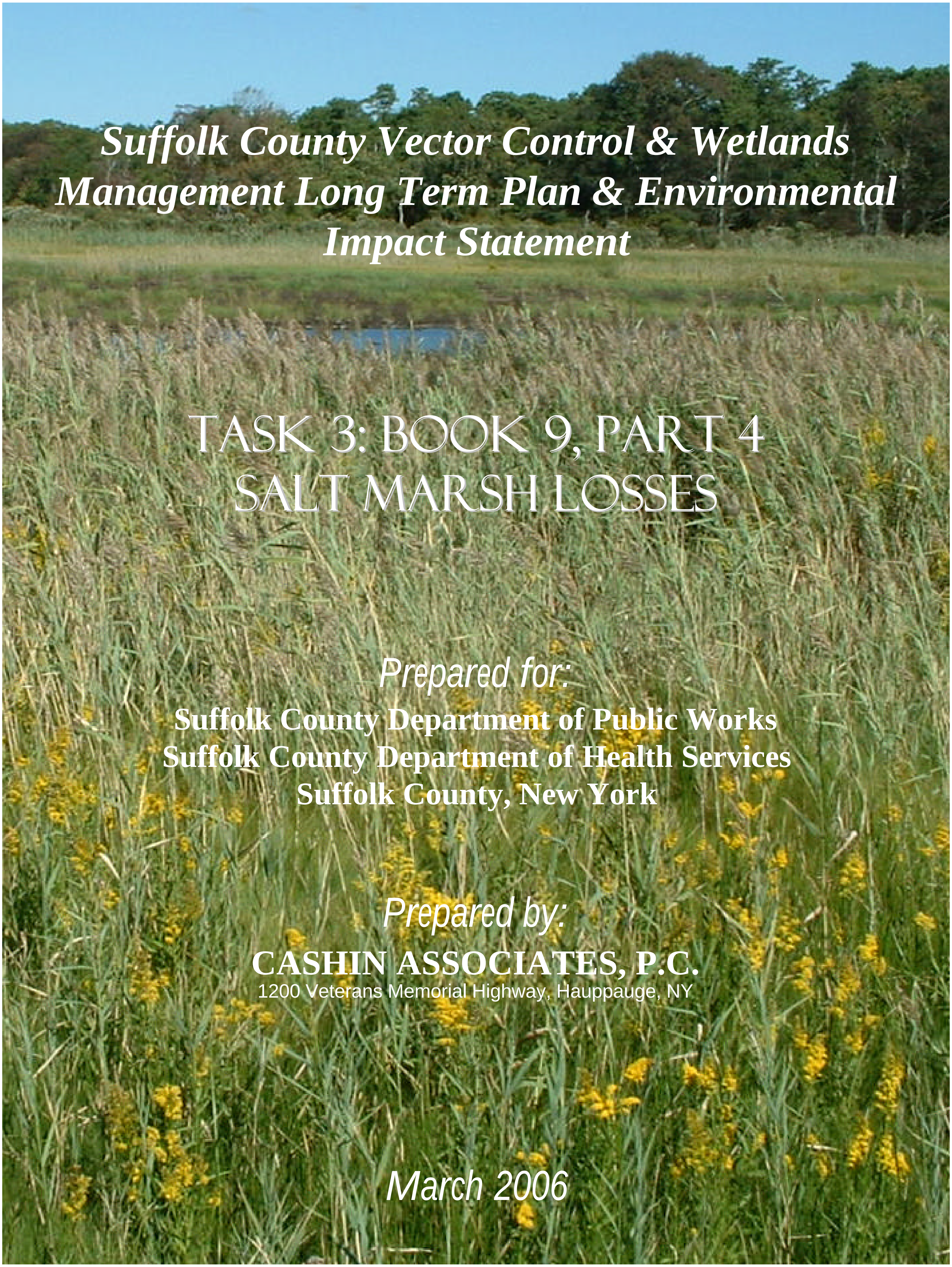

# *Suffolk County Vector Control & Wetlands Management Long Term Plan & Environmental Impact Statement*

## Task 3: Book 9, Part 4
## Salt Marsh Losses

*Prepared for:*

**Suffolk County Department of Public Works**
**Suffolk County Department of Health Services**
**Suffolk County, New York**

*Prepared by:*


**CASHIN ASSOCIATES, P.C.**
1200 Veterans Memorial Highway, Hauppauge, NY


*March 2006*

**SUFFOLK COUNTY VECTOR CONTROL AND WETLANDS MANAGEMENT LONG - TERM PLAN AND ENVIRONMENTAL IMPACT STATEMENT**

## PROJECT SPONSOR

**Steve Levy**
**Suffolk County Executive**

**Department of Public Works**
Charles J. Bartha, P.E.
*Commissioner*
Richard LaValle, P.E.
*Chief Deputy Commissioner*
Leslie A. Mitchel
*Deputy Commissioner*

**Department of Health Services**
Brian L. Harper, M.D., M.P.H.
*Commissioner*
Vito Minei, P.E.
*Director, Division of Environmental Quality*

**PROJECT MANAGEMENT**

Project Manager: Walter Dawydiak, P.E., J.D.
Chief Engineer, Division of Environmental Quality, Suffolk County Department of Health Services

**Suffolk County Department of Public Works, Division of Vector Control**
Dominick V. Ninivaggi
*Superintendent*
Tom Iwanejko
*Principal Environmental Analyst*
Mary E. Dempsey
*Biologist*

**Suffolk County Department of Health Services, Office of Ecology**
Martin Trent
*Acting Chief*
Kim Shaw
*Bureau Supervisor*
Robert M. Waters
*Bureau Supervisor*
Laura Bavaro
*Senior Environmental Analyst*
Phil DeBlasi
*Environmental Analyst*
Jeanine Schlosser
*Principal Clerk*

| SUFFOLK COUNTY LONG TERM PLAN CONSULTANT TEAM | |
|---|---|
| **Cashin Associates, P.C.** | **Hauppauge, NY** |
| **Subconsultants** | |
| Cameron Engineering, L.L.P. | Syosset, NY |
| Integral Consulting | Annapolis, MD |
| Bowne Management Systems, Inc. | Mineola, NY |
| Kamazima Lwiza, PhD | Stony Brook University, Stony Brook, NY |
| Ducks Unlimited | Stony Brook, NY |
| Steven Goodbred, PhD & Laboratory | Stony Brook University, Stony Brook, NY |
| RTP Environmental | Westbury, NY |
| Sinnreich, Safar & Kosakoff | Central Islip, NY |
| Bruce Brownawell, PhD & Laboratory | Stony Brook University, Stony Brook, NY |
| Anne McElroy, PhD & Laboratory | Stony Brook University, Stony Brook, NY |
| Andrew Spielman, PhD | Harvard School of Public Health, Boston, MA |
| Richard Pollack, PhD | Harvard School of Public Health, Boston, MA |
| Masahiko Hachiya, PhD | Harvard School of Public Health, Boston, MA |
| Wayne Crans, PhD | Rutgers University, New Brunswick, NJ |
| Susan Teitelbaum, PhD | Mount Sinai School of Medicine, NY |
| Zawicki Vector Management Consultants | Freehold, NJ |
| Michael Bottini, Turtle Researcher | East Hampton, NY |
| Robert Turner, PhD & Laboratory | Southampton College, NY |
| Christopher Gobler, PhD & Laboratory | Southampton College, NY |
| Jerome Goddard, PhD | Mississippi Department of Health, Jackson, MS |
| Sergio Sanudo, PhD & Laboratory | Stony Brook University, Stony Brook, NY |
| Robert Cerrato, PhD | Stony Brook University, Stony Brook, NY |
| Suffolk County Department of Health Services, Division of Environmental Quality | Hauppauge, NY |

This report was prepared by Cashin Associates (personnel including Jeffrey Kassner, John Schreck, PE, Kimberly Somers, and David Tonjes, PhD).

# TABLE OF CONTENTS



# LIST OF TABLES



# LIST OF FIGURES

# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| CCMP | Comprehensive Conservation and Management Plan |
| CDs | Conservation Districts |
| CMP | Coastal Management Plan |
| CWA | Clean Water Act |
| ECL | Environmental Conservation Laws |
| FINS | Fire Island National Seashore |
| FWA | Freshwater Wetlands Act |
| GIS | Geographical Information System |
| LISS | Long Island Sound Study |
| LWRP | Local Waterfront Revitalization Program |
| MTBE | *methyl tert butyl ether* |
| NASA | National Aeronautics and Space Administration |
| NOAA | National Oceanic Atmospheric Administration |
| NPS | National Park Service |
| NWI | National Wetland Inventory |
| NYSDEC | New York State Department of Environmental Conservation |
| NYSDOS | New York State Department of State |
| OMWM | Open Marsh Water Management |
| PEP | Peconic Estuary Program |
| SCDHS | Suffolk County Department of Health Services |
| SCVC | Suffolk County Department of Public Works, Division of Vector Control |
| SSER | South Shore Estuary Reserve |
| TNC | The Nature Conservancy |
| TWA | Tidal Wetlands Act |
| ULV | ultra low volume |
| USEPA | US Environmental Protection Agency |
| USFWS | United States Fish and Wildlife Services |
| USGS | United States Geological Survey |

## EXECUTIVE SUMMARY

The loss of vegetated salt marsh has historically been a troubling artifact of development in the US, although for many centuries the importance of these ecosystems was not realized. Beginning in the 1960s, protections for these systems were set in place. Federal policy is now "no net loss" of wetlands, in general. This is also the policy of New York State.

Nonetheless, there appear to be places where marshes are still being lost. Explicit filling and draining actions are generally not the cause any longer. Rather, marshes are being lost through natural processes or as a result of deliberate actions that are not intended to have impacts to the marshes. Some researchers believe one or two factors (increasing sea level rise, possibly coupled with losses of natural sedimentation) may account for these phenomena generally, but most believe more nuanced descriptions of conditions are required to understand the root causes of the losses. The most simple relationship is that increasing amounts of surface water seem to correlate well with marsh loss, but that may be a description of the effect of the loss of vegetation, not the cause.

Many researchers have found recent trends documenting marsh loss in or in the vicinity of Suffolk County. In Jamaica Bay, it is clear that large areas of once (relatively) stable marsh have deteriorated fairly quickly. Researchers are not clear about the cause of this loss, and it is not certain if Jamaica Bay is an isolated example of unmatched stresses on an ecosystem, or a harbinger of the general fate of Long Island salt marshes. Some New York State Department of Environmental Conservation analyses indicate the latter may be more likely than not, based on trends that appear to indicate general decay of Long Island's vegetated marshes, especially along a gradient from New York City eastward along the south shore and also eastward in Long Island Sound. Others, such as the New York State Department of State, do not see such general trends in their analyses.

The discussion is generally impaired by a lack of good data that are agreed upon as useful by all interested parties. Some of the important underlying measurements, such as sedimentation rates, are only now being made across many marshes; formerly, one or two spot measurements were all that were available, and the relevance of such limited data sets for regional discussions were often debated. Growing availability of GIS (Geographical Information System) digitized photography holds promise for simplified comparisons of the extent of land areas, and more sophisticated analyses including comparisons of vegetation types and areas may be possible using satellite remote sensing technologies. However, the lack of resources that make digitized historical records unavailable for easy analysis is a key problem. Confounding issues such as differing tidal stands, time-of-year, and adjustments for oblique attitudes with aerial or satellite imagery, as well as potential imprecision in older mappings, need to be accounted for in a regularized fashion in order to make various analyses comparable. It may be that sweeping generalizations have been made based on biased, incomplete, or local studies. Continuing losses of vegetated marsh areas, if occurring on a widespread basis in Suffolk County, are an extremely important element for the future presence of these important resources. However, it may be that not enough information has yet been gathered to make firm judgments as to whether Suffolk County's salt marshes are disappearing at an untoward rate or not, and if specific kinds of marshes are more threatened than others. Since it is not clear that the County's marshes are generally disappearing, it is not possible to determine if a specific cause (or causes) of marsh loss needs to be addressed through marsh management, and exactly which steps should be taken to avoid aggravating the condition assumed to be causing extra-ordinary marsh losses.

## 1. INTRODUCTION

The US Environmental Protection Agency (USEPA) defines the term *wetlands* as:

> those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

Wetlands generally include swamps, marshes, bogs, and similar areas (40 CFR 230.3 [t]).

Coastal or tidal wetlands are those that are closely linked to estuaries where sea water mixes with fresh water to form an environment of varying salinities, and one that experiences fluctuating water levels due to tidal action. Coastal wetlands contain many shallow environments, such as unvegetated mud flats or sand flats, as well as the more widely recognized vegetated areas. Some tidal fresh water wetlands form beyond the upper edges of tidal salt marshes where the influence of salt water ends (USEPA, 1995).

Inland, fresh water wetlands are common on floodplains along rivers and streams, in isolated depressions surrounded by dry land, along the margins of lakes and ponds, and in other low-lying areas where the groundwater intercepts the soil surface or where precipitation sufficiently saturates the soil forming vernal pools and bogs. Inland wetlands include marshes and wet meadows dominated by herbaceous plants, swamps dominated by shrubs, and wooded swamps dominated by trees (USEPA, 1995).

New York State defines tidal wetlands as:

> those areas which border on or lie beneath tidal waters, such as, but not limited to, banks, bogs, salt marsh, swamps, meadows, flats or other low lands subject to tidal action, including those areas now or formerly connected to tidal waters …

specifically:

> all banks, bogs, meadows, flats and tidal marsh subject to such tides, and upon which grow or may grow some or any of the following: salt hay (*Spartina patens* and *Distichlis spicata*), black grass (*Juncus gerardi*), saltworts (*Salicornia spp.*), sea lavender (*Limonium carolinianum*), tall cordgrass (*Spartina pectinata* and *Spartina cynosuroides*), hightide brush (*Iva frutescens*), cattails (*Typha angustifolia* and *Typha latifolia*), groundsel (*Baccharis halmilifolia*), marsh

> mallow (*Hybiscus palustris*) and the intertidal zone including low marsh cordgrass (*Spartina alterniflora*).
>
> (New York State Environmental Conservation Laws [ECL], Title 1, Section 25)

Fresh water wetlands are defined by New York State as:

> lands and waters of the state as shown on the freshwater wetlands map which contain any or all of the following:
>
> a) lands and submerged lands commonly called marshes, swamps, sloughs, bogs, and flats supporting specific species of aquatic or semi-aquatic vegetation (as listed in Section 24-0107 of the Environmental Conservation Law);
>
> b) lands and submerged lands containing remnants of any vegetation that is not aquatic or semi-aquatic that has died because of wet conditions over a sufficiently long period, provided that such wet conditions do not exceed a maximum seasonal water depth of six feet and provided further that such conditions can be expected to persist indefinitely, barring human intervention;
>
> c) lands and waters substantially enclosed by aquatic or semi-aquatic vegetation as set forth in paragraph (a) of Section 24-0107 or by dead vegetation as set forth in paragraph (b) of Section 24-0107, the regulation of which is necessary to protect and preserve the aquatic and semi-aquatic vegetation; and
>
> d) the waters overlying the areas set forth in (a) and (b) and the lands underlying (c).
>
> (ECL, Title 1, Section 24)

## 2. WETLANDS REGULATIONS

The first law adopted to protect wetlands by regulating activities in and adjacent to wetlands was enacted by Massachusetts in 1963 and required a state permit for the filling or dredging of tidal wetlands (Adler, 1999). In 1965, Massachusetts passed a second wetlands law that extended its regulatory authority to fresh water wetlands (Town of Needham Conservation Commission, 2006). Similarly, Connecticut in 1969 (Dreyer and Niering, 1995) and New York in 1973 (Atlantic States Marine Fisheries Commission, 2004) passed laws that regulated activities in tidal wetlands. In 1972, Connecticut (Connecticut Association of Conservation & Inlands Wetlands Commissions, Inc., 2006) and New York in 1975 (NYSDEC, 2006) passed laws regulating activities in fresh water wetlands. While the federal government has not adopted a law that specifically protected and regulates activities in or near wetlands, many local municipalities under their zoning and land use powers have.

### 2.1. Federal Regulation

The Federal government regulates wetlands under the Federal Water Pollution Control Act (1972) ("The Clean Water Act" [CWA]), which covers all "waters of the United States" which may have been or are used in interstate or foreign commerce. Wetlands are defined in accordance with three criteria:

- Hydrology
- Vegetation
- Soils

Wetlands are defined as "waters of the United States" (NYSDOS, 1997). This definition has received some modification through a 2001 Supreme Court decision (*Solid Waste Agency of Northern Cook County v. United States Army Corps of Engineers*), which limits the Federal government in its regulation of isolated wetlands that are not hydraulically connected to other waters. The discharge of dredge or fill material or the construction of any kind in a wetland requires a permit from the US Army Corps of Engineers, under the CWA (§ 404). The Federal government does not regulate "adjacent" areas near wetlands (NYSDOS, 1997).

The Federal government can also regulate wetlands under Section 10 of the Rivers and Harbors Act of 1899 (33 USC 403). Section 10 regulates navigable waters and includes activities such as beach nourishment, dredging, filling, and the construction of boat ramps, piers, pilings, and shore protection (NYSDOS, 1997).

In addition, President George W. Bush established a federal policy of "no-net loss" of wetlands, on Earth Day, 2004 (www.whitehouse.gov/news/releases/2004/04/20040422-4.html).

The National Marine Fisheries Service has review responsibilities for actions involving activities seaward of the high tide line, and special responsibilities for designated Essential Fish Habitats, which may affect wetlands projects (NYSDOS, 1997).

The New York State Department of State (NYSDOS), through the Coastal Zone Management Act (1972), was delegated authority to address coastal zone problems, including environmental issues (which can include wetlands) (see below) (NYSDOS, 1997).

There are two Federal estuary programs that potentially affect the County's wetlands, the Long Island Sound Study (LISS) and the Peconic Estuary Program (PEP). Both are administered by USEPA.

The LISS Comprehensive Conservation and Management Plan (CCMP) (LISS, 1994) identified habitat enhancement (including wetlands) as an important goal. Tracking reports on the progress of the CCMP implementation note with approval that Connecticut abandoned its mosquito ditching maintenance practices with Open Marsh Water Management (OMWM) and that New York State has been phasing out its ditching practices. It was recommended that New York State continue to phase out mosquito ditching and implement OMWM to control mosquitoes and improve the value of wetlands by restoring wetland ponds and pools. Technical guidance in achieving the habitat restoration goals (LISS, 2003a) listed twelve habitat types, five of which were specifically addressed. Tidal wetlands were included. The focus was on Connecticut marshes, but included those marshes found on Long Island. Seven specific impacts to marshes were identified as requiring restoration:

- grid (parallel) ditching
- draining
- impoundments
- filling/burying
- phragmites invasion
- stormwater impacts
- sea level rise impacts

For each impact, preferred means of restoration were cited. OMWM was not specifically identified as a restoration means, although ditch plugs and pond creation were identified as useful means of restoring salt marshes. Although mosquito management was identified as a means of causing impairments to habitat, mosquito management was not included as an element to be addressed during restoration activities. No Suffolk County marsh was identified on the primary priority list for restoration.

The PEP CCMP (SCDHS, 2002) contains many brief mentions of mosquito control effects on the estuary. Mosquito control ditching was listed as a cause of habitat loss, fragmentation, and degradation of the marshes where it was conducted.

The CCMP recommends improved coordination between the Suffolk County Department of Health Services (SCDHS), the Suffolk County Department of Public Works, Division of Vector Control (SCVC), other agencies and departments, and municipalities in maintaining existing mosquito ditches and developing coordinated planning efforts relating to mosquito control in wetlands. The Plan recommends that OMWM techniques be employed. OMWM helps to ensure that fish life that feed on mosquito larvae can survive and be present in areas where mosquitoes breed. A no new ditch policy was established, and it was urged that SCVC work cooperatively with all governments and government agencies in planning mosquito ditch maintenance. *Phragmites* control was also emphasized (SCDHS, 2002).

Policies have also been established by major federal landholders regarding management of wetlands. For instance, the National Park Service (NPS) generally (and the Fire Island National Seashore [FINS], specifically) has determined:

> The establishment and maintenance of ditches in Fire Island tidal marshes as a means of mosquito control are extremely disruptive to the natural evolutionary processes of the ecosystem. Furthermore, the effectiveness of the grid drainage system for mosquito control is generally believed to be of little, if any, value. Considering the National Park Service's mandate to preserve Fire Island's natural environment and the lack of knowledge of ditching effects, the maintenance of existing ditches will be terminated on all Park Service owned lands. Ditching activities on other lands within the legislated boundary of Fire Island Seashore should also be terminated with the exception of designated experimental sites. The cessation of ditching as a mosquito control method will remain in effect until its utility can be proven and its effectiveness is shown to outweigh the associated environmental degradation.

(Fire Island National Seashore, 1977)

The NPS has also identified poor salt marsh quality and the potential for the need for more active salt marsh management as major issues for FINS. However, NPS has not yet determined what management might be permissible to address both an apparent need for marsh management and a general distaste for grid ditching and the maintenance of the grid ditch system (Milstead et al., 2004).

