

A WETLANDS CLIMATE CHANGE IMPACT ASSESSMENT FOR THE METROPOLITAN EAST COAST REGION

Ellen Kracauer Hartig¹, Frederick Mushacke², David Fallon², and Alexander Kolker³

¹Center for Climate Systems Research, Columbia University.

²New York State Department of Conservation, Division of Fish, Wildlife & Marine Resources.

³Department of Ecology and Evolution, State University of New York, Stony Brook.

INTRODUCTION

This section examines the impact of future wetland loss from sea-level rise, storm surges and other forces over the next twenty to 100 years, with an emphasis on a case study in Jamaica Bay, Queens County, New York City. Change over the previous 100 years is documented through use of historic maps, aerial photography and field observations. Projections of future change are extrapolated from current trends and several global climate models (GCMs). Intertidal wetland plant communities are discussed in relation to their zonation, which is strongly correlated with extent of tidal flooding that may become accelerated with global warming (IPCC 1998, Titus 1988 and 1998, and Allen and Pye 1992).

Coastal salt marshes of the Northeastern United States (Maine to New Jersey) formed within the last 4000 to 7000 years, following deglaciation of the last Ice Age initiated about 15,000 years ago, as the rise in sea-level slowed (Teal and Teal, 1969; Redfield 1972, Thomas and Varekamp, 1991). Included in these shoreline alterations was the development of a string of highly productive coastal wetland marshes extending from the easternmost tip of Long Island to what is now New York City, and north along the Hudson River (Tiner 1987). More recently however, alterations in marsh geomorphology consists of a reversal of the marsh-building process through land loss from marsh erosion and inundation.

Tidal wetland loss through shoreline erosion and related water-induced processes is well documented in Louisiana, Chesapeake Bay, Southern New Jersey and Cape Cod (Dean et al., 1987; Titus, 1988; Wray et al., 1995), however the phenomenon has not yet been reported in the Metropolitan East Coast (MEC) region where losses cannot be easily

compensated for through expansion of the salt marsh onto adjacent upland or freshwater zones. Intertidal marshes associated with Jamaica Bay in New York City offer an opportunity to study a well-mapped coastal area with an available historic record from aerial photographs, in part because of its association within the highly urbanized MEC region (Fig.1).



Fig. 1. View eastward of low marsh *Spartina alterniflora* with Jesse Thomas, GISS Research Assistant, at the northern tip of Broad Channel Island, Gateway National Recreation Area, Queens, NY.

Most studies of sea-level rise (SLR) in salt marshes are based on long-term age-depth profiles in accreted layers of peat. Studies have shown that long-term surface deposition rates are correlated with historical changes in sea level (Orson et al. 1998, Bricker-Urso et al. 1989, Redfield 1972). Many marsh-dating techniques have a resolution of several years (i.e., feldspar markers) and these may be very useful to document continued marsh loss in Jamaica Bay. Radioisotope analysis can establish vertical accretion in the marsh for periods of more than thirty years (^{210}Pb and ^{137}Cs) (Orson et al. 1998). However this study seeks to compare original extent of marsh in Jamaica Bay before and after protective mechanisms were promulgated, and to project future losses. Since changes occurred rapidly within the last 100-year time period, including major dredge and fill operations for navigation and upland construction, emphasis for this analysis relies on historic charts, maps and aerial photography. These tools are used to document marsh change over the last 100 years. In addition, Global Climate Models (GCMs) based on extrapolations of historic trends and continued increase of simulated anthropogenic outputs of CO_2 and other greenhouse gases

into the atmosphere are used to project future land loss in local marshes. The results are analyzed and compared with current federal and state wetland regulatory policies to consider preparedness from sea-level rise and other climate change impacts on affected residences in the floodplain areas, regional infrastructure networks including airports, and on public health.

Study Area

This report concentrates on saltwater marshes of the Jamaica Bay Wildlife Refuge in Queens County, New York, protected since 1948 as a sanctuary by New York City Department of Parks and Recreation, and since 1972, by legislation as part of the Jamaica Bay Unit of Gateway National Recreation Area (GNRA) administered by the National Park Service (National Park Service 1979, 1981; Tanacredi and Badger, 1995). Located near John F. Kennedy International Airport, the geographical coordinates of Jamaica Bay are 41° N, 74°W (Fig. 2). While other units of GNRA are found in Staten Island and New Jersey, the Jamaica Bay Unit encompasses uplands, wetlands and waters south of the Belt Parkway in Brooklyn and Queens. While most of the island marshes are part of the Jamaica Bay Wildlife Refuge within the GNRA, some shoreline marshes are located outside the refuge boundaries and some are located outside the GNRA boundaries. Jamaica Bay is an estuary with diverse habitats including open water (littoral zone), coastal shoals, bars, and mudflats, and intertidal zone low and high marshes and upland areas. (For description of these wetland types see <http://www.dec.state.ny.us/website/dfwmr/marine/twcat.htm>).



Fig. 2. Islands of the Jamaica Bay Unit of Gateway National Recreation Area. Note location of Big Egg Marsh, Rulers Bar Hassock Yellow Bar Hassock and Black Wall Marsh. Sources: Hagstrom Map of the Borough of Queens, City of New York, Hagstrom Map Company, Inc. and USGS Far Rockaway and Jamaica, N.Y. Quadrangles, 7.5 minute topographic series.

Much of the original tidal wetlands of Jamaica Bay have disappeared due to human activities for infrastructure development. According to Englebright (1975) Jamaica Bay in 1900 encompassed 24,000 acres (9717 hectares) of waters, marsh islands, as well as an extensive

network of shoreline marshes extending beyond today's Belt Parkway. Waters of the Bay covered 7,830 acres (3170 hectares) much of it shallow channels averaging 3 feet in depth.

Marshes covered an estimated 16,170 acres (6549 hectares). By 1970 total acreage with remaining shoreline marshes covered 13,000 acres (5263 hectares) of which 4000 acres (1619 hectares) were marshland.

Wetland Value, Function and Policy

Wetlands and their adjacent areas serve a number of economic and environmental functions and values. They form a protective barrier for coastal urbanized areas, buffering buildings and transportation networks from wave impacts during storm surges (Cowardin et al. 1979; Tiner 1984; Mitsch and Gosselink, 1993; and Bertness 1999). Tidal wetlands can serve to improve degraded waters by recycling nutrients, processing chemical and organic wastes and capturing sediment loads; the cleansed water helps maintain aquatic organisms. The decomposed detritus from salt marsh vegetation contributes to the base of the food chain of estuarine and marine environments, although its relative importance for nutrient supply for nekton assemblages has not been wholly determined (Kneib, 1997). The intertidal zone serves as breeding and over wintering grounds for migratory waterfowl and other birds. Thick layers of carbon-rich peat play a role in the global carbon cycle by binding poorly decomposed plant material into the substrate (Mitsch and Wu 1995; Patterson 1999). Each of these wetland values diminishes when loss of marsh acreage occurs.

The different wetland types vary in function, contour, biota, tidal action, water quality, and in their respective contribution to the marine food chain. The high marshes areas of New York City tend to be confined to narrow strips in the landscape because often all but the most waterward edges have been filled for urban development. In many areas the high marsh and accessible low marsh were filled for development. However, as exemplified by Jamaica Bay, island marshes, tended to be left free of development activity. Remaining wetlands are predominantly intertidal low marsh areas, coastal shoals, bars and flats, and the littoral zone. The contribution of coastal shoals, bars, flats, and littoral zones to the marine ecosystem is highly variable. Under a rising sea level the more aquatic wetland types are likely to gain in extent as the intertidal zone becomes submerged. Concerns regarding continued loss of intertidal marshes are in part due to relatively large acreage remaining, their vulnerability to filling activity, and their relatively high wetland value (they are considered to be among the most productive of all tidal wetlands areas). The wetlands studied for this climate assessment encompasses mainly the intertidal, or low marsh zone.

Federal and state legislation protect wetlands through a permit process whereby permits are issued or denied for filling and dredging for construction, navigation and other activities in wetlands.

- The U.S. Army Corps of Engineers regulates dredging, the discharge of dredged or fill material, and construction of structures in waterways and wetlands through Section 404 of the Clean Water Act (1977).
- New York State enacted the Tidal Wetlands Act, Article 25 of the Environmental Conservation Law (ECL), effective September 1, 1973, in order to “...preserve as much as possible the remaining wetlands in their present natural state and to abate and remove the sources of their pollution.”

Additional permits, notification and determinations from federal and state government agencies may be required.

