



LONG ISLAND SOUND HABITAT RESTORATION INITIATIVE



TECHNICAL
SUPPORT
FOR
COASTAL
HABITAT
RESTORATION

Submerged
Aquatic
Vegetation



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SECTION 3: SUBMERGED AQUATIC VEGETATION

Technical Support for Coastal Habitat Restoration

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DESCRIPTION

Submerged aquatic vegetation (SAV) is a term used to describe rooted, vascular plants that grow completely underwater except for periods of brief exposure at low tides. The term SAV is generally used for marine, estuarine, and riverine angiosperms, and macrophytes. Most of these plants have leaves and stems with an extensive system of lacunal air spaces for buoyancy; thin cellulose walls for diffusion of gases, and high concentrations of chloroplasts in the epidermal layer for light absorption (Thayer and Fonseca, 1984).

Factors influencing SAV distribution and growth include light penetration, nutrients, substrate, temperature, current velocity, wave energy, and salinity. Table 3-1 defines the terminology used to define salinity ranges in this section of the document:

TABLE 3-1. Terminology to Describe the Different Salinity Ranges (parts per thousand)

System	Salinity modifier	Salinity (ppt)
Marine	euhaline	>30.0
Estuarine (brackish)	polyhaline	18.0-30.0
	mesohaline	5.0-18.0
	oligohaline	0.5- 5.0
Riverine	fresh	<0.5

SAV commonly grows in beds. These beds can be dense or sparse and contain one species or many. Generally, species diversity increases as the salinity decreases. For example, while only two species (eelgrass and widgeon grass) grow in Long Island Sound's polyhaline waters, 17 species are found in the tidal freshwaters of the Connecticut River (Barrett et al., 1997).

Studies conducted in the Chesapeake Bay have found other differences between tidal freshwater and more brackish or saline species. Freshwater SAV exhibit a shorter growing season and reduced biomass production when compared to marine and estuarine species. Some freshwater species can root at greater depths than salt and brackish species by forming surface canopies that allow light to be intercepted before it is attenuated in turbid, shallow water environments. This adaptation in some freshwater species allows for deeper maximum depth limits than the more meadow-forming species such as eelgrass and tapegrass. (Batiuk et al., 1992).

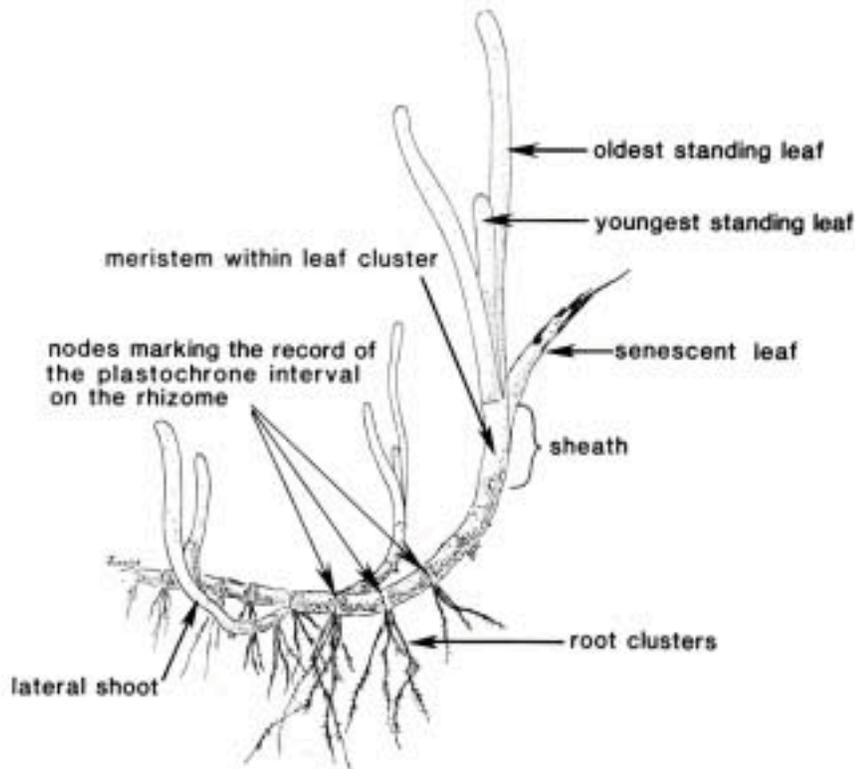
Mesohaline, oligohaline, and freshwater species of SAV have not been well studied in the Long Island Sound watershed. Until the status, trends, and water quality requirements of these species can be further researched, it is not possible to define goals for habitat restoration efforts. For this reason, restoration efforts under the Habitat Restoration Initiative will focus on eelgrass (*Zostera marina latifolia*), a polyhaline/marine species that has been more thoroughly researched.

EELGRASS

Historically the most abundant SAV species in Long Island Sound, eelgrass was widely dispersed in the eastern, central, and western sections. Its current distribution in the Sound is limited to the eastern shoreline of Connecticut. The ecological importance of eelgrass is derived from its productivity and the substantial habitat it creates. Eelgrass may form extensive meadows or patchy beds interspersed with bare areas, and the location of these beds can shift over time.

Eelgrass, a kind of seagrass, is the only true marine SAV found in Long Island Sound. Seagrasses are characterized as having linear, grass-like leaves and an extensive root and rhizome system. An eelgrass plant is composed of 3-7 strap-like leaves bound together in a sheath attached to an underground rhizome (Figure 3-1). The rhizome is produced by the basal meristem, which also produces new leaves and lateral shoots. Root clusters from rhizome nodes function as anchors and as the primary sites for nutrient uptake. The base of the lateral shoot pushes through the sediment as the plant grows

FIGURE 3-1. Major Features of the Morphology of *Zostera Marina*
(From Thayer and Fonseca, 1984)



(Costa, 1988). The plants may reproduce vegetatively by lateral shoots or sexually through flowering, pollination, and seed germination. Eelgrass is perennial, but annual populations do exist in shallow areas where ice scouring, freezing, or other stresses exist. These environmental factors, as well as genetics, may contribute to a high incidence of flowering in these populations (Costa, 1988). Successful sexual reproduction is dependent on a number of conditions. For example, even though flowering and seed production may occur, seedling recruitment may be absent in areas of high currents (Fonseca et al., 1985).

Eelgrass grows in areas of specific, though diverse, environmental conditions. Substrate requirements range from sand and gravel to mud. Morphologic flexibility among populations is responsible for this species' ability to occupy such a wide range in habitats, including variations in wave/current energy

and nutrient content of sediments. For example, Costa (1988) noted that plants growing in shallow, wave-swept bottoms tend to have short narrow leaves, grow in high densities (fewer than 95 shoots per square foot), and produce dense root and rhizome clusters; whereas plants growing in deeper water have longer broader leaves, grow in lower densities (less than 20 ft²), and produce less root and rhizome material.

The maximum depth of eelgrass growth is determined by the maximum depth of sufficient light penetration necessary for photosynthesis. The degree of light penetration is dependent upon amounts of phytoplankton chlorophyll a (CHLA), total suspended solids (TSS), color, dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorous (DIP) in the water column (Batiuk et al., 1992; Hurley, 1991). Levels of nitrogen and phosphorous indirectly affect light attenuation by controlling the growth of phytoplankton and algal epiphytes, which can significantly shade SAV leaves.

