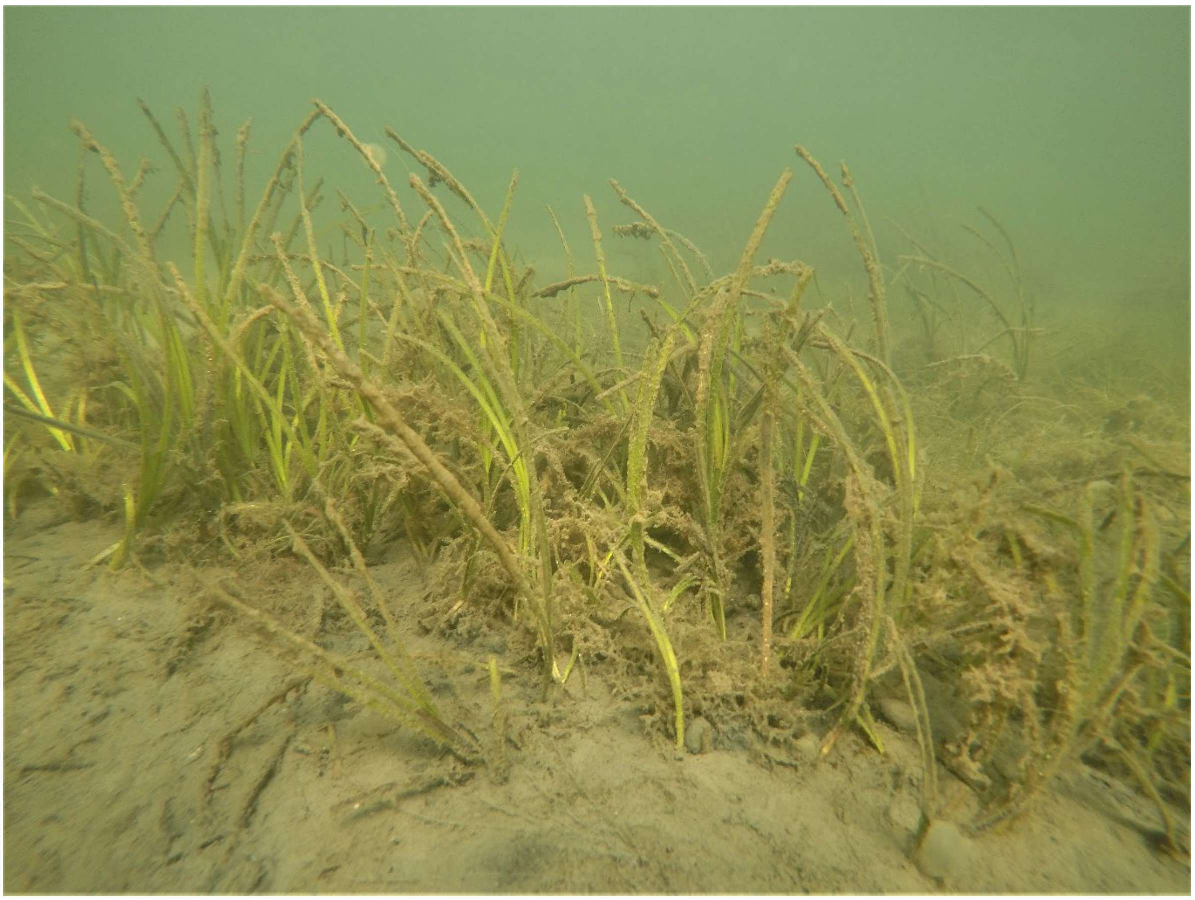
Long Island Sound Eelgrass Management and Restoration Strategy



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Summary

The Long Island Sound Study (LISS), established under Section 320 and 119 of the Clean Water Act, is one of the inaugural EPA National Estuary Programs. EPA, joined with the states of Connecticut and New York, established the LISS Management Conference - a partnership of federal and state agencies, user groups, concerned organizations, and individuals dedicated to improving the health of the Sound. First developed in 1994, the LISS issued a revised Comprehensive Conservation and Management Plan (CCMP) in 2015. The CCMP is organized around four major themes: 1) Clean Waters and Healthy Watersheds, 2) Thriving Habitats and Abundant Wildlife, 3) Sustainable and Resilient Communities, and 4) Sound Science and Inclusive Management. The plan also sets 20 quantitative ecosystem recovery targets to drive progress towards attaining restoration goals.

The Thriving Habitats and Abundant Wildlife theme includes the ecosystem target, *Eelgrass Extent* with a goal to restore and maintain an additional 2,000 acres of eelgrass by 2035 from a 2012 baseline of 1,893 acres. Eelgrass meadows (*Zostera marina* L.), an essential and valuable coastal submerged aquatic vegetation species, is identified as a priority habitat by LISS. Since 2002, eelgrass meadows have been intermittently monitored through US Fish and Wildlife Service (USFWS) aerial surveys. The most recent aerial survey in 2017 showed a decline in eelgrass extent since 2012 to 1,465 acres (Figure 1). While these aerial surveys provide valuable insight on eelgrass distribution, there is a lack of proactive restoration efforts due to knowledge gaps related to distribution trends and their drivers (i.e., water quality). Furthermore, water quality and climate issues pose major threats to eelgrass meadows' distribution and productivity, threatening eelgrass extent in Long Island. Before LISS can effectively restore eelgrass meadows, there is a need to effectively manage the existing beds and allow for both natural expansion and restoration.

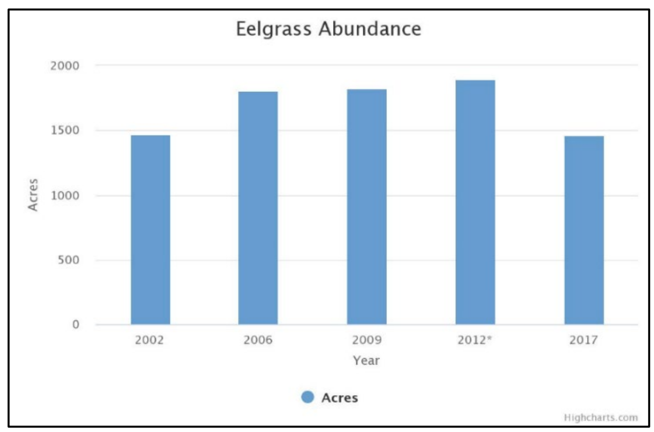

Figure 1 – Eelgrass abundance measured by the USFWS Aerial Surveys (published on LISS Microsite).

In order to make progress on this ecosystem target, the EPA Region 2's Long Island Sound Office convened a group of local experts to develop a targeted Long Island Sound Eelgrass Management and Restoration Strategy. Over the course of three meetings, held on July 25, September 19, and November 15 of 2022, the group outlined recommendations and specific actions to implement starting in Federal Fiscal Year 2023 (October 1, 2022). More specifically, the group identified current issues/threats, resources, and gaps (meeting 1), identified a prioritization system for management areas and actions/next steps (meeting 2), and finalized this strategy (meeting 3). This document provides guidance for short and long-term actions that should be taken to manage and restore eelgrass meadows in the Long Island Sound and act as a resource for other estuaries in the region facing similar issues. This is a living document meaning that as new research, resources, and information becomes available, the gaps and required actions may change. The development of this document was led by the EPA Region 2's Long Island Sound Office in collaboration with the Long Island Sound Study and other local expert and stakeholder input. Any questions or comments can be directed to EPA Region 2's Long Island Sound Office (Cayla Sullivan, sullivan.cayla@epa.gov).

Eelgrass

Seagrass Background

As defined by the Atlantic States Marine Fisheries Commission (ASMFC, 2022), submerged aquatic vegetation (SAV) are rooted, vascular, flowering plants that live and grow below the estuarine and marine water surfaces. Compared to algae, SAV anchor themselves into the sediment through their extensive roots and rhizome system, rather than attaching the hard substrate (Figure 2). Seagrass, a type of SAV, are the only true marine angiosperm meaning that in addition to asexual reproduction, the plants can reproduce sexually through flowering, pollination, and seed germination. Seagrass species, varying in size and shape, are found in both tropical and temperate systems globally.

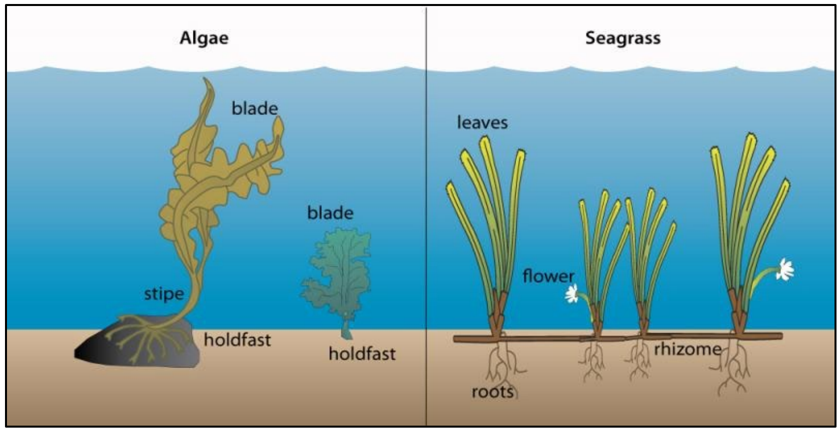

Figure 2 – Differences between algae and seagrass characteristics – showing their extensive roots and rhizome system Source: Reynolds, 2018.

Globally, seagrasses provide essential ecosystem services including serving as important nursery habitat, predation refuge, and food source for key recreational and commercial fishery species (Unsworth et al., 2019); stabilizing sediment and reducing wave action therefore increasing shoreline resiliency (Hemminga and Duarte, 2000; Christianen et al., 2013); acting as a sink for nutrients and carbon (i.e., major blue carbon hotspot) (Duarte et al. 2005); and removing excess nitrogen from the water column through denitrification (Zarnoch et al. 2017) – valuing at $1.9 trillion per year (Costanza et al., 1997; Waycott et al., 2009) (Figure 3 from Orth et al., 2006).

Natural and anthropogenic impacts pose substantial threats to this foundation species; such as storms, herbivory, diseases, eutrophication, and temperature increases (Figure 3). With increasing pressures from anthropogenic threats, seagrass distribution is declining at a rate of 7% per year (Waycott et al., 2009). Furthermore, recent analysis has corroborated previous trends in long-term decline in seagrass extent, estimating a global net loss of 5602 km^{-2} since the 1880s – with Temperate Northeast Atlantic, Tropical Atlantic, Temperate Southern Oceans, and Tropical Indo-Pacific regions having the greatest net losses (Dunic et al., 2021).

