NEW YORK STATE
SALT MARSH RESTORATION
AND MONITORING GUIDELINES

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New York State
Salt Marsh Restoration and Monitoring Guidelines

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PREFACE

All salt marsh restoration activities are regulated, and require permits and approvals. Using this guidance document does not relieve the reader of regulatory requirements, nor does it guarantee receipt of a permit. This document does not waive existing regulatory standards. Using this document should not be substituted for communication with permit staff regarding a proposed salt marsh restoration project. Regional permit staff should always be contacted by a project proponent early in the planning process and prior to submission of permit applications.

This document is primarily intended to guide voluntary restoration projects, not mitigation projects. Mitigation projects are constrained by specific regulatory standards. This document does not modify or waive any program standards for mitigation. In addition, while voluntary projects are more flexible in goal-setting and design, such projects will nevertheless be subject to regulatory requirements, including permits and approvals from the State and federal government.

The Salt Marsh Restoration and Monitoring Guidelines are primarily intended for use with projects sponsored by municipalities. Individuals with ideas for restoration projects are strongly encouraged to collaborate with their municipality, and to contact regional Department of Environmental Conservation staff prior to project planning. Activities in identified tidal wetlands, including salt marshes on private property, are regulated by the State of New York, and require permits and approvals.

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1. INTRODUCTION

Planning, design, and implementation of publicly and privately sponsored salt marsh restoration projects in the northeast United States is rapidly increasing. Both governmental and non-governmental entities are looking beyond habitat protection alone, and are turning their attention to the possibilities of habitat restoration. Increased implementation of salt marsh restoration projects is partially attributable to the availability of funding (*e.g.*, Natural Resources Damage Assessment Program, Partners for Fish and Wildlife Program), and the incorporation of restoration considerations into ongoing resource management programs (*e.g.*, National Estuary Programs, National Estuarine Research Reserves). The increase in implementation is also a result of improving science and information on practical salt marsh restoration.

The guidelines have been developed as part of the State's overall policy "to conserve, improve, and protect its natural resources and environment...", as stated in Title 1, section 0101 of the New York State Environmental Conservation Law (ECL). This policy is echoed and expanded upon in several other sections of the ECL and in the State's Coastal Management Program with several specific charges to restore degraded habitat for the purposes of maintaining the health and viability of fish and wildlife populations (ECL Title 3, §0301.1(n); Title 11, §0303.2(b)(1), Title 13, §0105.1, Executive Law Article 42, §913). Salt marshes are a vital part of healthy coastal ecosystems and the fish and wildlife populations that depend on them.

With the increase in state funding opportunities for aquatic habitat restoration through the 1996 Clean Water/Clean Air Bond Act and several years of full funding of the Environmental Protection Fund, local planning and implementation of aquatic habitat restoration projects has substantially increased. Notably lacking, however, is state guidance on restoration planning, project design, and implementation.

The guidelines also seek to address common shortcomings noted by scientists and natural resource managers in past restoration projects. Some consistently highlighted issues (Kusler and Kentula, 1990) include:

- poorly planned and designed projects,
- lack of baseline site information (no pre-project monitoring),
- lack of workplan compliance (no compliance monitoring),

- lack of post-project monitoring,
- inadequate monitoring (too short, wrong parameters),
- project information and data lost or inaccessible,
- data lack comparability among different projects or over time, and
- no determination, or a faulty determination, of success or failure is made.

The guidelines in this report attempt to provide a framework for salt marsh restoration activities, including planning, design, implementation and monitoring.

Tidal wetlands, including salt marsh habitats, are protected in the State of New York under Article 25 of Environmental Conservation Law, the Tidal Wetlands Act. All tidal wetland restoration projects are regulated activities in New York State and require both state and federal permits. Use of these guidelines does not waive regulatory requirements, nor does is guarantee receipt of required permits and approvals. Use of these guidelines also should not be substituted for consultation with Department of Environmental Conservation permit staff prior to submission of permit applications. You must research your project's regulatory requirements, consult with appropriate permit staff, and file all required permit applications. Appendix D contains a listing of state and federal statutes that regulate activities in tidal wetlands. The Appendix also lists statutes that support federal involvement in ecosystem restoration.

1.a. Purpose of the Salt Marsh Restoration and Monitoring Guidelines

This guidance document should assist in improving standards of practice for the burgeoning array of salt marsh restoration activities in the State of New York. The increase in funded habitat restoration projects highlights the need for accepted reference standards to guide project planning, techniques, and monitoring to measure success. Holding all projects to more consistent standards increases the likelihood of achieving success and ensures that public dollars are wisely spent.

To this end, the guidance document has been designed to provide a comprehensive, accessible, and understandable source for current technical information on salt marsh restoration and ecology, to increase the quality of restoration project planning. The guidelines include restoration monitoring protocols that were researched and developed to provide essential and standardized pre-project, compliance, and post-project information for the evaluation of project success. The protocols are designed to be understandable and useable by a wide variety of user groups, including trained volunteers. Finally, the protocols are presented in workplan format, to facilitate their incorporation into contracts, memoranda of understanding, and requests for proposals associated with restoration projects.

1.b. Intended Audience and Format of the Guidelines

This document is designed to serve several audiences. First, it is intended to assist individuals with little or no restoration experience by providing basic information regarding salt marsh restoration. For these individuals, there are brief characterizations of the salt marsh ecosystem and common disturbances to New York salt marshes. The effects of these disturbances on salt marshes are also discussed. Despite some overlap, these sections are kept separate to facilitate the user's access to needed information. The Restoration Methods section briefly presents the main topics in this area, while providing documentation of alternatives, additional considerations, and references to more detailed information. While the idea of a salt marsh restoration "cookbook" is appealing, the topic is too complex for such an approach. This document familiarizes the reader with the extent of detail associated with the main topics while remaining manageable and intelligible to the non-specialist. Ideally, readers with little experience should exit the document informed about the fundamentals of salt marsh restoration planning and the ability to seek out additional information and the appropriate expertise required for a restoration project.

Second, this document is expected to serve experienced natural resources managers by providing explicit documentation of the topics and a compilation of references. While the formulation of a restoration "cookbook" is not feasible, some aspects of the habitat restoration process can greatly benefit from a degree of standardization, especially methods for post-project monitoring and the goals for habitat restoration programs and projects from the perspective of the State of New York. Experienced natural resources managers benefit from this standardization because their individual projects become more comparable, communication is facilitated, and the potential for conflicts in strategy and/or goals is removed. Also, while an experienced restoration practitioner may have expertise in one particular area of salt marsh or restoration ecology, he or she may lack strength in other important areas and therefore may also benefit.

This guidance document contains the following sections:

•**Overall goal setting for habitat restoration in New York State**, intended to serve as general guidance for developing project-specific restoration goals, objectives, and tasks;

•**Definitions** of terms related to restoration;

•**Principal planning considerations**, discussing identification of site-specific goals, objectives and limitations, and the difficulties encountered in the restoration planning process;

•**Salt marsh habitat characterizations** outline the habitat zones associated with tidal wetlands, their vegetation, common fish and wildlife species, habitat functions, and generic impacts to these habitats;

•**Human disturbance characterizations** discuss common human activities in New York State that adversely affect salt marshes;

•**Natural disturbance characterizations** discuss natural events and processes influencing, often substantially, salt marsh structure and function;

•**Post-disturbance conditions in the marsh** describes a number of common, undesirable situations that occur in salt marshes as a result of the anthropogenic and natural disturbances described previously;

•**Restoration methods** discusses the most important considerations and techniques for the restoration of salt marshes;

•**Salt marsh restoration monitoring protocol** recommends an approach that should be used in New York State funded or authorized salt marsh restoration projects and, when appropriate, used for non-state funded or authorized projects;

•**Salt marsh restoration bibliography**, drawn from peer reviewed literature, government-sponsored studies and reports, conference proceedings, books, magazines, and the internet;

•**Common reed control monitoring protocol**;

• **Common reed control bibliography**, derived from the same sources listed above;

• **Salt marsh conceptual model** discusses and lists measurable parameters to help construct site-specific monitoring programs and assist in general restoration planning;

• **Appendices,** with tables and other graphics summarizing and expanding on important information contained within the document.

1.c. Overall Goal Setting for Habitat Restoration in New York State

One component of adequate habitat restoration planning is identification and articulation of goals. Therefore, the following goal statements were developed to serve as the basis for an overall State of New York habitat restoration program:

1. **To the greatest extent practical, achieve functional, community, and/or ecosystem equivalence with reference sites when undertaking restoration.**

Many restoration efforts to date have evaluated success based only on measures such as post-project percent coverage of vegetation. Percent cover of vegetation at a restoration site alone does not indicate the presence of a fully functional habitat. Important characteristic functions such as provision of habitat for key species, support of a diverse food web, primary productivity and export of organic material, nutrient cycling, and other factors are essential to a successful restoration project.

2. **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.**

There are many New York State listed animal species dependent on salt marshes for food, shelter, breeding, rearing of young, or other critical life stage needs. Attention should be focused on those species listed as endangered, threatened and of special concern in the State of New York. Such species currently include: black rail (Endangered, *Laterallus jamaicensis*), least tern (Threatened, *Sterna antillarum*), northern harrier (Threatened, *Circus cyaneus*), common tern (Threatened, *Sterna hirundo*), least bittern (Threatened, *Ixobrychus exilis*), and osprey (Special Concern, *Pandion haliaetus*). Current New York State protected plants of salt or brackish marshes include: saltmarsh loosestrife (Endangered, *Lythrum lineare*), Slender marsh-pink (Endangered, *Sabatia campanulata*), clustered bluets (Threatened, *Hedyotis uniflora*), swamp sunflower (Threatened, *Helianthus angustifolius*), marsh fimbry (Threatened, *Fimbristylis castanaea*), marsh straw sedge (Rare, *Carex hormathodes*), cyperus (Rare, *Cyperus polystachyos* var. *texensis*), and others.

3. Plan and implement restoration initiatives using a regional perspective to integrate and prioritize individual restoration projects and programs.

While it is important to support the implementation of individual, well-planned restoration projects, a long-term restoration program including objectives for the state is needed. This program should include planning restoration on a landscape ecology or regional scale. Such planning involves the identification of those habitats most in need of restoration in a given region and the areas in that region where this type of habitat restoration is feasible. Individual projects from a given region can then be evaluated against the landscape-oriented restoration goals for that region.

4. To the extent practical, use historical acreages, proportions, and/or spatial distributions to prioritize habitats from a state or regional perspective.

State and regional planning initiatives help frame goals and give important context to restoration strategies and programs. Regional planning can identify status and trends and examine the feasibility of restoring certain habitats locally while addressing regional needs. Historical acreage is not always attainable at an individual site, but may be cumulatively achieved at several sites within a region through thoughtful planning and evaluation. Determination of the target historical acreage or proportion of salt marsh habitat is beyond the scope of this document, but is recommended as part of future expansion of state habitat restoration planning.

5. **To the extent practical, ensure where appropriate that historical acreages, proportions, and/or spatial distributions of priority habitats are restored and preserved in New York State.**

In many cases, restoring sufficient historical acreage may not be feasible. Some types of habitat restoration are less likely to succeed. These habitats should be given higher priority for protection than for restoration. In all cases, where restoration is associated with a higher degree of uncertainty, special consideration should be given to long-term protection and preservation opportunities for those habitats.

These overall goals for habitat restoration in New York State can serve as a basis for framing goals and objectives for individual habitat restoration projects. The overall goals are intended as a planning guideline, and should not be substituted for project-specific articulation of goals and objectives.

1.d. Definitions of Terms

Restoration ecology is a scientific discipline requiring consistent use of terms. Unfortunately, the lack of standardization for key terms associated with restoration complicates its practice and clouds general understanding of what restoration can and cannot accomplish.

The terms defined below represent the key terms commonly used by the practitioners of the discipline. There are other terms that are often misused interchangeably with some of those listed below. For example, the terms “rehabilitation” and “reclamation” have been, by some, equated with “restoration”. However, “rehabilitation” has also been applied to the conversion of a former wetland (now upland) of one type into some other type of wetland not previously present. “Reclamation” is used in many places to indicate the filling of wetlands for the purpose of reclaiming the land (Lewis, 1990). Perhaps the most problematic misuse of terminology equates “restoration” and “mitigation”. While these terms are not interchangeable, habitat restoration can be part of mitigation requirements.

To respond to these problems and decrease the general uncertainty surrounding the complex field of restoration, key terms are defined below. Use of these definitions by entities involved in restoration and related activities throughout the State of New York would greatly benefit the long term practice and understanding of wetland restoration as a discipline.

1. Restoration

Re-establishment of previously existing wetland or other aquatic resource character and function(s) at a site where they have ceased to exist, or exist only in a substantially degraded state. In practice this may be achieved by re-establishing the functions of a wetland or other aquatic resource that have been degraded or lost by such actions as filling, draining, altering hydrology or introduction of contaminants.

2. Enhancement

Activities conducted in existing wetlands or other aquatic resources to achieve specific management objectives or provide conditions which previously did not exist, and which increase one or more aquatic function. Enhancement may involve trade-offs between aquatic resource structure, functions, and values. A positive change in one function may result in negative effects to other functions.

3. Creation

The establishment of a wetland or other aquatic resource where one did not formerly exist.

4. Function

A physical, chemical, or biological process which takes place in wetland areas. Commonly recognized functions are food chain production, provision of fish and wildlife habitat, barrier to waves and erosion, storm and flood water storage, and nutrient and chemical uptake.

1.e. Principal Planning Considerations in Salt Marsh Restoration

The methods selected for a given project greatly influence cost, expertise needed, labor, time to complete, level of maintenance required, and the potential for success. Lessons learned from past successes and failures with similar restoration projects should help guide the development of current projects. It is essential to research past experience and to contribute new scientific knowledge to an information base on restoration that is generally accessible to the public. Salt marsh restorations are currently supported by an extensive knowledge base and success record, relative to other types of habitat restoration. Therefore, a failure to research and fully understand previously employed methods, past experience, stumbling blocks, and both project successes and failures will perpetuate the past mistakes.

Figure 1 outlines the basic steps involved in conducting restoration projects, including planning and design, construction, monitoring, and information dissemination. Important considerations associated with each of these phases are also listed.

Planning for individual projects should not be conducted in a vacuum. It will be helpful to research the regional context for habitat restoration in a proposed project area. Restoration plans may already be in development in the area. Not only does context research avoid duplication of effort or potential project conflicts, but additional information, data and other resources and expertise become available. There are a variety of knowledgable contacts to assist in planning individual restoration projects in New York State, including regional National Estuary Program staff, Department of Environmental Conservation staff, Department of State Division of Coastal Resources staff, and others (see Appendix E, Knowledgable Contacts).

Goals and objectives for each restoration project must be articulated early in the planning process. Clearly-stated goals and objectives will assist during planning when trade-offs are required. Articulating goals will provide insight, for example, into whether planting salt marsh vegetation should be conducted, at greater expense, rather than depending on natural recolonization. If erosion of low marsh and creek banks is a concern, planting may be warranted. However, if common reed control in the high marsh is a higher priority, the resources that would be required for low marsh planting should be allocated to common reed control. Without knowledge of project goals, selection of options in situations requiring trade-offs becomes arbitrary. Once goals and objectives have been

1. **Planning and Design Phase**

a. Define Goals and Objectives
   i. Ecological
   ii. Economic
   iii. Public Benefit (recreational, educational, cultural value)
   iv. Aesthetic
b. Develop Specific and Quantifiable Performance Criteria
   v. Define Time Scale for Assessment
   vi. Define Spatial Scale for Assessment
   vii. Determine Target Plant and Animal Community
   viii. Determine Target Ecosystem Functions
   ix. Should Be Self-sustaining
   x. Should Be Resilient
c. Research Restoration Site
   xi. Historical Conditions (aerial and historical photos, local records)
   xii. Degree of Alteration (physical, chemical, biological)
   xiii. Landscape Setting (adjacent land uses, ownership, watershed)
   xiv. Allometry
   xv. Hydrology
   vi. Contamination
   vii. Seed Sources
d. Refine Objectives Based on Site Research
e. Plan Restoration Project
   xvi. Level of Physical Effort
   ii. Technology Requirements
   iii. Cost
   iv. Schedule
   v. Site Constraints (access, flooding, nuisance species)
   vi. Legal Restrictions
f. Obtain Required Permits
g. Develop a Contingency Plan for Unexpected Outcomes
h. Do Engineering Designs

2. **Construction Phase**

a. Consider Effect on Resources (at site and adjacent sites)
b. Consider Best Times to Plant, Lay Fallow, Develop Channels, *etc*.
c. Monitor Construction Activities and Workplan Compliance

3. **Assessment Phase**

a. Collect Minimum Standard Baseline Data
b. Tailor Monitoring Program to Project Goals and Objectives
c. Make Needed Adjustments to Correct Course of Development

4. **Documentation and Communication Phase**

a. Share Results (internet technology, conferences, workshops, outreach)
b. Keep Good Records (engineering, construction, monitoring data, cost information)
c. Keep Information Accessible (designate contact person, develop central file or database)

Figure 1. Process and Considerations for Restoration Projects (based on R. Thom, 1998).

determined, performance criteria and monitoring parameters may be selected and an assessment program developed.

It should be noted that trade-offs involving habitat exchange are often unacceptable. In such cases, fully functional habitats are altered to create a different type of habitat. For example, an intertidal mudflat might be graded and planted to create low salt marsh, *i.e.*, salt marsh is added to this area at the expense of the mudflat community. It is important to consult with existing planning efforts to discuss regional priorities with regard to habitat type, and to verify that a proposed project is not a habitat exchange. Because habitat manipulations involve some degree of risk in terms of outcome, habitat exchanges should be avoided.

Figure 2. Recrational shellfishing in an intertidal mudflat.

In addition to the ecological value, societal value of restoring salt marshes should also be considered in restoration planning. Potential values derived from salt marsh restoration activities may include educational, recreational, and commercial benefits. The recreational and aesthetic values of the restored salt marsh often will be more important in garnering public and political support for a project than the degree of ecological function achieved.

Generally, the likelihood for success increases and costs of a project decrease if pre-project site research is appropriately conducted. Historical information on a site, from government and other records, should be collected. Historical aerial photographs and false-color infrared photography should be obtained and used in planning the extent and type of restoration. Often local and regional natural resource management agencies and organizations will have valuable information on a potential restoration site, and should be contacted.

Site-specific characteristics of each restoration locale also influence restoration planning. Although the impacts to and the generic characteristics of salt marshes are often similar, restoration of these resources must be planned and evaluated on a case-by-case basis. Site-specific characteristics (*e.g.*, long wind fetch), coastal processes (*e.g.*, 2 foot tidal range), disturbances (*e.g.*, filling), the surrounding environment (*e.g.*, adjacent golf course), and other micro- and macrocharacteristics will affect project success, and must be examined and understood prior to undertaking restoration activities. Site surveys to assess these and other site-specific characteristics should occur for every restoration project early during planning. The guidelines presented here should be used keeping the limitations associated with site-specificity in mind.

The degree of salt marsh restoration possible may be limited by a number of factors. Salt marshes in the northeast United States have been affected by human activities since before colonial settlement. It is not practical or even possible to restore salt marshes to pre-disturbance conditions. Unaffected reference marshes are not available for comparison in planning and evaluation processes.

The degree of restoration possible is also limited by human encroachment. Even recently disturbed salt marshes may not be restored to pre-disturbance conditions because critical salt marsh processes like tidal inundation conflict with human development in the area. In such cases only partial restoration is feasible, targeting a smaller total acreage of salt marsh for restoration, or particular functions of the marsh may be improved.

Monitoring must become a regular part of restoration projects, and standard, accepted methodologies must be followed. Failure to adequately monitor may mean that problems are not identified in time for correction; project comparisons are difficult; and expenditure of time, labor, and funds are hard to justify. Information on appropriate salt marsh restoration monitoring parameters is available. Salt marsh monitoring protocols that are implemented now may be modified in the future as the knowledge base of restoration science grows.

Increased use of standardized monitoring should also be accompanied by selection of and comparison to reference sites. These sites are generally high quality examples of a habitat that are used to assist design and evaluation of restoration projects in a nearby area. This type of reference site provides an example of ecological structure and function of a habitat in its current context. Without comparison to a reference site, it is impossible to establish realistic restoration goals during planning, or track restoration progress after project implementation.

Finally, to decrease the number of trial-and-error restoration projects implemented, information availability must be improved. First and foremost, good records for all projects must be kept, including budgets, workplans, site plans, survey data, monitoring programs, photographs, and post-project monitoring data and analysis. Project information and data should be disseminated to restoration practitioners and other interested parties through conferences, workshops, public outreach, and the use of internet technology. Central repositories for restoration data and information should be designated, and specific contact people identified. Regional restoration planning, through National Estuary Programs for example, should assist in increasing information availability and accessibility.

Although there are many complicated planning considerations and limitations associated with habitat restoration, this does not mean that undertaking such projects cannot succeed and provide benefit to a community, municipality, or region. Restoration projects do not have to be vast in size or scope to be of value. Those without experience planning and conducting restoration are encouraged to start small, and take advantage of knowledgable contacts and information resources available. With adequate research, planning, site investigation, and monitoring, a salt marsh restoration project has an extremely high likelihood of success.

2. TEMPERATE SALT MARSH HABITAT CHARACTERIZATION

2.a. Salt Marsh Development

Present day salt marshes in the northeastern United States appear to have been established only during the last 3,000 to 4,000 years, subsequent to a rapid fall in sea level followed by a rapid rise (~16 mm per year) in sea level 7,000 to 8,000 years ago. After this period sea level rise slowed to approximately one millimeter per year, and salt marshes were established (Nixon, 1982).

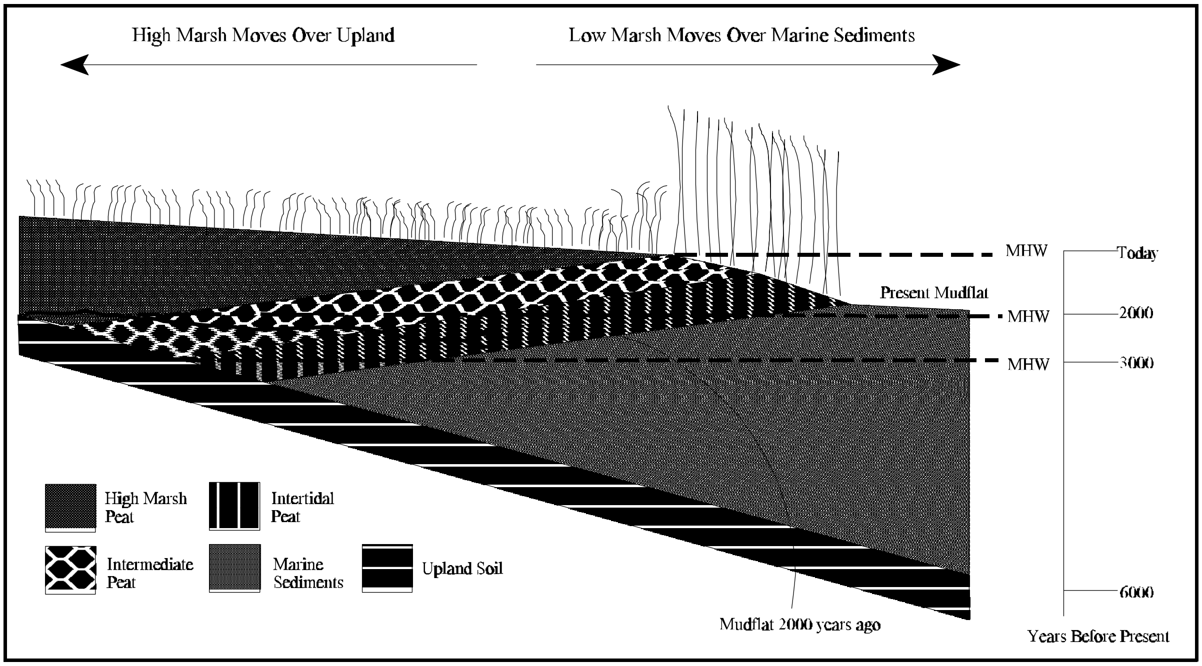

Figure 3. Salt marsh development over time (based on Warren, 1995).

Over time, the gradual accumulation of sediments in shallow coastal waters leads to the formation of mudflats. *Spartina alterniflora* (smooth cordgrass) colonizes these intertidal mudflats, and the presence of *Spartina alterniflora* accelerates sediment deposition at the seaward edge of the vegetated area. The belowground roots and rhizomes begin to form salt marsh peat. As the marsh peat accumulates, high marsh *Spartina patens* (salt-meadow cordgrass) replaces low marsh *Spartina alterniflora* in areas nearing the high tide limit. The high marsh continues to accumulate peat, and also accumulates sediment in response to sea level rise. In this manner, salt marshes grow upward and outward over time (Nixon, 1982; Teal, 1986).

2.b. Salt Marshes in New York State

In New York, salt marshes can be found across Long Island in north and south shore embayments and in the Peconic estuary at the eastern end of the island, as well as around New York City, in Westchester County on Long Island Sound, and in the Hudson River north to approximately the Tappan Zee Bridge. The Hudson River is tidal north to the Federal Dam at Troy, New York, but is in general not greatly influenced by salinity north of Poughkeepsie, New York (NYS DOS, 1990).