In Long Island Sound, eelgrass is found at depths between 1.8 and 12 feet below mean low water (Koch and Beer, 1996). There are, however, historical accounts of specimens collected in water just over five yards deep from Bushy Point Beach in Groton, Connecticut (New England Botanical Society, 1970). The historical maximum depth record in the western Sound is negative one yard mean low water in Cold Spring Harbor (Johnson and York, 1915). The upper limit of growth is determined by physical factors such as wave action, ice scour, and desiccation.

Faunal species associated with eelgrass beds include protozoans, nematodes, polychaetes, oligochaetes, hydroids, bryozoans, molluscs, decapods, barnacles, and fish (Thayer and Fonseca, 1984) (see Table 3-2).

TABLE 3-2. Partial Listing of Species Associated with SAV Beds

mudsnail	<i>Ilyanassa obsoleta</i>	sand shrimp	<i>Crangon septemspinosa</i>
northern lacuna	<i>Lacuna vincta</i>	blue mussel	<i>Mytilus edulis</i>
common periwinkle	<i>Littorina littorea</i>	blue crab	<i>Callinectes sapidus</i>
lunar dovesnail	<i>Mitrella lunata</i>	hermit crab	<i>Pagurus longicarpus</i>
bay scallop	<i>Argopecten irradians</i>	horseshoe crab	<i>Limulus polyphemus</i>
northern quahog	<i>Mercenaria mercenaria</i>	bluefish	<i>Pomatomus saltatrix</i>
softshell clam	<i>Mya arenaria</i>	striped bass	<i>Morone americana</i>
common clamworm	<i>Nereis virens</i>	winter flounder	<i>Pleuronectes americanus</i>
isopod	<i>Idotea triloba</i>	lobster	<i>Homarus americanus</i>

VALUES AND FUNCTIONS

Eelgrass beds rank among the most productive of marine and estuarine plant habitats. Under optimum growing conditions in August, leaf production near Woods Hole, Massachusetts was reported to range from 292 - 730 g C m² yr⁻¹ (Dennison and Alberte, 1982). One reason for this high productivity is that old leaves are shed and replaced by new leaves on a three-week cycle. The timing of peak biomass production corresponds with peak epiphytic algae and bacteria production. Other secondary biological productivity includes the support of eggs, barnacles, and bryozoans that attach to the surface of plant leaves and stems. Some of these organisms and others that live among the plant roots in the sediment are grazed upon by snails, worms, and other invertebrates that, in turn, provide food for fish and larger invertebrates. For example, winter flounder feed on shrimp and sandworms living within the beds.

Beds of eelgrass are also important as a food source for several species of birds. Waterfowl consume the nutritious seeds and tubers, as well as the root stalks. Species such as Atlantic brant, Canada geese, and many species of ducks eat eelgrass leaves and seeds as a principal food source (Buchsbaum,

1987). Small prey fish associated with the beds create concentrated feeding areas for predatory birds such as terns, osprey, and cormorants (Buchsbbaum, 1995; Colarusso, pers. comm.).

Eelgrass beds not only supply food, but also provide shelter to a number of organisms. Studies have shown that eelgrass beds have a consistently greater diversity and abundance of marine organisms than adjacent unvegetated areas (Kenworthy et al., 1988; Heck et al., 1989). The dense underwater canopy with vertical and horizontal complexity is highly attractive to marine organisms. For example, some fish species lay their eggs on the surface of eelgrass leaves; newly-molted crabs and lobsters seek refuge in eelgrass beds while their shells harden; and juvenile and larval stage bay scallops (*Argopecten irradians*), starfish, snails, mussels, and other creatures attach themselves to eelgrass leaves (Prescott, 1990; Orth, 1992). Other species that use the beds for food or shelter include killifish, silversides, sticklebacks, northern pipefish, scup, tautog, rock crabs, and green crabs.

Eelgrass leaves are a critical source of attachment for juvenile bay scallops, a species whose population has plummeted in the Sound. The Chesapeake Bay suffered a similar loss of its scallop fishery in the 1930s, corresponding with a demise of eelgrass. One of the best populations of scallops in the Sound was found in Niantic Bay, Connecticut, an area which also historically contained dense eelgrass beds.

Other economically important species benefiting from the presence of eelgrass include winter flounder, menhaden (*Brevoortia tyrannus*), blue crab, American lobster, hard-shell clam or northern quahog, bluefish, and striped bass.

The presence or absence of eelgrass beds can be excellent indicators of water quality (Dennison et al., 1993). Inventories of eelgrass distribution and abundance function as long-term monitoring tools of an estuary's health. For example, studies conducted in the Chesapeake Bay indicated that nutrient enrichment and increased turbidity were associated with a decline in eelgrass as well as other SAV (Kemp et al., 1983 and Batiuk et al., 1992). In Massachusetts, a study found housing developments and increased groundwater nitrogen loading resulted in a significant decrease of eelgrass habitat (Short and Burdick, 1996). Resource managers can use this information as guidelines in the establishment of conservation goals.

Eelgrass and other SAV contribute to chemical processes such as nutrient absorption, oxygenation of the water column (Hurley, 1991), and assimilation of certain contaminants (Levine et al., 1990). Dense beds may buffer water currents, thus reducing shoreline erosion and resuspension of bottom sediments. Roots and rhizomes further help to reduce ambient turbidity by binding sediments.

STATUS AND TRENDS

There are three convenient reference periods for summarizing the status and trends of eelgrass populations in the Sound: pre-1931, 1931–1995, and present day.

PRE-1931

Historical information indicates that eelgrass was once “common” along the entire coastline of the Sound and in sheltered bays, harbors, rivers, and creeks. This observation was reconstructed, in part, from the following historical botanical and vegetation literature of the Connecticut coast:

- Berzelius Society (1878) – “Abundant along the coast”
- Bishop (1885) – “Common on coast” (i.e., within 30 miles of Yale University)
- Graves et al., (1910) – “Common along the coast in bays, salt rivers and creeks, growing on muddy or sandy bottoms.”

- Nichols (1920) – “The most distinctive plant of muddy bottoms along the seacoast is eelgrass . . . this also grows on sandy bottoms but it never attains there the luxuriance, which it exhibits where growing on muddy bottoms. . . . So prolifically does it thrive in the shallow waters of protected harbors and coves that at low tide large areas of muddy bottom here will be almost completely hidden by its cluster of long, slender leaves.” [Note: the description is accompanied by a photograph showing eelgrass growing on the shallow subtidal flats at the mouth of the Oyster River on the border of West Haven and Milford, Connecticut.]

The distribution of eelgrass in the New York portion of the Sound is poorly known except that there are several key references that establish the historical presence of this species in western Long Island Sound:

- Transeau (1913) – “in tidal creeks, such as that on the east side of Center Island or the north side of Lloyds Neck, the Eel Grass Formation is dominant”
- Johnson and York (1915) - This report describes the relationship of estuarine plants to tide levels within Cold Spring Harbor. The investigation notes that eelgrass “gives character to large areas of the harbor bottom” and that “the densest stands of *Zostera* seen in the harbor are that east of the channel to the Outer Harbor On these areas there may be from 500 to 2,000 leaf clusters of *Zostera* to each square yard of bottom.” Johnson and York also reported the average lower limit of eelgrass as -3.0 feet mean low water with extremes to -4.5 feet mean low water.