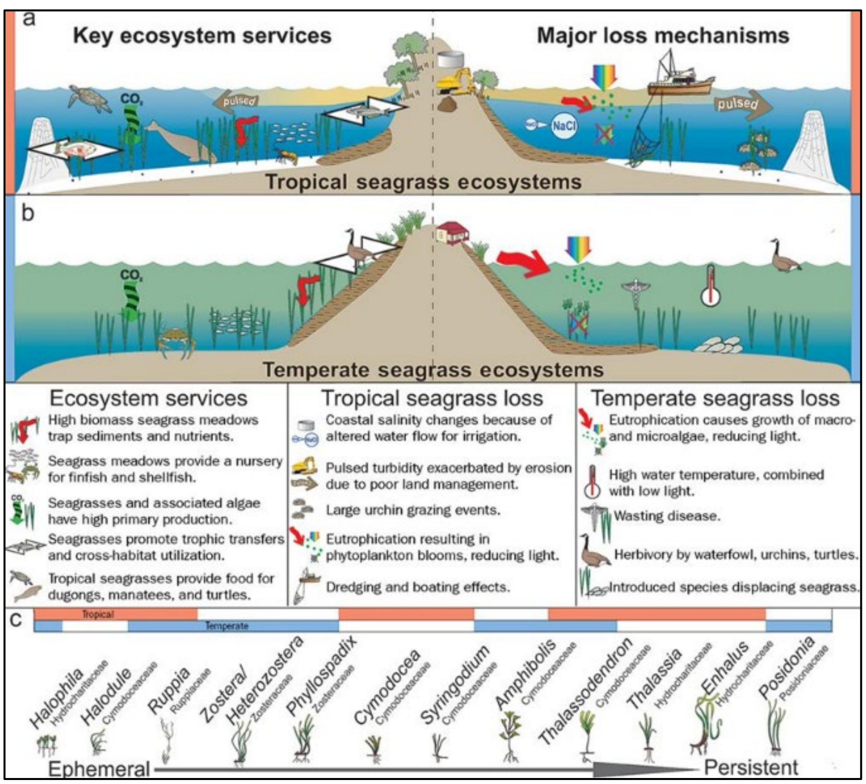

Figure 3 – Conceptual model depicting key ecosystem services and major loss mechanisms in temperate and tropical systems. Source: Orth et al. 2006

Eelgrass in Long Island Sound

Eelgrass (*Zostera marina*) is the dominant seagrass species in the Northeast and Mid-Atlantic regions (ASMFC, 2022) and is recognized as a priority habitat within Long Island Sound. The Long Island Sound Habitat Restoration Manual, Chapter 3: Submerged Aquatic Vegetation, developed in 2003, thoroughly describes eelgrass physical characteristics, values and functions, status and trends, restoration methods, objectives, and success and monitoring (see Appendix A for reference). This strategy will focus on the current status, threats, gaps, and proposed restoration and management actions and recommendations that use the most recent scientific findings (2003 – present).

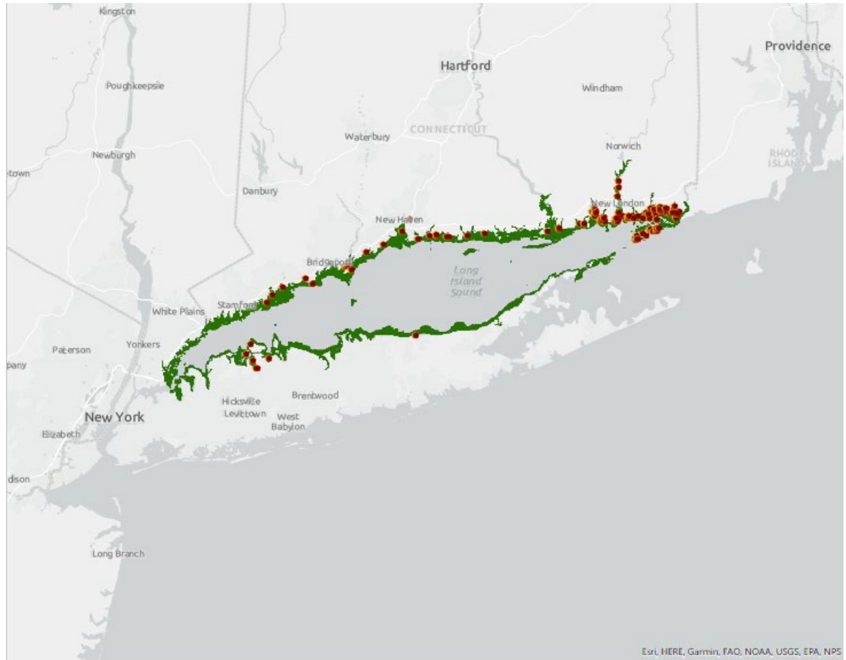

Figure 4 – Map of Long Island Sound showing the historical records and observations of eelgrass meadows (indicated by the red dots); whereas the green layer indicates the probable extent of eelgrass meadows (source: Vaudrey et al., 2013).

History

Historically, eelgrass was found in embayments from the western to the eastern Sound (Figure 4). The Long Island Sound Habitat Restoration Manual, Chapter 3: Submerged Aquatic Vegetation (2003) defines three time-periods of distinct differences in eelgrass distribution: pre-1931, 1931-2003, and 2003-present. For more detail refer to Appendix A, but to summarize:

- Pre – 1931: Eelgrass in Long Island Sound was abundant and common along the entire coastline. The red dots in Figure 4 depict the historical eelgrass observations in the Sound. Anecdotal observations indicate gaps along the shoreline; however eelgrass was found on both coasts – on the north shore of Long Island the eelgrass was found from Bayville to Orient Point and Fishers Island and on the Connecticut shoreline eelgrass was found from Stamford to Stonington. Developed by the Eelgrass Habitat Suitability Index Model (Vaudrey et al., 2013), the green layer shows the probable extent of eelgrass meadows.
- 1931 – 1995: Eelgrass extent declined dramatically due to a die-off induced by the wasting disease (Cottam 1933, Cottam and Munro, 1954). The wasting disease is caused by a fungus (*Labyrinthula zosterae* Porter et Muehlstein) that infects to eelgrass leaves (Muehlstein et al., 1991).
- 1995 – 2003: After the die-off, eelgrass returned but only to the eastern Sound in Connecticut and the north fork of Long Island, Plum Island, and Fishers Island in New York. Eelgrass may not have returned to the historic western Sound embayments due to other influences including nitrogen inputs and limited light availability (Koch and Beer, 1996).

- 2003 – present: Eelgrass is still only present in the eastern Sound embayments in Connecticut and the north fork of Long Island, Plum Island, and Fishers Island in New York. The most recent aerial survey conducted in 2017 mapped 1465 acres of eelgrass (Figure 5) (Bradley and Paton, 2018). Since 2003, the threats to eelgrass have remained the same and continue to contribute to lack of widespread success of eelgrass. However, one factor not mentioned in the 2003 report is temperature. Since 1960, water temperature in the open Sound has increased by 11.27% (with winter temperatures showing a 15.24% increase) (LISS, 2020). This finding is consistent with global trends, where the global average water temperature increase is 0.32°F/decade and the Sound is currently well above that at approximately 1°F/decade (NOAA, 2019). See threats for more details on temperature and other climate change driven impacts.

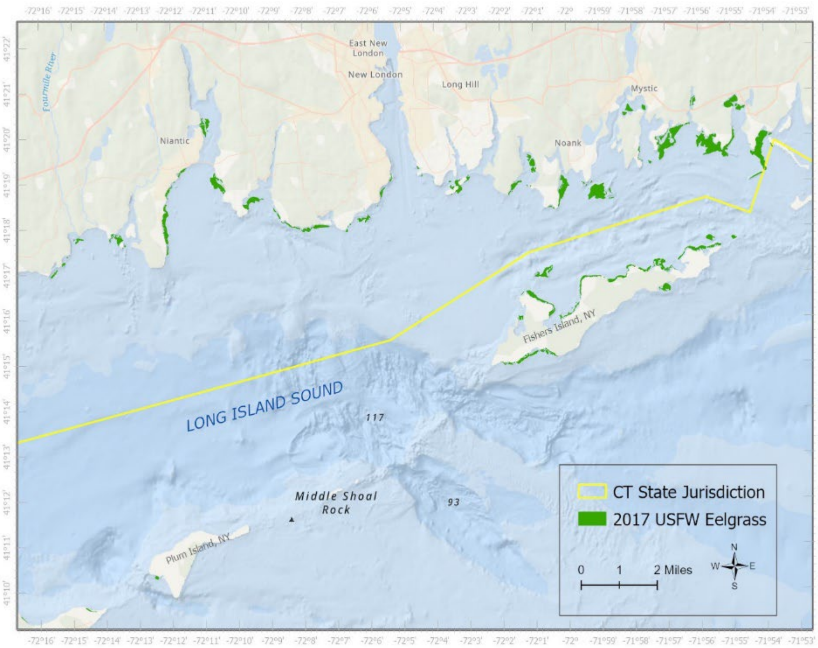

Figure 5 – Map of eastern Long Island Sound showing the eelgrass abundance, in green, mapped by the 2017 USFWS aerial survey (Source: Bradley and Paton, 2018).

Threats

The Habitat Restoration Manual identifies the following threats that are still present today (Appendix A):

- Impaired Water Quality
- Fishing and Vessel Related Activity
- Waterfowl and Storm-Related Damage
- Shoreline Erosion Control Structures
- Shading of Beds
- Dredge Activities & Fill

In the last few decades, with the help from new science and data, there have been new identified threats derived or enhanced by climate change:

- Temperature: Since the early 1990s, when Connecticut Department of Energy and Environmental Protection (CT DEEP) started the Long Island Sound Water Quality Monitoring Program, increases in both surface and bottom water temperatures have been observed (Figure 6 from Whitney and Vlahos 2021). A 30-year eelgrass dataset from Niantic River Estuary in Connecticut, collected by Millstone Environmental Laboratory at Dominion Energy, shows intense interannual variability (ranging from 4 to 92 hectares) primarily driven by temperature and followed by wind speed and sunlight (Vaudrey, Krumholz, and Calabretta, 2019). Plaisted and colleagues (2022) found that average summer water temperature, collected from eight sites spanning from New Hampshire to Maryland, can be used to predict the following year's eelgrass presence – where above average temperatures resulted in a decrease of eelgrass presence. In this study, annual summer mean temperatures were calculated from the daily mean summer temperatures from the continuous monitoring data available. Furthermore, in the Peconic Estuary, adjacent to the Long Island Sound, temperatures above 25°C caused metabolic imbalances in eelgrass and therefore emphasize the need to start monitoring temperature as a limiting factor, similar to light attenuation (O'Toole, 2020). Additionally, the decline in eelgrass induced by temperature increases impacts the species composition and diversity patterns in meadows, and impacts key ecosystem services such as habitat provisioning (Namba et al., 2018). If the increases in water temperature continue in Long Island Sound, and similar estuaries found in the Northeast and Mid-Atlantic region, eelgrass will also continue to decrease.

