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# Bulletin No. 34: Tidal Marshes of Long Island Sound: Ecology, History and Restoration

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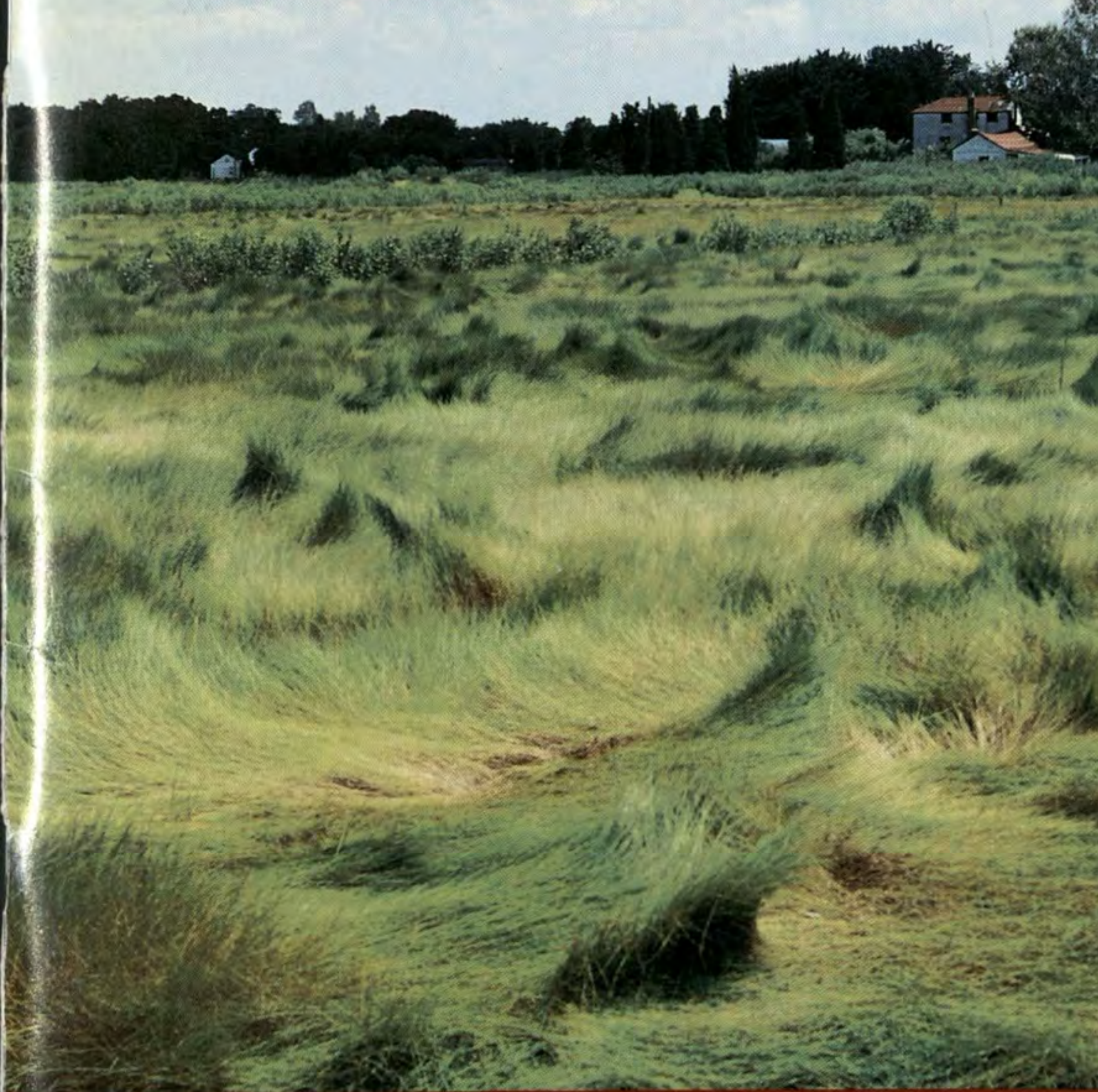
# TIDAL MARSHES OF LONG ISLAND SOUND

## ECOLOGY, HISTORY AND RESTORATION



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# TIDAL MARSHES OF LONG ISLAND SOUND:

## ECOLOGY, HISTORY AND RESTORATION

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AND WILLIAM A. NIERING

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THE CONNECTICUT COLLEGE ARBORETUM

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# FOREWORD

This bulletin represents the culmination of several decades of work on the part of both the citizens of Connecticut and State agencies, such as the Department of Environmental Protection, to not only protect coastal wetland resources by enforcing the regulations in the Tidal Wetlands Act, but also launching an aggressive program in marsh restoration. An impressive effort has been made in Connecticut with at least 600 hectares (1,500 acres) restored due to the efforts of Department of Environmental Protection Staff, especially Ron Rozsa and Paul M. Capotosto. Ron, an ecologist with the Office of Long Island Sound Programs, has pioneered in restoration efforts. Paul, a Wetlands Restoration Biologist in the Wetlands Restoration Program, Wildlife Division, has moved the traditional mosquito control program into one involving open marsh water management, where biological controls - small fish - take over the removal of mosquito larvae wherever possible. These efforts, instead of constantly degrading our wetland resources, are reestablishing valuable lost habitat. The continuing pace of tidal marsh research over the past three decades has further documented the significant ecological role of these vital "liquid assets."

William A. Niering, Research Director
Connecticut College Arboretum

## ACKNOWLEDGMENTS

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# INTRODUCTION

Glenn D. Dreyer, *Director,*
*Connecticut College Arboretum*

Thirty-five years ago the Connecticut College Arboretum issued an alarm to the citizens of the State with the publication of Arboretum Bulletin No. 12, "Connecticut's Coastal Marshes: a Vanishing Resource" (1961). At that time the ever increasing pace of coastal development - marinas, transportation facilities, residential and commercial construction - threatened to swallow up most of these important and fragile estuarine ecosystems. During the height of coastal development, some estimates put the loss of tidal marshes at the rate of four-tenths of a hectare (one acre) per day. Historically it appears that about 30 percent of all tidal marshes in Connecticut were destroyed, with the greatest losses in the western part of the State. One of the most dramatic events was when Sherwood Island Marsh, in Sherwood Island State Park, was buried by hydraulic fill. This was documented by the late Louis Darling, noted local author and artist, in the Bulletin mentioned above.

In addition to the story of Sherwood Island marsh and the politics involved in trying to save it, the Bulletin explained the scientific, economic, and aesthetic values of the marshes. The final chapter, by Arboretum Director Richard H. Goodwin, entitled "The Future: a Call to Action," suggested five areas which required immediate attention: 1. protection of marshes through acquisition; 2. protection of marshes in public ownership; 3. control of dredging and filling; 4. zoning changes; 5. education "on a broad front." As an indication of the great progress made in tidal marsh protection, it is worth while to address each of these concerns.

### Protection Through Acquisition

The Connecticut Department of Environmental Protection presently owns nearly 30% (1,956 hectares or 4,833 acres) of all tidal wetlands in the State, which reflects a long history of land acquisition for parks, forests and wildlife purposes. These lands came into State ownership in a variety of ways; for example, through private grants like that from the White Memorial Foundation in 1962. A portion of these funds was used to purchase 19 parcels, totaling 42 hectares (103 acres) on the Connecticut River. Other State acquisitions on the river at about the same time included tidal marshes in Lord Cove, Haddam Neck and Higganum.

Salt Meadow National Wildlife Refuge, Connecticut's first such national preserve, was established in Westbrook in 1971 and includes 14 hectares (35 acres) of tidal wetland. In 1994, the U.S. Fish & Wildlife Service acquired over 120 hectares (300 acres) of tidal wetland at the Great Meadows in Stratford, as an addition to the Stewart B. McKinney National Wildlife Refuge. This refuge contains the largest area of unditched high marsh along the Sound. At the municipal level, many towns own tidal wetlands and, through municipal regulations, marshes may be set aside as permanent open space during commercial development projects.

In the 1960s the Connecticut Land Trust movement began with early organizations in Madison, Guilford, Old Lyme and Westport. A principal focus of these pioneer groups was the acquisition of tidal wetlands. Today there are at least 26 different land trusts along the Connecticut coast and major river systems which aid in wetland protection.

Since 1961, The Nature Conservancy has become the largest private land conservation organization in this country and the world. In Connecticut it owns over 160 hectares (400 acres) of tidal wetland, including large portions of the tidal freshwater system at Chapman Pond in the Connecticut River, and Pattagansett Marsh in Niantic. The Conservancy also works actively in supporting local land trusts, and in creating conservation easements which assure protection while keeping the property in private hands.

### Preservation of Marshes in Public Ownership

Louis Darling, in Bulletin No. 12, described the loss of a tidal wetland at Sherwood Island State Park through the disposal of dredged sediments from the construction of Interstate 95 and a parking lot. Today tidal marshes in State ownership are protected by the same laws which affect private lands.

Of the four other State-owned areas with significant tidal marshes specifically mentioned in Bulletin 12, three - Barn Island, Hammonasset and Bluff Point - have received attention and protection in the ensuing years. At Barn Island, several of the formerly impounded valley marshes have been restored by increasing tidal flushing. For example, Impoundment No. 1 is in the process of restoration with most of the area back in *Spartina* grasses after being dominated by Cattail and Phragmites for many years.

Large portions of the tidal marshes within Hammonasset State Park were designated as a State Natural Areas Preserve in 1985. The goals of the Preserve are to protect the integrity of the ecosystem, to preserve rare and endangered species, and to promote education and research.

By a special act of the State Legislature in 1975, Bluff Point, including the tidal marshes of Mumford Cove and the Poquonock River, was declared a State Coastal Reserve. This is the only state owned land preserved with this special category.

The Parks Division of the Connecticut Department of Environmental Protection (DEP) has recently completed a master plan for Silver Sands State Park in Milford. This abandoned municipal landfill, which has been closed and covered, will accommodate active recreation and parking. Critical associated resources will be restored, including tidal wetlands. Here the DEP recently restored tidal flushing to the seven hectares (18 acres) of Fletcher's Creek and will construct several boardwalks across the marsh to provide public access and education about tidal wetland restoration.

In October 1994, at a ceremony held at Gillette Castle State Park, Secretary of the Interior Bruce Babbitt announced that portions of the tidal wetlands and waters of the Connecticut River, from Portland to Long Island Sound, had been designated as "Wetlands of International Importance" (Fig. 1). This is a

*Fig.1 Bruce Babbitt, US Secretary of the Interior, speaking at the October 1994 ceremony which declared tidal wetlands in parts of the lower Connecticut River "wetlands of international importance." (P. Fusco)*

program of the Ramsar Convention, an intergovernmental treaty that provides a framework for international cooperation in the conservation of wetland habitats. The Connecticut DEP included all of its Connecticut River tidal wetlands within both State Parks and Wildlife areas. It also includes a series of wetlands protected by The Nature Conservancy, the town of Old Saybrook, the East Haddam Land Trust, the Middlesex Land Trust, the Deep River Land Trust and the Connecticut Audubon Society.

## Control of Tidal Marsh Dredging and Filling

The Connecticut Tidal Wetlands Act of 1969 (see appendix) effectively ended the destruction and despoliation of estuarine wetlands in this State, and a similar New York Act in 1973 solidified protection for all of Long Island Sound. Draining, dredging, excavating and filling are now regulated activities, for which authorization must be issued from the Connecticut DEP (or the New York Department of Environmental Conservation) after due consideration is given to the effects of the proposed work on the ecology of these systems.

## Zoning Changes

Connecticut has not directly pursued protection via zoning for a variety of legal reasons. However, zoning is used to regulate the type and density of development at a given site. Wetland setbacks are specified in some towns, and wetlands are often used to satisfy requirements for open space as part of new subdivisions

The Coastal Area Management Act of 1980 gave the 36 coastal towns the authority and responsibility to consider the impacts of a proposed development upon a variety of coastal resources, including tidal wetlands. In part, this requires the consideration of alternatives that minimize wetland impacts. The Act also established a voluntary planning process called Municipal Coastal Programs, which provides towns with the opportunity to improve resource protection and balance competing uses by updating both the municipal zoning regulations and plan of development. Most of Connecticut's coastal towns have participated in this program.

## Education

Connecticut College has continued its leadership role in wetlands education in a number of ways. To help educate students and the general public, the Arboretum has published five bulletins about tidal marshes since 1970. A complete list of Arboretum Bulletins may be found at the end of this publication. In 1978 the College initiated an upper division undergraduate course entitled Tidal Marsh Ecology. Soon after, Coastal Marine Biology also became part of the curriculum.

The Connecticut DEP has also played an important role in educating our citizens about the importance of the State's natural resources in general, and those of the coastal zone in particular. Publications such as "A Moveable Shore - the Fate of the Connecticut Coast," "A Salt Marsh Primer," and "Long Island Sound: a Natural Resource Atlas" have targeted a variety of audiences. Staff members have participated in hundreds of speaking engagements for schools, municipal groups and public organizations. The DEP operates the Meigs Point

Nature Center and Boardwalk at Hammonasset Beach State Park, where it offers interpretative walks of the salt marsh ecosystem led by trained educators. The Department also sponsors a variety of programs, from tidal wetlands ecology field techniques workshops to teacher training sessions at shoreline State parks.

We have come a long way in the last three and one half decades. From an historical perspective the 1969 Tidal Marsh Act was truly a watershed event, one which signaled a changing environmental ethic felt at the national level during the first Earth Day in 1970. From that time forward the wholesale destruction of tidal marshes in Connecticut was stopped and serious preservation and research efforts began. The formation of Conservation and Inland Wetlands Commissions in each of Connecticut's towns further aided in the protection of these and other wetland ecosystems.

Perhaps one of the most significant aspects of our societal relationship with tidal wetlands, one not foreseen in 1961, is the effort to restore degraded marshes. In 1992 the DEP created a team of professionals to begin tidal wetland restoration in Connecticut. By the close of 1992 over 600 hectares (1,500 acres) had been restored. Lessons learned from these efforts are also highlighted in this bulletin.

This publication is a continuation of the educational effort begun in 1961 with Bulletin No. 12, in which we present an overview of Long Island Sound's tidal marshes. Previous bulletins have emphasized specific groups of organisms, or special techniques used to understand marsh development. Here we emphasize the history, ecology, and restoration of tidal marshes.

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# GEOLOGIC HISTORY OF LONG ISLAND SOUND

Ralph Lewis, *Geologist,*
*Connecticut Geological and Natural History Survey,*
*Connecticut Department of Environmental Protection*

The earliest beginnings of Long Island Sound can be traced to a period of great continental collisions, lasting from about 500 million years ago to about 250 million years ago, that resulted in the formation of the supercontinent of Pangaea. Pangaea survived as a supercontinent for roughly 50 million years. By around 200 million years ago, a different set of forces was working to tear the joined landmasses of Pangaea apart. The tearing apart, or rifting, of Pangaea set the stage for the development of Africa, North America, and the Atlantic Ocean as we know them. The geologic foundation of Long Island Sound began to take shape at this time as well.

Africa and North America split apart in a configuration that left the Appalachian Mountains as the western border of the emerging Atlantic Ocean basin. Over the next 200 million years, weathering took its toll on these once majestic mountains and only their core survives today. Much of the sediment that was created during this long erosive process was deposited along the edge of the expanding Atlantic Ocean. By about 3 million years ago, a seaward-thickening wedge of sediment buried most of the hard, crystalline, Appalachian Mountain rocks that formed the eastern flank of North America. Today we know the landward, above-water portion of this wedge as the Atlantic coastal plain. Its thicker, submerged, offshore component forms the continental shelf (Fig.1).

Up to about 3 million years ago, when the North American glaciations probably began, the major force that worked to erode the top of the coastal-plain sediment wedge was stream action. Long Island Sound occupies a lowland that was initially carved into the coastal-plain by rivers, and subsequently glacially modified. The combined erosive effects of the ice advances included re-exposing, wearing down and smoothing the crystalline Appalachian rocks that now form the Connecticut coast, cutting back and sculpting the remaining coastal plain wedge (which now forms the foundation of Long Island), and redistributing eroded material in the form of glacial deposits.