United States Fish and Wildlife Services (USFWS) is a large landholder in east coast US salt marshes. USFWS would also like to eliminate pesticide use in its refuges, but also maintain its policy of being a good neighbor to surrounding communities. Its perception is that this role includes preventing, as much as possible, mosquito problems to exist due to breeding on the refuges. OMWM holds a promise of meeting these two goals, and, potentially, of providing collateral wildlife values enhancements.

Initial guidance had been offered that closed (ditch plug) systems and semi-open (sill systems) were preferable over open systems. The exception was the use of open systems to address *Phragmites* invasion. USFWS appeared concerned that open systems would serve to drain the water table excessively (Taylor, 1998). However, noting the lack of standardized information on OMWM benefits and potential impacts, the advisory was slightly altered in 1999 so that determinations regarding OMWM projects would be made at the specific refuge level (USFWS, 1999), pending the outcome of initial (Roman, 1998) and long-term (James-Pirri et al., 2001) projects. The initial evaluation, in Maine for ditch plugging, found shifts in vegetation toward *S. alterniflora* due to increased water levels, Bird responses were variable across the sites, but fish populations were either stable (at two sites) or significantly enhanced (at one site) (Adamowicz and Roman, 2002). The larger, longer project by James-Pirri et al., has only published interim data sets (James-Pirri et al., 2003); a project report was due in 2004, but has been delayed while undergoing review by USFWS and United States Geological Survey (USGS) (the project sponsors). Reportedly, USFWS will use the findings of the James-Pirri et al. study to determine the Region 5-wide response to OMWM proposals.

## 2.2. State Regulation

New York State has two different regulatory programs and sets of requirements for wetlands protection:

- one for fresh water wetlands as set forth under Article 24 of the ECL.
- one for tidal wetlands under Article 25 of the ECL.

Article 24 was adopted in 1975. Article 25 was adopted in 1973 but its implementing regulations did not become effective until 1977 (NYSDOS, 1997).

The regulations for fresh water wetlands are contained in 6 NYCRR Part 662, Part 663, Part 664, and Part 665. The implementing regulations for tidal wetlands are found in 6 NYCRR Part 661. Both laws and their regulations define wetlands based largely on vegetation. They map regulated wetlands (New York State does not have jurisdiction over "unmapped" wetlands). They also identify regulated activities (but almost any activity requires a permit) and set forth standards for permit issuance. The permitting process itself is governed under the New York State Department of Environmental Conservation (NYSDEC) Uniform Procedures Act (NYSDOS, 1997).

Two of the more significant differences between the two wetland laws and their regulations are:

- the Freshwater Wetlands Act (FWA) regulates activities within 100 feet of the edge of wetlands while the Tidal Wetlands Act (TWA) regulates activities within 300 feet of the edge of wetlands.
- the regulation of fresh water wetlands can be delegated to local municipalities provided the regulations are at least as restrictive as the regulations in effect pursuant to the FWA.

Ditch maintenance activities have been found to be acceptable under the TWA. Other forms of marsh management require further review, and generally are determined to require a permit. Suffolk County has applied for and received general permits for its marsh management activities, including replacement of in-kind water control structures and ditch maintenance, for example.

The application of pesticides directly to any regulated body of water in New York (that is, "waters of the State") is considered an aquatic application. As such, it requires an NYSDEC Article 15 Aquatic Pesticides Permit. This regulation covers the application of any larvicide to standing water, except for water solely within artificial containers or other, isolated waters not considered "waters of the State." The County maintains such a permit (through SCVC). Ultra low volume (ULV) adulticides are not applied directly to water, do not target the aquatic stage of mosquitoes, and so do not require an Article 15 permit.

The NYSDEC Article 24 regulations (6NYCRR Part 663) state that the application of a pesticide covered under an Article 15 permit also requires a separate Freshwater Wetlands permit. The County also maintains an Article 24 permit to allow for its fresh water wetland larvicide program. Application of adulticide within 100 feet of an NYSDEC regulated fresh water wetland area requires a permit. NYSDEC has indicated that ULV adulticide applications that take place 150 feet or more from fresh water wetlands will be considered out of Article 24 jurisdiction. The County therefore maintains such a setback on its vector control adulticide applications.

If an application of adulticide over a regulated fresh water wetland is deemed necessary, an emergency authorization can be requested from NYSDEC if the Commissioner of the State Department of Health has previously declared a Health Threat. The emergency request to NYSDEC needs to present the specific reason the application is needed, with maps delineating the application zone. Emergency actions required to respond to a public health threat are exempt from regulation under Article 24.

The NYSDEC Article 25 regulations (6NYCRR Part 661) state that the use or application of any pesticide, where otherwise authorized by law, does not require a permit. Thus, if a pesticide is registered in New York State and is applied per the label, a permit is not needed (except if the application is made to NYSDEC-owned lands, see below). Application of adulticides over tidal wetlands is generally avoided. If required due to a public health threat, such applications can be made without a specific permit if the product label specifically allows such use of the product over tidal marshes.

Application of pesticides to NYSDEC-owned lands requires NYSDEC permission. This permission had been received in the form of a sign-off on Article 15 permits for larvicide use. In March, 2006, SCVC received a letter stating this would no longer be the case, although NYSDEC had not yet determined how such permission might be granted (D. Ninivaggi, SCVC, personal communication, 2006).

NYSDEC implements several other programs that indirectly affect wetlands:

- Coastal Erosion Hazard Areas Program: actions that may affect mapped coastal erosion zones receive further regulation.
- Use and Protection of Waters (Stream Protection Program): regulates disturbances of stream beds, or excavation and fill of any navigable waterway.
- State Pollution Discharge Elimination Program: regulates discharges into surface water by industrial, commercial, and municipal sources, and some residential areas as well, including a ban on the discharge of untreated stormwater to wetlands.
- Water Quality Certification Program: under the CWA, New York was delegated the authority to regulate discharges to navigable waters.
- Endangered Species Program: regulates activities that might harm Federal or State listed endangered or threatened species.
- Natural Heritage Program: this program identifies occurrences of rare biota and amps natural communities, and is funded jointly with The Nature Conservancy (TNC).
- Wild, Scenic and Recreational Rivers System: designated systems receive extra protections.

(NYSDOS, 1997)

NYSDOS developed a State-wide Coastal Management Plan (CMP), which was approved by the US Secretary of Commerce in 1982. The policies established in this plan are used by NYSDOS when it reviews Federal and State actions in the coastal zone, subjecting them to a single set of locally-determined criteria. There are now 13 criteria that must be complied with in these "consistency" reviews. NYSDOS can further delegate coastal management authority through the Local Waterfront Revitalization Program (LWRP) (see below) (NYSDOS, 1997).

Another element of the State CMP was the designation and mapping of Significant Coastal Fish and Wildlife Habitats. These sites are further protected, with the intent of preventing impairment. A goal is to restore any such habitats to improve them, where practical (NYSDOS, 1997).

In 1999, NYSDOS completed a management plan for Long Island Sound, designed to help spur implementation of the State CMP. The Long Island Sound CMP recognized four arenas for action:

- The developed coast
- The natural coast
- The public coast
- The working coast

Under the natural coast, protection and restoration of tidal and included fresh water wetlands was identified as a priority. One of the important identified impairments of the mid-Sound coast was ditches installed for mosquito control purposes. Invasive plants, presumably including *Phragmites*, were also identified as a problem. Recommendation 11 of the Plan was to reach a net gain in quality and quantity of tidal wetlands, and no net loss for fresh water wetlands. The primary means of achieving the gains was to be reconstruction of lost physical features that would result in natural wetlands functioning. Sites for restoration were to be identified by LISS. In addition, 13 regionally important natural areas were identified, 10 of which lie at least partially in Suffolk County, and all but one of which have important wetland resources (Oyster Bay-Cold Spring Harbor, Lloyd Neck-Eatons Neck, Crab Meadow-Fresh Pond, Sunken Meadow-Nissequogue River, Stony Brook-Setauket, Mount Sinai, Wading River, Wildwood-Bating Hollow, Riverhead Bluffs [no wetlands], eastern islands [Plum Island, Great Gull Island, etc.], Fishers Island) (NYSDOS, 1999).

The South Shore Estuary Reserve (SSER), a planning effort under the direction of NYSDOS, determined that, in order to meet estuarine water quality objectives, stream corridors (especially fresh water wetlands along the streams) would need to be managed as described by New York State in its guideline to prevent non-point pollution, including sediment erosion, from stormwater (NYSDEC, 1996). The Comprehensive Management Plan also identified wetlands as key elements of the biological landscape, and called for increasing the quantity and quality of wetlands, especially tidal wetlands. The means of doing this were identified as primarily being:

- hydrological modification of formerly connected wetlands

- restoration of dredge spoil sites
- OMWM
- Establishing protective buffers
- Identifying existing high quality wetlands

(SSER Council, 2001)

NYSDOS and NYSDEC collaborated on the production of *Salt Marsh Restoration and Monitoring Guidelines* (Niedowski, 2000). This apparently was the result of considerations of the Seatuck OMWM demonstration project in 1986 (see Lent et al., 1990), plus other pressures to develop a state guidance for salt marsh projects. The Guidelines do not appear to have any regulatory authority, nor do they seem to be referred to by those proposing or enforcing the State regulations.

The document is intended to serve as a framework for New York salt marsh restoration activities, including planning, design, implementation, and monitoring for restoration projects sponsored by municipalities. The goal statements for habitat restoration in New York State are summarized as follows:

- To the greatest extent practicable, achieve functional, community, and/or ecosystem equivalence with reference sites when undertaking restoration.
- Restore critical habitats for priority fish, wildlife, and plant species, including those listed as threatened, endangered, and of special concern by Federal and State governments, and species of historical or current commercial and/or recreational importance in New York State.
- Plan and implement restoration initiatives using a regional perspective to integrate and prioritize individual restoration projects and programs.
- To the extent practical, use historical acreages, proportions, and/or spatial distributions to prioritize habitats from a state or regional perspective.
- To the extent practical, ensure where appropriate that historical acreages, proportions, and/or spatial distributions of priority habitats are restored and preserved.

Two desirable OMWM techniques described in the manual are closed systems and semi-tidal systems. According to the guidelines, closed systems should consist of shallow ponds and pannes ranging from two to 18 inches deep, sump ponds ranging from 30 to 36 inches deep, and pond radial, spur ditches approximately 30 inches deep. Ponds with gentle slopes are recommended in areas where mosquito breeding is evident. More shallow areas may be constructed in a pond for shore bird foraging areas. Excavated spoil resulting from pool and ditch creation is recommended to be used to raise the bottom of ditches, and for plugging ditches. The use of rotary ditching equipment is advised to minimize the impacts of spoil disposal. The semi-tidal systems are described as consisting of 30 inch deep ditches with sills, so that they are only partially tidal. A sump pond and connector ditch system is recommended for semi-tidal systems as well (Niedowski, 2000). Open systems are not discussed.

The New York State Department of General Services administers all State lands below high tide, and issues any grants, easements, or leases required for any private use of such lands (NYSDOS, 1997).

### 2.3. County Regulation

Suffolk County does not regulate wetlands. However, in the late 1970s, there was a fresh water wetlands law (Local Law 20-1976, Chapter 488 of the Suffolk County Code “Freshwater Wetlands”) that referred to a Commissioner of Environmental Control, criteria, and applications (W. Dawydiak, Suffolk County Department of Health Services, personal communications, 2005). It is not clear if the County ever implemented the law, which was repealed in 1993 by Local Law 16-1993.

### 2.4. Local Regulation

Nine of Suffolk County’s 10 townships have local laws that regulate activities in wetlands; in some cases, the local laws regulate the adjacent area. The Town of East Hampton Trustees regulate wetlands, but this is not codified in the Town Code. The town laws typically describe the value of wetlands and the need to protect them, and then define prohibited activities, identify regulated activities, and set forth a permitting procedure for proposed activities in or adjacent to wetlands. The local laws may include standards for permit issuance. Wetlands are protected by denying a permit, or issuing a permit that contains conditions designed to minimize or mitigate impacts. Unlike New York State, which maps wetlands, the Towns do not map the wetlands. In some Towns, they explicitly reference the State maps.

Review of the nine Town Codes found the following:

**Babylon**

*Chapter 108 Dredging*

A permit is needed to remove any material from any waterway, watercourse, or upland abutting or adjoining a waterway or watercourse.

*Chapter 128 Freshwater Wetlands*

This law is very similar to the New York State FWA. A permit is needed for activities within 100 feet of a fresh water wetlands including:

- draining
- dredging
- excavating
- dumping
- filling
- erecting any roads or structures
- discharging pollutants or effluents

Public health activities are exempt.

**Brookhaven**

*Chapter 81 Wetlands and Waterways*

A permit is needed for activities within 150 feet of tidal and fresh water wetlands including:

- draining

- dredging
- excavating
- dumping
- filling
- erecting any roads or structures
- discharging pollutants or effluents

**Huntington**

*Chapter 141 Streams, Watercourses & Wetlands*

*Article I Filling, Diversion, or Draining of Streams and Watercourse*

A permit is needed to:

- fill or divert the course of streams, creeks, or watercourses
- divert any stream, watercourse, or creek from its natural course
- drain any pond or impoundment.

*Chapter 141 Streams, Watercourses & Wetlands*

*Article II Freshwater Wetlands*

The Town assumes the implementation of the New York State FWA.

*Chapter 137 Marine Conservation*

*Article II Removal or Deposition of Material*

A permit is needed to remove/place material on wetlands or watercourses owned by the Town.

*Chapter 137 Marine Conservation*

*Article III Construction or Reconstruction*

A permit is needed to construct or reconstruct a dam or impounding structure and docks, piers and pilings.

**Islip**

*Chapter 67 Wetlands and Watercourse*

A permit is needed to dig, dredge, excavate, or dump on tidal waters, tidal marshes, fresh water wetlands, coastal wetlands, tidal wetlands, and watercourses.

**Riverhead**

*Chapter 107 Tidal and Freshwater Wetlands*

A permit is needed to dig, dredge, excavate, or dump on tidal waters, tidal marshes, fresh water wetlands, coastal wetlands, tidal wetlands, and watercourses, and within 150 feet of a wetland.

**Shelter Island**

*Chapter 129 Wetlands*

A permit is needed for dredging, disturbing, filling, or excavating in tidal and fresh water wetlands, and within 100 feet of a wetland.

**Smithtown**

*Chapter 170 Freshwater Wetlands*

Pursuant to the New York State FWA, the Town assumes the implementation of the Act.

*Chapter 138 Dredging*

A permit is needed to remove or deposit fill from any wetlands or watercourse.

**Southampton**

*Article VII Regulating Dredging, Docks, Bulkheading and Channels (Board of Trustees)*

A permit is required to dredge or deposit material on the bottom of any waters in the Town.

*Chapter 325 Wetlands*

A permit is needed undertake open water marsh management measures and to place, deposit, or dredge material in a tidal or fresh water wetland area, or within 200 feet of a wetlands boundary.

**Southold**

*Chapter 97 Wetlands and Shorelines*

A permit is needed to remove material from wetlands or to deposit or discharge material on tidal or fresh water wetlands

**Town Trustees**

Suffolk County has a special wetlands regulatory situation, which is the result of local history and practice. This is the establishment of town trustees, who in three cases are entirely separate from other elements of Town government.

In 1664, King Charles II granted all lands "from the west side of the Connecticut River to the east side of the Delaware River," including associated islands, to his brother, the Duke of York. Colonel Richard Nicolls was sent to ensure the Dutch (former rulers of this area) recognized this claim. It had been determined in English law that when the King conquered a kingdom, he could alter laws as he saw fit, and so Col. Nicolls imposed English law throughout the new territories on behalf of the King. In 1665, Col. Nicolls established the Duke's Laws, in consultation with the settlers of the area. The Duke's Laws also included the town patents. These designated several patentees, who could act on behalf of "themselves and their associates, the freeholders and inhabitants" as proprietors of the towns. The land grants included "havens, harbors, creeks, quarries, woodland, meadows, pastures, marshes, lakes, fishing, hawking, hunting and fowling" and established the Town. It also required that each purchase of land from the Indians would need approval from the Duke (or his governor). Generally, the lands were held as "tenants in common" where shares of the land were held by the original purchasing families, and could be inherited and otherwise transferred. The land grants extended to high water, and also to the mouths of protected bodies of water. It appears that "swamps," "bogs," and "boggy meadows" referred to fresh water wetlands, "marsh" was low marsh, "foreshore" was the area between low and high tides, "salt meadow" was high marsh, and "thatch" and "creek thatch" was grass growing along streams. These terms apparently were not used precisely at the time, but rather were determined later through interpretations of particular filings and court decisions (Kavanagh, 1980).

The Towns, and their time of foundations, are:

- Brookhaven (1655)
- Easthampton (*sic*) (1649) (Gardiners Island was separate, settled 1640)
- Huntington (1653) (included Babylon, not established until 1872)
- Islip (1710)
- Shelter Island (1649)
- Southampton (1640)
- Southold (1640) (including Riverhead, not established until 1792)

War flared up again in 1673; the King renewed his brother's charter in 1674. In 1683, the fourth English governor of New York, Colonel Thomas Dongan, arrived with instructions to call an assembly to reestablish the "good weal and government" of the colony. To improve on the collection of rents for the Duke, Col. Dongan rewrote the patents for the Towns between 1686 and 1688. This was also done to impose English and catholic authority on the colonists, reflecting the protestant upheavals that had been causing turmoil and civil war in England over the previous hundred years, and would lead to the loss of throne for James II within several years (Kavanagh, 1980).

Dongan quickly persuaded Brookhaven, Easthampton (*sic*), and Southampton to surrender their patents, and receive new ones. Southold, resisted, and operated under a patent issued by the second Governor, Major Edmund Andros. Smithtown and Shelter Island were private proprietary grants, and so did not require a patent (as was the case for Gardiners Island). Huntington was resistant, but acceded to the Governor, and agreed to a new patent in 1688 (Kavanagh, 1980).

Turmoil followed in 1689 with the Glorious Revolution that led to the reign of William and Mary and the deposition of James II. In 1691, Colonel Henry Sloughter was appointed governor, and held an assembly for "settling, quieting, and confirming" the various patents. Thus Shelter Island, Smithtown, Southold, and when incorporated, Islip (by virtue of patents issued to individual landholders) are "Andros Patent" towns, as the Andros patents they held were confirmed by Col. Sloughter. Brookhaven, Southampton, and Southampton are "Dongan Patent" towns, as their Dongan patents were also confirmed by Col. Sloughter. Huntington, on the other hand, had its Dongan Patent originally affirmed by the sitting governor during an unsettled time locally called the Leisler Rebellion (after the James II-appointed governor hanged by Col. Sloughter when he took command of the colony). Col. Sloughter voided all laws and decisions made during the rebellion. Therefore, Huntington applied for a re-confirmation of its patent, and finally received one in 1694 from the new Governor, Benjamin Fletcher. Huntington thus has a "Fletcher Patent," which is of the same form and essentially the same content as a Dongan patent (Kavanagh, 1980).

All of the patents described and assigned land to the landholders, and, as described above, the Nicolls patents (which became Andros patents) also assigned certain rights to the landholders. The Dongan patents went further, however. They expanded the rights of the Towns to be equivalent to towns and boroughs in England, so that they could own and hold land in and of themselves, and sue and be sued. In addition, the Dongan patents created trustees for each Town to hold and manage all unappropriated land for the use and benefit of the freeholders of the towns. The scope of the trust was listed as:

> houses, messuages, tenements, buildings, mills, mill dams, fencing, enclosures, gardens, orchards, fields, pastures, woods, underwoods, trees, timbers, feedings and common pasture, meadows, marshes, swamps, plains, rivers, rivulets, waters, lakes, ponds, brooks, streams, beaches, quarries, creeks, harbors, highways and easements, fishing, hawking, hunting and fowling, mines and minerals (gold and silver mines excepted), and all franchises, profits, commodities, and heriditaments whatsoever to the … tract of land and premises…

This was due to the practice of having common lands for the use of all, and established a means for the ordering and management of those lands. The trustees were bound by previous land grants and use, and were to be elected annually. This meant that although the trustees had great power over the towns, the practice of holding town meetings meant that many aspects of governance were outside of their realm, and these meeting eventually provided the basis for separate Town governance (under Town Boards) (Kavanagh, 1980).

When the State formed its constitution in 1777, it affirmed common law and acts of the colonial legislature, as well as colonial land charters and patents. It also took title to all unappropriated navigable waters and the lands under them (exclusive of lands already granted to New York City, Long Island towns, and certain individuals, by kings of England). Subsequent court cases determined the extent (and limits) of those preexisting arrangements. Generally, trustees were sometimes lax in maintaining public land title to wetlands areas that were surrounded by uplands and so were easily utilized by surrounding landowners. They have tended to be more vigilant with low marsh and foreshore areas, although historical use patterns led to many leaseholders to fill and otherwise destroy wetlands still under trustee ownership (Kavanagh, 1980).