Salt Marsh Ecology

The dominant plant species of the low marsh intertidal zone is the salt marsh cordgrass, *Spartina alterniflora* (Fig. 3). *S. alterniflora* provides food and nest material for birds, shelter for diamond-backed terrapins and other animals, and physical structure (for peat accretion) to the marsh. *S. alterniflora* may be useful as a prime indicator of habitat vulnerability (e.g. erosion damage) and of adaptation (e.g. inland migration of *S. alterniflora*) during periods of global warming-induced sea-level rise because of its unique characteristics and responsiveness to sea level rise (SLR) and tidal cycles.



Fig. 3. View of low marsh and tidal channels at Yellow Bar Hassock with Manhattan in

the background.

Coastal plants form distinct zones in response to a combination of physical and biological factors. *Spartina alterniflora* is replaced by the high marsh species *Spartina patens* (salt hay) at mean high water (MHW) (Bertness 1991b). Flooding becomes irregular in the high marsh portion of the intertidal zone. While *S. patens* is rarely found in the low marsh, where oxygen flow to its rhizomes becomes limiting, *S. alterniflora* is restricted from the high marsh by *S. patens* competition (Bertness 1991b). *Salicornia virginica* (glasswort) can also be present in the low marsh (Bertness and Ellison 1987). Floristically the high marsh is much more diverse than the low marsh, although all are halophytes—plants adapted to saline environments. The dryer high marsh zone contains species such as *Juncus gerardii* and *Distichlis spicata* (Bertness 1991a). In the highest regions of marsh *Iva frutescens* (high tide bush) and *Phragmites australis* (common reed) are found. In lower regions of the marsh physical and chemical forces dictate the species composition. Higher up in the marsh interspecific competition determines the plant community (Bertness 1991a).

Frequency of tidal flooding is the dominant force in determining species location (Bertness 1991b, Cowardin et al. 1979). The correlation between inundation time and zonation is strong enough that changes in salt-marsh plant community zonation may themselves be useful as indicators of sea-level rise. Responses of wetland plant communities to sea-level rise include shifts from high marsh to low marsh, shifts from low marsh to coastal shoals and mudflats, and migration of marshes inland. On an unobstructed coastal plain, upland habitat will be converted to salt marsh.

Warren and Niering (1993) described the transformation of marsh zones in a Connecticut salt marsh. In 1987 and 1988, they resurveyed an area of which the vegetation had been studied 50 years earlier by Miller and Egler (1950) and compared the species. At the site, sea levels had risen by 2.5 mm yr^{-1} , approximately 1.5 mm yr^{-1} faster than in the previous thousand years. High marsh plant communities were replaced by low marsh communities. The high marsh community of *Juncus gerardii* had been converted to a lower elevation high marsh community consisting of *Spartina patens* and forbs such as *Triglochin maritima*. *S. patens*-dominated marshes had been converted to short *S. alterniflora*, *Distichlis spicata* and forbs. Warren and Niering's study demonstrates that modest rates of sea-level rise, of even less than 3 mm/yr can have a detectable and ecologically significant effect on salt marshes.

In Long Island's Shinnecock Bay, island marshes have either become reduced in size or have disappeared altogether while shoreline marshes have expanded landward, indicating a discernible inland migration of the marshes (Fallon and Mushacke, 1996). Thirteen intertidal marsh islands covered 30 acres in 1974; seven marshes covering 15 acres remained in 1994.

In former nontidal areas including adjacent area and dredged spoils, wetland extent gained with 161 acres of high marsh formation. Projected increases in sea-level rise will further inundate marshes vulnerable under current accretion rates, and may cause adjacent uplands to be converted to wetlands. The Connecticut and Long Island examples may serve as a model for how plant communities will respond to future sea-level rise elsewhere.

Role of Climate

Global climate change may alter hydrologic parameters upon which wetlands, and the species that inhabit them, depend (IPCC 1995). Future projections, extrapolated from both current trends and climate-change scenarios, indicate that Metropolitan East Coast tidal wetlands are at risk from sea-level rise and increased storm surges.

While marshes can withstand some environmental stress, more frequent storm surges and greater wave action superimposed on rising sea level will exacerbate marsh erosion. Ice and storm events create significant disturbances by scouring the vegetated marsh surface thus disrupting peat formation (Bertness 1999, Richard 1978). If not balanced by new accretion, salt marsh inundation and erosion could lead to permanent loss of this productive ecosystem undergoing conversion to a more aquatic wetland type. Marsh-drowning events have been documented in marshes at Clinton, Connecticut during previous periods of rapid sea level rise such as between 1200 AD and 1450 AD (Varekamp et al. 1992).

Climatic events such as freezes and storms are important for salt marsh geomorphology and landscape-level ecology. Crucial variables include patterns of disturbance, creation of habitat diversity, and temporal distribution of organisms. Ice is a distinguishing feature between northern salt marshes, such as those found in MEC and southern salt marshes (Bertness 1999). Ice can act as both an erosive and depositional force on the salt marsh. Richards (1978) found that freezes in Flax Pond, a Long Island salt marsh, can pull chunks of marsh off the land to create little islets of marsh, called tussocks. The tussocks can hold growing *Spartina alterniflora* plants and can be important for extending the range of marshes seaward.

Ice can also scour and remove plant material and sediments from salt marshes. A single severe freeze in Flax Pond, Long Island, destroyed 16 months worth of accretion (Richard, 1978). While ice scoured regions may create habitats for microinvertebrates in crevices and muddy strata in the marsh, repeated extensive scouring can diminish marsh landmass over the long-term. Solomon et al. (1994) estimated that less extensive ice distribution increased coastal erosion rates comparable to maximum observed rates under present climate conditions.

The rate of local sea level rise (SLR) in Jamaica Bay is around 2.7mm per year as determined by tide gauge data (1961-1990) from Battery Park in Manhattan. This can be compared to the mean global sea-level rise (SLR) of 1.8 mm/yr since the 1900s, due in part to

anthropogenic causes (IPCC 1996, Gornitz, 1995, V. Gornitz, Coastal Zone chapter of this report). Using an extrapolation of the current trend and two GCMs, local SLR projections indicate that mean sea level rise is estimated to be between 2.7 and 7.3 mm/yr by the 2020s, and between 2.7 and 13.7 mm/yr by the 2050s (Table 4). The difference between the global and the New York average sea-level rise is due, in part, to local subsidence resulting from crustal readjustments to the removal of ice following the last ice glaciation. Erosion of Jamaica Bay marshes could be caused by a combination of SLR, changes in inshore wave energy, dredging and channel modification for navigation, and reduced sediment loads available for vertical marsh accretion, due to channelization of streams and tributaries that prevent upland sediments from reaching the Bay.

Saltwater inundation and erosion from SLR will affect coastal wetlands and the wildlife they support. Elevated sea levels may enlarge tidal pools and channels. While marshes can withstand wave action to a certain degree, erosion may escalate with more frequent storm surges (e.g. nor'easters, tropical storms and hurricanes) superimposed on a higher sea level (Brampton 1992; Gornitz 1995; Rosenzweig et al. 1999). With a rising sea level, salt marsh vegetation may become inundated for more hours in the tidal cycle than can be tolerated for sustained growth. It should be noted that a salt marsh requires some sea level rise to maintain itself, the process is somewhat self-regulating and salt marsh accretion rates, at a minimum, approximates SLR (Allen and Pye, 1992). The correlation between accretion rates and SLR has been used as a tool to determine historical SLR (Nydyck et al. 1995; Varekamp et al. 1992; and Nuttle 1997). Present rates of marsh accretion have been reported as exceeding or keeping pace with sea-level rise except in Louisiana, parts of Chesapeake Bay (e.g. Blackwater Marsh, Maryland), and Barn Island, Connecticut (Boesch et al. 1994, Dean et al. 1987, Stevenson and Kearney, 1996 and Wray et al. 1995).

METHODS

Aerial Photograph Interpretation and Mapping

To determine if marshes of Jamaica Bay are stable, or undergoing erosion, three sets of historic photographs of a center section of Jamaica Bay, from 1959, 1976, and 1998, were examined. Stereopairs with greater than 60% overlap were obtained from two aerial photograph companies. For two island marshes, Yellow Bar Hassock and Black Wall Marsh, and one marsh associated with Broad Channel Island (Big Egg Marsh), landmass was calculated using a transparent grid overlay, 4 x 4 squares to the inch, over the photographs. Squares with greater than 50% vegetated land cover were counted three times for each year-interval, and the average of the counts for each marsh was recorded (Fig. 4, Table 1).