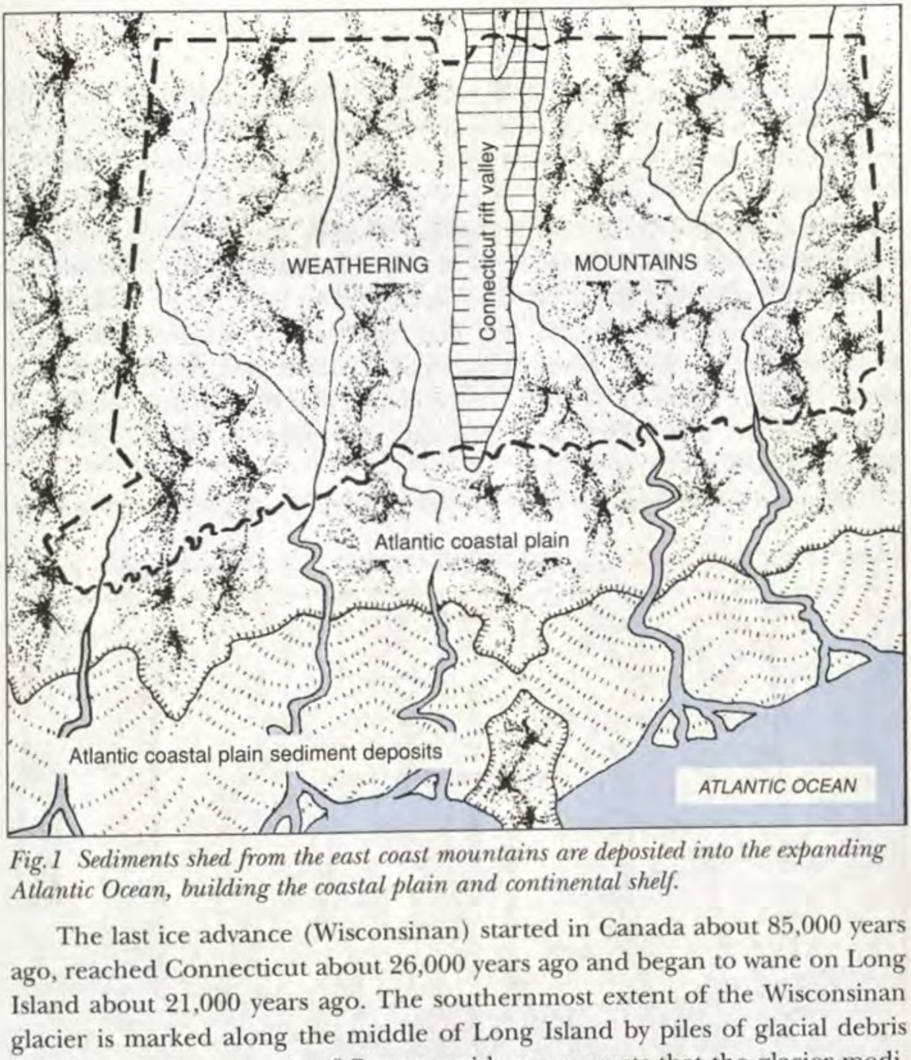


*Fig. 1 Sediments shed from the east coast mountains are deposited into the expanding Atlantic Ocean, building the coastal plain and continental shelf.*

The last ice advance (Wisconsinan) started in Canada about 85,000 years ago, reached Connecticut about 26,000 years ago and began to wane on Long Island about 21,000 years ago. The southernmost extent of the Wisconsinan glacier is marked along the middle of Long Island by piles of glacial debris called a "terminal moraine." Present evidence suggests that the glacier modified but did not entirely alter the pre-Wisconsinan configuration of the Long Island Sound basin. When the Wisconsinan glacier was at its maximum, sea level was about 91 meters (300 feet) lower than it is today, and the shoreline was 80 to 110 kilometers (50 - 70 miles) south of Long Island.

By about 20,000 years ago, the glacier could no longer maintain itself at its terminal position because it was melting faster than new ice was being pushed south. As the ice front receded from its southernmost position, it stuttered and paused several times. At each of these pauses (recessional positions), it left a pile of glacial debris known as a recessional moraine. The bulk of the above-water portions of Fishers Island, Plum Island, and northernmost Long Island are parts of the Harbor Hill-Roanoke Point-Fishers Island-Charlestown recessional moraine.

Because this moraine stood high on the southern margin of the Long Island Sound basin, it made an ideal dam for meltwater from the glacier. As the ice continued to retreat northward, glacial Lake Connecticut formed north of the moraine dam (Fig. 2). The glacier paused briefly and deposited small recessional moraines near Old Saybrook, Madison and Branford along the Connecticut shore. The Captain and Norwalk Islands are also moraine segments. The expanding glacial lake eventually grew to be about the same size as present-day Long Island Sound, and may have been connected with similar freshwater lakes in Block Island Sound and Buzzards Bay. The fairly shallow depth (average 20 meters or 64 feet) of today's Long Island Sound is attributable to the fact that Lake Connecticut was nearly filled in by clay sediments brought southward by the glacier.

By about 15,000 years ago, the glacier had retreated out of the State and

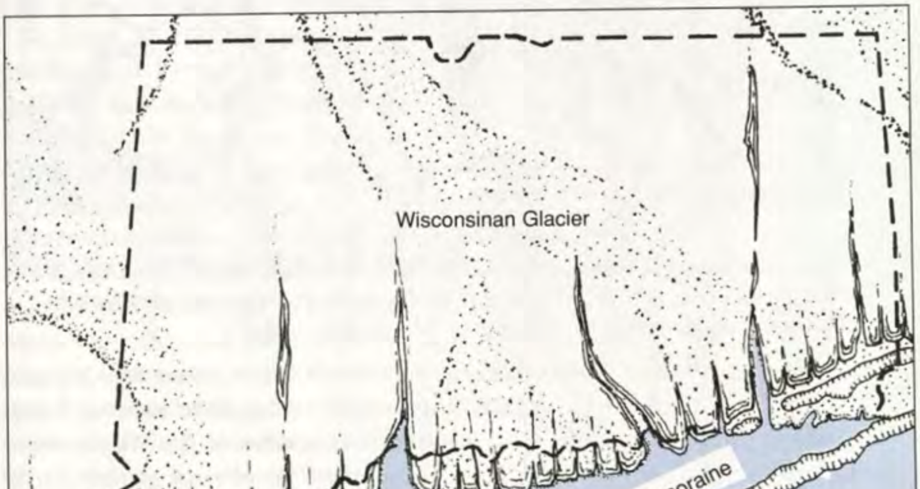


*Fig.2 As the Wisconsinan Glacier retreated northward, glacial Lake Connecticut formed north of the Harbor Hill-Roanoke Point-Fishers Island-Charlestown recessional moraine. Sea level was about 90 meters (300 feet) lower than it is today.*

glacial Lake Connecticut had just about completely drained to the sea through an outlet in the moraine dam at the Race (between Fishers and Long Islands). The land had been pushed down by the weight of the glacier, and it was "rebounding" upward in response to the absence of the ice. The upward "rebound" of the land was accompanied by a rise in sea level as water from the melting glacier returned to the sea. For an unknown period, there was a complex interplay between the rising sea and the rising land. During this time, the sea probably entered the Long Island Sound basin through the Race.

A shallow sea, at a stable elevation of about -40 meters (-130 feet), probably existed in the basin from around 13,500 years ago to around 9,000 years ago. After that the rate of "rebound" appears to have lessened, and sea-level rose continuously relative to the land. Current evidence indicates that the rate of relative sea-level rise decreased about 5,000 to 3,000 years ago (Fig. 3). This


*Fig.3 As the rate of sea level rise slowed, the Long Island Sound estuary assumed its present shape.*

event marked the birth of the Long Island Sound which we all recognize. Sedimentation started to keep pace with sea-level rise, and marshes began to develop along the margins of the estuary. Since wave energy is fairly low in the Sound, wave action has not greatly modified the shore, and the Connecticut coast is very much a reflection of the shape of the land before it was drowned by the sea.

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# EVOLUTION AND DEVELOPMENT OF TIDAL MARSHES

R. Scott Warren, *Professor of Botany, Connecticut College*

The previous chapter on the geologic history of Long Island Sound (LIS) discussed a steady rise in sea-level of about 3 to 4 millimeters per year, or an average of a foot or more per century, which began about 9,000 years ago. As the waters of Long Island Sound flooded the coastal uplands they moved the shoreline inland, a process termed "marine transgression." The drowned coastal stream and river valleys are now our present day coves, embayments, and tidal marshes.

Tidal marshes formed in quiet, "low energy" environments, protected from the direct wave energy of the open shoreline. In these areas fine grained suspended sediments settled out, filling the coastal basins with marine silts and clays. About 5,000 to 3,000 years ago sea level rise began to slow, and by 2000 years ago the rate reached about one millimeter per year or less, roughly 10 centimeters (four inches) per century. Under this new regime of slower marine transgression a single species of tidal marsh grass established the first permanent footholds in the low energy, sedimentary environments of the drowned valleys and developing embayments. Grass shoots slowed water movement, trapping and accumulating even more sediments. This enhanced sedimentation, coupled with the increasing volume of below-ground roots and rhizomes, allowed the elevation of these newly developing marshes to keep up with rising sea level.

The initial invader, Smooth Cord-grass (*Spartina alterniflora*), thrives at elevations between mean high tide and a bit below mean sea level, roughly the upper two-thirds of the mean tide range, where it is flooded by tidal waters twice a day. These new Cord-grass stands created habitat for Ribbed Mussels (*Guekensia demissa*) and fiddler crabs (*Uca* spp.), both of which, in turn, enhanced the growth of the Cord-grass. Denser stands of grass stems slowed tidal water even more, further increasing sediment deposition. With the right conditions Cord-grass could expand seaward, encroaching over mudflats, and also landward, over flooding uplands. Continued sedimentation and rhizome growth raised elevation on the landward side of these new marshes above the mean high tide level, creating the less frequently flooded high marsh habitat. Salt Meadow Cord-grass (*Spartina patens*), Black Grass (*Juncus gerardii*) and Spike Grass (*Distichlis spicata*) became the high marsh dominants. These plants are shorter in height than their low marsh counterpart, with finer stems and leaves and, unlike Smooth Cord-grass, their roots and rhizomes tend to form a dense turf. These two communities, low and high marsh, will be described in detail in the following chapter.

As sea-level continued to rise, Smooth Cord-grass could continue its spread from the seaward or bayfront edge of these new marshes out over aggrading tidal flats. At the same time the marine transgression, driven by sea-level rise, continued to flood more and more surrounding uplands, moving the high marsh community landward. This movement of marsh out over mud flats and adjacent upland, as sea level slowly rose, is illustrated in Figure 1.

At the highest elevations, the marine-upland transition, where flooding occurs only during extreme spring high tides, other marsh plants formed a distinctive upper marsh border. Characteristic upper border species include the shrub Marsh Elder (*Iva frutescens*), often mixed with or even replaced by Switch Grass (*Panicum virgatum*) or Phragmites (also called Common Reed, *Phragmites australis*).

With continued sea-level rise roots and rhizomes of the oldest plants, the ones that really started the marsh building process, were buried, submerged under new sediments, roots and rhizomes, and the slowly deepening waters of Long Island Sound. This anaerobic, salty, soil environment inhibited the normal decomposition of these underground plant remains. They are preserved as peat and today provide an historic record of marsh development and vegetation change over the past 3000 - 4000 years. The oldest salt marshes, which are more common toward the western end of the State, have about three meters (10 feet) of peat, which overlie either mud flats of marine clays and silts, or, less frequently, upland soils. More recently formed marshes have shallower depths, with high marsh peat found over upland soils and low marsh Smooth Cord-grass peat over marine sediments (Fig.1). Except for Phragmites, the roots and rhizomes of the upper border plants decompose fairly quickly, and their remains are usually harder to find.

Ecologists and geologists have pieced together the story of marsh development by analyzing peat and sediment cores removed from marshes and embayments. Peat sampling tools have been developed which can be forced down through the marsh, cutting out a plug or long tube of peat which is continuous from the current surface to the bottom layers. These cores can be

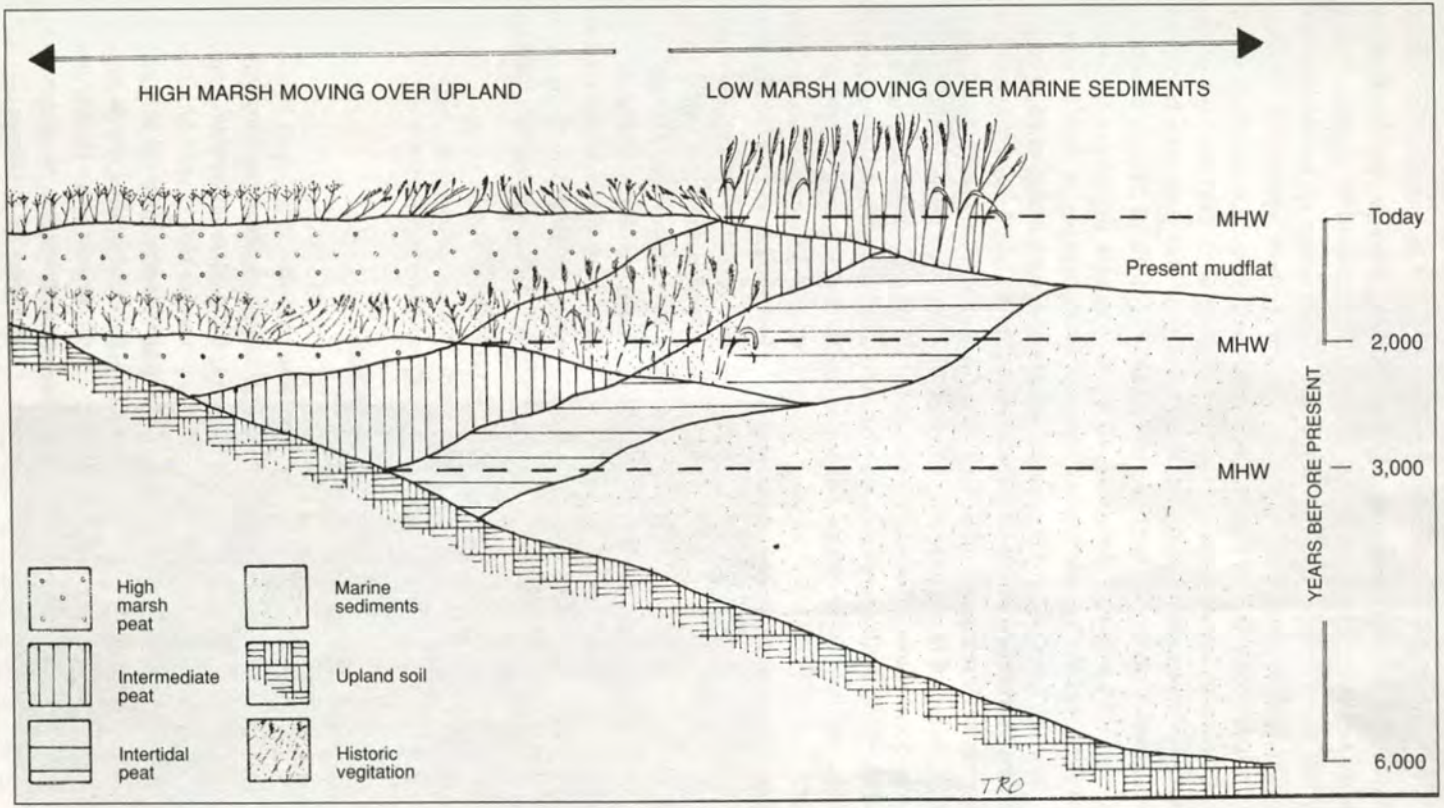


*Fig.1 Hypothetical cross-section of a salt marsh showing its development over time. As sea level rises, sediments, roots and rhizomes build up at the same rate to form peat. As the marsh rises, it expands out over mud flats toward the water, and also landward. The illustration shows a marsh surface, with its vegetation, at 2,000 years before the present (yrs bp). Past levels of mean high water (mhw) are also shown for 3,000 and 2,000 years ago and for the present.*

removed intact, and plant roots and rhizomes, as well as the preserved shells of microscopic animals called Foraminifera, can be identified to species. Since the different marsh plants and Foraminifera characterize different habitats within tidal marshes (high marsh, low marsh, etc.), their preserved remains can be used to reconstruct the historic marsh environment as one moves down through a core, and simultaneously back through time. A time line for plant, animal and environmental changes recorded within the peat can be dated using the naturally occurring isotopes of carbon 14 and lead 210. In addition, horizons, distinct horizontal bands which act as markers in the core, can be associated with specific known historic events. One example of such markers in a peat core are lines of sand deposited on the marsh by hurricanes (Fig. 2).

Peat cores have been analyzed from a number of Long Island Sound tidal marshes, and the developmental history of a few marsh systems has been studied in detail. Some of the pioneering work on the history of tidal marsh development was done during the early 1960s on the Hammock River Marshes in Clinton. This system still serves as a site for increasingly sophisticated research in this field, and has also been the subject of marsh restoration projects. A very detailed investigation has also been made on the formation and development of the Pataguanset River marshes in East Lyme (Fig. 3), and the Barn Island marshes in Stonington have also been sites of research into tidal wetland community change over time.

