LONG ISLAND SOUND STUDY
A Partnership to Restore and Protect the Sound

LONG ISLAND SOUND HABITAT RESTORATION INITIATIVE

TECHNICAL SUPPORT FOR COASTAL HABITAT RESTORATION

Tidal Wetlands

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SECTION 1: TIDAL WETLANDS

Technical Support for Coastal Habitat Restoration

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SECTION 1: TIDAL WETLANDS

DESCRIPTION

The textbook tidal wetland is the salt marsh of the estuarine shoreline. There are also brackish and fresh tidal marshes, which support reeds, bulrushes, and even shrubs and trees. Healthy tidal wetlands are dynamic systems subject to constant changes in elevation and vegetation patterns in response to natural events such as erosion, sedimentation, and sea level rise. The occurrence of tidal wetlands is determined by the geology and resulting topography of Long Island Sound and its shoreline. For example, the shoreline in Connecticut and Westchester County is more conducive to the formation of these marshes than Long Island's Sound shoreline east of Port Jefferson. The reason for this phenomenon is the Sound's glacial history; as the last glacier retreated from the Long Island Sound basin 19,000 years ago, it left a recessional moraine atop the scoured-out coastal plain wedge of Long Island's north shore. In the eastern section, this moraine directly borders the Sound. The resulting high, sandy bluffs erode easily. This erosion produces a straight shoreline and prevents the development of wetlands.

In the western section of Long Island, the moraine is set back further from the shore. Instead of following the moraine, the shoreline follows the edge of the ancient coastal plain. The coves and bays in this region are the result of north flowing rivers and streams carving valleys into the coastal plain. Tidal wetlands are found in these coves and bays.[1]

The coves and inlets of the Connecticut and Westchester County coast are defined by underlying bedrock. This geology, as well as the overlying substrate, is conducive to the formation of tidal wetlands; fine-grained sediments, as deep as 43.7 yards, were deposited by the melting glacier along much of the coast. These deltaic deposits support most of the Sound's major tidal wetland complexes.

SALT MARSHES

The most abundant and best known type of tidal wetland is the salt marsh. The soil salt content ranges from approximately 18 to 30 parts per thousand (ppt). These grassy communities represent the "climax" vegetation on these tidal shores since there are no temperate zone trees or shrubs that can tolerate regular flooding with salt water. Four grasses dominate this marshscape: black grass (***Juncus gerardii***), spike grass (***Distichlis spicata***), salt meadow cordgrass (***Spartina patens***), and saltwater cordgrass (***Spartina alterniflora***). Saltwater cordgrass is dominant in the low marsh zone, which is flooded twice daily by the tides. This zone occurs along the seaward edges, creeks, and ditches of the wetland. Black grass, spikegrass, and salt meadow grass occur on the higher elevations of the marsh known as the high marsh zone, which is irregularly flooded (***Figure 1-1***). The upland border zone of the wetland, flooded only several times a month, contains plants such as switchgrass (***Panicum virgatum***), marsh elder (***Iva frutescens***), and groundsel tree (***Baccharis halimifolia***).

The high marsh zone may contain permanent ponds and depressions called pannes. The ponds often contain widgeon grass (***Ruppia maritima***), a submerged aquatic vegetation important in the diet of waterfowl. Pannes may be devoid of vegetation or may support stunted cordgrass and/or saltwort (***Salicornia*** spp.).

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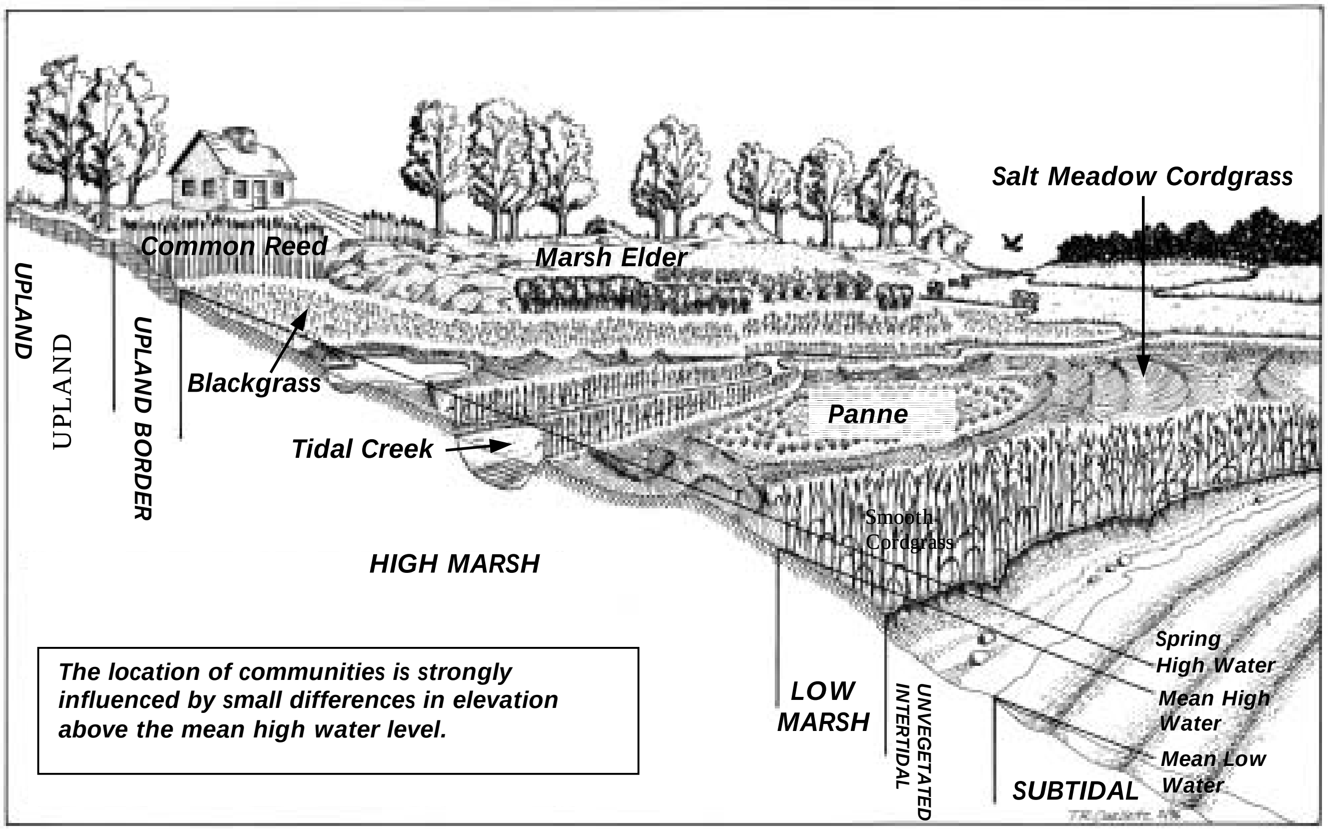
[1]It is interesting to note that, because of the slope of these ancient valleys, homes were not built adjacent to the wetlands, but at higher elevations. This unique situation enabled these marshes to escape being mosquito-grid ditched because mosquitoes were not an immediate threat to coastal homeowners.

FIGURE 1-1. Generalized Zonation of Plant Communities in a Typical Long Island Sound Salt Marsh



Common reed (***Phragmites australis***) may be present on the upland border of salt marshes. Since the plant cannot tolerate salinity levels greater than approximately 18 ppt (Rhodes and Simmers, 1978), or high sulfide levels (Chambers ***et al***., 2001), it does not invade salt marshes. However, degraded marshes that have had their salinity lowered to less than 18 ppt are subject to invasion.

The invertebrate animal communities found among the salt marsh plants and in the creeks and ditches include crabs, snails, shrimp, mussels, insects, and spiders (Olmstead and Fell, 1974). These species may be found in zones similar to those of the plant communities. For example, the mud snail (***Nassarius obsoletus***), is commonly found in creeks and ditches; the rough periwinkle (***Littorina saxatilis***) is found in the saltwater cordgrass of the low marsh; and the saltmarsh snail (***Melampus bidentatus***) is found in the high marsh. Other low marsh fauna include ribbed mussel (***Geukensia demissa***), fiddler crabs (***Uca*** spp.), striped sea anemone (***Haliplanella luciae***), and the common clamworm (***Nereis virens***) (Warren and Fell, 1996). In addition to the saltmarsh snail, high marsh invertebrates include isopods (***Philoscia vittata***) and amphipods (***Orchestia grillus***).