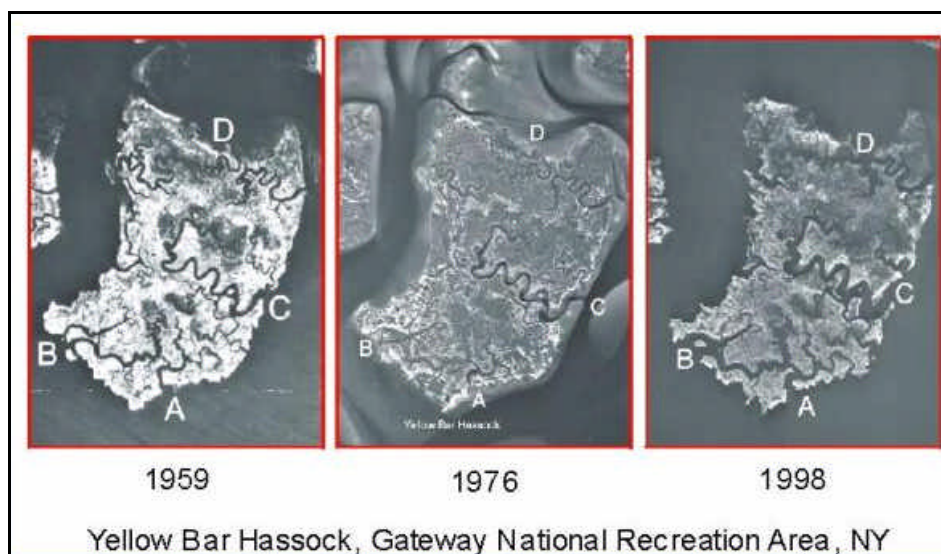


Fig. 4. Aerial photographs of Yellow Bar Hassock, part of Jamaica Bay Wildlife Refuge (a) dated April 7, 1959 at 9:15am (high tide 7: 45 am), (b) dated March 29, 1976 at 12:40 pm (low tide 1:28 am), and (c) dated March 13, 1998 (mid-tide). Sources were Robinson Aerial Surveys, Inc. (4a) and AeroGraphics Corp., Bohemia NY (4b and 4c).

Table 1. Acreage and percent remaining since 1959 at three protected salt marshes at Jamaica Bay Wildlife Refuge, Gateway National Recreation Area, Queens, New York.

Marsh Name/ (Saltmarsh Zone)	1959	1976		1998		
		% Loss		% Loss	% Loss	
	Acres	Since 1959	Acres	Since 1976	Since 1959	Acres
Yellow Bar Hassock (Low)	189	8	173	5	13	165
Black Wall Marsh (Low)	44	2	43	5	7	41
Big Egg Marsh (Low)	75	-1	76	16	15	64
Total acreage	308	5%	292	8%	12%	270

For a trends analysis over the longer term covering all of Jamaica Bay, land loss or gain was quantified by computerized Geographic Information System (GIS) analysis. Navigation charts and topographic maps dating from 1899 and 1900 have been digitized by the Army Corps of Engineers (ACE) (Stephen McDevitt and Bob Will), and by New York State Department of Environmental Conservation (NYSDEC) (Fred Mushacke and Dave Fallon). The maps were being compared with more recent aerial photographs for proposed restoration projects and regulatory purposes. Determination of marsh size between different periods over the century with the aid of the GIS will help clarify wetland losses. The

NYSDEC map series covering years 1900, 1974 and 1994, was used to compare wetlands extent prior to and after the 1970s. A comparison of losses before and after the 1970s when stricter regulation limited filling activities in and adjacent to wetlands and marshes is discussed. Land loss of wetlands up to 75% through the early 1970s (Black 1981), were primarily due to human activity. However, losses after 1972, once the wetlands of the Jamaica Bay Unit were under the jurisdiction of NPS as well as ACE and NYSDEC, has not been previously documented.

The New York State Official Tidal Wetlands Inventory is maintained by the New York State Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources, Bureau of Marine Resources, Geographic Information System Unit. The tidal wetlands were first mapped in 1974 during the New York State tidal wetlands mapping inventory. The inventory is based on aerial infrared photography 1 inch = 1000 feet. The wetlands are defined by a combination of tidal influence and vegetation. They are divided into 3 vegetative categories; intertidal marsh (IM), high marsh (HM), and fresh marsh (FM) and 2 non-vegetated categories; littoral zone and coastal shoals bars and flats.

During the last 26 years since the initial mapping, losses of tidal wetlands were suspected in the Jamaica Bay island complex but empirical evidence was limited. Using GIS software (ArcView) and digitizing the Tidal Wetlands Boundary (TWB) from historic photos and maps produced definitive results. All digital data was referenced to the 1974 TWB then overlain onto the USGS quad for reference. The overlays include the 1900 USGS TWB (green), the 1974 TWB (red) and a coverage of the TWB developed using the 1994 NYS Digital Ortho Quads (yellow) (Fig. 5). The outer perimeter of all vegetated wetlands was digitized and used for the TWB, even though the 1974 wetlands delineation defined the islands into high and intertidal marsh categories. Four marshes where acreage revealed the scope of loss were measured (Table 2). Three small marshes were measured that were greatly diminished in size, including Elders Point Marsh, Nestepol, Fishkills Hassock. For comparison Jo Co marsh was measured because its' losses appeared minor. Total marsh losses for all islands were then estimated using the GIS map overlays for 1974 compared to 1900, and for 1994 compared to 1974. Cumulative losses for the entire period 1900-1994 are also given.

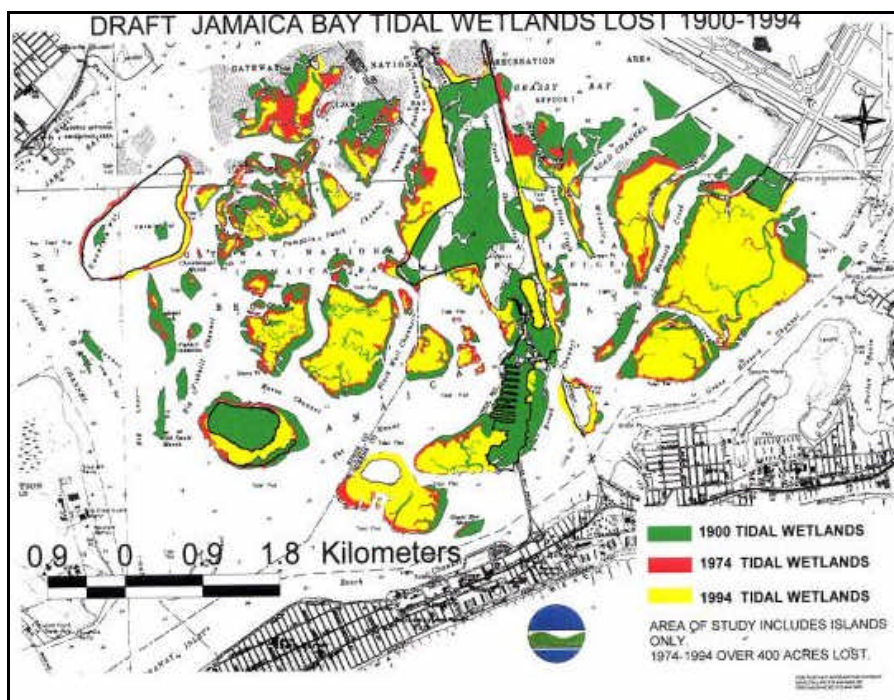


Fig. 5. Jamaica Bay Tidal Wetlands Lost 1900-1994 digitized by Fred Mushacke, NYSDEC, Division of Fish, Wildlife & Marine Resources.

Sources: Topographic map of 1900 and color infrared aerial photographs 1974 and 1994.

Table 2. Trends analysis of 1) Estimated loss in several individual island marshes of Jamaica Bay, 1900-1994. 2) Wetland loss for more than 15 named island marshes of Jamaica Bay 1900-1994.

Marsh Examples (Saltmarsh Zone) / Total Island Marshes	1900	1974		1994		
	Acres	Acres	Percent remaining since 1900	Acres	Percent remaining since 1974	Percent remaining since 1900
Nestepol (Low)	36.6	5.7	16	0.6	9	2
Jo Co (High and Low)	485.0	414.0	85	374.0	90	77
Elders Point (Low)	120.0	93.0	77	37.6	40	31
Fish Kill Hassocks (Low)	4.9	1.3	27	0.05	4	1
Total Island Marshes (>15 Named Islands)	3146	1972	63%	1572	80%	50%

In order to evaluate the effectiveness of the New York State's tidal wetlands program from 1974 to 2000 in protecting total acres of wetlands, a tidal wetlands trends analysis (TWTA) using geographic information system (GIS) technology is being conducted for the tidal area in New York State south of the Tappan Zee Bridge. This report presents preliminary results for the Jamaica Bay island complex.

