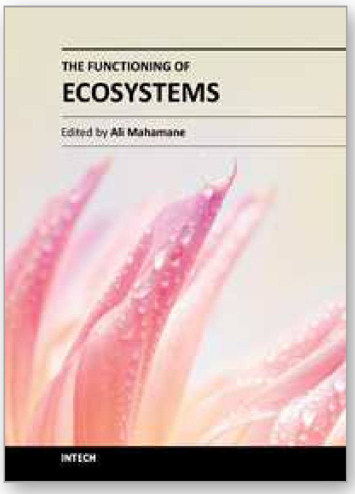

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The ecosystems present a great diversity worldwide and use various functionalities according to ecologic regions. In this new context of variability and climatic changes, these ecosystems undergo notable modifications amplified by domestic uses of which it was subjected to. Indeed the ecosystems render diverse services to humanity from their composition and structure but the tolerable levels are unknown. The preservation of these ecosystemic services needs a clear understanding of their complexity. The role of the research is not only to characterise the ecosystems but also to clearly define the tolerable usage levels. Their characterisation proves to be important not only for the local populations that use it but also for the conservation of biodiversity. Hence, the measurement, management and protection of ecosystems need innovative and diverse methods. For all these reasons, the aim of this book is to bring out a general view on the biogeochemical cycles, the ecological imprints, the mathematical models and theories applicable to many situations.