Because of their high productivity, tidal wetlands provide critical spawning and nursery habitat for a wide variety of fish species. These species, in turn, are important prey for valuable commercial and recreational fish species such as striped bass (***Morone saxatilis***), blue fish (***Pomatomus saltatrix***), and winter flounder (***Pleuronectes americanus***). Fish species found in the creeks and ditches include common mummichog (***Fundulus heteroclitus***), striped killifish (***Fundulus majalis***), the sheepshead minnow (***Cyprinodon variegatus***), American eel (***Anguilla rostrata***), Atlantic silverside (***Menidia menidia***), and young-of-the-year winter flounder.

Common birds of the tidal marsh include osprey (***Pandion haliaetus***), herons, egrets, rails, swans, shorebirds, ducks, and two species of marsh sparrow. Although there is much overlap in avifaunal use of salt, brackish, and freshwater marshes, there are some important differences in the distribution of bird species. The distribution of marsh breeding bird species can often be linked to change in vegetation from salt to freshwater marshes. Species that are habitat specific for ***Spartina*** spp.-dominated marsh (salt and mesohaline brackish) are seaside sparrow (***Ammodramus maritimus***), saltmarsh sharp-tailed sparrow (***Ammodramus caudacutus***), willet (***Catoptrophorus semipalmatus***), and clapper rail (***Rallus longirostris***). These species decrease in abundance with increasing distance from the mouth of the river. Marsh wren and swamp sparrow, on the other hand, build nests in tall reedy vegetation and are most abundant in oligohaline brackish marshes where cattail and ***Phragmites*** are the dominant plants (Benoit and Askins, 1999). Although no studies have directly linked freshwater marsh vegetation to any breeding bird species, a number of species, including wood duck (***Aix sponsa***) (Benoit, 1997; Craig, 1990), sora rail (***Porzana carolina***), song sparrow (***Melospiza melodia***), spotted sandpiper (***Actitis macularia***) and American bittern (***Botaurus lentiginosus***) (Craig, 1990), are found almost exclusively in freshwater habitats.

Many wading birds, wetland generalists that use marshes for foraging rather than nesting, can usually be found in tidal marshes throughout the range of salinities. However, even these non-marsh breeders can exhibit a preference for marsh type: snowy egret (***Leucophoyx thula***) and great egret (***Casmeroduis alba***) are much more common in salt and brackish wetlands, while great blue heron (***Ardea herodias***) prefer freshwater areas.

BRACKISH MARSHES

Brackish marshes occur in embayments and tidal rivers where the waters of Long Island Sound are significantly diluted by freshwater. In these wetlands, the salt content of the soil ranges between 0.5 and 18 ppt (oligohaline to mesohaline). At the upper salinity range, black grass, spike grass, and salt meadow grass may be dominant. Salt marsh aster (***Aster tenuifolia***) and silverweed (***Potentilla groenlandica***) grow in this area as well, reaching a greater abundance here than in the salt marsh. The distinction between this community, referred to as brackish meadows, and the superficially similar salt marsh community was first recognized by Nichols (1920). The difference between the two is important to recognize when determining restoration techniques and establishing restoration goals.

As the soil halinity decreases, blackgrass, spike grass and salt meadow grass decrease in abundance and are replaced by locally dominant species such as common three-square (***Scirpus americanus***), bulrush (***Scirpus robustus***, ***Scirpus paludosus*** v. ***atlanticus*** and ***Scirpus cylindricus***), water hemp (***Amaranthus cannibina***), big cordgrass (***Spartina cynosuroides***), slough grass (***Spartina pectinata***), and common reed. Nichols (1920) notes that brackish reed marshes "are usually occupied by a dense growth of cattails (especially ***Typha angustifolia***) or of the reed (***Phragmites australis***), together, particularly in the drier situations (as, for example, on marginal embankments)." Narrow-leaved cattail (***Typha angustifolia***) is the dominant species in many of the brackish reed marshes although in very low salt environments the dominant cattail is a hybrid known as ***Typha*** X ***glauc***a. Narrow-leaved cattail is a species that prefers alkaline areas and thus is probably present in brackish marshes not because of the salt content but because of the alkaline nature of the soils.

Many animal communities of the salt marsh may also be found in the brackish marsh. Differences include the absence of the ribbed mussel and the fiddler crab (***Uca pugnax***) from the brackish marsh. Conversely, species not found in the salt marsh, but found in the brackish marsh, include the high marsh snail (***Succinea wilsoni***) and the red-jointed fiddler crab (***Uca minax***). Brackish high marsh areas provide important foraging habitat for a variety of fish species (Weisberg and Lotrich, 1982; Fell ***et al***., 1998). These species, in turn, provide an important trophic link between the highly productive marsh and near shore estuarine waters (Kneib and Stiven, 1978).

TIDAL FRESH MARSHES

Fresh tidal marshes occur in areas where the tide rises and falls but the waters have no detectable concentration of salt. Technically, these marshes are not considered a part of the estuary. Fresh tidal marshes are the most diverse tidal wetland type and support a great variety of plants such as wild rice (***Zizania aquatica***), arrow arum (***Peltandra virginica***), river bulrush (***Scirpus fluviatilis***), sweetflag (***Acorus calamus***), and broad-leaved cattail (***Typha latifolia***). Nichols (1920) reported common reed as an associated or local dominant with cattail. Tidal fresh marshes have 25 to 40 species growing intertidally, and 60 to 100 species in sections of the marsh that are flooded infrequently (Odum, 1984).

The wild rice community in the lower/mid-tidal flats is often associated with pickerelweed (***Pontederia cordata***), arrowhead (***Sagittaria*** spp.), marsh purslane (***Ludwigia palustris***), false pimpernel (***Lindernia dubia***), and golden club (***Orontium aquaticum***). The sweetflag community in the mid-tidal range is associated with three-way sedge (***Dulichium arundinaceum***), common beggar's tick (***Bidens frondosa***), a sedge (***Carex stricta***), water horsetail (***Equisetum fluviatile***), spotted jewelweed (***Impatiens capensis***), yellow iris (***Iris pseudacorus***), water smartweed (***Polygonum punctatum***), water duck (***Rumex verticillatus***), bur-reed (***Sparganium eurycarpum***), and rice cutgrass (***Leersia oryzoides***). Wild rice, pickerelweed, and some bulrush species are also found in this tidal range. The regularly-flooded zone often contains a community of arrow arum, river bulrush, and cattail. Many of the mid-tidal range species are also found in this zone. Common reed, though it does not expand as rapidly compared to brackish marsh, can outcompete freshwater vegetation to form monocultures.

While these patterns of dominance exist, there is no distinct zonation such as that found in salt marshes. The tidal fresh marsh also differs from the salt marsh in that it usually has numerous co-dominant species as opposed to one species growing in a certain zone, such as saltwater cordgrass dominating the low zone of the salt marsh.

The faunal community of the tidal fresh marsh is similar to that of the salt marsh, but composed of different species. The invertebrate community contains amphipods, especially ***Gammarus fasciatus***, oligochaete worms, freshwater snails, and insect larvae. Copepods, cladocerans, and freshwater shrimp (***Macrobrachium*** spp.) may also be found in the tidal fresh marsh (Mitsch and Gosselink, 1986). Numerous juvenile and adult fish, including killifish (***Fundulus*** spp.), bluegill (***Lepomis macrochirus***), largemouth bass (***Micropterus salmoides***), sunfish (***Lepomis*** spp.), and shad (***Alosa*** spp.), are found in these areas. Some of the same bird species that use the salt marsh also use the tidal fresh marsh. In addition to these species, sparrows, finches, blackbirds, wrens, and other ground and shrub birds may be abundant.

While tidal fresh marshes are diverse and ecologically important, they comprise only a small percentage of the tidal wetlands within the Habitat Restoration project boundary. For this reason, the tidal wetlands chapter will focus on brackish and salt marshes where salt concentrations become the major factor in restoration efforts.

VALUES AND FUNCTIONS

Wetlands are ecologically, economically, and socially valuable. The health and productivity of a wetland depend on the intricate interactions of marsh organisms, both plant and animal.