At this time, towns maintaining separate town trustees are:

- East Hampton: nine trustees, two year terms

The Trustees own and/or manage waters, lands underwater, and adjacent beaches. In discharging their duties as the owners and/or managers of the above, the Trustees have developed policies and regulations designed to improve water quality, increase the productivity of their holdings and protect public rights. These include regulating docks, controlling boat discharges, involvement in shellfish propagation and quality enhancement programs, and designating areas in their harbors for various activities, such as water ski, mooring, windsurfing, fish trap, and duck blind areas. They review, and must approve, all dredging projects. They review, and must approve, all bulkheads, revetments and other erosion control devices proposed to be constructed (or which may have an impact) on their lands. They have adopted rules governing beach driving and work with the Town Board to coordinate efforts toward more responsible beach use. The Trustees also own many upland parcels, numerous roads in all areas of Town, and many properties between the ocean and "oceanfront" residences (Town of East Hampton, 2006).

- Southampton: five trustees, two-year terms

Duties of the trustees are to preserve public access to the water, uphold the traditions of a maritime community, advise the Town Board on coastal related issues, inform the public of the facts of coastal issues and policy, represent the best interest of the freeholders, maintain and protect surface water quality, regulate dock and bulkhead construction and impacts, promote sustainable harvest of commercial shellfish and finfish, provide a safe marine environment, and inspect all structures built on bay bottom (Town of Southampton, 2006).

- Southold: five trustees, four year terms

Duties of the trustees are the regulation of any activity along the shoreline of the Town and its inland wetlands, per Chapter 97 of Town Code, and to approve moorings (Town of Southold, 2006).

In the other patent towns, town trustees have become subsumed into the Town Boards. Nonetheless, Town Boards will often need to become the "Town Trustees" to settle certain issues. Trustee issues have been extensively litigated and are often subject to intense interest on the part of some community activists, even where the practice of trusteeship is otherwise largely ignored.

**Local Waterfront Revitalization Programs**

The approved and adopted LWRPs for Suffolk County were closely reviewed. The following six municipalities have the only approved and adopted LWRPs in Suffolk County:

- the Town of Smithtown (1989)
- the Town of Southold (2005)
- the Village of Greenport (1989)
- the Village of Head-of-the-Harbor (1991)
- the Village of Lloyd Harbor (1997)
- the Village of Sag Harbor (1986, amended 1999)

(NYSDOS, 2006)

The following notes specifics in each LWRP which could bear on wetlands management.

Town of Smithtown

There are no direct mentions of vector control actions. Indirect policies that may affect wetlands management include:

- Policy 25 states, "protect, restore and enhance natural and man-made resources."
- Policy 25B states, "prevent the irreversible modification of natural geologic forms and the removal of vegetation from dunes, bluffs and wetland areas."
- Policy 35B states, "wetland channels maybe altered only if the action results enhancing the viability of the wetland area."
- Policy 44 intends to preserve and protect tidal and freshwater wetlands and preserve the benefits derived from these areas.

Town of Southold

There are no direct mentions of vector control in the document, with the exception of one reference, when discussing Hashamomuck Pond, of ditching as a potential cause of loss of tidal connection, and therefore something that should be avoided. Indirect references to wetlands management and/or vector control activities include:

- discussion of a restoration of 80 acres of diked agricultural land by the US Department of Agriculture, where tidal flow had been lost, on the east bank of West Creek;
- Policy 6.1, which states, "protect and restore ecological quality throughout the Town of Southold;"
- Policy 6.2, which states, "protect and restore Significant Coastal Fish and Wildlife Habitats," noting specifically that actions that destroy habitat values through physical alteration or significantly impair the viability of the habitat (causing a reduction in vital resources or change in environmental conditions beyond the tolerance range of important species) should be avoided;

- Policy 6.3, which states, "protect and restore tidal and freshwater wetlands," where restoration is defined as reconstruction of physical values, adjustment of adverse chemical characteristics, or the manipulation of biological characteristics back to some prior, preferred state.

Village of Greenport

There are no direct mentions of vector control. Indirect policies that may affect wetlands management include:

- According to Policy 12, "activities or development in the coastal area will be undertaken so as to minimize damage to natural resources."
- Policy 44 aims to preserve and protect tidal and fresh water wetlands and preserve the benefits derived from these areas.

Village of Head of the Harbor

The LWRP does not specifically make mention of mosquito management within its boundaries. There are some policies which may or may not be compatible with marsh management.

- On page II-31, the extreme frailty of the Village's beaches, dunes, escarpments, and extensive tidal wetlands is discussed, and a need to protect these assets natural state as best as possible is recognized.
- Page II-52 discusses Village concerns regarding the preservation of its fresh water wetlands and tidal marshes.
- Under Policy 44, tidal and fresh water wetlands, as well as the benefits derived from them, must be preserved and protected.
- The report asserts that fish and wildlife habitats are within the wetlands and marshes of the village. Policy 7 states that "significant coastal fish and wildlife habitats…shall be protected, preserved, and…restored." Policy 7D states that reducing or eliminating these areas for a "regional public purpose" is allowable, with the condition that there is creation of new habitat in a ratio of two to one.

Village of Lloyd Harbor

There are no direct mentions of vector control. Indirect policies that may affect wetlands management include:

- Policy 7 states, "coastal fish and wildlife habitats…shall be protected, preserved, and where practicable…restored so as to maintain their viability as habitats."
- Policy 12 requires that all activities in the coastal area must be undertaken so as to minimize damage to natural resources.
- Policy 24 addresses preventing impairment of scenic resources. This impairment includes irreversible modification of geologic forms.
- Policy 25 intends to "protect, restore or enhance natural and man-made resources which…contribute to the overall scenic quality of the coastal area."
- Policy 44 states its goal is to "preserve and protect tidal and freshwater wetlands and preserve the benefits derived from these areas."
- Chapter 137 of the Town of Huntington Code is discussed. This code section addresses Marine Conservation. It was established to protect and preserve the watercourses, coastal shorelines, tidal marshes and watersheds. This law also regulates the removal or deposition of soils within wetland areas of the Town.

Village of Sag Harbor

There are no direct mentions of vector control. Indirect policies that may affect wetlands management include:

- The Village Conservation Districts (CDs) are described. These were created to preserve the tidal and fresh water marshes found within any one or all of the CDs. The CDs restrict use of the wetlands by permit. The major intent of the CDs is to preserve the water quality of natural areas.
- Policy 6.3 on page III-21 is intended to protect and restore tidal wetlands.

Generally, policies that relate to wetland preservation generally intend to maintain and enhance wetlands with as little activity in them as possible. Although water management for vector control purposes is nowhere mentioned explicitly, it may be that the policies would be interpreted that water management could not occur unless it resulted in "improvements" to the wetlands. Alteration of a wetland can occur, even to the point of total destruction (see Head of the Harbor), although mitigation may be required.

## 3. GENERAL FACTORS ASSOCIATED WITH SALT MARSH LOSSES

One of the first wetland surveys in the United States based on wetland habitat values rather than on values for agriculture was carried out in 1954 and published by the USFWS two years later as Circular 39 (Shaw and Fredine, 1956). This was not a comprehensive effort, but focused on defining areas of value as water fowl habitat.

Trends for salt marsh areas are difficult to construct. Even in Europe, where marsh studies have been undertaken for much longer than in the US, it is said that most wetland trend data are generated from indirect measures (Allen, 2000). The National Wetland Inventory (NWI) was a program established to create comprehensive maps of wetlands in the US. 88 percent of the continental US (excluding Alaska) has been mapped. The first of a series of trend documents was produced in 1983 (Wilen et al., 2002). The report documented trends in the nation's wetlands from the 1950s to the 1970s (Frayer, et al., 1983). The data from that early report has been generally revised by later efforts, and Dahl (1990) has become the standard reference for historical wetlands losses.

The extent of wetland losses in the United States is both widespread and severe. An analysis of losses between the 1780s and the 1980s indicates that a 53 percent loss occurred in the continental US, excluding Alaska (Dahl, 1990). Losses to coastal wetlands have occurred due to:

- excessive harvesting of their production
- hydrologic modification and seawall construction
- coastal development
- pollution
- other less important factors

Fresh water wetlands have been lost because of:

- hydrologic modification and development, including drainage for agriculture, forestry, and mosquito control

- filling for residential, commercial, and industrial development
- filling for solid-waste disposal
- mining of peat

(Mitsch and Gosselink, 2000).

Frayer et al. (1983) estimated a net loss from the 1950s to the 1970s of more than 3.7 million ha (over nine million acres), a loss rate of approximately 0.4 percent per year. That averages to 185,000 ha (450,000 acres) each year. Although wetland loss rates are slowing, according to some estimates the United States continues to lose approximately 70,000 to 90,000 acres of wetlands on non-federal, rural lands each year (USEPA, 1995). USFWS, through the NWI program, estimates the rate is lower but still substantial at 58,500 acres per year (USFWS, 2000). Another estimate is that 162,800 acres of wetlands on privately-owned lands were lost between 1992 and 1997 (NRCS, 2000). President GWH Bush set a goal of no net loss of wetlands throughout the country in the late 1980s (his son later established this as an explicit policy). More ambitiously, a National Research Council report (1992) called for the fulfillment of a goal of gaining 4 million ha of wetlands by the year 2010, largely through the reconversion of crop and pasture land.

Gosselink and Bauman (1980) estimated the US loss rate of coastal wetlands at 8,100 ha per year between 1922 and 1954. This increased to 19,000 ha per year between 1954 and the 1970s. Frayer et al. (1983) estimated that 73,000 ha of estuarine wetlands were lost each year from the 1950s to the 1970s. The rate was said to slow to 2,900 ha per year from the mid-1970s to the mid-1980s with the promulgation of wetland protections (Dahl and Johnson, 1991). Generally, good estimates of historical loss have not been agreed upon, although all researchers have found that losses have been substantial.

Redfield (1972) codified the classic description of marsh development, based on a number of cores in a New England marsh. He described how a marsh can increase in area both by extension out into an estuary by trapping sediment and accreting material to raise its elevation, and through growth over former uplands as they become flooded by rising sea level. However, this was recognized a relatively simplistic view that does not apply to all marshes. For example, back barrier marshes were found to be much younger (1,000 years old at most) compared to mainland marshes (4,000 years old or more) (Newman and Munsart, 1968), suggesting they may be continually reconstituted due to landward migration of the barrier islands. Other marshes clearly do not grow at constant rates. Nearly all regional salt marshes were unlikely to have formed prior to the major reduction of sea level rise that occurred 5,000 years ago (Rampino and Sanders, 1981). Stevenson et al. (1986) suggest that generally marsh accretion or loss is a complex function that is under the overall control of relative sea level rise. Important environmental factors that increase sediment deposition rates include higher tidal ranges and riverine inputs. It was also noted that too much sedimentary input leads to autocompaction of the sediments, which can contribute to marsh submergence. In sum, whether a marsh adds or loses vegetated area over time is determined by processes that combine in ways that are determined on local scales, by and large.

Kennish (2001), on the other hand, identified different anthropogenic causes of marsh loss, on different geographical scales. Local causes can be direct or indirect causes of marsh loss. Direct impacts that modify or destroy the marsh, and which tend to occur on very short time scales, include:

- dredging
- spoil placement
- ditching
- canal cutting
- constructing levees
- salt hay farming

Local, but indirect, causes of marsh loss, which tend to occur over longer time periods than the direct causes above, include actions that:

- interfere with normal flooding patterns
- alter drainage processes
- reduce mineral inputs

Regional causes of salt marsh loss are those that cause subsidence, which occurs at time scales measured in decades, and may be irreversible. Anthropogenic subsidence is due to subsurface withdrawals of:

- groundwater
- oil
- natural gas

Global-level changes that cause salt marsh loss are those relating to climate change, as warming is causing eustatic sea level rise. The factors involved in sea level rise tend to be those that vary on a multi-decadal to century scale. Eustatic sea level rise is occurring or is anticipated to occur because of:

- potential destabilization of Antarctic continental glaciers
- Greenland and other high Arctic continental glacier melting
- thermal expansion of ocean waters

Loss of salt marsh must be understood in the context of salt marsh expansion, or, at least, maintenance. North American salt marshes were enabled when sea level rise decreased several thousand years ago, allowing accretion rates for the marshes to match or outstrip relative sea level rises. The general process has been well described (Redfield, 1965; Teal and Teal, 1969; Redfield, 1972). Halophytic plants gain a foothold in a sheltered portion of an estuarine setting, and then expand their domain out into the estuary through sediment accretion and into the uplands as invading salt water displaces less hardy vegetation. Every marsh is the function of local forces influencing these overall processes.

Marsh sediments are derived from autochthonous (that is, "imported") minerals or allochthonous (that is, marsh-derived) detritus and roots of macrophytes (Anisfield et al., 1999). The percent of material that is inorganic or organic depends upon the physical setting and the vegetation regime. Marshes along the southern part of the east coast of the US tend to be at the mouths of rivers, and therefore often receive large inputs of inorganic matter transported by the rivers (Wiegert and

Freeman, 1990). The New England marsh type, on the other hand, derives less of its accretion from minerals, and more from plant materials (Bertness, 1988; Frey and Basan, 1985).

Within a marsh, the low marsh tends to have more inorganic matter, while the high marsh has more organic matter. Partly this is a function of inundation frequency, as the low marsh is flooded more often than the high marsh and so can collect more mineral material from tidal deposition (Cahoon and Reed, 1995). In addition, with high hydrogen sulfide levels in the saturated low marsh soils, a mineral buffer containing iron is important to help manage this toxic gas. Sulfide precipitates as an inert mineral, pyrite, in contact with iron, which is delivered to the marsh through inorganic sedimentation (Lord and Church, 1983). Thus, accumulation of inorganic matter on the low marsh can foster this chemical transformation, which helps macrophytes to survive in such a harsh environment.

The input of inorganic material from routine flooding events is not sufficient to explain most marsh accretion rates. Calculations for south shore Long Island marshes, for example, suggest that even if all of the inorganic matter in a tidal prism were to be deposited in the marsh, the marsh would only receive approximately 50 percent of the material necessary to match long-term sea-level increases (Cashin Associates, 2005). Extraordinary events, particularly large storms, however, deliver vast amounts of materials over short periods of times (Donnelly et al., 2001). Years with more storms have been shown to deposit more sediment in high marshes (Harrison and Bloom, 1977). Sediment rates in Louisiana depend on the resuspension of sediments from nearby bodies of water, which is largely caused by stronger storms (Cahoon and Reed, 1995). In Delaware, tidal sediment sources were found to be inadequate to keep marshes above rises in sea level, but the marshes were found to be maintaining themselves due to storm-derived sediment sources (Stumpf, 1983).

Peat accumulates faster in the high marsh than the low marsh (Redfield, 1972), and tends to form uneven tussocks there (Nixon, 1982). Low marsh microtopography tends to be smoother, although low marsh sediments tend to be composed of larger grain sizes. Peat formation is enhanced when winter ice shears plants off, creating greater detritus loadings (Frey and Basan, 1985). Generally, for east coast US marshes, peat accumulation is five times more important than inorganic inputs (Turner et al., 2000). However, overall sedimentation rates are greater in the low marsh compared to the high marsh, even in New England (Chapman, 1974; Jordan and Valiela, 1983; Richard, 1978; Bricker-Urso et al., 1989). The natural tendency is for low marsh to develop into high marsh, raising itself above the daily tide level (Redfield, 1972), although high marsh accounts for less than half of all New England type marshes (Nixon, 1982); high marsh does comprise the vast majority of southern marshes (Wiegert and Freeman, 1990).

Invasive *Phragmites australis* (*Phragmites*) can raise the marsh surface where it is growing. This is due to the tremendous density of roots and rhizomes that it develops, and the above-ground stalk density of this plant. The below-ground structure creates additional organic inputs, and the density of the above-ground growth catches additional sediment beyond what other salt marsh plants might accumulate (Meyerson et al., 2000; Rooth et al, 2003), although Leonard et al. (2002) found differently for the Chesapeake Bay area. This process benefits *Phragmites* as it is thought to be not as tolerant of salinity as other marsh plants, and so raising the marsh surface may insulate it from some salinity effects (Meyerson et al., 2000).

Sea level rise is often cited as a primary concern regarding salt marsh loss, for the obvious reason that as sea level increases, it threatens to flood the salt marshes, perhaps to too great a height. Exactly how sea level increases are affected by various processes must be understood, because relative sea level is not changing at the same rate, or even in the same overall direction, at all places throughout the world. Overall world-wide sea level is controlled by changes either in the volume of water in oceans or the volume of ocean basins. The volume of water in the oceans is dominated by glaciation, which can produce very large changes (100 m or more) over relatively short time scales (thousands of years). Other, potentially rapid (tens of meters over a thousand years) changes in water volume include the growth or disappearance of marginal seas, thermal expansion of water, and changes in storage for groundwater and fresh surface waters. Changes in ocean basin geometry (the overall volume between the continents) tend to be much slower (tens of meters per million years), and are dominated by variations in sea floor spreading and ocean ridge lengths, although the net effect of these changes can be as great as glacial changes (hundreds of meters of change in sea level). Smaller effects result from greater or lesser ocean basin sedimentation generation, or the subsidence of ocean plateaus (although the creation of such plateaus can cause 50 m or more of sea level change over a million years) (Miller et al., 2005).

Local sea level rise is linked to world-wide change, but also is a function of local tectonic forces. These may cause the land mass to rise or sink relative to the ocean surface due to sediment loading on the continental shelf or slope or because of mountain building or erosion, which affect the overall attitude of the continental land mass. Other forces that affect relative sea levels include isostatic rebound from glaciation, where portions of the continent may have been depressed due to the weight of the glaciers lying on them. The depressed areas will eventually rebound past their former elevation, and then oscillate back to the "correct" (i.e., unglaciated) elevation once the ice sheet retreats. This means that various shorelines may be rising or sinking relative to sea level. To complicate matters, areas where the glaciers did not reach may have experienced relative increases in elevation relative to sea level during glaciation, much as a leaning on a floating wooden block causes the unweighted opposite side to tip up. These changes tend to be measured at time scales best understood to be thousands to tens of thousands of years. Therefore, even along the same coastline, the shoreline itself may be rising or sinking relative to sea level (Kennet, 1982).

Generally, the earth is thought to be in an interglacial period. A glacial maximum occurred approximately 20,000 years ago. At that time, due to the cold temperatures (since water has less volume when it is cold) and the incorporation of ocean water into the continental glaciers, global sea level may have been 50 to 100 m (or even more) lower than it is today. As the glaciers melted and the world warmed, sea level rose. The rate of rise, some three mm per year, slowed some 5,000 years ago to the vicinity of one mm, which allowed for the initiation of New England-type salt marsh formation, as the marshes could not maintain themselves under prior sea level increase rates. Salt marshes formed on river delta sediments did exist prior to 5,000 years ago (Mitsch and Gosselink, 2003). Some marshes that are tidal today, such as along the Hudson River, appear to have formed earlier than 5,000 years ago, as well (Montalto and Steenhuis, 2004), but would have had to have been fresh water systems then.

Over the past five thousand years, sea level has continued to rise due to continuing warming, producing thermal expansion and further melting of continental ice, although clearly at a slower rate than the preceding 15,000 years post glacial maximum. However, it is also clear that global climate change is affecting sea level by increasing the warming trend (Karl and Trenburth, 2003). Generally, sea level rise is said to have been one to three mm per year over the past century (accurate estimates being complicated by the varying local forces affecting coastline geology, discussed above), with more recent calculations suggesting 1.9 mm is likely to be the most accurate estimate. That 1.9 mm rate is composed of 0.5 mm due to thermal expansion and 1.4 mm due to continental ice loss (Munk, 2003). Satellite imagery analysis of the actual world-wide level of the ocean has found that due to increasing world-wide temperatures, the rate of ocean expansion is increasing, too, and so the newest estimate for sea level rise from 1993 to 1998 was 3.2 mm per year – approximately 50 percent faster than the longer term rate (Cabanes et al., 2001). Therefore, there are concerns that marshes that developed under one rate of sea level rise may not be able to maintain themselves with accelerations in that rate. Partially, this is because the low gradient of marsh surfaces amplifies small vertical changes into the horizontal plane. Pilkey and Cooper (2004) note that a sea level increase of one cm, which is the result of three years of average sea level rise, at the coastal plain slope for North Carolina could result in inundation of 100 m or so of shore lands.

One particular study found relative sea level rise (with respect to coastal marshes) was greatest along an arc from Cape Cod to central New Jersey, and decreased both north and south of this area over the past thousand years. Coastal Connecticut was also found to have lower rates of marsh submergence. This was thought to result from the New York Bight area reacting differently under glacial rebound than other portions of the coastline (Newman and Munsart, 1968). Compilations of long-term sea level trends from National Oceanic Atmospheric Administration (NOAA) records (Table 1) support the observations of Newman and Munsart to some degree, but also suggest that they oversimplified the situation somewhat. For instance, the NOAA data do not support a finding that the entire New York Bight region is subsiding more than other areas of the East Coast. Generally, local sea level rise at New York stations is greater than that in Maine, but less than that in New Jersey and most points to the south. Local sea level rise is much less than that measured for coastal Louisiana (data not shown in Table 1), where long-term rates approach 1 cm per year.