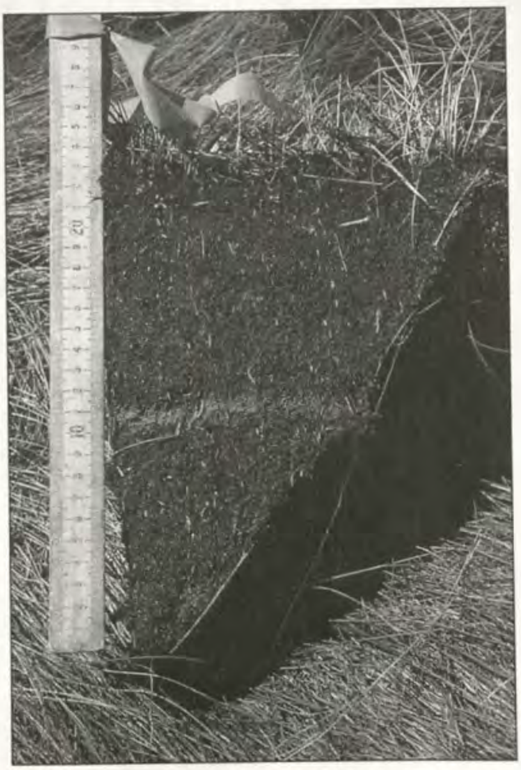

*Fig.2 A slice of peat from the Barn Island salt marsh which clearly shows a sand line 12-15 centimeters below the surface, produced by the 1938 hurricane. All the peat above the line has accumulated on the marsh since that date. (R.S. Warren)*

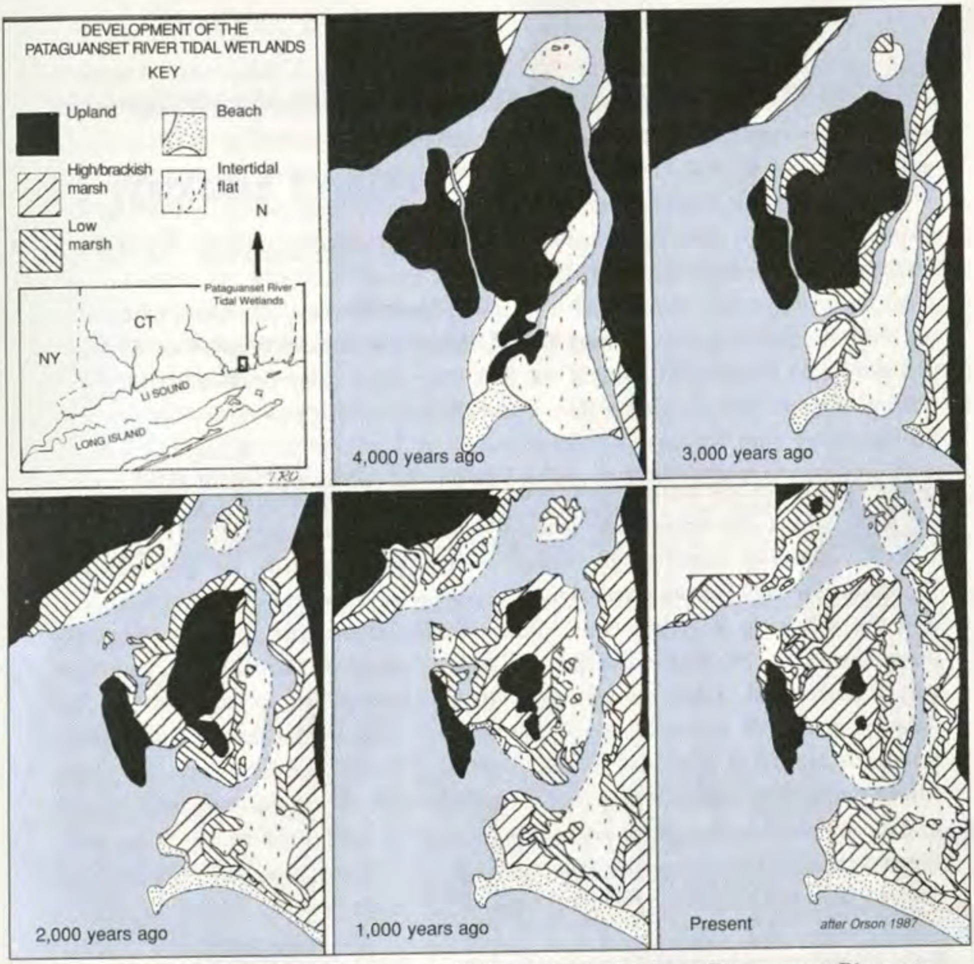


*Fig. 3 Proposed historic development of tidal marshes in the lower Pataguanset River estuary. Sediments accumulated at an average rate of about one meter per thousand years. Thus the 4,000 year old marsh surface is about four meters below the current surface.*

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# Tidal Wetland Ecology of Long Island Sound

R. Scott Warren, *Professor of Botany,*
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Wetlands are transitional zones between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is actually covered by water either permanently or periodically. Wetlands typically support hydrophytes (plants adapted to wetland conditions) and the substrate is hydric (wet) mineral and/or organic soil that is usually poor to very poorly drained. Tidal wetlands occur at the land/ocean interface where daily tidal action moves water in and out of the systems. Along the Atlantic and Gulf coasts of the United States, tidal wetlands are found from northern Maine to southern Texas. From all but the southern tip of Florida, where mangrove swamps occur, these coastal wetlands are tidal marshes, where grasses are the predominant vegetation. Long Island Sound marshes are technically classified as Estuarine Emergent Wetlands, because the Sound is an estuary, and the vegetation emerges above the water level.

## Tidal Wetlands as Estuarine Ecosystems

Although these wetlands have a north-south range of over 2000 kilometers (1200 miles), Atlantic and Gulf tidal wetlands are remarkably homogeneous in their plant and animal communities. The basic physical and biological structure of these communities comes from a few species of Cord-grass in the genus *Spartina*, particularly Smooth Cord-grass *(Spartina alterniflora)*. Tidal marsh animal communities are dominated by various snails in the genera *Melampus* and *Littorina*, the Ribbed Mussel *(Guekensia demissa)*, three different fiddler crabs *(Uca spp.)*, and several different minnows *(Fundulus spp)*.

Between Maine and Texas, however, there are regional differences in the vegetation and animal populations reflecting both climate and coastal geomorphology. Long Island Sound's tidal marshes are within the New England type and are representative of the tidal marshes found from southern New Jersey to central Maine. In this region the marshes have often formed in drowned river valleys and contain considerable deposits of peat. Below New Jersey there is a transition to Mid-Atlantic tidal marshes, while moving north of Penobscot Bay in Maine, with extreme tide ranges and cool, short growing seasons, the shift is to a Fundy type tidal marsh. The last takes its name from the Bay of Fundy, located between Maine, New Brunswick and Nova Scotia.

The sun, tides and salts in water all play important roles in the functioning of tidal wetlands. They are the principal non-living influences which "organize" these complex communities, and help to differentiate the regions within a marsh system, as illustrated in Figure 1. Marsh areas at the lowest elevations are submerged by all or most high tides and are termed low marsh. In all but low salinity and freshwater tidal wetlands, low marsh is vegetated by essentially pure stands of Smooth Cord-grass. The upper border, inundated only by occasional spring high tides, lies along the upland edge, at the highest elevations. This border between wetland and upland is dominated by a few characteristic grasses and shrubs. Between these two extremes of very wet to very dry habitat lies

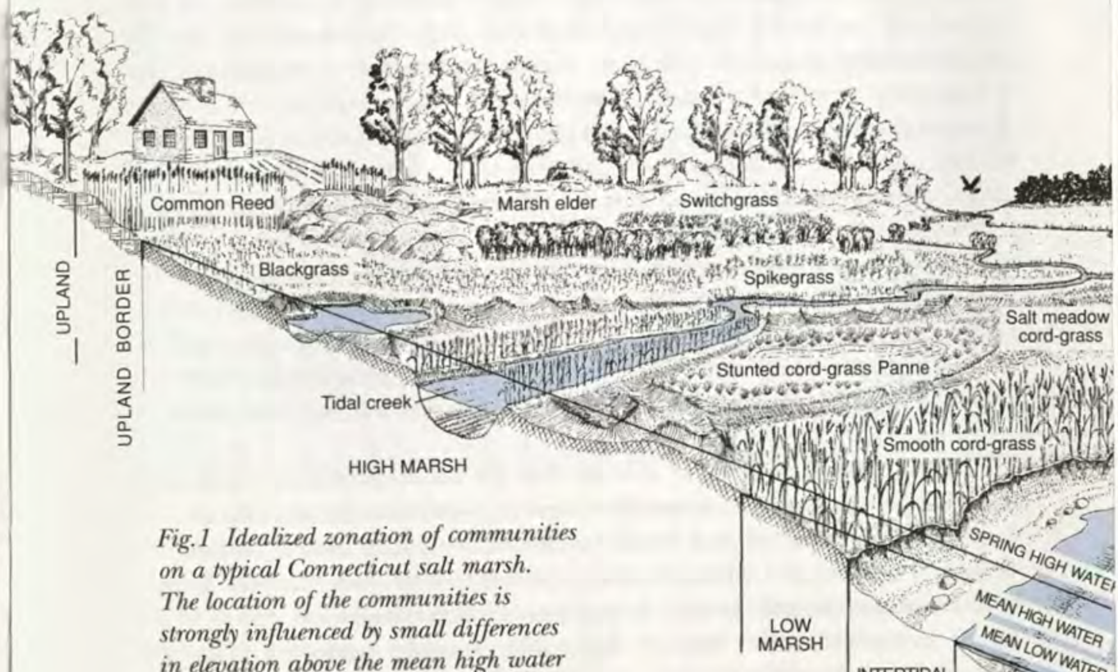



*Fig.1 Idealized zonation of communities on a typical Connecticut salt marsh. The location of the communities is strongly influenced by small differences in elevation above the mean high water level.*

the high marsh, which is flooded by most spring high tides, but may also be continuously free of tidal water for a week or more at a time. Relatively short, fine-stemmed grasses dominate high marsh vegetation. Transitions between low marsh, high marsh and upper border may be gradual or quite abrupt and, although linked by tidal flooding, these three regions are characterized by distinctive assemblages of plants and animals and they are, in many ways, very different environments.

Virtually all earth's ecosystems are solar powered - photosynthesis by green plants converts light energy into sugars, the biological energy unit which sustains all other forms of life. In tidal marshes this solar power is supplemented with tidal power – the movement of tidal water. Tidal circulation does many different kinds of work for these wetlands (analogous to the work farmers put into their fields) and this tidal powered work allows the extremely high biological productivity of these communities. For example, tides deliver the suspended sediments necessary for the continued vertical growth of the marsh surface in the face of continuing sea level rise (see the accompanying Evolution and Development of Tidal Marshes article). Flooding tides also enhance plant growth since they deliver oxygen enriched water to marsh soils and remove potentially toxic materials as they exit. Tidal waters are also the vehicle carrying plant nutrients onto the marsh in periods of abundance, and transporting excess nutrients back to the estuary at other times of the year. These exported nutrients support the growth of phytoplankton (single celled plants suspended in the water) which are the foundation of marine food chains. Flooding frequency and duration, and marsh surface relief also strongly influence patterns of soil saturation and resulting oxygen availability, which in turn are major factors controlling the distribution of plant species within these wetlands. Tides also link the marshes to estuarine waters and the offshore coastal zone environment. They deliver saltwater from the marine environment, which mixes with and is diluted by freshwater from uplands, to produce salinity gradients which also act to characterize and help organize these systems.

Finally, tides are critical to animals that live on the marsh as well as those in estuarine waters, both for nutrition and reproduction. As described below, flooding tides allow fish and crabs access to prey on the marsh surface and deliver nutrients to sessile (stationary) organisms like Ribbed Mussels *(Guekensia demissa)* and Striped Anemones *(Haliplanella luciae)*. Stems of low marsh grass, accessible only at high tide, provide protected places for Mummichogs *(Fundulus heteroclitus)* to lay their eggs. Reproduction of a number of invertebrates is also dependent upon the spring tides which regularly flood the high marsh in two week cycles.

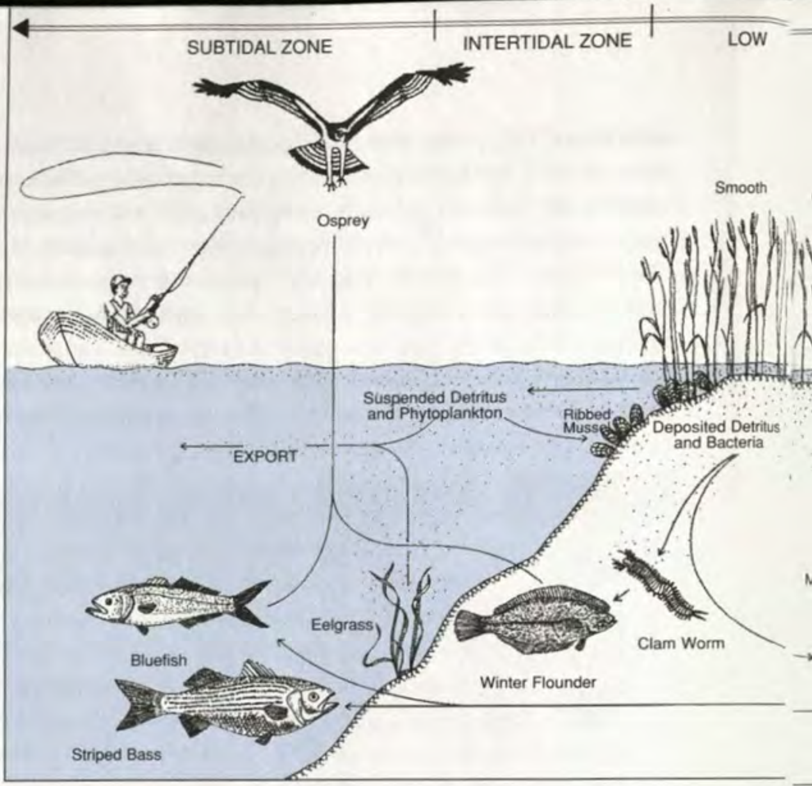
The common bond between all types of tidal wetlands is tidal action; the amount of salt present in the flood waters and soil is what distinguishes one type of tidal wetland community from another. The concentration of salts (principally sodium chloride, common table salt) dissolved in the open ocean is approximately 3.5% or 35 ppt (parts per thousand). Salinity in Long Island Sound varies seasonally and with proximity to major sources of fresh water such as the Connecticut, Housatonic and Thames Rivers, but is generally between 27 and 32 ppt. Sea water is carried into estuaries and embayments by tidal action, where it mixes with and is diluted by freshwater from rivers and streams. The resulting ocean to fresh salinity gradient is constantly moving and changing over hours, weeks and seasons.

### Tidal Wetlands Productivity

The amount of plant material produced annually by an ecosystem is called productivity. Coastal salt marshes rank among the systems with the highest productivity of any in the world. They rival the tropical rain forests in the amount of plant material, or biomass, produced each year. Those along the southern United States shoreline are more productive, with a longer growing season than those in the Northeast. However, marsh productivity in our area ranges up to 1000 grams/square meter, which is still high compared to other ecosystems. This high productivity is due to three living parts of the saltmarsh-estuarine ecosystem: mud algae, diatoms and seaweeds; phytoplankton in the water; and salt marsh plants. Only a small percent of the marsh grasses are directly consumed or grazed; most is decomposed by bacteria which results in an "organic soup" fed on by a myriad of organisms – amphipods, crabs, snails, shellfish and some small fishes. These organisms in turn support a broad food chain which ultimately supports shellfish and finfish populations. High productivity of tidal wetlands is just one reason we are protecting and restoring these valuable "liquid assets."

Most of the tidal wetlands along the Sound are salt marshes, where summer salinity averages about 20 to 30 ppt. Such an environment is termed polyhaline. This high and variable salinity is an important factor contributing to the relatively low species diversity. In contrast, brackish marshes occur where salinities range from 0.5 to 18 ppt, and freshwater tidal wetlands are located where there is no detectable salt in the water (less than 0.5 ppt). An important concept is that *all coastal marshes are tidal, but not all tidal marshes are salty.*

Moving up an estuary, away from the Sound, salinity starts to drop while species diversity begins to increase. Tidal action is still operative, and typical




salt marsh plants and animals still dominate, but some characteristics of salt marshes are lost, while less salt tolerant plants and animals appear. This transition is gradual, but by the time salinity averages 15 ppt there is a distinctive brackish marsh community. The technical term for such relatively salty brackish environments is mesohaline. Farther up the estuary, where salinities average just 5 ppt - 8 ppt, typical salt marsh plants and animals have largely disappeared; these low salinity brackish wetlands are termed oligohaline. Continuing upstream on the Sound's two major tidal rivers, the Connecticut and Housatonic, tides remain important but salinity essentially disappears. Distinctive fresh tidal marsh communities border the rivers in these areas. Freshwater tidal marshes are limited in Connecticut, but they are highly productive and support an extremely diverse assemblage of plants and animals.

## THE SALT MARSH COMMUNITY

As previously explained, there are many factors, such as marsh elevation, duration of tidal flooding, salinity and soil aeration that can affect the distribution of both the plant and animal populations as one moves from the tidal creeks that dissect these wetlands to the low and high marsh and on to the upper border. Often four rather distinctive belts from the creek or bay front to the upland can be recognized, as shown in Figure 1. The following discussion of

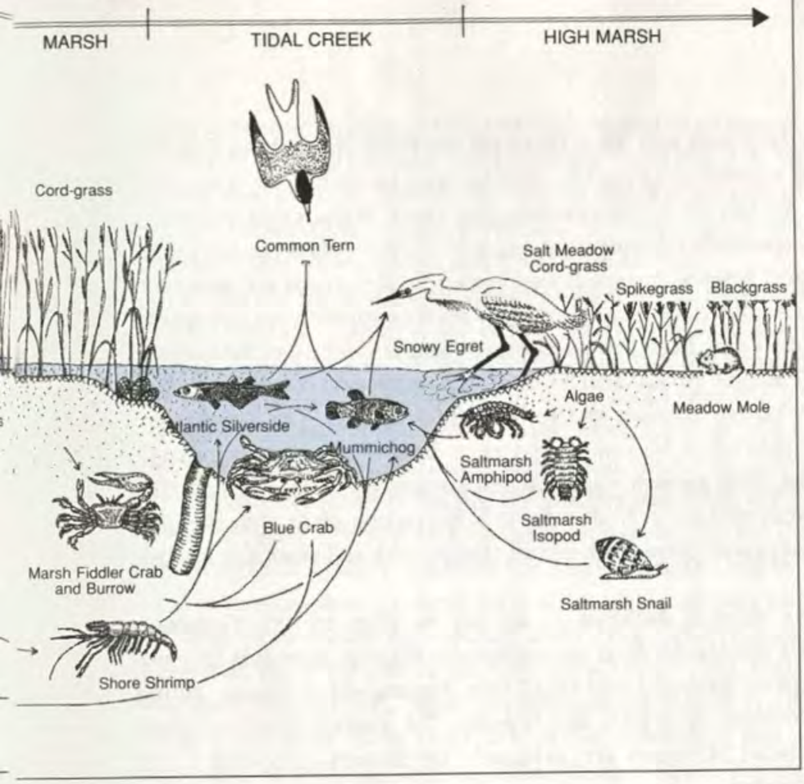



*Fig.2 Major salt marsh animals, their habitats and their positions in the food web. Communities are indicated across the top of the diagram.*

the ecology of salt marshes is also organized by elevation, beginning with tidal creeks and ending at the upper edge of the marsh.