Wetlands are an important source of food for fish and wildlife. The primary productivity of wetlands rivals that of rainforests and high yield agricultural fields. Above-ground production of salt marsh angiosperms along the Connecticut coast ranges from 650 $g/m^2/yr$ to 2000 $g/m^2/yr$ (Niering and Warren, 1980). Many species of wildlife, particularly waterfowl, directly consume the wetland plants and their seeds. An even greater number of species, including zooplankton, shrimp, snails, clams, worms, and forage fish eat the detritus from decaying plants or the bacteria, fungi, diatoms, and protozoa growing on plant surfaces (Crow and Macdonald, 1979; de la Cruz, 1979). These species become the primary food for commercial and recreational fishes, including bluefish, striped bass, flounder, and weakfish. The marshes' high productivity contributes to it being an important feeding ground for migrating waterfowl, raptors, shorebirds, and wading birds.

Wetlands also provide critical habitat as spawning and nursery areas for finfish. ***Table 1.1*** lists finfish species commonly captured during Connecticut Department of Environmental Protection surveys in and around Connecticut coastal marshes from 1990-1996.

TABLE 1-1. Finfish Using Connecticut Marshes and Adjacent Open Water for Spawning and Nursery Grounds (Species in bold type have commercial and/or recreational importance)

Species	*Spawning*	*Nursery*
American eel		*
American shad		*
anchovy	*	
Atlantic tomcod	*	*
blueback herring	*	
cunner		*
four-beard rockling	*	*
grubby	*	*
hogchoker	*	*
menhaden	*	
northern puffer	*	*
northern kingfish	*	
oyster toadfish	*	*
rock eel (gunnel)	*	*
smooth flounder	*	
striped searobin		*
Summer flounder	*	
tautog (blackfish)		*
windowpane flounder		*
winter flounder	*	*

There are more than 40 plant and animal species of special concern, threatened, or endangered status that depend on the presence of tidal marshes for one, or many, of their life stages. The diamond-back terrapin (***Malaclemys terrapin***) is found only in brackish and salt water marshes. Seaside and saltmarsh sharp-tailed sparrows, both species of special concern in Connecticut, nest in salt marshes and, to a lesser extent, brackish meadow marshes. The stunted cordgrass areas, found in pannes of the high salt marsh, are critical foraging habitat for these sparrows. See ***Table 1-2*** for a partial list of other trust species (New York, Connecticut or federal) using the marsh.

TABLE 1-2. Partial List of Other Trust Species (New York, Connecticut or federal) Using the Marsh

Common Name	Scientific Name
least shrew	***Cryptotis parva***
American bittern	***Botaurus lentiginosus***
least bittern	***Ixobrychus exilis***
willet	***Catoptrophorus semipalmatus***
king rail	***Rallus elegans***
osprey	***Pandion haliaetus***
golden club	***Orontium aquaticum***
Eaton's beggar-tick	***Bidens eatonii***
sea-coast angelica	***Coelopleurum lucidum***
Parker's pipewort	***Eriocaulon parkeri***
salt marsh bulrush	***Scirpus cylindricus***

There are also a number of species featured in state and federal management plans that depend on tidal wetlands. For example, a priority recommendation in the North American Waterfowl Management Plan is to protect tidal marshes for the declining population of American black duck (***Anas rubripes***). The black duck and species such as willet ***(Catoptrophorus semipalmatus***), clapper rail (***Rallus longirostris***), marsh wren (***Cistothorus palustris***), mallard (***Anas platyrhynchos***), and Canada goose (***Branta canadensis***) use tidal wetlands for nesting. Non-trust species frequenting the marsh include fox, racoon, deer, turtles, snakes, frogs, beavers, muskrats, and voles.

Tidal wetland values are not limited to food production and habitat. Wetlands function to maintain water quality, filter nutrients and pollution, and remove sediments from water. The roots of tidal wetland vegetation and underlying substrate remove nutrients, especially nitrogen and phosphorus, from surface runoff. Studies on the Tinicum marshes near Philadelphia reported a 50-70 percent reduction in nitrogen and phosphorus after wastewater had passed through the marsh (Grant and Patrick, 1970). As the vegetation and soil filter out nutrients, they also remove pesticides, heavy metals, and other chemical constituents. The marsh not only acts as a filter for these pollutants, but it also functions as a settling basin (Bastian and Benforado, 1988). Vegetation acts as a buffer to slow water velocity, increasing settling time for suspended and particulate matter.

Other wetland values involve the protection of adjacent shoreline from flood and wave damage and erosion. As waves, storm surges, and currents move through the marsh, their energy is deflected by plant stems and leaves (Knutson, 1988). A reinforced root system helps to stabilize the marsh and resist erosion. The dissipation and absorption of energy by the marsh increases the potential for sediment deposition and decreases the potential for shoreline erosion. Also, the ability of wetlands to quickly absorb and then slowly release flood waters helps prevent flood damage.

Wetlands also provide aesthetic values and direct and indirect economic benefits as important sites for recreational fishing, waterfowl hunting, canoeing, nature observation, hiking, photography, and boating.

STATUS AND TRENDS

Current estimates place the acreage of all Long Island Sound tidal wetland types at 20,820 acres. Eighty-five percent of these wetlands occur in Connecticut. Prior to the implementation of current tidal wetland regulations, an estimated 25 to 35 percent of the Sound's tidal wetlands were destroyed by dredging, filling and development (Long Island Sound Study, 1994). Examples of specific activities that led to wetland loss include: dredging to create open water for commercial shipping lanes and recreational marinas; disposal of municipal waste (***i.e.*** landfills); and the placement of fill or disposal of dredged sediment to create upland transportation facilities (roads, railroads, and airports), or commercial, industrial, and residential development. In Connecticut, annual permitted wetland losses due to these types of activity currently average 0.25 acres.

Other activities may not destroy a marsh, but instead impair its functions and values. For example, many marshes are grid-ditched, drained, impounded, or impacted by stormwater runoff. Approximately 90 percent of the Sound's marshes have been grid-ditched, an activity that has had a negative impact on water levels in the marsh, resulting in declines in muskrat abundance (Stearns ***et al.***, 1940) and changes in species composition of bird communities. An on-going, natural form of degradation involves the spread of common reed into brackish marshes at a rate of 1-2 percent per year (Warren, 1994).

Human activities that destroyed marshes contributed to an estimated 30 percent loss in Connecticut. Estimates of historical acreage range from 23,360 acres (Niering, 1961) to 26,500 acres (Goodwin, 1961). Presently, there are approximately 17,610 acres[2]. The average annual loss rate was 125 acres. The estimate of a 30 percent loss was supported by a recent analysis that compared a limited geographic area from 1880s Coast and Geodetic Charts to the same geographic area in 1974. There is a distinct geographic trend with wetland losses diminishing from west to east, corresponding to the trend from the most urbanized to the most rural area of the coast. Specific wetland losses in acres for individual counties ranged from 2.4-57.4 percent (***Table 1-3***).

TABLE 1-3. Wetland Losses (in acres) for Four Connecticut Counties

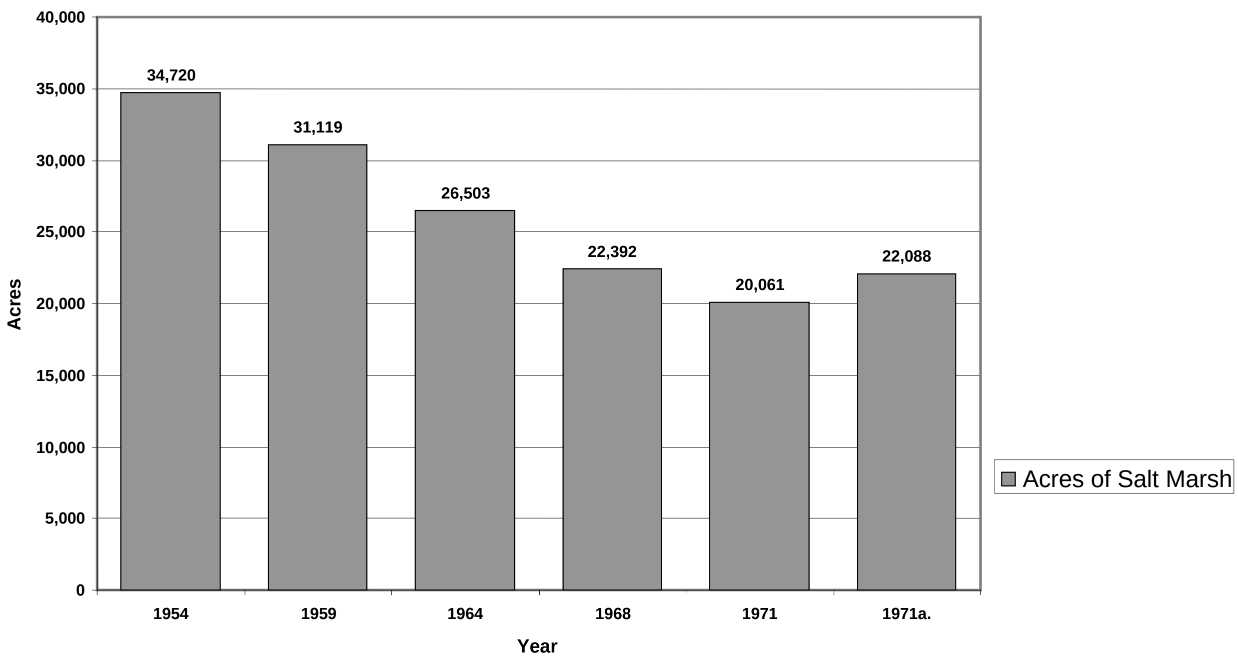
	Fairfield	New Haven	Middlesex	New London
1880s	5423.5	7653	4023	3762.6
1970s	2111.8	5733.6	3101.5	3670.7
Acres Lost	3111.7 (57.4%)	1919.4 (25.8%)	921.5 (22.9%)	91.9 (2.4%)