Table 1. Sea Level Rise Rates, US East Coast (from NOAA Tide Gage Records)

| State | Station Name | Time Period | Rate (mm) | SE (mm) |
|---|---|---|---|---|
| Bermuda | | 1932-99 | 1.83 | 0.30 |
| Florida | Fernandina Beach | 1897-1999 | 2.04 | 0.12 |
| | Mayport | 1928-99 | 2.43 | 0.18 |
| | Miami Beach | 1931-81 | 2.39 | 0.22 |
| | Key West | 1913-99 | 2.27 | 0.09 |
| Georgia | Fort Pulaski | 1935-99 | 3.05 | 0.20 |
| South Carolina | Charleston | 1921-99 | 3.28 | 0.14 |
| North Carolina | Beaufort | 1973-99 | 3.71 | 0.64 |
| | Wilmington | 1935-99 | 2.22 | 0.25 |
| Virginia | Kiptopeke | 1951-99 | 3.59 | 0.27 |
| | Colonial Beach | 1972-99 | 5.27 | 0.72 |
| | Lewisetta | 1974-99 | 4.85 | 0.79 |
| | Gloucester Point | 1950-99 | 3.95 | 0.27 |
| | Sewell's Point | 1927-99 | 4.42 | 0.16 |
| | Portsmouth | 1935-87 | 3.76 | 0.23 |
| | Chesapeake Bay-Bridge Tunnel | 1975-99 | 7.01 | 0.86 |
| Maryland | Cambridge | 1943-99 | 3.52 | 0.24 |
| | Baltimore | 1902-99 | 3.12 | 0.08 |
| | Annapolis | 1928-99 | 3.53 | 0.13 |
| | Solomons Island | 1937-99 | 3.29 | 0.17 |
| | Washington DC | 1931-99 | 3.13 | 0.21 |
| Delaware | Lewes | 1919-99 | 3.16 | 0.19 |
| Pennsylvania | Philadelphia | 1900-99 | 2.75 | 0.12 |
| New Jersey | Canly Hook | 1932-99 | 3.88 | 0.15 |
| | Atlantic City | 1911-99 | 3.98 | 0.11 |
| | Cape May | 1965-99 | 3.88 | 0.53 |
| New York | Montauk | 1947-99 | 2.58 | 0.19 |
| | Port Jefferson | 1957-92 | 2.44 | 0.39 |
| | Willets Point | 1931-99 | 2.41 | 0.15 |
| | New Rochelle | 1957-81 | 0.54 | 0.85 |
| | The Battery | 1856-1999 | 2.77 | 0.05 |
| Connecticut | New London | 1938-99 | 2.13 | 0.15 |
| | Bridgeport | 1964-99 | 2.58 | 0.41 |
| Rhode Island | Newport | 1930-99 | 2.57 | 0.11 |
| | Providence | 1938-99 | 1.88 | 0.17 |
| Massachusetts | Boston | 1921-99 | 2.65 | 0.10 |
| | Woods Hole | 1932-99 | 2.59 | 0.12 |
| | Nantucket | 1965-99 | 3.00 | 0.32 |
| Maine | Eastport | 1929-99 | 2.12 | 0.13 |
| | Bar Harbor | 1947-99 | 2.18 | 0.16 |
| | Portland | 1912-99 | 1.91 | 0.09 |
| | Scavey Island | 1926-86 | 1.75 | 0.17 |

Morris et al. (2002) found that in systems with high rates of sediment loadings, such as the southeastern US, marshes should be able to sustain themselves better against sea level rises than those with smaller sediment inputs such as the northeast US. This is because peat formation, which is more important for northeast US marshes, may not increase over time to be able to ensure sufficient material inputs. However, generally, most northeast US salt marsh sedimentation rates have been measured to meet or exceed sea level increases over recent history (Orson et al., 1998; Redfield, 1967; Bricker-Urso et al., 1989; Redfield and Rubin, 1962; Armentano and Woodwell, 1975; Harrison and Bloom, 1977; DeLaune et al., 1978; Stumpf, 1983; Wood et al., 1989; Orson and Howes, 1992; Warren and Niering, 1993; Roman et al., 1997; see also the calculations in the Seatuck-Wertheim Retrospective study, part of the Early Action projects). Partially, this is because sedimentation rates seem to be closely linked to relative water levels experienced by the salt marsh (Anisfield et al., 1999). Note that Roman et al. (1997) found that the steady pattern of sedimentation is augmented by storms, and hypothesized that these episodic pulses are necessary for marshes to exceed the rate of sea level rise.

In many ways, sedimentation in a marsh has negative feedback systems associated with relative sea level rise. In a broad way, if a marsh accretes material too rapidly, it will elevate itself above the tidal forces that control its accumulation of mineral sediment, and change the means by which organic material is produced through changes in the vegetation regime. If sedimentation is insufficient to match sea level rise, greater tidal inundation occurs, which can potentially increase exposure to sediment laden tidal flooding. Perhaps due to more flooding, or greater productivity by *S. alterniflora*, low marsh accretion rates are often much greater than high marsh accretion rates (see Morris et al., 2002). The signal that causes accretion needs to be damped in some way, however, as salt marsh sediment levels do not fluctuate over relatively short time cycles as sea level measurements do; rather, marshes tend to show regular accretion of materials, implying that accretion and sea level changes are only linked indirectly (McCaffrey and Thomson, 1980). However, it is not always the case that marsh accretion inevitably matches sea level rise (although many measurements do show a general concordance).

Also, it has been noted that in many instances rising sea level can even lead to increased marsh area, as the rise in water levels allows the marsh to expand landward. If the low marsh can maintain itself against the rise in sea level so that there is no loss along the perimeter, the area of the marsh will expand (Teal and Teal, 1969; Gornitz et al., 2004). However, if development precludes retreat landward, and sedimentation does not exceed sea level rise, then the marsh will shrink. This has been the gross process that has been implicated in wide-spread marsh losses of the late 20th century (Gornitz et al., 2004). Also, one study concluded that as sea level rise accelerated from the mid-1980s to the late 1990s, *S. alterniflora* expanded its area in the marsh relative to other marsh grasses. This change in the pattern of zonal segregation for marsh plants is attributed to greater stresses on the system, and continuing increases in the stresses could lead to *S. alterniflora*-dominated marshes in the relatively near future. This kind of marsh is suggested to be more at risk from drowning with increasing sea level rise rates (Donnelly and Bertness, 2001).

It is not true that all salt marshes are maintaining themselves in light of increasing sea levels. Certain marsh systems have suffered recent large areal losses, although it is not clear that sedimentation rates are the key factor (Reed, 1995; Kolker et al., 2004; Kolker et al., 2005). Adam (2002) particularly warns against sweeping generalizations regarding impacts from sea level rise. The impacts can be different not only on continental scales, but locally, where changes in sediment budgets over relatively limited portions of the coastline can mean radically different responses to the same increase in sea level.

In particular, one study has strongly suggested that island marsh systems may be most in peril from increasing sea level rise rates. This may be partially due to the lack of upland sediment inputs for such systems. The Chesapeake Bay was found to be experiencing a sea level rise of 3 mm/yr in the mid-1980s. Marsh accretion rates were found to be less than this at sites experiencing major areal losses (Stevenson et al., 1986). At Bloodsworth Island, in particular, three mechanisms were found to be causing marsh loss. These were:

- Perimeter erosion by wave action
- Channel formation and subsequent enlargement
- Interior pond formation and expansion

Over one-quarter of the island's area was lost between 1849 and 1992, most of which occurred due to perimeter loss. Ponds and channel widening caused most interior marsh losses prior to 1942. A brief period of accelerated sea-level rise (to 7 mm/year from 1930 to 1948) was thought to be linked to the creation of new, non-channel ponds (although it may also be an artifact relating to the non-inclusion of small, non-connected ponds in older maps). Non-channel ponds have also been found to be growing in area in other, mainland marshes. The ponds appear to form due to waterlogging of vegetation, almost exclusively *Juncus roemerianus* (black needle rush). *J. roemerianus* is a high marsh plant, and so cannot withstand daily tidal inundation. If the underlying substrate fails to maintain itself against sea level rise, there will be more frequent inundations of the plants, leading to die backs. Continuing losses in interior wetland areas appear to be linked to new pond formation, rather than expansion of existing ponds (which appear to be fairly stable in size) (Downs et al., 1994). Potentially, the relative submergence might be linked to excessive groundwater withdrawals on a regional scale. The removal of subsurface water might have hastened local submergence, so that the removal of subsurface water in turn led to drowning of the marsh because the surface subsidence allowed for more tidal penetration across the depressed marsh surface (Stevenson et al., 2000). In Louisiana, it was found that internal ponds did appear to form in marshes following waterlogging, due to collapse of the fine root structure in the peat, rather than erosion of the surface sediments. The collapse of the peat substructure meant that overall marsh elevation could rapidly decrease although overall water levels remained essentially constant (DeLaune et al., 1994).

Perimeter loss is generally a consequence of erosion. Five lagoonal marsh areas from Cape Cod, Massachusetts to the southern Delmarva peninsula, Virginia, were all found to have experienced marsh losses over the period 1932 to 1994. The amount of change varied among sites but each site lost the greatest amount of salt marsh vegetated area due to deterioration of marsh edges. The majority of marsh edge loss occurred at areas adjacent to large open bodies of water or navigation channels with high boat traffic (Erwin et al., 2004). Waves and boat wakes can attack the edge of the marsh, potentially undercutting root mats along the marsh edge (Schwimmer, 2001).

A comparison of lagoonal and shoreline marsh systems found that, due to rising sea level, the lagoonal systems appeared to be losing area while the mainland systems were increasing. The losses for the lagoon-based marshes were along the marsh front, but the gains at the mainland sites were primarily through encroachment up onto shoreward areas (not extension outwards into the estuary). No interior losses were found at this Virginia site (Kastler and Wiberg, 1996).

However, along the southeast English coast, where marsh loss is a problem, too, the general cause was thought to be "coastal squeeze." Coastal squeeze describes the situation where marshes are trapped between increasing sea levels and hardened shorelines. For most of these English marshes, however, this explanation has been rejected, for several reasons:

- Previously, marshes have accreted sediment at a rate exceeding sea level. This generally leads to an expansion of marsh seaward.
- If marsh squeeze were occurring, the predominant losses would be in high marsh plant area. Most marsh losses have been in low marsh plant area.
- The apparent applicability of an alternate hypothesis, associated with changes in intertidal biota (especially increases in a polychaete, *Nereis diversicolor*), which may cause the loss of pioneer plants and increase sediment instability.

(Hughes and Paramor, 2004)

Kearney has found that increasing marsh loss directly correlates to the percentage area of standing water. In one sense, this is a tautology, since for marshes, which are generally mostly vegetation, as they gain water area they must inversely lose marsh vegetated surfaces. However, Kearney proposes that waterlogging, which he hypothesizes can be directly measured via the percentage of open water in a system, is the proximate cause of vegetated marsh loss. Kearney measured the amount of water in a variety of marshes using remote sensing data from satellites. This technique was developed in microtidal regimes in the Chesapeake Bay system, and needs adjustment when applied to higher tidal range regimes (Kearney et al., 1999).

This has resulted in the identification of four classes of marsh quality, based on the satellite quantifications of open water within the marsh and subsequent developments in the marshes:

- Class 1: zero to 20 percent water: healthy marsh, stable substrate
- Class 2: 21 to 30 percent water: tidal streams will widen

- Class 3: 31 to 50 percent water: ponds will enlarge and coalesce, and streams widen further
- Class 4: more than 50 percent water: large ponds remain all year, streams cut off islands and enlarge ponds, allowing greater wind fetch, creating a positive feedback leading to more degradation

The National Aeronautics and Space Administration (NASA) Coastal Marsh Project has mapped the east coast of the US according to these classifications. The general finding has been that there is a much greater marsh quality problem than previously thought, and that many marsh systems are under tremendous strain (Kearney et al., 1999).

Conversely, it has also long been known that reducing water levels in a marsh system causes subsidence, as up to 75 percent of the volume of peats are lost when they become exposed to the air and dry out (Snowden et al., 1977).

Generally, there seems to be a golden mean that sustains marshes:

- diversity of biota – but not an excess of any one kind
- sufficient tidal inputs to support plant growth, but no too much to cause erosion or waterlogging
- sufficient sediment inputs (of the right kind)
- a minimum of anthropogenic inputs of almost all kinds – except when restoration is required

It is not clear if the areas that have experienced large losses are illustrative of the future for other areas, or if they are anomalous. Two areas of widespread interest are Louisiana and Jamaica Bay. Louisiana has more salt marsh than any other part of the continental US, and has been the subject of much marsh research. Jamaica Bay may be a local model for Long Island, or at least a nearby example that lessons can be drawn from, and has recently attracted a good deal of research interest.

# 4. US EXAMPLES OF RECENT MAJOR SALT MARSH LOSSES

## 4.1. Louisiana Coastal Marshes

Louisiana experienced an average loss rate of coastal salt marsh of 10,800 ha per year from 1958 to 1974 (Dunbar et al., 1992). The prime factor in these losses was said to be a relative sea level increase. The sea level increase relative to marsh surfaces appears to have been caused by land subsidence, sediment starvation, altered hydrology, and a number of other human activities (Bauman and Turner, 1990; Turner, 1997). This rate of wetland loss along the Gulf of Mexico represented a very high 0.86 percent per year. The loss rate declined to 6,600 ha yr from 1983 to 1990 (Dunbar et al., 1992). USGS data for 1978 to 1990, using a technique that is sensitive to changes on the order of 50 to 60 m of linear loss, showed a loss of 108,500 ha of land for 1978 to 1990, with another 61,900 ha lost from 1990 to 2000 throughout the entire Louisiana Coastal Area. The mean annual loss per year was calculated to be 7,740 ha per year over the entire 22 year period. Not all land loss measured by USGS was wetlands. The report specified that wetlands losses slowed over the study time, although there were breakups noted in previously intact interior marshes in the Chenier Plain. Gains were noted at certain wetland restoration sites, but most of the gains in land area were associated with delta building at the Atchafalya and Wax Lake outlet deltas (Barras et al., 2004).

Oil and gas extraction activities in the inshore coastal marshes peaked in the 1970s and canal dredging decreased concurrently. Canals were cut for access to drill sites, and for other navigation purposes related to the oil industry. The decline in in-shore petroleum product extraction, along with more stringent environmental control of permits for and design of wetland related activities, has been cited as a cause of the falling rate of marsh loss (Mitsch and Gosselink, 2000). Nonetheless, the sum of wetlands loss in the Mississippi delta since 1950 has been estimated to total 40,000 ha (Stokstad, 2005, reporting on an as of March 2006 unpublished National Academy of Science report).

The losses in Louisiana are not evenly distributed. Some of the localized losses occur in understandable ways, such as when storms with high wave energy cause erosion of underlying sediments along the gulf front (Nyman et al., 1994). Overall blame for recent losses are linked to river control efforts of the 1940s, which robbed the system of sediment inputs, canal construction associated with oil and gas extraction, and grazing by the invasive nutria. The prime actor is believed to be the disruption of sediment inputs, as the deltaic soils naturally subside through consolidation unless new inputs are received (Stokstad, 2005). Other losses occur in what are called "hot spots," where the causes of loss are not as easy to distinguish.

The Missisippi dikes force the river to flow directly to the sea out the "Birdclaw" delta, although there is evidence that the river was actually in the first stages of changing its mouth to the Atchafalya River in the recent past (Penland et al., 1988). This robs the western portion of the state of potential sediment inputs and tends to input all river-borne sediments out onto the continental shelf. In addition, watershed diking has apparently outweighed continuing agricultural erosion elsewhere in the river system, so that the suspended sediment load of the river has decreased by nearly 50 percent since the 1950s (Turner and Rao, 1990).

Canals associated with petroleum product extraction changed salinity patterns and water levels in various marshes. They disrupted sedimentation patterns, especially when spoil banks inhibited the natural overwash of tides or storm waters onto the marsh surface. Spoil banks are extensive due to the depths of the canals, with one estimate suggesting that more than twice as great an area of salt marsh was filled with spoil compared to the dredged surface area of canal (Craig et al., 1979). Turner (1997) makes a compelling statistical case that the predominant force causing marsh loss along the gulf coastline is the impacts of canals, due to the indirect effects of the canals insertion and associated construction of the spoil banks. He tested impacts from canals against three other hypotheses (declining mineral inputs due to decreasing Missisippi River sediment loads; decreasing mineral inputs due to levee prevention of overbank flooding; and salt water intrusion from offshore) and found statistically significant correlation only for the canal hypothesis, based on geographic interpretations of marsh loss over time. Day et al. (2000), criticizing this study, found that the use of USGS quadrangle maps was an inappropriate scale, and, reexamining the same data sets using a variety of statistical transformations, found that canals at most accounted for 9.2 percent of marsh losses overall (although perhaps as much as half in some basins). This analysis instead found that there appeared to be a myriad of potential causes for the loss of marshes, but generally found many linked to the changes in hydrologic inputs associated with the hardening of the Mississippi River. Gosselink (2001) vigorously objected to the analysis means as well. He noted that Turner, for example, did not account for pre-1930s marsh losses, did not determine if effects from individual canal construction varied over time or spatial scales (as might be anticipated), and may have inappropriately linked canals and marsh losses based on arbitrary geographical divisions, such as the tiling of USGS quadrangle maps. Although Gosselink agreed canal construction obviously plays a role in the loss of wetlands, he noted that the Turner hypothesis provided no biological aspect for the losses, and said little about the mechanisms involved in the phenomenon. In his reply to these comments, Turner (2001) noted that it cannot be denied that marsh loss rates peaked with canal construction. He agreed that the statistical analysis depends on the scale chosen; his chosen analogy was detecting the curvature of the earth, which cannot be done at small distance scales, but instead requires a larger, more appropriate scale, which suggests that certain measurements need to be made at certain scales. This meant Day et al. had no good rationale for criticizing his (Turner's) choice of scale, and Turner instead found that the scale used by Day et al. was inappropriately chosen, and so missed the global aspects captured in Turner's original work. Day et al. (2001), in a response to Turner's response, noted that the findings made by the Day group represent the consensus views of many close observers of the marsh loss issue, and that initial results of remedial work (based on the consensus view) appeared to be successful. This argues that the consensus view is at least adequate for operational purposes.

Another oft-cited cause for marsh loss is deep geological processes. In Madison Bay, Terrebonne Parish, in southeastern Louisiana, former marsh surfaces are now one meter or more under water. The subsidence rate over the past 40 years, approximately 23 mm per year, is an order of magnitude more than the long-term local subsidence rate two mm a year, calculated over time spans ranging from 400 to 4,000 years. The long-range rate appears to be the result of overall increases in global sea level coupled with local subsidence due to sediment loading from the Mississippi River. The recent rate also appears attributable to geological fault activation following natural gas mining (Morton et al., 2003).

Additionally, shipping canals have been linked to marsh losses, especially in the New Orleans area (in association with the Mississippi River Gulf Outlet). Marsh losses were caused by directly by erosion from ship wakes and indirectly through salt water intrusion that killed fresh water cypress swamps (Day, 2005).

The practice of using impoundments in the wetlands (to promote bird usage or for agricultural reasons) has resulted in nearly 10 percent of Louisiana's wetlands being under such regimes. Impoundments are thought to experience lower sedimentation rates, and distinct changes in vegetation. The dikes associated with impoundments can preclude landward migration in the face of sea level rise (Kennish, 2001).

Turner and Rao (1990) clearly linked the creation of open water in the interior of the marsh to the general loss of wetlands, finding that it greatly exceeded losses from the edge of the habitat.

It is thought that different factors may be important for different hot spots. One theory is that the marshes become waterlogged, the plants die back, and then there are no stabilizing roots to hold the sediments in place. Experiments that raised the level of marshes, reducing waterlogging, resulted in more vigorous growth, and tended to support this hypothesis (Webb et al., 1995). Alternately, there has also been evidence that the cause of the die back is initiated in the subsurface, and that the loss of root matter leads to peat destabilization, and this leads to the loss of the above-ground vegetation (DeLaune et al., 1994). Such a die back could occur due to the generation of reducing conditions which allow for sulfide production. *Spartina alterniflora*, under some conditions, can control its root-zone environment to prevent poisoning by sulfide (Mendelssohn and McKee, 1988). However, in the absence of sufficient mineral inputs, it has been suggested that not enough sulfide will be fixed to allow for successful plant growth (Lord and Church, 1983). A transplantation experiment in Barataria Bay showed that the soil chemistry in the die back zone in the interior of the marsh was different from that found along creek banks. In the die back zone, sulfide prevented the transplanted *S. alterniflora* from succeeding, whereas it flourished along the creek banks (Mendelssohn and McKee, 1988).

