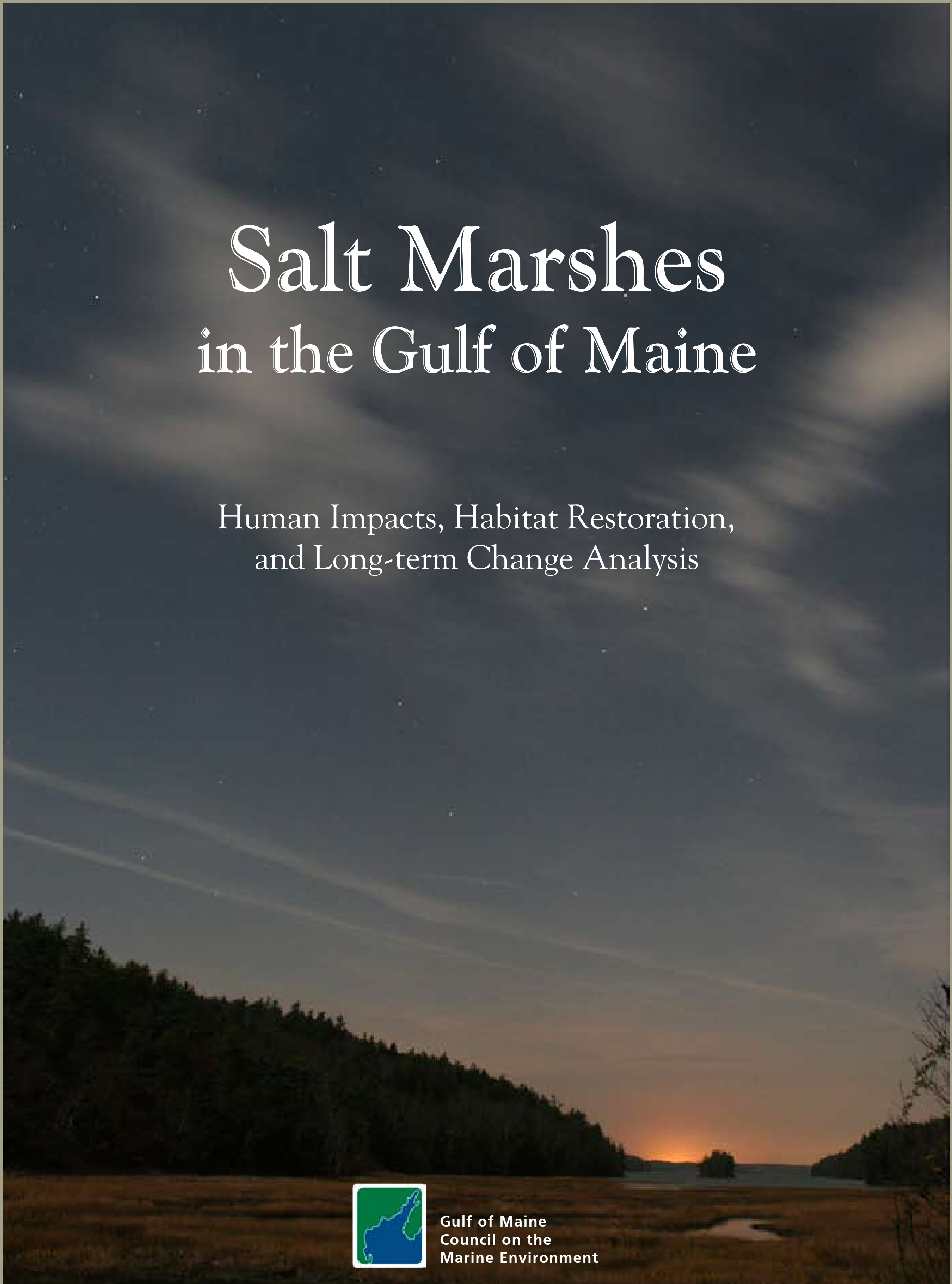


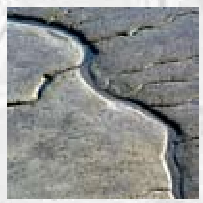
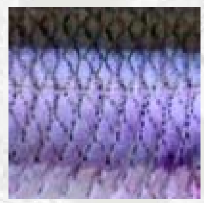
Salt Marshes in the Gulf of Maine

Human Impacts, Habitat Restoration, and Long-term Change Analysis

Gulf of Maine Council on the Marine Environment


USFWS - John and Karen Hollingsworth

Salt Marshes
in the Gulf of Maine

Human Impacts, Habitat Restoration, and Long-term Change Analysis

Gulf of Maine Council on the Marine Environment
Habitat Restoration and Monitoring Subcommittees

The Gulf of Maine Council's mission:

"To maintain and enhance environmental quality in the Gulf of Maine and to allow for sustainable resource use by existing and future generations."

Gulf of Maine Council on the Marine Environment

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The Gulf of Maine Salt Marsh Monitoring Protocol on pages 34 and 35 was developed through the collaboration of approximately sixty coastal ecologists and resource managers from the United States and Canada, especially those who participated in a workshop in September 2004 in Wells, Maine. The Protocol is an updated version of regional salt marsh monitoring standards established in 1999 at a Global Programme of Action Coalition for the Gulf of Maine workshop. For information about the updated Protocol, go to www.gulfofmaine.org/habitatmonitoring

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Cover: A salt marsh in Maine under the night sky. © Peter H. Taylor
Inside front cover: Parker River National Wildlife Refuge, Massachusetts. John and Karen Hollingsworth
Title page insets: Marsh grasses and a mudflat. © Peter H. Taylor
Fish scales. © Ethan Nedeau
Title page background and table of contents: Aerial photograph of a salt marsh channel and creeks near Sandy Neck in Barnstable, Massachusetts. Massachusetts Executive Office of Environmental Affairs/MassGIS
Back cover: An egret catches a fish in a salt marsh. © Peter H. Taylor

Table of Contents

Introduction

Along the Gulf of Maine's coast from Massachusetts to Nova Scotia, hundreds of road embankments, railroad berms, undersized culverts, dikes, dams, and other manmade barriers block salt marshes from the natural ebb and flow of tides. Many of these were constructed decades ago, but they continue to degrade the health of twenty percent or more of the region's salt marshes (Cornelisen 1998). Reduced tidal flooding impairs the ability of salt marshes to sustain coastal food webs, provide nursery habitat for fish, and remove pollutants from the water.

If manmade barriers are removed to restore tidal flooding, the affected salt marshes can regain approximately their natural state and function (Sinicrope *et al*. 1990, Burdick *et al*. 1997). Although many government and non-government organizations now emphasize salt marsh restoration, many tidal restrictions remain throughout the Gulf of Maine (Wells 1999, MWRP 2005, HRSC 2006). In Maine alone, more than 140 culverts and other tidal restrictions were affecting salt marsh health as recently as 2004 (Bonebakker, unpublished data). Scientists are investigating the ecological impacts of tidal restrictions around the Gulf of Maine, the effectiveness of habitat restoration methods, and the ecological benefits of habitat restoration. A priority is to expand and standardize salt marsh monitoring programs to allow better assessment of marsh health.

Restoring the health of salt marshes is often quite feasible and straightforward. For example, one common remedy is to add or expand culverts under roads and railways, which can improve salt marsh health by increasing tidal exchange. A major challenge, however, is the availability of funding for habitat restoration projects. The U.S. National Oceanic and Atmospheric Administration (NOAA), the partners in Canada's Eastern Habitat Joint Venture, and other funding sources are supporting habitat restoration in the Gulf of Maine, but more funding is needed to achieve the full ecological and economic benefits.

This document summarizes current scientific understanding about salt marshes in the Gulf of Maine. It describes the valuable ecological roles of healthy salt marshes; human impacts on salt marshes; methods for restoring salt marsh habitats; and the need for a regional salt marsh monitoring program.

Parker River National Wildlife Refuge near Newburyport, Massachusetts.


Ethan Nedeau

Salt Marsh Ecology

Salt marshes are coastal wetlands that are flooded regularly by the tides. They range in size from narrow shoreline fringes to vast meadows. Salt marshes play an integral role in improving water quality by removing contaminants, excess nutrients, and sediment washed downstream from the watershed. Acre for acre, salt marshes can produce an amount of plant biomass similar to intensively farmed cropland. This abundant plant growth helps to sustain food webs of shellfish, fish, birds, and wildlife, not only in the marshes but offshore and in surrounding terrestrial ecosystems. Winter flounder, striped bass, clams, and other species of commercial and recreational value are among the animals and plants that thrive in healthy salt marsh ecosystems.

Tidal creek near the mouth of the Mousam River and Parsons Beach in Kennebunk, Maine.

Salt marshes are found along the coasts of all five states and provinces bordering the Gulf of Maine. Ethan Nedeau

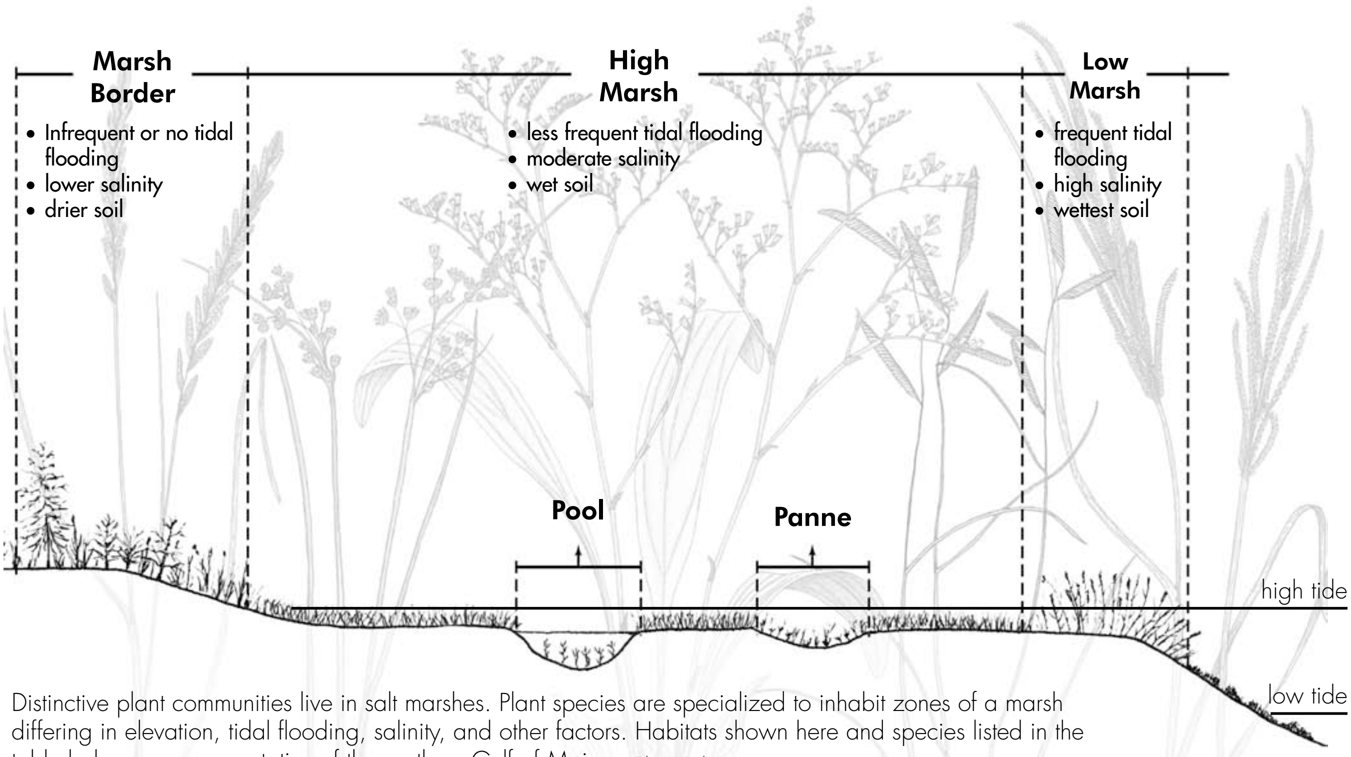
Marsh Distribution in the Gulf of Maine

A large percentage of salt marsh habitat has been destroyed in the last four centuries, but salt marshes still occur in many places along the Gulf of Maine coast. They tend to be biggest and most common in New Brunswick, Nova Scotia, and Massachusetts. The Great Marsh in northeastern Massachusetts, for example, covers some 30 square miles, making it the largest marsh in New England. Sizable marshes also exist in New Hampshire and southern Maine. The Hampton-Seabrook marsh in New Hampshire includes approximately eight of the state's ten square miles of salt marsh. The Webhannet/Little River system in Wells, Maine, encompasses six square miles, while the Scarborough Marsh near Portland is 4.2 square miles. To the north and east along the Maine coast, salt marshes tend to be smaller (Jacobson *et al.* 1987), until expansive marshes are reached along the Bay of Fundy.