In New York State, tidal wetland losses have been fairly well documented from the 1950s to the 1970s. Unfortunately these inventories were conducted using varying methodology and did not differentiate between water bodies. Therefore, it is difficult to make an accurate comparison over time, and not possible, from extant studies, to determine losses solely in New York's portion of Long Island Sound. The studies available examined, for the most part, large wetland complexes considered of high value to waterfowl and wildlife. It appears that all but one of these inventories may have underestimated the total amount of wetland by omission of fringing marshes, especially those so

[2] This figure is based upon Connecticut's tidal wetland mapping that was completed in the 1970s, and includes a 1994 revision for the Connecticut River. The original 1970s maps did not include all of the state's tidal wetlands and in certain areas such as the mouth of the Housatonic River, new wetland areas have formed. This figure, therefore, underestimates the tidal wetland acreage present in Connecticut.

prevalent along the exposed shorelines of the Sound. However, it is doubtful that these relatively small areas of fringing marsh would alter the overall trend over the twenty year period examined. ***Figure 1-2*** depicts the total salt marsh acreage of Nassau and Suffolk Counties in specific years from 1954 to 1971. The data indicate a 36 percent loss during this period (U.S. Fish and Wildlife Service, 1965; N.Y. State Office of Planning Services, 1972) when the studies of comparable methodology are considered. The data labeled "1971a." in ***Figure 1-2*** represents a more comprehensive inventory undertaken by O'Connor and Terry (1972) that includes the fringing marshes as well as large complexes in the two counties. Individual data for Bronx county, where the majority of that county's salt marshes bordered the Sound, indicate a 90 percent loss of large wetland complexes from 1954 to 1964 (U.S. Fish and Wildlife Service, 1965). The NYSDEC conducted a full inventory of tidal wetlands in 1974 as required by the passage of the Tidal Wetlands Act. At that time there were estimated to be 3,200 acres of vegetated tidal wetlands in the New York portion of Long Island Sound. This estimate includes the Long Island Sound shoreline and all the bays and harbors opening on the

Figure 1-2. Wetland Inventory Figures for Nassau and Suffolk Counties, NY 1954 - 1972



Sound in Bronx, Queens, Nassau, Suffolk, and Westchester counties.

In the subestuaries (i.e., tidal rivers) of central and western Long Island Sound (LIS), with a tide range of 5 to 8 feet, emergent tidal wetland, especially low marsh habitat, is converting to intertidal flat. This phenomenon was first noticed in the mid to late 1980s in the Fivemile River in Darien. The pattern of loss is not uniform within any particular subestuary. On average, the losses appear to be the greatest in the mid-estuary segments and maximum loss rates since 1974 are approximately 60 percent. The single greatest loss is occurring in the mid-section of the Quinnipiac River, affecting an area of brackish wetland of approximately 80 hectares. The biophysical changes in these marshes bear a striking resemblance to other eastern seaboard wetlands that scientists attribute to accelerated relative sea level rise. Initial investigations of marshes in the New York portions of the Sound have revealed similar losses in several areas. These losses also appear consistent with reports from other estuaries of the eastern United States.

Rates of sediment accumulation in marshes must equal or exceed rates of sea level rise if the wetland is to persist and not “drown”. Historic rates of sea level rise over the last 1500 years averaged ~1 mm/year, but rates over the last 100 years in southern New England have been averaging 2.4 mm/year (Donnelly and Bertness, 2001), a modern day phenemenon that may be responsible for the patterns of wetland vegetation change and loss seen in the Sound. Preliminary analysis of tide data for the New London tide station shows sea level rise rates of 3.6 mm/year and 9.0 mm/year for the period 1970 to 2000 and 1989 to 2000 respectively (R. S. Warren, personal communication). In both Connecticut and New York, research is underway to assess trends of tidal wetland losses and impacts due to sea level rise. The New York State Department of Environmental Conservation is conducting a tidal wetlands trends analysis by digitizing and comparing wetland areas from historic and current aerial photographs. The goals are to identify specific areas of loss, determine reasons for loss, and then pursue remediation and restoration with partners. In Connecticut, a series of sedimentation erosion tables will be installed in a number of marshes in order to measure changes in marsh surface elevation. This will allow researchers to determine if marsh surface elevation is keeping pace with sea level rise.

The first law to protect coastal wetlands in New York State, passed in 1973, is under Article 25 of the New York State Environmental Conservation Law. This law, called the Tidal Wetland Act, establishes policy allowing for the protection of wetlands balanced with reasonable economic development for the state. Activities in or near wetlands are subject to a regulatory review process. The regulatory program, administered by the New York State Department of Environmental Conservation (NYSDEC), has been in effect since 1977. Article 15, the Protection of Waters Act, is also administered by NYSDEC. This law regulates the placement of structures, dredging and filling activities, and alteration of water courses in navigable waters of the state. Waters of the state have been defined to include bordering wetlands.

Connecticut passed its Tidal Wetland Act in 1969. This Act establishes a policy that requires the preservation of tidal wetlands and is executable through a regulatory program that requires permits in order to conduct activities in tidal wetlands. Activities that are inconsistent with the state's policy, which includes all of the policies and standards of the state’s coastal management act, cannot be authorized.

In recognition of long-term and on-going tidal wetland degradation, the Connecticut Coastal Management Program of 1979 drafted a policy that "encourages the rehabilitation and restoration of degraded tidal wetlands." In 1980, the Coastal Area Management Program (now called the Office of Long Island Sound Programs) of the Connecticut Department of Environmental Protection (CTDEP) began a long-term program for restoring heavily degraded tidal wetlands.

DEGRADED MARSHES AND RESTORATION METHODS

Degraded and altered tidal marshes of Long Island Sound are grouped into the following categories:

- Grid-ditched
- Drained
- Buried/Filled
- Common reed-dominated brackish marshes
- Impounded
- Stormwater impacted

These categories are listed in the order of greatest to least amount of acreage impacted. Grid ditching has affected more acreage of salt and brackish marshes than any other type of degradation. Fortunately, its impacts on the marshes’ value and functions are mild when compared to degradation such as filling, which completely eliminates all tidal wetland values and functions. The second most common form of degradation, draining, alters plant species composition dramatically and reduces some of the values and functions.

The categories of marsh degradation and some specific changes in the marshes' value and functions are discussed below. Methods of restoration for each type of degradation are also presented.

GRID-DITCHED MARSHES

In the early part of this century, the prevention of mosquito-spread disease was a major concern of health officials. The draining of intermittent shallow pannes and ponds on the marsh surface was the focus of efforts to eliminate salt marsh mosquito (***Aedes solicitans*** and ***Aedes cantator***) breeding habitat. Grid ditches were constructed in order to drain these areas. More than 90 percent of the short-grass meadow communities of salt and brackish marshes were ditched in the Sound region. These ditches were approximately 30 inches wide and 30 inches deep. Parallel ditches 100 feet apart ran perpendicular to the shoreline and to lateral ditches every 400 feet.

Ditches effectively lowered a marsh's water table by several inches, eliminating ponds and intermittent pools, as well as creating drier soil conditions. While salt meadow grass production improved, the stunted cordgrass associated with pannes disappeared. Other changes included the elimination of pools containing widgeon grass and an increase in the tall form of saltwater cordgrass. This change in plant species composition led to an overall decrease of values and functions. For example, studies have shown that avifauna species abundance and diversity is greatest on the natural marsh and significantly lower in ditched marsh habitats (Reinert ***et al***., 1981 and Clarke ***et al***., 1984).