Another alternative is to blame consumption of grasses for the loss of vegetation. Herbivory by snow geese has been identified as the means of some local losses of marsh vegetation. Nutria are also cited as major herbivores, and may cause much more damage than geese. The loss of surface vegetation to consumption may be compounded by impacts to soils from loss of shading (changes in soil chemistry due to heating and degassing), and ultimately loss of the binding root materials. Furthermore, statistical analyses find nutria population levels correlate well with marsh loss rates in areas where sediment inputs are low (Ford and Grace, 1998).

It has also been suggested that the overharvesting of blue crabs (*Callinectes sapidus*) can cause marsh die back. Blue crabs have been identified as a major control on the population of *Littoria irrorata* (marsh periwinkle). In its turn, *L. irrorata* is commonly found grazing on *Spartina alterniflora*. Increases in catches of crabs could reduce the predator controls on snail populations (abetted by decreases in another important *L. irrorata* predator, *Malaclemys terrapin* [diamondback terrapin]) (Silliman and Bertness, 2002). This description is slightly complicated by the fact that the snails actually graze not on the *Spartina*, but on fungi growing on the grass (Silliman and Zieman, 2001). However, more snails result in increased grazing on the *S. alterniflora* fungi, which invariably causes collateral damage to the underlying grass. The damage leads to pathogenic fungal invasion of the *Spartina*, which can cause plant death. The potential for this to occur was demonstrated through experimental exclusions of blue crabs from marsh plots in Virginia. This has also been proposed as a mechanism for at least part of the impacts experienced in Louisiana (Silliman and Bertness, 2002). The hypothesis is somewhat shaken by later research implying that another crab (the black-clawed mud crab, *Panopeus herbstii*, which is not commercially important) is a dominant predator for snails (Silliman et al., 2004). The overall process of indirect, top-down impacts is called a trophic cascade, and has been demonstrated for other systems, such as kelp (Paine, 2002) and seagrass communities (Duffy et al., 2001), and so was thought to potentially apply to marsh loss as well.

Experimental work in areas of Georgia and Louisiana impacted by die back implied that physical stress or snail impacts alone cannot account for the measured losses. It is possible that the combination results in synergy, especially when the snails form consumer fronts that can sweep from one affected area outwards, abetted by decreased predation on the snails due to overharvesting of key species (Silliman et al., 2005).

The phenomenon of sudden marsh die back of *Spartina* (mostly *S. alterniflora*) has been dubbed “brown marsh” in Louisiana. It was first noted to affect large areas of the coastline in the spring of 2000, and approximately two-thirds of the Barataria-Terrebonne estuary was affected to some degree, amounting to approximately 250,000 acres of intertidal marsh. At a conference on the subject in 2001 (“Coastal Marsh Dieback in the Northern Gulf of Mexico: Extent, Causes, Consequences and Remedies,” www.brownmarsh.net/reports.htm), various hypotheses regarding its cause have been offered. Correlated events/measurements that have been linked to sudden die-offs include:

- drought-related events, such as high salinity, low water levels, decreased groundwater inputs, increased sulfide-other fermentation products, metals bioavailability (both less and more). For many of these factors, although *S. patens* has been shown to have susceptibility, other plants that should have been similarly affected did not show such signs, or were not as seriously impacted. In most cases, relevant measures were not made, or were not made in a timely fashion.
- biotic stressors, such as pathogens or herbivores. Pathogens (fungi) were found in Florida and Texas, but not in Louisiana, and while snails have been found eating dead vegetation, there is no evidence of snail or insect infestations causing the damage. Rather, the snails appear to opportunistically benefit from earlier impacts.
- chemical contamination could cause the pattern of die-offs, but are not known to have occurred.
- high water levels, as the impacts seem greatest in lower elevation areas – but plants with less flooding tolerance than *Spartina* have survived.
- sediment starvation, which could be a root cause of various of the effects above, but which does not adequately explain the spotty nature and rapidity of development of the phenomenon.
- clonal susceptibility, in that genetically identical plants could all fall prey to the same phenomenon, which helps to explain the patchy nature of the events.

Reports made at the conference implied that die-off patches could be successfully replanted.

Similar events may have occurred in Florida over the 1990 to 1995 time period. There was another episode in Georgia in the spring of 2002, which may also have been occurring in Charleston Harbor at the same time (Flory and Alber, 2002).

All of the processes and causes may be inextricably linked. For example, tests on the impact of concurrent salinity reductions and nitrogen concentration increases (as would result in certain marshes if Mississippi waters were redirected into marshes instead of being channeled into the Gulf of Mexico) on *S. patens* found increased growth rates. The experimenters concluded that the diversion of river water into salt marshes could thus stabilize imperiled vegetation, in and of itself (DeLaune et al., 2005) – although the additional sediment inputs that would also result from river water inputs would also be a positive factor in resuscitating the marshes.

### 4.2. Jamaica Bay

Jamaica Bay was once one of the largest expanses of salt marsh on the east coast of the US. It has suffered extensive losses of its marshlands since the early 1900s. Major shoreline developments that led to the loss of fringing wetlands included the initial construction of Floyd Bennet Field (1909) and several extensive landfills, including the Pennsylvania Avenue and Fountain Avenue landfills on the north shore, and the Edgemere Landfill on the Rockaway Peninsula, in the 1930s and 1940s. The construction and continued expansion of Idlewild (Kennedy) Airport post World War II also destroyed vast expanses of shoreline marsh. Incremental shoreline development, including diking and bulkheading, also resulted in general marsh loss. The construction of a roadway and elevated "subway" line across the center of the marsh, and dredging to provide structural fills, also eliminated large areas of marshes. By one account, although 4,000 acres of salt marsh remained in the center of the bay, construction of Idlewild Airport alone consumed some 4,500 acres along the eastern shoreline, and all peripheral wetlands were filled along the Brooklyn and northern part of the Queens shoreline (as much as 12,000 acres of marsh) (Swanson et al., 1992).

Over the past thirty years or so, however, the remaining island marsh system has also suffered a catastrophic collapse. This has been marked by a tendency for the islands to hollow out from the inside, leading to remnant, isolated fragments of vegetation, so that in some instances the entire island is lost. The total loss of the island marshes now exceeds 50 percent (comparing 1924 to 1999); for the period 1974 to 1999, the Bay as a whole has lost 34 percent of its wetlands, with some particular islands losing up to three-quarters of their vegetated area (Hartig et al., 2002).

NYSDEC historical map analysis found that between 1857 and 1924, intertidal marsh on the islands varied by up to ten acres a year, with no consistent trends towards loss or gain. Significant storms caused marsh losses, but marshes rebuilt between these events. For 50 years prior to 1974, there was a loss of 780 acres of marsh in the islands, due to dredging and filling operations; another 510 acres were lost for unspecified reasons. This meant there was a net loss of approximately 26 acres per year (but only 10 acres a year lost for reasons other than dredging and filling). Following the institution of strict regulations in 1974, losses of marsh continued unabated: another 524 acres were lost, a mean loss rate of 26 acres a year. The next five years (until 1999) were calamitous, with the rate of loss increasing by over 50 percent to 44 acres a year (220 acres of net loss). Inspection of aerial photographs showed that vegetated wetlands were being converted to unvegetated open waters. In many cases, channels and pools within islands expanded, as at Black Wall Marsh. In other areas, such as Duck Point Marsh, major portions of islands disappeared, while the remaining part of the island maintained its former creek-pond structure with little alteration. At Elders Point Marsh, most of the island was lost, but that marsh that remained has been drastically reworked with new channels and inlet areas appearing. In other areas, such as East High Marsh, losses seemed to be concentrated along one particular edge of the marsh (NYSDEC, undated).

Hartig et al. (undated) collected various measurements (such as sedimentation rates and vegetation composition and productivity) at three marshes where NYSDEC noted conspicuous marsh loss trends. This work confirmed that much of the losses occurred through pool enlargement and development in the interior of the marsh, and through growth of mudflats at the expense of low marsh along the marsh fringe. The growth of pools was coupled with decreases in the health and vigor of *S. alterniflora*, with unusually large populations of *Geukensia demissus* (ribbed mussels) found on dead *S. alterniflora* stalks. However, overall, the above-ground productivity of the *S. alterniflora* was near the upper end of regional values.

Early reports on the losses linked mussel populations to the phenomenon. Banks of ribbed mussels died in areas where losses occurred, but thrived on stable islands. It was not clear if there was one cause for both vegetation and mussel demise, if the loss of plants was killing the mussels, or if the death of mussels meant the shells helped smother the plants (Stewart, 2001). It was suggested that perhaps the banks of mussels were impeding drainage of the marshes, thus helping to drown the interior plants (Hartig et al., 2002). Some researchers found mussel banks helped to form berms on the marsh edge, largely through biodeposition of sediments that they filtered from the water column. Whether this served to keep the marsh above rising sealevel or helped lead to its demise was not clear (Franz and Friedman, 2004). Sea lettuce (*Ulva lactuca*) has been noted at high densities on mudflats in the Bay, and along the wrack line within marshes. It was suggested that high enough volumes of wrack could result in smothering of *Spartina* (Hartig et al., 2002; Frame et al., 2004). Another biological agent that can cause marsh loss is water fowl. Jamaica Bay supports a large population of ducks and geese; although it is not documented whether these populations have increased over the past several decades, herbivory on the island marshes might result in marsh die-offs (Hartig et al, 2002).

Zeppie (1977) found accretion rates to be 8 mm per year for the low marsh and 5 mm per year for the high marsh; Hartig et al. (undated) note that this relatively high rate was measured for a time period when there was much dredging and filling associated with airport construction, and sediments might also have been being introduced into the system from uncapped landfills, upland development, and relatively unrestricted combined sewer overflows; none of these forces now act on the system. Unpublished data collected by the Goodbred laboratory (Marine Science Research Center, Stony Brook University) found that the sedimentation rate at Big Egg Marsh was 5.2 mm/yr, and appears to have been increasing over the past several decades. Big Egg Marsh has been cited as one of the areas most impacted by marsh loss, and was selected for a restoration project, yet it clearly has no dearth of sediment supply. Similarly, the Goodbred laboratory measured sedimentation rates to be 4.4 mm/yr at East High Marsh, and 2.8 mm/yr at JoCo marsh. These rates were reported to be similar to rates recorded at apparently stable marshes elsewhere on Long Island (Branca, 2004).

Generally, marsh health in the Hudson-Raritan Estuary has been linked to hydrologic integrity (Montalto and Steenhuis, 2004). It is clear that the hydrology of the Jamaica Bay system has been altered, perhaps more than any other system in the New York City area that still possessed extensive salt marshes. Exactly how hydrologic alterations could cause the observed marsh losses is not especially transparent.

Jamaica Bay is a system with many stressors. Natural fresh water inputs are now restricted to submarine groundwater discharge. All fresh water streams were sewered, and now serve predominantly as combined sewer overflow output points or sewage treatment plant discharges. Approximately $10^9$ liters of sewage effluent are discharge to the Bay every day, along with 5 x

$10^8$ liters of stormwater run-off (Swanson et al., 1992). It is clear that the quality of sewage effluent and storm water is different from more natural drainage into the Bay pre-development. Although current submarine discharge of groundwater has not been determined other than through modeling (see Misut and Monti, 1998), there has been some reasoned speculation that the amounts now discharging are different from former amounts, the chemistry of the groundwater may very well be altered, and either one of such changes could affect the health of the island wetland systems (Beck and Rapaglia, 2005). It was found, for example, that only in the upper 30 cm of sediments is there evidence of *Salicornia*, suggesting that until recently (the past 100 years) has the Bay been salty enough to support those species (Poteet and Lieberman, undated).

Sediment dynamics have certainly been altered. The sewering of the fresh water streams has eliminated them as potential sources of mineral material (Swanson et al., 1992). Long shore drift westwards along the Rockaway Peninsula (indicated by the explosive growth of the spit from the early 1800s to approximately the 1930s) was changed with the hardening of the Rockaway inlet prior to World War II. Development along the Rockaway peninsula now prevents overwashes of sand into the Bay (Hartig et al., 2002). Tidal circulation in the Bay, with residence times increased due to dredging, is now flood-tide dominated. Mean tidal currents are greater on the ebb tide for flood-tide dominated systems (because the same volume of water must be transported over a shorter period of time). This suggests a greater potential for the export than import of sediment each tidal cycle (see, for example, Georgas, 2001). Nonetheless, the Goodbred research suggests the amount of sediment inputs is not inadequate compared to those found at other marshes in the region.

The deeper channels associated with dredging may directly lead to local erosion of marshes. The channels serve as sediment sinks, thus robbing nearby marshes of potential mineral inputs. In addition, boat wakes and higher wave heights permitted by the deeper water might increase shoreline erosion. Bulkheads and other shoreline armoring also increase wave refraction and reflection back onto the marsh edges (Hartig et al., 2002). However, most losses are initiated internally in these marshes, and the Goodbred data suggests that adequate volumes of sediment are accreting in most areas. Hartig et al. (undated) thought that one reason for the increase in marsh loss rates recently is that mineral sediment input losses reached a critical value, however, leading to increasing cascades of impacts related to hydrogen sulfide poisoning.

It is hypothesized that although *S. alterniflora* can oxygenate sediments, if sea level rise causes intertidal pools on the interior of an island to contain more water, the local marsh water table may rise, and increase the anoxia in the sediments. Decreases in the depth to the anoxic layer would increase exposure of marsh plants to hydrogen sulfide. Roots might die back, the peat structure collapse, and the marsh would suffer a die back (Hartig et al., undated). USGS research supports some of this theory, finding that sediments that experience flooding and drying cycles also cycle from reducing to oxidizing conditions over relatively short time scales, but those sediments that remain flooded are almost always reducing (Catallo, 1999).

Another process leading sulfide poisoning is associated with eutrophication of the Bay. The increase in nutrients in the Jamaica Bay system might lead to greater plant growth, and greater deposition rates of organic material. The organic to inorganic ratio in the sediments might have been altered due to decreases in sediment transport, relating to the changes wrought by dredging and the sewering of streams. Increases in organic content in the marsh sediments might lead to more consumption of organic matter by microbes. In waterlogged sediments, oxygen is rapidly consumed, and anaerobic processes lead to reduction of sulfates to sulfides. Where mineral sediments are present, this sulfide production can be buffered. When mineral sediments are lacking, *Spartina* (including the hardier *S. alterniflora*) may be unable to cope. Roots might die back, which could lead to collapse of the marsh substrate – a die back from the interior of the marsh island (Kolker, in press).

NYSDEC has recently sponsored a restoration project on Elders Point Marsh. This project involves spraying a slurry of sediment back onto the portions of the marsh that had lost elevation (the sediments would be gained from a navigational dredging project in Rockaway Inlet (Atlantic States Marine Fisheries Council, 2004). This project is based on the hypothesis that the marshes are drowning in place due to sediment starvation in the face of rising sea levels (Hartig et al., 2002). Early reports on the project were promising (Cahoon et al., 2004).

# 5. LONG ISLAND SALT MARSH OBSERVATIONS

## 5.1. NYSDEC

NYSDEC has traced salt marsh losses in specific marshes in each of the major estuaries associated with Long Island. The NYSDEC work does not ascribe specific causes to its observations, but rather has tended to use these trends as a powerful justification for an overall conservative management approach to the region's salt marshes. NYSDEC has not formally published this information, but has made it available at its website (www.dec.state.ny.us/website/dfwmr/marine/wetlands/index.html).

NYSDEC selected the sites for study based on qualitative observations of losses, and so this is a biased data set, selected to determine how much marsh loss has been occurring. Comparisons were made between the 1974 aerial infrared photography and contemporary aerial photography (some infrared, and some not). All photos were digitized and placed into a GIS.

None of the losses were due to dredging or filling. Various reasons for losses were proposed, including:

- Sediment budget disruption
- Ponding in interior sections
- Wind and wave erosion
- Ice shearing
- Ice rafting
- Sea level rise

**Long Island Sound**

There are an estimated 20,820 acres of tidal wetlands associated with Long Island Sound, and that 85 percent lie in Connecticut (LISS, 2003b). CA quantified the salt marsh area in Suffolk County along Long Island Sound at 2,575 acres, which is in rough agreement with the estimate.

It is estimated that 25 to 35 percent of the Sound's tidal wetlands were destroyed by dredging, filling and development (LISS, 1994). However, NYSDEC has quantified wetlands loss in certain of the embayments of Long Island Sound (Table 2).

Table 2. North Shore Wetlands Trends

| Harbor | Wetlands | 1974 Acreage | 1990s Acreage | Percent Change |
|---|---|---|---|---|
| Manhasset Bay | Kings Point | 2 | 0.48[1] | -79 |
| | Plum Point | 7.36 | 4.32[1] | -42.5 |
| | Manorhaven | 8.91 | 3.42[1] | -61 |
| | South Manhasset Bay | 5.34 | 1.28[1] | -26 |
| Nissequogue River | Cedar Island-East Shore | 61.14 | 54.18[2] | -11.4 |
| Stony Brook Harbor | Youngs Island | 70.58 | 29.96[3] | -57.5 |
| Flax Pond | | 73 | 58[3] | -20 |
| Mount Sinai Harbor | Center Marsh Island | 95.32 | 48.65[3] | -49.0 |

[1] 1994 survey
[2] 1992 survey
[3] 1999 survey

The findings show variable losses ranging from approximately 10 percent to nearly three-quarters of the vegetation, over a 20 year period. At South Manhasset Bay, it appears that the loss was due to drowning of the marsh, perhaps because it could not maintain itself against sea level rise. Erosion does not appear to be an important factor, as shoals and mudflats contiguous with the wetlands were not affected. At Manorhaven, the vegetated wetlands were converted to mudflats, without any clear change in other conditions within the marshlands.

**Peconic Bay**

Only two marshes were surveyed. Both showed significant losses.

Table 3. Peconic Bay Wetlands Trends

| Wetlands | 1974 Acreage | 2002 Acreage | Percent Change |
|---|---|---|---|
| Corey Creek | 28.16 | 20.41 | -27.5 |
| Cedar Beach Creek | 19.72 | 11.16 | -43.4 |

**South Shore Estuary**

There were major losses in several large salt marshes on the south shore.

Table 4. South Shore Wetlands Trends

| Embayment | Wetlands | 1974 Acreage | 1990s Acreage | Percent Change |
|---|---|---|---|---|
| South Oyster Bay | Gilgo Island | 108 | 70[1] | -36 |
| | Goose Island | 61 | 46[2] | -25 |
| Middle Bay | West Island | 527 | 404[1] | -23 |
| East Bay | East Bay Island | 606 | 498[2] | -18 |

[1] 1998 survey
[2] 2001 survey

Aerial photographs of East Bay Islands generally appear to show channel widening as the cause of the acreage losses, although there also appears to be more interior open water on several islands. The photographs along the south shore are not orthogonal, and so interpretation of changes is not straight forward. In the Middle Bay photographs, the major morphology of the channels appears to be similar, although perhaps the channels are wider. The islands now appear to be pockmarked with small ponds or pannes.

NYSDEC also looked at marsh loss in Shinnecock Bay. This mapping was made in anticipation of an update of the 1974 Tidal Wetlands Mapping, but that process has not proceeded well. The 1994 Shinnecock Bay study found shoreline marshes had expanded significantly (by 161 acres), mostly into uplands area (apparently spurred by sea level rise). Marsh islands did not fare well, however. In 1974, there were 13 islands with 30 acres of intertidal marsh. Only seven marshes, totaling 15 acres, remained in 1994 (Hartig et al., 2000).

### 5.2. NYSDOS

NYSDOS has also analyzed various areas of Long Island's salt marshes. The NYSDOS findings do not always agree with those of NYSDEC. NYSDOS has not generally publicized its findings. The following is based on interviews with Jeffrey Zappieri and review of a powerpoint presentation on the marsh measurement methodology being employed by NYSDOS for its analyses.

NYSDOS is the program manager for the SSER; much of its analyses have been conducted in this estuary. In some ways, its findings parallel those of NYSDEC. Comparisons of accurate charts from the 1800s to current aerial photography seem to show that as much as 400 to 500 feet of marsh have been lost in certain areas of the estuary over the past 125 years. Much of the significant perimeter losses appear to have occurred because of erosion. Channel slumping and boat wakes also have been contributors. Mouths of mosquito ditches have been found to have widened, causing significant perimeter losses in some marshes. In some instances, mosquito ditch mouths were now as wide as 50 feet.

Nonetheless, NYSDOS draws an different overall conclusion from its analyses than does NYSDEC. This is because NYSDOS has determined wetlands losses are not universal, nor is loss occurring a particular rate generally (which might have a link to sea level rise, for instance). NYSDOS recently focused its analysis on marsh islands in the SSER that occur in landscape positions that do not subject them to major sources of perimeter erosion. NYSDOS has identified the correlations to perimeter marsh losses as exposure to a northeast storm fetch and proximity to boat channels. Where these two factors are not significant, there was a small overall loss in marsh area between mappings from 1974 and 2001. There was significant variation throughout the estuary. Some marshes were observed to have no change in size, and some were found to have expanded.