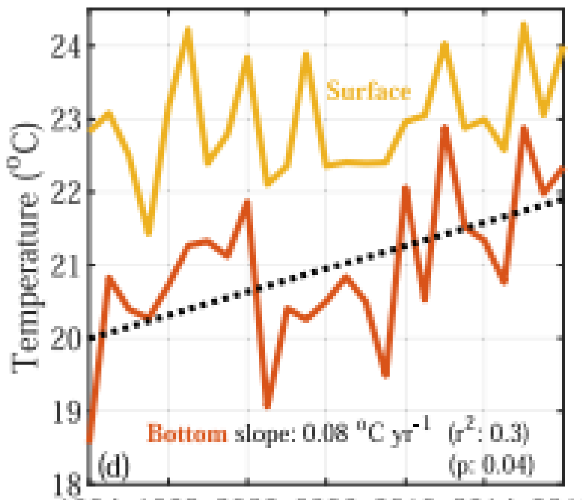

Figure 6 - Connecticut Department of Energy and Environmental Protection's (CT DEEP) Long Island Sound Water Quality Monitoring Program long-term temperature trends in the open Sound. Source: Whitney and Vlahos 2021.

- Sea Level Rise: In Long Island Sound, sea level is increasing along the shorelines of both New York and Connecticut. In the Sound, National Oceanic and Atmospheric Administration's (NOAA) long-term datasets show a ~1/10 of an inch increase each year – 50 percent higher than the global average (LISS, 2021). Changes in sea level impacts on the suitable range where eelgrass can grow. For example, previously available habitat may not be as suitable as light availability is limited. An estimated 0.5 to 3% of suitable habitat (based on depth at the deep edge of the suitable habitat in 2012) may be lost by 2030, with 1 to 7% lost by 2050 (Vaudrey et al., 2013). However, new habitat may become available along the shoreline where mud flats or marshes used to occupy space.
- Storm Disturbance: Increases in extreme weather events (i.e., storms, hurricanes) can also have implications on eelgrass meadows. The Bio-Optical Model developed for the Peconic Estuary Partnership in 2019 depicts eelgrass declines where bulkheads are located (O'Toole, 2020).

Not only will changing climate conditions impact eelgrass extent and productivity, but it will also severely impact the ecosystem services provided by eelgrass meadows (see Figure 7 from Reed et al., 2022). In addition, it is critical to consider the amplified impacts of multi-stressor interactions on eelgrass meadows. For example, the interaction between impaired water clarity and increased water temperatures are the main driver of eelgrass decline in Chesapeake Bay – particularly in shallow environments (Lefcheck et al., 2017).

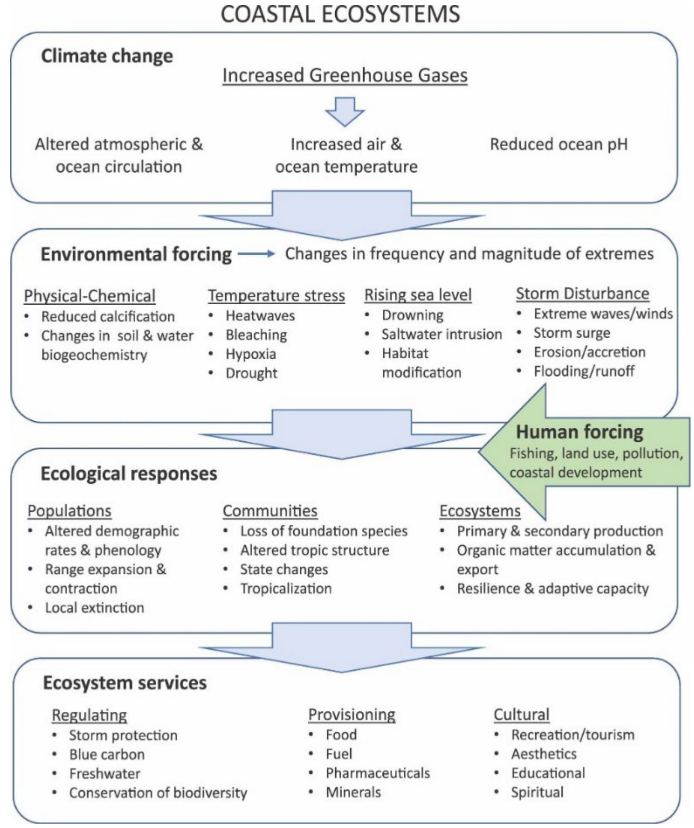

Figure 7 - Conceptual model showing how climate change impacts can scale-up to impact ecosystem services provided by seagrass meadows. Source: Reed et al., 2022

Gaps Hindering Progress

The following section outlines current gaps in addressing and progressing eelgrass management and restoration.

Aerial Surveys: Since 2002, eelgrass meadows have been intermittently monitored through USFWS aerial surveys. The most recent survey was conducted in 2017 and the next one is planned for 2023. These surveys provide valuable insight on eelgrass distribution, but there is a need to increase the frequency of surveys. These surveys have been conducted yearly for the Chesapeake since 1984 (Orth et al., 2010). At a minimum, a three year cycle for these surveys has been recommended by Bradley and Paton (2018). However, more frequent cycles (i.e., annual) are the best approach as eelgrass systems are dynamic. Additionally, these aerial surveys are weather dependent and therefore delays or missed surveys will disrupt the cycle. There are two main limitations to the aerial survey approach: consistent funding for more frequent surveys and a methodology to determine percent cover of eelgrass accurately and consistently within an area. There are other options for eelgrass distribution surveys, such as, drones and satellite imagery. Although it is possible to use these methodologies instead of aerial surveys, there is a need to determine the intercalibration between the approaches. There are some efforts completed or underway to explore these other methodologies:

- Aerial Photography Monitoring: The USFWS, with the University of Rhode Island, photographed the area previously identified with eelgrass in the Long Island Sound at a 0.5-1 meter resolution (Tiner et al., 2013; CT DEEP, 2007). Following data collection, photographs were interpreted and validated with ground-truthing. Please refer to the 2017 Report for more information (Bradley and Paton, 2018).
- Developing Methods to Use Drones for Embayment Assessments: CT DEEP is working to develop a methodology to conduct embayment assessments of eelgrass and terrestrial plant habitats using aerial drones. Pilot embayment sites (Niantic River and Beebe Cove) were selected, data will be collected, synthesized and assessed to produce a final report and recommended methodology.
- Determining the areal extent of seagrass in Long Island Sound using high resolution remotely sensed imagery (EPA Regional Applied Research Effort (RARE); ORD-025643): This project demonstrated the use of extracting eelgrass distribution, biomass, and forecasting primary productivity from Landsat 8 and Sentinel 2 spectral data in the mapped locations in Connecticut, Rhode Island, and Massachusetts (though some limitations exist with this methodology as mapped SAV could potentially be seaweed (i.e., *Cladaphoraceae* in Connecticut's and Rhode Island's Little Narragansett Bay, (Vaudrey, pers. comm)). In

these locations, using satellite imagery, the investigators were able to map leaf area index, biomass, and primary productivity (Figure 8). Please request the report for more information (Keith et al., 2018)

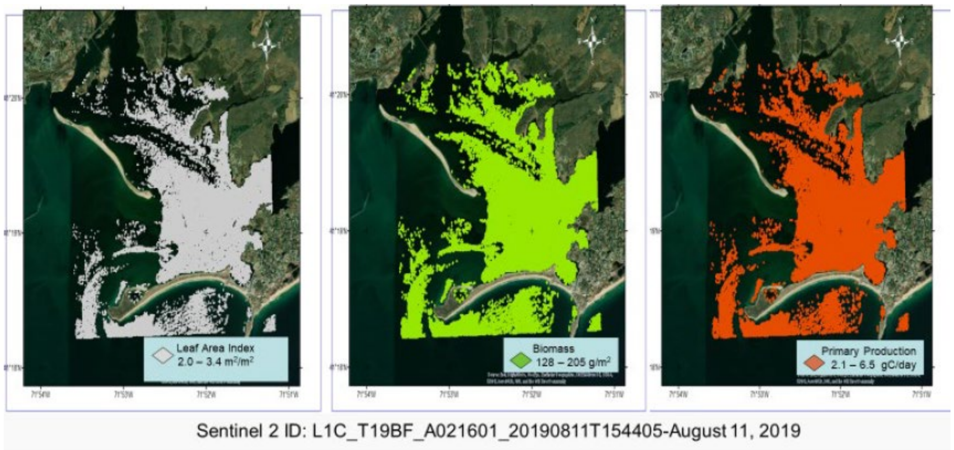

Figure 8 - The distribution of Sentinel 2-based leaf areas index, biomass, and primary productivity in Little Narragansett Bay in 2019

- Long Island Sound Study Water Quality Management Tool: The EPA Region 2's Long Island Sound Office, in collaboration with EPA Region 1, Office of Information Management, and Office of Research and Development, are developing a LISS Water Quality Management Tool to better understand water quality and climate drivers on eelgrass distribution and productivity. Open-science tools will be developed by compiling multiple embayment-specific water quality (i.e., water clarity, bottom water temperature, sediment texture, sediment organic matter, point source nutrient loadings) collected by LISS partners and climate (sea surface temperature and precipitation) datasets. The tool will utilize the pre-developed methodology (from the EPA RARE project) to estimate eelgrass distribution and productivity via satellite imagery that will then be overlaid with embayment-specific water quality (i.e., water clarity, water temperature, sediment texture, sediment organic matter, point source nutrient loadings) and climate (sea surface temperature and precipitation) datasets. This tool will help streamline management, synthesis, and analysis of large water quality and habitat quality data to provide data to inform management decisions by targeting locations for specific projects; improve assessment of program implementation and progress by understanding ecosystem health on a larger spatial and temporal scale that includes climate-driven trends; and improve communication of complex environmental data to decision makers at multiple levels of government (local, state, and federal), citizen science and community groups, academic researchers, and the public.