Restoration Methods:

① <u>Abandoning the Maintenance of Grid-Ditching</u>: This method allows the ditches to naturally fill with sediment. When the ditch becomes sufficiently shallow, saltwater cordgrass will begin to grow. The rate at which this process occurs varies according to the marsh and the specific hydrologic conditions. For example, forty years after a dike was constructed at the Barn Island marsh in Stonington, Connecticut, a tidal creek that had been cut off from tidal flow had converted to vegetated marsh. Sixty years after the Great Meadow marshes in Stratford, Connecticut were ditched, the majority of never-maintained ditches received only partial tidal exchange and contained intermediate-height saltwater cordgrass. A smaller percentage of the ditches received full tidal exchange and supported tall saltwater cordgrass along their banks. Ten years after stopping the maintenance of grid ditching in Connecticut's Hammonasset State Park many of the ditches have filled with sediment (soupy substrate) and vegetation. There was also a dramatic increase in pannes and panne vegetation, which has led to increased wildlife utilization.

② <u>Ditch Plugs:</u> This method has been used to restore grid-ditched marshes in both Connecticut and New York. The placement of soil plugs into the ditch restores the high water table in the adjacent marsh almost immediately. Studies in Old Lyme, Connecticut, have shown that after only a year, a large expanse of pannes reappeared on the marsh surface. At another site in Westbrook, Connecticut, a dramatic increase in wildlife use was observed immediately after plugging.

Preventing scour of the plug during spring high tides requires the placement of fill in a 20-25 foot length of ditch where the peat is firm and a 50 foot length where it is soft. Marine plywood may be used to stabilize the ends of the plugs and prevent erosion, but the longevity of the structure is not known at this time. Due to the interconnected nature of these ditches, it is usually necessary to plug several of them in order to restore a section of marsh.

③ Pond Creation: This method may be used to enhance unditched salt marshes or to help restore ditched salt marshes. Unfortunately, most of the mosquito ditching was conducted prior to the first aerial surveys, so no exact blueprints exist as to the historic location and number of ponds.

To create ponds, small, irregularly-shaped areas are excavated on the marsh surface. These ponds are a minimum of 25 feet in diameter and have a shallow perimeter averaging 6-12 inches in depth. Greater depths are excavated in the middle, usually covering one-quarter of the pond's size. The shallow shelf provides access for wading birds such as shorebirds and egrets, while the deeper area provides permanent habitat for aquatic organisms such as killifish. It is common practice to use excavation material from the ponds to plug adjacent grid ditches. For this reason, pond locations are selected based on their proximity to ditches.

DRAINED MARSHES

Gate structures and culverts are the two most common types of tidal flow structures resulting in the restricted draining of a marsh. A common type of gate structure used along the coast for mosquito and flood control is the flapper or sluice gate (***Figure 1-3***). These gates are constructed from wood or metal, are hinged at the top and suspended on a frame. The gates are usually set so that the door swings out toward Long Island Sound. Thus, when the tide ebbs, water moves unrestricted from upstream to downstream. When the tide floods, the gate closes, reducing the tidal range to about a foot. Greater flows occur when the gates have not been maintained, have become wedged open with tidal debris, or have become warped.

FIGURE 1-3. One of Four Flap Tide Gates Open at Hammock River

One of four flap tide gates was opened at Hammock River in Clinton, Connecticut. If more than one gate was opened, it could cause flooding of low-lying residential properties built close to the wetland.

Culverts, if not properly sized or set at the wrong elevation, can reduce tidal flow volumes and tidal heights. When not well maintained, blockages and collapsed pipes will significantly reduce tidal flows.

If culverts are set at too high an elevation, they prevent the water level from reaching its natural low tide level. Salt marshes are further stressed when high culverts prevent freshwater from draining, thus diluting the incoming saltwater.

The restriction of tidal flow into a marsh by culverts or tide gates usually lowers the water table from one inch below the surface to one to four feet below the surface and results in the following: increase in oxygen content of the soil above the water table; increase in the rate of decomposition of the organic matter in the dry soil; subsidence; reduced salinity and sediment accumulation rates; anoxia or hypoxia during summer months; and decrease in pH levels from circum-neutral or slightly alkaline conditions (typical of estuarine waters) to highly acidic (pH 3 to 4).

In general, the lower water table causes the tidal wetland soils to become a source of nonpoint pollution. Under normal conditions, pyrite (iron sulfide) forms in salt and brackish marshes in the presence of wet, anaerobic soils with a high organic content. Oxidation of the soil caused by the lower water table converts the pyrite into sulfuric acid. This action leads to a change in the soil pH from neutral or circum-neutral to highly acidic. Acid sulphate soil is created (Dent, 1986). Soil acidity values as low as three to four have been reported. At these levels, the aluminum found in natural clay particles is mobilized. Aluminum is generally very toxic to aquatic organisms at low concentrations. The water quality is further degraded by soil changes affecting dissolved oxygen levels. Following rainfall events, marsh leachate contains compounds that compete for oxygen, thus increasing the likelihood of a hypoxic event (Portnoy, 1991).

These chemical and physical changes are often accompanied by changes in the biological community. There may be a general loss of aquatic organisms such as salt marsh snails, amphipods, ribbed mussels, blue crabs, and killifish. Plant species composition can also be dramatically altered. If the soil salinity falls below 18 ppt, a drained salt marsh becomes open to invasion by common reed.

Restoration Methods:

Reintroduction of tidal flow is the principal technique used to restore salt marshes degraded by tide gates and undersized culverts. It is also applicable for achieving some fresh and brackish marsh restoration goals. The following information is required in order to determine the appropriate tidal elevation:

- tidal data (downstream and upstream of the structure)
- marsh elevation (downstream and upstream of the structure)
- baseline vegetation (high marsh, low marsh, common reed, etc.)
- creek and soil salinity (downstream and upstream of the structure)
- elevations of lowest lying structures (***i.e.*** homes, property, etc.)

If restoration has the potential to create flooding problems, then either special flood protection measures need to be incorporated into the project (***e.g.***, raising house elevations, construction of dikes around the upland perimeter) or tidal flow must be restored to the extent that flooding problems are not exacerbated. However, partial restoration of tidal flow may result in only partial restoration of the wetland. The following restoration activities are presented in the context that no flooding problems will ensue.

Planting of wetland vegetation is not recommended for this type of restoration. The natural stock of native plant species will spontaneously reestablish themselves. It usually takes several years for undesirable species to die-off. Saltwater cordgrass can often establish a dense cover in a year or two.

① Culvert Replacement: The decision to replace or eliminate a culvert is based on the size of the marsh system, the original reason for the culvert, and the amount of subsidence. If the marsh system is large and has been drained through a single, small culvert, excessive subsidence may have occurred, which requires special design considerations (see discussion below under manual tidal gate management). In small marsh systems, undersized culverts do not usually result in subsidence significant enough to require special engineering and detailed hydrological studies and modeling. If the culvert is associated with a structure such as a road, eliminating the culvert with the intent of restoring an open channel would not be an option. However, there are some locations where the undersized culvert can be removed and the original open channel restored.

If culvert replacement is an option, the original creek dimensions can be used to gage the appropriate size. When there is no potential to increase the risk of flooding to low lying properties, the culvert can be oversized to guarantee a natural flow of water. Another consideration for culvert replacement may be to set the bottom elevation so that at low tide, the upstream creeks and ditches retain some water as permanent habitat for aquatic organisms such as fish.

② Tide Gate Removal: This technique can be used successfully if marsh subsidence is not extreme. Under the appropriate conditions, gate removal can result in the formation of a low marsh system. Connecticut has successfully restored several marshes using this technique; examples include Branford River, Farm River, and Gigamoque Creek. It is projected that the low marsh may eventually turn into a high marsh over decades or centuries. A benefit associated with restoring to a low marsh type is that mosquito breeding will be minimal or non-existent.