The historical documentation from New York and Connecticut is supported by herbaria collection specimens and by other forms of documented observations, such as coastal survey maps (Appendix 1).

1931 - 1995

Beginning in 1931, eelgrass experienced a massive die-off all along the Atlantic Ocean in both Europe and North America. Both sides of the Atlantic were believed to have lost at least 90 percent of existing eelgrass populations (Thayer and Fonseca, 1984; Costa, 1988). Losses in some areas were even higher; for example, there were estimates of less than 0.1 percent of the original population remaining in Buzzards Bay, Massachusetts. By the summer of 1931, eelgrass leaves became somewhat darkened, broke from the roots, and washed ashore in great windrows from New England to North Carolina (Cottam, 1935).

Although the cause of this catastrophic decline is not certain, it is referred to as a wasting disease in most literature. The most often cited culprit of wasting disease is *Labyrinthula macrocystis*, a fungus that attacks the leaf surfaces of eelgrass. Although originally thought to be the primary cause of the decline, it is now more commonly suspected of being a symptom. According to Thayer and Fonseca (1984), “bacteria, fungi, commercial harvesting of fishery organisms, pollution, and competing species have been implicated as possible causative agents in the decline, but they have never been conclusively shown to have contributed to the ‘wasting disease’ event.” More recently, Rasmussen (1973, 1977) presented evidence that the decline in Denmark (and possibly elsewhere) was associated with a period of warm summers and exceptionally mild winters. Another theory suggests that extremes of low and high precipitation levels may have played an important part in the decline and in five prior documented declines (Martin, 1954).

The decline prompted concerned fish and wildlife biologists to make eelgrass population surveys a priority for the next two decades. The results of these surveys showed evidence that rhizomes persisted for many years and that eelgrass populations returned where water quality was suitable. The following references support this theory:

“. . .in most of the Chesapeake Bay section of Virginia and Maryland, the plant has returned to almost normal condition...In general, the best return of the plant has been restricted to areas of reduced salinity, such as the more inland coastal bays and estuaries and mouths of large rivers” (Lewis and Cottam, 1936)

“The situation has been most variable and sporadic since the initial destruction of eelgrass in 1931 to 1932. Little or no improvement could be detected for several years after 1931. Often some recovery was noted, only to be wiped out again . . . Along most of the Atlantic Coast of the United States and Canada, the situation is now somewhat better than it has been since 1931. Local units may be called fully recovered; other areas still are almost completely¹ without eelgrass. During the first half of the summer of 1944 a most gratifying recovery was noted in the majority of areas along the coast. In August, however, the disease reappeared in a number of areas, especially along the Massachusetts coast, so that the situation in part of this area was considerably less favorable than it had been during the preceding two or three years. The situation along the United States coast is perhaps least favorable in the more open bays and estuaries of New Jersey and Maryland, and most favorable in the sandy loam areas of reduced salinity of Chesapeake Bay, Long Island, and part of the Maine coast. Though the situation in any local area is highly variable and unpredictable, the trend is toward restoration of the plant in all favorable areas along the coast.” (Cottam, 1945)

This trend, established along the rest of the coast, occurred in Long Island Sound (LIS) as well. While some local populations returned, other areas of the Sound supported no eelgrass. Records of eelgrass following the 1931 decline include locations listed in Appendix 2.

A report by Muenscher (1939) on aquatic vegetation of Long Island made no references to eelgrass in any of the north shore harbors that were surveyed. Cottam (1945) recorded the observations of Dr. W. S. Bourn, a biologist with the U.S. Fish & Wildlife Service, after a visit to the Connecticut shore in 1944; while rough waters prevented a survey by boat, Bourn watched for drift and found it only in the Barn Island area where he observed a “considerable windrow of healthy eelgrass plants that had been obviously dug up by feeding waterfowl.” He added that “the individual plants appeared healthy and were approximately four feet in length.”

Addy and Johnson (1947) reported on the success of several transplant attempts in Connecticut with eelgrass taken from Niantic Harbor:

Location	Survival
East Lyme, Patagausett Cove	not checked
Old Lyme, Black Hall River	successful
Branford, Hotchkiss Grove Beach	successful
Norwalk, Norwalk River	failed

The same survey reported a failed attempt at transplanting eelgrass on the south shore of the Sound in Huntington Harbor. Both the stock plants and, consequentially, the transplant beds showed symptoms of the wasting disease.

In 1954, Cottam and Munro reported the following about the north shore of the Sound:

“Though eelgrass is perhaps less abundant in this state than along most of the New England coast, the plant has shown encouraging improvement. In a few coves and bays, notably Stonington Harbour, Mystic, Poquonock, and Niantic Rivers, it is now regarded as abundant.

¹ This remark may suggest that viable rhizomes were still present.

Yet, in some adjacent areas beds are scarce or even nonexistent. Eelgrass is said to be practically absent² near New Haven, Milford Harbour, Southport, and Rowayton. Reestablishment on Long Island's north shore is noticeably poorer than that on adjoining coastal areas."

PRESENT DAY DISTRIBUTION

After the dramatic decline of eelgrass during 1931 to 1932, populations rebounded somewhat in the eastern Sound but not along the western Connecticut coast. Currently, along the Connecticut coast, beds occur from the Rhode Island border at Stonington west to Clinton. Mapping of these beds was completed in 1996 by a team of researchers from the University of Connecticut (C.Yarish, University of Connecticut, pers. comm.). A number of factors may limit the return of eelgrass to western LIS including high nitrogen levels and the much higher tidal range, which reduces light availability and restricts the vertical distribution of eelgrass (Koch and Beer, 1996).

There are no known eelgrass populations along the north shore of Long Island (Black, pers. comm.; NYSDEC surveys). Figures 3-2 and 3-3 show historical and current locations of eelgrass in Long Island Sound.

² "Practically absent" suggests that eelgrass was present in the central and western Long Island Sound, but bed recovery was poor.