In addition to monitoring current eelgrass conditions, there is a need to conduct an analysis on historical eelgrass distribution in the Long Island Sound. Historic distribution of eelgrass based on historic botanical and vegetation literature (Rozsa, 1994) plus a review of herbarium specimens (Yarish et al., 2006) strongly indicates that eelgrass was common along all coasts of Long Island Sound. As noted by Rozsa (1994), modern taxonomic surveys indicate that early botanists accurately recorded plant distribution, paying special attention to noting absences of species and odd or sparse distributions. Thus, the paucity of eelgrass records in the botanical literature and among herbarium specimens prior to the 1930s is an indicator that the species was indeed widespread in Long Island Sound, as observed by a few authors. A number of reports indicate eelgrass presence along the Connecticut coast (as cited by Rozsa, 1994; Berzelius Society, 1878; Bishop, 1885; Graves et al., 1910; Nichols, 1920). Reports along New York are more sparse, likely due to less monitoring and research activity along the western shore of Long Island prior to the 1930s; though reference to eelgrass in Lloyd Harbor and inner Cold Spring Harbor support the notion that eelgrass was present along Long Island through the western Sound (as cited by Rozsa, 1994; Transeau, 1913; Johnson and York, 1915). Following the 1931 wasting disease epidemic, which was said to have reduced the population of eelgrass from North Carolina to New England by 99% (Cottam, 1931), little is known about the specific impacts of the epidemic in Long Island Sound. Scant evidence in the literature points to remaining populations being located in mesohaline waters, which Rozsa (1994) theorizes may have been a refuge for eelgrass from the wasting disease and likely allowed for the recolonization of eelgrass in eastern Long Island Sound that happened in the subsequent decades. To provide insight and confirm these historical trends in eelgrass abundance, there is a need to conduct an analysis using historical records (Yarish et al., 2006; Rozsa, 1994).

Monitoring: There is a lack of sediment and water quality monitoring, as well as physical conditions, related to eelgrass growth in Long Island Sound. In addition to the LISS *Eelgrass Extent* Ecosystem Target, there is also the *Water Clarity* Ecosystem Target in which the goal is to improve water clarity by 2035 to support healthy eelgrass communities and attainment of the *Eelgrass Extent* target. There is a need to increase sediment and water quality monitoring in eelgrass meadows to better understand drivers of distribution and productivity and determine the sediment and water quality conditions required to support growth in the Sound. Additionally, to better understand the eelgrass phenology and growth characteristics, there is a need to monitor areas where eelgrass is well-established and also struggling (i.e., biomass, shoot density, percent cover, etc.). For example, the LISS should consider monitoring well-established eelgrass meadows, like Fishers Island in New York and Mumford Cove and Beebe Cove in Connecticut, as reference sites for water quality conditions and enable the partnership to respond quickly if monitoring shows declines related to a specific threat. The table below shows current or planned monitoring programs in Long Island Sound:

Table 1 - Ongoing or future planned monitoring programs within eelgrass meadows in Long Island Sound embayments.

Monitoring Program	Organization	Location(s)	Parameters	Ongoing or Planned?	Seagrass Present?	Other Information
Unified Waters Study	Save the Sound	Stonington Harbor, Inner Niantic River, Mystic Harbor	Dissolved Oxygen, Water Clarity, Water Temperature, Salinity, Chlorophyll *a*, quantitative macrophytes (Tier 1); Continuous Dissolved Oxygen, Nitrogen, Phosphorus, Quantitative Macrophytes (Tier 2)	Ongoing	Yes	Other embayments included as well that do not have seagrass, but may score high under EHSI.
Weather Station	Connecticut National Estuarine Research Reserve	Avery Point (and also Ledge Lighthouse)	Air Temperature	Planned	No	
Seagrass Monitoring	Connecticut National Estuarine Research Reserve	Mumford Cove?	TBD	Planned	Yes	Contact: Jamie Vaudrey
University of Rhode Island Watershed Watch	Fishers Island Seagrass Management Coalition	Hay Harbor, West Harbor, Barleyfield Cove, East Beach	Water Clarity, Algal Chlorophyll *a,* Dissolved Oxygen, Water Temperature, Total and Dissolved Phosphrous, Ammonia, and Total and Nitrate-Nitrogen;	Ongoing	Yes	

			Not URIWW: Continuous Water Temperature; Boats and Beach Activity			
Weather Station	Flax Pond Marine Lab	Flax Pond, NY	Air Temperature	Ongoing	No	
Annual Monitoring Program	Dominion Energy's Millstone Environmental Laboratory	Niantic River	Water Temperature, Salinity/Conductivity, Dissolved Oxygen, pH, Inorganic Nitrogen and Phosphrous, Nitrate, Shoot Density, Macrophytes, Sediment Organic Matter, meteorological data (including light) collected year-round	Ongoing	Yes	
Embayment Data Collection	CT DEEP/USGS/UConn	Mystic River	Nutrients, Carbon, Total Suspended Solids, Silica, Alkalinity, Biological Oxygen Demand, and Chlorophyll *a;* Continuous Water Temperature, Specific Conductance, Salinity, Dissolved Oxygen, Turbidity, and Chlorophyll *a,* macrophyte area, percent cover, and leaf nutrient content, sediment grain size, sediment nutrients (C, N, P), pore water sulfide, benthic microalgae	Ongoing	Yes	
National Coastal Condition Assessment	EPA and CT DEEP	60 LIS embayments	Biological Conditions, Nutrients, Dissolved Oxygen, Chlorophyll *a,* Water Clarity, Sediment Quality, Fish Tissue Contamination	Collected in 2020 and 2021	Potentially	Eelgrass not targeted but there could be some sites in /around eelgrass areas. Data should be available in 2023.

Water Quality Management: The LISS has made great achievements in reducing nitrogen loading to embayments – specifically by reducing point sources from wastewater treatment plants through the implementation of the 2000 Dissolved Oxygen Total Maximum Daily Load (TMDL). Following implementation of the TMDL, nitrogen loading to Long Island Sound has been reduced by 64 percent through 2021. A load-response example can be seen in Mumford Cove where prior to the TMDL, the removal of a wastewater treatment plant discharge in Mumford Cove resulted in the subsequent expansion of eelgrass back into the cove. During 1945-1987, a municipal wastewater treatment plant had discharged nitrogen into the embayment in Mumford Cove, supplying nutrients to the Cove that fueled a massive macroalgae bloom of *Ulva lactuca* L. Once the outfall was diverted elsewhere, the macroalgae declined substantially by the growing season. With reduced nutrient inputs, the system recovered naturally over a period of 15 years, finally allowing for the unaided re-seeding of eelgrass to the Cove from beds located in nearby Long Island Sound (Vaudrey et al., 2010). To this day, eelgrass in Mumford Cove is present and abundant in the Cove, with some interannual variability observed (Vaudrey, pers. comm.).

Reducing nitrogen loading from point sources is an effective way to allow natural expansion of eelgrass meadows. However, nonpoint sources are an issue hindering the overall ecosystem health. Long Island Sound is surrounded by the north shore of Long Island, parts of New York City, Westchester County, and Connecticut. In addition, it is important to note that upper basin states, like Rhode Island, Massachusetts, New Hampshire, and Vermont, all contribute to this nonpoint source pollution problem as well. There is a need to better understand and mitigate nonpoint sources on a watershed-level. Furthermore, a recent assessment, performed by the New York and Connecticut Sustainable and Resilient Communities Extension Professionals, found that stormwater and associated flooding are the most common issues faced by coastal communities. The increase in stormwater and associated flooding leads to increased runoff and therefore nutrient loading that impairs water quality conditions in embayments. There is a need to better control nutrients from nonpoint sources to embayments and their resources like eelgrass meadows.

Changing Climate: Increases in water temperatures pose serious threats to eelgrass meadows that can amplify degradation and increase die-offs. Stony Brook University developed a Bio-Optical Model for the Peconic Estuary Partnership that identifies the following environmental factors dictating suitable habitat: light, temperature, depth, wind exposure, and hardened shorelines – in which the two most limiting factors were temperature and hardened shorelines (O'Toole, 2020).

There is a need to further investigate approaches to combat warming temperature implications on eelgrass meadows. One way to do this is to explore eelgrass genetics that are more resilient to stressors like warm water temperatures. A study performed in 2012 (Short et al., 2012) investigated genetic traits of eelgrass meadows in New England and New York. Out of the 39 sites samples, the investigators evaluated the resilience of 10 eelgrass populations and identified three metapopulations in the region that experience gene flow. More specifically, in New York, Great South Bay did the best in lateral shoot production under all stressors – specifically in high sediment organic matter conditions when water nitrogen was low (but independent of temperature and light stressors). Furthermore, other sites tested in the Long Island Sound region—Shelter Island, NY; Duck Island, CT; Ram Island, CT— did poorly under all stressors, suggesting that eelgrass resiliency is low in these sites. The next steps highlighted by the investigators is to perform more genetic screening of the Great South Bay metapopulation, particularly in relation to high temperatures associated with climate change. Additionally it is recommended to further investigate the value of populations with private alleles: Ram Island, Duck Island, Fishers Island, Plum Island, Moriches Bay, and Shinnecock Bay. Once further genetic analysis and mapping is completed, the next step identified by the investigators is to develop common garden studies to test the responses of identified resilient plant species in various in-situ environmental conditions. A common garden is an approach to bring in a wide array of plants (from many locations with differing environments) in a strategically selected location, determine which phenotypes survive and are productive, and then investigate if there are particular genotypes that were self-selected by the garden (Rellstab et al., 2021). This is the best approach to determine the phenotype and genotype responses to environmental conditions.

Utilizing genotypes that are identified as resilient to specific stressors, like temperature, are becoming a more common approach for various species (i.e., corals, oysters, etc.). To advance this approach for eelgrass, a Steering Committee, including representatives from Stony Brook University, Ocean Sewage Alliance, US EPA, The Nature Conservancy, Smithsonian Institute, and Northeastern University, held a series of workshops designed to discuss emerging techniques to address declining eelgrass populations which face pressures from warming waters along our coastline. The workshop discussed the benefits, risks, feasibility and scalability of identifying resilient populations/genetics, increasing genetic diversity/assisted gene flow, and selective breeding/hybridization/artificial selection. As mentioned previously, die-offs in the Long Island region occur at 25°C while in Virginia eelgrass die-off occurs at 30°C (Carr et al., 2012). There is a need to explore the potential of moving more resilient eelgrass species to the Long Island Sound region; however, transplants or seeding eelgrass into high organic sediments should only be conducted in shallow waters with high water clarity (Short et al., 2012). Additionally, the experts participating in this meeting noted transplant techniques to minimize or effectively eliminate the risk of invasive species introduction to consider. For example, bleach treatment of seeds followed by a distilled water rinse has been shown to have no additional negative impact on seed viability (though seed viability overall was about 47%) (Marion and Orth, 2010). A

In addition, there is a need to explore of restoration opportunities to combat climate change. For example, there is evidence that submarine groundwater discharge areas may act as temperature refugia for extant populations and/or restoration in embayments. There is a need to further explore temperature refugia sites in Long Island Sound to target for restoration efforts. With increases in extreme weather events, there is also an increase in hardened shorelines to protect coastal communities from storms. Currently, the US Geological Survey (USGS) is developing a Compound Flood Risk model to better understand the risks of compound flooding from the combined efforts of sea level rise on storm surge, tidal flooding, groundwater, and stormwater over multiple timescales ranging from short-term storm events to decadal-scale sea level rise. This modeling effort will produce outputs that can used to better understand storm and hardened shoreline impacts on eelgrass meadows. There is a need to reduce bulkhead development through policy change (town and state level). Additionally, implementation of more nature-based solutions, like living shorelines, should be capitalized on to reduce wave action and therefore stress to eelgrass meadows. As defined by the US EPA, a living shoreline is a green infrastructure approach to coastal improvement through the use of plants, reefs, sand, and natural barriers to reduce erosion and flooding while maintaining natural shoreline processes (EPA, 2022). In addition to reducing erosion and flooding, living shorelines can also provide habitat for fish and wildlife, enhance nutrient storage and cycling, and improve water quality and clarity. Some states, like Connecticut (CT General Statute 22a-92), are encouraging the use of living shorelines, rather than hardened structure to address flooding and erosion issues.