In cases where marsh subsidence has been extreme, the likelihood of successfully restoring a marsh by removing the tide gate is minimal. In the early 1950s a hurricane destroyed tide gates that had been draining the Great Harbor and Lost Lake marsh complexes in Guilford, Connecticut. Prior to the destruction of the tide gates both these subsided areas supported a high marsh community complex. When full tidal flow was reestablished several months after the destruction of the tide gates, marsh vegetation was dramatically altered; there was an immediate 80 percent reduction in plant growth. The increased tidal flow over the subsided marsh created a condition that was too wet to support vegetation. After a forty-year period, the unvegetated portion of Great Harbor had been colonized by tall saltwater cordgrass. The Lost Lake area has almost no emergent vegetation and in light of the rapid rate of sea level rise, will probably never support vegetation. At low tide, it is an exposed peat flat.

③ Manual Tide Gate Management: Tide gate management is used to establish a suitable hydrology to maximize the amount of emergent marsh without creating a "Lost Lake" condition. Where there are two or more tide gates, individual gates can be opened to study the effect of increased tidal flow upon marsh vegetation. Monitoring will help to determine whether additional gates require opening. This approach is being used on the Hammock River marsh in Clinton, Connecticut. In 1985, one tide gate was opened resulting in the replacement of reeds by the native salt marsh grasses throughout a large area of marsh. However, there were significant areas where reeds were tall and persistent, prompting a second tide gate to be opened.

Another method used to determine the required number of open tide gates is a two-dimensional tidal hydrology model. Unfortunately, these computer simulations do not take into account the physical barrier that reed presents to the movement of water across the marsh surface. The interior of a reed patch will often be dry even though the surface elevation is below that of the water level in adjacent tidal creeks. The water that cannot penetrate the reed remains in the creek and creates an artificial high water level. As restoration proceeds and reed is converted to short-grass meadow, water spreads across the marsh surface more quickly and the water levels in the creek drop. It may be necessary to open an additional gate to compensate for the drop in water level. Computer models cannot predict this situation.

Flooding problems caused by major storm events such as hurricanes and Nor'easters are most appropriately dealt with through the use of manual gates. In advance of these storm events, the gates can be closed to prevent flooding and reopened after the storm has passed.

④ Automatic Gates: The use of automatic gates is most appropriate when the flooding of low-lying structures occurs so frequently that manual gate operation becomes expensive and impractical. Some automatic gates have electric water level sensors that close the gates when a critical level is reached. A potential problem with this type of gate is the power failures associated with major storm events.

A second type of automatic gate, called a self-regulating tide gate, uses a mechanical means to sense the water level. One or more adjustable floats are attached to the tide gate. When the water level reaches a predetermined critical elevation, the gates close.

IMPOUNDED MARSHES

Raising mean water level elevations through the construction of a dike or dam at the mouth of a cove or tidal river is referred to as an impoundment. The two types found in the Long Island Sound are millponds and wildlife impoundments. In a typical wildlife impoundment, the top of the dam is higher than the wetland surface, so little or no tidal water flows into the site. Freshwater, that would otherwise flow into the Sound, collects and forms a pond over the marsh reducing salinity levels and causing a die-off of the emergent salt marsh vegetation. These areas remain flooded in the spring to attract migrating waterfowl and shorebirds. Water, drawn down in late spring to allow annual plants to grow on the marsh surface, is replaced when the marsh is reflooded in the fall to provide waterfowl with shallow water habitat and easy access to submerged annual plants.

A type of impoundment unique to western Long Island Sound was the tidal millpond. Dikes in combination with tide gates (installed on the upstream side) allowed the millpond to fill with water during the flood tide. On the ebb tide, the gates closed and water returned to the Sound via a sluiceway or channel containing a waterwheel to drive the mill. Although the tidal range was decreased in the pond, daily fluctuations were still encouraged for the mill's operation. The high tide elevation remained more or less the same, but the low tide elevation was raised. When mills were abandoned, the sluiceways were often eliminated and the tidal fluctuations were significantly reduced. Little or no water returned to the Sound during the ebb tide cycle. The prolonged flooding cycle of the wetland surface resulted in the conversion of vegetated wetland to unvegetated intertidal flat or shallow subtidal wetland. The tidal wetland zone contracted and persists today only as a narrow fringe around the tidal pond. When water levels are not managed in a millpond, the pond becomes a large settling basin that allows for a rapid accumulation of sediment.

Restoration Methods:

① Culvert Installation At Wildlife Impoundment Sites: The only wildlife impoundments in the Sound were located at Barn Island in Stonington, Connecticut. Most of these have been restored through the installation of culverts to restore tidal flow. Subsidence values appear to be less than six inches and the vegetation is a mix of high and low marsh communities.

② Tidal Flow Restoration To Millponds: No millponds have been restored to natural conditions in Connecticut as abutting property owners prefer to see open water rather than emergent wetland. Unfortunately, these open water ponds require maintenance. For example, in some Connecticut millponds, the dams have been raised to restore shallow water habitat that was lost due to excessive sedimentation. Since the maximum dam height is dictated by peak flood tide elevation, a point will be reached where the only remedy for sedimentation is dredging.

In theory, the millpond gates and associated structures can be opened or removed to restore tidal flushing. In many places, the bottom elevations are such that within several years, most of the ponds will support low marsh vegetation.

FILLED/BURIED MARSHES

When tidal wetlands were perceived to be mosquito infested wastelands, it was a common practice to fill them in or use them as disposal sites for sediments dredged from navigation channels. Dikes were constructed with marsh sediments and the dredged sediments were hydraulically pumped into the containment area. Wetlands were also commonly filled for sanitary landfills and airports. Unfortunately, the opportunity to restore this type of degraded marsh is limited because most fill sites support various types of development including residential, commercial, and industrial. On sites that have not been developed, common reed is usually the dominant plant in response to the low salt or fresh nature of the soil.

In filled or buried marshes, all the functions and values of the former tidal wetland have been lost. In some cases, the resulting degradation may not be totally undesirable. For example, the sandy dredged sediments that were disposed on Nott Island in the Connecticut River are functioning as critical nesting habitat for diamond back terrapins (***Malaclemys terrapin***). Also, it may be possible to manage these sandy soils to promote the establishment of little bluestem (***Schizachyrium scoparium***) grassland habitat, a rare habitat type. In these cases, the value and uses of the filled marsh must be weighed against the cost and benefit of restoring a tidal wetland.

Restoration Methods:

① <u>Excavation</u>: Excavation is a technique used to remove fills placed over former tidal wetlands (***Figure 1-4***). The goal is to remove the amount of fill necessary to obtain a tidal hydrology

Figure 1-4. Mumford Cove Marsh Restoration


Photo on left shows Mumford Cove marsh restoration site during excavation of fill. The restored marsh, shown on right, has naturally revegetated and now serves as a nursery for Spartina alterniflora plugs used in other restoration projects.

appropriate for emergent wetland vegetation. It should be noted that excavation is one of the more expensive marsh restoration techniques on an area basis.

Fill can cause the underlying peat to be compressed. If compression is minimal, all of the overlying fill can be removed. Wetland peats, due to their fibrous nature, tend to resist excavation. Thus, the blade of a bulldozer or grader will usually pass over the old soil surface and easily locate the contact between the two soil types. This soil variation eliminates the need for continuous checking of the grades to establish a suitable final elevation. Excavated materials are usually disposed on the adjacent uplands.

② Creek Restoration: Aerial photography of pre-disturbance conditions can greatly aid in finding the location of the original creek system. Once a location has been established, sediments are removed with an excavator and subsequently transported to the upland. Monitoring the project site will identify the areas of persistent reed monocultures. Additional distribution channels can be added in these areas to increase the soil salinity.

③ Pond Construction: Either aerial photography or shallow surface depressions can be used in determining restoration sites. As in the case of creeks, the excavated material is transported to the upland. See grid-ditched marsh section for general pond design parameters.

④ Planting: Planting of native wetland vegetation is a restoration option used in combination with other techniques. In general, planting is usually not necessary because marsh vegetation can spontaneously reestablish itself through seeds already present in the fibrous peat soil or seeds transported by the tides from local marshes. If planting is chosen as a restoration option, it is most appropriately used for filled marshes because a natural supply of plant material in or adjacent to the site may not be readily available. Successful planting is based upon the individual tidal elevation requirements of the marsh vegetation. Since the depth and frequency of flooding (hydroperiod) varies across the marsh surface, it may be difficult to determine the most appropriate location for a particular species. Detailed elevation and hydrologic data may be necessary. Unfortunately, this information is not usually immediately available and can be expensive to obtain.