## Creeks and Ditches

We'll start our look at the plants and animals that make up a typical Connecticut salt marsh community in a tidal creek. Although some creeks may drain completely, the center of others will contain a few centimeters to a third of a meter or more of water, even at low tide. The almost constantly flowing water results in a moderately firm, even a bit sandy, channel bottom. Ditch-grass *(Ruppia maritima)*, not really a grass at all, may grow here. This highly branched little plant is covered with a thin layer of mud at low tide, and often extends onto the small mud flat that separates the channel from the grasses of the marsh itself. It also occurs in tidal pools and mosquito ditches on the high marsh.

The tidal creeks and mosquito ditches are nursery areas which provide food and refuge for fish, crabs and other animals (Fig. 2). The most abundant fish of the creeks and ditches are the Common Mummichog *(Fundulus heteroclitus)*, the Striped Killifish *(Fundulus majalis)*, the Sheepshead Minnow *(Cyprinodon variegatus)* and the Atlantic Silverside *(Menidia menidia)*. Young-of-the-year Winter Flounder *(Pleuronectes americanus)* may also be found in these creeks.

Mummichogs often enter creeks and ditches on the flooding tide with relatively little food in their guts and leave them on the following ebbing tide full of food. This is true regardless of marsh inundation, and therefore it appears that the creeks and ditches are important foraging areas. Major components of the diet are detritus (partially decomposed organic matter), algae, amphipods, isopods, copepods and insects. Annelids and young fiddler crabs are also consumed in significant amounts. Mummichogs also feed extensively on the marsh surface when it is covered by high tides. Saltmarsh Snails *(Melampus bidentatus)*, Saltmarsh Isopods *(Philoscia vittata)* and Saltmarsh Amphipods *(Orchestia grillus)* are among the high marsh animals in the Mummichog diet. On a Delaware marsh, it was found that when Mummichogs were denied access to the marsh surface by enclosures, their growth was retarded compared to that of fish able to forage on the marsh surface at high tide. It is becoming clear that in some systems the emergent marsh provides a significant nutritional resource for this fish (Fig. 3).

The diet of the Striped Killifish is similar to that of the Common Mummichog. Atlantic Silversides feed on copepods, shrimp, annelids (including *Nereis succinea*), plant material and small fish, among other things. Young Winter Flounder consume annelids, amphipods, flat worms, detritus, algae and shrimp. Sheepshead Minnows are primarily herbivores, ingesting living plant material and detritus.

The fish of the tidal creeks and ditches are eaten in turn by larger predatory fish such as Bluefish *(Pomatomus saltatrix)*, Fluke *(Paralichthys dentatus)* and Striped Bass *(Morone saxatilis)* that forage in shallow water. In addition, at least some Atlantic Silversides, and perhaps large numbers of them, appear to

*Fig. 3 Authors R. Scott Warren and Paul Fell and students collecting fish in a tidal creek. (P. J. Horton)*

migrate during the winter to inner continental shelf waters where they become prey to offshore predators. Consequently, these fish may be important in transferring energy from shallow saltmarsh-estuarine systems to open water as secondary production. Other predators of marsh fish include crabs and birds such as terns, snowy egrets and great blue herons.

Common Mummichogs spawn at night during high water of spring tides. In New England, the eggs are deposited in mats of algae on the marsh, on the mud-detritus substrate around the bases of Smooth Cord-grass or in sand near the high water mark. Spawning in these sites keeps the embryos well aerated and tends to protect them from adult Mummichogs and other aquatic predators. The eggs are resistant to drying and hatch when they are submerged, usually by the next series of spring tides. After hatching, the larvae are transported by the rising tide to pools on the high marsh. The fry (baby fish) may spend 6 to 8 weeks in shallow pools on the marsh surface; and by the time they reach 3 cm in length, most of them have entered the ditches and tidal creeks.

Blue Crab *(Callinectes sapidus)* and Green Crab *(Carcinus maenas)* are often present in the tidal creeks and ditches. Green Crabs, which may be especially abundant, eat shrimp, algae, detritus, small clams, annelids, fish and living marsh Cord-grass. Blue crabs are active scavengers but also prey upon fish, clams and small crabs, among other things. Shore Shrimp *(Palaemonetes spp.)* and Sand Shrimp *(Crangon septemspinosa)* may also be numerous in the creeks and ditches. The first is a detritus-algae feeder, whereas the Sand Shrimp is a predator that feeds on amphipods, other small invertebrates, and small fish, including young winter flounder.

Just a couple of meters of smooth, dark mud separate the low tide channel of the creek and the first stems of grass marking the lower edge of the marsh proper. It may be covered with slowly moving snails, up to more than 1000 per square meter, appropriately called Mud Snails *(Ilyanassa obsoleta)*. These forage on the mud surface, eating microscopic algae, dead plants and animals, and algae such as Sea Lettuce *(Ulva lactuca)*.

The mud separating the creek bottom from the marsh grass may not be wide, but it is quite soft and can easily be more than knee deep. It is principally fine grained silts and clays deposited by the slower moving water away from the main channel. Walking through it may be difficult until you reach the grass, where roots and rhizomes give these sediments at least a bit of structure.

### Low Marsh – The Smooth Cord-grass Belt

The low marsh itself is essentially a pure belt of Smooth Cord-grass that extends from a bit below mean sea level to approximately mean high tide, with the actual width of this belt varying with the steepness of the intertidal slope (Fig. 4). Smooth Cord-grass stems, which can reach more than one centimeter in diameter, are scattered, with densities of ten to a couple of hundred per square meter. This grass can be extremely productive, converting sunlight, carbon dioxide, and water into plant material at a rate that matches high yielding corn crops. The height and productivity of this grass are directly related to the mean tide range. By flowering in mid August, plants at the western end of the Sound, where mean tide range exceeds two meters, can reach over two meters tall; at the eastern end of Connecticut, where Long Island Sound becomes Fishers Island Sound and mean tide range is only about 0.8 meters, low marsh Cord-grass is only about one meter in height.

The most conspicuous animals of the low marsh are the Ribbed Mussel *(Geukensia demissa)* and Fiddler Crabs *(Uca sp.)*. These animals may be found along the seaward edge of the marsh, as well as along the banks of the tidal creeks and mosquito ditches. The Ribbed Mussel is usually partly buried in the marsh mud and anchors itself by means of byssal threads, which are produced by its foot, to the Cord-grass rhizomes and other firm objects such as shells (Fig. 5). It may occur at densities of more than 1000/square meter; small mussels may also occur at low densities on the high marsh. Where they occur in large numbers, mussels stabilize the sediments and help prevent erosion by binding the soil-root complex with byssal threads. This animal is a filter feeder, removing phytoplankton, bacteria and detritus from the water that it pumps through its gills. The smaller particles are ingested, whereas the larger particles, together with wastes, are deposited on the marsh surface, thus enriching the sediment. It has been shown that the productivity of the Cord-grass is positively correlated with the abundance of the Ribbed Mussel. For example, removal of mussels from experimental plots results in a reduction in grass productivity or biomass at the end of the growing season and conversely, addition of mussels increases Cord-grass growth.

Two species of fiddler crabs are common on Connecticut marshes: the Marsh Fiddler or Black Fiddler *(Uca pugnax)* and the larger Red-jointed Fiddler *(Uca minax)*. In the very sandy marshes on Cape Cod or the south bays of Long Island, a third species, the Sand Fiddler *(Uca pugilator)*, is found. The male and female fiddler crabs look remarkably different, the males being distinguished by the possession of one very large claw that is used for sound production, mating displays and aggression. These crabs inhabit burrows which they dig in the marsh mud and from which they emerge to feed. The burrows allow tidal water carrying oxygen and nutrients to more easily reach the Cord-grass roots, and as the burrows collapse and are re-dug by the crabs, the upper layer of sediments is extensively tilled. These facts probably help explain why the growth and productivity of Cord-grass are greater in places with high fiddler crab densities. Roots and rhizomes of the Cord-grass, in turn, stabilize the soft muds in which they grow and reduce the tendency of the crab burrows to collapse at

*Fig.4 Smooth Cord-grass and a Green-backed Heron in the low marsh community. (R. Rozsa)*

*Fig.5 Ribbed Mussels clustered around Smooth Cord-grass stems in a low marsh community. (W.A. Niering)*

high tide. In addition, the tall stems and dense leaves of the Cord-grass provide the crabs cover from predators.

The Fiddler Crabs feed during the day, primarily at low tide, but they are inactive during cold weather and the hottest part of warm days. They eat detritus, bacteria and algae from the marsh surface. Using their small claw(s), they scoop up mud and transfer it to their mouth, where their mouthparts separate edible organics from sand, silt and clay. The organics are ingested while the inorganics are returned to the marsh surface. Alert to potential predators, the Fiddlers rapidly dart into their burrows when they are disturbed.

Marsh crabs *(Sesarma reticulatum)*, which also dig burrows in the mud, are relatively rare on southern New England marshes but are common farther south. They are omnivores, with the outer leaves of Smooth Cord-grass as a major portion of their diet, supplemented by the occasional Fiddler Crab. Other invertebrates of the low marsh include the Striped Sea Anemone

*(Haliplanella luciae)*, the Common Clamworm *(Nereis succinea)*, the Rough Periwinkle *(Littorina saxatilis)*, and the Mud Snail *(Ilyanassa obsoleta)*.

### High Marsh – The Salt Meadow Cord-grass and Black Grass Belts

Moving up the intertidal slope, the Smooth Cord-grass gets a little shorter as elevation approaches mean high water. At or a bit above this point, Smooth Cord-grass generally is replaced by the much shorter, fine stemmed Salt Meadow Cord-grass on what is called the high marsh. Smooth Cord-grass often persists along the frequent mosquito ditches dissecting the high marsh. Shoots of Salt Meadow Cord-grass are often 30 to 50 centimeters long, but a weak spot at the base of the stems lets them fall down, often forming large characteristic "cowlicks" by mid season (see front cover photo). Its roots and rhizomes form a dense turf, out competing the intertidal Smooth Cord-grass at these higher, less frequently flooded, elevations.

On natural levees which form along creeks and bay fronts, Salt Meadow Cord-grass may mix with or be replaced by Blackgrass *(Juncus gerardii)*, which also is often found as a belt along the upper border. This grass-like rush, with a characteristically darker green color than Salt Meadow Grass, is also usually a bit taller and has less of a tendency to form cowlicks. One might say Blackgrass is "on the fast track." It starts spring growth in May, before the other high marsh plants, flowers in June and by the beginning of August is beginning to turn brown. The end of August finds most Blackgrass shoots dead or dying. On some marshes the Blackgrass belt near the upland has decreased in abundance over the last few decades, often being replaced by bare, algae-covered peat with occassional patches of Arrow-grass *(Triglochin maritima)* and other broad-leaved plants (see below). This phenomenon may be related to the recent increase in the rate of sea level rise, which is favoring marsh development landward.

A short form of Smooth Cord-grass frequently occurs in relatively pure stands in depressions on the high marsh. This stunted growth form is due to a complex of incompletely understood factors. Oxygen levels in the root zone of these stands are very low, and the soil salinities in such sites are high, often reaching up to 40 to 60 ppt by the end of August. These factors probably contribute to the distribution of Short Smooth Cord-grass on the high marsh as well as to its stunted condition.

Wiry, stiff, Spikegrass *(Distichlis spicata)* with its light green leaves is usually scattered within the high marsh meadow, but occasionally may occur in pure stands. It is the last of the grasses to flower in late summer, and is easily recognized by its terminal flowering spike. Spikegrass has a relatively high salt tolerance and can be found mixed with Short Smooth Cord-grass; it is also frequently found in patches or belts near the upland, often in wetter depressions.

Forbs, a group of plants which have more showy flowers and usually broader leaves than the grasses, frequently occur in slight depressions or pannes on the high marsh. They include Sea Lavender *(Limonium nashii)*, Pink Gerardia *(Gerardia maritima)*, and Saltmarsh Aster *(Aster tenuifolius)*. Arrow-grass is not a grass but has long, grass-like leaves as does seaside plantain. These forbs may exhibit wide variation in their size and vigor depending upon site conditions. They are found both as occasional scattered plants within the expanses of dominant grasses or in relatively pure patches. When dominant, they indicate the site may have been subjected to disturbance.

It is not uncommon for the high marsh grasses to be killed in places by flotsam (floating debris) or other causes. Jointed Glasswort *(Salicornia europaea)* is often the first plant to colonize the newly opened sites. Two other species of Glassworts may be found on Connecticut salt marshes – *Salicornia bigelovii*, an annual, and *S. virginica*, a perennial. These succulent, cactus-like plants turn a brilliant red in autumn. Such open, annual dominated areas are usually colonized by Spikegrass or Stunted Smooth Cord-grass.

The high marsh is basically a terrestrial environment much of the time, but it is more or less regularly flooded by spring tides. Among the most characteristic invertebrates of the high marsh are the Saltmarsh Snail, the Saltmarsh Isopod *(Philoscia vittata)*, and the Saltmarsh Amphipods *(Orchestia grillus* and *O. uhleri)*, (Fig. 6). These tiny animals are deposit feeders which ingest partly decomposed marsh grasses, algae and other material.

The Saltmarsh Snail is frequently a dominant member of the high marsh community and may occur at densities exceeding 1000/square meter. This is a pulmonate snail which has a lung-like respiratory organ adapted for aerial respiration. It is somewhat unique in that while leading a largely terrestrial existence, it possesses an aquatic larval stage. Egg-laying, hatching of the larvae

*Fig.6 Salt Marsh Amphipod, only about 15 mm in length, are one of the more common invertebrate species on the high marsh. (P.E. Fell)*

into the water column, and subsequent settling of the larvae back onto the marsh occur during spring tides when at least portions of the high marsh are flooded. The larvae spend two or more weeks in the adjacent estuary where they feed on phytoplankton. Another pulmonate snail, *Succinea wilsoni*, may occur at the upland border of the marsh, as well as in brackish marshes. The isopods and amphipods of the high marsh are typically less abundant than the Saltmarsh Snail. Adult *Philoscia* and *Orchestia grillus* may reach densities of 20 to 100/square meter.

Other important invertebrates of the high marsh community are mites, spiders and insects. Spiders such as the Wolf Spider *(Pardosa sp.)*, which are abundant on the marsh, are predators. Common insects of the marsh include Meadow Grasshoppers *(Conocephalus sp.)*, Ground Crickets *(Nemobius sp.)*, planthoppers, leafhoppers, aphids, Plant Bugs *(Trigonotylus sp.)*, beetles, Greenhead Flies *(Tabanus sp.)* and Saltmarsh Mosquitoes *(Aedes sollicitans)*. Of these, the Plant Bug is the only insect that is typically most abundant in the tall Cord-grass of the low marsh. The grasshoppers and crickets graze directly on the grasses of the high marsh meadows. Leafhoppers, planthoppers, aphids and Plant Bugs suck plant juices. Although these insects may be abundant, they consume relatively little plant material. Some beetles are plant or detritus feeders, whereas others prey on other insects. Greenhead Fly larvae, which are voracious predators, are found throughout the marsh. The Saltmarsh Mosquito breeds on the high marsh in shallow depressions which dry out and then reflood. Dragonflies and Praying Mantis are predatory insects that may also be present on the marsh.

The Meadow Vole *(Microtus pennsylvanicus)* is a frequent high marsh resident during the warmer months. This rodent feeds primarily on the stems of Salt Meadow Cord-grass and Spikegrass, but also on grass seeds during the dry summer. Voles cut down entire plants in order to eat the stems. Portions of the plants that are unconsumed enter the detrital cycle sooner than they would if voles were absent from the marsh. The voles make runways that crisscross the high marsh. Progressive deepening of the runways may contribute to the hummocky nature of some marshes.

### Upper Border – The Marsh Elder/Switchgrass Belt

At the upland-marsh interface, Marsh Elder *(Iva frutescens)*, a shrub typically 0.5 to 1.5 meters tall, may form a distinctive belt (Fig. 1). Marsh Elder also grows on the locally elevated areas of the high marsh, especially along the banks of mosquito ditches. Groundsel Tree *(Baccharis halimifolia)*, when present, is found landward of Marsh Elder. It is really a shrub growing from two to three meters in height.