FIGURE 3.2. Historical Eelgrass Distribution

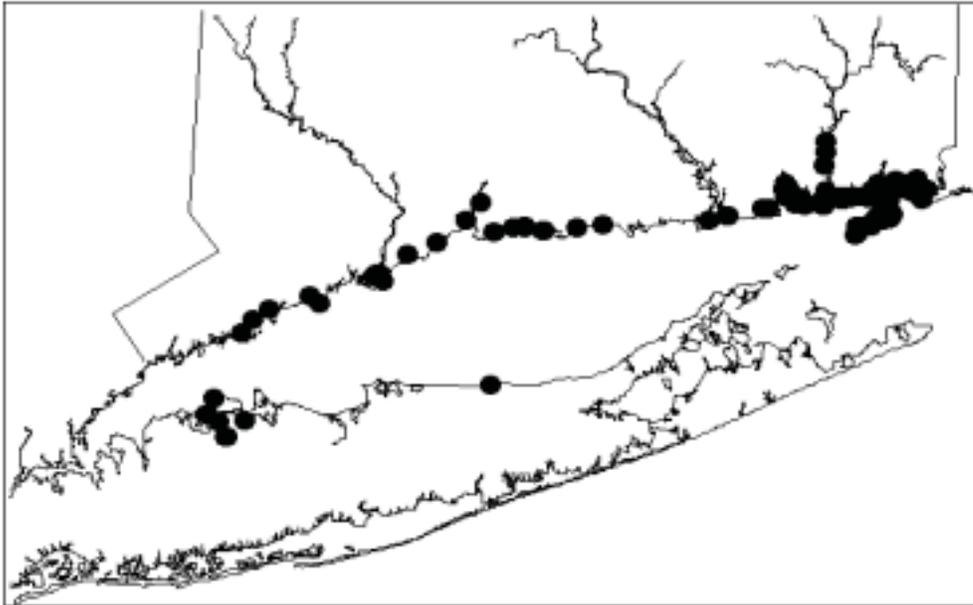
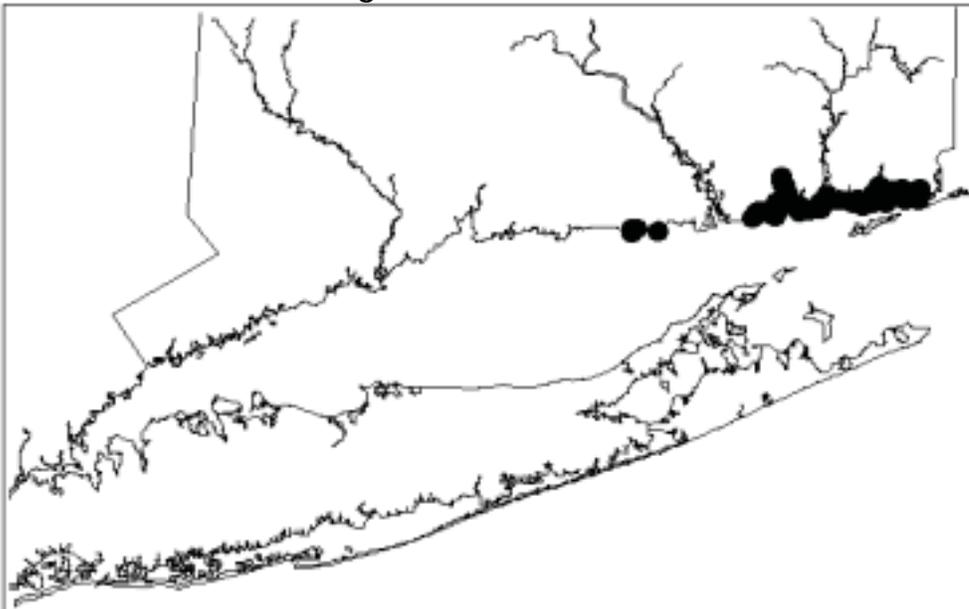


FIGURE 3.3. Current Eelgrass Distribution



REGULATIONS PROTECTING SAVS

SAV is broadly protected under the Connecticut Coastal Management Act. Activities subject to regulation pursuant to the Act are reviewed for consistency with applicable coastal policies and assessed for adverse impacts to coastal resources. Adverse impacts to SAV are defined pursuant to C.G.S. Sec. 22a-93(15)(G) as those impacts “degrading or destroying essential wildlife, finfish or shellfish habitat through . . . significant alterations of the natural components of the habitat.”

The Act also establishes policies to preserve and enhance coastal resources. Eelgrass in estuarine embayments is a resource protected by the Act. This policy is

“to manage estuarine embayments so as to insure that coastal uses proceed in a manner that assures sustained biological productivity, the maintenance of healthy marine populations and the maintenance of essential patterns of circulation, drainage and basin configuration; to protect, enhance and allow natural restoration of eelgrass flats except in special limited cases most notably shellfish management, where the benefits accrued through alteration of the flat may outweigh the long-term benefits to marine biota, waterfowl, and commercial and recreational finfisheries” [C.G.S. Sec. 22a-92(c)(2)(A)].

In the Spring of 1997, the Atlantic States Marine Fisheries Commission adopted an SAV policy that calls on states to protect existing beds, reduce pollution to promote comebacks, and set quantifiable SAV recovery goals. Specifically, member states are responsible for: monitoring programs at 1-5 year intervals; evaluating current regulatory program effectiveness and recommending improvements; setting SAV restoration goals; educating the public; and supporting SAV research.

DEGRADED EELGRASS BEDS AND RESTORATION METHODS

In many cases of eelgrass bed degradation, there is a combination of stresses. For example, a widespread problem such as impaired water quality may be coupled with localized physical disturbances. It is important to note that bed density, size, and distribution naturally fluctuates. In areas where stressed beds exist, growth may appear sparse, leaf blades may be short and narrow, and seed production may be sporadic (Koch et al., 1994).

BEDS IMPACTED BY IMPAIRED WATER QUALITY

Studies conducted in Chesapeake Bay (Kemp et al., 1983; Orth and Moore, 1983) have shown that degraded water quality is the most significant cause of eelgrass declines. Poor water quality not only degrades or destroys healthy beds, but also prevents the reestablishment of beds at historical locations. Light availability, the most important parameter, is measured with special light meters or derived from water clarity measurements with a Secchi disk. The reduction or attenuation of light in the water column occurs in a number of ways (Figure 3-4), and is most greatly influenced by nutrient enrichment.

The Comprehensive Conservation and Management Plan (CCMP) of the Long Island Sound Study (LISS) identifies *acting water quality*. Excessive amounts of nitrogen encourage phytoplankton and epiphytic growth, thus increasing the amount of material in the water column and on the leaf surface. This material shades the eelgrass and prevents or inhibits growth. Nitrogen loading can also favor macroalgae growth at the expense of eelgrass resulting in dramatic changes to the food web (Deegan et al., in press). At locations where eelgrass beds were converted to macroalgae-dominated sites or to unvegetated bottom habitat, fish abundance, biomass,

and richness decreased (Deegan et al., in press; Hughes et al., in review) and decapod abundance and biomass decreased (Deegan et al., in press).

Considerable efforts have been directed towards understanding the water quality requirements for SAV. In the Chesapeake Bay these efforts involved extensive water quality sampling where SAV beds occurred and where they were absent. Water quality data at restoration sites (successes and failures) have been further used to refine these requirements. Similar but more stringent habitat parameters were identified for SAV in Long Island Sound (Table 3-3). The more conservative values are based on the findings that regenerating eelgrass beds require better conditions than those needed for simply maintaining existing beds (Okubo and Slater, 1989). The Chesapeake studies have shown that if several of the water quality requirements are not met, eelgrass is usually not present.