Tidal ranges differ greatly among these areas, ranging from 0.2 meters in the South Shore Estuary at Bayshore, Long Island, to 0.7 meters at Montauk Point and Plum Gut in eastern Long Island, to 1.3 meters at The Battery in New York City, and approximately 2.0 meters at both Willets Point in the East River in New York City and at Port Jefferson on Long Island's north shore. Because of these variations in tidal regime, salt marsh communities within New York State differ, particularly in terms of vegetation. Salt marshes with large tidal ranges are often dominated by tall form *Spartina alterniflora*, while those found in areas with more restricted tidal ranges will maintain a short form *Spartina alterniflora* zone, and more expansive high salt marsh areas.

2.c. Salt Marsh Vegetation

Salt marshes constitute some of the most diverse and biologically productive habitats of the coastal region. Typical zonation in a salt marsh includes low marsh, high marsh, and mudflats. This zonation can extend to include brackish and freshwater tidal habitats as well. However, restoration of brackish and freshwater tidal marsh habitats are not within the scope of this document.

Salt marsh zonation is generally defined by salinity gradients and duration of inundation. Salt marshes are, however, a dynamic ecosystem. The extent of zonation can be influenced by a number of natural processes. For example, as peat accumulates under marsh grasses, higher marsh elevations are subject to less frequent flooding by tides, which may lead to conversion from low to high marsh.

Low marsh, which is submerged at high tide but exposed at low tide, is dominated by smooth cordgrass (*Spartina alterniflora*). Smooth cordgrass can grow to three meters (ten feet). Few other higher plant species are present in the low marsh; species of algae like rockweed (*Fucus vesiculosus*), green algae (*Enteromorpha* spp.), and sea lettuce (*Ulva lactuca*) may be present between cordgrass stems. Glasswort (*Salicornia europaea*) can sometimes be found, in low densities, in the low marsh zone.

High marsh, which is only periodically flooded by spring and flood tides, is dominated by a mix of salt-meadow cordgrass (*Spartina patens*) and short-form smooth cordgrass, with lesser amounts of spikegrass (*Distichlis spicata*), and black grass (*Juncus gerardii*). High marsh may also support switchgrass (*Panicum virgatum*), sea-lavender (*Limonium carolinianum*), saltmarsh plantain (*Plantago maritima*), seaside gerardia

(*Agalinis maritima*), and glassworts (*Salicornia* spp.). This zone also supports a salt panne community in the depressions and pools of the high marsh surface. Inundation of these areas fluctuates greatly, often causing substantial increases in salinity in soil water. The salt panne community generally exhibits glassworts, short-form smooth cordgrass, and arrowgrass (*Triglochin maritimum*); widgeon grass (*Ruppia maritima*) grows in permanent pools.

Tidal creeks frequently occur in conjunction with coastal salt marsh. These creeks flow sinuously through marsh vegetation, and have vertical banks that may erode and slump into the water, which is fresh to saline. Salt marsh tidal creeks also distribute seawater throughout the marsh, and transport wrack, detritus and aquatic species into and out of the vegetated marsh.

Figure 4. Tall form *Spartina alterniflora* in the low marsh zone.

Intertidal mudflats are comprised of sandy or muddy substrates lying between low and high tide. Intertidal mudflats are entirely exposed during low tide. The chemical properties of intertidal mudflats are primarily determined by substrate grain size, *i.e.*, fine or coarse. Mudflats do not support any rooted vegetation but are characterized by communities of micro- and macroalgae. These algal communities often form extensive mats on the surface. Intertidal mudflats also support important bacterial communities.

2.d. Salt Marsh Fish and Wildlife

There are a number of bird species that nest in tidal marshes, including marsh wren (*Cistothorus palustris*), sharp-tailed sparrow (*Ammodramus caudacutus*), red-winged blackbird (*Agelaius phoeniceus*), black-crowned night heron (*Nycticorax nycticorax*), Canada goose (*Branta canadensis*), American black duck (*Anas rubripes*), and sometimes clapper rail (*Rallus longirostris*) and willet (*Catoptrophorus semipalmatus*).

Many more birds depend on tidal marshes for food, feeding on small fish, invertebrates, insects, and vegetation. This group includes Canada goose, which breeds and winters in salt marshes near ice-free, shallow water, and American black duck, a permanent resident requiring nearby open water and thick marsh vegetation. Green heron (*Butorides striatus*), great egret (*Casmerodius albus*), snowy egret (*Egretta thula*), glossy ibis (*Plegadis falcinellus*), tree swallow (*Tachycineta bicolor*), and terns (*Sterna* spp.) also feed in tidal wetlands. Northern harrier and short-eared owl (*Asio flammeus*) hunt in marshes for small mammals like meadow vole (*Microtus pennsylvanicus*).

Characteristic fishes in tidal creeks and flooded marsh areas include Atlantic silversides (*Menidia menidia*), sheepshead minnow (*Cyprinodon variegatus*), and mummichog (*Fundulus heteroclitus*). Many fish species reside in salt marshes for most of their life cycle, including mummichog , striped killifish (*Fundulus majalis*), and sheepshead minnow. Atlantic silversides spawn in salt marshes. Other fish depending on salt marsh habitat, associated tide creeks, and adjacent mudflats for nursery areas include winter flounder (*Pleuronectes americanus*), tautog (*Tautoga onitis*), sea bass (*Centropristes striata*), alewife (*Alosa pseudoharengus*), menhaden (*Brevoortia tyrannus*), bluefish (*Pomatomus saltatrix*), mullet (*Mugil cephalus*), sand lance (*Ammodytes americanus*), and striped bass (*Morone saxatilis*).

Invertebrate macrofauna are an important component of tidal salt marsh systems, providing food for many birds and fish of the marsh, as well as contributing to the structural and functional characteristics of the habitat. The macrofauna are significant consumers of algae, detritus, and smaller invertebrates; infauna rework marsh sediments and inoculate them with microbes while feeding. Among those macrofauna most frequently observed in salt marshes are ribbed mussel (*Geukensia demissa*), fiddler crabs (*Uca* spp.), and salt marsh snail (*Melampus bidentatus*).

2.e. Salt Marsh Functions

Salt marshes perform many functions, including nutrient and organic matter production and transport, nutrient and contaminant removal, reduction of wave energy during storms, flood water storage, and sediment trapping. Salt marsh areas also provide critical habitat for the larval and juvenile stages of many fish and invertebrate species, and are used for spawning by adults of these species. Marshes are important feeding and nesting grounds for many bird and other vertebrate species.

Gross Primary Productivity of Various Ecosystems

Marine	(cal/cm²/yr)
Open Ocean	100
Coastal Zones	200
Upwelling Zones	600
Estuaries and Reefs	2000
Terrestrial	(cal/cm²/yr)
Grasslands	250
Dry Forests	250
Cultivated Land	300
Moist Temperate Forests	800
Mechanized Agriculture	1200

Table 1. Comparison of ecosystem primary productivity in calories/cm²/year (based on Odum, 1971).

The primary productivity of *Spartina* species on Long Island and in Rhode Island ranges from 430 to 510 g dry weight/m^2/yr (Nixon, 1982). Dry weight value may be roughly converted to an organic carbon value (g C/m^2/yr) by dividing the dry weight value by two, as approximately one-half the dry weight of marsh grasses is carbon (Peterson & Peterson, 1979). The resultant carbon productivity ranges can be expressed as 215 to 255 g C/m^2/yr for Long Island and Rhode Island marshes.

Salt marshes are the primary source of much of the organic matter and nutrients forming the basis of the coastal and estuarine food web. As salt marsh vegetation decays, a steady supply of detritus is released into surrounding waters, promoting the secondary production of finfish, shellfish, crustaceans, and birds. Salt marshes export an estimated 40% of the aboveground *Spartina alterniflora* biomass, ranging between 200-400 g dry weight/m^2/yr (100-200 g C/m^2/yr; Teal, 1986). For comparison, the world's average agricultural production from corn fields is 412 g C/m^2/yr. Salt marshes, therefore, provide the resources for some of the most productive ecosystems on Earth (see Table 1).

Mudflats are also important contributors to primary production and breakdown of organic materials. Algal communities on mudflats are primary producers and provide a food source for snails and other benthic organisms. Bacterial communities contribute to the breakdown of organic materials.

The presence of salt marsh grasses such as *Spartina alterniflora* reduces the energy of waves moving shoreward. At the seaward edge of salt marshes, a wave energy reduction of 26% m^{-1} vegetation has been reported (Fonseca & Cahalan, 1992). Wave energy reduction decreases with distance into the marsh. The ability of salt marsh vegetation to reduce wave energy in this manner helps prevent shoreline erosion.

Reduction of wave and current energies in salt marshes causes them to trap sediment. As flow velocity decreases, water loses its capacity to carry sediment particles (Nixon, 1982). Sediment then settles to the bottom. The large initial reduction in flow velocity at the seaward edge of salt marshes concentrates sediment accumulation at this location, contributing to long-term maintenance and development of the salt marsh (Teal, 1986). Salt marsh grasses also reduce the velocity of terrestrial runoff. Water leaving the marsh, therefore, carries less particulate material and is less turbid (Desbonnet *et al*., 1994).

Reduction of flow velocities by salt marsh grasses contributes to flood control. Decreased flow velocities allow water to be transferred into soils and underground watercourses (Desbonnet *et al*., 1994), decreasing the impact of flood waters on adjacent upland.

Salt marshes remove nutrients, especially nitrogen, from coastal waters, contributing to water quality. Experimental addition of nutrients during the growing season showed retention of between 80% and 94% of added nitrogen and phosphorus; in spring and fall retention dropped to between 60% and 75% of added nutrients (Teal, 1986). Salt marsh productivity is stimulated by the addition of nitrogen (Nixon, 1982), and consequent increases in productivity by herbivores and detritivores are also reported (Teal, 1986). Highly productive areas of salt marshes are characterized by tall form *Spartina alterniflora* plants with thick, widely spaced stems. These characteristics make the marsh surface more accessible to predatory fish, increasing species diversity (Teal, 1986).

Salt marsh sediments filter and accumulate heavy metals (Teal, 1986). Most heavy metals form insoluble sulfides that adsorb onto clays, organics, and precipitates in the sediments. Salt marsh vegetation stabilizes the sediments, allowing formation of the anoxic environment required for deposition of heavy metal-sulfide complexes. Salt marsh grasses also take up metals to varying extents, sequestering them in plant tissues until death. At this time, the metals are exported into surrounding coastal waters with plant detritus. Although salt marshes are generally thought to be a heavy metal sink, chronic contamination can damage the marsh. Salt marshes carrying high heavy metal loads may also become a long-term source of contamination in coastal waters (Teal, 1986).

2.f. Conceptual Model for Salt Marsh System Restoration

2.f.1. Introduction to Conceptual Models

The conceptual model is a tool to assist the restoration practitioner in understanding important connections among ecosystem attributes (physical, chemical, and biological). The model should also assist in selecting the best monitoring parameters to assess the system with respect to project goals (Thom & Wellman, 1996). Tailored conceptual models can be constructed for individual restoration projects, defining the specific parameters controlling development and maintenance of the restoration site structure, its important characteristics, and the functions for which it is being restored (Thom & Wellman, 1996).

In such models, a small number of critical, site-specific controlling factors, structural elements, and functions are defined and the relationships between them outlined (often graphically). Below is a generic listing of conceptual model components for salt marsh ecosystems, and specific parameters associated with these components that may be selected for use in a more tailored monitoring program. The best conceptual models and restoration monitoring programs will be based on site-specific information, data, and goals, *i.e.*, the listing below may not be comprehensive for every project's purposes. However, basic planning may be conducted using this listing, and the use of a conceptual model is recommended for all restoration projects (Thom & Wellman, 1996).

2.f.2. Controlling Factors

The controlling factors of the salt marsh include 4 main categories. These are:

- Hydrology,
- Morphology,
- Water Chemistry and Physical Properties, and
- Substrate Properties.

The controlling factors of a habitat are those that determine the structural and functional parameters at a given site. These factors determine whether establishment of a salt marsh habitat is indeed possible at a given site. In planning salt marsh restoration projects, the controlling factors should be carefully considered.

The hydrology of a potential restoration site involves the presence/absence and cycling of water at the site. Sources of water may include groundwater, rivers and streams, tides, tidal creeks, rainfall, snowmelt, terrestrial runoff, Combined Sewer Overflows (CSOs), and others. How these water sources enter and exit the site, in terms of quantity, form, frequency and duration, constitute site hydrology.

The morphology, or physical form, of a site is particularly important to salt marsh habitat because certain physical forms interact with site hydrology to produce favorable conditions for salt marsh plant growth. Salt marsh morphology is determined by a variety of attributes, including elevation, slope, micro- and macrotopography, and the presence/absence of channels, among others.

All salt marsh restoration projects will require detailed elevation maps and information on tidal range. To maximize the potential for success, knowledge of local tidal elevations is critical. These elements are associated with the hydrological and morphological controlling factors of a restoration site.

Chemical and physical properties of the water entering and exiting a potential restoration site will be an additional controlling factor governing establishment of salt marsh habitat. Important properties of water include salinity and temperature. Individual species of both flora and fauna have different tolerance thresholds for these water properties. Specific chemical properties can therefore influence the community structure of the habitat.

Finally, substrate properties of a potential restoration site influence the interaction between the hydrology and morphology of the site. The size and type of sediment particles influences water drainage and the location of the water table. Other properties, such as organic matter content, pH, salinity, and others determine the presence/absence and growth rate of salt marsh flora and fauna.

2.f.3. Attributes of the Controlling Factors

The controlling factors described above are characterized by more specific attributes. These attributes can often be measured and tracked, and therefore can be used to construct a monitoring program for a salt marsh restoration project. Often, controlling factor attributes offer the most insight when used in pre-project planning and post-construction assessment. This is particularly true of hydrological and morphological attributes. In other words, data on the hydrological and morphological attributes of a potential restoration site can guide planners in determining whether and how to restore a site into salt marsh habitat. After the site has been manipulated, measuring these attributes can help planners determine whether the planned morphology and hydrology of the site have been achieved.

However, water chemistry and substrate attributes may provide the most insight over time as part of an ongoing, post-project monitoring program. These attributes can be examined in relation to data on flora and fauna to assess cause and effect relationships between controlling factors and structural factors. For example, the presence of an undesired plant species may be explained by data on water chemistry and/or substrate properties. Further, resolving the cause of an undesired result then allows the practitioner to more effectively and efficiently make plans to correct the situation.

Hydrologic attributes include the following:
Tidal elevations, duration of inundation, wave energy, height of water table, terrestrial water inputs, frequency of storm/rain/snow events, and timing of storm/rain/snow events.

Morphologic attributes include the following:
Number of tidal inlets, tidal inlet width/depth/shape, slopes, elevation of site features, number of tidal channels/creeks, sinuosity of channels/creeks, channel/creek width/depth/shape, and nearshore bottom topography.

Water property attributes include the following:

Salinity, temperature, pH, biochemical oxygen demand (BOD), contaminant concentrations.

Substrate properties include the following: Grain size/drainage, organic matter content, pH/oxygenation, and soil/porewater salinity.

2.f.4. Structural Elements

The structural elements of the salt marsh include 7 main categories. These are the following:

- Intertidal Flats/Primary producers,
- Intertidal Flats/Fauna,
- Low Marsh/Vegetation,
- Low Marsh/Fauna,
- High Marsh/Vegetation,
- High Marsh/Fauna, and
- Upland Fringe/Vegetation.

The structural elements of a site are not to be confused with the morphology, or physical shape, of the site. In a habitat, the structure is considered to be the plants and animals that occur there. In other words, a salt marsh habitat is not a salt marsh habitat until the appropriate community of plants and animals inhabit a site with favorable morphological, hydrological, water, and substrate properties. The true structure of the habitat, then, is indeed the flora and fauna present at the site.
Often, achieving a certain community structure, *i.e.*, the occurrence of several specific attributes simultaneously, will be the primary goal of a restoration project. Alternatively, influencing a single structural attribute may be the project goal, *e.g.*, increasing the numbers of low marsh nesting birds inhabiting the site. Therefore, those structural attributes most closely associated with the restoration project's goals should be included in the project's monitoring program. In general, the structural attributes chosen will be tracked both before and after site manipulation for purposes of comparison. Often, the same structural attributes will also be tracked at a similar site nearby the restoration site (the "reference site") that is not undergoing any manipulation. This allows the practitioner to resolve project-caused results from environment-caused results during the ongoing, post-project monitoring program.

2.f.5. Attributes of the Structural Elements

The community structure of salt marsh habitat encompasses several distinct zones, where characteristic flora and fauna appear. These zones most generally include the intertidal mudflats, where topography is fairly level, with vast expanses of substrate exposed at low tide; the low salt marsh, usually dominated by a single tall grass species tolerant of daily, prolonged inundation; the high salt marsh, which is more irregularly flooded and supports a more diverse array of plant and animal species; and the upland fringe, or salt shrub area, where conditions are sufficiently dry that some woody vegetation may grow, and the influence of freshwater inputs can substantially increase plant diversity, supporting both salt-tolerant and brackish species.

To construct an appropriate monitoring program for structural attributes of a restoration project, it will generally be necessary to first define the zone or zones (as described above) that will be manipulated or created. Only specific attributes associated with those zones need to be monitored. Again, the goals of the restoration project generally provide the most insight into the structural attributes of highest priority. It is not necessary to track all the specific attributes of a particular zone to adequately assess the status of that zone; however, an adequate understanding of the relationships among structural attributes, and between structural and controlling attributes, is essential in order to construct a monitoring program that effectively and efficiently assesses restoration success. Below is a listing of some key species found in the different salt marsh structural elements.

The ***Intertidal Flats/Primary Producers*** category includes:
Sea lettuce (*Ulva lactuca*), green fleece (*Codium fragile*), green algae (*Enteromorpha* spp.), epibenthic microalgae/bacteria, epiphytic algae, and phytoplankton (in pools and during inundation).

The ***Intertidal Flats/Fauna*** category includes:
Macro- & microinvertebrate infauna, salt marsh snail (*Melampus bidentatus*), mud snail (*Ilyanassa obsoletus*), oyster (*Argopecten irradians*), softshell clam (*Mya arenaria*), hard clam (*Mercenaria mercenaria*), ribbed mussel (*Geukensia demissa*), marsh fiddler crab (*Uca pugnax*), sand fiddler crab (*Uca pugilator*), green crab (*Carcinus maenas*), mud crabs (*Panopeus* spp.), great egret (*Casmerodius albus*), snowy egret (*Egretta thula*), cattle egret (*Bubulcus ibis*), tricolor heron (*Egretta tricolor*), little blue heron (*Egretta caerulea*), green heron (*Butorides striatus*), willet (*Catoptrophorus*

semipalmatus), greater yellowlegs (*Tringa melanoleuca*).

The ***Low Marsh/Vegetation*** category includes:
Tall form smooth cordgrass (*Spartina alterniflora*), rockweed (*Fucus vesiculosus*), and glassworts (*Salicornia* spp.).

The ***Low Marsh/Fauna*** category includes:
Ribbed mussel, marsh fiddler crab, mummichog (*Fundulus heteroclitus*), sheepshead minnow (*Cyprinodon variegatus*), Atlantic silverside (*Menidia menidia*), juvenile fish and fish larvae including winter flounder (*Pleuronectes americanus*), alewife (*Alosa pseudoharengus*), bluefish (*Pomatomus saltatrix*); clapper rail (*Rallus longirostris*), willet, marsh wren (*Cistothorus palustris*).

The ***High Marsh/Vegetation*** category includes:
Salt meadow cordgrass (*Spartina patens*), short form smooth cordgrass, spike grass (*Distichlis spicata*), black grass (*Juncus gerardii*), switchgrass (*Panicum virgatum*), sea-lavender (*Limonium carolinianum*), glassworts, and widgeon grass (in pannes).

The ***High Marsh/Fauna*** category includes:
Mummichog (in pannes/high tide), sheepshead minnow (in pannes/high tide), Atlantic silverside (in pannes/high tide), salt marsh snail, periwinkle (*Littorina littorea*), hydrobia (*Hydrobia totteni*), northern harrier (*Circus cyaneus*), wading birds (in pannes), American black duck (*Anas rubripes*), sharp-tailed sparrows (*Ammodramus caudacutus*), marsh wren, meadow vole (*Microtus pennsylvanicus*), muskrat (*Ondatra zibethicus*), raccoon (*Procyon lotor*), mosquitoes (*Aedes* spp.), grasshoppers, and spiders.

The ***Upland Fringe/Vegetation*** category includes:
Marsh elder (*Iva frutescens*), groundsel bush (*Baccharis halimifolia*), switchgrass, three-square rush (*Scirpus pungens*), seaside goldenrod (*Solidago sempervirens*), and prairie grass (*Spartina pectinata*).

2.f.6. Functions

The functional elements of the salt marsh include 9 main categories. These are:

- Provision of habitat,

- Primary production,
- Support of food web dynamics,
- Cycling of nutrients,
- Export of organic matter,
- Removal of contaminants,
- Attenuation of wave energy,
- Storage of flood water, and
- Enhancement of sedimentation/accretion.

Salt marsh ecosystems can support an array of functions that provide ecological services to native flora and fauna, other habitats, and also economic services to human beings. Functions can be thought of as the "activities" of the salt marsh, regardless of whether they are caused actively or passively by the flora and fauna. These functions are the products of the interaction of controlling factors and structural attributes.

Attaining one or more of these functions is often the goal of a restoration project, *i.e.*, to reach a state where the ecological and/or economic salt marsh services are available. For example, a project goal might be to increase primary production and support higher trophic levels in the food web, such as commercial and recreational fish species. An obvious functional goal of many salt marsh restoration projects is provision of habitat, either for a single priority species or a suite of native species. Many functions are closely associated with specific structural attributes: Provision of habitat is again an obvious example, as the particular structure of the animal community is largely influenced by the structure of the plant community, and also *vice versa*. Also, attenuation of wave energy and storage of flood waters are directly determined by plant community structure; food web dynamics are determined by both plant and animal community structure.

Tracking functional attributes of the ecosystem during a restoration monitoring program is important; however, some functions may be inferred by monitoring the structural attributes with which they are closely associated. In general, at least one important function of salt marshes should be monitored as part of the ongoing restoration monitoring program to assess the development of the natural processes underlying the structure. Monitoring these processes can provide an early warning of problems with the restoration; that is to say, an appropriate structure may exist at the site, but sub-optimal or abnormal functioning may indicate degradation of this structure, or an inability to provide other related functions.

2.f.7. Specific Functional Parameters

The salt marsh functions discussed above can be tracked by measuring or observing specific parameters. Some of these specific functional parameters may be auxiliary project goals, *e.g.*, community resistance and resilience, low water column turbidity, or a low frequency of flooding in adjacent terrestrial areas. Choice of one or more of these specific measurement parameters should be dictated by the restoration project's goals, and more specifically by an adequate understanding of the relationship among functions and between functions, ecosystem structure, and controls.

Provision of habitat parameters include:
Landscape patchiness, species richness (number of species), species dominance (relative abundance), community resilience (after disturbance), and community resistance (to disturbance).

Primary production parameters include:
Aboveground biomass, belowground biomass, and gross/net production.

Support of food web dynamics parameters include:
Number of trophic levels, trophic organization, and ecological efficiency (trophic transfer).

Cycling of nutrients parameters include:
Nitrogen fixation (N_2 to $NO_3/NO_2/NH_3$), denitrification (NO_3 to N_2), nitrification (NH_3 to NO_3), organic nitrogen (urea, amino acids, peptides), and detrital N/C ratios.

Export of organic matter parameters include:
Primary production gradients, dissolved organic matter (DOM), and particulate organic matter (POM).

Removal of contaminants parameters include:
Heavy metal concentrations (in H_2O), plant tissue heavy metal concentrations, pesticide concentrations (in H_2O), benthic macroinvertebrate tissue contaminant concentrations, and pollution gradients (sediments/water column).

Attenuation of Wave Energy parameters include:
Flow velocities, erosion rates/patterns, and sedimentation/accretion rates.

Storage of Flood Water parameters include:
Frequency/duration of flood events (of adjacent terrestrial areas).

Enhancement of Sedimentation/Accretion
Water column turbidity, sediment cores, and sedimentation rate (using sediment traps).

2.g. Generic Activities Affecting Salt Marshes and Adjacent Habitats

Activities that cause disruptions in the hydrologic regime, or cause minor elevational or gradient changes, can have profound adverse effects on vegetated tidal wetlands. Degradation and loss of upland buffers may cause increased sediment flow, altered ground water elevations and flow, loss of nutrient filtering vegetation, and loss of wildlife habitat for wetland edge species. Changes in ambient soil and water salinities will affect species compositions in tidal wetlands and creek communities, *e.g.*, invasion by common reed. Other activities that have an adverse effect on tidal wetlands include ditching, diking, fill, excavation, channel dredging, application of pesticides, and stormwater discharge. Finally, tidal creeks are affected by alterations to their bank structure, *e.g.*, bulkheading, and by changes in the size or shape of their inlet. Mudflat areas adjacent to salt marshes are an extremely dynamic and somewhat resilient habitat. However, activities such as dredging and filling alter the area's morphology, water circulation patterns, substrate type, and oxygenation, and can expose or bury organisms. Sediment resuspension can clog filter- and suspension-feeding mechanisms in species like bivalve molluscs and substantially decrease primary production as a result of light attenuation. This could lead to hypoxic substrates and a decline in benthic habitat quality.