Switchgrass *(Panicum virgatum)*, an attractive grass from one to two meters tall, is also a resident of the upper border. Its clumps or tussocks sometimes form its own distinctive belt of vegetation. Another important plant in the upper border is Phragmites or Common Reed *(Phragmites australis)*, a very tall (two to four meters) grass that forms dense, nearly pure stands. Its establishment is favored by disturbance or by fresh water runoff. Landward of the upper border, true upland soils and vegetation are present. A few high marsh animals, such as the Saltmarsh Snail, may also be found in the upper border, but species not usually found on the high marsh are also present. These include the snail, *Succinea wilsoni*, and the isopod, *Porcellio* sp.

### Salt Marsh Birds

Birds are the most conspicuous animals of tidal marshes. Salt marsh birds include ospreys, herons, egrets, rails, swans and ducks, to name a few. Some of these birds may nest in or near the marsh, whereas others visit the marsh primarily in search of food.

The Osprey or Fish Hawk *(Pandion haliaetus)* hunts while in flight and dives feet first into the water to capture prey. It is able to plunge only about a meter below the surface of the water and therefore takes surface fish and those that occur in shallow water. Ospreys generally feed on fish that are between 25 and 35 centimeters in length. Winter Flounder constitutes about half of their diet during the breeding season, but almost any accessible fish of appropriate size may be eaten. Herring *(Alosa aestivalis)* and Menhaden *(Brevoortia tyrannus)* are taken in substantial quantities. Ospreys nest near the water on the tops of solitary trees, utility poles, nesting platforms erected in the marsh, and other similar structures.

Herons and egrets are long-legged, long-necked wading birds that possess a long tapering bill. The Great Blue Heron *(Ardea herodias)*, the Green-backed Heron *(Butorides striatus)*, the Black-crowned Night Heron *(Nycticorax nycticorax)* and the Snowy Egret *(Egretta thula)* are common on southern New England marshes. These birds feed extensively on small fish but also prey on crabs and a variety of other animals. They employ several hunting strategies: 1) wait motionless and ready to strike at prey that comes within range; 2) stealthily stalk prey by slowly walking or wading with little disturbance of the water; and 3) make a disturbance and then actively pursue potential prey that are aroused. The Herons normally use the first two methods, whereas Snowy Egrets often employ the third as well. The Great Blue and Green-backed Herons are usually solitary feeders; Snowy Egrets and Black-crowned Night Herons sometimes feed in flocks. As the name implies, the Black-crowned Night Heron is a nocturnal forager, except during the breeding season when it hunts for food both day and night to feed its young. Green-backed Herons often nest in trees along the upland border of the marsh.

The Clapper Rail *(Rallus longirostris)* is a true marsh bird, being restricted to the salt marsh habitat. Its diet includes snails, small crabs and fish. Fiddler Crabs are a major food item. This rail may nest almost anywhere in the marsh, frequently on an elevated platform. Its grass and reed nests are occasionally washed away when storm tides flood the marsh to exceptional depths. Other marsh specialists include Marsh Wrens *(Cistothorus palustris)*, Seaside Sparrows *(Ammodramus maritimus)* and Sharp-tailed Sparrows *(Ammodramus caudacutus)*. Mute Swans *(Cygnus olor)*, a European introduction, and ducks such as Mallards *(Anas platyrhynchos)*, often feed in shallow water at the edge of the marsh. These birds may also nest in the marsh.

### The Tidal Brackish Marsh Community

As previously mentioned, extensive tidal brackish and freshwater communities occur along major river systems like the Connecticut (Fig. 7) and Housatonic where tidal action is still present despite low to undetectable salinities. Smaller areas of brackish marsh are also common at the upper reaches of many smaller tidal rivers and inlets. As with salt marshes, each has characteristic zones defined by marsh elevation in relation to tidal inundation. In locations where average salinity is below 18 ppt, one can distinguish several tidal brackish communities, such as the short-meadow grass type and the taller reed marshes. The short-grass meadows of brackish high marshes are characterized by Smooth Cord-grass, Salt Meadow Cord-grass and Blackgrass (Fig. 8). Common associates are Seaside Goldenrod *(Solidago sempervirens)*, and Silverweed *(Potentilla anserina)*. Patches of Bulrushes such as Common Threesquare *(Scirpus pungens)* and Olney Threesquare *(S. americanus)* may be present in addition to a diversity of other fresher water species including Bent Grass *(Agrostis stolonifera v. palustris)*, Spike Rushes (Eleocharis palustris, E. rostellata), Straw Sedge *(Carex straminea)*, Mock Bishop Weed (*Ptilimnium capillaceum*, a member of the carrot family), New York Aster *(Aster novibelgii)* and Saltmarsh Fleabane *(Pluchea purpurascens)*.

As salinity falls, taller reed marshes dominated by Narrow-leaved Cattail and Phragmites can form extensive stands with the latter growing several meters in height (Fig. 8). Two colony forming sedges, Salt Marsh Bulrush *(Scirpus robustus)* and Olney Threesquare may also be associated with this community type. The low marsh zone is still dominated by Smooth Cord-grass, but that is gradually replaced by Common Three Square and Rough or Prairie Cord-grass *(Spartina pectinata)* as the salinity decreases. Several rare or uncommon plants may be found on the intertidal mud flat, including Mudwort

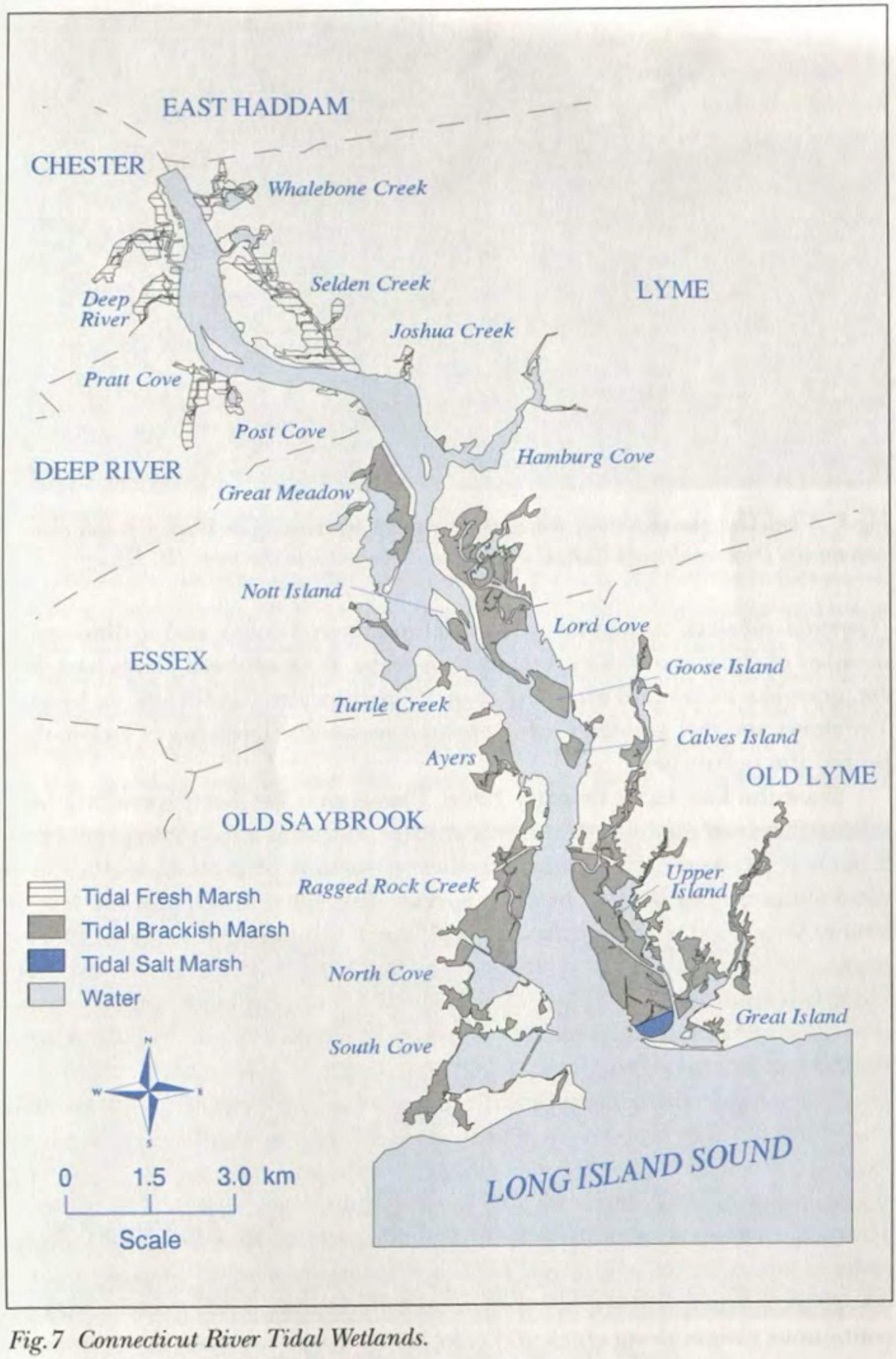



*Fig. 7 Connecticut River Tidal Wetlands.*

*Fig.8 A brackish marsh with a short-meadow grass community in front of a tall reed community (Narrow-leaved Cattail with some Phragmites to the rear).(R. Rozsa)*

*(Limosella subulata,* a member of the Snapdragon family) and a diminutive member of the carrot family, *Lilaeopsis chinensis.* Both of these plants have linear, grass-like leaves and grow less than 15 centimeters (six inches) in height. The showy and rare Golden Club *(Orontium aquaticum),* a relative of Jack-in-the-pulpit, also occurs here.

Since the late 1950s or early 1960s, Phragmites has been spreading into tidal wetlands of the lower Connecticut River system at an alarming rate (1 to 2 percent per year), converting the diverse natural plant communities into monocultures. The decline in plant species diversity and the possible loss of habitat for typical wetland animals are major concerns of wetland ecologists. Recent studies by Connecticut College faculty and students suggest that Phragmites dominated brackish marshes may be performing some of the same basic ecological functions as the uninvaded marshes. Rapid breakdown of Phragmites foliage yields detritus that apparently is consumed by the many marsh detritus feeders. These marshes support populations of typical invertebrates and birds, and provide foraging areas for fish (primarily Mummichogs) when the marsh surface is flooded by high tides.

It is important to note that those marshes studied are well flushed by tides. Marshes situated behind impoundments that restrict tidal flow may not be functioning in the same way. Furthermore, Phragmites on the marshes of the lower Connecticut River tends to form relatively narrow and somewhat discontinuous fringes along creek and river banks. Large expanses of continuous

Phragmites marshland may provide less favorable habitat for many animals, including large marsh birds (herons, egrets and waterfowl). Generalizations about the effects of Phragmites invasion cannot be made with confidence based on our present state of knowledge. More studies are needed.

## THE TIDAL FRESHWATER MARSH COMMUNITY

As the salinity decreases below the measurable level, one enters the very species rich tidal fresh water communities. Over 100 different kinds of higher plants have been recorded in this community compared to only about 36 in the brackish marsh and only 17 in salt marshes. This elevated species richness is primarily related to salt stress, which continues to decrease up river until salt is hardly detectable (<0.5 ppt) in the tidal freshwater marsh. However, tidal action still operates and serves in a positive manner by helping to keep nutrients and oxygen available throughout the system. On the Connecticut River, freshwater tidal marshes are located north of Joshua Cove in Lyme and Post Cove in Essex.

Wild Rice *(Zizania aquatica)*, a tall annual grass, is the indicator species on the lowest marsh sites, and its many associates include both grass-like and more showy broad-leaved flowering plants (Fig. 9). The diversity of plants provides an interesting sequence of flowering activity with the perennials Pickerel Weed *(Pontederia cordata)*, Water Arum *(Peltandra virginica)* and Bullhead-lily *(Nuphar variegatum*, a water-lily) especially showy in the low marsh during the early part of the growing season and the annuals Jewel Weed *(Impatiens capensis)*,

*Fig. 9 A tidal freshwater marsh dominated by wild rice. (R. Rozsa)*

Common Bur-marigold *(Bidens frondosa)* and Smartweeds *(Polygonum* spp.*)* flowering in the summer. Other species on the high marsh are Reed Canary-grass *(Phalaris arundinaceum)* and Purple Loosestrife *(Lythrum salicaria)*, a beautiful invasive introduced species which is rapidly increasing in many of our freshwater wetlands and crowding out our native flora. The tall River Bulrush *(Scirpus fluviatilis)* is a distinctive sedge found between the high and mid-marsh zones.

### Animals of the Brackish and Freshwater Marsh Communities

These less salty tidal wetlands also support a diversity of animal life. Many invertebrates typical of salt marshes extend up estuaries into brackish regions. For example, the Marsh Amphipod *(Orchestia)* and Marsh Isopod *(Philoscia)* occur in marshes where the salinity of the water flooding the marsh is in the range of 1-13 ppt, but these crustaceans are not present in freshwater tidal marshes. Although the Marsh Snail may exist in brackish marshes, its numbers rapidly decline with decreasing salinity and it is progressively replaced by another pulmonate snail, *Succinea*. In freshwater tidal marshes, *Oxyloma*, a snail closely related to *Succinea*, may be common, together with Limacid Slugs *(Agriolimax laevis)*. In addition, small pomatiopsid snails often are present in large numbers. Earthworms (Lumbricid oligochaetes) may also occur in these marshes. As in salt marshes, spiders and insects are important components of the high marsh community.

The Ribbed Mussel occurs along the lower edges of slightly brackish marshes, but generally is not found where the salinity of the water at high tide drops much below 10 ppt. Also, as the salinity declines, the Black Fiddler Crab becomes less abundant and is replaced by the larger Red-jointed Fiddler *(Uca minax)*.

Some of the common salt marsh fishes, including Mummichogs and Silversides, occur in waters of low salinity, and Mummichogs are even present in fresh water. However, other species, such as the Striped Killifish, disappear as salinity declines, and still others, the Banded Killifish *(Fundulus diaphanus)*, Pumpkin Seed *(Lepomis gibbosus)*, and Spottail Shiner *(Notropis hudsonius)* become more abundant. The latter species are typical of brackish and freshwater marshes.

Bird studies in brackish and freshwater marshes along the Atlantic coast reveal that 280 species frequent these wetlands. This group includes 44 species of waterfowl, 35 rails and shore birds, 23 birds of prey and 15 species of waders. Wild Rice can cover extensive areas of the low marsh, and in the autumn its seeds are an important food source for neotropical migrants such as Red-winged Blackbirds *(Agelaius phoeniceus)* and other birds that travel to wintering grounds in Central and South America. Historically, these marshes also attracted large numbers of Sora Rail *(Porzana carolina)* in the autumn. In addition to most of the previously mentioned tidal marsh bird species, brackish and freshwater marshes are home to the Swamp Sparrow *(Melospiza georgiana)*, the Belted Kingfisher *(Megaceryle alcyon)* and the Wood Duck *(Aix sponsa)*.

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# HUMAN IMPACTS ON TIDAL WETLANDS: HISTORY AND REGULATIONS

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## THE PREHISTORIC PERIOD

Human use of tidal wetlands could not have been important until about 1,500 to 2,000 years ago, when sea level rise slowed and tidal wetlands became a more permanent aspect of the landscape. There is recent archeological evidence that Native Americans living in southern New England had established seasonal settlements near these productive wetlands, particularly after the gradual adoption of horticulture circa 1000 AD. Digs along the lower sections of the Connecticut River indicate that during the next 600 years there was a shift toward larger, year-round settlements. It is believed that the ecological diversity and richness of these tidal wetlands were keys to sustaining multi-season occupation by larger groups of people.

## THE COLONIAL PERIOD

The first European colonists in southern New England arrived in the early decades of the 17th Century, and immediately recognized the value of these vast, flat expanses of tidal grasslands. Salt Meadow Cord-grass *(Spartina patens)*, Spikegrass *(Distichlis spicata)* and especially Blackgrass *(Juncus gerardii)* where all preferred species for livestock fodder and bedding. Connecticut salt marshes were both hayed and, to a lesser extent, pastured continuously into the beginning of the twentieth century (Fig. 1). The Continental Marsh in Stonington, owned by the Davis family, was named as a reminder that hay from this marsh supplied General Washington's Continental Armies during the American Revolution. It is one of the few marshes which is still part of a working farm in which the marshes are periodically mowed.

Very early on farmers began digging shallow ditches into the marsh peat to drain standing water. This tended to increase yields of Salt Meadow Cord-grass and made access with equipment easier. Today, salt marsh hay is only harvested on a few marshes, and is sold at a premium as a weed-free garden mulch.

*Fig. 1 A meandering tidal creek and hay stacks on a salt marsh. Painting "Sudden Shower" by Martin Johnson Heade (ca 1870), private collection.*

By 1900, nearly 50% of the marshes between Southport and the Connecticut River had been ditched. Ditches were also used as boundary markers between properties. In some marshes such as Leetes Island and Sluice Creek in Guilford, complete drainage was achieved through the installation of tidal gates (doors hinged at the top which are suspended across a bridge or culvert to eliminate the inflow of salt water, Fig. 2).