FIGURE 3-4. Conceptual Model of SAV/Habitat Interactions

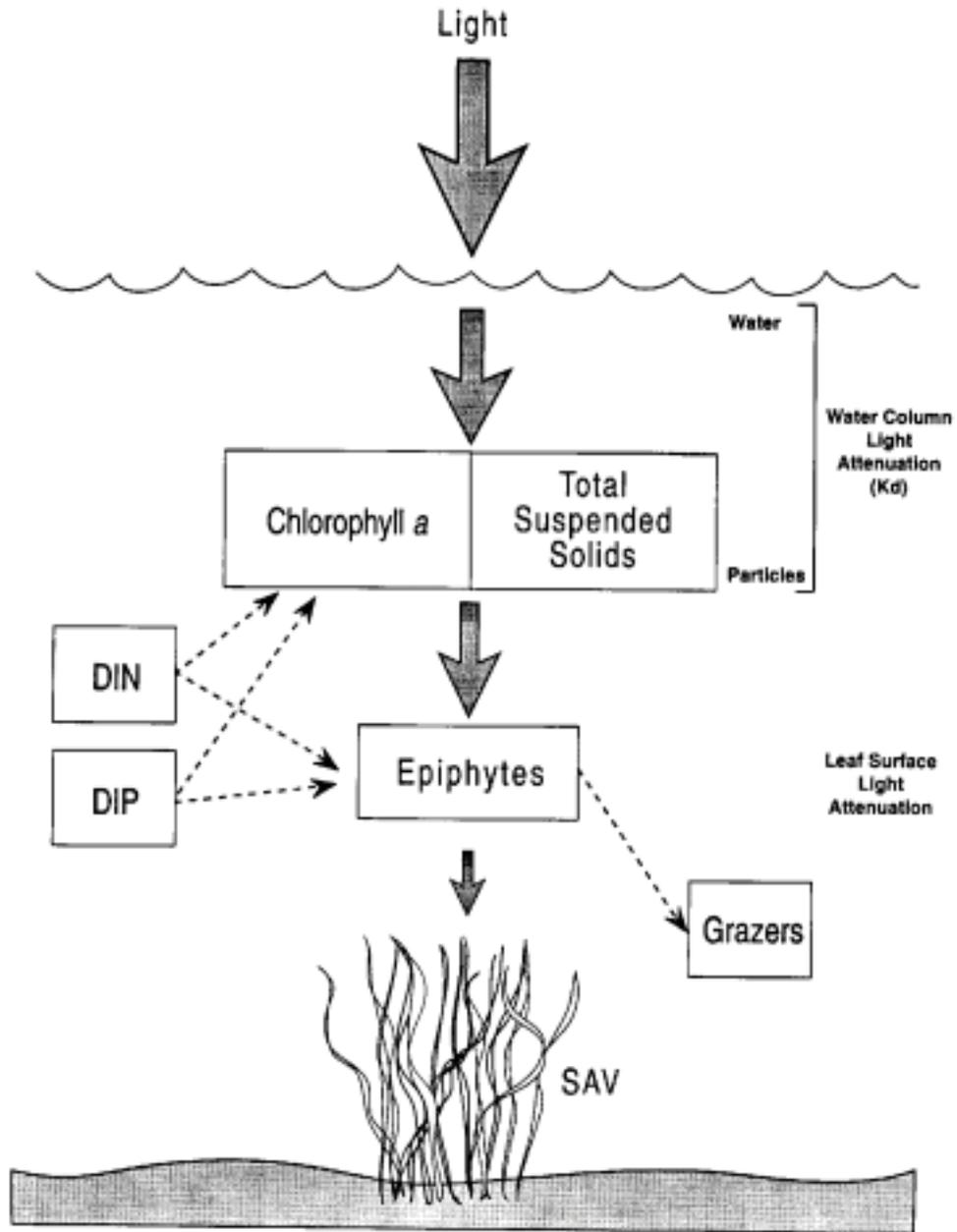
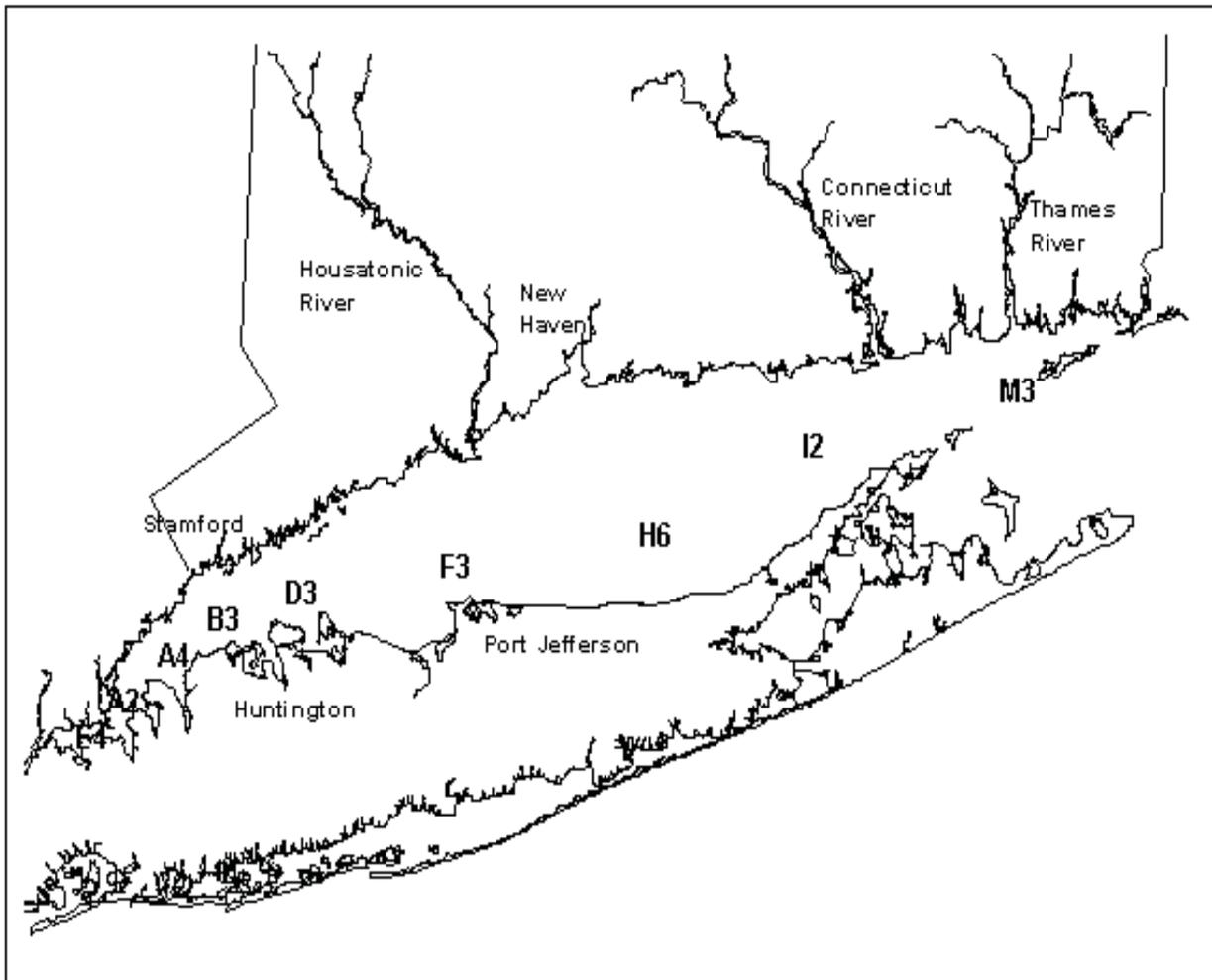


TABLE 3-3. Suggested Water Quality Criteria for Eelgrass. Parameters are based upon environmental data collected at three seagrass sites in Long Island Sound over 18 months (Koch et al., 1994).