Marsh Formation

Salt marshes develop over centuries in places along the coast where shelter from strong waves and currents allows sediment to accumulate. Salt marsh plants colo-

Development of surrounding land often degrades the ecological functioning of salt marshes.
Massachusetts Executive Office of Environmental Affairs/MassGIS



Distinctive plant communities live in salt marshes. Plant species are specialized to inhabit zones of a marsh differing in elevation, tidal flooding, salinity, and other factors. Habitats shown here and species listed in the table below are representative of the southern Gulf of Maine. Ethan Nedeau

Common Salt Marsh Plants

Marsh Border	High Marsh	Pool	Panne	Low Marsh
Switchgrass (*Panicum virgatum*)	Smooth cordgrass (short) (*Spartina alterniflora*)	Widgeon grass (*Ruppia maritima*)	Seaside plantain (*Plantago maritima*)	Smooth cordgrass (tall) (*Spartina alterniflora*)
Slough grass (*Spartina pectinata*)	Salt meadow hay (*Spartina patens*)		Glasswort (*Salicornia* sp.)	
Common reed (*Phragmites australis*)	Spike grass (*Distichlis spicata*)		Smooth cordgrass (*Spartina alterniflora*)	
Marsh elder (*Iva frutescens*)	Black rush (*Juncus gerardii*)		Blue-green algae	
	Sea lavender (*Limonium nashii*)			

nize the sediment because they are uniquely adapted to the wet and salty environment. Their dense stems trap even more sediment and organic matter, and gradually a foundation of peat develops. Over time, the peat accumulates, allowing the marsh to expand horizontally and vertically. On the whole, the Gulf of Maine region has fewer, smaller salt marshes than the southeastern U.S. coast because glaciers scoured the bedrock of the Gulf of Maine watershed.

Dominant Plants

Approximately thirty plant species commonly inhabit Gulf of Maine salt marshes, but the dominant plants are two closely related grasses called *Spartina alterniflora* (smooth cordgrass) and *Spartina patens* (salt meadow hay). *Spartina alterniflora* grows along the edges of creeks and channels at the low fringes of the marsh, where tides flood the peat and plants twice daily. *Spartina patens* grows in slightly elevated, interior portions of the marsh that are flooded less often, during the higher (spring) tides. Salt marshes in New Hampshire and Maine have a higher ratio of high marsh (characterized by *Spartina patens*) to low marsh (characterized by *Spartina alterniflora*) than salt marshes in southern New England (Nixon 1982).

Values of Salt Marshes

Salt marshes remove pollutants from water

River water and groundwater flowing into a salt marsh often contain sediments, excess nutrients, and toxic contaminants from land-based human activities. Salt marshes filter some of these pollutants in the following ways:

- Dense vegetation in the salt marsh slows the water, which causes suspended particles to settle, clarifying the water.
- During spring and summer, marsh plants take up nutrients that otherwise might cause algal blooms and eutrophication in coastal waters.
- Denitrification by microbes in marsh sediments removes nitrogen from the ecosystem.
- Plants and microbes remove some toxic contaminants, which eventually become incorporated into peat, resulting in long-term burial and removal from the food web.

Salt marshes have a remarkable capacity for removing nitrogen from groundwater. This function is notable because it helps to protect coastal marine ecosystems from eutrophication caused by fertilizers, septic systems, and other nitrogen sources. Unlike other habitats along the coast, salt marshes tolerate large inputs of nitrogen. Nitrogen entering a marsh as nitrate or nitrite in the groundwater can be transformed to nitrogen gas by denitrification and released to the atmosphere. Nitrogen taken up by plants eventually

Nitrogen Removal Benefits Eelgrass

Even animals and plants that do not live in salt marshes reap benefits from nitrogen removal by marsh plants. For example, research by Valiela *et al.* (2000) in Waquoit Bay, Massachusetts, provided compelling evidence that salt marshes help nearby eelgrass beds to thrive. Eelgrass beds are an important habitat for many fish and invertebrates, so nitrogen removal by salt marshes likely benefited these species. For many years, high levels of nutrients had entered Waquoit Bay from the land. Valiela *et al.* found that areas of the bay that featured large salt marshes tended to have large eelgrass beds. Areas with less salt marsh had smaller eelgrass beds. By removing nitrogen, the salt marshes apparently reduced growth of phytoplankton and seaweed, which block the sunlight needed by eelgrass. Large salt marshes did a better job of removing nitrogen than small marshes, so they had larger eelgrass beds nearby.

Waquoit Bay is located in Falmouth, Massachusetts, along the coastline of Cape Cod. Residential development in the watershed has increased the input of nitrogen to the bay.

Massachusetts Executive Office of Environmental Affairs/MassGIS

Nitrate Removal from Groundwater

Weiskel *et al*. (1996) studied ecosystem processes at Namskaket marsh on the north side of Cape Cod. Groundwater entering the marsh carried nitrate from the surrounding residential areas and a sewage treatment plant. The nitrate concentration of the groundwater was 35 μM (490 ppb). Remarkably, 44 percent was denitrified within the first 100 meters. Even when the scientists experimentally elevated the nitrate concentration to 240 to 620 μM (3.4 to 8.7 ppm), denitrification reduced that level by one third within the first 100 meters.

Key points for management

- Salt marshes remove some nitrate from groundwater, essentially providing tertiary treatment for no cost.
- By **removing excess nitrogen and preventing growth of algae**, salt marshes enhance the condition of other habitats such as eelgrass beds.
- Loss and fragmentation of salt marshes in the Gulf of Maine has **reduced capacity for nitrogen removal**, while human population and nitrogen loading have increased.

is released as organic matter in the fall or buried in peat. Because primary productivity in salt marshes tends to be limited by the amount of nitrogen that is available, when more nitrogen enters the marsh in groundwater or surface water it enhances the growth of plants and algae. Higher nitrogen levels can improve plants' food value for grazing animals (Buchsbaum *et al*. 1981), and they can also change the relative abundance of plant species and encourage invasive plants like common reed (*Phragmites australis*) (Bertness *et al*. 2002).

Salt marshes have more capability to remove nitrogen from groundwater than from tidal and surface waters. Groundwater seeps through the marsh soil and sediments, enabling plants and microbes to take up nitrogen carried by the water. In contrast, tidal and surface waters flow in channels through the marsh, having little contact with the anoxic sediments where microbes remove nitrogen. In addition, only a small proportion of tidal and surface water is absorbed by the vegetated marsh, so plants have little opportunity to take up nitrogen from the water.

Research suggests that salt marshes at Waquoit Bay promote growth of eelgrass by removing excess nitrogen.
Ben Werdmuller

Values of Salt Marshes

Salt marshes fuel coastal food webs and fisheries

Although few animals eat the live plants in a salt marsh, salt marshes contribute to the coastal food web in two major ways: export of partially decayed plant matter, or detritus, from the marsh by tidal currents and the "food web relay" that moves nutrients from the marsh into coastal waters. Salt marshes act as breadbaskets that help to support commercial and recreational fisheries in the Gulf of Maine.

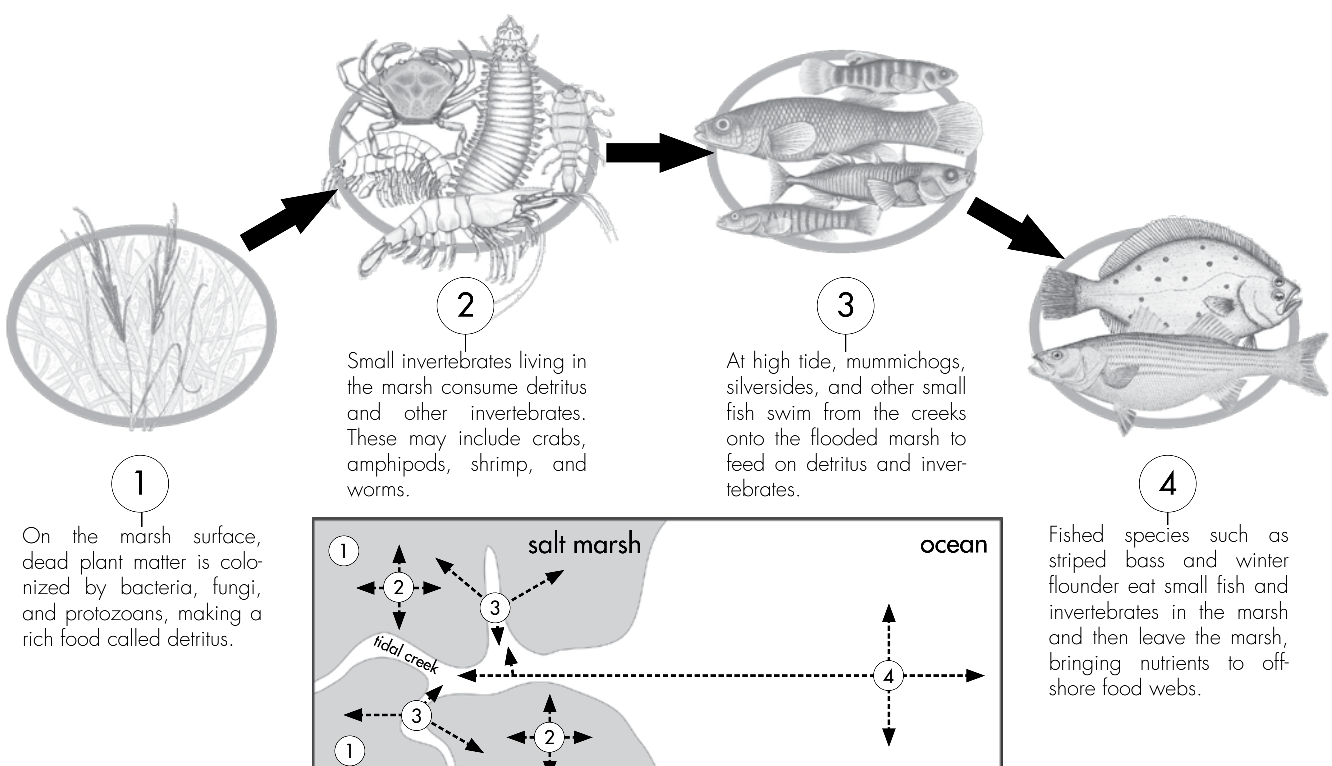
The export of waterborne detritus and dissolved nutrients from salt marshes supports the growth of phytoplankton, shellfish, and other organisms living outside marshes. Gordon (1985) showed that planktonic crustaceans in the Gulf of Maine have chemical "signatures" indicating that their nutrient supply originates in salt marshes. In the food web relay, or trophic relay (Kneib 1997), the energy captured by salt marsh plants is like the baton in a track-and-field race. Through predator-prey interactions, energy is relayed from salt marshes to the offshore food web.