The conversion of tidal coves and embayments into millponds began in the 1700's, primarily in central and western Long Island Sound where the greater tidal range provided more tidal energy for the mill operation. Sherwood Mill Pond, Holly Pond, and Sluice Creek are each examples of former millponds. The inlets to these coves were modified through the installation of tide gates which allowed tidal flow into the cove but closed at high tide. Water was returned to the Sound through a narrow channel called a sluiceway, which contained the waterwheel for the mill. In many places the gates caused prolonged flooding of areas of salt marsh, contracting the once extensive vegetation to a narrow fringe along the elevated borders of the millpond. This pattern can still be observed today at Gorham Pond in Darien. Although tidal mills no longer exist along the coast, many of the original water control structures have been retained in order to create permanent ponds. The reduced tidal flows to these sites often cause water quality problems and increased sedimentation.

*Fig. 2 A pair of tidal gates on Sybil Creek, Branford (R. Rozsa)*

## POST-COLONIAL PERIOD

Since colonial times, transportation facilities have caused notable direct losses of wetlands. Among the earlier projects were the construction of the shoreline railroad in the mid 1800s and the shoreline trolley in the late 1800s. However, major impacts came in the mid 1900s with the large east-west roads such as Interstate 95. Fill was placed in tidal wetlands to create an elevated base for the various projects. The last major loss of marsh in highway construction was on I-95 when a portion of the Sherwood Island State Park salt marsh was filled for a parking lot, as documented in Arboretum Bulletin No. 12 (1961). Some of the largest wetland areas filled for transportation facilities include what are now the Quinnipiac River railroad yard and Bridgeport Airport. The latter is entirely constructed on fill placed over tidal wetlands.

In recent years, concerns have been expressed regarding secondary impacts of modern, narrow bridge spans. Most of the wetland or water is now crossed via filled causeways and the actual new bridges span a much smaller distance than did the older, trestle bridges they replaced. It was thought that the newer causeway/bridges restricted tidal flow, which in turn reduced the amplitude of the tide and promoted increased sedimentation. Recent investigations in eastern Connecticut found no significant changes in tidal hydrology or increased sedimentation behind at least two of these narrow span bridges.

Boats were a primary means of travel and commerce until the early part of this century. Extensive areas of wetland were filled and bulkheaded, creating upland to support shipping facilities, or were dredged providing deep water for navigation. The sediments dredged from harbors were often dumped on nearby wetlands. Many examples exist: Morris Creek in East Haven; West River in West Haven; Great Meadows in Stratford; East River in Guilford; and Mumford Cove in Groton. As the need for waterborne commerce diminished, the recreational boating industry blossomed and numerous wetlands were dredged and filled to create sheltered water bodies for marinas.

### Mosquito Control

Virtually all salt marshes adjacent to the Sound were altered by a variety of mosquito control activities. Mosquito control practices began after the Civil War as homeward bound soldiers brought malaria to Connecticut. The disease soon reached epidemic proportions, and wetlands of all types were filled or drained to prevent malaria transmission by Anopheles mosquitoes. With the elimination of malaria as a health threat, control efforts targeted the large broods of nuisance mosquitoes that originated on tidal wetlands, especially salt marshes. Hundreds of kilometers of mosquito ditches were hand dug to drain marsh surface waters, especially the intermittent pools or pannes which are the preferred breeding habitat for salt marsh mosquitoes (Fig. 3). While ditching did not destroy the salt marshes, it did change the abundance of certain plants and animals. In some wetter high marshes where the pannes were dominated by Stunted Smooth Cord-grass *(Spartina alterniflora* - short form), they were replaced by Salt Meadow Cord-grass. The loss of pannes also probably contributed to reduced populations of the Seaside Sparrow *(Ammodramus maritimus)* which today is an increasingly rare species. Use of the salt marsh by waterfowl, shorebirds and wading birds also declined as their preferred shallow water habitats disappeared. In other cases, the levees created along the edge of the ditches actually improved wildlife habitat, since tidal water could not readily drain off.

By the 1940's nearly all of Connecticut's salt marshes were ditched, with much of the labor supplied by government programs to put unemployed men to work during the Great Depression. In some towns the original ditches were not maintained after their initial construction, but are still very much in evidence. A good example is Great Meadows, Stratford, where sixty years after being dug, all ditches are still visible on aerial photographs and some are still functioning to remove surface water. Clearly salt marshes recover very slowly from such physical alterations (Fig. 4).

In 1985, Connecticut abandoned maintenance ditching in favor of a lower impact and more ecologically sound approach known as open marsh water

*Fig.3 Many miles of mosquito ditches were hand-dug during the Great Depression. (DEP)*

*Fig.4 The extent of mosquito ditching is best seen in aerial photographs. (DEP OLISP)*

management (OMWM). Mosquitoes are now controlled by Fundulus and other native minnow species which live in newly created, permanent, deep water ponds. The ponds are constructed only at those locations where mosquitoes regularly breed, and act as reservoirs to keep the fish on site and alive during low tide periods. The small fish leave the pond during high spring tides to feed voraciously on mosquito larvae on the high marsh. In some situations ditches are plugged with a sill to maintain a continuous source of water for the minnows. In addition to controlling mosquitoes, OMWM is also a simple yet effective marsh restoration technique. The abandoned ditches will slowly fill, allowing restoration of pre-ditching hydrology, and the construction of ponds replaces those that existed prior to their draining by the ditching.

Tide gates were also used in an attempt to control mosquito breeding by draining the salt marshes. Unfortunately, this caused significant impacts to tidal wetlands and eliminated the critical tidal link between marshes and the adjacent estuary, and thus limited productivity. Ironically, the only effect of tide gates on mosquito populations was to replace breeding by salt marsh mosquitoes with breeding by freshwater mosquitoes.

### Flood Reduction and Landfills

Tidal gates have also been used to reduce coastal flooding in locations such as Pine Creek in Fairfield. Several thousand hectares of Connecticut wetland have been degraded in this manner. Draining causes the soil salinity to become fresh or nearly fresh and soil moisture to decrease. This creates ideal conditions for the replacement of the native marsh grasses by the tall Phragmites or Common Reed *(Phragmites australis)*. This grass not only reduces plant and animal biodiversity, but creates a fire hazard (Fig. 5). Drainage enhances peat decomposition and leachate from this process and can also have negative effects on water quality (see the accompanying Tidal Wetland Restoration article).

Tidal wetlands were often a preferred location for municipal landfills. Examples include Farmill River in Shelton, Fletchers Creek in Milford, Pine Creek in Fairfield, Seaside Park in Bridgeport, Short Beach in Stratford, Sybil Creek in Branford and North Cove in Old Saybrook. On a positive note, a landfill proposal for Nells Island in Milford led to the protection of this, the largest unditched salt marsh in Long Island Sound, and its designation by the State of Connecticut as the Wheeler Wildlife Management Area.

## TIDAL WETLANDS LAWS

Level terrain, proximity to coastal water, saturated soil conditions and inexpensive purchase prices made tidal wetlands an easy target for development and alteration, especially in the twentieth century (Fig. 6). As early as the

*Fig.5 Drained tidal marshes favor Phragmites, which is very flammable. (T. J. Steinke)*

*Fig.6 Projects like this salt marsh filling in Old Saybrook, 1970, are no longer permitted thanks to the Tidal Wetlands Act. (W.A. Niering)*

1930s, wildlife biologists and hunters recognized the ecological value of tidal wetlands for species groups such as waterfowl and shorebirds, which led to the first concerted effort to protect tidal wetlands through acquisition. Examples include Barn Island, Great Island, Great Harbor Marsh, and Nells Island. Later, in the 1950s and 1960s, scientists and conservation groups began to recognize the ecological significance of tidal wetlands and the alarming rate at which these wetlands were being filled or dredged. In 1965, the Connecticut General Assembly appropriated $100,000 for marshland acquisition. In the same year, Massachusetts passed protective salt marsh legislation, and a group of concerned Connecticut citizens formed the "Save the Wetlands Committee," with the goal of providing similar legal protection for Connecticut marshes.

A look at the actual loss of wetlands helps put the push for legal protection of wetlands in perspective. Present day estimates place the total tidal wetland acreage for all of Long Island Sound at just over 8,456 hectares (20,895 acres) with Connecticut's portion 84% or 7,126 hectares (17,608 acres). Historic tidal wetland area in Connecticut around the turn of the century is believed to have been from 9,000 to 10,725 hectares (22,265 to 26,500 acres). Unfortunately, none of these historic estimates are accompanied by a methodology that explains exactly which wetlands were included in the calculations. The Connecticut Department of Environmental Protection (DEP) recently completed a wetland trend analysis by calculating wetland acreage for the same areas on both the 1880's Coast and Geodetic Charts and the DEP's 1970 wetland maps. Table 1. shows a clear trend from Fairfield, the most urbanized county, to more rural New London. Towns with over 60 percent tidal wetland loss include Stamford, Fairfield, Bridgeport, Stratford, New Haven and New London, many of which were major port areas in the past. Based on this new analysis, the average annual loss rate for the State over this 90 year period was approximately 28 hectares/year (70 acres/year). The total loss of wetlands State-wide was 30%.

TABLE 1- The amount of tidal wetland, by counties, in the 1880s and the 1970s, and the difference (losses) in hectares. One hectare equals about 2.5 acres.

| | Fairfield | New Haven | Middlesex | New London | Total |
|---|---|---|---|---|---|
| 1880's | 2195 | 3097 | 1628 | 1523 | 8443 |
| 1970's | 855 | 2320 | 1255 | 1486 | 5916 |
| **LOSSES** | 1340 (61%) | 777 (25%) | 373 (23%) | 37 (2%) | 2527 (30%) |

The long-term loss and destruction of tidal wetlands ceased with the adoption of the Tidal Wetlands Act in Connecticut in 1969 (see Appendix) and in New York in 1973. These laws do not prohibit development in tidal wetlands, but rather require individuals proposing to conduct activities in wetlands to obtain authorization from the DEP (or the Department of Environmental Conservation in New York). In order for authorization to be issued in Connecticut, an applicant must demonstrate, and the Commissioner must find, that the proposed activity is consistent with all applicable statutory standards and criteria. Chief among these standards is to "preserve the wetlands and prevent the despoliation and destruction thereof in order to maintain their natural functions." Accordingly, activities which destroy and degrade wetlands, such as filling and dredging, cannot be authorized. The Connecticut standards further require an analysis of alternatives, which is used to identify means to mitigate any wetland impact. That regulatory programs can result in wetland protection is shown by the fact that in Connecticut permitted wetland losses currently average less than one-tenth hectare per year.

In both Connecticut and New York, detailed maps showing the boundaries of wetlands were initially used to identify regulated areas. Under regulation are the traditional tidal salt marshes found near the shore of Long Island Sound, tidal brackish marshes in areas where salt water mixes with freshwater, and tidal freshwater marshes, which on the Connecticut River may occur some 65 kilometers (40 miles) inland of the Sound. Lack of funding to update tidal wetland maps, and the need to regulate wetlands of fact regardless of mapped status, led to an amendment to the Connecticut Tidal Wetlands Act in 1990. The amendment eliminated the mapping requirement and clarified that the boundary of regulated tidal wetlands includes that area which is identified as meeting the statutory tidal wetland definition on the ground at the time an application is filed.

The Connecticut Coastal Management Act (CMA) supplements the State's direct regulatory authority by requiring application of the same preservation oriented standards through municipal planning and zoning, and by requiring State review of federal activities. Specifically, any federal activity, and activities within coastal towns subject to planning and zoning review, must be found consistent with the tidal wetlands standards of the CMA in order to obtain authorization.

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# TIDAL WETLAND RESTORATION IN CONNECTICUT

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Ecological Restoration is defined as *the intentional alteration of a site to establish the approximate biological, geological and physical conditions that existed in the predisturbance indigenous ecosystem or habitat.* Restoration projects attempt the re-establishment of all the predisturbance characteristics of a site, including plant and animal species and a variety of community attributes such as structure, function, and habitat values. This should not be confused with wetland creation in which a habitat that did not previously exist, at a particular site, is brought into existence.

As previously explained, tides are the primary abiotic factor organizing these complex wetland ecosystems. Most restoration projects in Long Island Sound have targeted salt marshes that were degraded as a result of activities which reduced or eliminated tidal flooding. In such marshes, the tidal marsh plant communities are usually replaced by a monoculture of Phragmites (also called Common Reed, *Phragmites australis*), a characteristic which makes identification of degraded sites quite easy. In some systems Narrow-leaved Cattail (*Typha angustifolia*) may replace the salt marsh species (see Barn Island example below). One of the problems resulting from this vegetation change is a drastic decrease in plant species diversity and reduced access to the marsh by the larger species of waterfowl, shorebirds and wading birds. Restoration of tidal flow is a highly successful method for the removal or suppression of Phragmites, because it is intolerant of salinity levels above 18 parts per thousand (ppt).

The following restoration case studies illustrate various bio-physical changes that result from human activities. Each is also an example of how habitat restoration can proceed. Since the 1970s Connecticut has restored over 600 hectares (1500 acres) of salt marsh, with most of the work supervised by the Department of Environmental Protection (DEP). In New York, restoration efforts have been directed largely towards the south shore of Long Island, where there are many more salt marshes than along the northern, Long Island Sound shore. As a policy, restoration projects are only implemented once it has been shown that the benefits of restoration outweigh the alternative of taking no action at all.

## BARN ISLAND WILDLIFE MANAGEMENT AREA, STONINGTON IMPOUNDED MARSHES

The Barn Island Marshes are a series of flooded valley tidal wetlands near the Rhode Island border in Stonington, Connecticut, which have been managed by the State as a hunting area (Fig. 1). In the late 1940s, the Connecticut Board of Fisheries and Game began constructing a series of impoundments across the valley marshes at Barn Island to offset the loss of waterfowl habitat caused by mosquito ditching. Low earthen dikes were built across several marshes, converting upstream, interior portions to non-tidal, shallow water habitat through the ponding of upland stream flows.

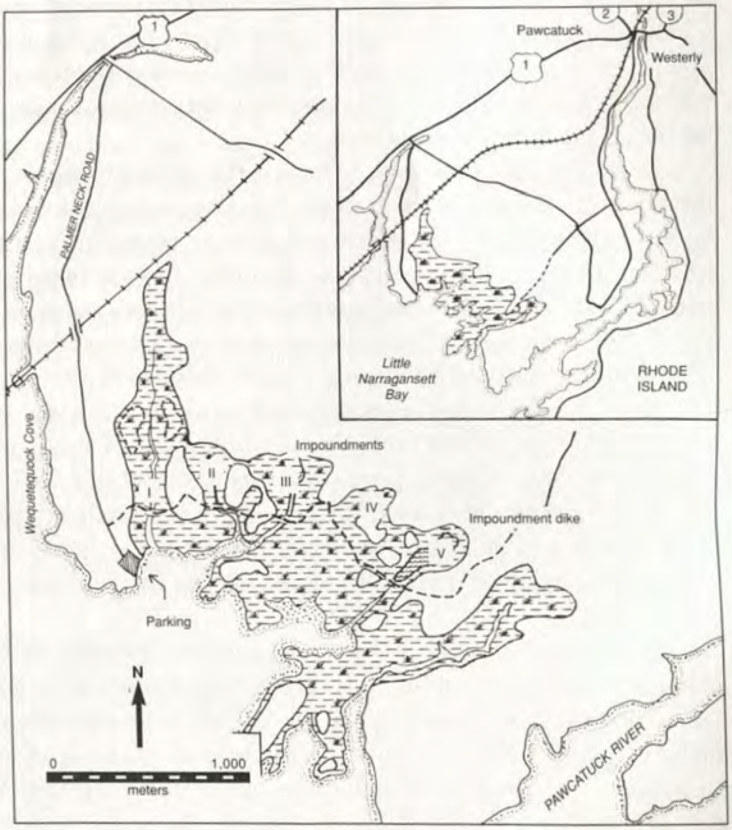


*Fig. 1 Map of Barn Island marshes.*

Waterfowl use initially increased, but declined over the long term as the new open water habitat was encroached upon by a new set of plants. By the 1970s, the impoundments were dominated by Narrow-leaved Cattail and expanding colonies of Phragmites. The muskrat population also increased dramatically. To reduce the amount of Cattail and Phragmites, which cannot tolerate salt water, in 1978 the DEP installed a four foot wide culvert on the westernmost impoundment (called No. 1). Restoration of tidal flushing resulted in the demise of the cattail and the re-establishment of salt marsh vegetation (Fig. 2). However, this only occurred in the southern part of the marsh, suggesting that the culvert was too small to pass sufficient volumes of saltwater to regularly flood the middle and upper marsh areas. The culvert was also found to restrict drainage of water off the impounded marsh back into the Sound, so a higher than average low tide elevation was maintained behind the dike.

*Fig. 2 Aerial view of impoundment 1, Barn Island marshes in 1982 showing dead Cattail and Phragmites on left and reestablished salt marsh vegetation on right.*

In 1982, a seven foot diameter culvert was added to the same impoundment, and today nearly all of the Cattail and much of the Phragmites have been replaced by salt marsh vegetation. Two former large open water pannes now support Smooth Cord-grass (*Spartina alterniflora*), and numerous shallow pools attract large numbers of shorebirds and wading birds. Re-establishment of the salt marsh vegetation occurred through spontaneous means and without planting, demonstrating that plant species restoration occurs naturally without the need for implementing expensive and often ineffective planting programs. With the re-establishment of salt marsh vegetation, typical marsh invertebrates and fish recolonized the area. Studies by students and staff at Connecticut College have documented this process of restoration (see Suggested Readings). Using similar methods three other impounded wetlands have been restored at Barn Island.