Parameter	LIS	Chesapeake Bay
Light attenuation coefficient, Kd (m ⁻¹)	<0.7	<1.5
Total suspended solids, TSS (mg/L)	<30.0	<15.0
Chlorophyll a, CHLA (ug l ⁻¹)	<5.5	<15.0
Dissolved inorganic nitrogen, DIN (mg/L)	<0.03	<0.15
Dissolved inorganic phosphorous, DIP (mg/L)	<0.02	<0.02
Sediment organic matter (%)	<3.0	
Secchi depth (m)	>0.7	>0.8

FIGURE 3-5. Long Island Sound Offshore Water Quality Sampling Locations. Data from CTDEP and NYCDEP monitoring programs.



Monitoring stations in the Sound (Figure 3-5) indicate that the maximum allowable level of several water quality parameters for eelgrass are being exceeded: dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorous (DIP), and chlorophyll a (CHLA). Five years (1992, 1994, 1996, 1998, and 2000) of offshore data are presented in Appendix 3. In general, the graphs show impaired water quality following an east to west trend with the least favorable eelgrass conditions occurring in western LIS. For each parameter, a horizontal line represents the maximum acceptable level for eelgrass growth.

Water column attenuation, measured as a light attenuation coefficient (K_d), results from absorption and scatter of light by particles in the water (phytoplankton is measured as chlorophyll a; total organic and inorganic particles are measured as total suspended solids) and by absorption of light by water itself. Leaf surface attenuation, largely due to algal epiphytes growing on SAV surfaces, also contributes to light attenuation. Dissolved inorganic nutrients (DIN and DIP) contribute to the phytoplankton and epiphyte components of overall light attenuation, and epiphyte grazers control accumulation of epiphytes. (From Batiuk et al., 1992.)

While eelgrass does not grow near the offshore stations, it was necessary to use this data for lack of consistent nearshore data collection. Offshore water quality is generally not as impaired as nearshore water quality due to increased mixing and dilution of point and nonpoint source pollution. Thus, the offshore data represents a conservative water quality estimate when used to graph trends in impaired water quality.

Restoration Methods:

It is important to consider water quality for all possible restoration sites, even when the original cause of degradation may be an obvious localized activity. For example, removal of fill from a former eelgrass site in the western Sound would be pointless if the maximum acceptable water quality levels are exceeded.

- ① **Public Education:** At a Long Island Sound watershed level, the on-going public education efforts that originated under the LISS have been successful and should continue. At a local level, where isolated areas such as coves are experiencing water quality problems, adjacent homeowners can be made aware of possible causes of degraded SAV habitat. For example, where septic systems contribute to nutrient enrichment and algal blooms, homeowners may be educated as to the impacts of septic system failure on the ecosystem and encouraged to correct the problem by repairing or upgrading their systems.

Additionally, homeowners can be educated about the effects of nitrogen runoff from lawn care products and encouraged to use sustainable practices to maintain their yards. This includes such techniques as using grass clippings to add nutrients to lawns and reducing chemical fertilizer use on their property. Also, topsoil runoff contributes to turbidity, so erosion prevention could be encouraged.

- ② **Educating Policy-Makers:** The large-scale issue of impaired water quality is being addressed under a separate component of the LISS Comprehensive Conservation and Management Plan (CCMP). Thus educational efforts aimed at informing policy-makers of the need for improved water quality necessary for the successful reestablishment of eelgrass habitat must be developed.
- ③ **Eelgrass Restoration through Transplantation or Seeding:** In undertaking any eelgrass restoration effort, water quality is one of the most important factors in selecting the most favorable restoration sites. The conservative water quality parameters established by Koch et al. (1994) may be used as a guide for selecting sites. Sites being considered for restoration

should be tested with experimental plantings to ensure water quality is adequate before embarking on any major restoration efforts. Experimental plot recommendations include an 11 x 11 yard area with predator control cages or nets made of material, such as inch-gill net (Short, 1995). While these cages prevent destruction by animals such as horseshoe crabs and green crabs, they will not prevent species such as clamworms from negatively impacting a bed. The cages must be checked frequently to remove algae or debris that will otherwise accumulate and shade the bed. These cages can be removed after three to four months; the shoot production of plants in established beds is substantial enough to prevent the bed from being impacted by predators.

A more rigorous model for determining appropriate restoration sites has been developed by Short and Kopp at the University of New Hampshire. Their model, called the Preliminary Transplant Suitability Index (PTSI) and the Transplant Suitability Index (TSI), take into account numerous ecological variables that can effect whether a site is conducive to eelgrass restoration (<http://marine.unh.edu/jel/fred/siteselection01.html>). For the PTSI a numerical ranking is given to the following variables:

- Historical eelgrass distribution
- Current eelgrass distribution
- Bathymetry (-2' to -5' MLW gets highest ranking)
- Water quality data (calculate a eutrophication index based on DO, DIN, TON, Secchi, and phytoplankton pigments)
- Sediment distribution
- Wave exposure
- Bioturbation
- Proximity to natural eelgrass beds

Test transplants of eelgrass are done concurrently with the development of the PTSI. The recommended method, called TERFS (Transplanting Eelgrass Remotely with Frame Systems), was developed by Short and Kopp (unpublished data). The TERFS method consists of tying eelgrass shoots to a metal checkerboard frame that is lowered into the water until it rests on the bottom. Once the eelgrass has rooted and the paper ties have dissolved the metal frames are retrieved. At the conclusion of the test transplantation, the final TSI is calculated to determine the best sites for full-scale eelgrass restoration. The TSI is calculated using the following parameters: PTSI, light, bioturbation, test transplant survival, and growth and leaf nitrogen content of test transplants.

Transplantation: Transplanting eelgrass involves harvesting mature plants from healthy donor beds. Transplantation should occur within several hours of being picked during which time the fragile plants are rinsed free of sediments and kept wet, cool, and intact (Fonseca, 1992 and Thayer et al., 1988). Transplanting techniques may include the use of: sod potters; plant bundles bound with edged metal staples; biodegradable plant staples; some other type of temporary holdfast; or the TERFS system. Intertidal areas are usually accessible during low tides, while work in deeper waters may require divers. One benefit of the TERFS method is that divers are not needed (see above description). The TERFS system shows promise as an efficient and low cost method of transplanting eelgrass.

The cost of transplanting is site and method specific and can vary dramatically. An estimate from a transplantation project in New Hampshire using divers is approximately \$100,000/acre (Colarusso, EPA, pers. comm.).

Seeding: Based on the preliminary results of studies conducted in Long Island Sound, the recommended technique consists of harvesting seeds from donor sites and spreading (or broadcasting) the bare seed into the areas to be restored (C.Yarish, University of Connecticut, pers. comm.). This technique is preferred over transplantation because it is less destructive to the donor site and less expensive. Depending on springtime conditions, seeds may be harvested from mature plants from the end of June to early July. Preliminary findings indicate the seeds should not be spread until mid-September to achieve the best germination. A parallel study of the Sound's eelgrass suggests the germination rate of seeds is roughly 70-80 percent (C.Yarish, University of Connecticut, pers. comm.). Alternatively, an experimental method of seeding eelgrass, currently under development at the University of Rhode Island, uses a boat-drawn sled to inject seeds suspended in gelatin into the sediments (<http://ciceet/unh.edu/additional/spotlight>).