Sea-Level Trends Analysis and Forecast Modeling

A rise in temperature of 1-5 degrees (C), mainly due to increased CO₂ and other greenhouse gases, will cause thermal expansion of ocean waters and melting of alpine and high latitude glaciers, in turn causing sea level to rise more than 1 meter above mean sea level in the MEC region at certain localities by the end of the century (see previous chapter by V.Gornitz). The assumption of the trends analysis is that sea-level rise could be a major contributing factor of shoreline change and land loss (Wray et al. 1995). The tide gauge at Battery Park, New York City was used to determine recorded historic changes in sea level at Jamaica Bay.

As yet there are no permanent tide gauges within the Jamaica Bay itself. An advantage of the one at Battery Park is that measurements for the location have been recorded since 1856, one of the longest records available in the United States (see chapter by V.Gornitz, Coastal Sector Zone).

The historic rate of SLR of 2.7 mm/year was compared with known accretion rates of the MEC region (Table 3). A survey of the literature indicated that accretion rates ranged from 2.0 to 10.0 for low marsh intertidal zones. One core was taken from within Jamaica Bay where the low marsh accreted at 8mm/year, and the high marsh accreted at 5mm/year (Zeppie 1977). Scenarios of future SLR were then constructed for comparisons with current rates to determine risk of cumulative land loss (Table 4). Global Climate Models (GCMs) were used to construct the rate of sea-level rise per year until the 2090s. GCM climate model simulation outputs are based on a gradual increase of CO₂ and other greenhouse gases over time. Observed sea-level trends have been adjusted for local land subsidence (see chapter by V. Gornitz). To study impacts of sea-level rise (SLR) on tidal marshes in New York City we use a suite of sea level rise scenarios based on 1) current trends, and 2) outputs from two GCMs. The GCMs are those of CCGG and CCGS (Canadian Climate Center) with greenhouse gasses (GG), the latter accounting for greenhouse gasses with sulfates (GS), and of HCGG and HCGS (United Kingdom Hadley Center). Since salt marsh accretion must keep pace with sea-level rise for the marsh to be sustainable, accretion would need to occur at a minimum at similar rates of rise. The relationship between rate of accretion and sea level rise actually can vary, and a single marsh can go through erosive and accreting periods, but to sustain itself overall accretion must exceed SLR.

Table 3. Surface accretion rates measured in the Metropolitan East Coast region compared with the mean rate of sea level rise.

State	Saltmarsh Zone	Accretion Rate (mm/yr)	Time (years)	Method	SLR (mm/yr)	Source
CT	low	8.0-10.0	10	Particle layer	2.6	Bloom (in Richard 1978)
CT	high	2.0-6.6	10	Particle layer	2.6	Harrison & Bloom 1977
CT	high	1.8-2.0	58	²¹⁰ Pb	2.2	Orson, Warren & Niering 1998
	low	3.3				
NY	low	4.7-6.3	103	²¹⁰ Pb	2.9	Armenanto & Woodwell 1975
NY	low	4.0	88	²¹⁰ Pb	2.9	Muzyka 1976
NY	high	5.0	100	²¹⁰ Pb	2.7	Zeppie 1977
	low	8.0				
NY	low	2.5	171	Historic record	2.9	Flessa et al. 1977
NY	low	2.0-4.2	1	Particle layer	2.9	Richard 1978

Sources: Harrison and Bloom, 1977, Zeppie 1977, Orson 1998, and Titus 1988 for all other listings.

Table 4. Minimum salt marsh accretion rates needed to keep pace with projected mean sea-level rise in mm x yr⁻¹. Calculations are based on 1961-1990 tide gauge data from New York City (Battery Park). Source: Data is derived from coastal zone chapter by V. Gornitz.

	2000s	2010s	2020s	2030s	2040s	2050s	2060s	2070s	2080s	2090s
Cur.Tr.	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
CCGG	6.4	8.2	7.3	13.3	6.4	13.7	17.5	13.0	19.0	--
CCGS	6.9	5.3	3.6	11.4	10.8	6.6	11.3	10.5	22.7	--

HCGG	4.1	3.4	6.0	5.0	5.4	6.4	7.4	8.1	6.2	--
HCGS	3.5	2.8	4.1	5.6	2.2	4.9	6.2	5.7	6.9	--

Field Investigations

Of more than 15 named marshes in Jamaica Bay, three were selected for sampling and observation and are listed in Table 5 with mean biomass obtained by oven drying to constant weight (Nixon & Oviatt 1973). Big Egg Marsh and Rulers Bar Hassock border on upland zones associated with the Broad Channel Island community and the Jamaica Bay Wildlife Refuge. An initial selection on the west side of West Pond was deemed inappropriate as it would have required going off heavily visited marked trails within Jamaica Bay Wildlife Refuge. Instead a more secluded site on the same island near its northern tip was selected. Adjacent to Rulers Bar Hassock Marsh are the uplands dominated by shrubs and thickets including extensive stands of Northern Bayberry (*Myrica pennsylvanica*) within the Jamaica Bay Wildlife Refuge. Bordering on Big Egg Marsh are baseball fields in use by the Broad Channel residential community, and some filled, but abandoned, parkland. Yellow Bar Hassock and Big Egg are peat-rich marshes with extensive meandering tidal channels, whereas Rulers Bar Hassock is a sandy shore tidal marsh with limited channel inlets. All three marshes are dominated by *Spartina alterniflora*. The tidal range for Jamaica Bay is typically 1.6 meters (5 feet).

Table 5. Mean biomass of *Spartina alterniflora* (grams dry weight per square meter) during 1999 field investigations at Jamaica Bay, Queens County, NY.

Location	Sampling Period	Mean Biomass gms x 1.0m ⁻²	Mean Biomass gms x 1.0m ⁻²
Big Egg Marsh	July	1065	
	August/Sept	768	
	October	1053	962
Rulers Bar Hassock	July	1442	
	August/Sept	1156	
	October	1012	1203
Yellow Bar Hassock	July	695	
	August/Sept	998	
	October	744	812
Total			992

Geomorphology

Field investigations were planned in cooperation with National Park Service for access, after ongoing erosional processes were noted in the aerial photographs. Noting that significant changes in marsh size had occurred between 1959 and 1976, and 1976 to 1998, evidence for erosion was searched and identified during field observations. The geomorphological changes resulting from erosion can have a profound effect on vegetation ecology and conservation value. Similar observations have been described for the Mississippi Delta in Louisiana, marshes of Blackwater National Wildlife Refuge in Maryland, and the Dengie marshes in Great Britain where combined local subsidence and sea-level rise have resulted in dramatic marsh loss. In 1999, field investigations at Jamaica Bay included photograph records of erosive forms. Where possible, descriptions of erosive features matched those given by other authors.

Vegetation Sampling

Biomass data collection

In order to provide estimates of general productivity and to establish a baseline for future measurements of the 4000 acres of salt marshes in Jamaica Bay, a study of *Spartina alterniflora* standing crop biomass was conducted from the middle, to close to the end, of the growing season, from July through September 1999. At three marsh sites in Jamaica Bay, Big Egg Marsh, Rulers Bar Hassock and Yellow Bar Hassock, quadrats were placed 50 feet apart along belt transects for sampling (Fig. 2, see insets A, B, and C). On the island marsh, Yellow Bar Hassock, transects were conducted with the aid of a compass from the point where the field team disembarked from the National Park Service-supplied boat, in a northwest direction facing the World Trade Towers in Manhattan, to where a large channel prevented further sampling (see Fig 2 inset A). Shoreline transects at Rulers Bar Hassock were traversed from the end of the most seaward vegetated zone accessible by foot, to the wetland-upland boundary, and vice versa at Big Egg Marsh (Fig. 2 insets B and C respectively). Within preselected swaths based on accessibility, transect starting locations were randomly selected. Transects were conducted at least three times within the growing season at each location. Sampling of the three sites was conducted over two non-consecutive days in July, six weeks later in August and September, and again in October. For each transect species composition was recorded in 1m² quadrats; *Spartina alterniflora* was clip-harvested from a 0.25 m² corner of each plot. Collected material was dried to constant weight at 105° C (Nixon and Oviatt, 1973). Such baseline data collection was conducted to estimate general salt marsh productivity in Jamaica Bay, and to estimate productivity loss during periods of marsh erosion.