A similar food web relay brings nutrients from the marsh into terrestrial food webs. Wading birds, migratory waterfowl, raptors, otters, and other animals spend part of their time feeding in salt marshes. When they defecate, die, or are eaten in the uplands, the organic matter that they obtained from the marsh enters the terrestrial food web.

Flounder Spawn in Estuaries

Winter flounder (*Pseudopleuronectes americanus*) spawn in bays and estuaries of the Gulf of Maine, and the young remain in shallow coastal waters until the age of one or two years. They feed on softshell clams, polychaetes, amphipods, isopods, and algae in the intertidal zone. As adults, the flounder migrate each summer to deeper waters. Their migratory patterns link salt marshes to offshore food webs.

Relay in the Salt Marsh Aquatic Food Web



Illustrations by Ethan Nedeau except striped bass (NOAA Archives)

Silversides Migrate Offshore

The Atlantic silverside (*Menidia menidia*) is among the most abundant species in tidal creeks, salt marshes, and shallow estuaries in the Gulf of Maine. In one study, this small silver fish, along with the mummichog (*Fundulus heteroclitus*), accounted for 90 percent of fish in a Cape Cod salt marsh. Silversides spawn in shallow intertidal areas, and their eggs adhere to *Spartina alterniflora* stems. As juveniles and adults, they live and feed in salt marshes. In late fall, the silversides migrate offshore to the inner continental shelf, where they are eaten by Atlantic cod, silver hake, Atlantic mackerel, and other commercially important fish.

Key Points for Management

- There are clear links between salt marsh habitats and offshore fisheries. Protection and restoration of **salt marshes benefit commercial and recreational fisheries**.
- Undersized culverts and other structures that restrict tidal flooding of salt marshes interfere with foraging of small fish, which swim across the flooded marsh to feed on invertebrates.
- Some fish do not swim through culverts.
- Consequently, undersized culverts reduce the amount that marshes contribute to coastal food webs and fisheries.

Fish Diversity

Fifty-five fish species have been documented in the salt marshes and estuaries at Wells National Estuarine Research Reserve in Wells, Maine.

Abundant | Common | Rare

Sea lamprey (*Petromyzon marinus*)	Rare
American eel (*Anguilla rostrata*)	Abundant
Blueback herring (*Alosa aestivalis*)	Common
Alewife (*Alosa pseudoharengus*)	Abundant
American shad (*Alosa sapidissima*)	Rare
Atlantic menhaden (Pogy) (*Brevoortia tyrannus*)	Rare
Atlantic herring (*Clupea harengus*)	Common
Atlantic salmon (*Salmo salar*)	Rare
Brown trout (*Salmo trutta*)	Common
Brook trout (*Salvelinus fontinalis*)	Common
Atlantic cod (*Gadus morhua*)	Rare
Fourbeard rockling (*Enchelyopus cimbrius*)	Rare
Atlantic tomcod (*Microgadus tomcod*)	Common
White hake (*Urophycis tenuis*)	Rare
Red hake (*Urophycis chuss*)	Rare
Pollock (*Pollachius virens*)	Common
Common mummichog (*Fundulus heteroclitus*)	Abundant
Banded killifish (*Fundulus diaphanous*)	Common
Striped killifish (*Fundulus majalis*)	Rare
Atlantic silverside (*Menidia menidia*)	Abundant
Inland silverside (*Menidia beryllina*)	Rare
Fourspine stickleback (*Apeltes quadracus*)	Abundant
Threespine stickleback (*Gasterosteus aculeatus*)	Abundant
Blackspotted stickleback (*Gasterosteus wheatlandi*)	Common
Ninespine stickleback (*Pungitius pungitius*)	Abundant
Northern pipefish (*Syngnathus fuscus*)	Common
Striped bass (*Morone saxatilis*)	Common
White perch (*Morone americana*)	Rare
Bluefish (*Pomatomus saltatrix*)	Rare
Spotfin butterflyfish (*Chaetodon ocellatus*)	Rare
Cunner (*Tautogolabrus adspersus*)	Rare
Striped mullet (*Mugil cephalus*)	Rare
Northern sennet (*Sphyraena borealis*)	Rare
Snake blenny (*Lumpenus lumpretaeformis*)	Common
Radiated shanny (*Ulvaria subbifurcata*)	Common
Rock gunnel (*Pholis gunnellus*)	Common
Sand lance (*Ammodytes americanus*)	Common
Atlantic mackerel (*Scomber scombrus*)	Rare
Butterfish (*Peprilus tricanthus*)	Rare
Grubby sculpin (*Myoxocephalus aeneus*)	Common
Longhorn sculpin (*Myoxocephalus octodecimspinosus*)	Rare
Slimy sculpin (*Cottus cognatus*)	Rare
Lumpfish (*Cyclopterus lumpus*)	Rare
Seasnail (*Liparis atlanticus*)	Rare
Windowpane (*Scopthalmus aquosus*)	Rare
Winter flounder (*Pseudopleuronectes americanus*)	Common
Golden shiner (*Notemigonus crysoleucas*)	Rare
White sucker (*Catostomus commersoni*)	Rare
Pumpkinseed (*Lepomis gibbosus*)	Rare
Bluegill (*Lepomis macrochirus*)	Rare

Ecological Linkages

Salt marshes are connected to other habitats along the coast and offshore. They play an important role in supporting animals and plants that live outside the marsh. This aerial photograph of Harpswell Sound, Maine, indicates potential linkages.

A Salt marsh

Salt marsh fringes an inlet between a landfill (brown clearing above A) and a growing residential development. The marsh may filter contaminants, sediments, and excess nutrients running off the land before they pollute the Sound. © Peter H. Taylor

B Clam flat

Clams in these mud flats may benefit from clearer water due to the marsh's filtering of sediments, and they may eat food particles coming from the marsh. © Peter H. Taylor

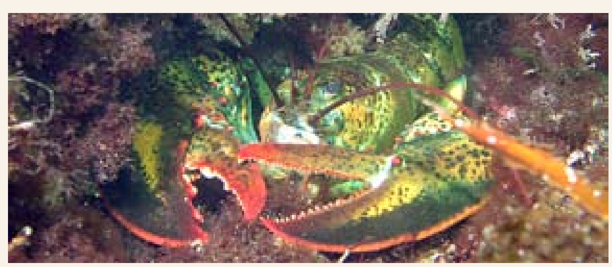
C Rockweed bed

Fish in these rockweed beds may swim into the marsh to feed at high tide. Snails, crabs, and other animals may eat detritus flushed from the marsh. © Peter H. Taylor

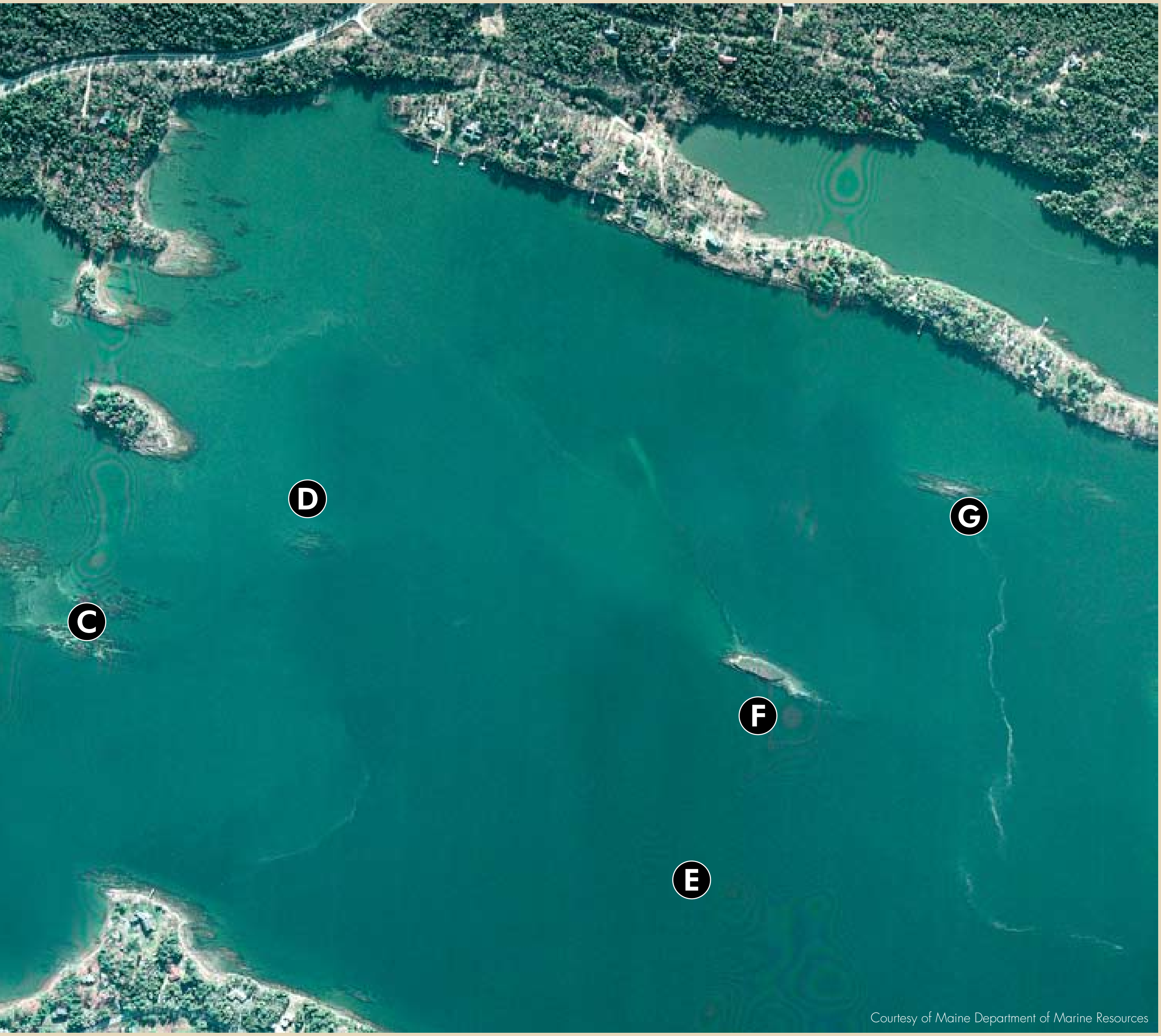
D Eelgrass bed

Eelgrass thrives in clear water without excess nutrients, and thus may benefit from the marsh's filtering. NOAA

E Rocky bottom



The salt marsh may supply food and clean water to nearby lobstering areas. Also, striped bass and other open-water fish feed in salt marshes. © Becca Toppin



F Bird staging and feeding area

Seabirds that use this island, such as the common tern, may depend directly or indirectly on the salt marsh for their food.
Andreas Solberg

G Seal haul-out and feeding area

Seals feed on fish among eelgrass and rockweed beds, and rest on this rock. Swimming offshore or along the coast, they connect the salt marsh's food web to the larger marine system.

Top left: Clapper rail T. Leahy. bottom left: Canada goose USFWS, Glen Smart. right: Snowy egret USFWS, Ryan Hagerty.

Birds That Use Tidal Marshes

Many birds use salt marshes for feeding, nesting, and shelter. This list provides examples.