BEDS IMPACTED BY FISHING AND VESSEL RELATED ACTIVITY

Fishing gear dragged through seagrass beds can break apart leaves or tear up the plant from its roots. Large unvegetated swaths can be left in the middle of an otherwise healthy bed. Most damaging to the beds are trawls, nets, lobster traps, and, historically, scallop dredges. An example of this type of disturbance occurred in Connecticut's Niantic River. Once a productive scallop area, the estuary was lined with scallopers' boats. Six-inch wide metal frames covered with chicken wire were attached to the end of 16-20 foot long poles and dragged along the bottom. Studies conducted on larger-scale scallop operations in North Carolina have shown that harvesting techniques not only damage the eelgrass beds, but may also have further negative impacts on the scallop fishery (Fonseca et al., 1984).

Vessel-related disturbances to eelgrass beds can be substantial. Motorboat propellers cutting through seagrass beds or digging into the sediment can leave long scars that persist unvegetated for years (Zieman, 1976). Turbulence from propeller wash and vessel wakes can dislodge sediments, break off seagrass leaves, or uproot plants (Lockwood, 1990). Also, mooring chains swinging around their mooring blocks can denude circular patches within eelgrass meadows (Short et al., 1991; Short et al., 1993; Burdick and Short, 1999).

Restoration Methods:

- ① **Natural Restoration:** Fishing and vessel related disturbances may affect isolated patches within a bed. Considering the resiliency of eelgrass, these beds have the potential to recover if the activity is not repeated on a regular basis. The likelihood of this natural restoration is elevated with increased proximity to beds with flowering plants. Mature seeds are dispersed by sinking, free floating stalks or waterfowl (Lamounette, 1977).

It should be noted that once a bed has been stressed by having a trawl or net dragged through it, poor water quality may prohibit its recovery.

- ② **Public Education:** To avoid repeated impacts upon eelgrass habitat, public education is imperative. To assist in public awareness and education campaigns, special buoys may be placed over eelgrass beds warning boaters to avoid the area. In addition, literature can be dispersed to those persons actively involved with the recreational and industrial use of the marine environment.

WATERFOWL AND STORM-RELATED DAMAGE TO BEDS

Feeding by herbivores can play a significant role in the reduction of eelgrass bed density. Non-migratory Canada geese (*Branta canadensis*) and the introduced mute swan (*Cygnus olor*) have been known to overgraze beds, leaving only chopped blades or rhizomes. Studies in Chesapeake Bay estimated that during the winter of 1978-1979, Canada geese consumed about 21 percent of the

standing crop of seagrasses in the shallow portion of the lower Chesapeake Bay (Wilkins, 1982). Connecticut's resident goose population, increasing from 1,000 in 1970 to approximately 35,000 today, has the potential to negatively impact eelgrass beds. Submerged aquatic vegetation of tidal estuarine waters may be especially vulnerable to waterfowl damage since the beds become more accessible to such foragers at low tide.

The mute swan population in the Atlantic Flyway increased from 200 in 1954 to 12,500 in 1999. More than 50 percent of the population was found in Connecticut and New York (Allin et al., 1987). Studies on penned molting swans found the average consumption of eelgrass and sea lettuce (*Ulva lactuca*) per swan over 24 hours to be 3.66 kilograms and 4.03 kilograms wet weight, respectively (Mathiasson, 1973).

Other natural disturbances to eelgrass beds include damage caused by catastrophic storms, periodic storms, sediment transport, and ice damage. While these disturbances have not been well-documented in the Sound, studies in southeastern Massachusetts have shown that, of all the natural disturbances, severe climatological events have had the greatest impact on eelgrass abundance (Costa, 1988).

Restoration Method:

Providing that these natural disturbances have not permanently altered the physical characteristics of a site, the eelgrass beds have the potential to regenerate without restoration. Population management of certain waterfowl species (e.g., mute swan and resident Canada geese) may be warranted if over grazing has degraded eelgrass beds. Reduction of nuisance waterfowl numbers may decrease grazing of eelgrass and allow for natural restoration.

BEDS IMPACTED BY SHORELINE EROSION CONTROL STRUCTURES

Structures that affect wave energy or currents can degrade or destroy eelgrass beds. Bulkheads, seawalls, and riprap "harden" the shoreline and reflect wave energy. The process of constructing or installing these structures creates temporary sediment plumes, thus reducing light penetration. The long-term negative impacts include changes in localized wave attenuation, longshore currents, and sedimentation patterns (Kurland, 1994). Beds can grow at sustained current velocities up to 59 inches sec⁻¹ and may tolerate brief exposure to higher velocities (Fonseca et al., 1982a). If the structure increases current velocity above this point for extended periods or if the point of wave breaking is shifted, the eelgrass bed may become weakened and degraded. In addition to these problems, the increased energy will contribute to greater turbidity. Jetties and groins similarly impact eelgrass beds.

Restoration Method:

Shoreline structures are created for the protection of property. Therefore, the removal of these structures for the sake of eelgrass restoration is, in most cases, not practical. However, if beach/shoreline restoration is being considered, eelgrass restoration may be an option. Refer to restoration techniques under the section "Beds Impacted by Impaired Water Quality."

SHADING OF BEDS

Docks, floats, and piers alter environmental conditions by reducing available sunlight, creating shaded areas. Shading decreases photosynthetic efficiency, flowering and vegetative density of eelgrass beds (Dennison 1987).

Restoration Method:

Height/orientation recommendations for dock building may be considered as a function of maintenance, reconstruction of dilapidated structures, or permitting new docks. For example, the greater the clearance above marine bottom, the less impact. For this reason, fixed-timber piers two

yards above water are preferred over floating docks. Axis of orientation is also important; north to south running docks shade less of an area than do east-west oriented docks (Short, 1995).

BEDS IMPACTED BY DREDGE ACTIVITIES

Dredging for the purposes of marinas, docks, pipeline crossings, and navigation channels physically removes eelgrass and its substrate, increasing water depth. Light availability in these deeper waters may be insufficient for bed reestablishment. Recolonization in the dredged basins and channels is further hindered by maintenance dredging or accumulations of organic matter. The dredging process indirectly impacts other beds in an area by creating turbidity that reduces the productivity of grasses and, if severe enough, eventually kills them.

Restoration Methods:

Sand and gravel dredge sites are more likely candidates for restoration than areas dredged for the purpose of boating/shipping. Restoring eelgrass near the edge of deep channels can help stabilize the area and possibly reduce the need for frequent dredging. But, in more shallow dredge sites, the presence of eelgrass may actually create conflicts by contributing to sediment deposition and shoaling (Colarusso, pers. comm).

Preliminary restoration steps: Eelgrass restoration at a dredge site is an option if the area can be filled to its former bathymetry. The determination of appropriate sites should be based on an assessment of various environmental variables using one of the methods described under the section “Beds Impacted by Impaired Water Quality.”

BEDS IMPACTED BY FILL

Eelgrass beds were completely destroyed by the historical placement of fill or dredge sediments in vegetated shallows to create dry land. This practice was common when waterborne commerce was the main mode of transportation and upland area was needed for uses such as boat yards or cargo ports. Relatedly, dredge sediments from navigation channels were often disposed of in shallow waters or cast alongside the channel. As with dredging, filling may have short-term impacts on other beds in an area because of increased turbidity.