Species composition

Species composition at Big Egg Marsh, Rulers Bar Hassock and Yellow Bar Hassock was

recorded from 1m² plots during transect sampling procedures. Additional species observed during a field survey at Jo Co Marsh were also recorded. Species were listed on field data sheets (Table 6). Their indicator status as a wetland species was recorded according to the 1988 National List of Plant Species that occur in wetlands (New Jersey Department of Environmental Protection, 1988). The National List provides regional species listings with their percent chance of occurrence within the range of wetland to upland habitats. Species are listed according to the frequency with a species occurs in a wetland versus upland situation. Obligate species occur within wetlands 99% of the time. Facultative species 66-99% of the time observed in wetlands. Abbreviations are often given for further facultative species divisions including FACW+ for those that are nearest to the obligate species in wetland zonation. These listings are a useful and frequent tool in demarcating wetland boundaries for regulatory purposes.

Table 6. Plant Species observed in 1.0m² plots along belt transects conducted in three intertidal marshes at Jamaica Bay, Queens County, NY.

Scientific name	Common name	Regional Ind. Status	Marsh
<i>Spartina alterniflora</i>	Smooth cordgrass	OBL	Big Egg, Rulers Bar Hassock, Yellow Bar Hassock
<i>Spartina patens</i>	Salt hay grass	FACW+	Big Egg, Yellow Bar Hassock
<i>Spartina cynosuroides</i>	Big cordgrass	OBL	Big Egg
<i>Phragmites australis</i>	Common reed	FACW	Big Egg, Rulers Bar Hassock
<i>Distichlis spicata</i>	Spike grass, Seashore saltgrass	FACW+	Jo Co
<i>Juncus gerardii</i>	Black grass	FACW+	Jo Co
<i>Salicornia virginica</i>	Glasswort, samphire	OBL	Big Egg, Yellow Bar Hassock
<i>Iva frutescens</i>	Marsh elder, Big-leaf sumpweed	FACW+	Big Egg, Rulers Bar Hassock
<i>Aster tenuifolius</i>	Marsh aster, Perennial saltmarsh aster	OBL	Jo Co
<i>Myrica pensylvanica</i>	Northern bayberry	FAC	Big Egg
<i>Toxicodendron radicans</i>	Poison ivy		Big Egg
<i>Fucus sp.</i>	Brown seaweed, Rockweed	NL	Yellow Bar Hassock

<i>Ulva sp.</i>	Sea lettuce	NL	Yellow Bar Hassock, Rulers Bar Hassock
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Notes:

1. OBL = Obligate wetland species—occurrence more than 99% of the time is in wetland habitats.
2. FAC, FAC+ = Facultative wetland species—occurrence more than 66-99% of the time is in wetland habitats.
3. NL = Not Listed—aquatic algae are not included in the National List for wetland species.

Surveyed elevation data were not available for marsh locations and these were estimated given the vegetation types found for cross-section drawings. Habitats were simply divided by vegetation into low marsh, high marsh and transitional upland areas depending on the species found during field observation or as determined by aerial photo interpretation. Low marsh, located between mean sea level (MSW) and Mean High Water (MHW) contained *Spartina alterniflora*. High marsh, located between Mean High Water and Mean Higher High Water (MHHW) contained *Spartina patens*, *Iva frutescens*, and *Distichlis spicata*. The transitional upland area located in the interface between MHHW and upland areas contained *Phragmites australis* (See Appendix 2, Coastal Zone chapter).

RESULTS

Aerial Photograph Interpretation and Historic Mapping

Land loss was immediately apparent from inspection of aerial photographs in the three-marsh analysis. Two features were clearly identified: 1) dramatic loss of shoreline on outer island edges 2) loss of internal marshland along large meandering tidal inlets and their tributaries. These two processes were separately examined to rule out erosion caused solely by barge and boat action or by maintenance dredging of navigation channels. Table 1 lists acreage and percent remaining since 1959 accounting for land loss from outer banks and within channels.

A comparison of points A-D in Fig. 4a, 4b, and 4c reveals changes at Yellow Bar Hassock. At Point A the sliver of land mass remaining in 1998 was larger in 1976 and 1959. Correspondingly the estuarine channel has widened dramatically. Whereas in 1959 at Point B, four land masses, including one small island are visible, by 1998 one island has disappeared entirely, and the second, once-inner island, is now isolated with much larger channelization. Along the island located between points A and B on Yellow Hassock Marsh, marshland has narrowed or disappeared by 1998. At Point C the channel width has increased. By 1998 the landmass at the south section of the channel inlet at point C is reduced to a sliver. The smaller channel to the north has also become enlarged, leaving a gouged out remnant land mass. At point D, by 1998 a marsh section with a meandering U-shaped channel curving around it is replaced by a much larger channel.

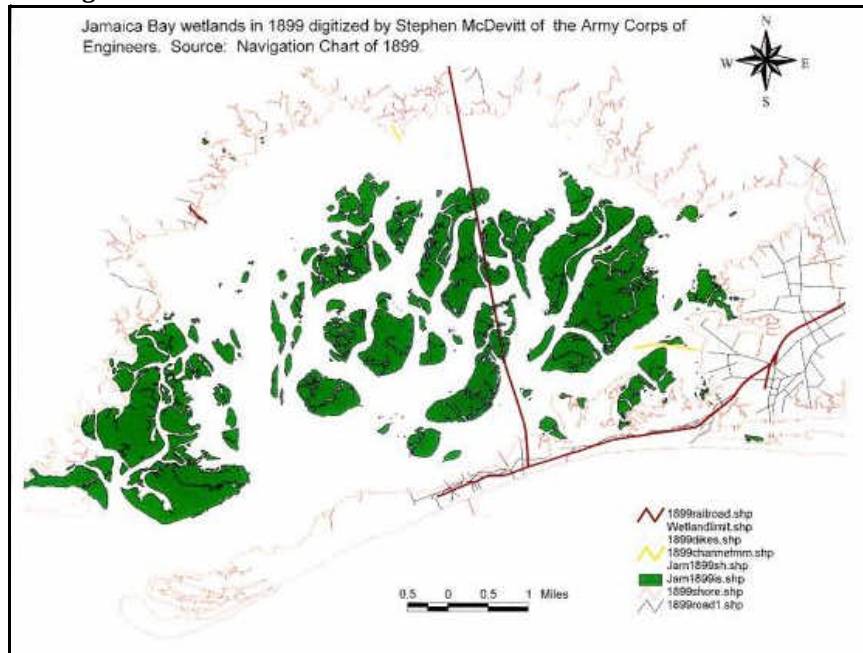
For the three-marsh study of Yellow Bar Hassock, Black Wall Marsh, and Big Egg Marsh, there was an approximate 12% reduction in landmass between 1959 and 1998. The more recent period, between 1976 and 1998, showed greater percent erosion than during the earlier period from 1959-1976.

The trends analysis conducted for more than 15 island marshes of Jamaica Bay from 1900 to 1974, and between 1974 and 1994 is given in Figure 5. Tidal wetlands remaining according to 1994 color infrared photography are shown in yellow in Figure 5. Wetlands lost between years 1900 and 1974 are shown in green. The difference between the wetlands remaining in 1974, and those remaining in 1994 is shown in red. Acreages for selected islands and totals from the 15 marshes are given in Table 2. From 1900 to 1974 a total of more than 1174 acres were lost, or approximately 16 acres per year. From 1974 to 1994 approximately 400 acres, or 20 acres per year, were lost. The causes of the former were primarily from filling, dredging or draining activities. However by 1974 these activities were stopped through environmental regulations and the creation of the Gateway National Recreation Area. Therefore the 20-acre per year loss is from other causes such as erosion. In Jamaica Bay there is a loss of over. According to aerial color infrared photography and field confirmation, much of the 400 acres of *Spartina alterniflora* marshes appear to have been converted to coastal shoals. This estimate is based on a draft comparison of the 1974 tidal wetlands lines and the 1994 digital orthoquads. New 1999 color infrared photography at 1 inch equals 1000 feet was flown in September of 1999 and is being processed to yield a more accurate result by late April.

Udel et. al. (1969) calculates that vegetated tidal wetlands produce about 3 tons of organic material per acre per year. Therefore, the 400 lost acres would have produced 1200 tons of tidal wetland biomass between 1974 and 1994. Thus the equivalent of at least 60 tons of organic material are being lost each year (???). To document the cause of this loss, and to obtain baseline information for future study of continued loss in the Bay, a number of measurements were initiated. Causes affecting the loss of the vegetated wetlands such as erosion, sea level rise, storms and ice flows were examined.