Nest in high marsh and feed in high and low marsh (*S. alterniflora*, pools, and pannes)
- Saltmarsh sharp-tailed sparrow
- Nelson's sharp-tailed sparrow
- Willet
- American black duck
- Clapper rail (rare)
- Canada goose
- Mallard

Nest in maritime shrub transition zone, feed in marsh
- Common yellowthroat
- Yellow warbler
- Eastern kingbird
- Gray catbird
- Common grackle

Nest in cattail or *Phragmites*
- Swamp sparrow
- Marsh wren
- Virginia rail
- Red-winged blackbird

Nest on offshore islands, feed in salt marsh
- Great egret
- Snowy egret
- Glossy ibis
- Great blue heron
- Little blue heron
- Common tern

Nest in cavities or next boxes, feed in salt marsh
- Tree swallow

Top: **Piping plover** USFWS, Gene Nieminen. bottom left: **Willet** USFWS, Gary Kramer. bottom right: **Least tern** USFWS, S. Maslowski.

Nest on beaches, feed in salt marshes, beaches, and mudflats

Least tern
Piping plover

Feed in salt marshes during migration

Semipalmated sandpiper
Least sandpiper
Short-billed dowitcher
Greater yellowlegs
Lesser yellowlegs
Savannah sparrow
Eastern meadowlark
Northern harrier

Winter in salt marshes

Snow bunting
Snowy owl

Use tidal creeks, bays, and mudflats

Red-breasted merganser (fall and winter)
Osprey
Great blue heron
Common loon (fall and winter)
Semipalmated plover (migration)
Gulls

Summary of Salt Marsh Ecological Functions

- **High primary productivity** rivals agricultural systems. Formation and accumulation of detritus fuels food webs inside and outside the marsh.
- Source of **food for shellfish and finfish**, including commercially and recreationally important species.
- **Nursery for some young fish**.
- **Filtration of water** to remove sediments, nutrients, and contaminants. **Recycling of some nutrients** in organic form to coastal food webs.
- Accumulation of peat as sea level rises, which elevates shorelines and stores carbon, two critical components to **buffer against climate change** and coastal submergence.
- **Foraging, staging, and sheltering habitat** for many bird and mammal species.
- **Protection of uplands** and **prevention of property damage**.
- **Enjoyed by people** for boating, hunting, canoeing, kayaking, hiking, sightseeing, bird watching, and the arts.
- Often used as **outdoor classrooms** for students and nature enthusiasts.
- Able to **self-maintain ecological functions** and values listed above as long as humans do not disrupt intrinsic processes.

Illustration © Barbara Harmon

Life in a Northeastern Salt Marsh

Shown above: Great blue heron...Green heron...Canada geese...Belted kingfisher...Black duck...Saltmarsh sharp-tailed sparrow...Willet...Osprey...Northern harrier...Smooth cordgrass...Salt meadow hay...Seaside lavender...Glasswort...Fiddler crab...Horseshoe crab...Periwinkle snail...Softshell clam...Ribbed mussel...Clamworm...Algae and diatoms...Zooplankton...American eel...Killifish...Atlantic silversides...Raccoon...Green darner (dragonfly)...Red fox

Boston metropolitan area, late 1990s

"…There are at present about 3240 acres of city real estate in an area that contains old Boston, Roxbury, and Back Bay…When the Puritans arrived to settle this area, there existed only 1185 acres of dry land on which to build. Four hundred eighty-five acres of the present 3240 acres were shallow water which was part marsh, part mud and sand flat, and part open water even at low tide. There was a gain of 2055 acres of dry land made by filling the marshes and lowlands."

John and Mildred Teal, 1969
From *Life and Death of the Salt Marsh*

Boston area, late 1700s

Human Impacts and Habitat Restoration

In the last four centuries, New Brunswick and Nova Scotia have lost some 75 percent of their salt marsh habitat (Reed and Smith 1972). Based on historical maps, Bromberg and Bertness (2005) estimated that New England states have lost an average of 37 percent of their salt marshes since 1777. Some 80 percent of salt marshes around Boston have been filled (Bromberg and Bertness 2005) to accommodate expansion of the city, as shown on the opposite page. Many salt marshes around the Gulf of Maine have been filled, drained, or diked, permanently changing wetlands to dry land. In practical terms, most of these marshes are lost forever.

Other human impacts on salt marshes can be reversed. Undersized culverts beneath roads and railways degrade marsh health by restricting tidal flow. Often they were installed decades or even centuries ago. Today many could be removed or enlarged. The natural functions of salt marshes often can be restored, if tides are allowed to flow more naturally.

Cumulative Impacts

Some marshes have all the luck. Rumney Marsh (above) has been degraded by nearly three centuries of ditching, draining, filling, tidal restrictions, pollution, and invasive species. Some of the impacts are indicated on the map and described to the right.

People's activities influence all salt marshes around the Gulf of Maine. Some marshes are severely affected—like Rumney Marsh—while others might seem pristine. Usually impacts accumulate little by little, not all at once. A road is constructed across the marsh with a small culvert, blocking the tides. Upland areas give way to homes and factories. Sections of marsh are filled to make room for more development. Seawalls are built to stop erosion. Added together, the cumulative impacts can destroy a salt marsh.

In addition, one impact can magnify the effects of another. For example, cutting down a buffer strip of trees at the marsh's edge might suddenly expose the marsh to more herbicides and fertilizers washed by rainwater from surrounding residential areas.

Addressing cumulative impacts usually requires a long-term, incremental approach. However, scientists have found that removing tidal restrictions provides tremendous benefits and can be done relatively simply.

Types of Human Impacts

This aerial photograph shows Rumney Marsh and environs in Revere, Massachusetts. The 1,800-acre marsh is one of the most important centers of biodiversity in coastal Massachusetts, and the state has designated it as an Area of Critical Environmental Concern. Nearly every class of human impacts on salt marshes occurs at this single site. Some instances are marked with letters.

- **A** **Filled marsh**: Areas filled with soil or debris, creating upland. *See page 20.*
- **B** **Tidal restrictions**: Roads, railroads, and undersized culverts that block the tides. *See page 21.*
- **C** **Invasion by common reed (*Phragmites australis*)**: Aggressively invasive plant that reduces wildlife value of marsh. *See page 24.*
- **D** **"Hardening" of marsh border and loss of vegetated buffer**: Seawalls, riprap, and other structures that block natural inland migration of marsh with sea-level rise. Lack of vegetation, which naturally filters out pollutants, between development and edge of marsh. *See page 24.*
- **E** **Impervious surfaces and runoff of freshwater and pollutants**: Pavement, developed areas, and agricultural fields that increase input of water and pollutants from land into marsh. *See page 25.*

Dikes that convert marshes to farmland: None at Rumney Marsh, but common in New Brunswick and Nova Scotia. *See page 26.*

See page 28 for a case study about habitat restoration efforts at Rumney Marsh.

"The Council's objective is to support restoration of natural tidal regimes—and thus the functions and values of tidal wetlands—to intertidal habitats through the removal of selected dikes, fill, water control structures, and inadequately sized culverts."

Gulf of Maine Habitat Restoration Strategy

IMPACT
Filled marshes

Background: Countless acres of salt marsh were once filled with dirt, rocks, waste, or dredge material, converting marsh to non-tidal wetlands and upland. The practice provided a way to dispose of unwanted fill material and created land for development and agriculture.

Effects: Artificial raising of the marsh surface eliminates tides for marsh plants, fish, and birds. The invasive common reed, *Phragmites australis*, often can become established in filled areas and then invade adjacent healthy marsh.

Restoration Options

- Remove fill and grade the terrain to elevations slightly below that of surrounding marsh; add creeks and pools
- Revegetate the area using plantings, soil seed banks, and wrack seed banks, or rely on natural revegetation (requires at least 10 years)
- Monitor the plant community and remove invasive species before they spread

Benefits of Restoration: The return of tidal conditions should allow the area to function once again as salt marsh.

Other Considerations: Some marsh functions may return quickly, while others may take years or decades. Another disposal site must be found for the removed fill.

Fishermens Bend marsh restoration site in Winthrop, Massachusetts. The marsh had been filled and used as a dumping ground (top). Restoration involved removing fill and trash and regrading the marsh (middle). The restored marsh (bottom) was a vast improvement. Massachusetts Office of Coastal Zone Management

Drowning Under Rising Seas?

Climate change has important implications for salt marshes—and for efforts to protect, restore, and monitor them (Frumhoff *et al.* 2007, Slovinsky and Dickson 2006, Scavia *et al.* 2002). The most direct threat of climate change is the rising sea level. According to the Intergovernmental Panel on Climate Change (2007), sea level could rise 2 to 2.5 feet (51 to 76 centimeters) by 2100. Normally, salt marshes have some capacity to shift inland as sea level rises. Problems could develop, however, in places where seawalls and other structures stand in the way. Unable to shift inland, blocked marshes could drown. Limiting construction on land adjacent to salt marshes is one long-term solution to help marshes survive sea-level rise.

The risk of salt marshes drowning is tempered by marshes' natural tendency to accumulate soil upward as sea level rises. As long as the rate of sea-level rise is not too fast, many salt marshes might keep their heads above water. One key factor is the amount of sediment coming from rivers into salt marshes. Sea level may rise unusually fast over the coming century, and scientists have scant data to determine if marshes are accumulating soil quickly enough to keep pace.

An aerial photo (top) shows the location of a culvert under Bridge Street in Dennis, Massachusetts. The culvert restricts tidal flow into the marsh area to the left, affecting the environmental conditions and types of plants living there. Differences in vegetation make the restricted and unrestricted areas have different colors in this aerial view. Three ground-level photos show the restricted marsh (left), Bridge Street culvert (center), and unrestricted marsh (right). Massachusetts Office of Coastal Zone Management

IMPACT
Tidal restrictions

Background: Hundreds of roads and rail lines have been constructed across salt marshes in the Gulf of Maine, often with undersized culverts and bridges that limit the flood and ebb of the tides in the marsh. Debris in culverts can further reduce tidal flow. Tide gates installed to regulate tidal flooding may be too restrictive or may become locked in closed position.

Effects: Impaired tidal flooding leads to changes in plant community composition, salinity, water quality, sediment characteristics, and animal populations.

Restoration Options

- Enlarge or add culverts and bridge spans
- Remove or improve tide gates
- Clean out debris in culverts and implement ongoing maintenance
- Identify and remove downstream tidal restrictions

Benefits of Restoration: When tidal restrictions are eliminated, physical conditions in the salt marsh may return to approximately normal. This allows the reestablishment of plant and animal communities.

Other Considerations: Restoration of tidal flooding can sometimes result in excessive flooding of vegetated marsh areas because the peat may have subsided during the period of tidal restriction. Excessive flooding can kill marsh vegetation and lead to erosion of the marsh. Therefore, project planning should include analysis of marsh and surrounding elevations above and below the tidal restriction relative to the potential tidal range. It is also important to consider the potential for higher amplitude tides in the marsh to flood the adjoining properties and human structures that were added while tides were restricted.

Restricting Tidal Flow Affects Ecosystems

Restricted tidal flow caused by undersized culverts or other structures affects not just the salt marsh but the entire coastal ecosystem. Tidal restrictions:

- Reduce the foraging area available to fish because there is less flooding of the marsh surface
- Block entry of marine fish into marshes if culvert openings are not consistently submerged
- Constrain waterborne export of nutrients, detritus, and forage fish from salt marshes
- Lower salinity in marsh, promoting spread of exotic plants that undermine ecological functions and pose a fire hazard
- Reduce floodwater storage capacity and amplify impacts from storm surges
- Impair peat accretion by cutting off sources of sediment and regular flooding, which increases the threat that the rising sea level will submerge the marsh and that erosion and flooding will harm marsh habitat and uplands

Small culverts (top) can be replaced with large culverts (bottom) to restore tidal flow to salt marshes.