In aquaculture practices, fill was added to provide a cultch base for settling oyster larvae. Around the turn of the 20th century, the tremendous boom in offshore oyster harvest and production spawned numerous inshore oyster operations or aquaculture projects. The nearshore water areas were often carved up into grids and individual parcels were leased to prospective oystermen. Oysters were relayed to nearshore sites for brief periods of time and then harvested and transported back to deep waters. The actual impacts of such operations are difficult to quantify but undoubtedly some amount of eelgrass habitat was lost through direct placement of live oysters and cultch, and indirectly through attempts to remove sediment in coastal embayments.

Restoration Method:

Removing fill, in most cases, is an extremely difficult and impractical option, especially if the site has been developed. If the cost of fill removal is not a deterrent and if pre-disturbance bathymetric conditions are known, eelgrass restoration is possible. Refer to restoration techniques under the section “Beds Impacted by Impaired Water Quality.”

SPECIFIC RESTORATION OBJECTIVES

The general goal is to restore eelgrass beds to historical locations as dictated by acceptable water quality. Specific goals include:

IMPROVE FISH AND WILDLIFE HABITAT

Eelgrass provides forage, shelter, and nursery habitat for marine life. Restoration will increase the overall productivity of shallow coastal embayments. Focus species will include: bay scallop, winter flounder, menhaden, blue crab, American lobster, hard-shell clam, bluefish, and striped bass.

MAINTAIN / IMPROVE WATER QUALITY

Eelgrass beds filter estuarine waters by removing suspended sediments and dissolved nutrients and by assimilating certain contaminants. In areas where water quality is suitable for restoration, further nutrient reduction goals should be established.

INCREASE EROSION CONTROL AND SEDIMENT STABILIZATION

Eelgrass roots and rhizomes help to bind sediments, while the three-dimensional canopy structure can act as a baffle and substantially reduce wave energy, further enhancing sediment stability. The loss of a bed can threaten other beds in the area by re-suspending sediments and contributing to increased turbidity. Restoring beds to disturbed areas with the goal of improving sediment stabilization may help maintain the health of local beds.

RESTORATION SUCCESS AND MONITORING

Fonseca et al., (1982b) suggest transplantation is basically successful if it survives and has increased its coverage after two growing seasons. But the definition of “success” varies. Vegetation may survive and persist, but restoring one acre with the goal of a fully functioning one-acre bed is not probable. In general, the long-term success of restored eelgrass habitat has not yet been well documented. To increase the chance of a successful restoration project one of the methods of assessing suitable restoration sites (either Koch et al., or Short and Kopp) should be used.

Factors to consider for monitoring may include the following:

- a. Water quality
- b. Coverage - density, leaf area, continuity of bed
- c. Persistence
- d. Functional equivalence

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APPENDIX 3-A

HISTORICAL (PRIOR TO 1931) EELGRASS DISTRIBUTION

Locations are listed from west to east.

Location	Source	Observation / Collection Date
New York		
Fishers Island	St. John, 1920	1920
Wading River	Brooklyn Botanical Garden	1873, 1914
Center Island, east side	Transeau, 1913	
Lloyds Neck, north side	Transeau, 1913	
Cold Spring Harbor	Brooklyn Botanical Garden	1890
Inner Harbor	Johnson and York, 1915	1905-1913
Connecticut		
Fairfield	G. Safford Torrey Herbarium	1915
Stratford, Housatonic River	U.S. Coast and Geodetic Survey Chart, 1892	1884-1887
Milford/West Haven Oyster River	Nichols, 1920	
Branford, Stony Creek	U.S. Coast and Geodetic Survey Chart, 1918	1833-1916
Madison	G. Safford Torrey Herbarium and Yale Herbarium	1874
East Lyme, west Watts Island	U.S. Coast and Geodetic Survey Chart, 1925	1917-1918
East Lyme/Waterford Niantic River	U.S. Coast and Geodetic Survey Chart, 1925	1917-1918
Waterford, Indian Cove	U.S. Coast and Geodetic Survey Chart, 1925	1917-1918
Groton: -Thames River, n. of sub base - Bluff Point	U.S. Coast and Geodetic Survey Chart, 1933 G. Safford Torrey Herbarium	1917-1933 1930

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APPENDIX 3-B

EELGRASS LOCATIONS 1931 - 1992

Location	Source	Observation/ Collection Date
New York		
Fishers Island - West Harbor	U.S. Coast and Geodetic Survey Chart, 1958	1958
-South Beach	New York State Museum collection #5539	1990
Wading River	Brooklyn Botanical Garden	1950
Connecticut		
Rowayton	Cottam and Munro, 1954	1954
Westport, Longshore Beach	Barske, 1993, pers. comm.	1947
Southport	Cottam and Munro, 1954	1954
Stratford, Frash Pond	Knapp, 1995, pers. comm.	1935-45
Milford, Milford Harbor	Cottam and Munro, 1954	1954
New Haven, Quinnipiac River	Addy and Johnson, 1947	1947
East Haven River	Lynch and Cottam, 1937	1936
Branford, Hotchkiss Grove	Beckley, 1982	1982
Guilford, Great Harbor	Barske, 1993, pers. comm.	1947
East Lyme, -Rocky Neck	Barske, 1993, pers. comm.	1947
East Lyme and Waterford	Cottam and Munro, 1954	1954
-Niantic River and Bay	Northeast Utilities Service Company, 1996;	1985-1996
-Niantic Bay	Lynch and Cottam, 1937	1936
Waterford:	Northeast Utilities Service Company, 1989	1985
-Jordan Cove and Bay	Knight and Lawton, 1974	1974
-White Point		
Waterford and New London Alewife Cove	Conn. College Herbarium	1945
New London, Alewife Cove	Lewis, 1995, pers. comm.	1963-1969
New London and Groton, Thames River	Welsh, 1984	1984
Groton:	Welsh, 1984	1984
-Shennecosett Beach	Barrett, 1991	1991
-Pine Island Bay	NOS NOAA Nautical Chart, 1985	1985
-Jupiter Point	Cottam and Munro, 1954	1954
-Poquonock River	CT Botanical Society	1970
-Bushy Point Beach	NOS NOAA Nautical Chart, 1985	1985
-Mumford Point		

Location	Source	Observation/ Collection Date
Stonington:	Barrett, 1991	1991
-Ram Island	U.S. Coast and Geodetic Survey Chart,	1958
-S.E. of Ellis Reef	1958	1954
	Cottam and Munro, 1954	1932; 1945
-Mystic River	Uhler, 1932; Cottam, 1945	1991
-Mystic Cove	Barrett, 1991	
-Dodges Island	Lynch and Cottam, 1937; Renn, 1937;	1936; 1989
-Quiambog Cove	Crawford, 1989	1991
	Barrett, 1991	1958
-Lyddy Island to Lords Point	U.S. Coast and Geodetic Survey Chart,	1954; 1991
-N.W. Stonington Harbor	1958	
	Cottam and Munro, 1954; Barrett, 1991	1991
-Stonington Harbor	Barrett, 1991	1958
-Bay bounded by Stonington,		1958
Sandy and Edwards Points	U.S. Coast and Geodetic Survey Chart,	1936; 1989
-Elihu Island	1958	
	U.S. Coast and Geodetic Survey Chart,	
-Wequetequock Cove	1958	
	Lynch and Cottam, 1937; Crawford, 1989	
-Barn Island area		

APPENDIX 3-C

GRAPHS OF WATER QUALITY DATA FOR FIVE OFFSHORE SAMPLING STATIONS