Plant stock should be indigenous to the Long Island Sound region. These plants will be adapted to local climate and tidal hydrology. The use of indigenous stock helps prevent the development of genetic hybrids that may be less desirable than the native species. Ideally, a number of wetland nurseries should be created in the Sound for the express purpose of providing transplant material. These types of nurseries assist in preventing localized degradation of neighboring healthy wetlands during plant extraction. Another option would be to cultivate plants in pots from seeds collected in the field. This method is more costly than transplanting. Additionally, plugs may be purchased from a small number of commercial nurseries in Connecticut and New York that grow native Long Island Sound tidal wetland plants.

BRACKISH MARSHES INVADED BY COMMON REED

Many natural brackish marshes in Connecticut and New York are experiencing rapid displacement of native vegetation by common reed. Although believed to be native to North America, the common reed was not described as an invasive, pestiferous species by Nichols (1920) in tidal fresh, brackish, or salt marshes. This description does not apply to today's common reed population which is spreading at a rate of one to two percent per year in ecologically-sensitive areas like the lower Connecticut River (Warren, 1994). One hypothesis suggests that an invasive strain of common reed may have been introduced from Europe. Recent research supports this hypothesis (K. Saltonstall, 2002). This invasive type of common reed forms a monoculture, reducing marsh value and functionality. Adverse changes in function and value include:

- Reduction in wildlife use by forming an almost impenetrable cover;
- Loss of scenic vistas;
- Increases in fire frequency in direct response to the woody nature of common reed, which can quickly produce a large amount of combustible material; and
- Reduction in plant species richness.

The most important variables that distinguish common reed-dominated from common reed-free areas are water depth and frequency of flooding (Warren et al. 2002) and porewater salinity and sulfide concentrations (R. Chambers, pers. comm.) In areas where these parameters do not meet some threshold level to prevent common reed expansion, the invasion of the non-native strain will continue. To restore some functions and values lost as a result of common reed expansion, a number of actions can be taken to reduce the amount of this plant and encourage other marsh vegetation.

Restoration Methods:

① Mowing: The purpose of mowing is to impose a physical stress on the plant that depletes the rhizomes of their nutrient reserves. The plant will no longer be capable of generating healthy new shoots. There are several theories regarding the best time of year to mow. Winter cuts have produced stunted growth the following season. One reason for this inhibited growth may be that the cut stems allow an entrance point for water, which interferes with the uptake of oxygen, a process identified in ***Typha***.

A more traditional theory promotes spring cuts. These cuts immediately follow the growth of the shoots in the spring, before the shoots have sufficient time to send surplus energy to the rhizome. The resulting new shoots are stunted and at a low density. This initial spring cut, in addition to several summer cuts over a two or three year period should greatly reduce the area of reed.

An example of this cutting routine occurred at a farm site in East Haven, Connecticut. One side of a wet meadow split by a fence supported tall, dense reed. The other side of the fence, which contained cattle, supported wet meadow vegetation with some sparse, very stunted reed plants. The grazing cattle successfully controlled the reed. Unlike the farm, mowed sites will need routine monitoring to identify problem areas and to determine mowing schedules.

Experimental mowing and herbiciding procedures undertaken in the brackish marshes of the lower Connecticut River have shown that mowing just once is an ineffective control of Phragmites. The most effective control was achieved through a combination of spraying with herbicide followed three to six months later with mowing.

② Prescribed Burning: Prescribed burning is a management technique similar to mowing. One of the major constraints to burning is that there must be a significant supply of dry combustible material. Prescribed burning is only effective at reducing the cover of common reed if it is done during the growing season when live shoots can be burned. In order to burn this fresh, wet vegetation, there must be sufficient dry combustible material present. This requirement presents a drawback because dead shoots from a previous year must be available; burning can only be conducted every other year after an intervening period where the grass is allowed enough recovery for dead shoots to accumulate.

Winter burning is not recommended. It can actually increase the rate of spreading. The elimination of shade over the marsh surface and the exposure of burned soil allow the ground to warm up earlier in the spring. The growth of reed may be further enhanced by the ash providing a source of nutrients. In general, winter burning provides only a temporary (several months) removal of this vegetation.

Prescribed burning opportunities along Long Island Sound are limited due to the extensive nature of development on adjacent uplands. On certain islands, this technique might be coupled with the use of herbicide instead of mowing to remove dead shoots.

③ Herbicide: The use of herbicides has been shown to significantly reduce the amount of reed growth and allow for accelerated restoration of native plant communities. The herbicide functions by killing active roots and rhizomes so that no new shoots can be produced. The most commonly used herbicide has the active ingredient known as glyphosate. While this is a broad spectrum herbicide (it kills all plants it comes in contact with), glyphosate has been shown through laboratory and field studies to have minimal impacts upon aquatic organisms. Additionally, glyphosate biodegrades quickly into natural products including carbon dioxide, nitrogen, phosphate, and water. Applications must be coordinated closely with weather patterns to minimize and prevent drifting of the spray onto non-target plants.

Most glyphosate applications are conducted in the late summer/early fall when all of the plants have been pollinated. Studies have shown these applications are most effective if the reed is mowed after the shoots turn brown. If dead Phragmites shoots are not removed, they persist upright for several years and inhibit native plant growth with a combination of shade and physical exclusion. Mowing, on the other hand, exposes the soil surface to sunlight and allows for colonization by native plants or, if there is an understory, competitive release of the shorter marsh grasses.

④ Ditch Plugs: As described previously under “Grid-ditched Marshes”, creating ponds and plugging mosquito ditches can enhance fish and wildlife habitat. However, these same techniques are currently being tested by the Connecticut DEP for effectiveness in reducing common reed. Previous work has shown that plugging ditches inhibits drainage, makes the area wetter, and causes linear pools to form in the plugged ditches. These hydrological changes, which increase flooding and hence increase root exposure to salinity and sulfides, are expected to reduce reed in localized areas. Additionally, it is hypothesized that combining the ditch plug treatment with either herbicide and mulching or mulching alone will be the most effective treatment for reed control.

STORMWATER IMPACTED MARSHES

Human activities on land can significantly impact the circulation of water in the hydrologic cycle. These changes may influence the development of wetlands. Under normal conditions, a percentage of precipitation that falls on undeveloped or unpaved land never reaches adjacent waters or wetlands. Processes such as evaporation, transpiration by plants, and absorption by soil particles all act to prevent a portion of the rainfall from reaching the closest body of water. These processes are accelerated with increased air temperature. This acceleration may occur to such an extent that there will be no precipitation transferred from upland sites to adjacent wetlands during low-volume summer rainstorms. Rainfall over paved project sites or road surfaces is channelized into storm drains. This stormwater is discharged directly into the nearest watercourse or wetland, by-passing the natural soil and vegetation complex that would otherwise store, evaporate, or transpire a significant percentage of this water. The resulting stormwater discharge into the wetland occurs faster and in greater quantities than rainfall transferred from undeveloped uplands to their wetlands. This discharge results in the deposition of sediment upon the wetland surface. The elevation increase results in a more aerobic soil, thus increasing the opportunity for the spread of common reed.

In the case of salt or brackish marshes, the discharge can radically reduce (***i.e.*** dilute) the soil salinity. Summer precipitation becomes a special concern because it is during this growing season that wetland plants are most sensitive to soil chemistry. This too favors the spread of common reed.

The impact of stormwater discharge into a tidal wetland can be extremely localized. But, it can also affect an entire wetland. In very developed urban and suburban areas, there may be multiple stormwater discharges into the water body. The resulting dilution or sediment deposition may influence large expanses of tidal wetlands.

Restoration Methods:

① Retention Retrofits: The goal of retention retrofitting is to retain high frequency, low-volume rainfall on-site. The general design storm in Connecticut is a one-inch rainfall event. This volume projection captures approximately 85 percent of all rainstorm events in a given year. (Most stormwater designs for flood protection target 10 to 25 year storm events.) Stormwater management manuals contain numerous techniques for stormwater retention. The technique of choice depends on specific site conditions, which may include soil type and depth to water table.

② Sediment Controls: Stormwater management manuals contain methods of best management practices to aid the prevention of sediment deposition. Catch basins, while commonly incorporated into a stormwater system, frequently fail to capture a significant percent of sediment, even coarse sand. The system of choice depends on specific site conditions.

MARSHES IMPACTED BY SEA LEVEL RISE

Rates of sea level rise over the past century have more than doubled compared to historic averages of 1mm/year. The accelerated rate of sea level rise may be causing changes in marsh vegetation, as in the conversion of high marsh to ***Spartina alterniflora***-dominated low marsh, and may be responsible for significant losses of tidal wetland acreage. In southwestern Connecticut and Westchester County, New York, there are numerous accounts of the conversion of low marsh to unvegetated tidal flats.