## GREAT HARBOR MARSH/LOST LAKE, GUILFORD
## DRAINED AND SUBSIDED MARSH

This 93 hectare (230 acre) complex consists of two major, interconnected wetlands - Great Harbor Marsh downstream of the railroad and State Route 146, and the upstream Lost Lake (32 hectares or 78 acres, also called Three Corner Marsh) (Fig. 3). Great Harbor Marsh is separated from Long Island Sound by a narrow coastal barrier. In the late 1880s the coastal trolley bed was constructed on this beach and in 1916 an elevated dike was constructed with a tide gate installed in the outlet channel to control tidal flooding. This situation persisted for nearly 40 years, when a hurricane destroyed the tide gates and restored full tidal flow in the early 1950s.

The gating and draining of this wetland complex caused a lowering of the water table in the marsh peat by nearly a meter. This exposed the upper portions of peat to oxygen for the first time, and it began to decompose very rapidly. The overall result was a loss of peat, which caused the marsh surface to drop, or subside, at least to 60 centimeters (two feet) below its former elevation. If we use a conservative estimate of a 60 centimeter decrease in elevation across the entire 93 hectare (230 acre) marsh surface, then the total peat loss is projected at over 765,000 cubic meters (1 million cubic yards). To imagine this much volume, think of it as equivalent to raising the height of a football field 140 meters (460 feet).

Due to the subsidence of the peat surface, within several years of the breach approximately 75% of the marsh was converted from a salt marsh community to intertidal flat/shallow water habitat with no marsh vegetation at all. Only that section of Great Harbor marsh adjacent to the barrier beach had sufficient elevation to retain emergent wetland plants. From there, Smooth Cord-

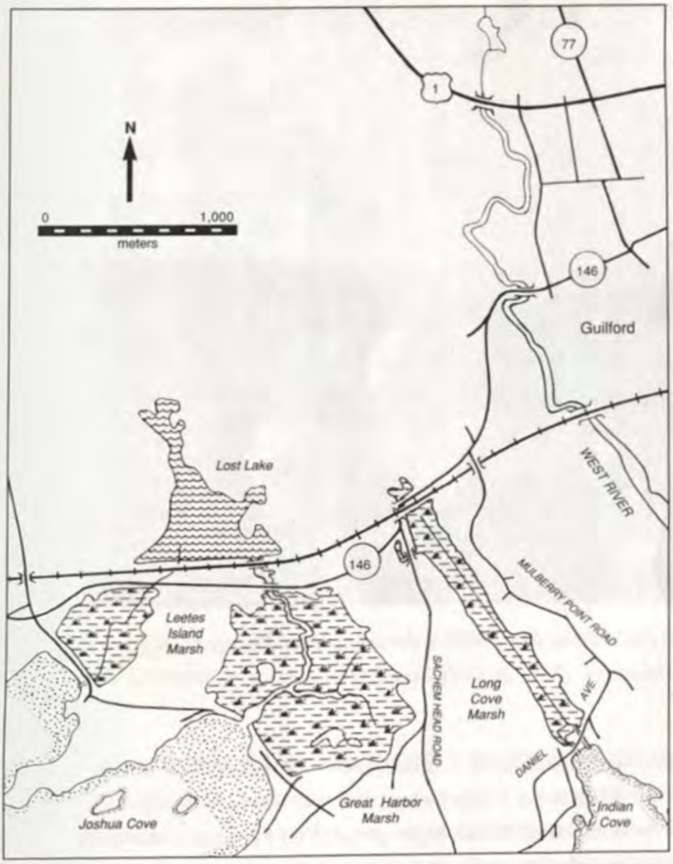


*Fig.3*
*Map of Great Harbor marsh/Lost Lake and Long Cove.*

grass began a gradual but progressive expansion out onto intertidal flat, in an upstream direction. Forty years after the loss of the tide gate, most of the Great Harbor marsh now supports wetland vegetation once again (Fig. 4 and 5). Upstream, the Lost Lake area is still largely devoid of vascular plants to this day.

Great Harbor Marsh has largely restored itself from the standpoint of the amount of wetland that now supports salt marsh vegetation. However, the plant communities are not what they once were. Before tide gates the vegetation was principally a high marsh community, but it is now dominated by the low marsh species Smooth Cord-grass. Draining caused subsidence, but subsequent restoration of full tidal flow to a significantly lower marsh surface did not lead to the re-establishment of the previous plant and animal communities. The lost peat has been replaced by salt water resulting in significant changes in current velocities and flow volumes. The creek has widened from 3 to 27 meters (10 to 90 feet) since the gates came out, a result of the scour from increased current

*Fig.4 Great Harbor marsh. In the late 1970's the tidal mud flats were beginning to be colonized by Smooth Cord-grass. (DEP) (A. Rocque)*

velocity. Furthermore, the marshland immediately upstream of the inlet has been converted to a 0.5 hectare (1.5 acre) pond. Its current diameter is over 60 meters (200 feet), and enlargement is projected to continue until the tidal exchange volume is reduced through the formation of peat and the subsequent increase in wetland elevation. This process is described in the previous chapter on marsh development.

The nearby Leetes Island marsh in Guilford is another example of a subsided marsh. Studies conducted by the U.S. Army Corps of Engineers have shown that restoration can only be accomplished by building a series of structures that will allow more water to leave the marsh on low tide than enters the marsh on high tide. Without such modifications of the natural tidal cycle, too much water will remain on the marsh at low tide, preventing the establishment of salt marsh plants.

Other examples of degraded marshes caused by tide gates include: Old Field Creek and Cove River, West Haven; West River, Mill River and Morris Creek, New Haven; Sluice Creek, Guilford; and Sybil Creek, Branford. The DEP is working with many of these communities in the development of salt marsh restoration plans.

*Fig.5 Great Harbor marsh, same location as Fig. 4 in the late 1980's where a thriving low marsh community had developed. (R. Rozsa)*

## LONG COVE, GUILFORD - RESTRICTED TIDAL FLOW

Long Cove is aptly named since it occupies a long but narrow valley, approximately one mile in length. With an area of only 17 hectares (43 acres), it is separated from Long Island Sound by a narrow, sandy barrier beach (Fig. 3). The road and bridge on this beach were destroyed in the 1938 hurricane and were reconstructed at a landward position. The bridge was replaced by a 42 inch concrete culvert; a short time later, a second culvert was installed with a tide gate for mosquito control. A linear ditch was excavated in the marsh from the new culvert to the upper reaches of the marsh. Eventually the original culvert filled with sediment and was abandoned.

In an attempt to control mosquito breeding, a two step water management program was developed in the 1940s. The tide gate was closed during the summer months to drain the marsh and reduce insect breeding habitat. After the first hard frost in fall, the gate was opened, and the resulting tidal flows removed sediments that accumulated in the creeks and ditches in the summer months. The alternating cycle of draining and flooding continued for forty years. Phragmites gradually and progressively replaced most of the typical salt marsh vegetation.

By the early 1980s, the tide gate had fallen off, reestablishing year-round tidal flushing. It was observed that most of the marsh area never flooded, even during the highest tides, and it was concluded that the remaining functioning culvert was undersized and restricted tidal flow. On the portions of the marsh which did flood with salt water, Phragmites was replaced by salt marsh plants

The deterioration of this marsh was brought to the attention of the DEP by William Tietjen, a long time resident and member of the Indian Cove Association who had personally witnessed the decline of the marsh since the 1940s. This served as the catalyst for the department's first multi-group partnership in tidal wetland restoration. The partnership included the Town of Guilford, the Guilford Land Trust which owned most of the wetland, the DEP and the Mosquito Control Unit (formally the Mosquito and Vector Control Section) of the Connecticut Department of Health Services. Taking into consideration long term changes to the marsh caused by draining, and recognizing the need to increase water levels only to that extent which would regularly flood the marshland (i.e., several centimeters), the reopening of the abandoned culvert was proposed. The DEP's Coastal Area Management Program (now the Office of Long Island Sound Programs) provided Guilford with a small grant to restore the channel across the beach and construct concrete training walls to the protect the channel. In 1986 the Mosquito Control Unit removed sediment upstream of the culvert and cleaned those ditches necessary to interconnect the culvert with the main channel

Eight years later, nearly all of the Phragmites in the central and upper marsh has been replaced by salt marsh vegetation. Phragmites is stunted and decreasing in abundance in the lower marsh. Approximately two hectares (five acres) of pool habitat have formed in the upstream marsh. It is predicted that much of the open water will be replaced by salt marsh vegetation, but in the interim it functions as significant wildlife habitat for waterfowl, shorebirds and wading birds.

Long Cove illustrates successful restoration of a marsh via partial flow restoration using culverts. Examples of salt marshes that have been restored through the installation of larger culverts to increase tidal flow volumes include: Cat's Island, Milford; Caroline Creek, East Haven; and Palmer Cove, Groton.

## HAMMOCK RIVER, CLINTON
## RESTORATION VIA TIDAL GATE MANAGEMENT

Upstream of Beach Park Road, on the Hammock River in Clinton, nearly 120 hectares (300 acres) of tidal wetlands, mostly salt marsh, have been drained for salt marsh haying and mosquito control purposes since the early part of this century (Fig. 6). Gradually the vegetation, dominated by high marsh plant communities, was replaced by Phragmites. Charles Roman, a graduate student at Connecticut College documented the environmental changes that had taken place by the early 1980s. His research demonstrated that the wetland surface had subsided at least 38 centimeters (15 inches) and, when all four tide gates were opened in the fall and winter months, the flooding depth and duration resembled that of the previously discussed Lost Lake case study. During the summer, the tide gates were closed to drain surface water from the marsh, thereby eliminating breeding habitat for the salt marsh mosquito. However, without daily tidal flow sediments accumulated quickly in the ditches, which in turn trapped rainwater, creating an ideal habitat for freshwater mosquitoes.

A cooperative program was begun in 1985 between the DEP and the Mosquito Control Unit to restore the degraded wetlands by utilizing modern

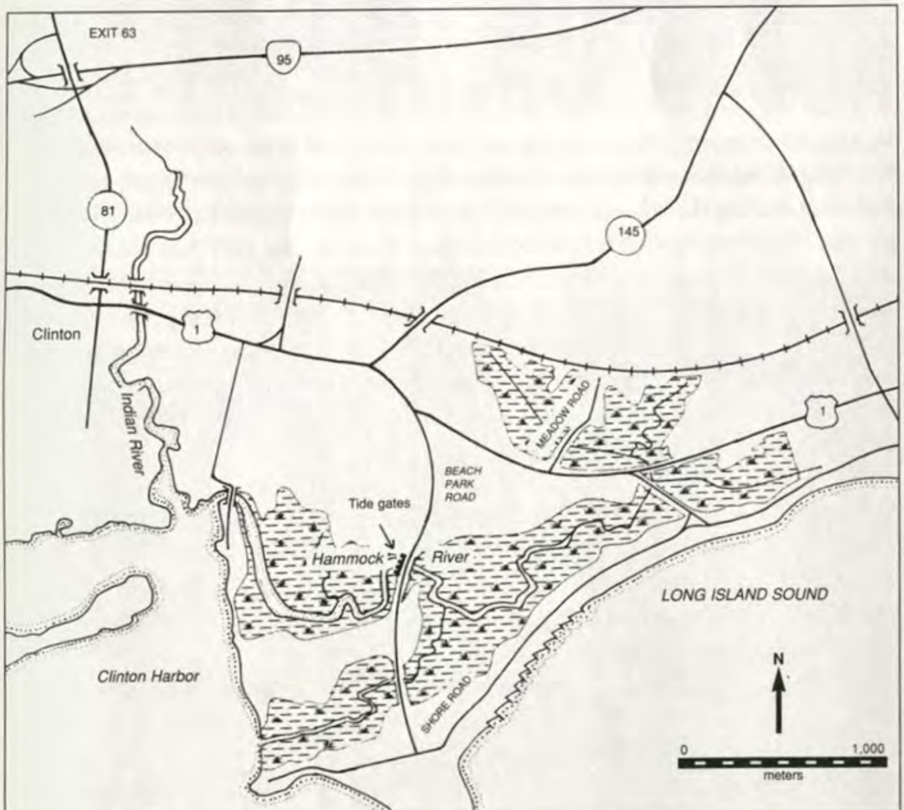


*Fig.6 Map of Hammock River marsh*

open marsh water management techniques. The plan was to restore tidal flushing during the summer to the extent necessary to maximize the emergent vegetation and minimize the conversion of salt marsh to open water (similar to the Lost Lake scenario). A single tide gate was opened in the spring of 1985 and photo stations were established to measure the replacement of Phragmites by native marsh grasses. Reference stakes were installed against which the reduction in the height of Phragmites could be measured at the end of the growing season. In the fall of 1985, the height reduction of Phragmites was one meter. During the next three years, the annual height reduction averaged 30 centimeters (one foot) (Fig 7). By the fifth and sixth years, Phragmites stopped growing, dead shoots no longer persisted and the exposed peat was being colonized by salt marsh grasses. Local residents reacted favorably to the restoration, remarking on the improving vistas and the return of wildlife such as egrets and waterfowl.

By 1992, Phragmites was decreasing throughout the entire marsh but it was apparent that in all areas, especially that west of Meadow Road, extensive colonies would persist. The next year, a second tide gate was opened to increase the area of marsh flooded, and monitoring stakes were again set out. In the summer of 1994, complaints were received with respect to backyard flooding. Interestingly, no complaints were received about the more extensive flooding during the winter, when all four gates were open. In order to continue this highly successful marsh restoration project, the DEP has received federal funding through the Department of Transportation's Intermodal Surface Transportation Efficiency Act to design and implement a flood protection program for several low-lying properties. To everyone's surprise, no significant mosquito breeding occurred during this restoration. This can be explained by the fact that tides flood nearly all of the marshland on a daily basis, which prevents breeding by the salt marsh mosquito.

The draining of the Hammock River marshes may have caused water quality problems in the river and adjacent Clinton Harbor (see sidebar on p. 62.). Studies have shown that restoring tidal flow can quickly reverse this problem. Restoration of water quality is probably critical to the health of the living resources in this area including the natural oysters beds that line the channel of the Hammonasset River.

This project illustrates how salt marsh restoration can be accomplished at very low cost and through the manual operation of tide gates. Gate adjustments or closures are only necessary in advance of major storm events, making manual operation easy and cost-effective. Manual gate operation is impractical at sites where low-lying properties would be regularly flooded. In those situations, automatic tide gates may be used in which a water level recorder moni-

*Fig. 7 Hammock River marsh. Above in 1988, three years after a tide gate was opened, Phragmites height was significantly reduced and patches were dying. Below by 1992 salt marsh vegetation had recolonized portions of the marsh. (R. Rozsa)*

tors the height of the tide and triggers the gate to close when the water reaches a pre-determined flood level (Fig. 8). A non-electric self regulating tide gate system which uses one or more floats to sense water elevations was developed by Thomas Steinke, Conservation Director of the Town of Fairfield.

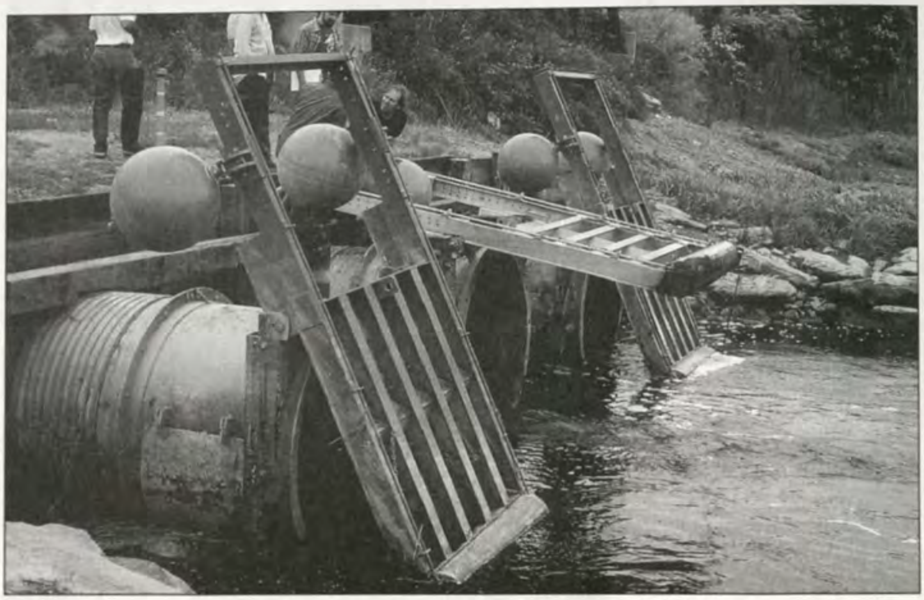

*Fig.8 Self-regulating tide gates. (R. Rozsa)*

### Marsh Draining Can Affect Water Quality

Studies on Cape Cod and elsewhere have demonstrated that draining salt marsh peat can create several significant water quality problems. Pyrite or iron sulfide, a common soil mineral, produces sulfuric acid when exposed to oxygen. If the soil in question has limited buffering capacity, the pH value in drained marshes can decrease to values as low as 3 to 4. These altered soils are referred to as *acid sulfate soils* and one such site has been located in a drained marsh in the Town of Fairfield. Following rainstorms, runoff from the marsh causes acidic conditions in tidal creeks. In addition, organic compounds in this leachate can consume oxygen, causing hypoxia or anoxia (lowering or complete depletion of oxygen in the water) which can cause fish kills. Reflooding the marsh usually corrects the water pollution problems caused by draining

Tide gate management programs are being used in Pine and Ash Creeks in Fairfield and Groton Long Point, in Groton. At the latter, the Groton Long Point Association manages the tide gates and closes them when a major storm is forecast. Examples of degraded salt marshes that have been restored through complete gate removal include: upper Farm River, East Haven; upper Branford River and Gigamoque Creek, Branford; and Indian River, Clinton.