The disagreement between the two agencies has not been openly presented, but rather is perceived through informal discussions with staff members. NYSDOS acknowledges its work is limited in scope. However, NYSDOS also believes that the NYSDEC analysis is also limited in scope, and is a biased sample. NYSDEC has explicitly stated at its website that its analysis focuses on areas where marsh loss was anecdotally reported to have occurred, and so does not dispute that its selection of sites is biased. NYSDEC simply believes that determining the seriousness of the potential problem requires focusing limited available resources on the areas where the problem is occurring. NYSDOS emphasizes that when NYSDEC analyses did not look for areas that were losing marsh, NYSDEC seemed to find similar results as NYSDOS did (in Shinnecock Bay, for example), where some marshes were found to have gained acreage although others lost acreage. NYSDEC suggests that the apparent correlation between marsh loss and proximity to New York City implies a cause that is likely to be anthropogenic, and most likely linked to some form of pollutant input. If marsh loss occurs because of some factor (or factors) linked to population density, then increasing development implies that problems will soon occur at other sites, as well. NYSDOS implies that there has been insufficient analysis to draw such broad conclusions.

NYSDOS is broadening its analysis of wetland loss to include a greater variety of marsh and landscape types. NYSDOS has developed a means of more efficiently comparing digital orthophotography, and is comparing photography from 1974 to 2001 aerial photography. Spectral analysis allows for surface water coverage within marsh interiors to be compared in a more automated way that may allow for greater spatial coverages. This will allow various landscape features to be compared in terms of impacts on marsh fragmentation much more efficiently. Initial results seem to show decreasing levels of water within most marshes of the SSER.

### 5.3. The Nature Conservancy

TNC has taken an active role in discussions regarding marsh health and trends during the development of the Long-Term Plan. Susan Antenen, served as the TNC representative to most Long-Term Plan committees, and provided the following perspective.

As with most local environmental organizations, the TNC view is that wetland loss is still occurring, and that the future of marshes is bleak. Historically, drastic wetland loss had occurred from filling and draining. This was reduced with the passage of the New York State wetland regulations in the mid-1970s. Presently, wetlands losses occur from various actions that lead to on-going marsh degradation.

Degradation along the perimeter of marshes is the direct result of human alterations of adjacent areas. Shoreline hardening and development of adjacent areas prevent or reduce a marsh's ability to migrate in the face of sea level rise. Dredging channels or canals at too steep a slope (greater than three on one) causes slumping of the perimeter of nearby marshes. Boat wakes and harvesting of ribbed mussels (which serve to hold banks together) also lead to perimeter losses.

Degradation within the marsh similarly has several potential causes. Marshes may drown, as a result of changes in sedimentation or increases in nutrient loadings. This is because large amounts of nutrients in marshes increase decomposition rates, which raises the risk of flooding. Even in healthy marshes, interior mudflats are known to expand. If they expand at too great a rate, overall degradation of the marsh may occur. Furthermore, the buildup of sulfide in a marsh impedes vegetation growth or colonization.

Degradation of marshes is also influenced by upland conditions. Conveyance of runoff into a marsh, additions of nutrients due to septic system and fertilizer use at adjacent (within basin) properties, and general intensification of land use all have or can lead to negative effects on existing marsh quality.

### 5.4. Other Studies

USFWS made periodic local updates of the Circular 39 coastal wetlands quantification. The local component was based on a set of 43 wetlands complexes (a complex might extend over several drainage basins) comprising the significant, important water fowl habitats in Kings, Queens, Suffolk, and Nassau Counties, and the Bronx, as determined by a New York State Conservation Department biologist, Donald Foley from 1949 to 1951. The quantification of areas was expanded somewhat with growing realization that coastal wetlands had ecological values for other than water fowl, but still had a major focus on bird habitat (38,000 acres of "high to moderate value" wetlands and 5,000 acres of "low to negligible value" wetlands in 1964, for example). Measurements in 1959 and 1964 were made via overflights, and calculated using planimeters, with ground surveys conducted in the western portion of the area where airplane traffic was too heavy to allow for many overflights. Six wetlands complexes were added to the Long Island lists between 1954 and 1964, making the loss of coastal wetlands even greater than is quantified in Table 5. These quantifications do not include many smaller wetlands, and so are not complete (USFWS, 1965).

Table 5. Suffolk County and Downstate Significant Water Fowl Coastal Wetlands Trends

| Year | Suffolk County Acres | Total Nassau, Suffolk, Kings, Queens, the Bronx Acres |
|---|---|---|
| 1954[1] | 20,590 | 43,215 |
| 1959[1] | 19,208 | 37,504 |
| 1964[1] | 17,008 | 30,580 |
| 1968[2] | 12,930 | |
| 1971[2,3] | 10,834 | |
| 11 year difference (1954-1964) [1,4] | -3,582 | -12,635 |
| 18 year difference (1954-1971)[5] | -9,756 | |

[1] from USFWS Circular 39 and updates
[2] NYSOPS, 1972, as reported in Kavanagh, 1980
[3] Kavanagh, 1980, notes this is les than O'Connor and Terry, 1972, who reported 12,725 acres of tidal wetlands in Suffolk County
[4] Areas surveyed on not comparable, as six complexes were added 1954-1964
[5] Measurements may not have used similar methodologies

USFWS attributed the acreage losses through 1964 to the following causes:

- housing (34 percent)
- miscellaneous fill (end use not known) (20 percent)
- recreational uses (17 percent)

- industrial uses (13 percent)
- marinas, docks, channels (six percent)
- airports (four percent)
- bridges, roads, parking (three percent)

In 1964, only 12 percent of the remaining wetlands in the Long Island region were deemed as being safe from destruction, although this forecast was aid to require "considerable optimism." This forecast is justified by the pace of consumption, which saw Suffolk County's share of the area's undeveloped wetlands rise from 47.6 percent to 55.6 percent in ten years. USFWS also notes the survey did not account for changes in marsh quality, as might occur due to dredge spoil fill resulting conversion from a *Spartina*-dominated marsh to a *Phragmites* monoculture.

It is noted that, especially in New England, marsh systems suffered from tidal restrictions as road maintenance responsibilities were transferred from individual property owners to local governments, and as improvements to the coastal road systems were implemented. Culverts and were often undersized or poorly placed to meet the environmental needs of salt marshes. This has caused transformation of formerly salt systems to fresh or brackish systems, and meant these systems did not perform ecological functions as well as when they had better connections to the estuaries (Boumans et al., 2002).

High marshes along the Connecticut coast were found to be accreting at a rates ranging from 2.0 to 6.6 mm/yr from 1963 to 1973. The higher rates were found at sites with greater tidal ranges, and so was related to the amount of "net flooding" experienced by the marsh (Harrison and Bloom, 1977). As is now understood, those sedimentation rates are on the same order as sea level rise rates.

The relationship of inorganic to organic matter in sediments accreting in the high marsh of a river valley salt marsh near New Haven appeared to be controlled by erosion processes occurring within the watershed. The amount of clay in the cores increased with records of increasing upland erosion. This study also emphasized that it is below ground growth that results in peat accumulation, and that nearly all above ground plant detritus appears to be exported from the high marsh. The marsh was found to be maintaining itself against long-term sea level rise trends, but to not be subject to the (sometimes wide) interannual fluctuations that mark the historical record to sea level measurements (McCaffrey and Thomson, 1980).

Warren and Niering (1993) found that although vegetation changes were occurring in the Wequetequock-Pawcatuck marsh (compared to an initial characterization by Miller and Egler [1950] from the 1940s), no loss in vegetated marsh area had occurred yet. They traced the changes to increasing sea level rise rates, and so forecast losses in northeast US marshes due to incapacity to manage changing sea levels. It was noted that other environmental factors could be affecting the vegetation on the marsh, however.

NYSDEC made an initial effort to update the 1974 wetlands mapping by conducting pilot work in Shinnecock and Moriches Bays from 1996 to 1998. There, NYSDEC found that there had been a net increase in vegetated wetlands amounting to 125 acres, because of landward migration of tidal wetlands in excess of any seaward losses. Approximately 100 acres of the gains were realized in Moriches Bay (NYSDEC, undated).

An analysis of the NWI by Tiner et al. (1998) (USFWS) was made for Suffolk County as part of PEP. The study compared the 1974 NWI based on black and white aerial photography interpretation to a 1994 update based on color infrared aerial photography. The technique was intended to identify all changes in area with accuracy between 0.01 and 0.1 acres. Although the study was not finalized, and therefore its interpretations may not be entirely complete, it is possible to read the presented data as suggesting that estuarine wetlands lost 115.46 acres over the twenty years, (including approximately one acre of salt shrub lands). The remaining inventory of estuarine wetlands was quantified as 5,678.58 acres. This suggests that the loss of tidal wetlands over the 29 years was 2.0 percent (0.1 percent, or 5.6 acres, per year).

GIS maps for Suffolk County of the NASA Coastal Marsh Project (see above) were accessed (http://www.geog.umd.edu/wetlands/data.htm). These are based on comparisons of the GIS NWI classifications to spectral analyses of the amount of water within defined salt marsh classifications (Kearney et al., 1999). CA similarly interpreted the NWI classifications to determine the acreage of salt marshes in Suffolk County. The interpretations were not in exact agreement, as the sum of the Coastal Marsh Project coverages was 15,400 acres compared to the CA sum of 16,839 acres (Cashin Associates, in prep) (Figure 1).

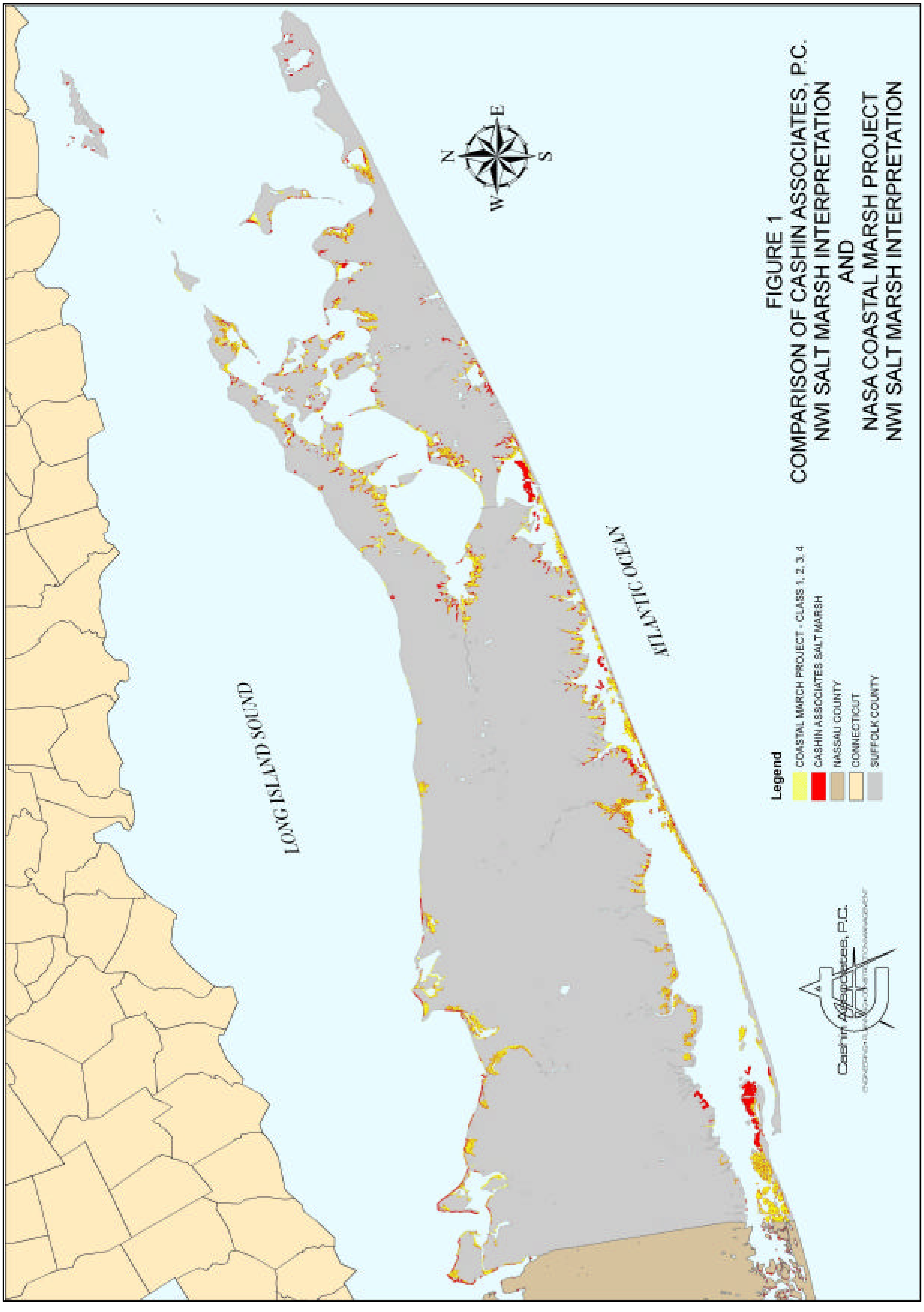
FIGURE 1
COMPARISON OF CASHIN ASSOCIATES, P.C.
NWI SALT MARSH INTERPRETATION
AND
NASA COASTAL MARSH PROJECT
NWI SALT MARSH INTERPRETATION
LONG ISLAND SOUND
ATLANTIC OCEAN
N
E
S
W
Legend
COASTAL MARCH PROJECT - CLASS 1, 2, 3, 4
CASHIN ASSOCIATES SALT MARSH
NASSAU COUNTY
CONNECTICUT
SUFFOLK COUNTY
Cashin Associates, P.C.

The Coastal Marsh Project classifications of the County's salt marshes, as computed by CA from the GIS coverages, are listed in Table 6.

Table 6. Coastal Marsh Project Classifications of Suffolk County NWI Salt Marshes

| Class | Percent Surface Water | Acres | Percent of County Salt Marshes |
|---|---|---|---|
| 1 | 0-20 | 8,847 | 57.4 |
| 2 | 21-30 | 3,323 | 21.6 |
| 3 | 31-50 | 2,040 | 13.2 |
| 4 | 50+ | 1,190 | 7.7 |

As discussed above, there are some acknowledged potential methodological problems in this analysis. Some relate to difficulties ensuring that proper notice is taken of tidal conditions. Additionally, the methodology was developed in a microtidal setting, and requires adjustments when translated to more robust tidal regimes. These problems may be reflected in the classifications of Suffolk County's wetlands. For example, the largest contiguous blocks of Class 4 wetlands are found along the western shoreline of the Carmans River (an area specifically identified by the NYSDEC Natural Heritage Unit as relatively high quality high marsh in 2000 [MacDonald and Edinger, 2000]), the barrier island area of Shinnecock Bay (but not the marsh islands, see the NYSDEC analysis above), scattered interior marsh areas along the north shore of the Peconic Bay, and many of the marshes in the mid-North Shore (most of Mount Sinai Harbor, most of Flax Pond, the middle of Stony Brook Harbor, and the middle part of the Nissequogue River). Much of the remainder of the North Shore salt marshes are classifed as Class 3, as are large sections of the northern marshes of the Peconic Bay and the barrier island systems in Moriches and Shinnecock Bay. Much of the south shore island systems are classified as Class 2 (see Figures 2 through 4).

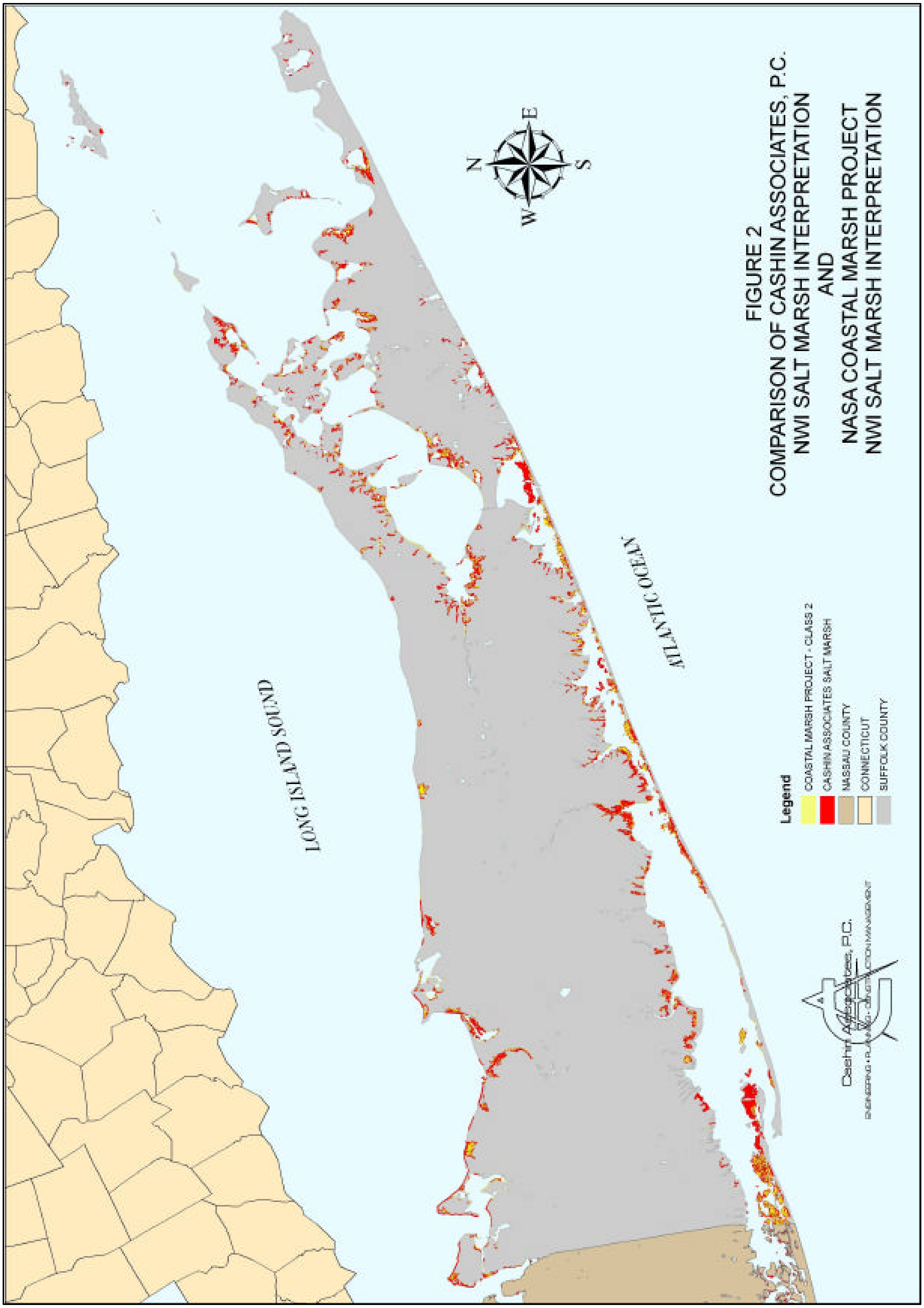
FIGURE 2
COMPARISON OF CASHIN ASSOCIATES, P.C.
NWI SALT MARSH INTERPRETATION
AND
NASA COASTAL MARSH PROJECT
NWI SALT MARSH INTERPRETATION
N
E
S
W
LONG ISLAND SOUND
ATLANTIC OCEAN
Legend
COASTAL MARSH PROJECT - CLASS 2
CASHIN ASSOCIATES SALT MARSH
NASSAU COUNTY
CONNECTICUT
SUFFOLK COUNTY
Cashin Associates, P.C.