Conversion of high marsh to low marsh will eliminate the habitat functions for nesting birds as well as other fauna that use the high marsh for breeding and foraging. Also, a decrease in plant diversity would occur when the assemblage of high marsh graminoids is replaced by ***S. alterniflora***. Conversion of vegetated marsh to peat flat or open water will result in the loss of all functions and values for plants and animals of tidal wetlands.

Restoration Methods:

① Coco-fiber Logs and Mats: Biodegradable Coco-fiber logs and mats may be used to increase elevation, trap sediments and hence promote marsh restoration in limited areas. Expense of the materials may preclude use in extensive areas. This method has been used with limited success in one site in New York, and will be tested at a site in Conecticut.

② Beneficial Use of Dredge Sediments: This method of restoration involves placement of clean sediments in drowned marshes to create an elevation that will support tidal wetland vegetation. Although use of dredge sediments for marsh restoration and creation is increasingly common in other parts of the country, particularly Gulf Coast states, it has never been used in the Sound. The potential to use this method in the Sound is limited by cost and by the logistical problems associated with transporting sediments from the dredge site to the restoration site.

SPECIFIC RESTORATION OBJECTIVES

Restoration is used here in the general sense to mean that a former salt marsh complex is restored to salt marsh as opposed to brackish marsh. The restored marsh should support similar functions and values as the pre-disturbed marsh even though the restored wetland does not precisely duplicate the original. Precise restoration of the pre-existing vegetation community is not possible for several reasons. First, there are no historic maps that show the distribution of low marsh, high marsh, pools and ponds, and the complex of vegetation types present throughout the high marsh. Without such blueprints, it is impossible to restore all of the original habitats and microhabitats to their original extent and at their precise historic location. Second, the activities that have caused the degradation often have changed the physical characteristics of the marsh and its soils. For example, several feet of soil may have been lost in drained salt marshes. This subsidence may reduce wetland elevations such that restoration of historic tidal flow alters the duration of tidal flooding and the types of plants that can grow under present day conditions. However, understanding the salinity regime and target hydrological conditions at the restoration site may help to predict the resulting plant and animal communities.

Specific restoration goals for tidal wetlands include the following:

RESTORE HABITAT FOR FEDERAL AND STATE PROTECTED SPECIES

Increases in the occurrence of the following species in tidal wetland complexes is a restoration goal:

Animals	Plants
Diamond-backed terrapin (***Malaclemys terrapin***)	Lesser sand-spurrey (***Spergularia canadensis***)
Saltmarsh sharp-tailed sparrow (***Ammodramus caudacutus***)	Bulrush (***Scirpus cylindricus***)
Osprey (***Pandion haliaetus***)	Bulrush (***Scirpus paludosus var. atlanticus***)
American bittern (***Botaurus lentiginosus***)	Goldenclub (***Orontium aquaticum***)
Least bittern (***Ixobrychus exilis***)	Mudwort (***Limosella subulata***)
Seaside sparrow (***Ammodramus maritimus***)	Arrowleaf (***Sagittaria subulata***)
King rail (***Rallus elegans***)	
Willet (***Catoptrophorus semipalmatus***)	
Great egret (***Casmerodius albus***)	
Snowy egret (***Egretta thula***)	
Little blue heron (***Egretta caerulea***)	
Glossy ibis (***Plegadis falcinellus***)	

RESTORE BIOLOGICAL PRODUCTIVITY AND BIODIVERSITY

These two functions are directly related to each other. Biological productivity is the amount of organic material produced per unit time. A healthy tidal wetland supporting maximum populations of plant, wildlife, and marine organisms will be high in biological productivity. In degraded tidal marshes, the species richness (biodiversity) decreases, contributing to an overall decline in productivity. Restoration would, therefore, increase productivity and biodiversity.

REDUCE COMMON REED COVERAGE

The impenetrable cover formed by common reed monoculture reduces the habitat value for many types of wildlife. Aesthetic value is also decreased through elimination of scenic vistas. The goal of restoration is to improve both wildlife use and scenic coastal vistas.

ELIMINATE FIRE HAZARDS

Fires are a common problem in degraded tidal wetlands dominated by common reed. Although fires may occur in brackish and freshwater tidal wetlands dominated by cattail or bulrushes, these marshes do not pose fire hazards as great as those posed by common reed-dominated marshes. Fires are of particular concern where homes are built to the edge of the marshes. By restoring a common reed-dominated marsh to its pre-disturbed condition, the fire hazard will be greatly reduced.

RESTORE WATER QUALITY RENOVATION FUNCTIONS

Healthy tidal wetlands help to filter pollutants from industrial and residential runoff. When tidal wetlands become degraded this beneficial function is greatly reduced or eliminated. This is because the water/soil interface in degraded wetlands is often confined to the primary creeks and channels, rather than to the marsh surface where plants serve as a sink for pollutants. This surface area limitation reduces the ability of the wetland soils to capture pollutants contained in coastal waters and runoff. Restoration of tidal flow to degraded wetlands returns the wetlands' functional value as a pollution filter.

ELIMINATE NONPOINT SOURCE POLLUTION

In drained tidal wetlands, the oxidation of peat can create a variety of water quality problems. Tidal flow restoration will reestablish anaerobic conditions throughout the soil. When this happens, the conversion of pyrite to sulfuric acid and the attendant nonpoint source problems emanating from the wetland soils are eliminated.

RESTORATION SUCCESS AND MONITORING

Depending on the type of degradation and the chosen restoration technique, successful restoration may require the use of equipment that is specifically designed to operate on the organic and compressible soils of tidal wetlands. Most conventional excavation and grading equipment cannot operate on these types of soils and certainly not without causing extensive damage in the form of ruts. Since many restoration projects require equipment access across healthy tidal wetlands, it is imperative to avoid damage caused by conventional equipment. In certain instances, without specialized wetland excavation equipment, temporary haul roads would need to be constructed. Such an approach would make many wetland projects cost prohibitive. Additionally, if the road can only be constructed across healthy wetland, the impacts might be unacceptable under the regulatory permitting process.

Specialized, low-ground pressure equipment exerts a ground pressure of two pounds per square inch or less. Amphibious machines are particularly important for accessing remote wetlands or islands that require water access. CTDEP owns several pieces of this specialized equipment, including a bulldozer, an excavator with grading blade, amphibious excavator, amphibious rotary ditcher, and an amphibious mulcher.

Tidal wetland restoration activities should be evaluated for both short- and long-term goals. The short-term assessment considers the immediate response of the hydrological and biological features. A study of six long-term restoration sites in Connecticut has shown that reintroducing appropriate tidal flow will set a degraded marsh on a trajectory towards restoration of ecological attributes and functions (Warren ***et al***., 2001). However, different attributes, such as vegetation and populations of macroinvertebrates, fish, and birds, recover at different rates (Fell ***et al***., 2000; Warren ***et al***., 2001). Also, due to the dynamic nature of tidal marshes, success in the early stages of restoration does not guarantee overall long-term success. The periodic monitoring of a site can assist with achieving long-term goals by catching design flaws and keeping the project on course. If available, aerial photography provides a method of tracking long-term changes for wetlands of large areal extent. A less expensive, but very useful method for monitoring includes a series of photo stations within or around the marsh.

Two recent publications provide general guidelines for monitoring biotic (vegetation, fish, invertebrates, birds) and abiotic (salinity, tidal regime, soil organic content, etc.) parameters of marsh restoration projects: New York State Salt Marsh Restoration and Monitoring Guidelines (Niedowski, 2000), and Regional Standards to Identify and Evaluate Tidal Wetland Restoration in the Gulf of Maine (Neckles and Dionne, 1999). The parameters to be measured and the methods suggested represent the baseline information generally required to adequately monitor the generic salt marsh restoration project. Depending on restoration goals and site-specific details, the suggested protocols can be tailored to individual projects.

Overall success depends on the extent to which the original restoration goals are met. Whichever value and functions are identified as being priorities for a particular site are the ones that should be the focus of

long-term monitoring. Annual monitoring of a combination of the following characteristics may help determine restoration success:

- extent of percent cover vegetation versus bare ground
- plant species composition (total list present)
- percent reduction of common reed
- plant cover (percentage) and height (for each common species)
- invertebrate species composition and abundance
- bird use (especially threatened species)
- fish species composition and abundance; use of creeks and high marsh.

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