A fuller image of the wetlands at the turn of the century is also shown in a newly prepared digitized replica of the 1899 navigation chart (Fig. 6). In addition to the island marshes, Figure 6 shows marshes that now comprise Floyd Bennet Field along the eastern shore of Brooklyn and shows the general outline of shoreline marshes around the Bay with their once-many tributaries.

Fig. 6



These shoreline marshes are more fully delineated in Figure 7, a map of the geologic history of Jamaica Bay, where horizontal hatch marks indicate extensive placement of artificial fill material (Engelbright 1975).

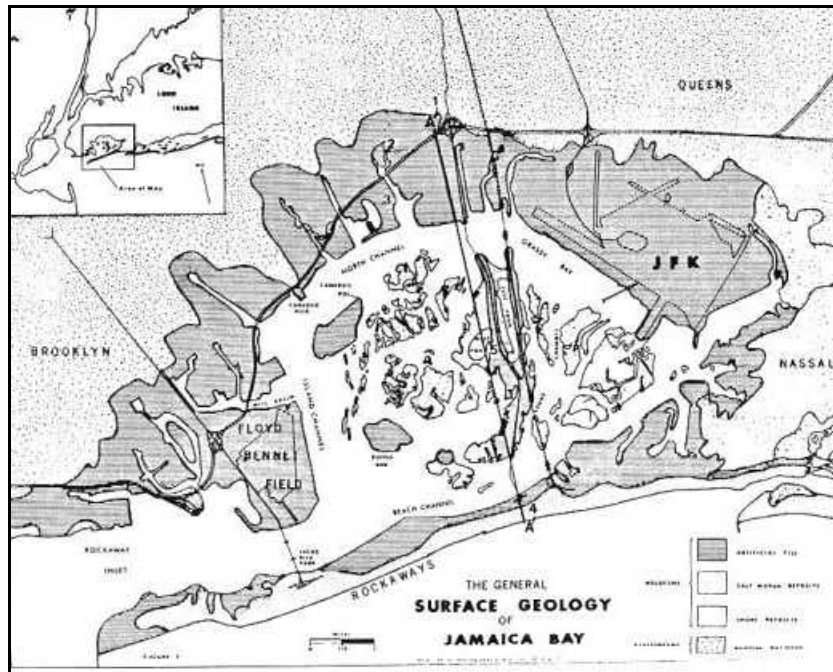


Fig. 7. General surface geology of Jamaica Bay. Horizontal hatching

indicates approximate extent of salt marsh in year 1907 (Engelbright, 1975).

The type of erosion found from the outer marsh edge extending into the most inland tributaries was consistent throughout the areas studied. Therefore, it is unlikely that erosion could be caused primarily from barge and boat traffic along the navigation channels. If boat traffic or dredging for navigation near the islands' outer edges were the prime cause, inland tributaries should have been spared. If the loss was from subsidence within a locally sediment-starved embayment, then island marshes in Long Island would not also have been undergoing loss, and there would be no inland migration of marshes along Long Island's South Shore where open space allows such shifts to occur (Fallon 1996).

Geomorphology

Examples of erosion observed during the field investigations were undercutting of peat at island and channel edges. At the edge of a wide channel of Big Egg Marsh, Figure 8 illustrates an area in which more than six inches of peat overhangs beyond the connected substrate. In Figure 9, at the same channel location as in Figure 8, small clumps of peat have detached completely, following a storm. Note that *Spartina alterniflora* stems are still attached in a hand-held example. Numerous clumps of peat were found strewn on the mudflat. At Yellow Bar Hassock, a large fallen rhombus-shaped segment of marsh peat was observed during low tide, carved from the adjacent intact marsh (Fig. 10a). Figure 10b shows same site later in the tidal cycle, when the detached peat segment has submerged, while the intact adjacent marsh temporarily remains above the water line.



Fig. 8. Extent of undercutting of low marsh embankment greater than 6 inches (15 cm) as indicated on carpenter's ruler.



Fig.9. Note section of peat hand-held by attached *Spartina alterniflora* stems (inside open bracket) found strewn on mudflat along wide channel of Big Egg Marsh.



Fig. 10a. Sloughed-off segment of peat carved from the adjacent intact marsh at Yellow Bar Hassock as observed during low tide.



Fig. 10b. Mid-tide view after sloughed-off peat becomes submerged under water while the intact adjacent marsh temporarily remains exposed above the water line.

Vegetation Sampling

Mean biomass in the three selected marshes ranged from 812 gm/m² to 1203 gm/m² with a total mean of 962 gm/m² (Table 5). Where microgeographic features such as pools and creeks crossed the transect, the nearest vegetated edge was sampled. Where these features were

most frequent, the total standing crop was diminished. This was most evident in Yellow Bar Hassock. The resulting low biomass nearest the pools was averaged with all other samples. High marsh communities were restricted or missing in the communities sampled, particularly Yellow Bar Hassock.

Species composition in low marsh areas, including all of Yellow Bar Hassock, were confined to predominantly *Spartina alterniflora*, with *Spartina patens* and *Salicornia virginica*, in a few higher elevation portions of the low marsh, as well as *Ulva sp.*, in the mudflats and interspersed in bare areas of *S. alterniflora* (Table 6). If Yellow Bar Hassock once had high marsh areas, as was suspected upon inspection of texture of some vegetation in the 1959 photographic print, then they were no longer in evidence during field visits. All species were either obligate wetland species (found in wetlands more than 99% of the time it is observed) or facultative species (found in wetland habitats more than 66% of the time it is observed). Additional facultative species were found in the high marsh zones of Big Egg Marsh and Rulers Bar Hassock including *Iva frutescens*, *Myrica pensylvanica*, and *Phragmites australis*. Due to logistical and budgetary constraints field observations in Big Egg Marsh were limited to the more landward marshes, as the large channels were not passable by foot during low tide.

To illustrate change over time a cross-section of Big Egg Marsh was constructed (Fig. 11). Field observations of the wetland vegetation and upland land-use (1999 and 2000) were used in conjunction with a 1900 navigation chart, 1988 aerial photograph (available as a large-scale paper print 1 inch = 400 feet), and GCM scenarios for sea-level rise. These were developed into transects representing three time periods 1900, 2000 and 2001. To illustrate future conditions, accretion rates previously estimated from sediment cores taken in Jamaica Bay as well other sites in or near the MEC region were used, together with a global climate model, in order to project the inland shift in vegetation community types and the estimated loss of marsh acreage to tidal inundation.

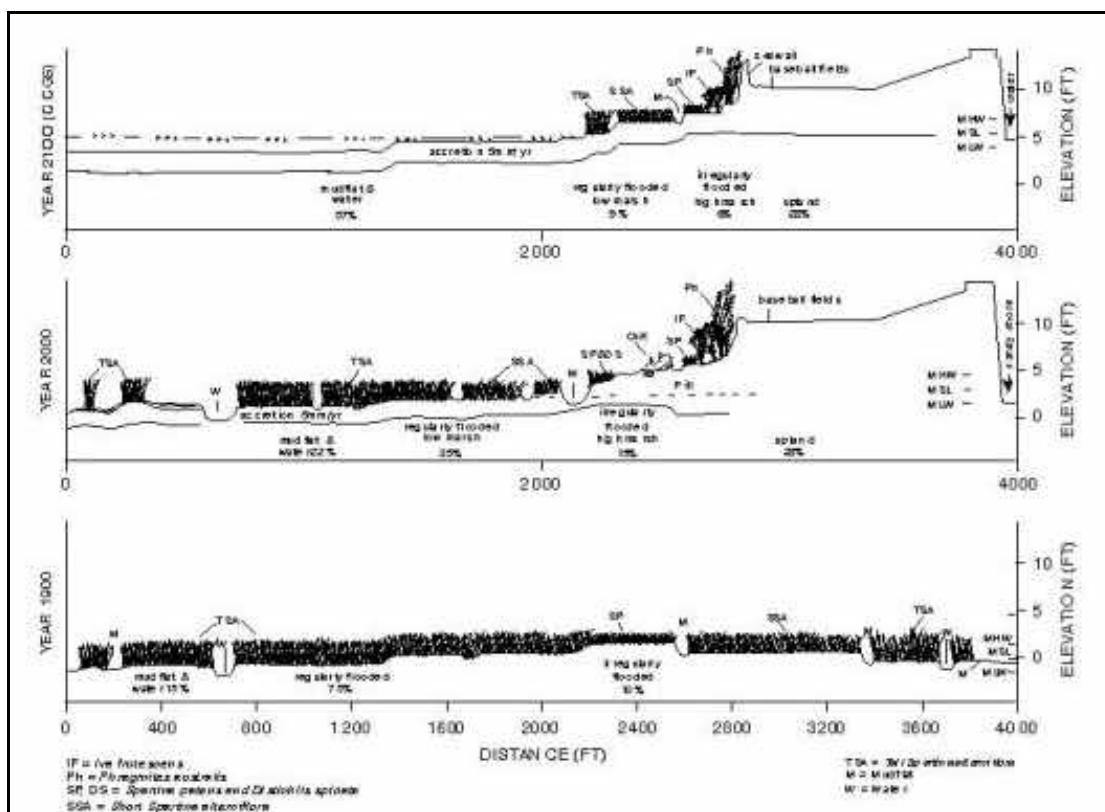


Fig. 11. Transect of historic, current and future conditions (years 1900, 2000 and 2100) in Big Egg Marsh. Source: Adapted from Kana et al. 1988 and Titus 1988.