3. HUMAN DISTURBANCES

Understanding human disturbances that cause negative impacts in the salt marsh habitat is important when planning and designing restoration projects. Ditching and filling account for the largest salt marsh losses in New York State. There may be more than one type of human disturbance in a salt marsh. It would not be unusual to see a salt marsh that has been ditched for mosquito control, partially bulkheaded to protect a shoreline development, and partially filled for adjacent development. Addressing these various human disturbances will involve trade-offs that may only be effectively chosen if these disturbances, their impacts, and the available restoration methods are understood. Therefore, the generic human activities that may disturb the salt marsh ecosystem, listed above, are discussed separately and in greater detail in this section of the document.

3.a. Ditching

Figure 5. Aerial photo of grid ditching in Long Island tidal wetlands.

Extensive grid ditching of salt marshes has been conducted in the northeast during this century, to eliminate or manage mosquito (*Aedes* spp.) populations (Taylor, 1998; Hruby, 1990; Clarke *et al.*, 1985; Niering & Warren, 1980). Grid ditching typically involved construction of parallel ditches at 100-150 foot intervals, and cross ditches to drain standing water areas (Taylor, 1998). Some of the natural standing pools and pannes on the marsh surface do provide a breeding ground for mosquito populations. However, ditching is non-specific in that it drains all pools, not only those standing pools serving as mosquito breeding areas. Impacts resulting from ditching include changes in original tidal regime and marsh vegetation. The functions and habitat value of a salt marsh are decreased as a result of ditching. Clarke *et al*. (1985) showed that foraging by shorebirds, waterfowl, and insectivores was greatly decreased in grid ditched marshes in Massachusetts. Other researchers have observed decreases in the numbers of birds using ditched salt marshes over time (Howe *et al*., 1978; Nixon, 1982; Taylor, 1998). Draining also results in the loss of important submerged aquatic vegetation habitat in natural pools on the high marsh (Taylor, 1998).

3.b. Filling

Many marshes have been filled, either as a result of the need to dispose of dredged

Figure 6. Wetland filling caused by golf course construction.

material from navigational channels and basins (Rozsa, 1995), or to "reclaim" the land for development, industry, and agriculture (NYS Office of Planning Services, 1972; Freese & Kulhawy, 1983). Coastal salt marshes have also been used extensively as a location for municipal landfills such as Pelham Bay, Pennsylvania Avenue, and Fresh Kills (Rozsa, 1995). Filling with upland substrates enhances the ability of invasive species to take hold in the area, due to low salt content, decreased moisture, and often the presence of seeds in these fill substrates. Filled marshes are subject to direct and substantial alteration of their tidal regime, natural morphology, and original marsh vegetation. Original salt marsh functions are generally lost.

3.c. Restricted Tidal Connection

Marshes were historically drained for a variety of purposes, including mosquito control, flood control, and for the production of salt hay, a combination of high marsh species used as animal feed (Hruby, 1990; Roman *et al.*, 1984; Nixon, 1982). To drain the marsh, flow control devices,

Figure 7. Perched culvert impeding tidal flow.

such as tide gates (flapper or sluice gates) are installed at tidal inlets or ditch mouths. These devices allow water to drain out of the marsh on the ebb tide, but restrict or prevent water flow from the incoming flood tide (Roman *et al.*, 1984; Niering & Warren, 1980). Structures such as road beds and railways often fully or partially block marsh areas from tidal flow (Hruby, 1990). Culverts below roads or railways are used to maintain some tidal connection despite the artificial obstruction. Many culverts provide insufficient inundation because of their size, placement, or from blockage by debris. These types of disturbances result in salt marshes mapped as "formerly connected wetlands" by the New York State Department of Environmental Conservation under Article 25, Environmental Conservation Law Implementing Regulations 6NYCRR Part 661. In these marshes, flow control devices and/or inadequate culverts decrease or eliminate the connection between the marsh and its inundating body of water. Impacts resulting from restricting tidal connection may include changes in the frequency, volume, and duration of tidal flooding. Tidal restrictions can also change marsh vegetation, morphology, subsidence, water quality, and salinity and soil oxidation. Some restrictions also provide a physical barrier to certain fish and wildlife species that normally migrate in and out of the marsh. The effects of these tidal restrictions have significantly degraded salt marsh functions and habitat value throughout the marine coast of New York.

3.d. Diking & Impoundment

Impoundments are flooded areas created by building dikes or placing weirs in the mouth of a creek or tidal inlet (Herke *et al.*, 1992). Diking and impoundment of salt marshes has sometimes occurred under the guise of habitat creation: recreationally important colonial waterfowl species prefer expanses of open water to emergent marsh areas (Peck *et al.*, 1994; Sinicrope *et al.*, 1990; Shisler, 1990). Unfortunately, after an initial increase in waterfowl use in such impoundments, a subsequent decline occurs as the open water habitat is invaded by new plant communities, like cattail (*Typha* spp.) and common reed (*Phragmites australis*; Rozsa, 1995). Impoundments were also created on some tidal creeks and embayments to power mills. Mill pond impoundments, which caused prolonged inundation of vegetated salt marshes , resulted in the elimination of this vegetation from all but a narrow fringe around the impoundments as water elevations increased (Rozsa, 1995). Impacts from diking and impoundment include changes in tidal regime, flooding, salinity, original vegetation communities, and possibly altered morphology. Many salt marsh functions are substantially altered by impoundment. Shisler (1990) notes that impoundments were often the cause of the worst mosquito problems associated with salt marsh habitats. In addition, Herke *et al*. (1992) showed that semi-impounded marshes result in a dramatic decrease in estuarine-dependent fish and crustacean use and export.

3.e. Pollution

Salt marshes can be damaged or destroyed by acute pollution events such as oil spills, and chronic exposure to petroleum hydrocarbons from marinas, boat traffic, and terrestrial runoff. Petroleum contamination kills marsh vegetation as well as fauna, and remains in the substrates, vegetation, and certain organisms for a long time subsequent to the initial pollution event (up to 12 years; Teal, 1986). Chronic input of small quantities of petroleum and other contaminants such as heavy metals, can also substantially damage marsh flora and fauna (Teal, 1986; Nixon, 1982).

Other types of pollution affecting salt marshes include traditional mosquito management techniques employing broad-spectrum chemical pesticides, applied directly to the salt marsh (Lent *et al.*, 1990). For example, DDT was used extensively to control mosquito populations in marshes throughout New York State until it was banned in eastern Long Island in 1966 and nationally in 1972 (Howe *et al.*, 1978). Marine and coastal birds were significantly impacted by environmental contaminants such as chlorinated hydrocarbons, including DDT. This category of compounds, mostly pesticides and herbicides, bioaccumulates in bird prey species and subsequently affects the reproductive processes of marine and coastal birds (Howe *et al.*, 1978). Contaminated sediments enter nearshore waters when they are resuspended in the water column by dredging (SCPD, 1985). Effects from chemical pollution include both acute and chronic toxicity to marsh vegetation and wildlife, and may cause indirect impacts across the coastal food chain.

Figure 8. Removing petroleum pollution from a marsh.

Stormwater discharges are a major source of pollution, including petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs). These chemical compounds are often derived from road and paved area runoff. The New York City Parks Department Natural Resources Group has conducted both field and laboratory research on heterotrophic bacteria capable of degrading petroleum hydrocarbons found in the root zone of smooth cordgrass. Petroleum-contaminated restoration sites are planted with *Spartina alterniflora* and fertilized. The *Spartina* plants aerate the root zone, promoting growth of these beneficial bacteria. Reductions in total petroleum hydrocarbons in field studies to date show that this process is working (Matsil & Feller, 1996).

Stormwater discharges also cause sedimentation in the marsh at rates far greater than those associated with natural marsh building processes. Stormwater sediment loads are primarily derived from sand and dirt running off roads and paved surfaces. While deposition of sediment over the long term from regular tidal flooding and periodic large storm events is integral to maintaining the natural configuration of the marsh and its vegetative communities (Stumpf, 1983), excessive sediment loads delivered by large pulses of stormwater runoff disrupt this process. These sediment loads can result in significant changes to salt marsh elevations. Stormwater discharges are also characterized by large pulses of fresh water into the system, which can disrupt the salinity regime in the marsh. Chronic fresh water influxes will alter soil salinities and the nutrient cycling regime, and influence the vegetative community found at the site. Both stormwater discharge impacts—excess loading of sediment and fresh water—may result in competitive exclusion of native salt marsh vegetation by invasive species. Functions and habitat can be severely impacted, if not eliminated, as a result of all types of anthropogenic pollution (chemical contaminants, excess sedimentation, freshwater pulses) in the salt marsh.

3.f. Shoreline Hardening & Structures

Figure 9. Bulkheaded shoreline of a tidal creek.

Increased residential and recreational use of the coastal area has led to a greater number of man-made structures intruding in and affecting natural habitat. In salt marsh areas, such structures are primarily bulkheads, revetments, groins, jetties, breakwaters, and docks. Bulkheads, generally constructed of wooden planks, steel sheeting, or concrete, are structures designed to minimize the loss of substrates from the shoreline by erosion (Freese & Kulhawy, 1983). Bulkheads and other structures such as revetments deflect waves from the shore face, but cause scouring at the toe of the structure and the adjacent shorelines. This process undermines the integrity of the structure itself, and alters the slope of the adjacent bottom areas. Single sections of bulkhead can actually increase erosion rates in adjacent unprotected areas; this "flanking" of the bulkhead results in erosion of the shore behind the bulkhead from either side (Freese & Kulhawy, 1983).

The presence of bulkheads initiates a cycle where toe scour causes a deepening of the water directly in front of the bulkhead; wave heights and flooding are thereby increased; and wetland areas that would naturally attenuate wave energy and store flood waters are eroded away.

New marsh formation, especially on the back side of barrier beaches on the south shore of Long Island, is dependent on overwash from storms. These processes are impeded by shoreline hardening structures. Marsh accretion and landward retreat are also prevented by bulkheads.

The construction of small, "light duty" docks, pedestrian catwalks or walkways, and observation platforms is common in marshes. Researchers examined the effects of docks on salt marsh vegetation, and found that dock height (measured from the marsh surface to the bottom of the longitudinal supporting beam) was a significant limiting factor for vegetation growth under those structures (Kearney *et al*., 1983). The presence of docks and other pile-supported structures create a shaded environment that may result in the loss of vegetation adapted to higher light intensity. In their study, Kearney *et al*. (1983) found that both height and density of all plant species examined were severely depressed at dock heights of < 30 cm. Normal heights were attained in different species of vegetation at different dock heights: spikegrass was largely unaffected by a dock of ~70 cm in height; salt meadow cordgrass required a dock height of ~85 cm to remain unaffected; smooth cordgrass required a dock height of ~200 cm to reach no effect status.

Figure 10. Walkway to a dock constructed over salt marsh.

Effects from shoreline hardening and the placement of other structures (such as docks) in or near salt marshes may alter marsh vegetation, structure, and hydrology. The New York State Department of Environmental Conservation, under 6NYCRR Part 661, has requirements for dock width and placement in intertidal marshes, flats, and adjacent areas. Cumulative impacts from a large number of individual, small scale projects negatively affect, if not eliminate, the function and habitat value of salt marshes.

3.g. Sea Level Rise

Sea level rise is thought to be induced largely by increasing concentrations of greenhouse gases from automobiles and industrial emissions (*e.g.*, carbon dioxide, methane) in the atmosphere and their concurrent impact on global temperature (Titus, 1991; Titus *et al*., 1991). Current estimates of sea level rise range from 50-200 cm (2-7 ft) over the next 150-200 years (Titus *et al*., 1991); a 30 cm (1 ft) rise is likely by the year 2050 (Titus, 1991; EPA Global Warming Site, 1998). Coastal marshes are particularly vulnerable to global sea level rise, as they occur primarily within a few feet of mean sea level (EPA Global Warming Site, 1998; Titus *et al*., 1991). Although marshes successfully developed despite sea level rise (and fall) over time (Teal & Teal, 1969; Orson *et al*., 1987), the current situation poses a serious threat to these areas for several reasons.

Sea level rise now occurs at a more rapid rate than in the past. Many coastal wetlands, which rise as a result of sediment accumulation and peat building, may not succeed in keeping pace (Titus *et al*., 1991). Concurrent with a rise through peat accumulation comes a landward migration of the marsh. However, many marshes are adjacent to bulkheaded and developed uplands, and inland migration of the marsh as sea level rises is precluded (see Shoreline Hardening & Coastal Structures above; Titus *et al*., 1991; Titus, 1991; Rozsa, 1995; Teal, 1986). Most adjacent upland areas are steeper than current wetland areas. Even if salt marsh development keeps pace with sea level rise a net loss of coastal wetland acreage would still occur (Titus, 1991). Researchers predict a one meter rise in sea level will inundate 36,000 km^2 (14,000 mi^2), divided equally between wet and dry land (Titus *et al*., 1991). This underscores the importance of identifying and protecting low lying areas to allow future landward migration of salt marshes.

Other anthropogenic factors not associated with global warming are also blamed for sea level rise over the past century. Groundwater withdrawal, surface water diversion, changes in land use, and deforestation are thought by some to be responsible for ~30% of this century's rise in sea level (Sahagian & Schwartz, 1994; Sullivant, 1994; Monastersky, 1994). Subsidence of coastal areas from groundwater withdrawal and landform modification will compound the effects of sea level rise on salt marshes (Fee, 1993; C. Rilling, personal communication).

4. NATURAL DISTURBANCES

Natural disturbances in the salt marsh may compound the effects of anthropogenic disturbances, and may influence the timing and methodology selected, as well as the likelihood of success, for restoration projects. Natural disturbances are not “bad” in themselves, but may be “bad” for a restoration project, especially if they are not considered during planning. The natural processes discussed below—seasonal disturbances associated with ice sheets, and acute natural disasters such as storms and hurricanes—are destructive forces at work in the marsh, and may substantially alter morphology and vegetative succession. They are nonetheless part of the natural ecology of the salt marsh, necessary for development and maintenance of the habitat over time. Existing anthropogenic stresses in the salt marsh, however, may adversely affect marshes’ resilience to natural events.

4.a. Seasonal Disturbances

Salt marshes in the northeastern United States can be covered with ice during the winter. Ice sheets uproot vegetation in the marsh when chunks of ice are dislodged by storms. Tidal action also causes ice sheets to shear the stems of cordgrass and other marsh plants (Bertness, 1992; Niering & Warren, 1980). Ice may cause changes in the elevation of a salt marsh through sediment erosion, transport, and deposition. Large debris (*e.g.*, boulders, lumber or concrete from coastal structures) may be transported by ice and deposited on the marsh surface, changing morphology and directly affecting vegetation (Shisler, 1990; Freese & Kulhawy, 1983).

Ice scouring can also cause indirect impacts to salt marsh environments. Uprooted plants and shorn stems are transported in extensive rafts onto upper high marsh areas by extreme high tides or storm waves. Rafts of material remain trapped on the surface of the marsh when high waters recede, where they may shade out existing vegetation. Patchy loss of marsh vegetation from both the ice scouring and subsequent deposition of debris rafts on the high marsh is important in maintenance and development of vegetative community structure in the salt marsh. Bare areas produced by this loss of vegetation are colonized by more opportunistic salt marsh vegetation, or form shallow pannes which can increase species diversity and habitat heterogeneity of the marsh (Bertness, 1992; Niering & Warren, 1980).

4.b. Natural Disasters

Weather events have disastrous effects on coastal environments. Wave energy during tropical (hurricanes) and extratropical (nor'easters) storms may cause severe shoreline erosion, changing the morphology of salt marshes, and of the nearby submerged landforms and protective features that influence them, such as sandbars and barrier beaches. Storm surge, a rise in overall water levels beyond that of normal tides, may cause severe impacts on coastal areas, largely due to flooding. Storm surge is influenced by direct wind action, atmospheric low pressure, heavy rainfall, and wave and swell transport of water. The timing of peak surge with respect to the tidal cycle will determine the degree of severity of surge-related flooding (Freese & Kulhawy, 1983). Sediment and debris may be deposited in excess on the surface of the marsh during hurricane and heavy storm events, resulting in morphological changes to the marsh and direct impacts on vegetation (Niering & Warren, 1980). However, it should be noted that storm-related sediment deposition also appears to be a crucial element in maintaining some marshes over the long term as they contend with sea level rise (Stumpf, 1983).

5. POST-DISTURBANCE CONDITIONS IN SALT MARSHES

Developing a successful restoration plan ultimately depends on an understanding of the on-the-ground effect(s) caused by a disturbance. A single type of disturbance may have several effects; for example, a tidal restriction placed within a salt marsh habitat will alter the tidal regime, possibly cause subsidence and aeration of the substrate, change the substrate salinity, and potentially promote the invasion of nuisance species. The details of a restoration plan must respond to site-specific issues, avoiding a generic response to disturbance type. Projects that do not respond to impacts in the habitat are more likely to be subject to unforseen problems and failure. The most prevalent on-the-ground impacts stemming from the anthropogenic disturbances discussed above and observed in salt marsh habitats of the northeastern United States are discussed in this section.

5.a. Changes in Tidal Regime

Tidal inundation is the primary physical characteristic of a salt marsh. Alterations in the tidal regime will have a profound effect on the vegetative communities present (Lefor *et al.*, 1987). Salt-tolerant vegetation will be replaced by other species in areas that are no longer inundated. *Phragmites australis* (common reed) will often invade these disturbed environments, outcompeting other species and often forming a monoculture (Roman *et al.*, 1984; Niering & Warren, 1980). Impounded or other areas with decreased salinities may become dominated by brackish species, such as cattail (*Typha angustifolia*; Beare & Zedler, 1987; Peck *et al.*, 1994; Sinicrope *et al.*, 1990). In addition, lack of inundation will cause marsh substrates to dry out, changing the chemical properties of these substrates and increasing erosion by wind, rain, and terrestrial runoff. Finally, tidal restrictions that prevent inundation reduce or eliminate the extent of fish use of the marsh (Burdick *et al.*, 1997).

Changes in tidal regime may also lead to increased inundation. Inlet dredging, for example, causes increased tidal flow into an embayment, raising the mean high tide elevation and changing the zonation of salt marsh vegetation. Low marsh *Spartina alterniflora* replaces former high marsh vegetation in the new intertidal zone. The overall area of the salt marsh is decreased as the former low marsh is lost underwater.

Reduction of tidal range in a salt marsh lowers the water table, and surface substrates become dry. In addition to drying, the oxygen content of these substrates increases. Associated with aeration of marsh substrates is a host of other chemical processes, including an increased rate of organic matter decomposition (oxidation), conversion of iron sulfide (pyrite) in marsh substrates to sulfuric acid, decrease in substrate pH to highly acidic conditions, and mobilization of potentially bioavailable heavy metals.

5.b. Subsidence

Subsidence is a drop in the surface elevation of the marsh below its former elevation. Tidal restrictions, in addition to reducing saltwater flooding, reduce the amount of sediment entering the marsh. Decreased sedimentation, compaction of dry marsh peat, and increased microbial decomposition of the peat can cause subsidence over time (Roman *et al.*, 1984; Rozsa, 1995). Subsided areas that are subjected once again to full tidal flow may be inundated for periods too long for the survival of salt marsh vegetation (Seneca *et al.*, 1985); *i.e.*, too much water remains on the marsh during low tides (Rozsa, 1995).

Restoration of tidal flow can result in the conversion of the area to a habitat other than salt marsh, such as shallow water habitat or unvegetated flats. Restoration of salt marsh in subsided areas can occur, but longer time frames are required. Rozsa (1995) observed that the Great Harbor Marsh (CT), which had subsided 60 cm (2 ft.) below its original elevation as a result of a tide gate, once again supported wetland vegetation 40 years after a hurricane destroyed the gate in the 1950s. However, despite nearly a half-century of self-restoration, the plant communities in Great Harbor Marsh did not replace those lost when the tide gate was installed—the area had supported a high marsh plant community, but now supports a *Spartina alterniflora*-dominated low marsh community (Rozsa, 1995).

Restoration of original plant communities in a subsided marsh may require more highly engineered solutions; Rozsa (1995) cites work conducted by the U.S. ACOE at Leetes Island Marsh (CT) modeling controlled flow restoration, which uses a series of structures that allow more water to leave the salt marsh on low tide than enters on high tide. Another solution may be the addition of fill to subsided intertidal or subtidal areas, creating suitable elevations for the establishment of salt marsh vegetation (C. Pickerell, personal communication).

5.c. Flooding

Drained salt marshes that have subsided due to oxidation and decomposition may increase the potential for freshwater flooding. When marsh elevations are lower, freshwater inputs from rainfall, snowmelt, creeks or rivers may remain trapped on the marsh surface. Standing water such as this may increase mosquito populations (C. Rilling, personal communication).

Flooding frequently occurs as a result of diking creeks and rivers. Salt marshes become flooded with fresh or brackish water, decreasing the ambient water and soil salinities and changing other chemical parameters (Shisler, 1990). The new ambient conditions influence the vegetative communities present, and invasive or brackish species generally dominate (Sinicrope *et al.*, 1990; Beare & Zedler, 1987). Impounded wetlands that have existed as standing water areas for some period of time may accumulate a great deal of sediment. In such instances, elevation of the former wetland surface, if drained, may no longer be appropriate for establishment of the original salt marsh community. Salt marsh vegetation can be lost due to prolonged inundation .

5.d. Changes in Salinity

Salt marshes that have been modified to decrease or eliminate tidal inundation will experience alterations in the salinity of both the "standing" water present, and their substrates. During dry periods, salinities in the marsh will increase as evaporation occurs and there is no tidal flushing or rainfall to dilute salt build-up (Nordby & Zedler, 1991). High concentrations of salt may burn plant roots, community composition may change, and barren zones may appear (Bertness, 1992).

Conversely, during wet periods (*e.g.*, rainfall, flooding, spring melt events, pulses of fresh water from sewer overflows), salinities will decrease as salt content is diluted and not replenished by tidal inundation. A similar situation may result from the impoundment of marshes at the mouth of a river or creek. The incoming brackish or fresh water will remain in the impoundment basin and no tidal flushing occurs to replenish salt content (Nordby & Zedler, 1991).

A decrease in salinity in the marsh to less than ~18 parts per thousand (ppt) will promote the invasion of common reed which is less tolerant of salt than naturally dominant species like smooth cordgrass and salt meadow cordgrass. In reduced-salinity marsh areas where *Phragmites* invasion does not occur, plant species diversity is often substantially increased, encompassing both salt marsh and brackish species. Cattail, for example, will germinate and grow in marshes whose salinities have decreased below 20 ppt (Beare & Zedler, 1987). However, Nordby & Zedler (1991) found that among fish and macrobenthic species, reduced salinities resulted in reduced species richness and abundances, population structures skewed toward young animals, and dominance by species with early reproductive development and long spawning periods.

5.e. Changes in Salt Marsh Vegetation

Salt marsh vegetation (primarily *Spartina alterniflora* and *S. patens*) may be lost as a result of chemical and physical changes in the ecosystem and through competitive exclusion by invasive species. Even minor changes in the elevation or salinity of salt marsh habitats will enhance competitive exclusion, especially by common reed. *Phragmites australis* is indigenous to the northeast (Orson *et al.*, 1987); however, an invasive form from Europe that spreads rapidly through brackish and freshwater marsh habitats is now believed to be present in North America (Besitka, 1996; Casagrande, 1997; R. Rozsa, personal communication). Recent research indicates that the invasive European form is phenotypically distinct from the native version (Besitka, 1996); current studies are underway at Yale University (Principal Investigator Professor K. Vogt/Research Assistant K. Sullivan) to establish genotypic differences between live, invasive examples of *Phragmites* and historical examples of native *Phragmites* (C. Rilling, personal communication).

Once established, *Phragmites* shades existing vegetation and hinders the germination and growth of other species. *Phragmites* stands are also thought to provide inferior nesting habitat for many marsh birds (Howe *et al*., 1978), including seaside sparrow, sharp-tailed sparrow, and willet. These marsh specialists are adapted to nesting in short grasses like *Spartina patens* and *Distichlis spicata* (Benoit, 1997). Conversion of salt marsh to *Phragmites* monocultures alters detrital cycling patterns due to the slower degradation rate of *Phragmites*' woody stalks, and increases the likelihood of fire as dead, woody stems accumulate (Niering & Warren, 1980). The slower degradation rate of *Phragmites* stalks can also raise the elevation of the marsh, thereby decreasing the area that can be flooded with salt water by tidal flow and further promoting *Phragmites australis* invasion (T. Diers, personal communication). Stands of *Phragmites*, growing up to 14 feet in height, are often considered to negatively impact the “viewshed” in an area (Tiner, 1987; Eastman, 1995).

Total loss of vegetation in the marsh, and the subsequent exposure of the substrate, will impact other important marsh functions. For instance, the presence of vegetation (any species) will decrease wave energy and retard erosion of the shore; store flood waters and decrease flooding of adjacent upland areas; remove nutrients and contaminants from terrestrial runoff; and foster sedimentation, which improves water quality in nearshore waters.