## MUMFORD COVE, GROTON
## BURIED AND EXCAVATED MARSH

In the 1950s, an earthen dike was built around a salt marsh located on the eastern shore of Mumford Cove, and sediments dredged from the cove were hydraulically pumped into the southern end of the marsh (Fig. 9). These sediments spread across the marsh in a northerly direction, and excess water returned to the cove via a sluiceway located in the northwest corner. Fill depths across this six hectare (15 acre) marsh ranged from 0.6 to 1.2 meters (two to

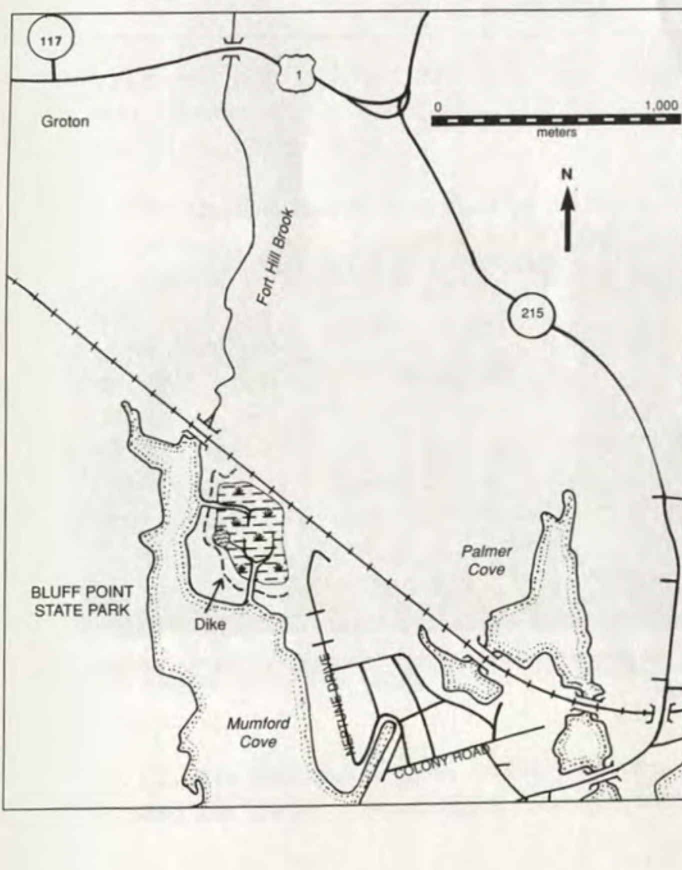


*Fig. 9*
*Map of Mumford Cove*

four feet), elevations too high to be flooded by the tides. Phragmites became the dominant plant, and the ponding of rainwater produced large, uncontrollable broods of freshwater mosquitoes.

Restoration began as a DEP and Mosquito Control Unit partnership in the fall of 1989, when the overburden of dredged sediment in the northwest corner was excavated by a lightweight bulldozer and transported to the adjacent uplands. Creeks and ponds were recreated using lightweight excavators (Fig. 10). The following spring, the U.S. Fish & Wildlife Service, through its Partners for Wildlife Program, joined the effort and provided equipment and operators to assist in the restoration. Over the next four years, the remaining wetland was unearthed, tidal creeks restored and wildlife ponds constructed. No planting was done, but vegetation re-established itself through the natural transport of salt marsh plant seed by the tides. Dense beds of the submerged aquatic plant Ditch or Widgeon Grass (*Ruppia maritima*), an important waterfowl food plant, spontaneously established in several of the ponds.

*Fig. 10 A low-ground pressure excavator digging a creek during the restoration of a buried marsh. (R. Rozsa)*

## RESTORATION RULES-OF-THUMB

- re-establishment of regular tidal flushing with saltwater (over 18 parts per thousand of salt) initiates the replacement of Phragmites by salt marsh plants and this conversion normally occurs over a five to ten year period.
- re-establishment of salt marsh plants proceeds spontaneously if a nearby salt marsh is present to supply a seed source. In most cases expensive planting or transplanting programs are not necessary.
- restoration of tidal flows to their pre-disturbance volumes is not always desirable, especially in the case of subsided wetlands.
- marsh restoration will reduce or eliminate mosquito breeding in subsided marshes.
- marsh restoration re-establishes scenic vistas.

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# THE FUTURE - SOME EMERGING TIDAL WETLAND ISSUES

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*Connecticut Department of Environmental Protection*

On the surface, tidal wetlands appear to represent a simple type of ecosystem but, since they occur at the land/water interface, they actually operate under the complexities of both environments. Furthermore, while tidal wetlands are among the best studied ecosystems on the globe, our knowledge of them is far from complete. Below are just some of today's emerging scientific questions and management issues.

### Sea Level Rise

Sea level rise is now occurring at an accelerated rate, probably in response to degradation of air quality caused by greenhouse gases. This results in global warming, and as temperatures rise, the polar ice caps continue to melt. Some coastal states have reported subsidence or drowning (loss) of tidal wetlands which can no longer accumulate peat fast enough to stay above sea level. In Connecticut, the effect depends on location. Sea level rise appears to be altering the zonation of plant communities in southeastern Connecticut, where the tidal range averages 0.75 meters. Here studies have documented that at least two marsh systems are currently not keeping up with sea level rise. Studies at Connecticut College also suggest that as sea level rises, marsh productivity decreases. On Connecticut's western shore, with a tidal range of up to two meters, extensive areas of low marsh vegetation have been drowned (e.g. Five-mile River, Norwalk). These losses are most likely due to sea level rise. Monitoring of sea level rise and its implications for tidal wetlands need to be expanded throughout Long Island Sound.

Another ramification of sea level rise is the tendency for marsh systems to migrate landward. As sea level rises, marshes which are able to stay above the rising water level will tend to move inland. For insensitively developed areas where seawalls, lawns and other structures occur to the very edge of the wetland, landward movement is severely limited (Fig. 1). An important question

*Fig. 1 Marshes with development right to their edge have no place to go as sea level rises. (DEP OLISP)*

for land managers is how to achieve sustainable development that allows for continued human use of the coastal fringe while also accommodating continued marsh development.

### Spread of Phragmites *(Phragmites australis)*

Perhaps the most significant problem confronting tidal wetlands, especially those with limited tidal flushing or low salinity waters, is the conversion of Spartina dominated marsh communities to Phragmites or Common Reed (Fig. 2). On the lower Connecticut River, this invasion appears to have begun in the 1960s and today it is spreading at a rate of 2 % per year. There is some evidence to suggest that the invasive form is not indigenous to North America and may have established here by means of seeds on ballast stones from ships, the documented path for establishment of other exotic plants. Research into the genetic characteristics that can identify native versus non-native Phragmites types may help formulate control strategies. Its rapid invasion of the tidal wetlands of the lower Connecticut River, many of which have been designated as

*Fig.2 Phragmites in flower. (W.A. Niering)*

"wetlands of international importance," is one of the single greatest habitat management issues on the river. The Department of Environmental Protection (DEP) is beginning to evaluate methods to control this grass along the Connecticut River.

## Stormwater Discharge

The traditional approach to land development has been to collect stormwater and direct it through a pipe to the nearest natural watercourse, often a wetland. Throughout the country, few regulatory programs consider the dilution effect of stormwater when such waters are discharged into estuaries and, specifically, tidal wetlands. Connecticut's DEP recognized that stormwater discharges into tidal wetlands were contributing to the spread of Phragmites through changing wetland elevations (i.e. deposition of sediment) and dilution of soil salinities. Presently, DEP requires new and existing stormwater systems to retain the runoff generated by a one-inch rainfall event. The purpose of this is to prevent chronic dilution and the deposition of sediment by high frequency, low volume storm events. While it is apparent that such discharges are adversely affecting the marsh vegetation, no studies have been done to evaluate the impacts upon associated animal populations.

### Harvesting of Marsh Grasses

The harvesting of grasses from the salt marsh is an activity that has occurred since colonial time. Only recently have scientists begun to examine the consequences of haying upon the wetland ecosystem. The first concern is that this activity removes a significant portion of organic matter that would otherwise be accumulated at the soil surface, thus adding to marsh elevation, a vital process in keeping up with sea level rise. Modern day farmers often use conventional farm equipment which is not designed for use on the compressible salt marsh soils and often leads to the creation of ruts and increased mosquito breeding. Such depressions have been known to persist for years and even decades.

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Nydick, K.R., A.B. Bidwell, E. Thomas, and J.C. Varekamp. 1995. A Sea-level Rise Curve From Guilford, Connecticut, USA. Marine Geology 124: 137-159.

Warren, R.S. and W.A. Niering, 1993. Vegetation Change on a Northeast Tidal Marsh: Interaction of Sea-level Rise and Marsh Accretion. Ecology 74(1): 96-103.

# APPENDIX

## EXCERPTS FROM THE CONNECTICUT TIDAL WETLANDS ACT, CONNECTICUT GENERAL STATUTES

### Sec. 22a-28.

Preservation of tidal wetlands. Declaration of policy. It is declared that much of the wetlands of this state has been lost or despoiled by unregulated dredging, dumping, filling and like activities and the remaining wetlands of this state are all in jeopardy of being lost or despoiled by these and other activities, that such loss of despoliation will adversely affect, if not entirely eliminate, the value of such wetlands as sources of nutrients to finfish, crustacea and shellfish of significant economic value; that such loss or despoliation will destroy such wetlands as habitats for plants and animals of significant economic value and will eliminate or substantially reduce marine commerce, recreation and aesthetic enjoyment; and that such loss or despoliation will, in most cases, disturb the natural ability of tidal wetlands to reduce flood damage and adversely affect the public health and welfare; that such loss or despoliation will substantially reduce the capacity of such wetlands to absorb silt and will thus result in the increased silting of channels and harbor areas to the detriment of free navigation. Therefore, it is declared to be the public policy of this state to preserve the wetlands and to prevent the despoliation and destruction thereof.

### Sec. 22a-29. Definitions.

(2) "Wetland" means those areas which border on or lie beneath tidal waters, such as, but not limited to banks, bogs, salt marsh, swamps, meadows, flats, or other low lands subject to tidal action, including those areas now or formerly connected to tidal waters, and whose surface is at or below an elevation of one foot above local extreme high waters; and upon which may grow or be capable of growing some, but not necessarily all, of the following: (list of plants that occur in tidal salt, brackish and freshwater marshes).

(3) "Regulated activity" means any of the following: Draining, dredging, excavation or removal of soil, mud, sand, gravel, aggregate of any kind or rubbish from any wetland or the dumping, filling or depositing thereon of any soil,

stones, sand, gravel, mud, aggregate of any kind, rubbish or similar material, either directly or otherwise, and the erection of structures, driving of pilings, or placing of obstructions, whether or not changing the tidal ebb and flow. Notwithstanding the foregoing, "regulated activity" shall not include activities conducted by the mosquito control division of the department of health services, conservation activities of the state department of environmental protection, the construction or maintenance of aids to navigation which are authorized by governmental authority and the emergency decrees of any duly appointed health officer of a municipality acting to protect the public health;

### Section 22a-32.

Regulated activity permit. Application. Hearing. Waiver of hearing. No regulated activity shall be conducted upon any wetland without a permit. Any person proposing to conduct or cause to be conducted a regulated activity upon any wetland shall file an application for a permit with the commissioner (of DEP), in such form and with such information as the commissioner may prescribe. Such application shall include a detailed description of the proposed work and a map showing the area of wetland directly affected, with the location of the proposed work thereon, together with the names of the owners of record of adjacent land and known claimants of water rights in or adjacent to the wetland of whom the applicant has notice.

### Sec. 22a-33.

Issuance or denial of permit. In granting, denying or limiting any permit the commissioner or his duly designated hearing officer shall consider the effect of the proposed work with reference to the public health and welfare, marine fisheries, shellfisheries, wildlife, the protection of life and property from flood, hurricane and other natural disasters,

# CONNECTICUT COLLEGE ARBORETUM BULLETINS

**No.9.** *Six points of Especial Botanical Interest in Connecticut.* 32 pp. 1956. The areas described are the Barn Island Marshes, the Connecticut Arboretum, the North Haven Sand Plains, Catlin Wood, Cathedral Pines and the Bigelow Pond Hemlocks. **$1.00**

**No.12.** *Connecticut's Coastal Marshes: A Vanishing Resource.* 36 pp. 1961. Testimony of various authorities as to the value of our tidal marshes and a suggested action program. Second printing with supplement 1966. **$1.50**

**No.17.** *Preserving Our Freshwater Wetlands.* 52 pp. 1970. Reprints of a series of articles on why this is important and how it can be done. **$1.00**

**No.18.** *Seaweeds of the Connecticut Shore. A Wader's Guide.* 36 pp. 1972. Illustrated guide to 60 different algae with keys to their identification. New edition 1985. **$3.00**

**No.19.** *Inland Wetland Plants of Connecticut.* 24 pp. 1973. Some 40 species of plants found in marshes, swamps and bogs are illustrated. **$1.00**

**No.20.** *Tidal Marsh Invertebrates of Connecticut.* 36 pp. 1974. Descriptions and illustrations of over 40 species of mollusks, crustaceans, arachnids, and insects found on our tidal marshes. **$1.50**

**No.21.** *Energy Conservation on the Home Grounds - The Role of Naturalistic Landscaping.* 28 pp. 1975. **$1.00**

**No.22.** *Our Dynamic Tidal Marshes: Vegetation Changes as Revealed by Peat Analysis.* 12 pp. 1976. Description of a method for sampling peat and identifying plant remains in order to document vegetation change on tidal marshes. **$1.50**

**No.23.** *Plants and Animals of the Estuary.* 44 pp. 1978. Descriptions and illustrations of over 70 estuarine species. **$1.50**

**No.24.** *Garden Guide to Woody Plants - A Plant Handbook.* 100 pp. 1979. Lists and descriptions of over 500 different trees and shrubs useful for landscaping. **$2.50**

**No.25.** *Salt Marsh Plants of Connecticut.* 32 pp. 1980. Illustrated guide to 22 plants which grow in our tidal wetlands. **$1.50**

**No.26.** *Recycling Mycelium: A Fermentation Byproduct Becomes an Organic Resource.* 32 pp. 1981. Documents the role of industrial mycelial residues as soil amendments on ornamental plants, agricultural crops, and in natural vegetation. **$1.00**

**No.27.** *Birds of Connecticut Salt Marshes.* 48 pp. 1981. Illustrations and descriptions of 24 birds commonly seen on our tidal marshes. **$1.50**

**No.28.** *The Connecticut Arboretum: Its First Fifty Years 1931-1981.* 56 pp. 1982. Historical accounts of the formation and growth of the Arboretum. **$2.50**

**No.29.** *Mushrooms of New England.* 49 pp. 1984. Descriptions of 89 species of fungi, 62 illustrated. **$2.50**

**No.30.** *Native Shrubs for Landscaping.* 40 pp. 1987. Descriptions and lists of the best native shrubs for home, commercial and institutional landscaping. Color photographs. **$5.00**

**No.31.** *Birds of the Connecticut College Arboretum.* 50 pp. 1990. An annotated list with seasonal records, and an account of the bird research program. Illustrated. Replaces Bulletin No.10. **$5.50**

**No.32.** *The Connecticut College Arboretum—Its Sixth Decade and a Detailed History of the Land.* 96 pp., 47 photos. 1991. Historical accounts of the formation and growth of the Arboretum. Supplements Bulletin No. 28. **$5.00**

**No. 33.** *Archaeology in the Connecticut College Arboretum.* 56 pp. 1992. Detailed descriptions of prehistoric and historic archaeological sites in the Arboretum. Photographs and illustrations. **$5.00**

**No. 34.** *Tidal Marshes of Long Island Sound: Ecology, History and Restoraton.* Describes the ecology and chronicles the history of Long Island Sound Tidal Marshes. Photographs and illustrations. **$5.00**

## OTHER PUBLICATIONS

*Connecticut's Notable Trees* by Glenn D. Dreyer. 93 pp. 1990. Memoirs of the Connecticut Botanical Society No. 2, 1989. Records the locations and stories of the historic trees that have witnessed major events in Connecticut's past, and the largest trees of each species: Connecticut Champions, New England Champions, and National Champions. **$12.95** (plus $2.00 postage & handling )

*The Wild Gardener in the Wild Landscape* by Warren G. Kenfield. (Memorial Edition) 232 pp. 1991. The results of decades of creative research involving the scientific control of unwanted plants, combined with an extensive knowledge of plant ecology and horticulture to create an original volume for the homeowner as well as the estate manager. **$25.95** (plus $4.00 postage & handling)

*Connecticut Lakes* by Richard Canavan IV and Peter A. Siver. 299 pp. 1995. A technical look at the physical and chemical aspects of 56 of the State's lakes, presenting both current information and summaries of previous studies.
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