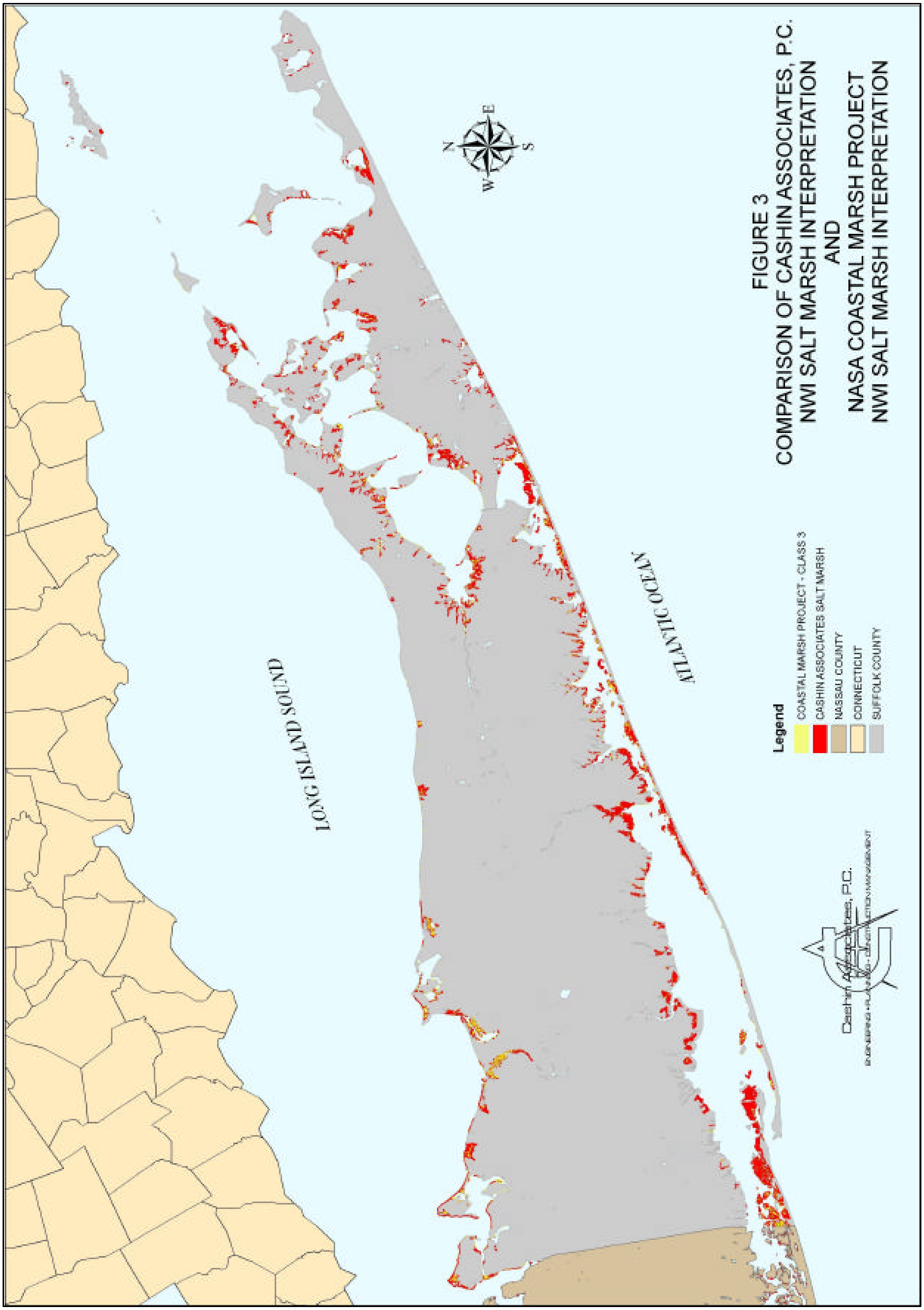
FIGURE 3
COMPARISON OF CASHIN ASSOCIATES, P.C.
NWI SALT MARSH INTERPRETATION
AND
NASA COASTAL MARSH PROJECT
NWI SALT MARSH INTERPRETATION
Legend
COASTAL MARSH PROJECT - CLASS 3
CASHIN ASSOCIATES SALT MARSH
NASSAU COUNTY
CONNECTICUT
SUFFOLK COUNTY
LONG ISLAND SOUND
ATLANTIC OCEAN
N
E
S
W
Cashin Associates, P.C.

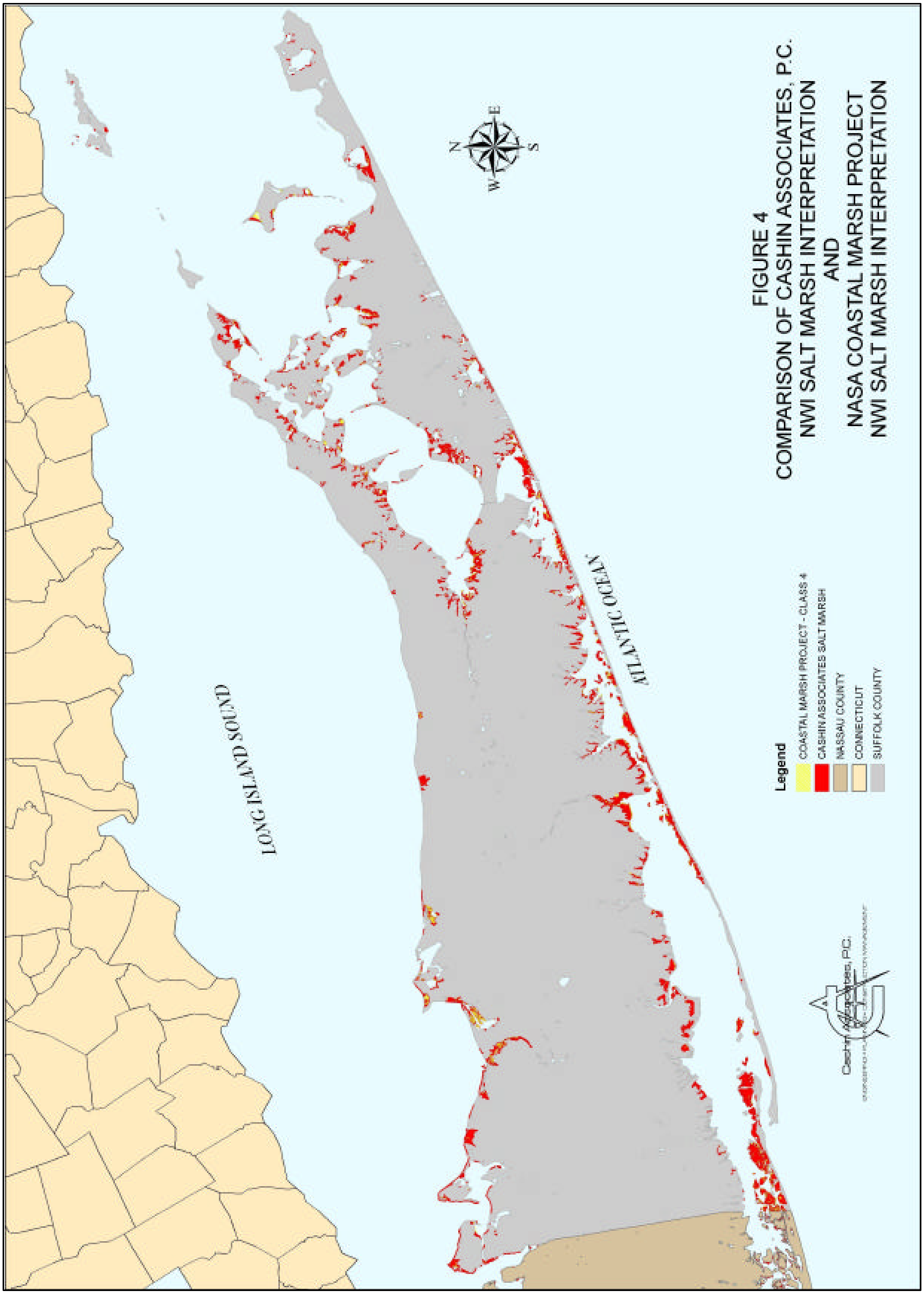
FIGURE 4
COMPARISON OF CASHIN ASSOCIATES, P.C.
NWI SALT MARSH INTERPRETATION
AND
NASA COASTAL MARSH PROJECT
NWI SALT MARSH INTERPRETATION
N
E
S
W
LONG ISLAND SOUND
ATLANTIC OCEAN
Legend
COASTAL MARSH PROJECT - CLASS 4
CASHIN ASSOCIATES SALT MARSH
NASSAU COUNTY
CONNECTICUT
SUFFOLK COUNTY
Cashin Associates, P.C.

In Stony Brook Harbor, a study of a potentially tidally-restricted marsh found that it, and other marshes around the harbor, generally accreted sediment at a sufficient pace to keep up with sea level rise. Where there were no barriers to doing so, the marsh also transgressed landward with increasing sea levels, thus increasing overall marsh acreage (Cademartori, 2000). An overall study of Stony Brook Harbor, however, found substantial marsh loss during the 20$^{th}$ century. Half of the loss was directly attributed to channel dredging projects. Measured accretion rates in the latter half of the century were elevated, which was attributed to periodic sediment inputs from dredging projects, and potentially related to storms. Thus, it seemed likely that although on short time scales (decadal) sea level rise sometimes exceeded accretion rates, by and large sediment inputs appeared great enough to maintain marshes against rising sea levels. The study suggested that dredging indirectly contributed to marsh loss by changing harbor hydrodynamics through the alterations in bathymetry and potentially supporting increased boat traffic and associated wakes (which lead to perimeter erosion) (Cademartori and Swanson, 2001).

LISS held a workshop in 2003 regarding the potential for "Jamaica Bay disease" to propagate in the Sound watershed. Although most observations of wetlands losses similar to those in Jamaica Bay are anecdotal, researchers agreed that significant effects from human alterations to the environment might be impacting the Sound wetlands. Stressors of marsh systems were determined to be nitrates, sulfides, salinity, pollutants (herbicides, lime, creosote, and MTBE [methyl tert butyl ether), diseases, boat wakes, and changes in shoreline morphology (bulkheads), exacerbated by local effects such as storm water outfalls. Forcing functions that may cause marsh losses include relative sea level rise, thermal and climate changes, increased hydrological variability, dredging, storms, and the presence of people in the coastal zone. The poor definition of marsh loss was also noted, as cover type conversions and fragmentation of the marsh may also be important factors to consider, besides mere loss of vegetated areas (LISS, undated).

Of extreme interest was the general finding that nearly all river mouth marsh systems in western Connecticut have suffered from extensive marsh loss, apparently due to marsh drowning where vegetated wetland is converted to mudflats. Lists of chemical, biological, and physical stressors to the salt marshes were compiled. The importance of baseline monitoring in order to detect change was stressed (LISS, undated).

A marsh on the north shore of the Sound (Rye New York) was studied over 17 years (1985 to 2002). Eight permanent plots were sampled in 1985, and reassessed in 2002. Overall vegetation and peat losses were averaged, and on an annualized basis amounted to 2.9 percent and 3.6 percent per plot, respectively. The low marsh border also retreated shoreward at a rate of 0.12 m/year (Endrenny, 2004).

Ron Rozsa (Connecticut Department of Environmental Protection) posted some anecdotal findings of sudden marsh die back in Connecticut inner harbor low marshes and across both low and high marshes on Cape Cod in 2005 (sites that he and Scott Warren, Connecticut College, visit each year with ecology classes). He suggested that at the Connecticut sites there might be a relation between drought and the low marsh impacts, as sediment elevation tables set at depth suggested the marshes were floating on groundwater. With the drought, the marshes lost relative height and the plants were drowned (Georgia Coastal Research Council website: alpha.marsci.uga.edu/coastalcouncil/capecod_dieback.htm).

An estimation of recent salt marsh loss in Connecticut was made, based on a GIS interpretation of aerial photography. Area estimates of annual loss rates were made, and found to vary along the coast (although the data were presented in terms of total area rather than percentage loss, or in terms of some sort of indexing factor). The study implied that loss along the shoreline was the greatest threat to the marshes (Valauskas and Zajac, 2005).

**REFERENCES**

Adam, P. 2002. Saltmarshes in a time of change. *Environmental Conservation* 29(1):39-61.

Adamowicz, SC, and CT Roman. 2002. *Initial Ecosystem Response of Salt Marshes to Ditch Plugging and Pool Creation: Experiments at Rachel Carson National Wildlife Refuge (Maine).* US Geological Survey, Narragansett, RI. 102 pp.

Adler, J.H. 1999. Swamp rules: The end of federal wetland regulations? *Regulation* 22 (Spring).

Allen, JRL. Morphodynamics of Holocene salt marshes: a review sketch from Atlantic and southern North Sea coasts of Europe. *Quarternary Science Reviews* 19:1155-1231.

Anisfield, SC, MJ Tobin, and G. Benoit. 1999. Sedimentation rates in flow-restricted and restored salt marshes in Long Island Sound. *Estuaries* 22(2A):231-244.

Armentano, TV, and GM Woodwell. 1975. Sedimentantion rates in a Long Island marsh determined by $^{210}$Pb dating. *Limnology and Oceanography* 20(3):452-456.

Atlantic States Marine Fisheries Commission. 2004. Fish habitat in urban environments: NY-NJ Harbor. *Habitat Hotline* 11(1):1-5.

Barras, J., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota, and J. Suhayda. 2004. *Historical and Projected Coastal Louisiana Land Changes: 1978-2050*. US Geological Survey Open-File Report OFR 03-334.

Beck, A., and J. Rapaglia. 2005. Multiple geochemical tracers of submarine discharge into Jamaica Bay, NY. Abstract, *Twelfth Conference of the Geology of Long Island and Metropolitan New York*, Long Island Geologists, Stony Brook, NY. April 16. pbisotopes.ess.sunysb.edu/lig/Conferences/abstracts05/abstracts/Beck.htm

Bertness, MD. 1988. Peat accumulation and the success of marsh plants. *Ecology* 69(3):703-713.

Boumans, RMJ, DM Burdick, and M. Dionne. 2002. Modeling habitat change in salt marshes after tidal restoration. *Restoration Ecology* 10(3):543-555.

Branca, BA. 2004. Are marshes losing ground? *Coastlines* 33(2):7.

Bricker-Urso, S., SW Nixon, JK Cochran, DJ Hirschberg, and C. Hunt. 1989. Accretion rates and sediment accumulation in Rhode Island salt marshes. *Estuaries* 12(4):300-317.

Cabanes, C., A. Cazenave, and C. Le Provost. 2001. Sea level rise during past 40 years determined from satellite and in situ observations. *Science* 294:840-842.

Cademartori, EA. 2000. *An Assessment of Salt Marsh Vegetation Changes in Southern Stony Brook Harbor: Implications for Future Management*. Masters Thesis, State University of New York at Stony Brook. 123 pp.

Cademartori, GM, and RL Swanson. 2001. Temporal changes in the salt marsh system of a north shore Long Island pocket bay. Expanded abstract, *Eighth Conference of the Geology of Long Island and Metropolitan New York*, Long Island Geologists, Stony Brook, NY. April 21. pbisotopes.ess.sunysb.edu/lig/Conferences/abstracts-01/cademartori/cademartori-abst.htm

Cahoon, DR, JC Lynch, C. Roman, and G. Frame. 2004. An evaluation of salt marsh accretion and elevation dynamics at Jamaica Bay, Gateway National Recreation Area, using the surface elevation table method. p. 13. In: New York Sea Grant (ed.). *Jamaica Bay's Disappearing Marshes*. Conference Proceedings from March 3, 2004. 53 pp.

Cahoon, DR, and DJ Reed. 1995. Relationships among marsh surface topography, hydroperiod, and soil accretion in a deteriorating Louisiana salt marsh. *Journal of Coastal Research* 11:357-369.

Cashin Associates. In prep. *Suffolk County Vector Control and Wetlands Management Long-Term Plan Draft Generic Environmental Impact Statement*. Suffolk County, Hauppauge, NY.

Cashin Associates. 2005. *Salt Marsh Health*. Book 9 Part 2 of the Literature Search. Suffolk County Vector Control and Long-Term Plan and Generic Environmental Impact Statement. Suffolk County Department of Health Services, Yaphank, NY. 53 pp. www.suffolkmosquitocontrolplan.org.

Catallo, WJ. 1999. *Hourly and Daily Variation of Sediment Redox Potential in Tidal Wetland Sediments*. US Geological Survey Biological Science Report USGS/BRD/BSR 1999-0001, Lafayette, LA.10 pp.

Chapman, VJ. 1974 *Salt Marshes and Salt Deserts of the World*. 2nd Ed. Strauss & Cramer GMBH, Leutershausen, Germany. 392 pp. + 101 pp. added for 2nd Ed.

Connecticut Association of Conservation & Inlands Wetlands Commissions, Inc. 2006. *The History of Conservation Commissions in Connecticut*. www.caciwc.org/library/hisotory_cc_27June03.pdf.

Craig, NJ, RE Turner, and JW Day, Jr. 1979. Land loss in coastal Louisiana (U.S.A.). *Environmental Management* 3:133-144.

Dahl, TE. 1990. *Wetlands Losses in the United States 1780's to 1980's*. US Department of the Interior, Fish and Wildlife Service, Washington, D.C. 13pp.

Dahl, TE, and CE Johnson. 1991. *Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States, mid-1970s to mid-1980s*. US Fish and Wildlife Service, Washington, DC. 28 pp.

Day, JW. 2005. Making a rebuilt New Orleans sustainable. *Science* 310:1276.

Day, JW, GP Shaffer, LD Britsch, DJ Reed, SR Hawes, and DR Cahoon. 2000. Pattern and process of land loss in the Mississippi Delta: a spatial and temporal analysis of wetland habitat change. *Estuaries* 23:425-438.

Day, JW, Jr., GP Shaffer, DJ Reed, DR Cahhon, LD Britsch, and SR Hawes. 2001. Patterns and processes of wetland loss in coastal Louisiana are complex: a reply to Turner 2001. Estimating the indirect effects of hydrologic change on wetland loss: if the earth is curved, then how would we know it? *Estuaries* 24(4):647-651.

DeLaune, RD, WH Patrick, Jr., and RJ Buresh. 1978. Sedimentation rates determined by $^{137}Cs$ dating in a rapidly accreting salt marsh. *Nature* 275:532-533.

DeLaune, RD, JA Nyman, and WH Patrick, Jr. 1994. Peat collapse, ponding, and wetland loss in a rapidly submerging coastal marsh. *Journal of Coastal Research* 10:1021-1030.

DeLaune, RD, SR Pezeshki, and A. Jugsujinda. 2005. Impact of Mississippi River freshwater reintroduction on *Spartina patens* marshes: responses to nutrient input and lowering of salinity. *Wetlands* 25(1):155-161.

Donnelly, JP, and MD Bertness. 2001. Raid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. *Proceedings of the National Academy of Science* 98:14218-14223.

Donnelly, JP, SS Bryant, J. Butler, J. Dowling, L. Fan, N. Hausman, P. Newby, B. Shuman, J. Stern, K. Westover, and T. Webb III. 2001. 700 yr sedimentary record of intense hurricane landfalls in southern New England. *GSA Bulletin* 113(6):714-727.

Downs, LL, RJ Nicholls, SP Leatherman, and J. Hautzenroder. 1994. Historic evolution of a marsh island: Bloodsworth Island, Maryland. *Journal of Coastal Research* 10(4):1031-1044.

Dreyer, GD, and WA Niering. 1995. *Tidal Marshes of Long Island Sound: Ecology, History, and Restoration*. The Connecticut College Arboretum, No. 34.

Duffy, JE, KS Macdonald, JM Rhode, and JD Parker. 2001. Grazer diversity, functional redundancy, and productivity in seagrass beds: an experimental test. *Ecology* 82(9):2417-2434.

Endreny, P. 2004. Low marsh vegetation changes in a western Long Island Sound salt marsh between 1985 and 2002. Abstract, *25th Anniversary Conference, International Society of Wetland Scientists*, Seattle WA. July 18-23.

Erwin, RM, GM Sanders, and DJ Prosser. 2004. Changes in lagoonal marsh morphology at selected northeast Atlantic coast sites of significance to migratory waterbirds. *Wetlands* 24:891-903.

Fire Island National Seashore. 1977. *General Management Plan*. National Park Service, Washington, DC. 147 pp.

Flory, J., and M. Alber. 2002. *Dead Marsh Information*. Georgia Coastal Research Council, November. Unpaged. www.marsci.uga.edu/coastalcouncil/PDFs/marshsummarygcrc.pdf

Ford, MA, and JB Grace. 1998. Effects of vertebrate herbivores on soil processes, plant biomass, litter accumulation and soil elevation changes in a coastal marsh. *Journal of Ecology* 86(6):974-982.

Frame, GW, MD Byer, MP Shreibman, WS Panagakos, MK Waaijer, and MK Mellander. 2004. Effects of wrack (straw and sea lettuce mats) on Smooth Cordgrass *Spartina alterniflora* survival and recovery in Jamaica Bay Wildlife Refuge, New York: a progress report. p. 24. In: New York Sea Grant (ed.). *Jamaica Bay's Disappearing Marshes*. Conference Proceedings from March 3, 2004. 53 pp.

Franz, DR, and I Friedman. 2004. Erosion and pool formation in a Jamaica Bay fringing marsh – the mussel berm hypothesis. p. 23. In: New York Sea Grant (ed.). *Jamaica Bay's Disappearing Marshes*. Conference Proceedings from March 3, 2004. 53 pp.

Frayer, WE, TJ Monahan, DC Bowden, and FA Graybill. 1983. *Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States, 1950's to 1970's*. Colorado State University, Fort Collins, CO. 32 pp..

Frey, RW, and PB Basan. 1985. Coastal salt marshes. pp. 225-301. In: Davis, RA (ed.). *Coastal Sedimentary Environments.* $2^{nd}$ Ed. Springer-Verlag, New York, NY. 716 pp.

Georgas, N. 2001. *Tidal Hydrodynamics and Bedload Transport in a Shallow, Vegetated Harbor (Stony Brook Harbor, Long Island, New York): a Modeling Approach with Management Implications*. Masters Thesis, State University of New York at Stony Brook. 166 pp.

Gornitz, V., S. Hale, K. Larsen, N. Levine, C. Rosenzweig, and L. Sacks. *Bracing for Climate Change in the Constitution State: What Connecticut Could Face*. Environmental Defense, www.environmentaldefense.org. 42 pp.

Gosselink, JG, and RH Baumann. 1980. Wetland inventories: wetland loss along the United States Coast. *Zoological Geomorphology NF Supplement* 34:173-187.