6. OVERVIEW OF RESTORATION METHODS

This overview of restoration methods is organized by types of impact (not disturbance) to assist with the development of restoration plans which respond to the specific conditions observed in a given salt marsh habitat. The impacts described in the previous section can generally be categorized as being associated with the tidal regime, the morphology, and/or the vegetation of the salt marsh habitat. For sites with impacts to tidal regime, for example, restoration planning will involve consideration of the factors discussed below under "Manipulating Tidal Regime". Most projects will be required to respond to more than one impact category.

6.a. Manipulating Tidal Regime

6.a.1. General Considerations

The most basic means of restoring salt marshes is reintroduction of a tidal regime. Ditches may be plugged to raise the elevation of tidal inundation in the marsh and reestablish natural pools and pannes in the marsh surface (Taylor, 1998). Tide gates and other flow restriction devices at tidal inlets may be removed or replaced with self-regulating devices that are calibrated for appropriate tidal hydrology in the marsh (Niering & Warren, 1980; ASCE, 1998). Culverts may be removed, replaced with wider culverts, or have clogging debris cleared from them (New Hampshire NRCS, 1998; Hruby, 1990). Dikes and other impoundments may be removed to drain flooded areas and restore a natural tidal range (Sinicrope *et al.*, 1990).

Reintroduction of tidal flushing to drained marshes that have subsided will result in flooding duration that is too long over most of the restoration area to achieve the original ratios of target plant communities (*e.g.*, low marsh, high marsh, salt shrub). Areas that were originally *Spartina patens*-dominated high marsh may be converted to *S. alterniflora* low marsh (Hruby, 1990; Rozsa, 1995). In extreme cases, the subsided area may be converted to unvegetated intertidal flat or standing water (Rozsa, 1995). Restoration may require some filling and regrading of the area to achieve the original, appropriate elevations before tidal inundation is reestablished. Conversely, for impoundments that have acted as settling basins, some excavation and regrading may be required to appropriate elevations before tidal inundation is reestablished. Otherwise, a significant area of the restoration site will remain above mean high water elevation.

6.a.2. Measuring Tidal Elevations

The first measurements required when planning the restoration of tidal regime at a site are tidal elevations. Mean High Water (MHW) at a specific site is a function of tidal prism, and is affected by adjacent bottom contours, prevailing winds, and currents (Lefor *et al.*, 1987; PERL, 1990; Lagna, 1975). Normandeau Associates (1992) note that salt marshes are associated with coastal features such as barrier spits and islands, embayments, and river mouths, all of which will modify tidal heights and ranges. Therefore, published tidal data are not likely to be sufficiently accurate for an individual salt marsh restoration site. McKee & Patrick (1988) found that growth range of *Spartina alterniflora* is positively correlated with mean tidal range (the elevation difference between low and high water), which explained ~70% of the statistical variation in upper and lower limits of growth. These researchers also found that *Spartina alterniflora* growth range differs by latitude among marshes with similar tidal ranges. Therefore, it is essential that tidal elevations be determined specifically for individual restoration sites.

There are a variety of simple methods available for measuring tidal elevations. The New Hampshire Coastal Program recommends a water-level maxima/minima gauge employing sliding magnets on a measuring rod developed by Richter (1997). In addition, they describe a "glue stick method", employing six foot tomato stakes marked at five centimeter intervals, covered with dried Elmer's glue colored with food coloring. A number of such stakes are placed throughout the restoration site; when the tide rises the glue will be washed off up to the elevation of high tide, and this elevation can be reconciled with known elevations at the site (NHCP, 1998). For example, a leveled string may be run from the stake (tied at the point indicating the highest elevation of the tide) to the point of intersection with the marsh surface. If the string is level between these points, the point of intersection should closely approximate the level of high tide in the marsh.

Another simple tide staff is described by Roman *et al.* (1984). Graduated poles housed within circular pipes are placed near tide gates or tidal creek inlets at the restoration sites. The graduated poles have a cup filled with cork dust attached. When the tide rises the cork dust floats up to the level of high tide adhering to the graduated pole at this level when the water falls. For any of these methods, a minimum measurement duration of two complete Spring tidal cycles is required (Burdick, unpublished).

6.a.3. Duration of Inundation

Tidal elevation data should be combined with information on topographic elevation and morphology of the site to determine duration of inundation. The duration of inundation at a particular elevation influences the vegetation found there. Seneca *et al*. (1985) studied the influence of duration of inundation on development of a planted *Spartina alterniflora* marsh. They found that through the first several growing seasons, *S. alterniflora* exhibited maximum well-being in the 7- and 4-hour inundation zones, but for the remaining period through 12 growing seasons *S. alterniflora* demonstrated a shift in maximum well-being to the 11- and 9-hour inundation zones, and dominated these zones for the duration of the study. The upper zones (7- and 4-hour inundation) became a mixed species marsh over the 12-year period, and by the twelfth year *Phragmites australis* came to dominate the uppermost, 4-hour inundation zone (Seneca *et al.*, 1985). These results compliment work from other researchers (Bertness & Ellison, 1987; Bertness, 1992) showing that *S. alterniflora* is limited to the lowest elevations of the marsh because of competition with other marsh species.

6.a.4. Sizing of Culverts

Where feasible, restoration tidal regime can be accomplished by removal of restrictions to the level of the natural marsh surface. If removal of some or all of the restrictions is not feasible, culverts can be placed or enlarged to improve tidal flow into the marsh. Site specific calculations must be made to determine the volume of tidal water required to flood the desired area.

Hruby (1990) provides a simplified method for estimating this volume. To calculate the volume of water required to flood the wetland, the surface area of the wetland and a topographic map of the area are needed. The amount of water needed to flood a given area of wetland can be calculated with this information by assuming an even grade between the two intervals.
In order to determine how many culverts, and of what size, are necessary to deliver the required amount of water the volume of water that will flow through a culvert of a given size must be determined. Such calculations are complex for round or oval pipes; Hruby (1990) suggests that the following estimates (based on data from Seatuck National Wildlife Refuge, Islip, NY) may be used: 1) A 12" round corrugated culvert

will pass ~1200 m^3 in one tidal cycle. 2) A 35" oval pipe will pass ~4000 m^3 in one tidal cycle. The number of pipes needed to flood the area of the marsh can then be roughly estimated using these figures (Hruby, 1990). These calculations should be employed to obtain estimates only; an engineering study should be conducted during the formal planning process to determine the actual area of inundation that will result.

6.a.5. Open Marsh Water Management

A series of techniques collectively termed "Open Marsh Water Management" (OMWM), designed to provide alternatives to grid ditching and chemical applications for control of mosquito populations, can be categorized as tidal regime restoration methods. OMWM centers on the creation of permanent, deep water areas in the high marsh that are connected by shallow channels to known mosquito breeding areas. Larvivorous fish, such as mummichog, thus have a habitat in the marsh (deep water pools), and access to mosquito breeding areas (shallow channels). When high water flooding of the marsh triggers larval hatches, the shallow channels are simultaneously flooded, bringing larvae-eating fish to the hatching mosquito population (Lent *et al.*, 1990).

Two desirable OMWM techniques are available: closed systems and semi-tidal systems. Taylor (1998) described optimum characteristics for the development of closed OMWM systems: Closed systems have shallow ponds and pannes (2"-18"), sump ponds (30"-36"), and pond radial ditches (~30"). Ponds are created at small depressions of mosquito breeding, by enlarging the area of the depression and excavating to a depth of 30"-36" in the deepest area of the pond. Peat depth is a limitation on any excavation for pannes, sumps, and ditches. Unconsolidated sands and gravels below the peat layer will not retain water (Hruby, 1990). Slopes should be gentle, ranging from 4:1 to 10:1. More shallow areas (such as the optimum migratory bird depth of 12"-18", 2"-3" shorebird foraging depth, or 7"-25" preferred *Ruppia maritima* depth range) may be created in the pond, as long as there is a 30"-36" sump area provided somewhere in the pond. Curvilinear ponds between 1/10 and 1/4 acre in size provide the greatest wildlife habitat benefit. Radial connector ditches that allow larvivorous fish access to and from sump ponds and mosquito breeding habitat should be at least 18" deep and 24" wide. Existing ditches greater than 36" in depth may be filled with marsh spoil to achieve a more appropriate ~30" depth. To create shallow ponds, pannes, and sump ponds, some parallel grid ditches must be plugged to hold permanent water on the high marsh. These ditches may be blocked with marsh spoil at or near their connection with the tidal channel. Plugs must be filled to slightly above marsh level, and extend laterally onto the marsh to prevent erosion around the edge of the plug. Plugs will settle and be impacted by water flow before revegetation and stabilization occurs. Lumber may be used to reinforce plugs, and wire may be used to discourage muskrat burrowing, during this stabilization period (Taylor, 1998). Another approach to ditch plugging involves use of 4' X 8' pressure-treated or marine plywood alone, driven into the peat with an excavator. The top may then be notched to the depth desired for the ditch water level (C. Rilling, personal communication).


Figure 11. Ditch plug in an OMWM system.

Some drawbacks to OMWM systems, especially the closed system, are reported. These systems may have high maintenance costs (T. Diers, personal communication). However, New Hampshire mosquito control divisions have found that properly-constructed closed systems do not require ongoing maintenance (J. Taylor, personal communication). OMWM systems have not been demonstrated as a common reed control method in salt marshes. Finally, the problem of spoil disposal resulting from pool and ditch excavation must be confronted (T. Diers, personal communication). In general, however, spoil from pool and ditch excavation may be used to bring up ditch depths and plug man-made ditches. Rotary ditching equipment may also be used to minimize spoil disposal impacts. This equipment, widely used in Massachusetts, New Jersey, and Delaware, shoots out a slurry that does not raise salt marsh elevation; vegetation is unchanged and the site fully recovered within one year (J. Taylor, personal communication).

The characteristics of semi-tidal systems are also described by Taylor (1998): This technique involves deep ditches (30") with sills, or shallow tidal outlets (4"-8"), that are only partially tidal. In this manner a sill drains very shallow standing water from the surface of the marsh, but does not excessively lower the water table. The depth of the sill controls the height of the water table. The sump pond and connector ditch system described for the closed system is also used for semi-tidal systems. However, some natural pond and panne formation will be precluded by the lower water table, impacting shorter-legged bird foraging area and vegetative community structure (Taylor, 1998).

Other biological methods of mosquito control have been suggested for use in salt marshes. The most commonly employed species, mosquito fish (*Gambusia affinis*), however, is native to the midwestern United States south to Mexico. This species has nonetheless been used for mosquito control in fresh and brackish water habitats from coast to coast. Mosquito fish are used by Suffolk County Vector Control (Yaphank, NY) only in contained freshwater areas, such as ornamental ponds, and measures to prevent escape into the natural environment are employed (T. Iwanejko, personal communication). The introduction of non-native species into the environment is not recommended. In addition, introduction of mosquito fish into New York salt marshes is unnecessary due to the presence of native species of larvae-eating fish such as killifish.

6.a.6. Low-lying Structures

Before tidal inundation can be reestablished at a site, the elevations of the lowest structures in the area (private property, homes, roads) must be determined. Restoration of the full tidal range may not be possible due to the potential for flooding nearby structures and property. Self-regulating tide gates are opened by a float that rises and falls with the tides. These devices can be set at the time of installation to restrict natural tidal inundation only to the extent required for the protection of low-lying structures. Self-regulating gates face the tidal side of an inlet and are hinged at the top; therefore, they float on the water's surface until counterfloats extending above the hinge point close them. The gates will be closed during high tides or storms, keeping excess water away from nearby homes and property. During ebb tide, a hydraulic head in the inlet reverses, and the gate reopens (ASCE, 1998). These devices require long-term maintenance to ensure continued proper operation, but are effective in balancing habitat restoration and protection of adjacent properties.

6.b. Manipulating Elevation, Slope, and Substrate

6.b.1. General Considerations

Salt marsh habitat is created by an interaction of the tidal regime and the morphology of the inundated landform. Specifically, proper elevations and slope are crucial for the establishment of native vegetation, which are specialized for different frequencies and duration of tidal inundation (Seneca *et al.*, 1985; Broome *et al.*. 1988). For example, the difference in elevation between the marsh edge and the bordering upland may be only 10-15 cm, or 4-6 in. (Lefor *et al.*, 1987). Therefore, reintroduction of tidal flushing alone may not meet your restoration goals.

Subsided or compacted areas which have lost elevation and lie below tidal elevations may require the addition of fill. Conversely, filled marshes, which have gained elevation and lie above tidal elevations need to be excavated to an elevation allowing tidal inundation. Similarly, impounded areas that have acted as settling basins (increasing marsh elevation) may require some excavation (after draining the impoundment) to achieve elevations that will result in an appropriate tidal cycle for marsh vegetation. In any of these scenarios, some grading and contouring will be necessary to achieve the necessary duration of inundation.

6.b.2. Slope

The slope of the site is an important factor to consider in restoration planning (Broome, 1990; Shisler, 1990; Normandeau Associates, 1992). The more gentle the slope at a restoration site, the greater the area on which intertidal marsh vegetation may become established. Broome *et al.* (1988) recommend slopes of 1-3% for marsh establishment. Gentle slopes dissipate wave energy over a greater area, thereby decreasing erosion and disruption to plantings. However, slopes that are too flat will decrease drainage, potentially leading to waterlogging and hypersaline conditions (Broome, 1990; Normandeau Associates, 1992). Mature marshes exhibit a variety of slope conditions (<1% to 10%), ranging from flat, high marsh surface to the nearly vertical low marsh creek banks (Broome *et al.*, 1988; Normandeau Associates, 1992). Some authors cite an observed range of marsh slopes of 6-20% (Reimold & Cobler, 1986, cited in Shisler, 1990 & Normandeau Associates, 1992). The type of restoration and the site conditions will help determine whether changes in the slope are required. Where excavation or fill are planned, target slopes should be carefully considered. Projects involving simple removal of tidal restrictions, by contrast, often will not require any change in slope.

6.b.3. Substrate Properties

Restoration of areas requiring the addition of fill, such as subsided or compacted marsh areas, may be accomplished using uncontaminated dredged material of proper grain size (Coastal America, 1996). The grain size of added fill influences both vegetative success and the level of difficulty encountered in handling the material at the restoration site (Normandeau Associates, 1992; Broome, 1990). Substrate properties affect colonization by important macrofauna, like *Geukensia demissa* and *Uca pugnax* (Kraus & Crow, 1985; Bertness & Miller, 1984). Coarse substrates, such as sand, are well drained, preventing chemical alterations associated with waterlogging from occurring (Normandeau Associates, 1992; Broome, 1990). These substrates are also more likely to resist excessive accumulation of salt (Broome *et al.*, 1988). Sand is more easily handled, contoured, and planted than finer-textured substrates (Normandeau Associates, 1992; Broome, 1990; Broome *et al.*, 1988). However, sand is low in nutrients and fertilization of plantings is required (Broome *et al.*, 1988; Normandeau Associates, 1992). Also, *Geukensia demissa* prefer substrates with a low sand content (0-20%) and high organic matter content (10-20%), and are found in decreasing concentrations on soils with increasing percentage of sand (Kraus & Crow, 1985).

Several authors cite specifications from Garbisch (1986) for wetland restoration substrates: a minimum of one foot in depth of clean inorganic/organic material of which 80-90% by weight will pass through a No. 10 sieve (Shisler, 1990; Normandeau Associates, 1992). Shisler & Charette (1984) recommend the following order of preference for substrates: 1) natural marsh peat; 2) clay and silty clay; 3) estuarine sediments (dredged material); and 4) sand (cited in Shisler, 1990). These authors caution that sand placed on marsh peat is unstable and will compact over time, resulting in pools of standing water on the marsh surface (Shisler, 1990). Broome *et al.* (1988) comment, however, that although most marshes naturally exist on peats high in organic matter, these marshes were initiated prior to organic matter accumulation, a process occurring over time through the development of the marsh itself. This organic matter accumulation will occur over time in a marsh established on sand or dredged material as well.

6.b.4. Tidal Channels

The creation of tidal channels is often necessary to facilitate the transport of seawater into back marsh areas. Filled marshes are more likely to require tidal channel creation than formerly connected or slightly disturbed areas. Tidal channels will often develop their own “fingers” (dendritic channels) and morphology through exposure to the natural tidal regime over time (Simenstad & Thom, 1996). Therefore, planning and engineering these dendritic channels at a restoration site may not be cost-effective (R. Thom, personal communication). Planning for tidal channel creation should be based on restoration goals as well as the size of the restoration site, its existing configuration, and the tidal regime to which it will be exposed.

6.b.5. Heavy Equipment

The use of heavy equipment in restoration activities (backhoes, bulldozers, trucks) may compact substrates that have been graded to an appropriate elevation, possibly resulting in restoration failure. In addition, compacted substrates greatly affect the survival, development, and rate of plant propagation at the site. Herbaceous species planted for restoration require unconsolidated substrates of four to six inches in depth for optimal development. There is special, low ground pressure equipment (less than 2 pounds per square inch) available to help prevent compaction problems during restorations (Hruby, 1990; for example, CT DEP).

6.c. Manipulating Vegetation

6.c.1. Planting *vs*. Natural Colonization

Often, restoration of tidal flushing, combined with the existence or creation of an appropriate marsh morphology (*i.e.*, elevation, slope, grade, substrate, *etc.*) will be enough to rapidly revegetate the area with native salt marsh communities (see Sinicrope *et al.*, 1990). However, if there is no peat layer, or the site is isolated from sources of recolonizing vegetation, planting may be required in order to decrease the length of time before natural revegetation occurs. Planting, though potentially costly, is beneficial in the restoration of sites damaged by pollution, *e.g.*, an oil spill (Matsil & Feller, 1996), and can hasten re-establishment of target salt marsh vegetative communities.

The following factors should assist in making this decision: surrounding land uses and their potential to contribute disturbances or invasive species; isolation of the site from similar, natural sites that could act as seed sources; the time of year the restoration will be accomplished; hydrologic considerations such as timing and duration of inundation, water level fluctuations, and flushing; and the characteristics of site substrates and any substrate augmentations planned (Kentula *et al.*, 1993).

6.c.2. *Spartina alterniflora*—Seeding

Seeding has been used to restore *Spartina alterniflora* marsh. However, seeding is not effective on sites subject to even moderate wave energies (Broome, 1990) and is not recommended in most cases. Seeds may be collected locally and propagated for planting as stems or plugs. *Spartina alterniflora* seed should be harvested near maturity but prior to shattering (usually in August-early September in the northeast). Seed heads may be clipped with knives or shears. Harvested seed should be transferred to burlap sacks for temporary storage and kept moist under refrigeration, for 3-4 weeks before threshing. After threshing, *S. alterniflora* seed should be stored in saline water (18-35 ppt) in covered containers at 2-4 degrees Celsius (36-39 degrees Fahrenheit). Seed life, when stored in this manner, is up to 1 year. For additional detail on harvesting seed heads, threshing, storage, and planting see Broome (1990) and Broome *et al.* (1988). The cost of *Spartina alterniflora* seed from a nursery runs from $15 to $35 per thousand pure live seed; the cost of pure live *Spartina alterniflora* seed needed to plant one acre (10 pure live seed per sq. ft., requiring a total of 440,000 pure live seed) is approximately $6,600 (Environmental Concern, 1998).

6.c.3. *Spartina alterniflora*—Stems, Plugs, and Potted Seedlings

Planting growing or dormant plants, or plant propagules, is the most reliable planting method for salt marsh restoration projects (Broome *et al.*, 1988; Garbisch *et al.*, 1975). *Spartina alterniflora* may be planted using single stems (no soil around roots) or plugs (intact root and soil mat included). Transplants of *S. alterniflora* may be dug from the field or grown from seed in pots or flats, either in a greenhouse or outdoors when temperatures permit (Broome, 1990; Broome *et al.*, 1988). Seedlings of *S. alterniflora* and other salt marsh plants may be greenhouse-grown in a medium of equal parts sand, top soil, and peat moss or vermiculite (Broome *et al.*, 1988).

Potted seedlings are desirable because they avoid disturbing natural vegetation, and can be held when delays are encountered. However, potted seedlings often result in much higher costs (especially if they are purchased from a nursery); require advance planning if not readily available from a commercial source or if propagated from harvested seed;

are inconvenient to transport; and do not contain native soil composition and microorganisms that will jump-start functional restoration (Broome, 1990).

6.c.4. *Spartina alterniflora*—Planting Methods

Mechanized planting has been accomplished at some sites--see Broome (1990) and Broome *et al.* (1988). However, hand-planting is generally required for intertidal vegetation. Planting should occur in spring or early summer (*e.g.*, May-June; Broome, 1990). Planting holes should be ~15 cm in depth, 5-7 cm in diameter; a soil auger of appropriate diameter may be used for this purpose (Broome *et al.*, 1988). Stems or plugs of *Spartina alterniflora* are then inserted into the planting hole. Soil should be firmly pressed around the plant to prevent dislodging by waves (Broome, 1990).

6.c.5. *Spartina alterniflora*—Fertilization

Better results are often achieved when a slug of fertilizer, containing both nitrogen and phosphorus, is added to each plant during planting (Garbisch *et al.*, 1975; Broome, 1990; Broome *et al.*, 1983). Slow release fertilizers (such as Mag Amp or Osmocote), are the most effective and widely used (Broome *et al.*, 1983; Broome, 1990; Broome *et al.*, 1988). Use of slow release fertilizers avoids pulsed nutrient additions, which may cause increased insect herbivory and defoliation (Langis *et al.*, 1991). Mag Amp, however, has the disadvantage of producing low growth early in the season as a result of extremely low solubility and an inappropriate ratio of nitrogen to phosphorus. A possible alternative nitrogen source to slow-release fertilizers is ammonium sulfate. This is more economical, but is soluble and therefore less persistent. An alternative source of phosphorus to the slow-release fertilizers is concentrated superphosphate (Broome *et al.*, 1983).

Osmocote or Mag Amp fertilizers should be placed directly in the planting hole beneath the *Spartina alterniflora* sprig or plug, about 15-30 grams (0.5-1 oz.) per plant. Conventional, soluble fertilizers may also be placed directly in the planting hole when applied at low rates of fertilization (Broome *et al.*, 1983). These should be placed in a separate hole near each plant (~5 cm distant), at a higher rate of fertilization than for conventional fertilizers (Broome, 1990; Broome *et al.*, 1988). This avoids direct contact with plant roots and the potential for root burn. Surface fertilization is ineffective for low salt marsh restoration (Broome *et al.*, 1983). Broome (1990, p. 57) provides a table of appropriate quantities for various fertilization rate formulations, for both slow-release and soluble fertilizers.

Less standard fertilizers composed of kelp meal, seaweed extracts, and fish meal may be appropriate for salt marsh restoration. Pelletized versions of these products exist and some are designed for long-term nutrient release. However, no research appears to have been conducted on the use of such fertilizers in intertidal environments. Some non-standard fertilizer formulations also contain growth hormones, which may not be appropriate for applications in the natural environment. Additional information on non-standard fertilizer formulations is necessary before their use in salt marsh restoration projects could be recommended.

6.c.6. *Spartina alterniflora*—Spacing of Plants

The spacing of plants is important to the success of vegetation re-establishment. Broome *et al.* (1986) found that plans for marsh plant spacing should be based on the harshness of the restoration environment. Restoration success in the first growing season, in high energy and exposed areas will depend on a higher planting density. In this type of environment, 45- and 60-cm spacings (~1.5-2.0 feet) resulted in the most successful aboveground standing crops of *Spartina alterniflora* populations near the lower elevation limits of this species. In more favorable environments, 90-cm to 1 m spacing (~3.0 feet) is adequate for establishment of similar aboveground crops (Broome *et al.*, 1986; Broome, 1990). One foot plant spacing is commonly used in New York for *Spartina alterniflora*. The advantage of closer spacing toward population establishment is provided by the greater density of plants emerging from rhizomes at the beginning of the second growing season, and possibly from the stabilizing effect of the more closely-spaced roots and rhizomes during the first winter. In addition to planting success, Broome *et al.* (1986) found that in the early post-restoration, belowground biomass is also affected by spacing. Belowground biomass after 3 growing seasons was greatest for areas planted at 45-cm intervals, with no significant difference in this parameter observed between areas planted at 60- and 90-cm spacings. After 4 growing seasons, however, no significant differences were observed in belowground biomass among spacing treatments (Broome *et al.*, 1986).

6.c.7. Other Plant Species

Spartina patens may be planted as described above for *S. alterniflora*. Direct seeding is not considered effective for restoration of *S. patens,* but seeds may be harvested and propagated for planting as potted seedlings. In general, however, *S. patens* seeds are not considered to be very viable (C. Pickerell, personal communication). Slow release fertilization is generally unnecessary in the high marsh, therefore conventional forms of fertilizer may be used when planting *S. patens* in these areas. Fertilization should ideally occur 3-4 weeks after planting to allow the root system to develop. Nitrogen fertilization provides the most vigorous response (Broome, 1990).