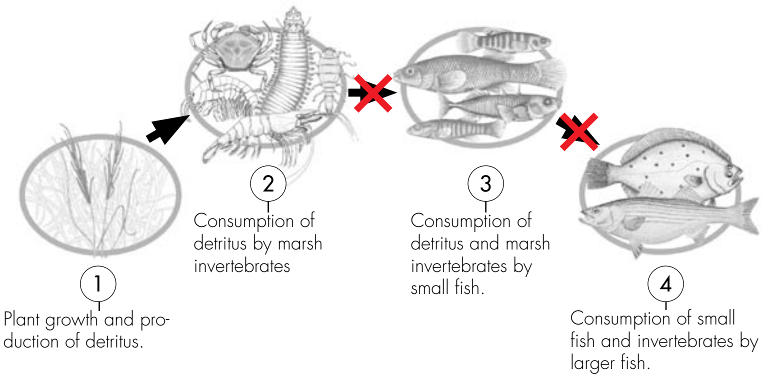
Massachusetts Wetlands Restoration Program (top), Jon Kachmar (bottom)

Methods for Restoring Tidal Flow

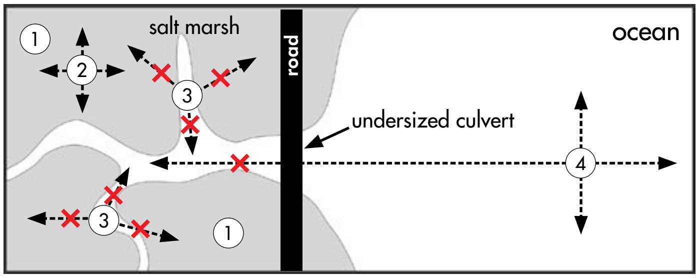
Many of the remaining salt marshes around the Gulf of Maine could be restored to approximately their natural state and function. Often this could be accomplished fairly easily and without interfering with present-day land uses and human activities. Habitat restoration experts have developed a toolbox of solutions that involve addition or enlargement of culverts, removal of tide gates, and excavation of dikes and fill. Exact remedies depend on site-specific conditions. A salt marsh might have multiple road crossings, dikes, and filled areas that need to be addressed, or it might have just a single culvert that needs to be enlarged.

Improperly Designed Culverts Break the Food Web Relay

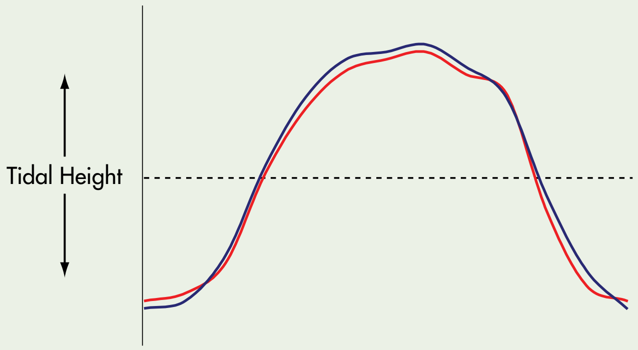
The salt marsh food web relay, first shown on page 8, relies on adequate connections between the salt marshes, tidal creeks, and offshore waters. Improperly designed culverts disrupt this relay by not allowing fish to feed on the marsh due to restricted tidal flooding or physical barriers, and by severing connections to offshore waters.



In this figure, arrows represent the movement of fish and invertebrates in a salt marsh at high tide. Their travels create links between the marsh's food web and the ocean's food web. Red Xs indicate links that are broken when culverts restrict tidal flooding in a marsh.



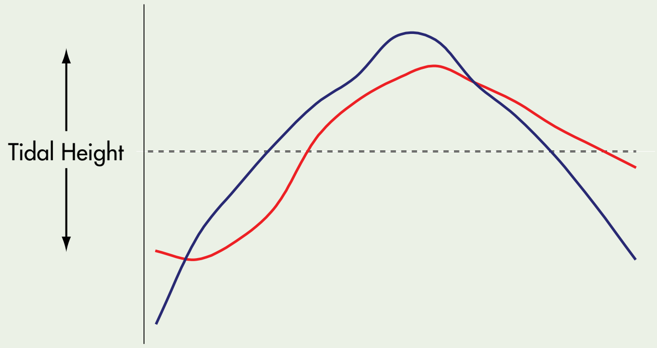
How do culverts affect tides in a salt marsh?



UNRESTRICTED CROSSING

This graph is indicative of an unrestricted crossing because the hydrographs on the seaward and inland sides of the crossing are nearly identical.

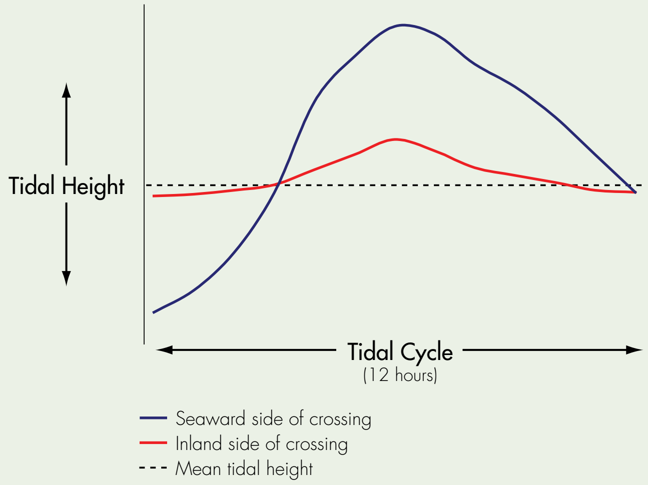
Peter H. Taylor



MODERATELY RESTRICTED

This graph is indicative of a perched crossing that is moderately restrictive. The graph shows a delayed reaction to tidal changes as water must reach the height of the crossing before flooding the inland side. Water levels on the inland side remain higher than the seaward side because water gets trapped once water levels drop below the level of the crossing.

Vivian Kooken



SEVERELY RESTRICTED

This graph is indicative of a severe tidal restriction, perhaps caused by an undersized or collapsed culvert. Though the tidal peak occurs at the same time, the tidal height is greatly diminished on the inland side because water cannot move freely from one side of the crossing to the other.

Massachusetts CZM

Source: Carlisle, B.K., A.M. Donovan, A.L. Hicks, V.S. Kooken, J.P. Smith, and A.R. Wilbur. 2002. *A Volunteer's Handbook for Monitoring New England Salt Marshes.* Massachusetts Office of Coastal Zone Management, Boston, MA.

"Often salt marsh restoration could be accomplished fairly easily and without interfering with present-day land uses and human activities."

Stand of common reed, *Phragmites australis*, encroaching on a salt marsh. Inset: Close-up of flowering structure of the common reed. Ethan Nedeau (marsh), Peter Taylor (inset)

IMPACT
Invasion by common reed (*Phragmites australis*)

Background: *Phragmites* typically invades areas where salinity has declined because of tidal restrictions, increased freshwater runoff, and/or buildup of fresh water on the marsh due to hydrological blockage. Disturbance of the soil and plants along the upland-marsh border raises the risk of invasion.

Effects: When *Phragmites* invades a salt marsh, it radically changes the ecological conditions. It grows in dense stands that exclude other plant species, offers little value to wildlife, increases peat accumulation and therefore marsh elevation, and creates a fire risk.

Restoration Options
- Raise soil salinity by removing tidal restrictions and fill, and by reducing/redirecting runoff
- Cut and remove *Phragmites* stems and rhizomes
- Use appropriate herbicides
- Revegetate with appropriate marsh plants

Benefits of Restoration: Removal of *Phragmites* improves health of salt marsh plant and wildlife communities, and it reduces fire risk.

Other Considerations: Presence of *Phragmites* is often a symptom of other human impacts, such as tidal restrictions, that may need to be addressed to restore the habitat.

IMPACT
"Hardening" of upland-marsh border and loss of vegetated buffer

Background: Land development practices often include construction of roads, seawalls, parking lots, buildings, and other hard structures at the upland-marsh edge without provision for a vegetated buffer.

Effects: Normally, continual build-up of peat allows salt marshes to expand gradually upward and inland in response to rising sea level. Where hardening of the marsh-upland boundary blocks inland migration, salt marshes will eventually be lost under the rising sea. Lack of buffers may increase the impacts of pollutants and nutrients on the marsh, encourage invasive species, decrease nesting habitat (Hanson and Shriver 2006), and reduce habitat quality.

Restoration Options
- Remove structures along the upland-marsh edge that block inland migration of marshes
- Avoid development of new structures along the salt marsh edge
- Require a vegetated buffer on uplands surrounding marshes and restore lost buffers

Benefits of Restoration: Long-term persistence of salt marshes despite rising sea level. Preservation of the high-diversity plant communities at the upper marsh edge.

Other Considerations: Although laws protect salt marshes from direct impacts, development of adjacent land is not regulated as strictly.

Roads, parking lots, and buildings around a salt marsh can increase the amount of fresh water and pollutants that enter the marsh, especially where little or no vegetation is present along the shoreline to act as a buffer. Also, when development extends all the way to the marsh's edge, it leaves nowhere for the marsh to migrate as the sea level rises. MA Executive Office of Environmental Affairs

IMPACT
Increased freshwater runoff and water pollution

Background: Development and agricultural activity in the watershed can increase freshwater runoff, nutrients, sediments, toxic contaminants, and disease-causing agents entering salt marshes.

Effects: Pollutants affect the health of fish, shellfish, birds, wildlife, and humans. Soil disturbance and decreased salinity enable invasion by the common reed, *Phragmites australis*.

Restoration Options

- Minimize impervious surfaces, erosion, fertilizers, and water contamination in the watershed
- Increase storm-water management and land-use practices that reduce runoff and pollution
- Create and maintain forested buffers along marsh-upland edges

Benefits of Restoration: Improvement in all-around health of salt marsh allows it to provide its natural functions as part of the coastal ecosystem and help to sustain fisheries.

On Cape Cod, a vegetated buffer (middle of photograph) helps protect a salt marsh from the negative impacts of developed land. MA Executive Office of Environmental Affairs

Other Considerations: These options have wide-ranging benefits, not just for salt marshes, and they complement the natural capacity of salt marshes for removing pollutants.

IMPACT
Dikes

Background: In New Brunswick and Nova Scotia, dikes have been built across the seaward edges of vast areas of marsh. These tide-blocking structures allow agriculture on the rich soils.

Effects: Loss of the salt marsh ecosystem. At some sites, the land is no longer farmed, but dikes prevent tidal flooding and return of salt marsh functions.

Restoration Options

- If no present agricultural use of diked area, grade soil to appropriate elevation and dig tidal channels and creeks; reestablish tidal flow by removing tidal blockages; vegetate with salt marsh species

Much of the agricultural land along the Bay of Fundy was formerly salt marsh. It was converted to farmland with dikes and drainage systems. Brian Atkinson/Communications New Brunswick

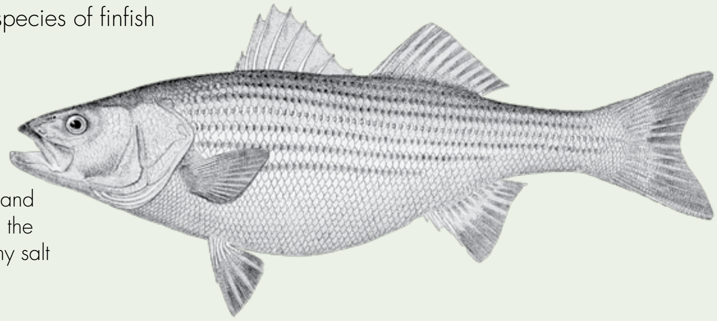
Benefits of Restoration: Restore marsh ecosystem.

Other Considerations: Diked areas may be below adjacent salt marshes due to drying of the soil, subsidence of the Earth's crust, and rising sea levels. When tidal flooding is restored, it may need to be increased in phases up to the natural tidal range. Otherwise, the marsh may drown under excess flooding.