As mentioned before, under a warming climate, it is important to consider the amplified impacts of multi-stressor interactions on eelgrass meadows. Multi-stressors, as we have seen in Chesapeake Bay with poor water clarity and increased water temperature (Lefcheck et al., 2017), can enhance degradation rates by cumulative impacts. Increases in water temperature are harder to combat and therefore it is important to prioritize decreasing the impacts from other stressors (i.e., dredging, nutrient inputs, moorings, etc.) to mitigate the overall impact on eelgrass.

Modeling Updates: In 2013, Drs. Jamie Vaudrey, Charles Yarish, and Jang Kyun Kim of University of Connecticut, working with Chris Pickerell, Lorne Brousseau, and Justin Eddings of Cornell Cooperative Extension of Suffolk County developed the Long Island Sound Eelgrass Habitat Suitability Index (EHSI) Model to assist in the evaluation of potential restoration sites by identifying areas where water quality conditions are ideal for eelgrass growth. The exclusive band, or total potential eelgrass habitat, was first generated based on bathymetry and the assumption of excellent water quality supportive of eelgrass being continuous throughout Long Island Sound, based on the following parameters: bathymetry, mean tidal amplitude, and percent light reaching the bottom (assuming water clarity throughout the Sound is similar to the level currently attained near Fishers Island). Then the Sum of Reclassified Parameters map was generated to include another set of parameters that are most related to eelgrass growth, utilizing current (not idealized) conditions: percent light reaching the bottom, temperature, dissolved oxygen, sediment grain size, and sediment total organic carbon. The model generates a suitability score on a 0-100 scale (least to most suitable) based on a weighted sum of the individual parameter scores (Figure 9). There is a need to incorporate both updated data related to these parameters, but also add new data that are influential on eelgrass growth. For example, although the 2013 model included bathymetry data, it lacked data in shallow waters, thus overestimating the potential distribution as the exclusive layer included mud flats and intertidal areas that are highly unlikely to support eelgrass (Koch and Beer, 1996). Future updates of the model should include the ability to identify the minimum depth for eelgrass at the lowest low tide. A recently completed project, led by CT DEEP, assessed depth profiles for embayments using NOAA data and therefore would be sufficient to update the EHSI model in Connecticut (and a similar analysis could be applied to New York waters). Additionally, since 2013, temperature data from water quality monitoring groups (i.e., Save the Sound's Unified Waters Study) increased and can be used to highlight these prominent limiting parameters previously not included in the model (see Framework section for more detail). As mentioned previously, the Bio-Optical Model, developed by Stony Brook University for Peconic Estuary Partnership, identifies the following environmental factors dictating suitable habitat: light, temperature, depth, wind exposure, and hardened shorelines (O'Toole, 2020).

Additionally, other ongoing modelling efforts may be useful to leverage and create linkages. For example, the New York City Department of Environmental Protection Living Resource Model may include SAV into their model, specifically, to calculate the water clarity standard for restoration and account for positive feedbacks from SAV that improve water clarity. The Living Resource TAC will help define needs/model approach for EHSI.

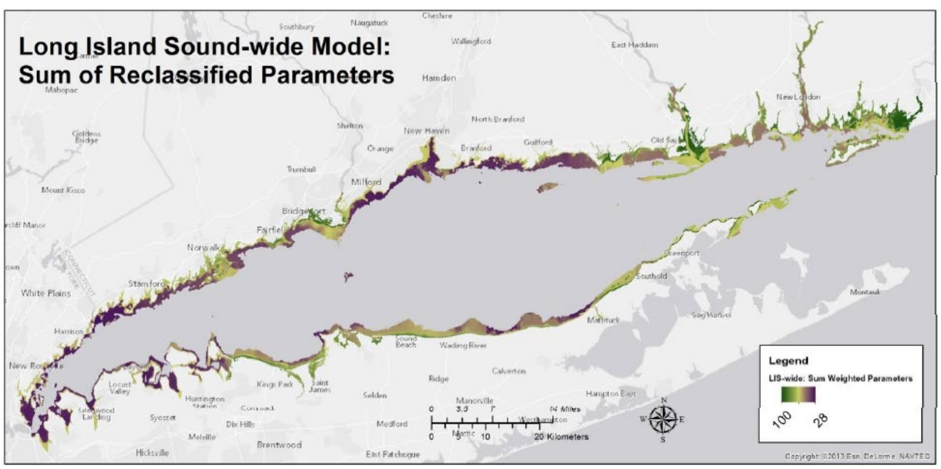

Figure 9 - The Eelgrass Habitat Suitability Index Model output showing the most suitable areas for eelgrass growth in green, and the least suitable in purple. Source: Vaudrey et al., 2013

Eelgrass and Aquaculture Interactions: Eelgrass and shellfish both thrive in intertidal and shallow subtidal habitats and there is the potential for overlap of eelgrass habitat and shellfish aquaculture in nearshore Long Island Sound and other estuaries. According to the last eelgrass aerial survey conducted in 2017, there is only one known location where eelgrass and active commercial aquaculture overlap – at the mouth of the Mystic River in Groton. Research conducted at this location found that short-term depuration of oyster aquaculture gear had no effect on eelgrass growth, water quality, and sediment; however, the authors noted that if depuration activity expands in terms of the amount of gear and/or individual operations, measurable effects may result (Vaudrey et al., 2009). Although, the overlap between the two resources is currently minimal; existing regulations inhibit the expansion of both eelgrass restoration and new aquaculture efforts, as there is a use conflict between eelgrass and aquaculture. In Connecticut, aquaculture beds are not allowed in eelgrass meadows, thus eelgrass restoration is highly unlikely to be approved in active shellfish lease areas. Much of Connecticut's submerged lands suitable for eelgrass are already designated as State or Town lease areas, though much of those designated leases are inactive (not currently under an active lease, but designated and available for leasing). This potential use conflict triggers the need to consider how to address the potential for human-assisted eelgrass restoration in designated leases that are not currently active. In New York, shellfish gear and harvesting are also restricted in eelgrass meadows. The two regulations protect, but also limit, eelgrass and shellfish growth in the Sound. There is a need to better coordinate among designated resource managers, regulators, and user groups to implement best management practices that protect the resources, but also enhance growth of both eelgrass and aquaculture. Washington State has implemented best management practices to allow the two resources to be present and grow, but also still be mindful of the conflict that may come into play. Specifying best management practices is key, for example, Washington indicates that oyster longlines and flipbags are to be spaced 10 feet apart laterally in eelgrass areas to minimize negative impacts of shading (Ferriss et al., 2019).

Although overlap is currently minimal, there is a need to further explore the interactions between eelgrass and aquaculture efforts in Long Island Sound to facilitate the shared goals of resource protection and sustainable industry growth. A quantitative meta-analysis by Ferriss and colleagues (2019) reviewed 31 research studies and concluded that eelgrass has varying responses to aquaculture depending on eelgrass characteristics, aquaculture gear type and grow-out methods, and geographic location. Overall, the on-bottom grow-out methods with no associated gear or predator exclusion devices decreased eelgrass density and biomass, had no effect on eelgrass structural characteristics, and increased eelgrass growth and reproduction (which is often a response to stressful conditions; see for example, Jarvis et al., 2012; Vercaemer et al., 2021). The authors noted that increased growth and reproduction may have been a response to disturbance (Feriss et al., 2019). Off-bottom grow-out methods (e.g., long-line and suspended bag) decreased eelgrass density, percent cover, and reproduction, and had no effect on biomass or growth. Authors documented recovery of eelgrass density after all harvest methods, but noted that mechanical harvest created greater initial impact and longer recovery times than manual harvest. However, the authors note that significant positive or negative impacts at a single site may have been masked, or neutralized, due to the combined analysis among the 31 study sites. The results of this review are informative, but identify that further research is needed as eelgrass responses to aquaculture varies depending on eelgrass characteristics (i.e., phenology and reproduction), grow-out, gear and harvest methodologies, and environmental conditions (i.e., regional or embayment specific).

Public Awareness: Another gap that hinders support for the natural expansion of eelgrass is the lack of public knowledge and awareness about its importance. Recreational activity like boating can cause harm to eelgrass meadows. For example, prop scars caused by boaters in shallow areas uproots the entire plant, leaving areas bare of roots and rhizome which allow the eelgrass to grow. Increasing public awareness about the importance of eelgrass meadows can facilitate the implementation of bylaws to increase protection. Some activities that can be covered in these bylaws are boating/anchoring restrictions to prevent disturbances in eelgrass meadows. Furthermore, Fishers Island Seagrass Management Coalition is working on education and outreach to Fishers Island and Connecticut stakeholders who are boating or landowners/property caretakers. More specifically, they are implementing a pledge campaign to encourage people to be seagrass safe when they are engaging in activities that could affect the eelgrass. The Fishers Island Seagrass Management Coalition Coordinator has found that during the coalition's work in community engagement, there are some people on Fishers Island who know about eelgrass beds, want to protect them, and are upset that people from other areas harvest seeds from around Fishers Island. To that end, there is a need to collaborate with the scientists harvesting seeds from Fishers Island to try to frame the harvesting in a more positive light as well as educating the local population on the minimal impact seed harvesting has on local beds.

Regulations and Implementation: Increasing public knowledge and awareness may also facilitate the implementation of rules and regulations that amplify the management and restoration of aquatic resources. For example, in response to increasing public awareness and concern for water pollution, the Federal Water Pollution

Control Act of 1948, known as the Clean Water Act (CWA), was amended in 1972. The following amendments improved the regulation of pollution (EPA, 2022):

- Established the basic structure for regulating pollutant discharges into the waters of the United States.
- Gave EPA the authority to implement pollution control programs such as setting wastewater standards for industry.
- Maintained existing requirements to set water quality standards for all contaminants in surface waters.
- Made it unlawful for any person to discharge any pollutant from a point source into navigable waters unless a permit was obtained under its provisions.
- Funded the construction of sewage treatment plants under the construction grants program.
- Recognized the need for planning to address the critical problems posed by nonpoint source pollution.