Distichlis spicata is another high marsh plant species. It may be restored by transplant, rhizomes, seeds, or plugs. *Distichlis spicata* should be transplanted in late winter-early spring (February-March). Seeds may also be propagated for use as potted seedlings as described above; seeds should be harvested in the fall and must be stored under refrigeration (Broome, 1990).

6.c.8. Estimated Costs for Plants

Planting a one acre restoration site with *S. alterniflora* peat pots, therefore, could cost between $24,200-$33,000 (assuming one 2" peat pot per square foot). Collection and propagation of native plant seed for use in the restoration project should be considered to insure use of the most appropriate plant variety at the site. For example, short form *S. alterniflora* may not be appropriate for some sites, *e.g.*, where tidal range is large and tall form *S. alterniflora* naturally dominates. The converse—tall form *S. alterniflora* is not appropriate for sites naturally dominated by short form *S. alterniflora*—would also be true. Use of native seed for plug propagation also promotes natural genetic diversity at the site, and the introduction of genetic stock that is most appropriate for conditions at the site.

Costs for several common salt marsh plants may be estimated using Table Two (Pinelands Nursery, 1998; Talmage Farm, 1998; Environmental Concern, 1998). This table shows costs for salt marsh plant materials, including additional high marsh and shrub fringe species.

Table 2. Cost of nursery-grown salt marsh plant species in 1998 dollars.

Species	Size/Form	Cost (1998 dollars)
Spartina alterniflora	1.5"-2" peat pots	$0.55-$0.75 ea.
Spartina patens	1.5"-2" peat pots bare root clump/plug	$0.55-$0.75 ea. $0.60 ea.
Distichlis spicata	1.75"-2" peat pots	$0.60-$0.85 ea.
Juncus gerardii	2" peat pot	$0.55-$0.70 ea.
Panicum virgatum	1.75"-2" peat pots 1 quart pot 1 gallon pot	$0.50-$0.85 ea. $1.60 ea. $4.35 ea.
Iva frutescens	1 gallon pot 12"-18" 18"-24" 2'-3'	$6.00 ea. $4.00-$5.00 ea. $6.00 ea. $8.00 ea.
Baccharis halimifolia	1 gallon pot 12"-18" 18"-24" 2'-3'	$6.00 ea. $4.00-$5.00 ea. $5.00 ea. $7.00 ea.

Vegetation at the restoration site, either planted or naturally re-established, may be damaged by grazing and foraging activities of waterfowl and other wildlife. Floating debris deposited on the marsh may also impact restoration success. Exclusion fencing and/or debris barriers may be required to prevent vegetative losses (Broome, 1990; M. Matsil, personal communication; C. Pickerell, personal communication). Large debris such as logs, however, will not be excluded by barriers and may still cause significant damage to the salt marsh. If possible, conduct periodic visual assessments of the marsh (separate from the standard monitoring protocol) to assist in timely mitigation of such disturbances, should they occur.

6.d. Invasive Species Control: Common Reed

6.d.1. General Considerations

Salt marsh vegetation may be absent as a result of competitive exclusion by invasive species, often *Phragmites australis*. In many cases, restoration of tidal inundation coupled with an appropriate morphology will gradually eliminate *Phragmites* without further intervention. However, in cases where *Phragmites* remains or site specifics dictate (the presence of freshwater seepage or springs), removal of this species may be more effectively accomplished by mowing or cutting, or by application of glyphosate herbicide, produced commercially by Monsanto under the name Rodeo. A variety of *Phragmites* removal techniques are discussed below.

Figure 12. Stand of invasive common reed.

6.d.2. Common Reed Habitat

Common reed is common in brackish environments associated with *Spartina*, *Carex*, *Typha*, and *Juncus* species. Common reed can be found almost anywhere wet but not inundated. Its more frequent occurrence in brackish areas is not preferential but a result of its competitive edge over freshwater species when waters are slightly saline. Observed maximum salinity tolerances from 10 to 30 parts per thousand (ppt) have been reported, with 10 to 18 ppt a more commonly observed range. Common reed will outcompete other vegetation in shallow, stagnant waters with poorly aerated sediments.

Reproduction by this species is primarily vegetative, although seed is produced. *Phragmites australis* flowers and sets seed between July and September, and seeds are dispersed between November and January. Investigations indicate that most seed produced by common reed plants is not viable. Once seeds are set, nutrients are translocated to rhizomes and the aboveground portions of plants die back for the winter.

6.d.3. Disturbances Favoring Common Reed

Anthropogenic disturbance has increased the quantity of favorable common reed habitat in the United States. Filling and construction activities that alter an area's hydrology promote the growth of *Phragmites australis* where elevations are increased or inundation is decreased. Common reed is adept at invading bare, sandy patches caused by excessive sedimentation. The proliferation of paved surfaces also contributes to the creation of bare areas because it promotes flashy passage of water through the environment, destabilizing substrates. Runoff containing deicing salts increases soil salinity, favoring common reed. High concentrations of nutrients, especially nitrates, also appear to favor this species, although European declines of *Phragmites australis* have been partially blamed on eutrophication.

6.d.4. Natural History of Common Reed

Common reed is an indigenous species of the northeastern United States. Evidence of its presence has been found in cores 3000 years old (Niering and Warren, 1977). In the twentieth century many populations of common reed exhibited extremely aggressive growth, forming vast monocultures and replacing indigenous, often rare plant communities. Currently, there remains some uncertainty regarding the natural history of this species and the cause of its sudden expansion. Similarly, there remains high uncertainty regarding when and how to manage common reed in coastal environments.

The aggressive form of *Phragmites australis* is believed to be a genetically different stock native to Europe transported to North America in ship ballast (Besitka, 1996; Casagrande, 1997; R. Rozsa, personal communication). Recent research indicates that the invasive, European form is phenotypically distinct from the native version (Besitka, 1996); current studies are underway at Yale University (Principal Investigator Professor K. Vogt/Research Assistant K. Sullivan) to establish genotypic differences between live, invasive examples of *Phragmites* and historical examples of native *Phragmites* (C. Rilling, personal communication).

6.d.5. Impacts caused by Common Reed

Common reed shades other indigenous vegetation, and hinders germination and growth by other species through shading and dense accumulation of litter. *Phragmites* monocultures alter detrital cycling patterns because *Phragmites*' woody stalks exhibit a slower rate of decomposition. *Phragmites* monocultures are also more susceptible to wildfires when the dead, woody litter from stalks accumulates (Niering & Warren, 1980). Slow degradation of *Phragmites* litter raises the elevation of an invaded marsh, decreasing tidal flooding and further enhancing habitat suitability for this species (T. Diers, personal communication).

Mammalian and avian diversity are low in *Phragmites* stands. This is partly caused because this species provides inferior nesting habitat for many marsh birds (Howe *et al.*, 1978), including seaside sparrow, sharp-tailed sparrow, and willet. These birds are marsh specialists adapted to nesting in short grasses like *Spartina patens* and *Distichlis spicata* (Benoit, 1997; Benoit, 1999).

Phragmites australis monocultures can produce large broods of mosquitos. Common mosquito control techniques are ineffective in *Phragmites*-dominated marshes because dense stands of this species prevent access to mosquito breeding areas.

Phragmites may also detract from an area's scenic quality. This species can reach 14 feet in height (Tiner, 1987; Eastman, 1995), shielding panoramas from view. Common reed invasion has caused this type of problem in Boston's Back Bay Fens, designed by Frederick Law Olmstead.

6.d.6. Ecological Value of Common Reed

In some cases, *Phragmites* control is not necessary. Since this species is indigenous to marsh habitats, eradication is not warranted. Stable stands, *i.e.*, those that are not increasing in size and invading adjacent habitat, should be considered a natural and appropriate part of the plant community.

A variety of recent research on the effects of *Phragmites australis* on habitat value indicate that this species may provide more beneficial functions than previously thought. *Phragmites* has a high capacity for nutrient assimilation. Rates of denitrification and concentrations of ammonium in porewaters are lower in areas where *Phragmites* is the dominant species, than in areas dominated by other indigenous marsh vegetation.

While some declining bird species are negatively affected by *Phragmites* invasion, stands of this species are not entirely devoid of habitat value. For example, marsh wren and swamp sparrow are marsh specialists that prefer tall, reedy vegetation. For certain bird species the presence of *Phragmites* has been observed to make little difference in use of an area.

Invertebrate populations also appear not to differ in their use of *Phragmites* stands and *Phragmites*-free areas. Studies using the common estuarine species marsh fiddler crab, grass shrimp (*Palaemonetes pugio*), and larval mummichog found no preference by these species for *Phragmites* or *Spartina* stems, preference given only to stems over bare substrates.

6.d.7. Determining the Need for Control

Stands of common reed should be assessed for stability before control methods are planned and implemented. If available, historical aerial photography may be used to determine trends in *Phragmites* coverage at a given location. To assess stability, the following parameters should be monitored over several growing seasons: percent aerial cover by *Phragmites*; stem density; culm height, especially at periphery of stand; and trends in species diversity among other plants in the community. In a single growing season, stability may be roughly assessed by monitoring growth beyond a set of markers delineating the front edge of a stand at the beginning of the season. A disputed indicator of expanding stands is the presence of long rhizomes spreading over new areas of the marsh surface; further information on this indicator is needed.

Clear goals and specific management objectives must be developed for *Phragmites australis* stands warranting control. Articulating these goals and objectives will assist in the selection of the most appropriate control method. The degree of control desired, time frame for results, species targeted for revegetation or for use of the restored salt marsh, and other factors should be determined for each control project. Each project can then be tailored to fit its particular goals and limitations.

6.d.8. Control Methods for Common Reed

Regardless of technique used, effective control of *Phragmites australis* requires knowledge of the plant's life cycle and its local growing season in order to most appropriately select and schedule control treatments (Cross & Fleming, 1989). Also, the likelihood for return of *Phragmites* after control strategies have been implemented, due to site characteristics or ongoing disturbances, should be carefully considered during the planning phase. Disturbances contributing to the presence of common reed should be identified and minimized prior to the implementation of any control strategy in order to maximize the likelihood for success.

Considerable care should be exercised in selecting a control method for *Phragmites australis* populations. Unfortunately, it is not appropriate to advocate a single method for all cases. Site specifics and project goals must be examined to determine which method or methods will be most effective and least disruptive. For example, the time windows for sensitive species in the area and control method implementation should not coincide. Adjacent land uses at a site may preclude certain control strategies, like prescribed burning or flooding. Also, the size of the *Phragmites australis* stand may also influence selection of control methods, *e.g.*, cutting or mowing may not be feasible for extremely large sites. These and other factors must be carefully examined prior to project planning once it has been determined that a *Phragmites* stand warrants control. Details and planning considerations associated with common *Phragmites australis* control methods are presented in the following sections.

6.d.9. Tidal Inundation

Where control is warranted, the most basic method involves reintroducing regular tidal flooding of the site (Rozsa, 1995). *Phragmites* seeds cannot sprout in salinities >10 parts per thousand (ppt) and most *Phragmites* plants cannot tolerate salinities >18 ppt. It is important to take flood considerations into account when planning for removal of tidal restrictions; self-regulating tide gates and other technologies, often expensive, may be required to balance ecosystem restoration with adjacent land use. Other methods for increasing tidal flow to a formerly flooded area involve simple measures such as removing blockages in culverts. After tidal inundation has been reintroduced, it may take many years to completely eliminate *Phragmites*, but stand height can be reduced by one to three feet per year during this period. Salt marsh vegetation often will naturally recolonize the site.

At some sites, such as areas near freshwater seeps, removal of tidal restrictions alone will not be effective. In these situations, an effective common reed control technique involves creation of 24" wide by 36" deep perimeter ditches dug at the upland edge of unrestricted tidal marshes. These perimeter ditches are then connected to grid ditches subject to tidal flooding. This drains fresh water and increases salt water flow into the back marsh, raising soil salinity (T. Diers, personal communication). In brackish marshes where saving specialized indigenous vegetation is a priority other control techniques are required.

6.d.10. Cutting and Mowing

Cutting and mowing are techniques frequently employed to control common reed. Conflicting reports are given for the best season to conduct mowing and cutting. Some researchers report that mowing may be conducted in either the winter or spring. Winter mowing has produced stunted growth in the following year, possibly as a result of interference with oxygen uptake mechanisms. Spring mowing immediately following the first appearance of shoots (around April) has resulted in stunted and low density of new shoots (OLISP, 1998). However, some reports cite increased growth of *Phragmites australis* following winter and spring mowing. Summer mowing or cutting may be the most consistently effective strategy. Cutting *Phragmites* plants after tasseling, *i.e.*, late July, may produce the most stress. This method should be conducted for several consecutive years for maximum effect.

All cut materials must be removed from the restoration site to prevent establishment of new *Phragmites* plants from cut pieces of rhizome. Cuttings may, however, be mulched or disked on site, although this generally increases the expense of the project. Mulching or disking still may not prevent the problem of plant reappearance from rhizome fragments. Low ground pressure equipment should be used when manual cutting or mowing is not feasible.

6.d.11. Cutting and Mowing Combined with Other Techniques

Research from Connecticut College has shown that mowing used in combination with herbicide application or flow restoration may elicit better results (C. Rilling, personal communication). Mowing or cutting and removal of litter subsequent to herbicide application removes combustible plant debris, minimizing a fire hazard and allowing reestablishment of other vegetation. Mowed or cut stands of *Phragmites* may be flooded for a prolonged period (~ 4 months), generally during the growing season. This latter strategy requires spring mowing, and such prolonged flooding may not be feasible in many areas. Mowing or cutting may also be followed by the use of a temporary clear or black plastic cover (Marks, Lapin & Randall, 1993; Tiner, 1998). It is thought that high temperatures under the plastic are the primary cause of *Phragmites* mortality resulting from this strategy. More information on long-term effectiveness of plastic covers used on mowed or cut *Phragmites* is needed.

6.d.12. Controlled Burning

Controlled burning may be employed in cases where a supply of dry, combustible litter is accumulated (OLISP, 1998). This strategy, therefore, may only be employed periodically (in alternate years at its most frequent). Controlled burning in *Phragmites* stands can be dangerous because there is a potential for remote spot burns to break out in the area.

Conflicting reports are also given regarding the optimal season to conduct controlled burns. The Office of Long Island Sound Programs (1998) recommends burning simultaneous with new shoot emergence in the spring (around April). Research from Europe supports this recommendation. However, others have reported enhanced *Phragmites* growth from spring and winter burns. It is hypothesized that enhanced growth after burns during these seasons is caused by elimination of shade, exposure of burned soil, nutrient enhancement from ash deposits, and generation of viable plant fragments (Weinstein, 1996). Mid to late-summer burning may be the most consistently effective alternative. For burning to be effective in reducing common reed growth, root burn must occur; burns penetrate the roots most easily during this period. *Phragmites* may also be vulnerable to late summer (July/August) burns because translocation of nutrients to roots may have begun. Burn timing must be planned with potential effects on wildlife, *e.g.*, nesting birds, in mind.

It should be noted that controlled burning is a regulated activity in the State of New York requiring a variety of approvals and permits. It is necessary to contact Department of Environmental Conservation permit staff, the local fire department and fire marshall, and the State Emergency Management Office prior to planning and undertaking a controlled burn for *Phragmites australis* control.

6.d.13. Controlled Burning Combined with Other Techniques

Controlled burning may be used most effectively in combination with other control strategies. Burning subsequent to herbicide application removes dead stems and litter, assisting revegetation by other plant species (Marks, Lapin & Randall, 1993). Burns may also be followed by prolonged manual flooding of the area (~ 4 months), generally during the growing season. Prolonged flooding of this nature would follow emergence (spring) burns, and may not be feasible in many areas.

6.d.14. Chemical Control

Chemical control of *Phragmites* is possible. It is important to note that chemical control should be carefully considered before implementation; particular attention should be paid to the likelihood of a return of the *Phragmites* after the control project is terminated, *e.g.*, in freshwater or brackish systems and in disturbed areas without mitigation.

Herbicides that have been used to control common reed include amitrole, dalapon, and glyphosate (Cross & Fleming, 1989). All three of these chemicals listed above are absorbed through plant leaves and are translocated to rhizomes (CCE, 1998a,b,c). Amitrole (Rhone Poulenc Agricultural Company, Research Triangle Park, NC; CCE, 1998b) is effective on both flooded or dry sites; Amitrole is, however, a Restricted Use Pesticide (RUP), and may be purchased and used only be certified applicators. Amitrole is considered a probable human carcinogen (CCE, 1998b). Dalapon (BASF Corporation, Agricultural Product Group, Research Triangle Park, NC; CCE, 1998c) and glyphosate, both general use pesticides, are not as effective on flooded sites but do work on moist or dry sites. Rates of application for Amitrole range from 2-12 lb. per acre, generally occurring during the summer. Dalapon has been used at rates ranging from 15-30 lb. per acre, applied throughout the growing season (Cross & Fleming, 1989). The third herbicide, glyphosate, will be further discussed below under one of its trade names, Rodeo (Monsanto Agricultural Company, St. Louis, MO; CCE, 1998a).

The herbicide Rodeo is the most common herbicide employed for *Phragmites* control, and can be effective in controlling monocultures of this plant. Rodeo is a moderately toxic herbicide containing glyphosate, the same active ingredient as Roundup, the common lawn and garden herbicide. The glyphosate in Rodeo is not, however, pre-mixed with a surfactant. As described above, this nonselective herbicide is absorbed through plant leaves and translocated to plant roots, where it disrupts an enzyme essential to protein production. Cell disruption, decreased growth, and death of the plant root and rhizome eventually follow (Rilling, 1998a).

Rodeo should be applied to actively growing plants following pollination and tasseling (between July and September; Magee, 1981; Marks, Lapin & Randall, 1993). All plants do not tassel simultaneously, and several treatments during the flowering period may be necessary (OLISP, 1998; Rilling, 1998a). Rodeo is generally applied at a rate of 4-6 pints per acre (Cross & Fleming, 1989; Rilling, 1998a). Cross & Fleming (1989) report that some researchers found an increased effectiveness when Rodeo applications were split, *i.e.*, administering two doses at ½ the dosage rather than a single full dosage. The second application should occur 15-30 days after the first (Cross & Fleming, 1989).

Rodeo should be applied during warm, sunny weather with no rain forecast for a minimum of 12 hours. Low wind conditions are also necessary to prevent spray drift onto non-target vegetation (OLISP, 1998; Rilling, 1998a). Late summer (around August) is a good target period for satisfying many of the above conditions. Rodeo has been applied using techniques ranging from manual spray equipment transported by backpack, to aerial application from a helicopter. Size of stand, accessibility, and proximity to rare plant species or other priority vegetation must be considered when planning herbicide application (Cross & Fleming, 1989). Wilting and yellowing generally begins within a week following application, and browning and deterioration of roots should be complete within 6-8 weeks (Rilling, 1998a). Removal of plants after shoots turn brown will assist recolonization by other plant species.

Rodeo is highly adsorbent on substrates with high organic content, where it becomes inert, and non-volatile. Rodeo is degraded into natural products, *e.g.*, carbon dioxide, nitrogen gas, phosphate, and water, by soil microorganisms between 1 and 174 days (CCE, 1998a; Weinstein, 1996; Rilling, 1998a). Because glyphosate is strongly adsorbed to suspended organic materials, it has half life of 12 days to 10 weeks in natural waters (CCE, 1998a; Rilling, 1998a). For this reason it is recommended that Rodeo be mixed with distilled water prior to application to minimize adsorbance onto particulate organic materials in tap or other water, decreasing the effectiveness of application.

Rodeo has been approved by the U.S. EPA for use in aquatic systems (Cross & Fleming, 1989). The protein production enzyme disrupted by glyphosate is found only in plants (Rilling, 1998a). Rodeo is therefore considered of low toxicity for humans, birds, mammals, fishes, and aquatic invertebrates (Rilling, 1998a; CCE, 1998a). There is low potential for accumulation of glyphosate in the environment or in animal tissues. No reproductive, teratogenic, mutagenic, carcinogenic, or organ toxicity effects have been found in field and laboratory evidence. Acute toxic effects are limited to eye irritation. Oral LD50 values for glyphosate range from 1,500 mg/kg to over 10,000 mg/kg for mice, rabbits and goats (CCE, 1998a).

Rodeo must be mixed with a surfactant prior to application. The surfactant acts as a wetting agent, softening the waxy layer on plant surfaces and allowing glyphosate to be absorbed. Without a surfactant, the herbicide "balls up" on the leaf surface (CCE, 1998a; C. Rilling, personal communication). Some surfactants used with glyphosate (*e.g.*, Induce or Chemsurf 90) may have toxic effects for humans and the environment. For example, the surfactant additive found in Roundup is a modified tallow amine toxic to fish (CCE, 1998a). Roundup should therefore not be used for the control of *Phragmites australis* in aquatic environments. Limited test data appears to indicate that other surfactants are relatively non-toxic, *e.g.*, X-77, LI-700, and Kinetic (Weinstein, 1996). Selection of an appropriate surfactant for Rodeo should be carefully researched; see Weinstein (1996) for additional information on surfactants.

It should be noted that pesticide application is a regulated activity in the State of New York. Department of Environmental Conservation permit staff must be consulted prior to planning and undertaking any pesticide applications for *Phragmites australis* control.

7. SALT MARSH RESTORATION—RECOMMENDED MONITORING PROTOCOL

Monitoring is a critical element of adaptive management, an interactive process that regularly reexamines prior choices in the light of current outcomes (Wilber & Titre, 1996). This incremental management process employs a flexible design, where management actions may continually change to respond to new information on progress generated by monitoring. This type of structure maximizes the success of management activities. Additional information on adaptive management may be obtained from Yozzo, Titre & Sexton (1996) and Thom & Wellman (1996).

This section includes the recommended components of a monitoring program for salt marsh restoration projects conducted in the estuarine waters of New York State. These components are not presented in a "discussion" format; several fine discussions of restoration monitoring are available elsewhere and are recommended as background (see Thom and Wellman, 1996; PERL, 1990; Kentula *et al*., 1993, pp. 43-72; Erwin, 1990, pp. 429-458; Broome, 1990, pp. 60-61). They are presented as a protocol and in contract work plan format to assist municipalities and other entities with the incorporation of a monitoring program into the restoration project planning process. The New York City Parks Department Natural Resources Group is the first to participate in a pilot initiative using this monitoring protocol for their state-funded habitat restoration projects (Bergen *et al*., 2000).

The monitoring protocols which follow can and should be tailored for individual projects. The parameters and methods suggested represent the baseline information generally required to adequately monitor the generic salt marsh restoration project. However, depending on restoration goals and the details of the project, a modification of the suggested protocol may be warranted. For example, the numbers and placement of transects and quadrats may be altered, different biotic elements may be tracked, or additional chemical parameters may be included. Also, although these elements are not included in the protocols which follow, pre-project monitoring must include site assessment of important characteristics (hydrological properties, elevations, tidal regime) needed to develop a feasible restoration project. In general, planning of the monitoring program should occur during the general project planning process. Alterations to the suggested protocol should be reviewed with the regulators in charge, the appropriate natural resources managers, and qualified ecologists.

A sample timeline for monitoring salt marsh restoration projects is included in Appendix C.

SALT MARSH RESTORATION MONITORING WORK PLAN

Modifications to the monitoring guidelines described below must be discussed with and approved by the Regulator(s) and representatives of the funding entity prior to all restoration activities. All approved modifications need to be clearly articulated in the work plan in a manner similar to that below.

1) Principle parties:

The party responsible for carrying out all restoration requirements will be referred to as the Responsible Party (RP). These restoration activities include the development and implementation of a monitoring protocol to assess the progress of the restoration during, and to evaluate the success or failure of the restoration at the conclusion of, the monitoring period (a period $\geq$ 5 years is recommended).

The RP for the ________(project name)____________ is __________(agency/name)__ ________.

Other parties that may be involved in restoration and restoration monitoring activities are:

- The Designer of the restoration, who is responsible for including monitoring specifications in the design and site plan, including specific locations of transects, quadrats, permanent fixed-point photo stations, and other features.

The designer for this project is ____________(agency/name)____________________ ________.

- An Ecologist to assist in planning and implementing a site-specific monitoring protocol.

The ecologist for this project is ___________(agency/name)_____________________ ________.

- The Contractor(s) is(are) in charge of construction and of maintenance of the site and its features, including all transects, quadrats, and fixed-point photo stations. When a contractor is not required , all site manipulation and maintenance activities are generally the responsibility of the RP.

The contractor(s) for this project is/are ______________ (name/names) ____________ ________.

•The Regulator(s) is(are) responsible for approving the restoration designs and monitoring protocols, and for any required permitting for restoration activities.

The Regulator(s) for this project is/are ______ (NYS DEC, NYS DOS, ACOE, other) _____.

•Volunteers may be involved in conducting monitoring activities. They may require training, and usually will be supervised by and/or report to the RP.

Note: The RP will be responsible for ensuring fulfillment of all monitoring requirements, including those of the Designer, Ecologist, Contractor(s), and Volunteers as specified in the work plan, and is responsible for reporting as specified to the Regulator(s), when applicable. The Designer and the Ecologist may be the same person or from the same agency, and this person/agency may also be the RP.

2) Purpose:

This monitoring protocol is designed to assess the progress towards, and the success or failure of, a restoration of salt marsh habitat and the achievement of acceptable standards of salt marsh character and function. At a minimum, this should include regular assessment, for a period $\geq$ 5 years, of vegetation development, soil properties, colonization by benthic invertebrates, and habitat usage by macrofauna, as described below.