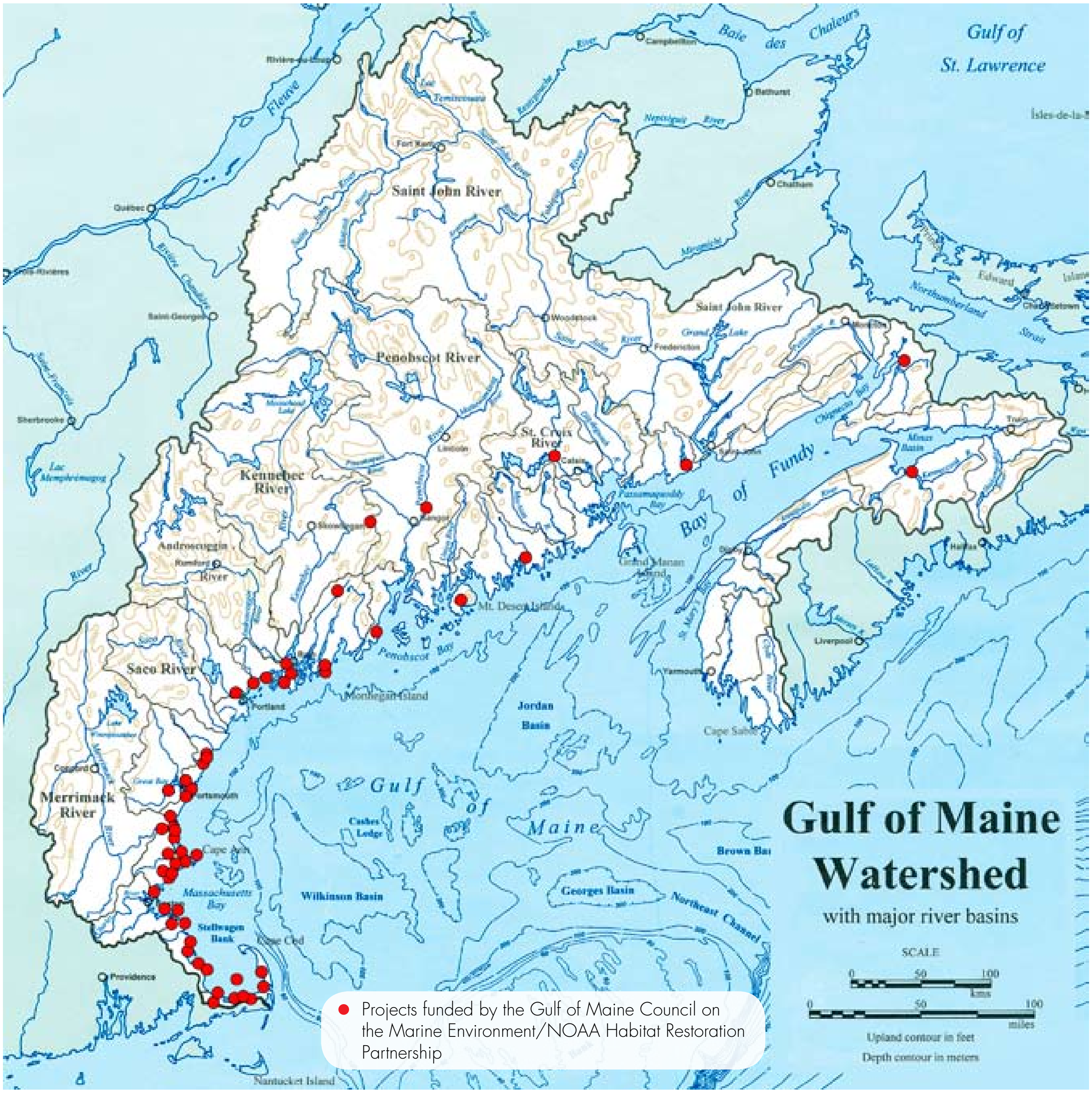
Restoration to Enhance Fisheries

Restoration projects intended to enhance fish habitat should:

- Maximize marsh/water edge habitat
- Increase the area of regularly flooded marsh
- Construct intertidal rivulets as marsh access corridors for fish
- Increase the amount of subtidal habitat available for forage and predaceous species of finfish
- Consider needs and restoration opportunities for anadromous and catadromous fish species
- Use current scientific knowledge and understanding of individual species' habitat requirements
- Consider influence of creek and channel size on distribution and abundance of fish within the marsh



The striped bass, an ecologically and economically important species in the Gulf of Maine that relies on healthy salt marshes and coastal ecosystems.
NOAA Archives



Restoration in Action

Since 1990, government agencies have initiated more than 100 salt marsh restoration projects in the Gulf of Maine (Cornelisen 1998). State, provincial, and federal agencies are collaborating with local governments and non-government organizations to prioritize and implement salt marsh restoration projects.

Partners in Restoration

The Gulf of Maine Council on the Marine Environment/National Oceanic and Atmospheric Administration (NOAA) Habitat Restoration Partnership was established in 2001 to provide grants for restoration projects in the Gulf of Maine and its watershed. Each year, a team of representatives from Massachusetts, New Hampshire, Maine, and the NOAA Restoration Center reviews grant proposals and selects projects on a competitive basis. Locations of habitat restoration projects funded by the Partnership are shown on the map above. For information, including project overviews, grant opportunities, and how to plan and implement a restoration project, visit the Gulf of Maine Habitat Restoration Web Portal (http://restoration.gulfofmaine.org).

Habitat Restoration Case Studies

For more information about habitat restoration projects in the Gulf of Maine region, go to http://restoration.gulfofmaine.org/projects/factsheets

Oak Island Salt Marsh Restoration

Revere, Massachusetts

Rumney Marsh is a 1,800-acre coastal wetland complex on the Massachusetts coast north of Boston (see also pages 18 and 19). The state designated Rumney Marsh as an Area of Critical Environmental Concern, and the U.S. Fish and Wildlife Service identified it as a significant center of biodiversity. However, it has been severely degraded by residential and industrial development, filling, and construction of roads and railroads. Local, state, and federal agencies such as the Massachusetts Wetlands Restoration Program, U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, and City of Revere have restored approximately 120 acres of the marsh.

Recent efforts have focused on restoring a 30-acre section, called Oak Island Marsh, lying between railroad tracks and highway Route 1A. An existing 60-inch culvert was cleaned, repaired, and stabilized, and a new 72-inch culvert was added under the railroad tracks to increase tidal flow. Self-regulating tide gates (SRTs) were installed on the culverts because of concerns about flooding in adjacent residential areas.

The project was intended to reduce the spread of the invasive common reed (*Phragmites*) in Oak Island Marsh. Restoration of the estuarine habitat could provide feeding and breeding areas for important bird, fish and invertebrate species.

Bridge Creek

Barnstable, Massachusetts

Bridge Creek flows to Cape Cod Bay through more than 40 acres of coastal wetlands. More than a century ago, Route 6A and a railway line were built across Bridge Creek and the salt marsh. Two culverts were installed to convey the creek beneath the highway and railroad, but they were too small and sharply cut the flow of tides. Over time, the upstream marsh showed signs of severe ecological degradation.

In the 1990s, a study identified Bridge Creek as a priority for habitat restoration, but the active rail line made it impractical to replace the railway culvert. When the railroad closed the line for repairs in March 2003, however, the Town of Barnstable and the Massachusetts Wetlands Restoration Program took advantage of the opportunity to install a larger culvert without disrupting rail service. After extensive planning, they removed the small pipe under the tracks. In its place, they installed a ten-foot-by-ten-foot square concrete culvert.

Next the project team turned its attention to the culvert under the highway. In May 2005, the team replaced the undersized culvert with another ten-foot-by-ten-foot concrete culvert. The natural flow of tides returned to the 40-acre marsh for the first time in more than 100 years. More than 38 groups were partners in the Bridge Creek restoration project.

Drakes Island Marsh Restoration

Wells, Maine

The Wells National Estuarine Reserve covers 1,600 acres of tidal marshland and uplands in the Little and Webhannet River watersheds of southern Maine. Within the Reserve lies Drakes Island marsh, a 77-acre salt marsh that historically was diked and used as a hayfield and cow pasture for over a century.

For many years, a small culvert under Drakes Island Road was the only connection from the marsh to the Gulf of Maine, but a flap gate on the culvert excluded salt water. Even after the flap gate broke in 1988, the culvert was too small for tides to flow freely. By causing lower salinity in the marsh, the culvert enabled the common reed to invade, making the habitat unsuitable for fish such as Atlantic silversides and sticklebacks. In addition, the undersized culvert did not allow adequate drainage of the marsh after heavy rainstorms, and nearby homes often flooded.

To promote the health of the marsh and reduce flooding potential, the Wells Reserve and the Town of Wells replaced the undersized culvert with a larger culvert. One challenge was that the elevation of the marsh surface had subsided several feet because of the historical uses and effects of the flap gate. To prevent the marsh from drowning, a self-regulating tide gate (above) was installed on the new culvert, allowing water levels to be controlled. Scientists from the Wells Reserve are studying changes in Drakes Island marsh to determine the outcomes of the habitat restoration project.

Cheverie Creek

Cheverie, Nova Scotia

Cheverie Creek is a small, tidal river that flows into the Bay of Fundy. Prior to 2005, an undersized culvert below a causeway across the creek limited tidal flow into more than 30 hectares of marsh. Roadway debris and damage at both ends of the culvert further constricted the flow of water.

Beginning in 2001, the Ecology Action Centre (EAC) in Halifax, Nova Scotia, led efforts to replace the culvert. The project site was selected because a large area of marsh would benefit at relatively little expense. In addition, the project was expected to enhance safety, as the old culvert created dangerous whirlpools and put the highway at risk of flooding.

In 2002 and 2003 before replacing the culvert, the habitat restoration team collected baseline data on hydrology, soil, sediment, vegetation, fish, mosquitoes, and birds. They also collected data in a nearby marsh that did not have tidal restrictions. The baseline data will allow changes at Cheverie Creek over time to be detected and compared.

In 2005, the EAC removed the old 1.5-meter (5-foot) wooden culvert at Cheverie Creek and replaced it with an aluminum arch measuring 9.2 meters (31 feet) across. The new culvert restored tidal flow to the salt marsh and reestablished the ecological connection between the marsh and the Gulf of Maine. Outreach and school-based programs engaged the local community throughout the project.


Ethan Nedeau

Salt Marsh Monitoring

Much information that would be invaluable for management of the region's salt marshes is not available, such as the original extent of salt marshes, historical losses, and current acreage that is healthy or is degrading due to indirect impacts like tidal restrictions. Management and restoration efforts could be improved through understanding the condition of the region's marshes and the changes that they are experiencing due to climate change, rising sea levels, increased freshwater runoff, and invasive species.

Since the early 1990s, salt marsh restoration projects have become increasingly common in the Gulf of Maine. Most experts consider ecological monitoring to be an integral component of habitat restoration. Indeed, many restored, impaired, and reference salt marsh sites in the region have been monitored. However, because monitoring has been conducted by many independent organizations with different protocols and objectives, the data are often incompatible or unavailable for sharing and integrative analysis. Despite the common goal of enhancing habitat, coastal decision-makers have not been able to gain a coherent regional perspective on salt marsh health and restoration. The Gulf of Maine Salt Marsh Monitoring Protocol, which was developed by dozens of scientists and managers, now makes that regional perspective attainable, especially when combined with regional initiatives to promote data sharing.