The better control over pollutants not only improved water quality conditions, and therefore public heath, but also environmental health (i.e., the re-establishment of Long Island Sound eelgrass in the 1990s). The CWA is an example why regulation and implementation is critical to protect and restore resources effectively. Establishment of the CWA led to the development of other regulations to fill in gaps and better protect the environment – for example, in 1996, the Magnuson-Stevens Act was created to protect essential fish habitat like submerged aquatic vegetation. Although it is advantageous to have multiple regulations and rules to better protect resources, there may be some associated limitations. For example, existing federal and state (i.e., New York State Seagrass Protection Act) regulations in place with the overall objective to protect seagrass, but there is a need to increase communication among federal and state regulators to ensure interpretation and messaging is consistent, and thereby maximize protection.

As highlighted in the previous section (Eelgrass and Aquaculture Interactions), there is a need for more coordination between federal, state, and local agencies and organizations. It is important to align strategies, goals, and objectives to better meet the ultimate goal of protecting and restoring resources. In 2009, the New York State Seagrass Task Force published a Final Report including recommendations to the New York State Governor and Legislature. More specifically, the report states that, "the New York State Seagrass Task Force, charged with developing recommendations to restore, research, preserve, and manage seagrass, acknowledges the critical need to protect seagrass resources, improve and maintain water quality, manage seagrass resources, monitor the health and extent of seagrass, research seagrass dynamics and impacts, restore seagrass and seagrass habitat, and educate and engage New Yorkers." Specific actions can be referred to in the report, but more coordination can help streamline and enhance implementation to meet goals.

Framework

Year 1-2:

- Create a Long Island Sound Eelgrass Collaborative Network (herein called Network) – the objective of this network is to oversee the implementation of the Eelgrass Restoration and Management Strategy. See below for specific sub-tasks that the Network would provide guidance and recommendations for:
    - Provide a platform for information sharing. For example, the network will host speakers from around the country that can provide additional guidance and lessons learned regarding seagrass restoration and management.
    - Closely work with state partners to identify and remove barriers to restoration (i.e., transplants, seed dispersal/sourcing, hardened shoreline, common garden logistics, use conflicts)
        - Develop a detailed implementation strategy/pilot project to identify resilient genotype populations in Long Island Sound embayments. Once identified, a next step would be to implement a common garden. A common garden is an approach to bring in a wide array of plants (from many locations with differing environments) in a strategically selected location, determine which phenotypes survive and are productive, and then investigate if there are particular genotypes that were self-selected by the garden (Rellstab et al., 2021). Once a population is selected as more resilient, the common garden can be used to efficiently increase production numbers (i.e., seeds) for future restoration projects. This effort is part of a broader regional effort led by the Steering Committee in which the Network will work closely with this Committee to ensure Long Island Sound efforts/timelines are aligned for future common garden implementation.
            - The Network will define what is a resilient genotype and the approach to do this (i.e., field and lab/mesocosm). More specifically, the goal is to identify a genotype that is more resilient to temperature changes.
        - In the event that a Long Island population cannot be identified as resilient, then the Network will explore alternative options. For example, investigating if there is a southern eelgrass population that is identified as more resilient to temperature increases. The Network will work closely with New York and Connecticut to ensure regulations are being met. There are methodologies to ensure marine pathogens from other locations are removed (Marion and Orth, 2010). Dr. Brad Peterson at Stony Brook University is currently working with Cornell Cooperative Extension and New York State Department of Environmental Conservation (NYSDEC). In 2008, Dr. Peterson and Dr. Fred Short identified resilient populations at Duck Island, however the phenotypes did not match genotypes. The next step of this effort, suggested by Dr. Peterson, is to plant the identified population elsewhere to determine if the phenotypes improve with different environmental conditions. The need associated with this next step is finding a partner who has capacity for genetic analysis
    - Advise and scope out requirements to update the Eelgrass Habitat Suitability Index (EHSI). Additionally, the Network will identify any data collection that should be done prior to the model update (i.e., data collection).
    - Work closely with CT DEEP and the Connecticut Aquaculture Permitting Work Group to alleviate user conflicts between eelgrass and aquaculture. More specifically, communicate and coordinate with the work group on site selection for eelgrass restoration, ensure research is aligned with management goals of the regulatory agencies, and explore approaches and best management practices for the two resources to co-exist. Additionally, the Connecticut Aquaculture Permitting

Work Group and Network will ensure that both the Connecticut Shellfish Restoration Plan and Long Island Sound Eelgrass Restoration and Management Strategy are complimentary.

- Work closely with NYSDEC and the New York State Seagrass Task Force to help implement the actions outlined in the Report of the New York State Seagrass Task Force: Recommendations to the New York State Governor and Legislature. Specifically, work with NYSDEC to establish management areas, advocate to fulfill the current vacant Seagrass Coordinator position, and identify aquaculture groups, such as Long Island Oyster Growers Association (LIOGA) and Long Island Farm Bureau (LIFB), to work closely with to alleviate user conflicts. Additionally, as NYSDEC develops their Shellfish Restoration Plan (to be completed by summer/fall 2023), the Network will work closely with the State to ensure the two plans are complimentary.
- Work with all LISS partners and regional Long Island Estuary Programs (South Shore Estuary Reserve and Peconic Estuary Partnership) to address similar priorities and actions outlined in this strategy and develop new actions as new science and needs arise.
    - Work with partners that would enhance communication and outreach efforts, including but not limited to: US Department of Agriculture's Natural Resource Conservation Service Outreach Specialist, Long Island Nitrogen Action Plan/NYSDEC, LISS Sustainable and Resilient Communities Extension Professionals, and LISS Bioextraction Coordinator. The goal is to increase public awareness about threats to eelgrass and the importance of protecting this resource – with emphasis on septic system upgrades/replacements, lawn care, and nature-based shoreline solutions. Identify a Community Based Social Marketing approach for education (i.e., boating safety). Additionally, the Sustainable and Resilient Communities Extension Professionals can conduct specific outreach to municipalities that have eelgrass in their embayments.
    - Work with regional partners to define what the edge of an eelgrass meadow constitutes (i.e., where does the regulatory authority extend out to). This gap comes up with eelgrass-aquaculture interactions, and needs to be defined to better protect both resources.
    - Work with other regional National Estuary Programs to implement a large-scale restoration effort.

- Update the Eelgrass Habitat Suitability Model and Data Collection (if needed) – As described under Gaps Hindering Progress, the EHSI was developed by Dr. Jamie Vaudrey and colleagues in 2013 to better inform decision-makers where eelgrass restoration projects would do well depending on the following parameters: percent light reaching the bottom, temperature, dissolved oxygen, sediment grain size, and sediment total organic carbon. However, since this update, there has been more data produced which may help further define these areas and better understand where eelgrass is absent and why. The following bullets are parameters suggested to be included in the update:
    - Nutrient inputs and transportation
    - Bathymetry in the shallow end of the spectrum
    - Climate conditions
        - Temperature – Rising temperatures, as mentioned under Threats, is becoming a main driver of eelgrass die-offs.
        - Wave Exposure – With changing shorelines, wave exposure is becoming more a driver in eelgrass growth.
        - Hardened Shoreline Impacts – With changing shorelines, wave exposure is becoming more a driver in eelgrass growth.

        - Currents – Some restoration techniques are being used (i.e., rock planting method) to combat currents/wave exposure. However, new issues arise with sediment type (i.e., finer sediment).
        - Frequency/Intensity of Storms – Increases in extreme weather event, like precipitation, increases freshwater inputs into embayments. This increase changes the salinity and nutrients in the water column.
        - Sea Level Rise – With rising sea levels, the potential habitat for eelgrass is changing; with previous habitat becoming less suitable due to increased depth and new shallow habitat becoming available. While previous modeling has shown that eelgrass will be able to tolerate sea-level rise (Carr et al., 2012), the change in suitable habitat needs to be taken into consideration for future restoration projects.
        - Sulfide Concentration – Although not directly linked to climate, increased temperatures can have a major impact on the sediment-plant interactions by influencing sulfide concentration (Koch et al., 2007). Therefore it is recommended to sample sulfide concentration in mid-July to early September when sulfide is most problematic.
        - Groundwater Inputs – There is evidence that submarine groundwater discharge areas may act as temperature refugia for extant populations and/or restoration in embayments. USGS groundwater budgets and transfers models in both CT and NY may provide insight for potential areas of restoration.
    - Scenario model – It would be useful if the update can also include scenarios related to water quality management, restoration implementation, and predictions of changing parameters. Users can utilize the model to then make more informed decisions regarding these types of projects and which techniques/practices are likely to be most successful in future environments (i.e., sea level rise, temperature, precipitation, etc.)
    - Incorporation of more resilient populations into the model
        - If populations are identified to be more resilient to higher temperature (2°C increase) or other parameters (i.e., bathymetry), how much habitat becomes available in the EHSI?
- Enhance Continuous Water Quality Monitoring and Initiate Human Activity and Eelgrass Monitoring – This is a three phased approach to enhance monitoring related to eelgrass meadows.
    - Phase 1: Continuous Water Quality Monitoring – Phase 1 will be focused on enhancing water quality monitoring specifically related to eelgrass meadows. Sites will be selected in established meadows, struggling meadows, and embayments with high eelgrass habitat suitability but no eelgrass present (identified by the EHSI). Continuous monitoring, at a minimum, needs to include temperature sensors (both water and/or air). Secondary parameters include turbidity and chlorophyll-*a*. Since sensors require a lot of maintenance, an alternative would be to use bioindicators, like using a periphyton sampler to measure epiphytic seaweeds. Eelgrass in the habitat acts as a substrate for organisms collected by these plates; too many epiphytes are stressful to eelgrass. These would be a good indicator for whether a location would be suitable for eelgrass, if all other conditions look suitable. Additionally the presence of *Laminaria* and *Chondrus* on rocks (but occurrence of green algae may suggest poor water quality; sand ripples and waves may indicate current or wave-driven sand movement; and debris, shell, mud, or macroalgae may indicate high organic matter, sulfides, ammonia, and bioturbation) (LISS STAC, 2020)
    - Phase 2: Initiate Eelgrass Monitoring – To better understand eelgrass productivity metrics (i.e., phenotypes), more regular monitoring should be initiated in selected site. There should be a goal of establishing several SeagrassNet monitoring sites within New York (i.e., Fishers Island) and

Connecticut (i.e., Mumford Cove and Beebe Cove). SeagrassNet is a global monitoring program with accepted methodologies. Sediment sampling (grain size, organic content, carbonate content) is included in the SeagrassNet protocol, but the addition of sulfide sampling is recommended.