Accretion Rates and Global Climate Models

Table 3 lists known accretion rates given for the intertidal zone in Connecticut and New York and these are used in Table 7 to consider rates of marsh accretion needed to keep pace with sea level rise. For Jamaica Bay, a single study known is known of accretion rate. The study was conducted by Zeppie in 1977. Low marsh accretion rate was 0.8 cm/year and for high marsh accretion rate was 0.5 cm/year. The rates lie toward the upper range of those found in the region by others. The sampling covered a 100 year time span when accretion may have been especially high due to dredging and filling activity such as construction of John F. Kennedy International Airport, land filling (Penn and Fountain Avenue, and Edgemere landfills) and uncontrolled outfall from sewage treatment plants and combined sewage overflow (CSO). New controls presently in effect, particularly at the 26th Ward Water Pollution Control Plant (at Hendrix Creek) and installation of aboveground CSO tanks (at the headwaters of a tributary to Spring Creek) likely reduced the accretion rate, in addition to landfill closure and completion of major construction activities around the Bay. The actual accretion rate at Jamaica Bay has not been measured since Zeppie's 1977 measurements, and

new determinations are urgently needed. To test the sensitivity of accretion rates, the GCM scenarios were applied to low (0.2cm), medium (0.5cm), and high (0.8cm), sedimentation rates (Table 7).

Table 7. Projections for inundation (cm) at Big Egg Marsh accounting for sea level rise and low, medium, and high rates of accretion.

GCM	2020s			2050s			2080s			2100		
	L	M	H	L	M	H	L	M	H	L	M	H
CCGG	13.2	5.7	-1.8	35	18.9	2	81	50	25	101.8	71.8	41.8
CCGS	9.0	1.5	-6	30.3	13.8	-2.7	61	35.5	10	92	62	32
HCGG	5.5	-2	-9.5	16.1	-.4	-16.9	31.9	6.4	-19.1	38.2	8.2	-21.8
HCGS	3.3	-4.2	-11.7	9.6	-6.9	-23.4	21.4	-4.1	-29.6	28.9	-1.1	-31.1

Note: L = Low (0.2cm/yr), M = Medium(.5cm/yr), and H= High (.8cm/yr) Accretion Rates.

Table 4 portrays the minimum salt marsh accretion rates needed to keep pace with projected SLR in mm/yr for five scenarios—Current Trends (Cur.Tr.), CCGG, CCGS, HCGG, and HCGS using the tide gauge data from New York City at Battery Park. Rates are relative to 1961-1990 sea level data. With a continuation of current trends (Cur. Tr.), which accounts for current levels of atmospheric greenhouse gases, the rate of sea-level rise is 2.7mm/year throughout the next 100 years. Scenarios from the global climate models (GCMs) indicate, for the most part, ever-increasing rates of sea level rise over time. We first assume that accretion rates approximately equal sea level rise (Table 4), and then assume a low, medium, and high rate of rise (Table 7). Under the first assumption the following occurs:

For the Current Trends scenario, Jamaica Bay marshes will need to accrete on average 2.7 mm each year (Table 4). To accommodate accelerating rates of sea level rise projected using the GCMs, Jamaica Bay marshes will require ever-increasing rates of accretion. For example, under the CCGG scenario, the minimum rate of accretion will need to nearly triple to 7.3 by the 2020s, and almost double again to 13.7 mm per year by the 2050s. By the end of the century, under the Canadian Climate Center models, with and without sulfates, (CCGG and CCGS), rates of SLR may reach and exceed the upper bound of salt marsh accretion. Under the Hadley Center GCMs the rate of SLR is projected to be slower. The minimum accretion rates would need to go from 3.5mm/yr in 2005, to nearly double—6.9mm/yr by 2085.

In a separate sensitivity test, accretion rates are used independently at fixed rates over the next 100 years with a low (0.2cm/yr), medium (0.5cm/yr), and high (0.8 cm/yr) accretion

rate. Table 7 indicates the amount of sediment (and plant material) that would accumulate as peat over three time periods: 2020s, 2050s and 2080s and then to 2100. The amount accreted is then subtracted from the amount of sea level rise projected in Table 3. In the Canadian Center scenarios sea level rise is almost always surpassing the accretion rate. In some cases, particularly in the Hadley Center projections (HCGG and HCGS), where the calculation is below zero, the accretion rate is higher than the projected change in sea level. Since field observations and aerial photograph analysis demonstrate that accretion is not keeping pace with tidal inundation and erosion, a Canadian Climate Center scenario was used to demonstrate the impact of sea level rise on marshes. The more conservative of the two Canadian Climate Center models was selected for a cross-section of Big Egg Marsh (Fig. 11). The figure illustrates the scenario for year 2100, for the CCGS GCM under a medium sediment accretion rate. The medium 5mm/yr rise was selected and applied to both the past 100 years and the next 100 years as an average measurement of accretion. Figure 11 illustrates a 62 cm (24 inch) rise in water under the medium scenario. The result indicates that 57% of the marsh will be covered in water compared to 17% in 1900 and 24% in 2000. The low marsh is reduced in extent to 9% in year 2100, compared with 33% coverage in year 2000 and 75% in year 1900.

DISCUSSION

These basic calculations confirm and support our conclusions and recommendations that attention be given toward managing tidal wetlands in response to changes in tidal inundation (Fallon and Mushacke 1996). Additional studies should be conducted to determine the causes of wetlands changes and contingency plans should be developed to address the losses including all needed permits.

Most of the tidal wetlands losses between 1900 and 1974 were caused by direct man-made factors: e.g., filling and dredging, residential development in Queens and Brooklyn in and around the bay including Broad Channel Island and JFK International Airport, and rail and road construction. The current losses are likely caused by several factors, including sea level rise, erosion, and storms. While these more recent losses appear to be natural, and may not be entirely anthropogenic, nonetheless the losses are real and they are rapid. Based on aerial photograph interpretation, the marsh loss is accelerating. If current trends hold, most of the island *Spartina alterniflora* wetlands will be lost within the next three decades. These wetlands appear to be drowning. The causes for this drowning have yet to be determined. Contributing factors could include SLR, subsidence, and erosion. Damage at some areas, such as the Elders Point Marsh, is already so severe that the loss may be irreversible unless action is quickly taken (Table 2). Unless an active and aggressive management of the Jamaica Bay *Spartina alterniflora* island marshes is undertaken, it is probable that significant portions of

many marshes in Jamaica Bay will disappear within the next century.

These losses will have significant effects on the Jamaica Bay ecosystem as it relates to wildlife habitat, marsh productivity, and biodiversity. These losses may be only partially compensated by the gains through conversion to more aquatic wetland types on the seaward side; compensation through shifts in vegetation landward is limited by urban development. It is unlikely that salt marshes of Jamaica Bay will accrete rapidly enough in the next decades to keep pace with projected rates of sea level rise--particularly given the diminishment in size that is already evident.

Erosion processes can be expected to accelerate with rise in sea level. According to Dean et al. (1987) shoreline erosion accounts for only about one percent of marsh loss annually because "most marshes will be long since submerged before extensive shoreline erosion occurs." The primary mechanism of marsh loss due to SLR will be from formation of extensive interior ponds accompanied by general tidal creek bank erosion. Rapid interior ponding has been documented in the Mississippi Delta and at the Blackwater Wildlife Refuge. At the Blackwater Wildlife Refuge in Maryland over one third of the total marsh area (5,000 acres) was lost between 1938 and 1979 by the growth of interior ponds, largely occurring during 20-year period after 1959 (Dean et al. 1987). Oxygen deprivation and root death are credited with vegetative losses as sea level outpaces the ability of the marsh to maintain elevation.