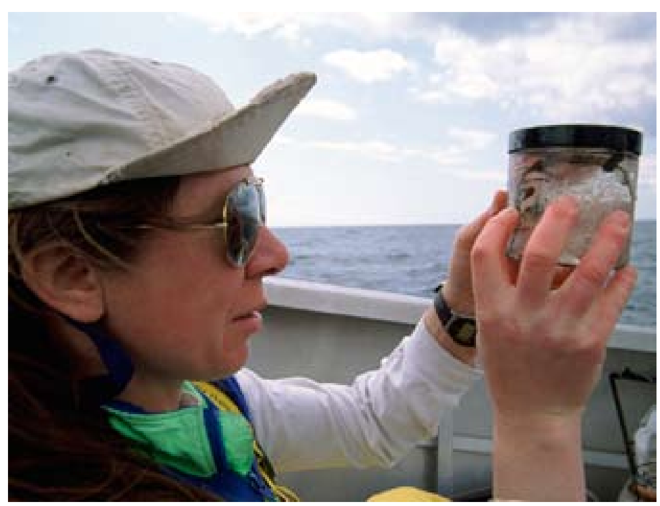
Scientists from the Massachusetts Office of Coastal Zone Management study sediments and invertebrates in a Cape Cod marsh. Ethan Nedeau

Why is Monitoring Needed?

Salt marshes are dynamic places. They change hourly with tides, daily with weather, monthly with seasons, and over years and millennia with changes in sea level and climate. Fish enter salt marshes on flooding tides and depart on the ebb. Migratory birds stop during spring and autumn to feed in salt marshes. The salt marsh plant community shifts in its composition as the physical and ecological conditions change.

Humans are a major agent of change in salt marshes, causing immediate and long-term effects. Disturbances from human activities include the direct impacts of physical alterations such as filling, the indirect impacts of tidal restrictions and land use in the surrounding watershed, and the long-term impacts of a changing global climate. Effects of human activities can be exacerbated by natural disturbances, including severe weather events and biotic, geomorphic, and climatic processes. Collectively, these anthropogenic and natural disturbances produce a multitude of stresses on coastal ecosystems with far-reaching but poorly understood consequences, ranging from degraded habitat structure to major shifts in ecosystem function.

Basic information on the status and trends of salt marshes around the Gulf of Maine and the causes and consequences of change is vital to identify and reverse trends of habitat loss and degradation in the region. It is clear that incorporating long-term change analysis into coastal restoration, management, and conservation is necessary to detect threats to critical habitats, identify sources of problems, and develop management solutions. Current national strategies for comprehensive assessments of natural resources highlight the overwhelming need for an integrated approach to ecosystem monitoring, research, and management (NSTC 1997; CRMSW 2000) and provide a framework for establishing and implementing monitoring of salt marshes in the Gulf of Maine.



Scientist Michele Dionne examines plankton and small fish caught with a towed net at the mouth of a salt marsh at Wells National Estuarine Research Reserve in Maine. Peter H. Taylor

Scientists use a net to collect samples of plankton and fish at the Little River salt marsh in Wells, Maine. Peter H. Taylor

Regional Monitoring Protocol

Regionally coordinated monitoring of impaired, restored, and intact reference marshes will provide an essential cornerstone of an integrated salt marsh assessment and management strategy in the Gulf of Maine. Long-term monitoring will identify changes in marsh extent and ecological condition, reveal sources of disturbance, and show the ecosystem-level effects of human impacts. In addition, it could provide early warning of new threats, allowing proactive management that preserves marshes and reduces the need for restoration in the future.

In 1999, approximately 50 wetland scientists and resource managers from around the Gulf of Maine convened to coordinate regional assessment of salt marsh ecosystem characteristics, management priorities, and restoration outcomes. Under the auspices of the Global Programme of Action Coalition for the Gulf of Maine (GPAC), they developed a comprehensive protocol for standardized monitoring of impaired, restored, and natural salt marshes (Neckles and Dionne 2000). In 2004, scientists revised the protocol to make it more streamlined and cost-effective. The Gulf of Maine Salt Marsh Monitoring Protocol (see pages 34-35) specifies a set of marsh indicators and data-collection techniques to allow assessment of geospatial attributes, hydrology, soils, plants, invertebrates, fish, and birds. The protocol enables the thorough characterization of salt marsh sites. When the data are collected before and after a habitat restoration project, as well as in unimpaired marshes, they can be used to determine the effectiveness of restoration and the degree of natural variability in salt marshes.

Measuring the Outcomes of Restoration

One major goal of monitoring is to measure outcomes of marsh restoration. Do salt marshes recover their natural structure and functions after tidal flooding is restored? How quickly, and how completely? Although people often assume that after a restoration project is implemented nature will do the rest, it is not known yet whether this is true. The definition of successful restoration depends on the goals of the specific project, but usually it means that the species and processes of the restored marsh become more similar to undisturbed salt marshes. Monitoring individual sites and building a regional database will allow scientists to gauge the outcomes of restoration and understand the natural range of variability of salt marshes in the Gulf of Maine.

Monitoring a marsh for at least one year before restoration provides a baseline against which changes can be measured. Then the marsh must be monitored for several years after restoration actions have been implemented. While some characteristics of the

Gulf of Maine Salt Marsh Monitoring Protocol

Implementation follows a tiered approach. **Tier 1:** Basic monitoring of hydrology, soils and sediments, and vegetation Core Variables should occur at all sites. **Tier 2:** Recommended monitoring includes Tier I variables plus one faunal Core Variable (nekton, birds, or invertebrates) wherever possible. **Tier 3:** Intensive monitoring of all Core Variables should occur at a small number of sites. **Tier 4:** Research to diagnose cause-effect relationships should include all Core and Additional Variables.

CORE VARIABLE	DESCRIPTION	SAMPLING METHOD	SAMPLING FREQUENCY[1]
TIER 1: HYDROLOGY			
Hydrology signal	Pattern of water-level change with respect to a reference point	Continuous water-level recorders upstream (impacted/restored) and downstream (reference) for non-ditchplug projects –OR– Permanent wells or piezometers for groundwater level at ditchplug projects only	For tides, one 2-4 week period of operation (before and 1-year after restoration) –OR– For groundwater, at low tide between early and mid-growing season, including spring/neap tides (6 times per year)
Elevation	Marsh-surface elevation at contour intervals of 15 centimeters or less	Contour map OR Hypsometric curve (cumulative frequency distribution of elevation points on marsh surface)	For all projects, once before (plus 1 year after restoration for excavation projects only)
TIER 1: SOILS AND SEDIMENTS			
Pore-water salinity	Parts dissolved salts per thousand (also referenced to Practical Salinity Scale) of soil water collected from 5- to 25-centimeter depths	Groundwater wells, soil cores, or sippers at impacted/restored and reference sites	At low tide between early (April/May) and mid- (July/August) growing seasons, including spring/neap tides (6 times per year)
TIER 1: VEGETATION			
Composition	Identity of all plant species occurring per square meter	Permanent or temporary plots (0.5-1.0 square meter) positioned random-systematically across the entire marsh or stratified by elevation (low marsh, high marsh, and upland edge) along transects running perpendicular to the main tidal channel at >10-meter intervals starting at a random distance within first interval, at impacted/restored and reference sites.	For all projects, at time of maximum standing biomass: mid-July through August (once per year)
Abundance	Percent cover per square meter by species		
Height	Mean height of 3 tallest individuals of each species of concern per square meter in plots (species of concern only)		
Density	Number of shoots per square meter in plots (species of concern only)	Permanent plots established within distinct stands of species of concern	
TIER 2/3: BIRDS			
Density	Number of birds per hectare, by species	*Methods apply to all variables:* 20-minute observation periods in the morning from site-specific vantage points that provide an uninterrupted view of at least a portion of the salt marsh, at impacted/restored and reference sites	For all projects, at high and low tides: 2 times in May/June for breeding season; once per week March-April and October-November for waterfowl migration; once per week in July-September during shorebird migration (minimum 7 times per year April-October)
Guild richness	Number of birds per guild: waterfowl, shorebirds, wading birds, aerial foragers, or passerines		

[1] Before and five consecutive years after restoration except as noted

CORE VARIABLE	DESCRIPTION	SAMPLING METHOD	SAMPLING FREQUENCY[1]
TIER 2/3: NEKTON			
Composition	Identity of each animal sampled	*Methods apply to all variables:* Seine and block nets (0.25-inch mesh) in larger creeks and channels at impacted/restored and reference sites (3 tows, 10-15 meters long per site). Record length, average width, average depth of towed area. AND Throw traps or lift nets in pools and throw traps, lift or ditch nets (all 0.125-inch mesh) in small creeks or ditches at impacted/restored and reference sites (5 pool and 5 creek and/or 5 ditch samples/site). Record length, width, and average depth of sample.	For all projects, at mid-tide during a spring tide in August (once per year)
Species richness	Total number of species represented		
Density	Number of animals per square meter		
Length	Length (fish, shrimp) or width (crabs) of 15-20 individual animals (randomly selected) per species, to nearest 0.5 millimeter		
Biomass	Wet weight of 15-20 animals per species already measured for length		
TIER 2/3: INVERTEBRATES			
Mosquitoes	Number of mosquito larvae and pupae per square meter	Permanent stations in pool/wet areas, with 3 dips of 350-milliliter cup in 3-meter-radius circles, at impacted/restored and reference sites (10 dip stations/site)	For all projects, at low tide, weekly from May-September (12-15 times per year)

ADDITIONAL VARIABLES (TIER 4)

HYDROLOGY

Tidal creek cross-section: Cross-section profiles of major tidal creeks measured at permanent locations
Surface water chemistry: Water quality parameters sampled in main tidal channel: dissolved oxygen, salinity, temperature, and pH
Current profiles: Tidal current in main channel assessed over several tidal cycles

SOILS AND SEDIMENTS

Organic matter: Organic content of 20-centimeter soil cores sectioned into 5-centimeter segments
Sediment accretion rate: Accumulation of inorganic and organic material above a marker horizon over a known time interval
Sediment elevation: Short-term changes in sediment elevation measured with Sediment Elevation Tables
Redox potential: Redox potential at depths of 1 and 15 centimeters
Peat depth: Vertical measure of subsurface peat layer
Sulfides: Concentration of sulfide in pore water

VEGETATION

Photo stations: Panoramic views of entire marsh from permanent stations using several compass bearings
Above-ground biomass: Biomass of above-ground living plant material from additional, randomly positioned quadrat near permanent or temporary quadrat
Stem density: Number of shoots per square meter, by species, within permanent or temporary quadrats
Proportion flowering: Proportion of shoots of each species that are flowering within permanent or temporary quadrats

NEKTON

Biomass: Wet weight of individuals in sample, by species, recorded from trap/net samples
Fish condition: Length/biomass within size classes for species collected in trap/net samples
Fish diet: Gut contents of subsample of fish collected in trap/net samples

BIRDS

Species richness: Total number of avian species represented
Feeding/breeding behavior: Type of behavior (e.g., feeding, roosting, breeding, preening) per observation interval, by species
Habitat suitability link: Habitat types used by bird species (e.g., mud flats, pool, creek, submerged aquatic vegetation, algal mats, marsh zone, etc.)
Small passerines and other cryptic species: 20-minute observation periods from center of 50-meter-radius counting circles established in the salt marsh
Birds in the buffer: 20-minute observation periods from center of 50-m radius counting circles established in the habitat adjacent to the salt marsh
Waterfowl in winter: 20-minute observation periods from site-specific vantage points continued throughout the winter (as long as marsh is ice free)

INVERTEBRATES

Macroinvertebrate density: Number of macroinvertebrates per sample area
Macroinvertebrate richness: Number of macroinvertebrate taxa per sample area

ecosystem such as plant species diversity may recover quickly within a few years, other characteristics such as soil organic content may respond more slowly over decades. A combination of baseline and post-restoration data enables scientists to identify clearly the outcomes of restoration.