- Phase 3: Initiate Human Activity Monitoring – To better understand community uses in embayments (boat anchoring, clamming, swimming, etc) on eelgrass productivity and distribution, future monitoring can include monitoring anthropogenic impacts on eelgrass meadows. Once a better understanding is obtained, municipalities can implement enclosures to limit and/or prevent disturbance from recreational activity (i.e., boating, swimming, etc.).

- Continue and Enhance Remote Sensing Surveys – Since 2002, eelgrass meadows have been intermittently monitored through USFWS aerial surveys. The last survey was conducted in 2017 and there is a need to not only continue these surveys, but ensure they are more frequent. The work group recommended conducting the aerial surveys annually with every three years as the minimum. The next aerial survey is scheduled for June 2023. If annual surveys cannot be completed, there are options to fill in the gaps including selecting a series of sentinel sites for survey using alternate techniques such as drones or underwater cameras to revisit either a select point or transect; a tiered structure for eelgrass monitoring which is a combination of aerial surveys, percent cover at random points at select sites, and establishment of SeagrassNet sites; use of in-water shoot density counts or video surveys; or use aerial imagery produced by Google Earth (but this is captured in the winter where water clarity is the best but biomass data may be lost). Another option is to use satellite imagery to estimate eelgrass distribution and productivity. For both aerial and satellite surveys, ground-truthing would be needed to assess the accuracy of mapping. However, there is a need to conduct an intercalibration study to assess the comparability between these methodologies (drones, aerial, underwater camera, and satellite) as detection limits pose concerns. While these surveys give a solid understanding of the current distribution of eelgrass, smaller patches or eelgrass sparsely mixed with macroalgae are harder to detect. In order to identify these smaller patches, which may not help meet our ecosystem target but may serve as potential successful restoration efforts, there needs to be a more coordinated effort. The following should be done to fulfill this gap:
  - Conduct an intercalibration study to assess the comparability between these methodologies (drones, aerial, underwater camera, and satellite) as detection limits pose concerns Leverage local knowledge.
  - Obtain local knowledge from fisher/water user groups as they could provide valuable information to identify cryptic eelgrass meadows.
  - Utilize drone surveys to cover smaller-scale areas
  - Ground-truthing for the update to the EHSI model may identify extant eelgrass meadows already growing at highly favorable sites.
  - Investigate other satellite imagery approaches. For example, Plant.com is a satellite company that has deployed 200 shoe-box size satellites that fly over the entire earth daily. This imagery is at a 3-meter pixel resolution. If you have a research subscription, the satellites can be tasked to fly over a particular area with a resolution of 1-meter.
  - Partners included in the Network will compile a database, similar to that used by SeagrassNet, where users will report a GPS location, GPS location methodology, environmental condition, and eelgrass conditions (if possible)
  - Develop a tiered approach specific to Long Island Sound that incorporates results and lessons learned from remote surveys and SeagrassNet sites
- Analysis of Historical Data: In order to confirm the eelgrass distribution trends in Long Island Sound before aerial imagery, there is a need to conduct an analysis of historical data. Historical data sources may include the botanical and vegetation literature, herbarium samples, nautical charts, Department of

Transportation aerial photographs, military photographs from World War II, University of Connecticut and CTECO's historical images, Cornell Cooperative Extension's aerial photos, and US Army Corporation of Engineer's permitting maps.

Year 2-3:

- Long Island Sound Eelgrass Collaborative Network will continue to progress and stay informed about action items from Year 1-2 and update priorities as needed.
    - Utilize the USGS Clearinghouse and QuickDrops to share data if these databases ready
    - Leverage off of C-GRASS, an International work group aiming to store seagrass data
- Move forward with Identification of Eelgrass Resiliency and Common Garden Implementation:
    - Identify current genotypes within Long Island Sound via genetic offset methodology. Genetic offset methodology is the approach combining genomic and environmental data from different time points and/or location to evaluate potential maladaptation to new conditions (i.e., temperature) (Rellstab et al., 2021)
    - A list of items to consider when ready to implement a common garden:
        - Costs and logistics (Defer to Steering Committee)
        - In-situ or mesocosm? If so, is there a facility space and resources?
        - Learn from Great South Bay common garden for assisted gene flows
        - Learn from University of Rhode Island as they had 12 tanks specifically designed for eelgrass common garden experiments
            - Other potential hosts may include Academic institutions (University of Connecticut, Stony Brook University); Cornell Cooperative Extension of Suffolk County; Flax Pond; Southhampton; shellfish hatcheries not in use
- Continue to conduct and expand aerial surveys (i.e., annually preferred)

Year 3-5+:

- Organize a workshop to identify trends, progress, and next steps
- Compile, synthesize, and analyze continuous eelgrass and water quality monitoring data to understand interannual variability
- Utilize the EHSI model outputs to make informed decisions about: 1) Embayment-specific water quality improvement projects to reduce nonpoint source nutrient loads and improve conditions for eelgrass meadows and 2) Eelgrass restoration projects
    - Leverage off of existing nutrient reduction plans: Nassau and Suffolk County 9 Element Plans and Connecticut Watershed Plans
    - Utilize information from CT DEEP's embayment modeling framework as the contractors provided information for each embayment regarding the potential to support eelgrass. The updated EHSI will also help CT DEEP in identifying areas that eelgrass can grow following water quality improvements. It can also be considered when prioritizing embayments for study and Total Maximum Daily Loads. When CT DEEP develops Total Maximum Daily Loads, the potential for eelgrass will trigger nutrient targets supportive of eelgrass. Those targets will be allocated to point sources and nonpoint sources, as appropriate.
- Continue eelgrass resiliency mesocosm experiments/common garden experiments; potentially expand common garden to other areas
- Following 3-4 years of monitoring and piloting small-scale restoration projects with common garden or existing meadow with high genetic resiliency seeds, aim to have a large scale restoration project installed in the Sound (in CT and NY)

Implementation

The purpose of the implementation section is to provide potential resources to implement the actions outlined in the framework.

Funding

Long Island Sound Study

Each federal fiscal year, the LISS supports our partners through various agreements to carry out proposed work addressing our identified priorities and CCMP. These priorities are identified by the following work groups in the partnership: Watersheds and Embayments, Water Quality Monitoring, Nitrogen Coordination, Habitat Restoration and Stewardship, Sustainable and Resilient Communities, Climate Change and Sentinel Monitoring, Community, Engagement, and Outreach, Environmental Justice, Indicators Review Team, and Federal Partners Coordination. For more information, please see the website.

Long Island Sound Research Grant Program

The Long Island Sound Research Grant Program, funded by EPA Long Island Sound Office (LISO) and administered by Connecticut Sea Grant and New York Sea Grant, awards funds to researchers to conduct work to help meet the needs of decision-makers to improve the management of the Long Island Sound. In addition to the research topics previously identified in the framework, additional research topics for future RFPs include:

- Investigate the relationship between eelgrass meadows and coastal acidification; specifically how eelgrass acts as buffer and therefore refugia for other important species (i.e., shellfish)
- Common garden experiments and genetic/phenotypic plasticity and phenology investigations
- Climate change impacts on eelgrass distributions
- Investigate southern eelgrass populations' response in Long Island Sound waters
- Utilize the Nutrient Pollution Index – potential collaboration with EPA ORD
- Confirm light deficiency in declining eelgrass habitats using physiological biomarkers in the eelgrass plants

Long Island Sound Futures Fund

The Long Island Sound Futures Fund, funded by EPA LISO and administered by National Fish and Wildlife Foundation, supports projects in local communities that aim to protect and restore the Long Island Sound.

- Community Based Social Marketing at public access sites
- Learn from Fishers Island Seagrass Management Coalition. Educate political leaders about their resource and then educate the public.
- Seagrass Spotter/community science effort
- Pilot new restoration techniques:
    - Building off the 2021-2023 LISS Research Grant Program-funded project: Improving Eelgrass Restoration Success by Manipulating the Sediment Iron Cycle (Drs. C. Tobias and J. Vaudrey, University of Connecticut)
    - Interactions between eelgrass and shellfish restoration efforts
    - Conservation moorings to protect eelgrass beds
    - Large-scale restoration with broadcast seeding (regional effort)

Other Potential Funding Opportunities:

- Offshore wind could act as a source of mitigation funds for restoration projects, especially as transmission lines are likely to traverse eelgrass habitat when closer to shore
- Explore funding within the Estuary Restoration Act

- NYS OCA Task Force – called out eelgrass (could be a management funding opportunity)
- Potential CT Legislation for stakeholder advisory group and/or directed state funding
- NOAA BIL (Habitat Restoration)

Conclusion

This document provides guidance for short- and long-term actions that should be taken to manage and restore eelgrass meadows in the Long Island Sound and serves as a resource for other estuaries in the region facing similar issues. This is a living document meaning that as new research, resources, and information becomes available, the gaps and required actions may change. This strategy focuses on previously known threats and expands on new threats exacerbated by climate change. The work group that was convened will continue to meet to progress this strategy through the Long Island Sound Eelgrass Network Collaborative. The Collaborative will tackle the following priority items: 1) increase coordination, 2) enhance monitoring, 3) update modeling efforts, and 4) investigate unique restoration techniques (i.e., genetic resiliency).

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

LONG ISLAND SOUND HABITAT RESTORATION INITIATIVE

TECHNICAL SUPPORT FOR COASTAL HABITAT RESTORATION

Submerged Aquatic Vegetation

LONG ISLAND SOUND HABITAT RESTORATION INITIATIVE

SECTION 3: SUBMERGED AQUATIC VEGETATION

Technical Support for Coastal Habitat Restoration

SECTION 3
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SECTION 3: SUBMERGED AQUATIC VEGETATION

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 modifer	Salinity (ppt)
Marine	euhaline	>30.0
Estuarine (brackish)	polyhaline mesohaline oligohaline	18.0-30.0 5.0-18.0 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).