3) Monitoring Protocol Design:

Plan and locate all salt marsh restoration project transects, 1.0 m^2 quadrats, and fixed-point photo stations according to the guidelines described below. Any modifications to these guidelines shall be discussed with the Regulator(s) prior to conducting any restoration activities, and, if approved, the modified monitoring protocol shall be clearly articulated prior to all restoration activities in a work plan.

A work plan should always be written by the responsible party for any restoration project undertaken, including any site-specific modifications to the recommended monitoring protocol, where necessary and appropriate. Monitoring parameters and activities, whether the recommended protocol below or some other approved protocol, should be clearly articulated and documented in the work plan in a manner and a level of detail similar to the guidelines below. All transects, 1.0 m^2 quadrats, and fixed-point photo stations should be assigned location codes, and this information should be documented on an official site map and in the project work plan.

Monitoring, except where noted below, shall be conducted at the restoration project site and at an appropriate reference site. This reference site will consist of, at a minimum, three control transects (including 3 quadrats each), and must be located contiguous with or nearby the restoration project site, and be similar in morphology and vegetation zonation (*i.e.*, compare restored high marsh with nearby unrestored, "natural" high marsh; restored low marsh creek bank with nearby unrestored, "natural" low marsh creek bank). An additional requirement of the reference site is that all major vegetation zones of the restoration site must be matched at the reference site; therefore, additional transects at the reference site may be needed to provide control data for all applicable vegetation zones or morphological features.

The purpose of the reference site is to help discern background environmental effects from the effects attributable to the restoration project. For example, vegetation parameters at a restoration site must be compared with the same parameters at a nearby reference site to determine whether an observed loss of vegetation is a restoration failure, or is caused by a natural event, such as a hurricane or winter storm, that has similarly affected all the marshes in the area.

• **Transects:** Place a minimum of 3 transects evenly spaced across the site. For large sites, transects should be evenly spaced, and although an absolute minimum of 3 transects is required, a larger number of transects is recommended based on the acreage to be covered and the number and type of vegetation zones present. Transects should run perpendicular to the main channel and/or parallel with the elevation gradient, across the restoration site approximately from the seaward edge of the *Spartina alterniflora* zone (*i.e.*, encompassing traditional areas of occurrence for *Geukensia demissa* and/or *Fucus* spp.) to at least the landward extent of the project. Transect locations should be permanently marked at the landward and seaward ends using two stakes that are sturdy and will be easily located.

During monitoring visits, a tape measure should be used to mark the transect line, starting at the upland end. Hook the tape measure onto the permanent landward stake and walk toward the seaward transect end, also marked by a permanent stake. To minimize trampling of the site, do not walk directly to the seaward transect end but walk diagonally from the upland marker toward some point a short distance away from the actual seaward marker, but in line with the marker to either the right or left. When you are in line with the seaward marker, walk to the seaward marker and wrap the measuring tape around the stake, making sure it is taut. This forms a transect line between the landward and seaward stakes. This procedure should be repeated for all pairs of upland/seaward transect ends at the restoration site.

Noteworthy features occurring along each transect should be recorded relative to the distance marked on the tape measure at the point of occurrence. It is imperative that a notation is made regarding which transect end is being used as zero distance (using the placement method above it should be the landward marker), and that the same transect end (the landward marker) be consistently used as zero distance for all transect monitoring at the restoration site.

• **Quadrats:** Place quadrats (1.0 m^2) along the transects at a minimum of three different elevations (*i.e.*, a minimum of three quadrats per transect) between the seaward edge of the *Spartina alterniflora* zone and the landward extent of the project, including, as applicable, all vegetation zones present. Within a single vegetation zone (*e.g.*, low marsh *Spartina alterniflora* zone), quadrats must be located at least 3.0 m apart along the length of the transect. Quadrats will be placed semi-randomly within an area 2.0 meters to either side of the measuring tape transect line. A stake, bar, length of PVC pipe, or other item 4.0 meters in length, carried or placed on the ground with 2.0 meters length extending on either side of the centerline, can be used to demarcate this area during monitoring visits. Placement of quadrats can be accomplished, *e.g.*, by walking in a zig-zag pattern back and forth across the demarcated area along the entire length of the transect line, dropping quadrats at random (with the exception of deliberate inclusion of all vegetation zones present and/or deliberate placement of quadrats $\geq$ 3.0 meters apart within a single vegetation zone). After placement, orient the quadrats so one side is parallel to the transect line and record the location of upper and lower quadrat boundaries with respect to the tape measure , *e.g.*, upper boundary at 3 meters, lower boundary at 4 meters. This should be done for all quadrats along all transects at the restoration site.

• **Permanent fixed-point photo stations:** The transect marker stakes (seaward end and landward end) should be used as permanent photo stations for photographic monitoring. Photographs each transect should be taken facing the seaward transect marker from the landward transect marker, and facing the landward transect marker from the seaward transect marker. This should be done for all pairs of transect ends at the restoration site.

Provide an overview photograph or photographs of the entire restoration site and consistently use this location for the duration of photomonitoring. Photographs should be taken at low tide (avoiding spring tide and full moon periods) and should be labeled with the location code, the direction of view, the date, the time, and the tide. Photographs must be in the form of prints no smaller than 4" x 6", and must be in color.

• **Video monitoring (optional):** Video monitoring is encouraged to supplement photomonitoring and provide additional qualitative information that cannot be provided by standard photographs. This includes close-up images of vegetation, benthic epifauna, and substrates; a panorama of the site is also easily filmed. The restoration site should be walked by the video monitor, using the transect lines as guides. Cards may be filmed, or voice may be used, to give the required information, such as location code, date, time of day, direction of view, and tide. At each transect end the location code and direction of view should be identified. Close up views should be filmed of all vegetation zones occurring along the transects.

•**Aerial infrared photography (optional):** Aerial IR photography, if available, is useful for assessing vegetation, both pre- and post-project, for large project areas.

4) Pre-Restoration Monitoring Activities:

On sites where planting is planned, take a complete set of color photographs including all permanent, fixed-point stations (transect ends and elevated overview) upon completion of the design phase and prior to any construction activities. Photographs should also be taken at the reference site.

On sites where some marsh habitat already exists (*e.g.*, formerly connected marshes, grid ditched marshes) and <u>no planting is planned</u>, all parameters described below under "Post-Construction Monitoring (Annual for 5 Years)" should be monitored at least once prior to the restoration at both the restoration site and the reference site. At a minimum, all parameters should be monitored once during the last August prior to the restoration. May, August and/or December parameters specified below can be included in pre-restoration monitoring during the year prior to the restoration, at the discretion of the RP or other overseeing entity.

5) Post-Construction Monitoring (Four-Five Weeks Post-Construction):

• The restoration site should be walked by the RP, the Ecologist, and/or the Regulator(s) 4-5 weeks post-construction to assess compliance with submitted work plans. Elevations should be double-checked prior to planting.

• Permanent fixed-point photo stations: Take color photographs at permanent, fixed-point photo stations articulated above, for the restoration site and the reference site. Photographs should be taken at low tide (avoiding spring tide and full moon periods) in the manner articulated above. Label photographs with the location code, direction of view, date, time, and the tide. Photographs must be in the form of prints no smaller than 4" x 6", and must be in color.

• The RP will determine, based on the 4-5 week post-construction assessment, whether any additional work is required to achieve work plan compliance, and above and beyond any standard regulatory review associated with the project.

6) Post-Construction Monitoring (Annual for 5 Years):

a) <u>Vegetation</u>

The following parameters should be monitored once annually for 5 years, during the last week in August or the first three weeks in September, at the restoration site and the reference site.

> **Plant species occurring:** All plant species occurring in each quadrat along the transect should be recorded.

Stem Density: All live stems of any plant species found within a 0.25 m^2 section of the quadrat are counted. Divide each 1.0 m^2 quadrat into four 0.25 m^2 sections and randomly select one 0.25 m^2 section for the stem density count. Use the same 0.25 m^2 section for plant height measurements; see below.

Plant Height: All live stems of any plant species within a 0.25 m^2 section of the quadrat are measured from the base of the plant to the top of the stem in meters. Use the same 0.25 m^2 section of the quadrat for height measurements as was used for stem density count; see above.

Signs of disease, predation, or other disturbance should be monitored in each quadrat and along the length of the transect, recording observations as necessary.

Vegetation Zones: Walk along the measuring tape that demarcates the transect line starting at the seaward transect end. Note the distance marked on tape measure at the transition between different vegetation zones, and the dominant species composition of these zones.

b) Fixed-point photo stations

Take color photographs from all designated locations once annually for 5 years at the time of vegetation monitoring (during the last week in August or first three weeks in September), for the restoration site and the reference site. The permanent transect marker stakes (seaward end and landward end) should be used as photo stations for the photographic monitoring. An overview photograph or photographs of the entire restoration site should be consistently used in all photomonitoring. Take photographs at low tide (avoiding spring tide and full moon periods) in the manner articulated above. Label with the location code, direction of view, date, time, and tide. Photographs should be in the form of prints no smaller than 4" x 6", and must be in color.

Video monitoring, if used, should also occur at the time of vegetation monitoring, annually for 5 years.

c) Soil Properties

The following parameters should be monitored once annually for 5 years, at the time of vegetation monitoring (during the last week in August or the first three weeks in September, at low tide avoiding spring tide and full moon periods). Measure each soil property parameter at least twice in each quadrat placed along the transect line.

Soil organic matter: Sediment cores (2 cores per quadrat) should be sampled to 10 cm depth using, *e.g.*, a cylindrical push corer ~5 cm in diameter. Soil organic matter (includes organic carbon and other organic compounds) from marsh substrates may be measured by loss on combustion. Samples for this procedure are dried, weighed, combusted at 500 degrees Celsius for ~8 hours, and weighed again. During the 8-hour combustion period, organic material burns and is lost from the sample as a result of the high temperature. Inorganic and refractory materials, which have even higher temperatures of combustion, remain in the sample after this period. Therefore, the difference in weight between the dried and combusted samples, which may be expressed as a percentage of the dried weight, represents the organic matter content of the marsh soil sample.

Soil salinity: The salinity of the soil may be determined in the field using a refractometer or conductivity meter. With a refractometer, pore water from a small soil sample is squeezed onto the lens and the resulting salinity reading is recorded as soil salinity. Pore waters with high concentrations of suspended solids may require rudimentary filtration in the field. In these cases, squeeze pore water through filter paper onto the lens of the refractometer.

d) Benthic Invertebrates in m^2 quadrats

The following parameters should be monitored annually for 5 years at the time of vegetation monitoring, during the last week in August or the first three weeks in September. Monitoring should be conducted at the restoration site and the reference site.

Ribbed mussels: Ribbed mussels in each quadrat should be counted and recorded. Two to six mussels per quadrat, as appropriate, should be measured lengthwise.

Fiddler crab burrows: Fiddler crab burrows in each quadrat should be counted and recorded. The presence of live fiddler crabs should also be recorded, where applicable.

Other benthic invertebrates: The presence of any additional species observed (*e.g.*, *Melampus bidentata*), and the number of individuals (when practical), should be recorded both within quadrats and along the length of the transect line, as applicable.

e) Macrofauna

The following parameters (except "Other macrofauna", see below) should be monitored at the restoration site once monthly in June and August for 5 years. Observe birds from an obscured location on the landward side of the restoration site, unless site-specific characteristics require otherwise. In this case, identify a location will minimize disturbance to bird species at the site when the monitor approaches. Document the location and assign a location code. The location should be easily locatable by monitors in subsequent years. The monitor should record observations as described below for a 3 to 4 hour period surrounding mid-tide (1.5 to 2 hours before and 1.5 to 2 hours after mid-tide). Record time of day, tide, weather conditions (temperature, wind strength, precipitation), location code, direction of view from the chosen viewing station on all observation sheets. Bird monitoring should not be conducted on days when there is high wind, rain, or low barometric pressure.

Saltwater-fish-feeding birds: Record presence, duration of stay, general location, and activity for wading birds, *e.g.*, great egret, snowy egret, tricolor heron, black-crowned night heron, and other species, if observed.

Benthic-invertebrate-feeding birds: Record presence, general location, duration of stay, and activity for wading birds, *e.g.*, little blue heron, yellow-crowned night heron (*Nyctanassa violacea*), and other species, if observed.

Other salt marsh associated bird species: Record numbers of species and individuals, general location, activities, and duration of stay.

Other macrofauna: Record presence, or reasonable evidence of presence, for any other macrofauna (small mammals, horseshoe crabs, terrapin) at the site, observed during any site visit.

Wintering waterfowl: If resources are available and the goals of the restoration are compatible, waterfowl species can be monitored <u>once annually in December</u>. Record species, abundance, general location, activities, and duration of stay.

f) <u>Contingency Inspections</u>

The restoration site (and its reference site) should be inspected for damage in the event of winter storms or other destructive events. These visits should be conducted subsequent to such events, and at a minimum once annually in late March/early April to ensure that damage is documented and plans for repair and debris removal are made at the earliest possible opportunity. If repair, debris removal, or other action is indicated, photomonitoring as described previously should be conducted during the contingency inspection.

7) Monitoring Reporting Requirements:

Annual monitoring reports should be written and submitted (by a mutually agreed upon date) to the applicable Regulator(s) and/or some other pre-designated, central repository. Reporting will begin after the first post-construction growing season. Include data and photographs, labeled as described above, as well as a brief summary of the collected data. Length measurements should be reported using the metric system.

The monitoring reporting deadline for this project is ______________________________ __________

8) Recommended Monitoring after 5 Years (optional):

It is recommended that photomonitoring for all restoration sites continue for an additional 3-5 years following the conclusion of the initial 5-year monitoring period. Photomonitoring during years 5-10 should occur at a minimum once annually during the last week of August or first three weeks of September, and consist of the <u>same</u> site overview and photographs as described above at all of the <u>same</u> permanent transect photostations used during the initial monitoring period. The additional 3-5 years of photomonitoring records should also be labeled, stored, and distributed in the same manner as occurred during the initial 5-year monitoring period.

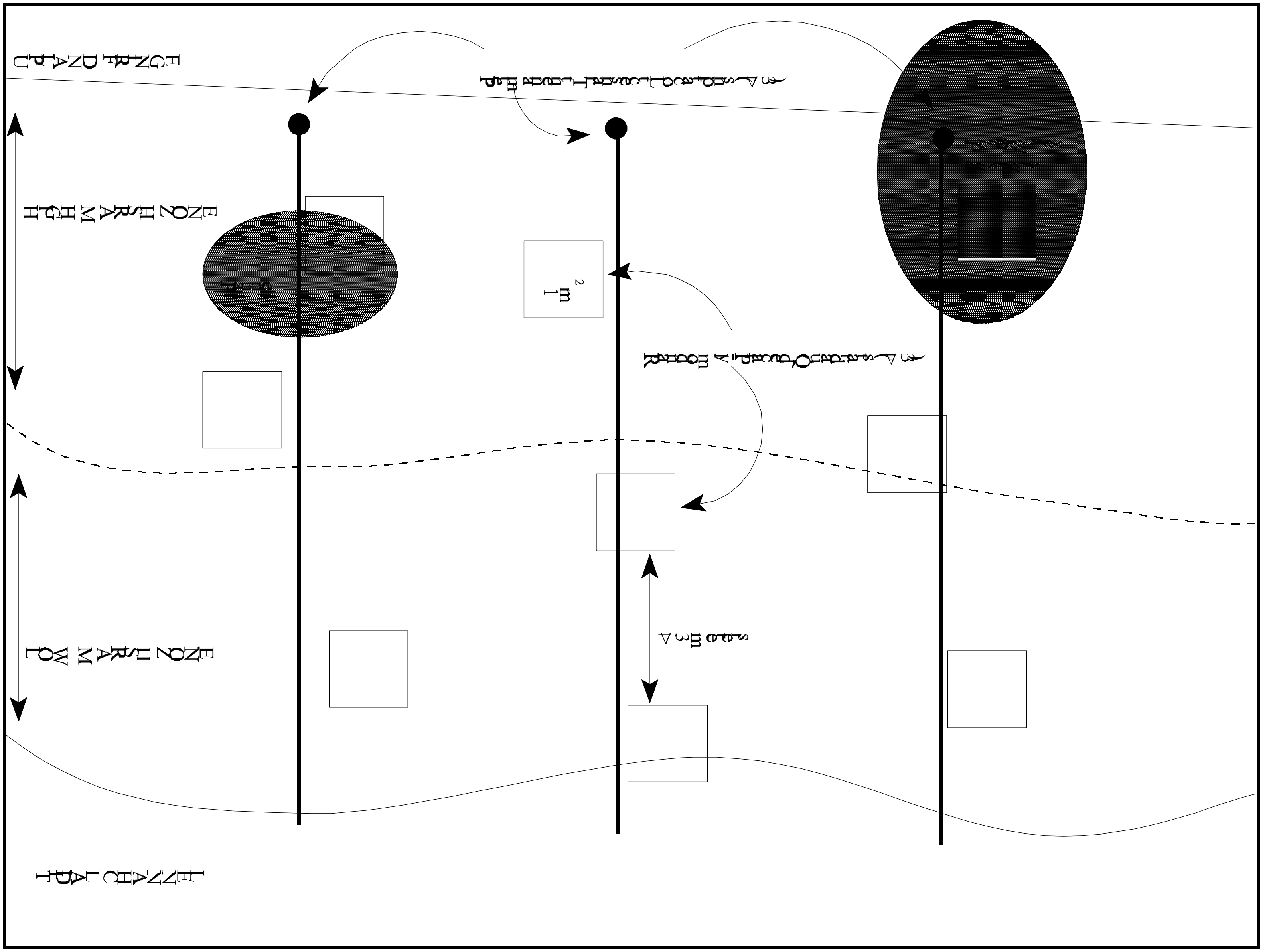

Figure 13. Diagram of hypothetical placement of transects and quadrats for monitoring a salt marsh restoration.

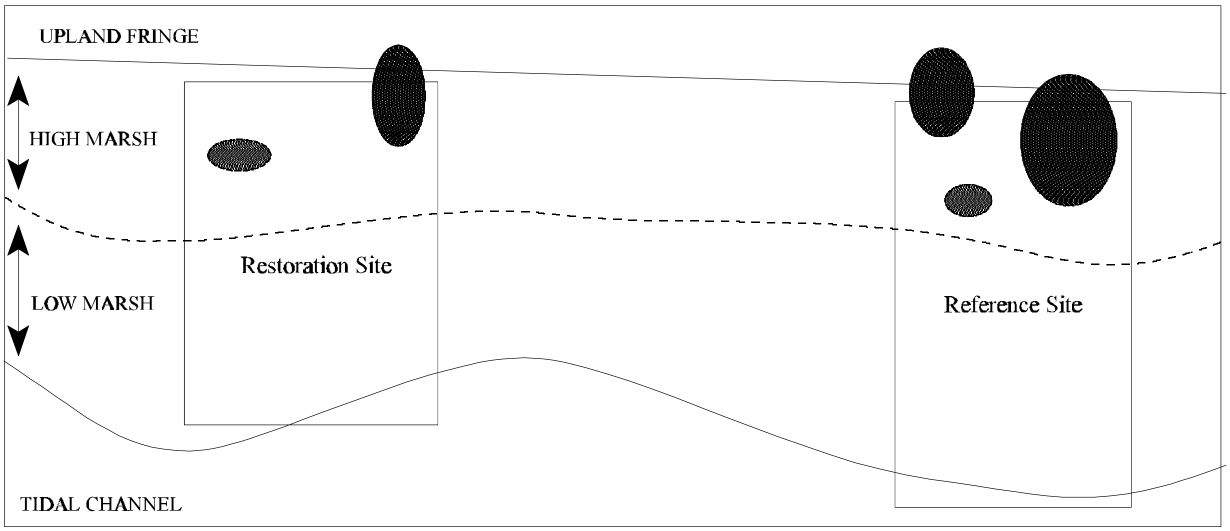

Figure 14. Hypothetical selection of an appropriate reference site for monitoring a restoration project.

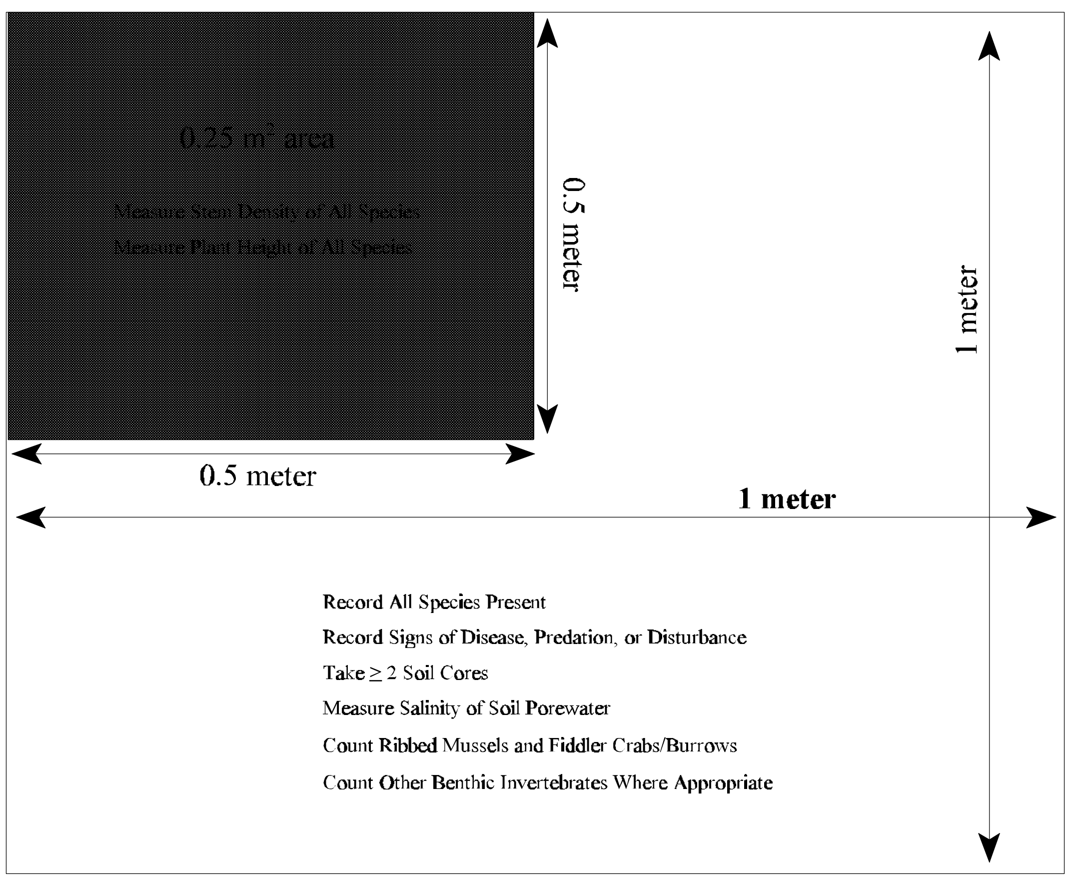

Figure 15. Diagram of the recommended quadrat and associated monitoring variables for a salt marsh restoration.

8. COMMON REED CONTROL—RECOMMENDED MONITORING PROTOCOL

Below is an outline of the recommended components of a monitoring program for common reed control projects, frequently associated with salt marsh restorations, in brackish and estuarine waters of New York State.

1) Principle parties:

The party responsible for carrying out all restoration requirements will be referred to as the Responsible Party (RP). These restoration activities include the development and implementation of a monitoring protocol to assess the progress of the restoration during, and to evaluate the success or failure of the restoration at the conclusion of, the monitoring period (a period $\geq$ 5 years is recommended).

The RP for the ________(project name)___________ is __________(agency/name)__ ___________.

Other parties that may be involved in restoration and restoration monitoring activities are:

•The Designer of the restoration, who is responsible for including monitoring specifications in the design and site plan, including specific locations of transects, quadrats, permanent fixed-point photo stations, and other features.

The designer for this project is ____________(agency/name)____________________ ________.

•An Ecologist to assist in planning and implementing a site-specific monitoring protocol.

The ecologist for this project is ___________(agency/name)_____________________ ________.

•The Contractor(s) is(are) in charge of construction and of maintenance of the site and its features, including all transects, quadrats, and fixed-point photo stations. When a contractor is not required, all site manipulation and maintenance activities are generally the responsibility of the RP.

The contractor(s) for this project is/are ______________(name/names)____________
________.

•The Regulator(s) is(are) responsible for approving the restoration designs and monitoring protocols, and for any required permitting for restoration activities.

The Regulator(s) for this project is/are _____(NYS DEC, NYS DOS, ACOE, others)
_____.

•Volunteers may be involved in conducting monitoring activities. They may require training, and usually will be supervised by and/or report to the RP.

Note: The RP will be responsible for ensuring fulfillment of all monitoring requirements, including those of the Designer, Ecologist, Contractor(s), and Volunteers as specified in the work plan, and is responsible for reporting as specified to the Regulator(s), when applicable. The RP will ensure that any herbicide applicator is New York State certified. The Designer and the Ecologist may be the same person or from the same agency, and this person/agency may also be the RP.