Gosselink, JG. 2001. Comments on "Wetland loss in the northern Gulf of Mexico: multiple working hypotheses. By RE Turner. 1997. *Estuaries* 20:1-13. *Estuaries* 24(4):636-639.

Harrison, EZ, and AL Bloom. 1977. Sedimentation rates on tidal marshes in Connecticut. *Journal of Sedimentary Petrology* 47(4):1484-1490.

Hartig, EK, V. Gornitz, A. Kolker, F. Muschacke. and D. Fallon. 2002. Anthropogenic and climate-change impacts on salt marshes of Jamaica Bay, New York City. *Wetlands* 22(1):71-89.

Hartig, EK, A. Kolker, and V. Gornitz. undated. Investigations into recent salt marsh losses in Jamaica Bay, New York. pp. 21-40. In: *Integrated Reconnaissance of the Physical and Biogeochemical Characteristics of Jamaica Bay*. Lamont-Doherty Earth Observatory, Columbia University. 121 pp.

Hartig, EK, F. Muschacke, D. Fallon, and A. Kolker. 2000. *A Wetlands Climate Change Impact Assessment for the Metropolitan East Coast Region*. Draft for review. Center for International Earth Science Information Network, Columbia University.

Hughes, RG, and OAL Paramour. 2004. On the loss of salt marshes in south-east England and methods for their restoration. *Journal of Applied Ecology* 41:440-448.

James-Pirri, M-J, RM Erwin, and DJ Prosser. 2003. *Data Report for 2001 & 2002, US Fish and Wildlife Service (Region V5) Salt Marsh Study*. US Geological Survey, University of Rhode Island, and US Fish and Wildlife Service. 150 pp.

James-Pirri, M-J, CT Roman, and RM Erwin. 2001. *Field Methods Manual: US Fish and Wildlife Service (Region 5) Salt Marsh Study*. US Geological Survey , Narragansett, RI. 62 pp.

Jordan, TE, and I. Valiela. 1983. Sedimentation and resuspension in a New England salt marsh. *Hydrobiology* 98:179-184.

Karl, TR, and KE Trenberth. 2003. Modern global climate change. *Science* 302:1719-1723.

Kastlert, JA, and PL Wiberg. 1996. Sedimentation and boundary changes of Virginia salt marshes. *Estuarine, Coastal and Shelf Science* 42:683-700.

Kavanagh, WK. 1980. *Vanishing Tidelands: Land Use and the Law in Suffolk County, NY 1650-1979*. New York Sea Grant (NYSG-RS-80-28). 265 pp.

Kearney, M., W. Lawrence, and J. Townshend (principal investigators). 1999. *Coastal Marsh Project*. Mission to Planet Earth at NASA and University of Maryland, sponsors. www.geog.umd.edu/wetlands/

Kennet, JP. 1982. *Marine Geology*. Prentice-Hall, Englewood Cliffs, NJ. 813 pp.

Kennish, MJ. 2001. Coastal salt marsh systems in the U.S.: a review of anthropogenic impacts. *Journal of Coastal Research* 17(3):731-748.\

Kolker, A. In press. *The Impacts of Climate Variability and Anthropogenic Activities on Salt Marsh Accretion and Loss*. PhD Thesis. Stony Brook University.

Kolker, A., SL Goodbred, JK Cochran, A. Beck, and T. Kroboth. 2004. Deciphering the role of climate and sea-level changes on observed decadal-scale variability in salt-marsh sedimentation. *American Geophysical Union Fall Meeting Abstracts*, San Francisco, CA.

Kolker, A., SL Goodbred, JK Cochran, and R. Aller. 2005. Marsh loss on Long Island: does biogeochemistry trump climate change? Expanded abstract. Eleventh Annual Conference on the Geology of Long Island and Metropolitan New York. Stony Brook, NY. pbisotopes.ess.sunysb.edu/lig/Conferences/abstracts05/abstracts/kolker.htm.

Leonard, LA, PA Wren, and RL Beavers. 2002. Flow dynamics and sedimentation in *Spartina alterniflora* and *Phragmites australis* marshes of the Chesapeake Bay. *Wetlands* 22(2):415-424.

LISS. Undated. *Long Island Sound Tidal Wetland Loss Workshop, June 24 & 25, 2003, Stony Brook, NY.* www.longislandsoundstudy.net/habitat/habitat_rest_wkshp_rpt03.pdf. 15 pp.

LISS. 2003a. *Long Island Sound Habitat Restoration Initiative. Section 1. Tidal Wetlands*. US Environmental Protection Agency, Long Island Sound Office. Stamford, CT. 25pp.

LISS. 2003b. *Technical Support for Coastal Habitat Restoration*. www.longislandsoundstudy .net/habitat.

LISS. 2000. *Long Island Sound Study Comprehensive Conservation and Management Plan Tracking Report: Long Island Sound Study Comprehensive Conservation and Management Plan Actions*. http://www.epa.gov/region01/eco/lis/reports.html

LISS. 1999. *The Long Island Sound Study 1998 Tracking Report January-December 1998: The Comprehensive Conservation and Management Plan May 1999*. http://www.epa.gov /region01/eco/lis/98track/98tracking.pdf

LISS. 1998. *The Long Island Sound Coastal Conservation and Management Plan Implementation 1997 Tracking Report*. http://www.epa.gov/region01/eco/lis/archives /1997track.pdf

LISS. 1994. *The Comprehensive Conservation and Management Plan*. US Environmental Protection Agency, Long Island Sound Office. Stamford, CT. 168 pp.

Lent, RA, T. Hruby, DP Cowan, and TS Litwin. 1990. *Open Marsh Water Management on Great South Bay, Islip, New York*. Seatuck Foundation, Islip, NY. 102 pp.

Lord, CJI, and Church, TM. 1983. The geochemistry of salt marshes: sedimentary ion diffusion, sulfate reduction, and pyritization. *Geochimica et Cosmochimica Acta* 47:1381-1391.

MacDonald, D., and G. Edinger. 2000. *Identification of Reference Wetlands on Long Island, New York*. New York Natural Heritage Program, Latham, NY. 106 pp. + appendices.

McCaffrey, RJ, and J. Thomson. 1980. A record of the accumulation of sediment and trace metals in a Connecticut salt marsh. pp. 165-236. In: Saltzman, B. (ed.). *Estuarine Physics and Chemistry: Studies in Long Island Sound*. Advances in Geophysics, V. 22. Academic Press, New York, NY. 424 pp.

Mendelssohn, IS, and KL McKee. 1988. *Spartina alterniflora* dieback in Louisiana: time-course investigation of soil water-logging effects. *Journal of Ecology* 76:509-521.

Meyerson, LA, KA Vogt, and RH Chalmers. 2000. Linking the success of *Phragmites* to the alteration of ecosystem nutrient cycles. pp. 827-844. In: Weinstein, MP, and DA Kreeger (eds.). *Concepts and Controversies in Tidal Marsh Ecology*. Kluwer Acadmic Publishers, Boston, MA. 875 pp.

Miller, KG, MA Kominz, JV Browning, JD Wright, GS Mountain, ME Katz, PJ Sugarman, BS Cramer, N. Christie-Blick, and SF Pekar. 2005. The Phanerozoic record of global sea-level change. *Science* 310:1293-1298.

Milstead, B, S. Stevens, M. Albert, and G. Entsminger. 1994. *Northeast Coastal and Barrier Network Vital Signs Monitoring Plan Phase III*. Northeast Coastal Barrier Network, Draft Report. 131 pp.

Misut, PE, and J. Monti, Jr. 1999. *Simulation of Ground-Water Flow and Pumpage in Kings and Queens Counties, Long Island, New York*. US Geological Survey Water Resources Investigations Report 98-4071, Coram, NY. 50 pp.

Mitsch, WJ, and JG Gosselink. 2000. *Wetlands.* 3rd Ed. Van Nostrand Reinhold Company, Inc., New York, NY. 920 pp.

Montalto, FA, and TS Steenhuis. 2004. The link between hydrology and restoration of tidal marshes in the New York/New Jersey estuary. *Wetlands* 24(2):414-425.

Morris, JT, PV Sundareshwar, CT Nietch, B. Kjerfve, and DR Cahoon. 2002. Response of coastal wetlands to rising sea level. *Ecology* 83:2869-2877.

Morton, RA, G. Tiling, and NF Ferina. 2003. *Primary Causes of Wetland Loss at Madison Bay, Terrebonne Parish, Louisiana*. US Geological Survey Open File Report 03-60. US Geological Survey Center for Coastal and Watershed Studies, St. Petersburg, FL. 44 pp.

Munk, W. 2003. Ocean freshening, sea level rising. *Science* 300:2041-2043.

NPS. Undated. *The Evolving Legacy of Jamaica Bay*. Gateway National Recreation Area, Brooklyn, NY. 25 pp.

NRC. 1995. *Restoration of Aquatic Ecosystems.* National Academy Press, Washington, DC. 552 pp.

NRCS. 2000. *Summary Report, 1997 National Resources Inventory*. National Resources Conservation Service, US Department of Agriculture, Washington, DC. 90 pp.

NYSDEC. Undated. *Strategy for Addressing Loss of Intertidal Marsh in the Marine District*. New York State Department of Environmental Conservation, Marine Resources. www.dec.state.ny.us/website/dfwmr/marine/twloss.html

NYSDEC. 2006. *A Brief Description of the Freshwater Wetlands Act and What It Means to Landowners*. http://www.dec.state.ny.us/website/dfwmr/habitat/wetdes.htm

NYSDEC. 1996. *Urban/Stormwater Runoff Management Practices Catalogue for Nonpoint Source Pollution Prevention and Water Quality Protection in New York State.* New York State Department of Environmental Conservation, Albany, NY. 86 pp.

NYSDOS. 2006. *New York State Coastal Management Program LWRP Status Sheet, February 1, 2006*. New York State Department of State. www.nyswaterfronts.com/downloads/pdfs/LWRP_Status_Sheet.pdf. 8pp.

NYSDOS. 1999. *Your Coast, Your Future: Long Island Sound Coastal Management Plan*. New York State Department of State, Albany, NY. 122 pp. + appendix.

NYSDOS. 1997. *Wetlands*. South Shore Estuary Reserve Technical Report Series. New York State Department of State, Albany, NY. 61 pp.

NYSOPS. 1972. *Long Island Marine Wetlands*. New York State Office of Planning Services, Albany, NY. 60 pp.

National Academy of Science. In press. *Drawing Louisiana's New Map: Addressing Land Loss in Coastal Louisiana*. Reported by Stokstad, 2005.

Niedowski, N. 2000. *New York State Salt Marsh Restoration and Monitoring Guidelines.* NYS Department of State, Albany, NY, and NYS Department of Environmental Conservation, East Setauket, NY. 135 pp.

Nixon, SW. 1982. *The Ecology of New England High Salt Marshes: A Community Profile*. FWS/OBS-81/55, US Fish and Wildlife Service, Washington, DC. 70 pp.

Nyman, JA, M. Carloss, RD Delaune, and JH Patrick, Jr. 1994. Erosion rather than plant die back as the mechanism of marsh loss in an estuarine marsh. *Earth Surface Processes and Landforms* 19:69-94.

O'Connor, JS, and OW Terry. 1972. *The Marine Wetlands of Nassau and Suffolk Counties, New York*. SUNY at Stony Brook. 99 pp.

Orson, RA, RS Warren, and WA Niering. 1998. Interpreting sea level rise and rates of vertical marsh accretion in a southern New England tidal salt marsh. *Estaurine, Coastal and Shelf Science* 47:419-429.

Orson, RA, and BL Howes. 1992. Salt marsh development studies at Waquoit Bay, Massachusetts: influence of geomorphology on long-term community plant structure. *Estuarine, Coastal and Shelf Science* 35:453-471.

Paine, RT. 2002. Trophic control of production in a rocky intertidal community. *Science* 296:736-739.

Penland, S., R. Boyd, and JR Suter. 1988. Transgressive depositional systems of the Mississippi Delta Plain: a model for barrier shoreline and shelf sand development. *Journal of Sedimentary Petrology* 58:932-949

Pilkey, OH, and JAG Cooper. 2004. Society and sea level rise. *Science* 303:1781-1782.

Poteet, D., and L. Lieberman. undated. Paleoenvironmental history of Jamaica Bay marshes, New York. pp. 41-43. In: *Integrated Reconnaissance of the Physical and Biogeochemical Characteristics of Jamaica Bay*. Lamont-Doherty Earth Observatory, Columbia University. 121 pp.

Rampino, ME, and J. Sanders. 1981. Episodic growth of Holocene tidal marshes in the northeastern United States: a possible indicator of eustatic sea-level fluctuations. *Geology* 9:63-67.

Redfield, AC. 1965. Ontogeny of a salt marsh estuary. *Science* 147:50-55.

Redfield, AC. 1967. Postglacial change in sea level in the western North Atlantic Ocean. *Science* 157:687-690.

Redfield, AC. 1972. Development of a New England salt marsh. *Ecological Monographs* 42(2)1-237.

Redfield, AC, and M. Rubin. 1962. The age of salt marsh peat and its relation to recent changes in sea level at Barnstable, Massachusetts. *Proceedings of the National Academy of Science* 48:1728-1735.

Reed, DJ. 1995. The response of coastal marshes to sea level rise: survival or submergence? *Earth Surface Processes and Landforms* 20:39-48.

Richard, GA. 1978. Seasonal and environmental variations in sediment accretion in a Long Island salt marsh. *Estuaries* 1(1):29-35.

Roman, CT. 1998. *Ecosystem Response of Salt Marshes to Open Marsh Water Management (OMWM): Experiments at Rachel Carson National Wildlife Refuge (Maine).* Study Proposal to US Fish and Wildlife Service Region 5. 19 pp.

Roman, CT, JA Peck, JR Allen, JW King, and PG Appleby. 1997. Accretion of a New England (U.S.A.) salt marsh in response to inlet migration, storms, and sea level rise. *Estuarine, Coastal and Shelf Science* 45:717-727.

Rooth, JE, JC Stevenson, and JC Cornwell. 2003. Increased sediment accretion rates following invasion by *Phragmites australis*: the role of litter. *Estuaries* 26(2B):475-483.

SCDHS. 2002. *Peconic Estuary Program: Comprehensive Conservation and Management Plan*. Suffolk County Department of Health Services, Riverhead, NY.

SSER Council. 2001. *Long Island South Shore Estuary Reserve Comprehensive Management Plan*. New York State Department of State. 107 pp. + appendices.

Schwimmer, RA. 2001. Rates and processes of shoreline erosion in Rehoboth Bay, Delaware, USA. *Journal of Coastal Research* 17:672-683.

Shaw, SP, and CG Fredine. 1956. *Wetlands of the United States – Their Extent and their Value to Waterfowl and Other Wildlife.* US Fish and Wildlife Service Circular 39. 67 pp.

Silliman, BR, and MD Bertness. 2002. A trophic cascade regulates salt marsh primary production. *Proceedings of the National Academy of Science* 99(16):10500-10505.

Silliman, BR, J. van de Koppel, MD Bertness, LE Stanton, and IA Mendelssohn. 2005. Drought, snails, and large-scale die-off of southern US salt marshes. *Science* 310:1803-1806.

Silliman, BR, CA Layman, K. Geyer, and JC Zieman. 2004. Predation by the black-clawed mud crab, *Panopeus herbstii*, in mid-Atlantic salt marshes: further evidence for top-down control of marsh grass production. *Estuaries* 27(2):188-196.

Silliman, BR, and JC Zieman. 2001. Top-down control of *Spartina alterniflora* production by periwinkle grazing in a Virginia salt marsh. *Ecology* 82:2830-2845.

Snowden, JO, WB Simmons, EB Traughber, and RW Stephens. 1977. Differential subsidence of marshland peat as a geologic hazard in the greater New Orleans area, Louisiana. *Transactions of the Gulf Coast Association of Geological Societies* 27:169-179.

Stevenson, JC, LG Ward, and MS Kearney. 1986. Vertical accretion in marshes with varying rates of sea-level rise. pp. 241-259. In: Wolfe, DA (ed.). *Estuarine Variability*. Academic Press, New York, NY. 509 pp.

Stevenson, JC, JE Rooth, MS Kearney, and KL Sundberg. 2000. The health and long-term stability of natural and restored marshes in the Chesapeake Bay. pp. 709-736. In: Weinstein, MP, and DA Kreeger (eds.). *Concepts and Controversies in Tidal Marsh Ecology*. Kluwer Acadmic Publishers, Boston, MA. 875 pp.

Stewart, B. 2001. Scientists are baffled by loss of marsh from Jamaica Bay. *The New York Times*, July 6. p.9.

Stokstad, E. 2005. Louisiana's wetlands struggle for survival. *Science* 310:1264-1266.

Stumpf, RP. 1983. The process of sedimentation on the surface of a salt marsh. *Estuarine, Coastal and Shelf Science* 17:495-508.

Swanson, RL, AS West-Valle, and CJ Decker. 1992. Recreation vs. waste disposal: the use and management of Jamaica Bay. *Long Island Historical Journal* 5(1):21-41.

Taylor, J. 1998. *Guidance for Meeting US Fish and Wildlife Service Trust Resource Needs When Conducting Coastal Marsh Management for Mosquito Control on Region 5 National Wildlife Refuges*. US Fish and Wildlife Service, Region 5. 27 pp.

Teal, J., and M. Teal. 1969**.** *Life and Death of the Salt Marsh.* Little, Brown, Boston, MA. 278 pp.

Tiner, RW, DBFoulis, GS Smith, J. Swords, S. Schaller, and D. Peterson. 1998. *The Peconic Watershed – Recent Trends in Wetlands and their Buffers*. US Fish and Wildlife Service, Ecological Services, Hadley, MA. Draft for review. 50 pp.

Town of East Hampton. 2006. *East Hampton Town Trustees*. www.ehtrustees.com/about.htm

Town of Needham Conservation Commission. 2006. www.town.needham.ma.us/ConCom/Index.htm

Town of Southampton. 2006. *Southampton Trustees – Responsibilities of the Town of Southampton Trustees*. www.town.southampton.ny.us/listing.ihtml?cat=Southampton%20Trustees&id=75

Town of Southold. 2006. *Board of Town Trustees*. southoldtown.northfork.net/trustees.htm

Turner, RE. 1997. Wetland loss in the northern Gulf of Mexico: multiple working hypotheses. *Estuaries* 20(1):1-13.

Turner, RE. 2001. Estimating the indirect effects of hydrologic change on wetland loss: if the earth is curved, then how would we know it? *Estuaries* 24(4):639-646.

Turner, RE, and YS Rao. 1990. Relationships between wetland fragmentation and recent hydrologic changes in a deltaic coast. *Estuaries* 13:272-281.

Turner, RE, EM Swenson, and CS Milan. 2000. Organic and inorganic contributions to vertical accretion in salt marsh sediments. pp. 583-595. In: Weinstein, MP, and DA Kreeger (eds.). *Concepts and Controversies in Tidal Marsh Ecology*. Kluwer Acadmic Publishers, Boston, MA. 875 pp.

USEPA. 1995. *America's Wetlands: Our Vital Link between Land and Water*. US Environmental Proetection Agency, Office of Water, Office of Wetlands, Oceans and Watersheds, Washington, DC. Unpaged brochure.

USFWS. 2000. *Status and Trends of Wetlands in the Conterminous United States 1986 to 1997*. US Fish and Wildlife Service, Washington, DC.

USFWS. 1999. *Concerns and Issues about Mosquito Control on the National Wildlife Refuges in the Northeast*. US Fish and Wildlife Service, Region V. 53 pp.

USFWS. 1965. *Supplementary Report, June 1965, on the Coastal Wetlands Inventory of Long Island, New York*. US Fish and Wildlife Service, Bureau of Soprt Fisheries and Wildlife, Region V. Boston, MA. 12 pp.

Valauskas, S., and RN Zajac. 2005. The changing face of Connecticut salt marshes: a look at marsh change and an estimation of potential rates of loss. Abstract, *Benthic Ecology Meeting*, Williamsburg, VA, April 6-10. www.vims.edu/bem2005/

Warren, RS, and WA Niering. 1993. Vegetation change on a northeast tidal marsh: interaction of sea-level rise and marsh accretion. *Ecology* 74(1):96-103.

Webb, EC, IA Mendelssohn, and BJ Wilsey. 1995. Causes for vegetation dieback in a Louisiana salt marsh: a bioassay approach. *Aquatic Botany* 51:281-289.

Wiegert, RG, and BJ Freeman. 1990. *Tidal Salt Marshes of the Southeast Atlantic Coast: A Community Profile*. Biological Report 85(7.29), US Fish and Wildlife Service, Washington, DC. 69 pp.

Wilen, BO, V. Carter, and JR Jones. 2002. *Wetland Mapping and Inventory*. US Geological Survey Water Supply Paper 2425. 11 pp.

Wood, ME, JT Kelly, and DF Belknap. 1989. Patterns of sedimentation in the tidal marshes of Maine. *Estuaries* 12:237-246.