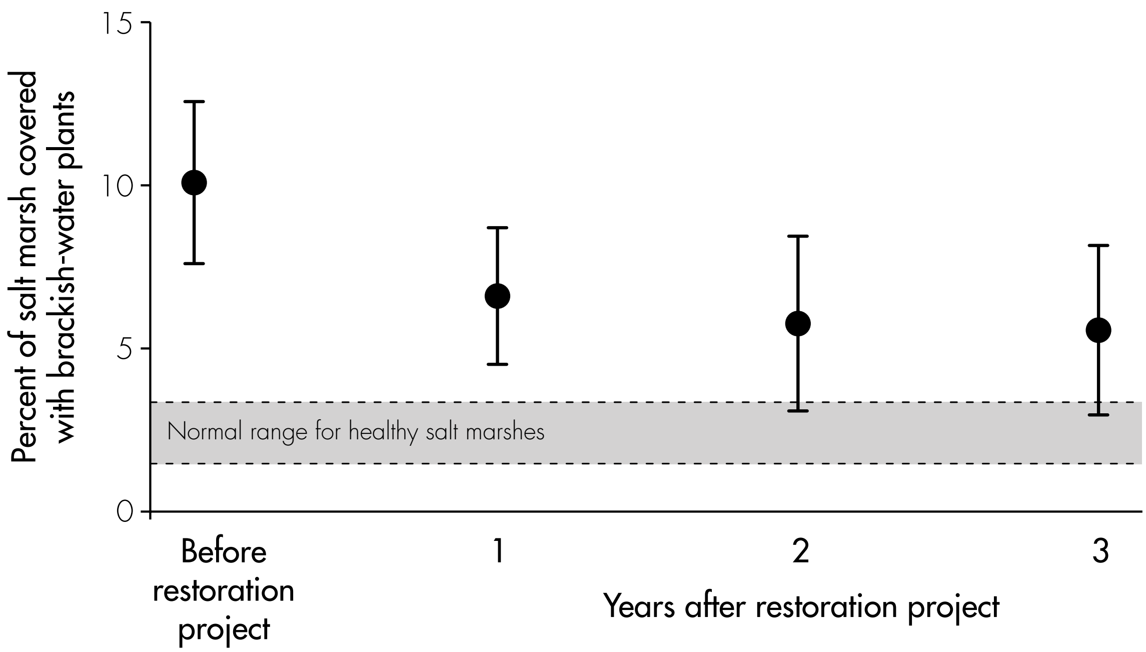
Post-restoration monitoring is also necessary for adaptive management and site maintenance. For example, the monitoring data might reveal that additional restoration is needed, such as removing new invasive plants or digging more channels to deliver tides to distant portions of the site. Monitoring might also indicate that a restored site requires maintenance such as cleaning culverts or re-planting seedlings washed away by storms.

Findings from Regional Data

Five years after the development of the Gulf of Maine Salt Marsh Monitoring Protocol, Konisky *et al*. (2006) compiled monitoring datasets from 36 salt marsh restoration projects—completed or planned—and conducted the first regional analysis of monitoring data and restoration practices. The monitoring data confirmed that salt marshes selected for restoration were degraded relative to reference areas. The degraded sites had lower tidal heights, reduced salinity levels, and plant communities with greater coverage of brackish plant species and less coverage of halophytes. After restoration, physical factors tended to rebound quickly. Tidal flow and salinity, for example, increased within one year. Biological responses were slower and less discernible. Plant communities seemed to shift toward increased cover of halophytes and lower cover of brackish species by three or more years after restoration. Fish and bird communities were indistinguishable among reference, impaired, and restored marshes, but this finding may be attributable to the fact that only a few programs collected data on fish and birds, and their sampling methods were inconsistent.

The study by Konisky *et al*. provides solid support for the widely held beliefs that degraded marshes differ from reference sites in important ecological characteristics and that restoration practices can set degraded marshes on a trajectory toward recovery from human impacts.

Revisions to the Gulf of Maine Salt Marsh Monitoring Protocol include additional acceptable sampling methods and identification of a subset of variables that should be monitored for all restoration projects. Refined and streamlined protocols should lead to greater adherence by monitoring groups.

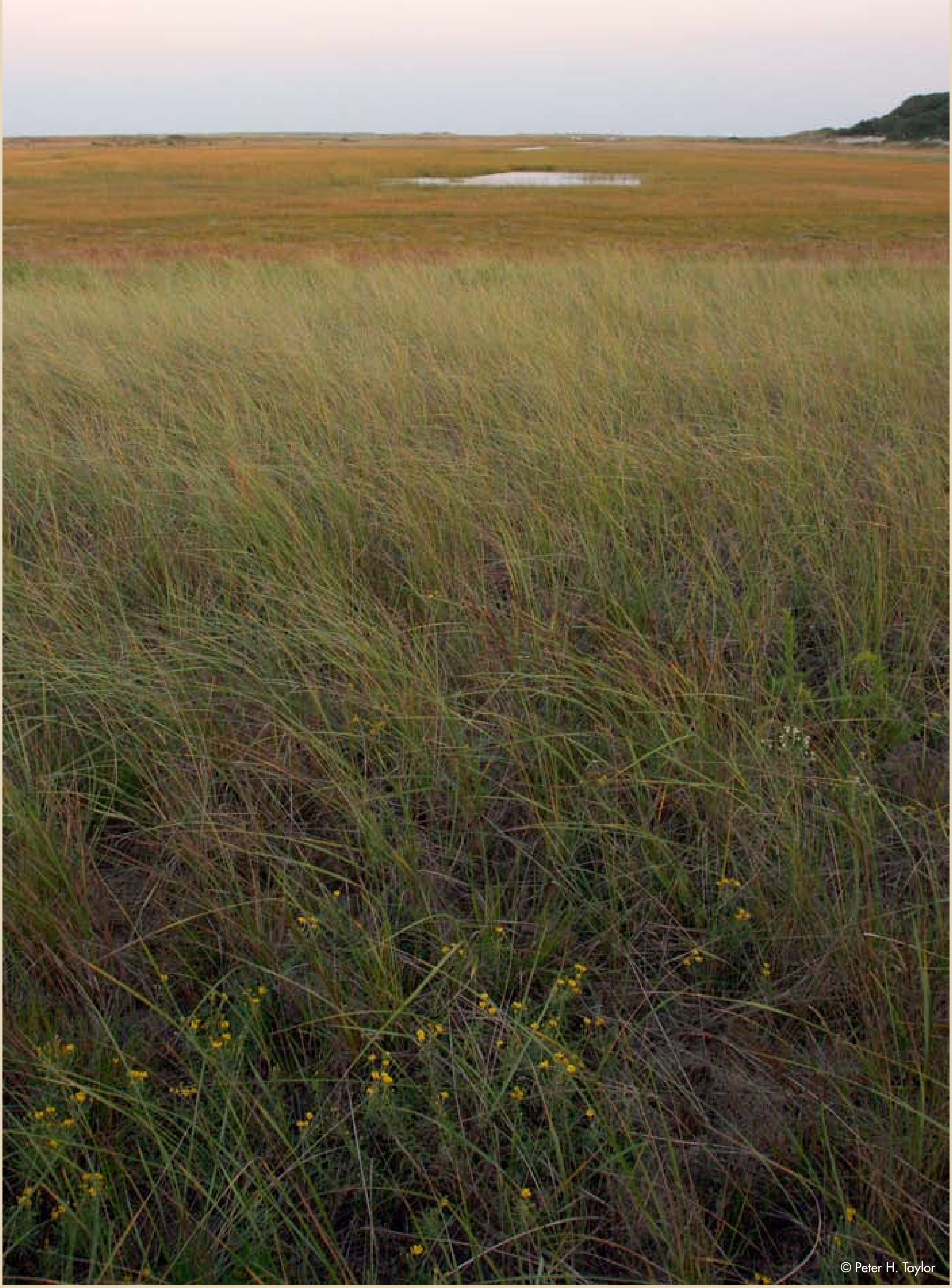


A regional analysis showed that prior to habitat restoration, degraded salt marshes had a higher than normal abundance of plants that favor brackish water, instead of the typical mix of salt marsh plants. Within a few years after habitat restoration efforts, abundance of these plants declined toward levels that are normal for healthy salt marshes. (Konisky *et al.* 2006)

The future is uncertain for the Gulf of Maine's salt marshes because of climate change, coastal development, and other human impacts. Long-term monitoring of salt marshes is necessary to reveal changes and indicate the best solutions for habitat restoration. © Peter H. Taylor

Next steps: Framework for Regional Monitoring

Existing monitoring programs around the Gulf of Maine provide the basis for a regional salt marsh monitoring network that is currently being developed by the Gulf of Maine Council on the Marine Environment. Planning of the framework builds on existing monitoring programs at the state (Massachusetts Office of Coastal Zone Management; New Hampshire Coastal Program), Gulf of Maine (GPAC restoration monitoring protocol), and federal (National Park Service Vital Signs Monitoring Program; NOAA National Estuarine Research Reserve biomonitoring protocol; Environment Canada/Environmental Monitoring and Assessment Network) levels, ensuring that complementary and compatible methods are used. By weaving together existing programs, a cost-effective regional monitoring network for salt marshes could be developed while providing a regional context for individual local assessments. The framework adopts the three-tiered approach of the Coastal Research and Monitoring Strategy (CRMSW 2000). Indicators will be monitored at scales appropriate for identifying and characterizing problems. Remote sensing and automated data collection will be used to sample over large spatial scales, and particular sites within a region will be examined in detail using rapid-assessment methods. Index sites with high spatial and temporal resolution will allow diagnosis of cause-effect relationships.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The Future of Salt Marshes in the Gulf of Maine

All around the Gulf of Maine, initiatives to monitor, manage, and restore salt marshes are gaining momentum. Dozens of habitat restoration projects have been completed and many more are planned and in progress, as recognition of salt marshes' importance continues to grow. Meanwhile, scientific studies are advancing the understanding of salt marsh ecology and the techniques for restoration and monitoring.

However, regional gaps in information, funding, and cooperation need to be addressed for salt marsh restoration and monitoring to fulfill their potential. Numerous partners, including Gulf of Maine Council on the Marine Environment and NOAA, are working to address these gaps. A major priority is to expand and standardize salt marsh monitoring on a regional scale to:

- Provide baseline information about the region's salt marshes
- Identify restoration needs and opportunities
- Measure the success of independent restoration projects and regional programs
- Determine whether the overall extent, distribution, and ecological condition of marshes is changing over time
- Reveal the causes and consequences of changes in salt marshes
- Evaluate science-based approaches for ensuring sustained productivity, use, and enjoyment of salt marsh ecosystems

An expansion of salt marsh restoration and long-term change analysis around the Gulf of Maine in Massachusetts, New Hampshire, Maine, New Brunswick, and Nova Scotia can help ensure that salt marshes support coastal food webs, fisheries, and water quality into the future.

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Links to references are provided at www.gulfofmaine.org/saltmarsh

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http://ciceet.unh.edu

Ecology Action Centre
www.ecologyaction.ca/coastal_issues/coastal_saltmarsh.htm

Great Bay National Estuarine Research Reserve
www.greatbay.org

Gulf of Maine Habitat Restoration Web Portal
http://restoration.gulfofmaine.org

Maine Coastal Program
www.maine.gov/spo/mcp

Maine Sea Grant
www.seagrant.umaine.edu

National Oceanic and Atmospheric Administration Restoration Center
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Linear drainage ditches are strikingly unnatural against the sinuous pattern of tidal creeks in a Barnstable, Massachusetts, salt marsh.
MA Executive Office of Environmental Affairs/MassGIS

View of salt marshes and the surrounding seascape in a Massachusetts salt marsh. MA Executive Office of Environmental Affairs/MassGIS

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