2) Purpose of the protocol:

This monitoring protocol is designed to assess the progress towards, and the success or failure of, a restoration of salt or brackish marsh habitat by control or eradication of common reed, through cutting, mowing, burning, flooding with salt water, use of plastic, and/or application of herbicide, such as Rodeo. At a minimum, this should include regular assessment, for a period of $\geq$ 5 years, of the parameters described below. This monitoring protocol would not be applicable for restoration projects involving excavation of *Phragmites* stands, followed by backfilling, grading, and re-planting with salt marsh species. For an excavation-type *Phragmites* removal project, use of the recommended salt marsh monitoring protocol is encouraged.

Note: Most *Phragmites australis* control strategies require multiple treatments (multiple cuttings, mowings, herbicide applications) to achieve success. Therefore, it is recommended that all monitoring activities commence following the first post-treatment growing season, and should continue for 5 years following the final treatment. During years 4-5 after the final treatment it is possible that a monitoring protocol tailored to development of salt marsh or other habitat (*i.e.*, the salt marsh restoration recommended monitoring protocol) will provide the best information if used in conjunction with this *Phragmites australis* monitoring protocol.

3) Monitoring Protocol Design:

All monitoring, except where noted below, should be conducted at the restoration project site and at an appropriate reference site. This reference site should consist of, at a minimum, three control transects, and must be located contiguous with or nearby the restoration project site. The control transects must represent stands of unmanaged common reed in similar habitat to the reed management site. For example, a high marsh area invaded by *Phragmites* and subject to eradication/management should be compared with control transects in a high marsh area dominated by *Phragmites* that will remain untouched by restoration activities.

The purpose of the reference site is to help discern background environmental effects from the effects attributable to the restoration project. For example, vegetation parameters at a restoration site must be compared with the same parameters at a nearby reference site to determine whether an observed loss of vegetation is a restoration failure, or is caused by a natural event, such as disease, a hurricane, or a winter storm that has similarly affected all the marshes in the area.

• **Transects:** A minimum of 3 transects, evenly spaced across the site, should be used for all restoration projects. For large sites, transects should be evenly spaced, and although an absolute minimum of 3 transects is required, a larger number of transects is recommended based on the acreage to be covered and the heterogeneity of the site. Transects should run perpendicular to the main channel and/or parallel with the elevation gradient, across the restoration site approximately from the mean low water (MLW) to at least the landward edge of the project. Transect locations should be permanently marked at the landward end only using stakes that are sturdy and will be easily located during future monitoring visits.

During monitoring visits, a tape measure should be used to mark the transect line, starting at the upland end. Hook the tape measure onto the permanent landward stake, and walk toward the MLW mark remaining roughly parallel with the elevation gradient. At the seaward end of the transect, wrap the measuring tape around a second, temporary stake, making sure it is taut. This forms a transect line between the landward and seaward stakes. This procedure should be repeated for all transect locations at the restoration site.

Noteworthy features occurring along each transect should be recorded relative to the distance marked on the tape measure at the point of occurrence. Note which transect end is being used as zero distance (using the placement method above it should be the landward marker), and that the same transect end (the landward marker) be consistently used as zero distance for all transect monitoring at the restoration site.

• **Permanent fixed-point photo stations:** The permanent and temporary transect end markers (landward end and seaward end, respectively) should also be used as the photostations for photographic monitoring. Photographs should be taken facing the seaward transect marker from the landward transect marker, and facing the landward transect marker from the seaward transect marker. It is particularly important that some standard height reference marker be included in all photographs taken for the purpose of monitoring a common reed eradication or control project, during every monitoring visit to the site for the duration of the monitoring period (~ 5 years). For example, a tall stake with regular height interval markings that will be visible in a photograph should be placed in the substrate or held by an assistant monitor at the head of each transect line and photographed. This should be done for all pairs of transect ends at the restoration site. Also, a location that provides an overview photograph or photographs of the entire restoration site should be identified and consistently used for the duration of photomonitoring. All photographs should be taken at low tide (avoiding spring tide and full moon periods) and should be labeled with the location code, the direction of view, the date, the time, and the tide if ambiguous. All photographs should be in the form of prints no smaller than 4" x 6", and must be in color.

• **Quadrats (optional):** A 25 (twenty-five) m^2 quadrat (a square 5 meters on a side) may be placed along each transect if the density of the *Phragmites* stand permits. This may be accomplished using a tape measure and 4 temporary stakes. The tape measure can be wrapped around the first stake, from where the monitor walks in a straight line for 5 meters, places a second stake wrapping the tape measure around this stake, walks again for 5 meters in a straight line perpendicular to the original 5 meter line, places a third stake wrapping the tape measure around this stake, turns and walks another 5 meters in a straight line perpendicular to the second 5 meters and parallel with the original 5 meters, *etc.*, until a square 5 meters on a side (25 m^2) is formed. The quadrat should be intersected by the transect line (placed within 5 meters of the transect line on either side) and the location along the transect from distance zero noted (*e.g.*, upper boundary at 8 meters, lower boundary at 13 meters). This should be done for all quadrats placed along all transects at the restoration site.

• **Video monitoring (optional):** Use of video monitoring is encouraged to supplement photomonitoring and provide additional qualitative information that cannot be provided by standard photographs. This includes close-up images of vegetation, benthic epifauna, and substrates; a panorama of the site is also easily filmed. The restoration site should be walked by the video monitor, using the transect lines as guides. Cards may be filmed, or voice may be used, to give the required information, such as location code, date, time of day, direction of view, and tide. At each transect end the location code and direction of view should be identified. Close up views should be filmed of all vegetation zones occurring along the transects.

•**Aerial infrared photography (optional):** Aerial IR photography, if available, is useful for assessing vegetation, both pre- and post-project, for large project areas.

4) Pre-Restoration Monitoring Activities:

<u>All required parameters</u> described below under "Post-Treatment Monitoring--Annual for $\geq$ 5 Years" should be monitored once prior to the first eradication/control treatment, at both the restoration site and the reference sites. This should occur during the last week in August or first three weeks of September, or immediately prior to the first treatment.

5) Post-Treatment Monitoring (Four to Five Weeks Post-Treatment):

• The restoration site should be walked by the RP, the Ecologist, and/or the Regulator(s) 4-5 weeks post-treatment to assess compliance with submitted work plans and initial effects of the treatment.

• Permanent fixed-point photo stations—A set of color photographs should be taken at this time at all permanent, fixed-point photo stations articulated above, for the restoration site and the reference site. All photographs should be taken at low tide (avoiding spring tide and full moon periods) and should be labeled with the location code, the direction of view, the date, the time, and the tide if ambiguous. It is particularly important that some standard height reference marker be included in all photographs taken for the purpose of monitoring a common reed eradication or control project, during every monitoring visit to the site for the duration of the monitoring period. All photographs should be in the form of prints no smaller than 4" x 6", and must be in color.

• The RP will determine, based on the 4-5 week post-construction assessment, whether any additional work is required to achieve work plan compliance, and above and beyond any standard regulatory review associated with the project.

6) Post-Treatment Monitoring (Annual for ≥ 5 Years):

a) Vegetation along transects

The following parameters should be monitored once annually for ≥ 5 years, during the last week in August or the first three weeks in September, at the restoration site and the reference sites.

> **Vegetation Zones:** Walk along the measuring tape that demarcates the transect line starting at the upland transect end. Note the distance marked on tape measure at the transition between different vegetation zones, and the dominant species composition of these zones. The location of the seaward front of the *Phragmites* stand should be recorded as precisely as possible in order to track dieback over time and with continued treatments. In areas where plant species diversity is low, the presence of all plant species other than *Phragmites* encountered along the transect should be recorded.
>
> **Signs of disease, predation, or other disturbance** should be monitored along the length of the transect, recording observations as necessary.

b) Fixed-point photo stations

All photomonitoring should be done for all transects at the restoration site. Color photographs should be taken from all designated locations once annually for $\geq$ 5 years at the time of vegetation monitoring (during the last week in August or first three weeks in September), for the restoration site and the reference sites. The permanent and temporary transect marker stakes (upland end and seaward end, respectively) should be used as photo stations for the photographic monitoring. Photographs should be taken facing the seaward transect marker from the upland transect marker, and facing the upland transect marker from the seaward transect marker. It is particularly important that some standard height reference marker be included in all photographs taken for the purpose of monitoring a common reed eradication/control project, during every monitoring visit to the site for the duration of the monitoring period (~ 5 years; see detail above). Also, an overview photograph or photographs of the entire restoration site should be consistently used in all photomonitoring. Photographs should be taken at low tide (avoiding spring tide and full moon periods) and should be labeled with the location code, the direction of view, the date, the time, and the tide if ambiguous. All photographs should be in the form of prints no smaller than 4" x 6", and must be in color.

Video monitoring, if used, should also occur at the time of vegetation monitoring, annually for $\geq$ 5 years.

c) Vegetation in 25 (twenty-five) m^2 quadrats

The following parameters are optional. If they are included, these parameters should be monitored once annually for $\geq$ 5 years, during the last week in August or first three weeks in September. In general, quadrat monitoring will be most informative in those sites where there is some diversity of plant species (*i.e.*, the site is not a *Phragmites australis* monoculture). Alternatively, the parameters below will provide a more quantitative *Phragmites australis* data set that can assist in evaluating the effectiveness of different control strategies or other hypotheses associated with the eradication/control project.

Percent cover: The percent coverage by all plant species present in the entire 25 (twenty-five) m^2 quadrat should be estimated visually according to the basal area occupied by the plants (and not the overall aboveground area).

Stem density: All live stems of *Phragmites australis* in a 1.5625 m^2 section of each 25 (twenty-five) m^2 quadrat should counted. Divide each 25 m^2 quadrat into four 6.25 m^2 sections (1/4 of the total quadrat area). Then divide one of these 6.25 m^2 sections into four subsections (1.5625 m^2 sections). The 1.5625 m^2 subsections represent 1/16 of the total quadrat area. Randomly select one 1.5625 m^2 subsection for the stem density count. Use <u>the same 1.5625 m^2 subsection for plant height measurements</u>; see below.

Plant Height: All live stems of *Phragmites australis* in a 1.5625 m^2 section of each 25 (twenty-five) m^2 quadrat are measured from the base of the plant to the top of the stem in meters. <u>Use the same 1.5625 m^2 section</u> of the quadrat for height measurements as was used for stem density count; see above.

7) Monitoring Reporting Requirements:

Annual monitoring reports should be submitted (by a mutually agreed upon date) to the applicable Regulator(s) and/or some other pre-designated, central repository beginning after the first post-treatment growing season. Include data and all photographs, labeled as described above, should be included, as well as a brief summary of the collected data. Length measurements should be reported using the metric system.

The monitoring reporting deadline for this project is ______________________________.

8) Recommended Monitoring after 5 Years:

It is recommended that photomonitoring for all restoration sites continue for an additional 3-5 years following the conclusion of the initial required 5-year monitoring period. Photomonitoring during years 5-10 should occur at a minimum once annually during the last week of August or first three weeks of September, and consist of photographs of the <u>same</u> overview site and from the <u>same</u> permanent transect photostations used during the initial monitoring period. The additional 3-5 years of photomonitoring records should also be labeled, stored, and distributed in the same manner as occurred during the initial 5-year monitoring period.

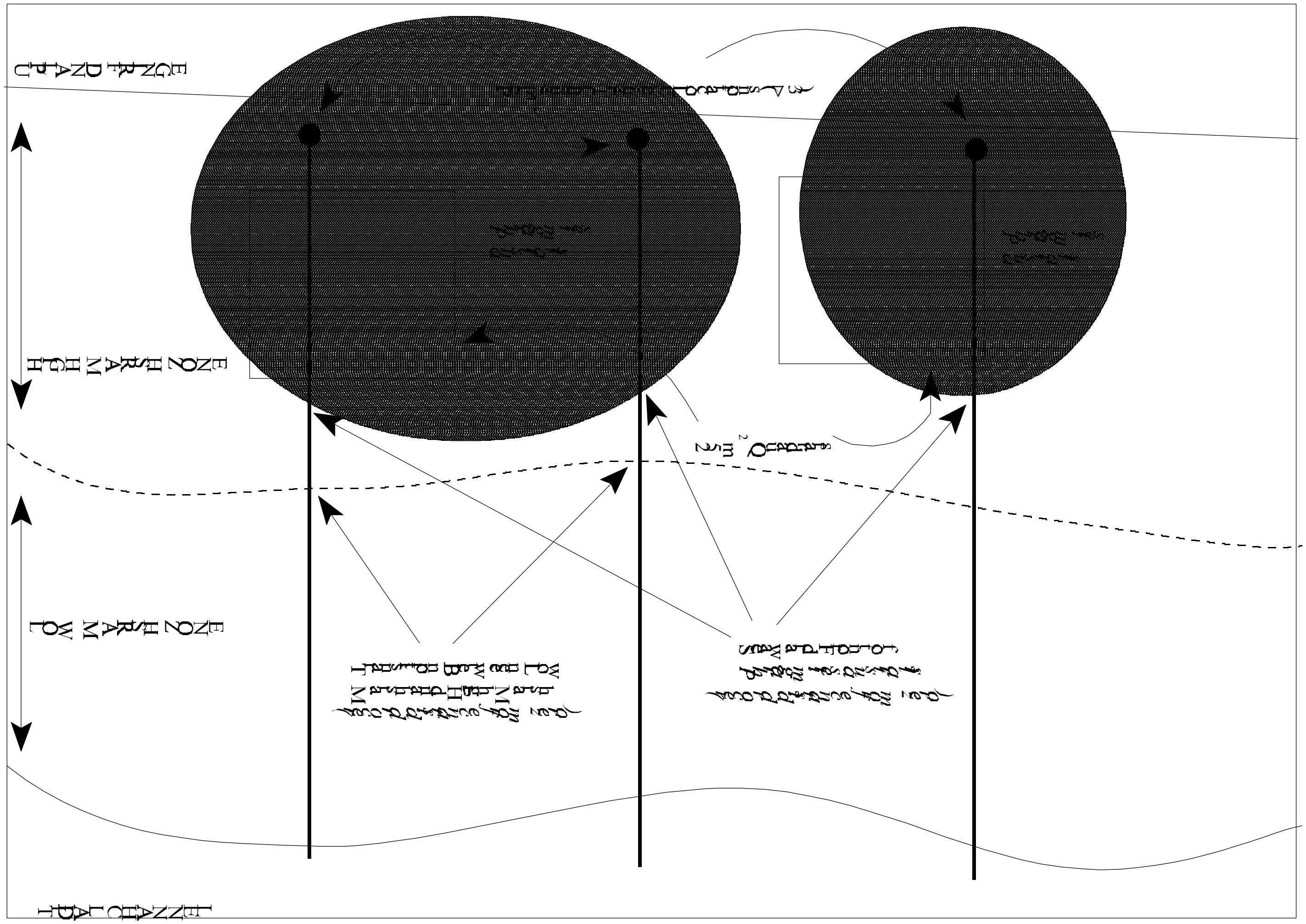

Figure 16. Diagram of hypothetical placement of transects and quadrats for monitoring a *Phragmites* control project.

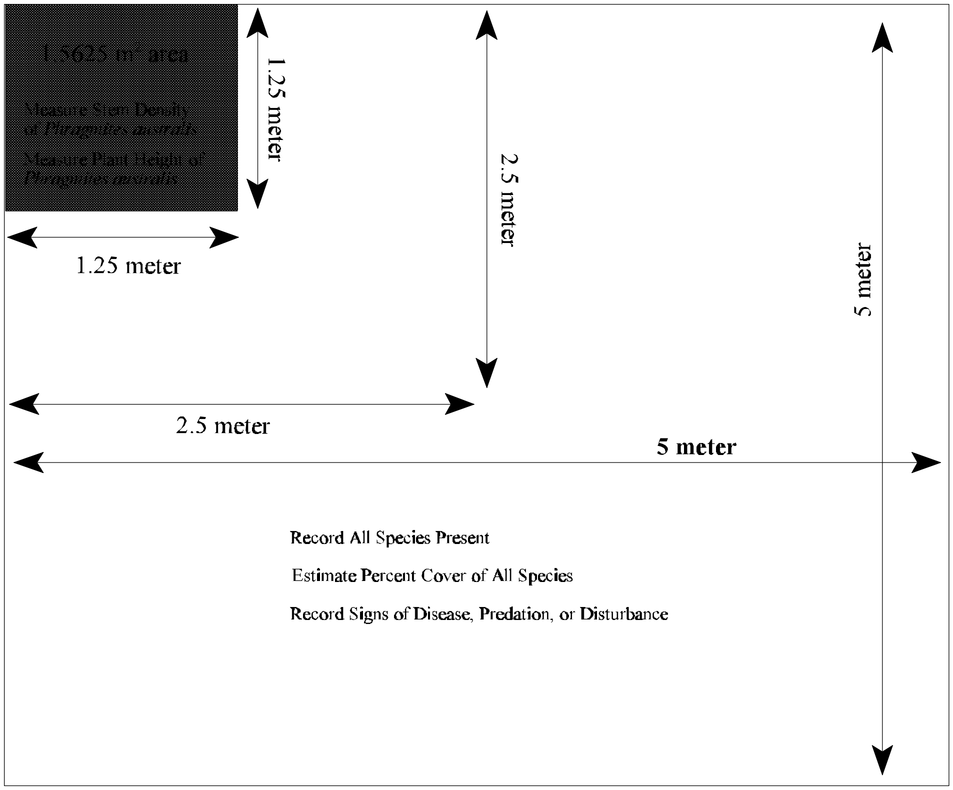

Figure 17. Diagram of the recommended quadrat and associated monitoring variables for a *Phragmites australis* control project.

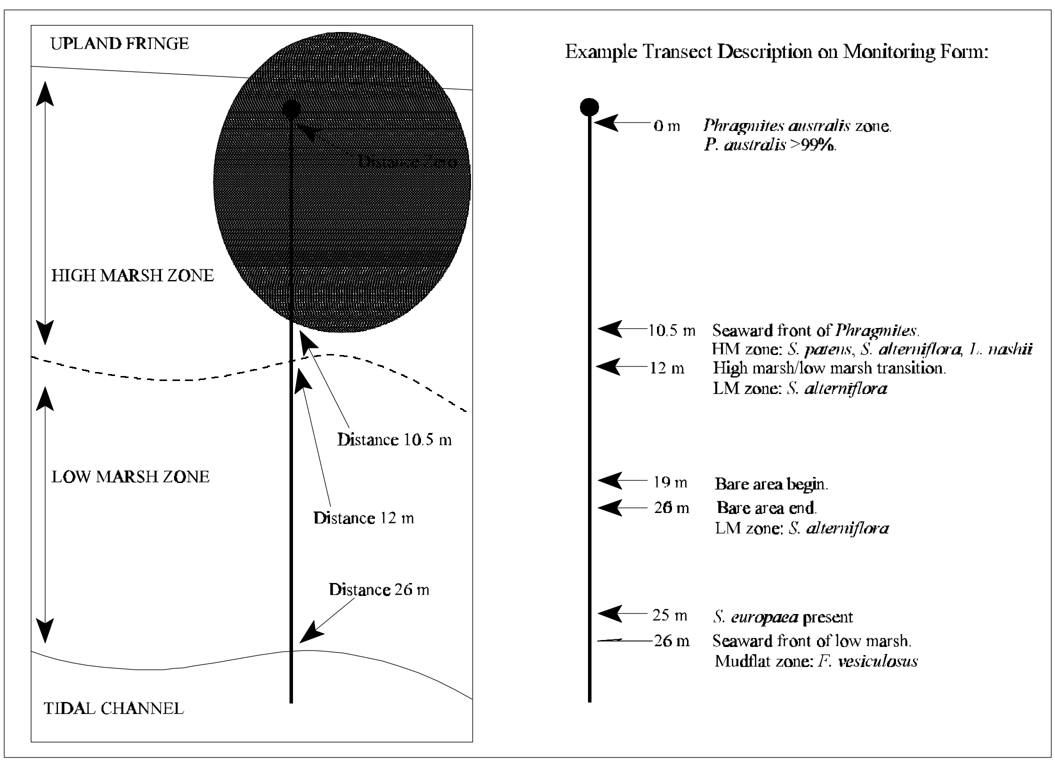

Figure 18. Reporting vegetation and other features along a transect.

9. SALT MARSH BIBLIOGRAPHY

The reference list that follows is comprehensive for salt marsh restoration and ecology in the northeast United States. Other bibliographies of salt marsh restoration literature have been compiled and may be of use for additional research (Matthews and Minello, 1994; and see their references). These bibliographies are comprised of a great deal of hard-to-retrieve conference proceedings and grey literature. An effort was made with the references below to rely more heavily on peer-reviewed literature drawn from scientific journals that can be found in a good science library (*e.g.*, the State University of New York-Albany library and the New York State Library were the primary sources for articles listed below. Most grey and other literature included below were available through the New York State Library). Most of these references are now housed in the New York State Coastal Management Program habitat library.

An "additional bibliographic materials" section follows the reference list below. This second section documents literature not cited in the Salt Marsh Restoration and Monitoring Guidelines, that may nonetheless be useful for those readers with more targeted needs or interested in conducting additional research.

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APPENDIX A
FIELD AND REPORTING FORMS FOR RECOMMENDED SALT MARSH RESTORATION MONITORING PROTOCOL

PROJECT INFORMATION

Project Name	
Project Code	
Project Location	
Project Description (project rationale, work planned)	
Responsible Party	
Affiliation	
Contact Information	Address: Telephone # : Fax # :

Other Involved Parties
(name, affiliation, telephone)

Please attach a site map showing photo stations, transects, quadrats, and bird observation location(s) labeled with their assigned codes.

MONITORING INFORMATION

Date of Monitoring	
Time of Monitoring	Began:________________ Concluded:________________
Tide (please circle one)	High Tide / Ebbing / Low Tide / Flooding Predicted low and high tides: Time of tidal measurements: Nearest tidal station:
Weather (temperature, wind, precipitation)	
Monitor(s) (name, affiliation)	
Type of Monitoring (please circle one)	Pre-Construction As-built (4-5 weeks) Annual Post-Construction: Year 1 / 2 / 3 / 4 / 5
Parameters Measured (please circle all that apply)	Vegetation Sediment Benthic Invertebrates Birds Other (please describe):

Photo Monitoring Conducted? (please indicate station codes)	Yes / No
Video Monitoring Conducted? (please provide brief description)	Yes / No

MONITORING PARAMETERS: QUADRATS

	Quadrat 1a (______)	**Quadrat 1b** (______)	**Quadrat 1c** (______)
Stem Density			
Mean Plant Height			
Sediment Core Codes			
Ribbed Mussel Count			
Fiddler Crab Burrows			
Other **(please describe):**			

	Quadrat 2a (______)	**Quadrat 2b** (______)	**Quadrat 2c** (______)
Stem Density			
Mean Plant Height			
Sediment Core Codes			
Ribbed Mussel Count			
Fiddler Crab Burrows			
Other **(please describe):**			

	Quadrat 3a (______)	Quadrat 3b (______)	Quadrat 3c (______)
Stem Density			
Mean Plant Height			
Sediment Core Codes			
Ribbed Mussel Count			
Fiddler Crab Burrows			
Other **(please describe):**			

Please attach sediment core analyses when lab work has been completed.

MONITORING PARAMETERS: TRANSECTS

Transect 1 (_______)

seaward landward

distance ____

distance 0

Notes:

Transect 2 (_______)

seaward landward

distance ____

distance 0

Notes:

Transect 3 (_______)

seaward landward

distance _____ distance 0

Notes:

MONITORING PARAMETERS: BIRD OBSERVATION

Species	Abundance	Location	Activity	Duration of Stay

Notes:

FIELD NOTES

APPENDIX B
WORLD WIDE WEB RESOURCES RELEVANT FOR SALT MARSH RESTORATION

1. New York State Department of Environmental Conservation (NYS DEC) Regulatory Information

   http://www.dec.state.ny.us/website/dcs/permits_level2.html

   Information and application materials for NYS DEC permits can be found at this address. Tidal wetlands permit information is found in the Uniform Procedures Act (UPA) Permits section.

2. New York State Assembly Consolidated Laws: Environmental Conservation

   http://assembly.state.ny.us/cgi-bin/claws?law=37

   Links to text of Articles 1-72 and associated Titles of New York State Consolidated Law. Article 25 is the Tidal Wetlands Act.

3. New York State Department of State Division of Coastal Resources

   http://www.dos.state.ny.us/cstl/cstlwww.html

   Information on New York's Coastal Management Program Policies, Local Waterfront Revitalization Programs (LWRPs), and the Environmental Protection Fund (EPF) is available at this address.

4. Environmental Protection Agency (EPA) Office of Water Office of Wetlands, Oceans and Watersheds (OWOW)

   http://www.epa.gov/owow/

   This site contains information on wetland restoration, volunteer monitoring, water quality, watersheds, marine pollution and debris, and a variety of other topics.

5. United States Fish and Wildlife Service (USFWS) Division of Habitat Conservation National Wetlands Inventory

   http://www.nwi.fws.gov/

The NWI site provides downloadable data, map coverage and availability, and other information.

6. National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS)

   http://www.opsd.nos.noaa.gov/

   This site provides tables of tide predictions, water level observations, and other data.