Erosional forms observed at Jamaica Bay and elsewhere was categorized by form as follows:

1. Shoreline erosion of the marsh edge
 1. Undercutting of peat (Fig. 8).
 2. Sloughing off of peat in-situ from bank ledge (Fig 10a and 10b). This can be caused by enlargement of biogenic holes until peat is carved away.
 3. Erosional spur and groove topography--spurs (mounds) alternating with inundated areas (grooves) along the margins (e.g. Dengie marshes, Essex, Great Britain, Allen & Pye, 1992).
2. Tidal creek bank erosion (Fig. 8, 9, 10).
 1. Residual mud mounds formed by internal marsh erosion, by bank collapse and headwall retreat, leading to coalescence and appearance of extensive areas of bare mudflat with residual vegetated hummocks (e.g., Tollesbury marshes, Essex, Great Britain, Allen & Pye, 1992).
 2. Series of ever-smaller residual mounds of mussel beds, some with low density, but growing, *Spartina alterniflora* stems (closest to intact marsh), ending in residual mud mounds with no mussels or vegetation attached.
 3. Flat layer of coastal shoals at tidal creek bank replacing once vegetated *S. alterniflora* salt marsh.

4. Chunks of peat displaced or strewn at a distance from bank ledge (Fig. 9).
3. Enlargement of internal tidal pools.
 1. Steady widening of creeks at their landward edge resulting in near circular or elongated pools at the head of many creeks (Pethick 1992).
4. Widespread deterioration of marsh vegetation, leading to generalized scour and surface lowering.

As enlargement these pools are enlarged over time, total biomass production by the marsh will be reduced. Some of this loss may be compensated by productivity of aquatic organisms. The impacts of future climate change on variability in productivity are a matter for future research. During a period of marsh retreat, a shift inland can theoretically preserve marsh extent. However human infrastructure severely restricts such occurrences in Jamaica Bay. The transect shown in Fig. 11 demonstrates how the Big Egg Marsh baseball fields and bridge supports for Cross Bay Bridge limit marsh migration. The topographic map of Big Egg Marsh (Figure 2, inset at C) includes buildings that were removed after 1988. The area was converted for additional ball fields by 1999. Comparisons of the 1988 aerial photograph with field conditions in 1999 showed that ball fields also extended waterward. New and old fencing accompanied by rock riprap and sand berms were in evidence. Such fill activity will prevent new marsh from forming along the wetland/upland boundary.

Adaptation and Policy

Climate change scenarios project a range of higher sea levels through the next century that will cause inundation of local marshes in the New York region. These marshes, if they are not on publicly owned land, are nevertheless under state and/or federal jurisdiction as waters of the United States. However with more frequent storms superimposed on higher sea levels will cause marshes to erode rapidly enough that they may be unable to compensate through accretion between storms. Historic photograph interpretation indicates that progressive loss of marsh has already occurred. Adaptation strategies, such as adherence to state regulatory policies that establish buffer zones beyond the wetland boundaries to allow for inland migration of shoreline marshes, are suggested (Titus 1998, Titus et al. 1991, and Titus and Narayanan 1995). If they are not buffered well beyond the wetland boundary by vegetated uplands, homeowners protecting their properties from flooding will erect seawalls and other stabilizing features.

Regulatory Policies

Over the last twenty-five years, thanks to federal and state regulations, filling of coastal wetlands has slowed and water quality has improved. Federal regulations require a permit for most alterations of wetlands. Many state environmental laws, including those of New York and New Jersey, require permits for alterations in upland adjacent areas in addition to protecting the wetland itself. Such buffers will aid in climate change preparedness by

allowing for shifting of vegetation types along an elevation gradient. For New York State regulations see: Tidal Wetlands Land Use Regulations 6 NYCRR Part 661, Article 25 (available at <http://www.dec.state.ny.us/website/regs/661a.htm>). While not originally intended for the purpose of increasing climate change preparedness, many of these regulations may indeed be helpful. In many cases, stricter enforcement or changes in regulatory guidelines may increase the utility of the regulations already in effect.

The federal government has jurisdiction of waters of the United States since 1899 with the Rivers and Harbors Act of 1899. Since the Clean Water Act of 1977 wetlands have been considered waters of the United States. This allows the federal government to regulate wetlands; however their jurisdiction stops at the wetland/upland boundary. Titus (1988, 1998) examines options that would allow coastal states to “retain some of their public trust tidelands in perpetuity, no matter how much the sea rises.” Once landowners (public or private) develop sites just inland of the wetland line the shorefront owner will protect that property from flooding, often by constructing seawalls and other features. As the sea rises and the bay waters encroach landward, the public loses its once-protected public wetland area along the newly eroded shoreline. Among several options Titus recommends, rolling easements, which would allow development according to regulation at today’s distance from the shoreline, but would prohibit construction that holds back the sea such as seawalls rip-rap and other hard armoring. Thus as the sea comes inland the regulated wetland area would roll back landward. Such a plan would require major changes in land rights that are beyond the scope of this report. Titus (1998) recognizes the difficulties in such options, and recommends a combination of adaptations to sea level rise being incorporated in future land use planning. In New York City, while an estimated 75% of the wetlands have already been developed through filling activity, there remain wetlands and adjacent areas in Queens, Staten Island and the Bronx that are undeveloped.

These undeveloped areas, where privately owned, could be subject to new adaptive land use regulations. Publicly owned sites could be transferred to one of several agencies that oversee parks and wetlands including: New York City Department of Parks and Recreation, New York City Department of Environmental Protection, National Park Service. Alternatively land can be transferred to Trust for Public Land –a not-for profit institution that manages wetlands, community gardens and other open spaces in urban areas–much like the Nature Conservancy does in less urban areas. These options would need to be carried out fairly soon as open space at the shoreline is shrinking rapidly. Land values are high, development is fast-paced, and the city is currently selling off many of its publicly owned open space parcels for private development.

A timely report published in the January-February 2000, National Wetlands Newsletter; Titled "Coast 2050: A master Plan for Louisiana's Coastal Wetlands by Robert Viguerie Jr.

discusses such actions and plans and proposes a number of strategies to achieve vegetative tidal wetland sustainability. A similar route should be taken for Jamaica Bay to ensure its productivity and value for future generations.

Inland Migration of Salt Marshes at Jamaica Bay

Potential for inland migration of marshes may be feasible at several of fourteen sites adjoining Jamaica Bay. Each was selected for potential acquisition or otherwise recommended for protection from development by Trust for Public Land and New York City Audubon Society in their “Buffer the Bay Revisited: An Updated Report on Jamaica Bay’s Open Shoreline and Uplands” (Blanchard and Burg, 1992). These tracts range in size from 2 to 230 acres in size and include filled but abandoned upland areas as well as some salt marshes. Several of these sites may offer some limited compensation for what would be lost from present marshes under future conditions if protected from development.

Site visits to two “Buffer the Bay” sites showed that restoration by removal of existing barriers could be conducted to promote inland migration of *Spartina alterniflora* marshes. These sites are contiguous with the Rockaway peninsula at the southern shoreline of Jamaica Bay as illustrated on the USGS topographic map (Fig. 12 and 13, insets). Bayswater Point State Park, part of the Mott Peninsula, and Dubos Point Wetlands Sanctuary (45 and 25 acres respectively) consists of low and high marshland with undeveloped wooded areas. These sites are not within the GNRA; Dubos Point Wetlands Sanctuary is under ownership by NYC Department of Parks and Recreation, and Bayswater Point State Park is under ownership by New York State Office of Parks, Recreation and Historic Preservation. Both sites are currently managed by New York City Audubon Society. At Bayswater Point State Park, removal of a deteriorating sea wall may stimulate marsh growth inland along 3600 feet of shoreline (Fig. 12). While not specifically sought as preparation for sea-level rise, site restoration has been proposed by the Army Corps of Engineers, NYSDEC and New York State Office of Parks, Recreation and Historic Preservation. At Dubos Point removal of large amounts of rusting debris and paved surface could extend salt marsh vegetation (Fig. 13).



Figure 12. *Spartina alterniflora* marsh thriving waterward of deteriorating seawall at Bayswater Point State Park, part of the Mott Peninsula, Queens NY. **Source:** USGS Far Rockaway Quadrangle, 7.5 minute topographic series