7. NOAA National Marine Fisheries Service (NMFS) Office of Habitat Conservation

   http://www.nmfs.gov/habitat/index.html

   This page links to the Habitat Restoration Center and to information on Essential Fish Habitat (EFH), wetlands, and other topics.

8. Coastal America Partnership National Web Site

   http://www.csc.noaa.gov/coastalamerica/

   This site provides habitat restoration project summaries and contact information for regional Coastal America partners.

9. United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Wetland Science Institute

   http://www.pwrc.usgs.gov/wli/

   The WLI site has national practice standards and technical notes for wetland restoration, and information on wetland assessment, delineation, and training.

10. United States Army Corps of Engineers (USACE) Waterways Experiment Station (WES) Environmental Laboratory

http://www.wes.army.mil/el/homepage.html

Under "Research Areas and Programs" there are links to USACE pages on environmental restoration, wetlands, dredged materials management, and other topics.

11. USDA NRCS New Hampshire

    http://www.nh.nrcs.usda.gov/what_rest.htm

    Under "Ecosystem Restoration", there is good background information, with pictures, on salt marsh impacts, as well as project profiles, a report on evaluating restorable salt marshes, and other information.

12. Parker River Clean Water Association (Byfield, MA) Tidal Crossing Handbook

    http://www.parker-river.org/tides/Handbook/

    This is a manual guiding volunteer-based tidal restriction assessment programs, containing good background information and pictures.

13. National Estuarine Research Reserve Estuary-Net Project

    http://inlet.geol.sc.edu/estnet.html

    This site is mainly about volunteer-based nonpoint pollution monitoring, but contains good background information on estuarine ecology, lists of monitoring equipment, and field data collection forms.

14. The Nature Conservancy Wildland Weeds Management and Research Program

    http://tncweeds.ucdavis.edu/esadocs/phraaust.html

    This site provides pictures and HTML, Adobe, and Word versions of the *Phragmites australis* Element Stewardship Abstract.

15. Environment Canada Ecological Monitoring and Assessment Network

http://www.cciw.ca/eman-temp/research/protocols/marine/

This site documents marine and estuarine biodiversity monitoring protocols used by Environment Canada to assess fishes, phytoplankton, benthic organisms, seabirds, and other parameters.

16. Massachusetts Coastal Zone Management Wetland Ecology and Assessment Website

http://www.state.ma.us/czm/wastart.htm

The MCZM site provides information on wetland ecology and function, habitat assessment, and ecological indicators.

APPENDIX C
RESTORATION PROJECT TIMELINE

Hypothetical Timeline for a Restoration Project

Project Planning (Months 1-6)

Define goals and objectives of the restoration project, and articulate site constraints.
Contact knowledgable groups (*e.g.*, National Estuary Programs) and State agencies for information about restoration planning in the project area.
Research the history of the proposed restoration site through aerial photography, historical photography, tax map records, and other resources.
Develop a draft restoration plan and appropriate monitoring protocol.

Permit Applications (Months 3-7)

Contact permit staff in the proposed project area for pre-application assistance, including representatives of:

- New York State Department of Environmental Conservation
- United States Army Corps of Engineers
- New York State Department of State Coastal Resources.

Apply for required permits and approvals, including but not necessarily limited to:

- Article 25 Tidal Wetlands
- Clean Water Act Section 404
- Federal Consistency Certification.

Project Design (Months 5-9)

Conduct site surveys, including elevations, hydrology, soil sampling, vegetation, wildlife and other parameters as appropriate.
Draw site maps showing vegetation zones and locations and codes for transects, quadrats, wildlife observation points, and photostations.
Develop final restoration plan and construction documents.

Funding applications (Months 1-9)

Apply for project planning or implementation funding if applicable.

Project Implementation (Months 9-12)

Conduct pre-project monitoring prior to site manipulation or construction (*see Monitoring timeline*).
Conduct implementation tasks as specified in the restoration plan.

Monitoring

Pre-Project Monitoring **(within one year prior to project implementation)**

	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Aug	Sep	Oc	Nov	De
Vegetati												
Soil												
Benthos												
Waders												
Waterfo												
Photo												
Conting.												

***** August/September parameters need to be monitored once during this period, *i.e.*, in either late August or early September

As-Built Monitoring **(four to five weeks after site manipulation or construction)**

Photos should be taken at all photomonitoring stations. Additional parameters may be assessed at the discretion of the Responsible Party or Regulator. Corrective measures may be developed.

Post-Project Monitoring **(annually for five years after site manipulation or construction)**

	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Aug	Sep	Oc	Nov	De
Vegetati												
Soil												
Benthos												
Waders												
Waterfo												
Photo												
Conting.			**									

***** August/September parameters need to be monitored once during this period, *i.e.*, in either late August or early September

** Contingency monitoring should be conducted once during March/April, and as often as necessary throughout the year, *e.g.*, after winter storms, hurricanes, or other natural disasters

APPENDIX D
FEDERAL AND STATE LAWS AND REGULATIONS RELATED TO WETLAND RESTORATION AND MANAGEMENT

FEDERAL

National Environmental Policy Act (NEPA) of 1969. The Act established a program for reviewing the environmental impacts of activities that fall within the jurisdiction of any federal agency. Under NEPA, the review of agency actions can require the drafting of an Environmental Assessment (EA) or an Environmental Impact Statement (EIS). These documents are the tools by which potential environmental effects of actions are identified and alternatives to the proposed actions evaluated (Silverberg and Dennison, 1993).

U.S. Environmental Protection Agency (USEPA). The USEPA administers and enforces federal environmental laws including NEPA, and the Federal Water Pollution Control Act (FWPCA) of 1972, more commonly known as the Clean Water Act (CWA). § 404 of the FWPCA was enacted to control pollution from discharges of dredged or fill materials into waters of the United States (Kruczynski, 1990). Wetlands are protected because they are defined as waters of the U.S.

U.S. Army Corps of Engineers (USACE). Most New York State salt marshes are within USACE New York District jurisdiction. The USACE implements § 10 of the Rivers and Harbor Act of 1899 (RHA). Generally, the RHA requires that a landowner secure a § 10 permit from the USACE before building a wharf, pier or other structure in any water of the United States outside established harbor lines.

Under the § 404 program, the USEPA and the USACE have concurrent authority over the dredging and filling of waters of the U.S., including wetlands (Silverberg and Dennison, 1993). The USACE is the permit authority for the program while the USEPA is responsible for developing the environmental guidelines used by the USACE in its permit decisions.

To implement objectives of the CWA, a Memorandum of Agreement (MOA) between the USEPA and the Department of the Army describes the sequence of impact avoidance, minimization, and compensation necessary to demonstrate compliance with § 404 guidelines. The MOA is a directive for USACE and USEPA staff and must be adhered to when considering mitigation requirements for permitted activities that will adversely affect wetlands.

National Park Service (NPS). The NPS manages a number of federal facilities that are within the marine and estuarine districts of New York State, including the Gateway National Recreation Area and Fire Island National Seashore. The NPS is formulating a technically-sound, habitat-specific monitoring and management plan for the Fire Island National Seashore (NYSGI, 1993).

U.S. Fish and Wildlife Service (USFWS). The USFWS has the regulatory authority, derived from Title 50 of the Code of Federal Regulations, to control most activities within the boundaries of National Wildlife Refuges. The Emergency Wetlands Resources Act of 1986 charged the USFWS to develop a *National Wetlands Priority Conservation Plan* to identify wetlands that should be acquisition priorities. It also directs the USFWS to continue the NWI mapping project (USDOI, 1989).

The Cortland, New York, field office of the USFWS reviews projects within the marine and estuarine districts of New York State requiring USACE permits. If it is determined that a proposed action will impact wildlife, endangered species, or habitat, the USFWS can recommend mitigation measures to ensure the continued existence and protection of the resource.

National Marine Fisheries Service (NMFS). This research and applied science agency is charged with the protection and enhancement of fishery resources and their habitats. Responsibilities for wetlands include review and analysis of proposed activities seaward of the high tide line and special projects involving headwaters.

In 1986, the U.S. Department of the Interior, through the USFWS, and the U.S. Department of Commerce, through the NMFS, established procedures to ensure that federal actions do not jeopardize endangered or threatened species, or modify or destroy their habitat.

Federal Emergency Management Agency (FEMA). FEMA administers the National Flood Insurance Program. The program benefits wetlands by designating "floodways", by that means restricting development within these areas, and by encouraging the preservation of open space by offering favorable flood insurance rates (WWF, 1995).

Coastal Zone Management Act of 1972 (CZMA). The U.S. Congress enacted the CZMA, and its subsequent amendments, to address coastal environmental problems, including the degradation of wetland values and functions. While recognizing a need for development, the CZMA encourages state regulation of activities in the coastal zone, and uses financial aid and federal consistency as incentives to merge national goals into state programs (Silverberg and Dennison, 1993). The main focus of the CZMA is for each state to resolve for its own area the basic choices among competing uses for finite resources; in other words, to draft its own coastal zone management (CZM) plan. A draft CZM must be approved by the secretary of commerce. New York State has an approved CZM plan. CZMA Reauthorization Amendments require each state with a federally approved coastal zone management (CZM) program to develop a Coastal Nonpoint Pollution Control Program to implement coastal land use management measures for controlling nonpoint source pollution (Silverberg and Dennison, 1993).

Coastal Barrier Resources Act of 1982 (CBRA). This program uses the denial of federal assistance essentially as a scheme to discourage new development in ecologically significant coastal areas. Wetlands benefit because protected barrier beaches buffer them from destructive storms.

NEW YORK STATE

State Environmental Quality Review Act (SEQR). Through SEQR, New York State has established a process that requires the consideration of environmental factors early in the planning stages of proposed actions involving local, regional and state agencies (NYSDEC, 1992). Like many other states, the law closely follows the provisions of NEPA (Silverberg and Dennison, 1993), and it is possible to jointly coordinate SEQR and NEPA reviews.

Just about all agencies of government are independently responsible to ensure that their discretionary decisions are consistent with the Act. Actions involving wetlands alteration, regulation, or adjacent land use may be subject to SEQR. The regulations have been amended to require agency actions to be consistent with coastal policies. Specific actions in the coastal area must comply with standards of New York State's Waterfront Revitalization and Coastal Resources Act.

New York State Department of Environmental Conservation (NYSDEC). This agency protects freshwater and tidal wetlands in New York State through its regulatory, management, and acquisition programs. It is important to recognize that the freshwater wetland (FW) program and the tidal wetlands (TW) program are separate and distinct. Each is empowered by unique legislation and regulation, and program goals do differ. The FW program seeks no net loss of wetlands, while the TW program desires to achieve a net increase of tidal wetlands.

The TW program has inventoried and mapped all tidal wetlands within New York State's Marine District and instituted a regulatory scheme to protect and conserve them. The NYSDEC governs activities conducted within or adjacent to tidal wetlands according to the provision of the Tidal Wetlands Land Use Regulations. Jurisdiction can extend as much as 300 feet landward of the tidal wetland boundary.

The FW program has inventoried and mapped Long Island's freshwater wetland resource. And like the TW program, the NYSDEC protects the resource through a permit program. Unlike the TW program, a procedure exists that allows local government to assume responsibility for the protection of its freshwater wetlands.

In 1990, the New York State Legislature amended Articles 24 and 25 of the Environmental Conservation Law, enabling the NYSDEC Freshwater and Tidal Wetlands programs to create the Adopt-A-Wetland stewardship program. Interested parties can adopt a state owned wetland and perform management, stewardship, or education activities. Only two adoptions have taken place to date (NYSDEC, 1995).

Coastal Erosion Hazard Areas Program (CEHA). New York State regulations have been adopted to control certain activities and development in mapped coastal erosion hazard areas. Implemented by NYSDEC, their regulatory authority may be delegated to municipalities that develop comparable programs. Within coastal erosion hazard areas, construction or placement of a structure, or any action or use of the land which would materially alter its condition, requires a permit from the NYSDEC, or in the case of program delegation, county or local government. CEHA's include natural protective features such as beaches and dunes, sandbars and spits, barrier bays and islands, and wetlands, including associated natural vegetation.

Use and Protection of Waters Program. Also known as the Stream Protection Program. Article 15 of New York State's Environmental Conservation Law (ECL) provides is the legislative basis for regulating the construction or repair of water impoundment structures, and any disturbance of a stream bed, its banks, or any excavation or fill of navigable waters. Regulated activities include the construction and placement of docks and moorings, the maintenance of dams, and the placing of piles and piers. Jurisdiction includes navigable waters and extends to waters that have been classified according to their best use. The excavation or filling of areas within jurisdiction requires a permit. Wetlands and areas adjacent are protected.

State Pollutant Discharge Elimination System (SPDES). NYSDEC regulates discharges into surface and ground waters from industrial, commercial, and municipal users, and those of certain residential subdivisions as well. Discharges are reviewed in light of the existence of wetlands. NYSDEC's technical operational guidance states that it is generally unacceptable to discharge untreated stormwater to naturally occurring wetlands.

Water Quality Certification Program. § 401 of the CWA gave the states the prerogative and authority to regulate water quality within their borders. The NYSDEC is normally the approving authority in New York State. § 401 requires that any applicant for a federal license or permit to conduct any activity that may result in any discharge into navigable waters must obtain a water quality certification from the state in which the discharge will originate. So, actions requiring a § 404 permit will first need § 401 certification. Water Quality Certifications are usually tied to Protection of Water permits, Tidal Wetlands permits, and Freshwater Wetland permits.

NYSDEC has received an Environmental Protection Agency grant to develop water quality standards which would provide greater protection to wetlands. NYSDEC began drafting these standards in late 1995. They will be incorporated into New York State's water quality certification program when finalized.

Flood Control Program. The Flood Control Program is designed to achieve the reduction of flood damages to public and natural resources. The program preserves areas which benefit water quality or maintain biota, protects natural integrity of water bodies and drainage systems, and limits destruction of natural conveyance systems, if such areas coincide with flood control projects designed primarily for flood protection. Restrictions placed on development in flood plains offer a degree of protection to wetlands. The program is administered by the NYSDEC.

Endangered Species Program. The program is administered by the NYSDEC, and pursuant to the State Endangered Species Act, is responsible for protection of federal and state listed endangered and threatened species. A large number of these species are associated with wetlands.

Natural Heritage Program. Established by The Nature Conservancy (TNC) and now jointly funded by them and the NYSDEC, the program's major purpose is to inventory the rare plants, animals, and natural communities of New York State. A database of occurrences is maintained and the information is used by NYSDEC and other agencies in permit application review.

Wild, Scenic and Recreational Rivers System. The program applies to land use, development, or subdivision of private lands, within designated wild, scenic and recreational river areas. A river area includes the river and the land area in the river's immediate environs, not exceeding the width of one-half mile from each bank of the river. Rivers and their immediate river area possessing outstanding natural, ecological, recreational, aesthetic, cultural, archeological and scientific values, are eligible for special protection under this program.

New York State Department of State (NYSDOS). New York State's Coastal Management Program (CMP) is administered by the NYSDOS Division of Coastal Resources. The CMP was developed pursuant to the Coastal Zone Management Act of 1972 and approved in 1982. State Executive Law Article 42 declares that it is the public policy of the State within its coastal area to "...conserve and protect fish and wildlife and their habitats...preventing permanent adverse changes to ecological systems...." The CMP ties together the numerous programs of State agencies including the protection and use of coastal resources to ensure, in part, that all State and federal actions in the coastal area comply with enforceable policies and purposes of the CMP.

Whenever an activity is subject to State or federal consistency with the CMP, the effects of the activity must be evaluated against the preservation and protection of tidal and freshwater wetlands and their benefits, and Significant Coastal Fish and Wildlife Habitats.

Significant Coastal Fish and Wildlife Habitats (SCFWH). Based on a quantitative evaluation of ecological factors, significant coastal fish and wildlife habitats are designated and mapped by NYSDOS. Activities within and outside a SCFWH are held to strict standards to prevent impairments to their important habitat functions or values. Approximately 120 SCFWH's have been designated in the marine and estuarine districts of New York State. The CMP SCFWH policy states that significant coastal fish and wildlife habitats will be protected, preserved, and where practical, restored so as to maintain their viability as habitats.

New York State Office of General Services (OGS). OGS manages all state-owned underwater lands and formerly underwater lands to the last known location of mean high water. Under the Public Lands Law, most private uses of State land requires a grant, easement, or lease from OGS. Most underwater lands, and lands formerly underwater to the last known location of mean high water, along the Atlantic Ocean, in New York City, in Long Island Sound, and in the Peconic Bays are owned by the State, while on Long Island most underwater lands within harbors and inshore bays are owned by towns. Many of the underwater lands managed by OGS are seaward of tidal wetlands. OGS can play an important role in wetland protection by limiting coveyances of underwater lands for uses that will maintain their biological productivity.

APPENDIX E
KNOWLEDGEABLE CONTACTS

New York State Agencies

Department of State

Division of Coastal Resources
New York State Department of State
41 State Street, 8th Floor
Albany, NY 12231
telephone: 518-474-6000
internet: http://dos.state.ny.us/cstl/cstlwww.html

Department of Environmental Conservation

Bureau of Marine Resources Headquarters
New York State Department of State
205 North Belle Mead Road, Suite 1
East Setauket, New York 11733
telephone: 631-444-0430
internet: http://www.dec.state.ny.us/website/dfwmr/marine/index.htm

Division of Fish, Wildlife and Marine Resources-Headquarters
New York State Department of Environmental Conservation
50 Wolf Road
Albany, NY 12233
telephone: 518-457-5690
internet: http://www.dec.state.ny.us/website/dfwmr/xoa1e.htm#central

Division of Environmental Permits-Headquarters
New York State Department of Environmental Conservation
50 Wolf Road, Room 423
Albany, NY 12233
telephone: 518-457-6180

Region One-Nassau and Suffolk Counties
New York State Department of Environmental Conservation
SUNY-Building 40
Stony Brook, NY 11790

telephone: 631-444-0354
internet: http://www.dec.state.ny.us/website/reg1/index.html

Regional Permit Administrator, Region One
Division of Environmental Permits
New York State Department of Environmental Conservation
SUNY at Stony Brook Campus
Loop Road
Building 40, Room 121
Stony Brook NY 11790
telephone: 516-444-0365
internet: http://www.dec.state.ny.us/website/dcs/EP_REGIONS/region1.html

Region Two-Bronx, Kings, New York, Queens, and Richmond Counties
New York State Department of Environmental Conservation
One Hunter's Point Plaza
47-40 21st Street
Long Island City, NY 11101
telephone: 718-482-4900
internet: http://www.dec.state.ny.us/website/reg2/index.html

Regional Permit Administrator, Region Two
Division of Environmental Permits
NYS Department of Environmental Conservation
One Hunter's Point Plaza
47-40 21st Street
Long Island City, NY 11101
telephone: 718-482-4997
internet: http://www.dec.state.ny.us/website/dcs/EP_REGIONS/region2.html

Region Three-Sullivan, Ulster, Orange, Dutchess, Putnam, Rockland and Westchester Counties
New York State Department of Environmental Conservation
21 South Putt Corners Road
New Paltz, NY 12561
telephone: 914-256-3000
internet: http://www.dec.state.ny.us/website/reg3/index.html

Regional Permit Administrator, Region Three
Division of Environmental Permits
NYS Department of Environmental Conservation
21 South Putt Corners Road
New Paltz, NY 12561
telephone: 914-256-3054
internet: http://www.dec.state.ny.us/website/dcs/EP_REGIONS/region3.html

Federal Agencies

United States Fish and Wildlife Service

Southern New England-New York Bight
Coastal Ecosystems Program
U.S. Fish and Wildlife Service
Shoreline Plaza, Route 1A
P.O. Box 307
Charlestown, RI 02813
telephone: 401-364-9124
internet: http://www.fws.gov/r5snep/snep1.htm

Long Island National Wildlife Refuge Complex
U.S. Fish and Wildlife Service
P.O. Box 21
21 Smith Road (Express Mail Only)
Shirley, NY 11967
telephone: 516-286-0485
internet: http://northeast.fws.gov/

Long Island Field Office
U.S. Fish & Wildlife Service
P.O. Box 608
Islip, NY 11751
telephone: 516-581-2941
internet: http://northeast.fws.gov/

National Wetlands Inventory-Region 5

U. S. Fish and Wildlife Service
300 Westgate Center Drive
Hadley, MA 01035
telephone: 413-253-8620
internet: http://www.nwi.fws.gov/

National Oceanic and Atmospheric Administration

NOAA Restoration Center
National Marine Fisheries Service
F/HC3 1315 East-West Highway
Silver Spring, MD 20910
telephone: 301-713-0174
internet: http://www.nmfs.gov/habitat/restoration/nspage.html

Habitat Conservation Division
Northeast Regional Office
NOAA Restoration Center
National Marine Fisheries Service
One Blackburn Drive
Gloucester, MA 01930
telephone: 978-281-9251
internet: http://www.wh.whoi.edu/ro/doc/nero.html

Environmental Protection Agency

Region 2-New York, New Jersey, Puerto Rico, U.S. Virgin Islands
United States Environmental Protection Agency
290 Broadway
New York, NY 10007
telephone: 212-637-3000
internet: http://www.epa.gov/Region2/index.html

United States Department of Agriculture

Riverhead Service Center
Natural Resources Conservation Service

United States Department of Agriculture
Riverhead County Center
Room N-210
Riverhead, NY 11901
telephone: 631-727-2315
internet: http://www.nrcs.usda.gov/

Highland Service Center
Natural Resources Conservation Service
United States Department of Agriculture
652 Route 299
Highland, NY 12528
telephone: 914-883-7162
internet: http://www.nrcs.usda.gov/

Millbrook Service Center
Natural Resources Conservation Service
United States Department of Agriculture
Farm & Home Center Route 44
Millbrook, NY 12545
telephone: 914-677-3952
internet: http://www.nrcs.usda.gov/

National Estuary Programs

Long Island Sound Study

EPA LIS Office-New York
Marine Science Research Center
SUNY Stony Brook
Stony Brook, NY 11794
telephone: 631-632-9216
internet: http://www.epa.gov/region01/eco/lis/

EPA LIS Office-Connecticut
Stamford Government Center
888 Washington Boulevard

Stamford, CT 06904
(203) 977-1541
internet: http://www.epa.gov/region01/eco/lis/

New York/New Jersey Harbor Estuary Program

US EPA Region 2
290 Broadway 24th Floor
New York, NY 10007
telephone: 212-637-3809
internet: http://www.hudsonriver.org/hep/

New Jersey Department of Environmental Protection
Division of Watershed Management
P.O. Box 418
Trenton, NJ 08625-0418
telephone: 609-633-7242
internet: http://www.hudsonriver.org/hep/

Peconic Estuary Program

Office of Ecology
Suffolk County Department of Health Services
Riverhead County Center
Riverhead, NY 11901
telephone: 631-852-2077
internet: http://www.co.suffolk.ny.us/health/pep/

New York State Estuary Programs

Hudson River Estuary Program

Region 3-Dutchess, Orange, Putnam, Rockland, Sullivan, Ulster and Westchester Counties
New York State Department of Environmental Conservation
21 South Putt Corners Road
New Paltz, New York 12561

telephone: 914-256-3016
internet: http://www.dec.state.ny.us/website/hudson/hrep.html

South Shore Estuary Reserve

Division of Coastal Resources
New York State Department of State
41 State Street
Albany, NY 12231
telephone: 518-474-6000
internet: http://dos.state.ny.us/cstl/cstlwww.html

South Shore Estuary Reserve Council
225 Main Street, Suite 2
Farmingdale, NY 11735
telephone: 631-470-BAYS (2297)

National Estuarine Research Reserves

Hudson River National Estuarine Research Reserve

NYS Department of Environmental Conservation
c/o Bard College Field Station
Annandale, NY 12504
telephone: 914-758-5193
internet: http://www.ocrm.nos.noaa.gov/nerr/reserves/nerrhudsonriver.html

Miscellaneous Contacts

New York City Parks and Recreation Department

Natural Resources Group
New York City Parks and Recreation
Arsenal North, 1234 Fifth Avenue
New York, NY 10029
telephone: 212-360-1417
internet: http://www.ci.nyc.ny.us/html/dpr/html/boomer.html

Cornell Cooperative Extension

Cornell Cooperative Extension Marine Program
3690 Cedar Beach Road
Southold, NY 11971
telephone: 631-852-8660
internet: http://www.cce.cornell.edu/suffolk/index.html

New York Sea Grant

New York Sea Grant Extension Program
Cornell University
348 Roberts Hall
Ithaca, NY 14853
telephone: 607-255-2832
internet: http://www.seagrant.sunysb.edu/

New York Sea Grant
SUNY at Stony Brook
146 Suffolk Hall
Stony Brook, NY 11794-5002
telephone: 631-632-8730
internet: http://www.seagrant.sunysb.edu/

New York Sea Grant
Cornell University Laboratory
3029 Sound Avenue
Riverhead, NY 11901
telephone: 631-727-3910
internet: http://www.seagrant.sunysb.edu/

New York Sea Grant
10 Westbrook Lane
Kingston, NY 12401
telephone: 845-340-3983
internet: http://www.seagrant.sunysb.edu/

APPENDIX F
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