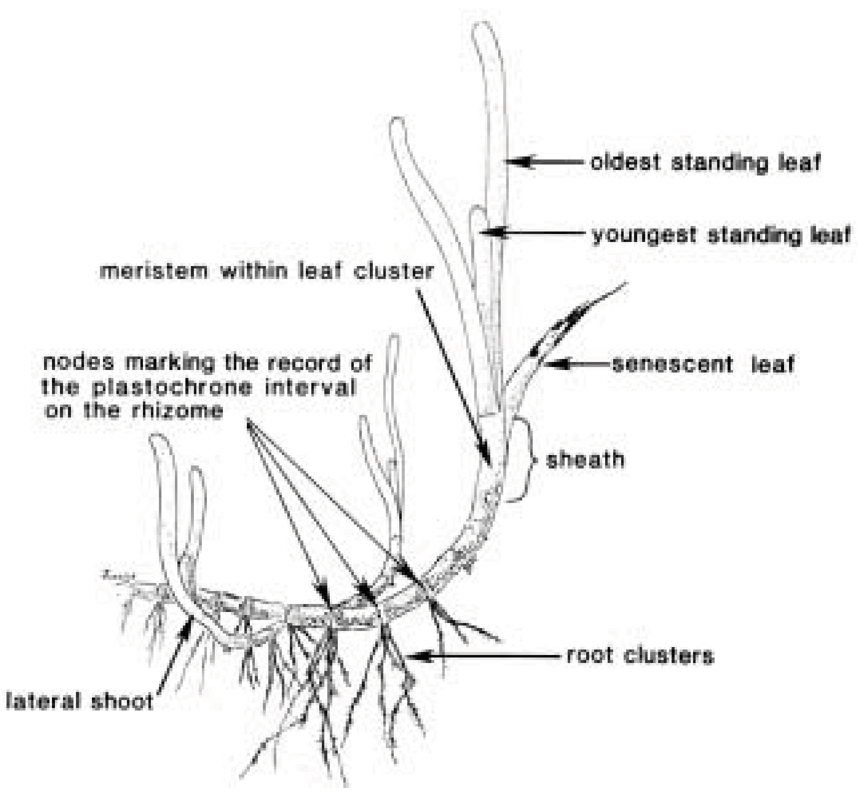
Mesohaline, oligohaline, and freshwater species of SAV have not been well studied in the Long Island Sound watershed. Until the status, trends, and water quality requirements of these species can be further researched, it is not possible to define goals for habitat restoration efforts. For this reason, 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 ft^{-2}), 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 and12 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	*Ilyanassa obsoleta*	sand shrimp	*Crangon septemspinosa*
northern lacuna	*Lacuna vincta*	blue mussel	*Mytilus edulis*
common periwinkle	*Littorina littorea*	blue crab	*Callinectes sapidus*
lunar dovesnail	*Mitrella lunata*	hermit crab	*Pagurus longicarpus*
bay scallop	*Argopecten irradians*	horseshoe crab	*Limulus polyphemus*
northern quahog	*Mercenaria mercenaria*	bluefish	*Pomatomus saltatrix*
softshell clam	*Mya arenaria*	striped bass	*Morone americana*
common clamworm	*Nereis virens*	winter flounder	*Pleuronectes americanus*
isopod	*Idotea triloba*	lobster	*Homarus americanus*

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 m^{-2} 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 (Buchsbaum, 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 *Labyrinthuyla 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 completely[1] 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 absent*[2] 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

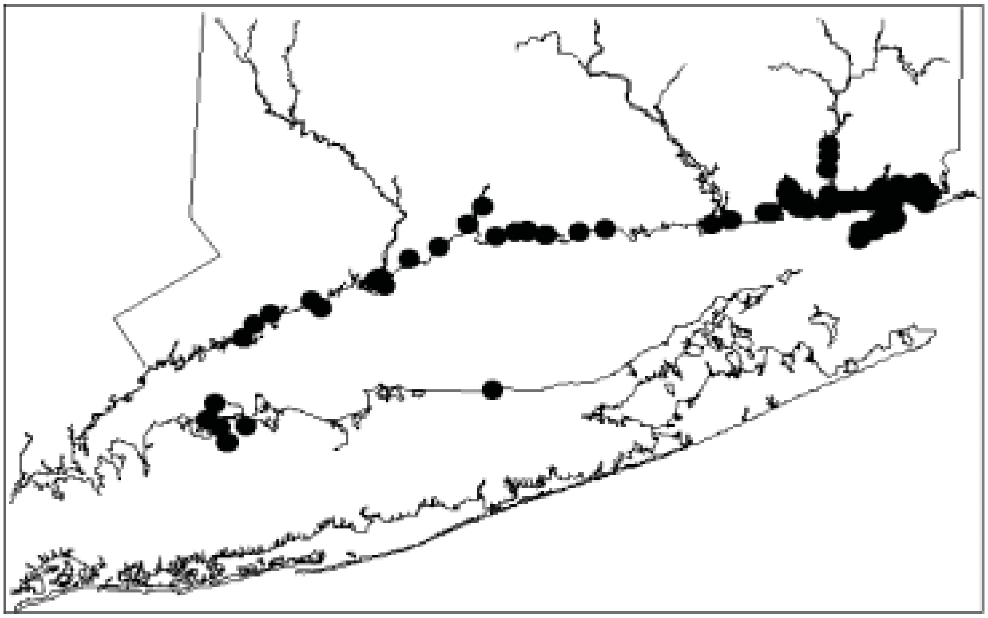
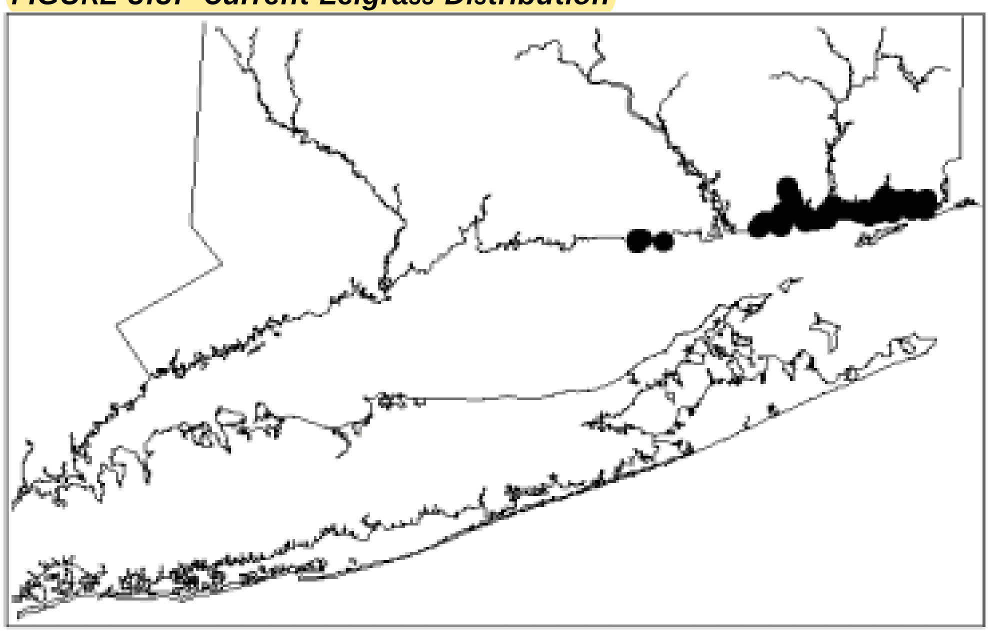


FIGURE 3.3. Current Eelgrass Distribution



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) ide[illegible]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

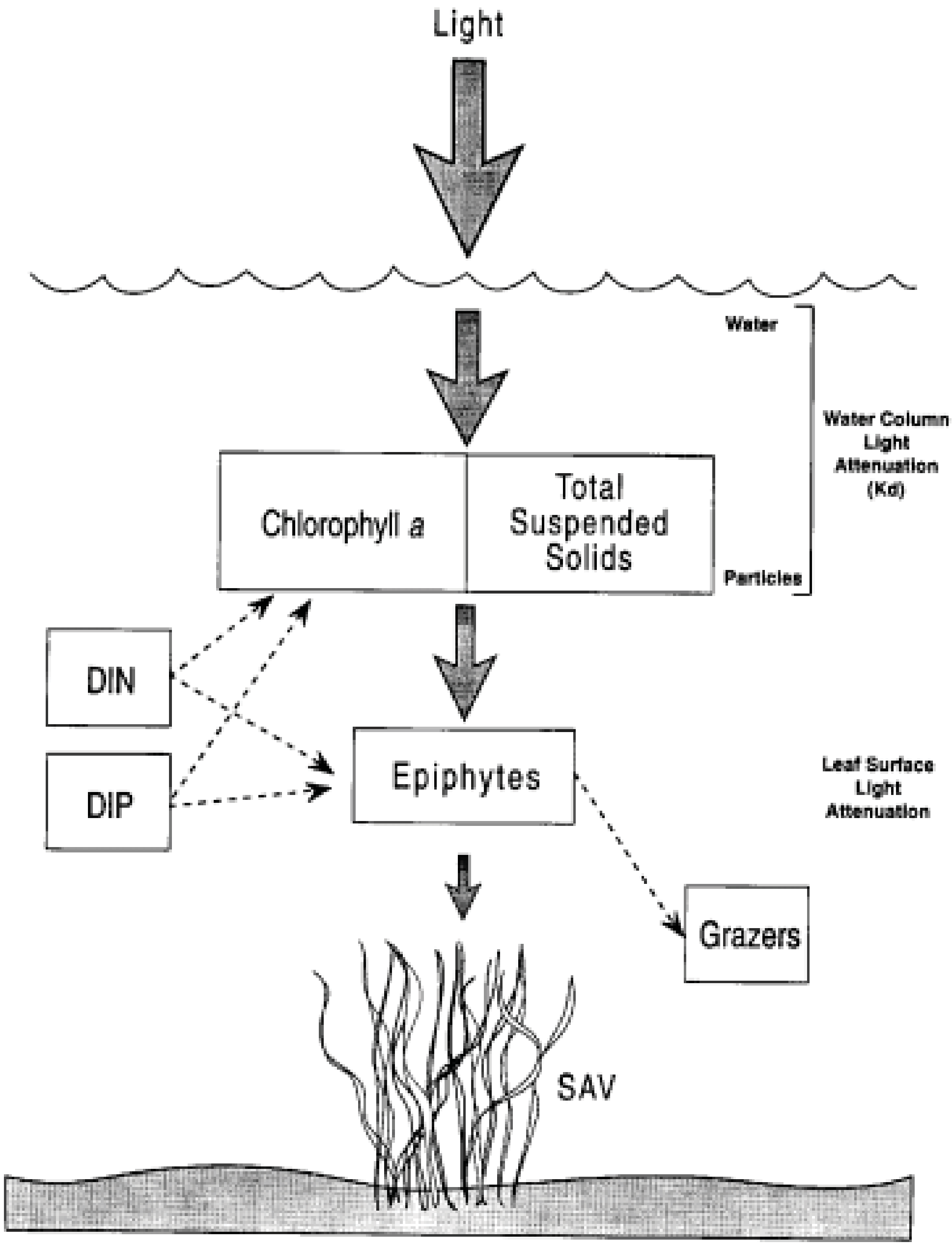
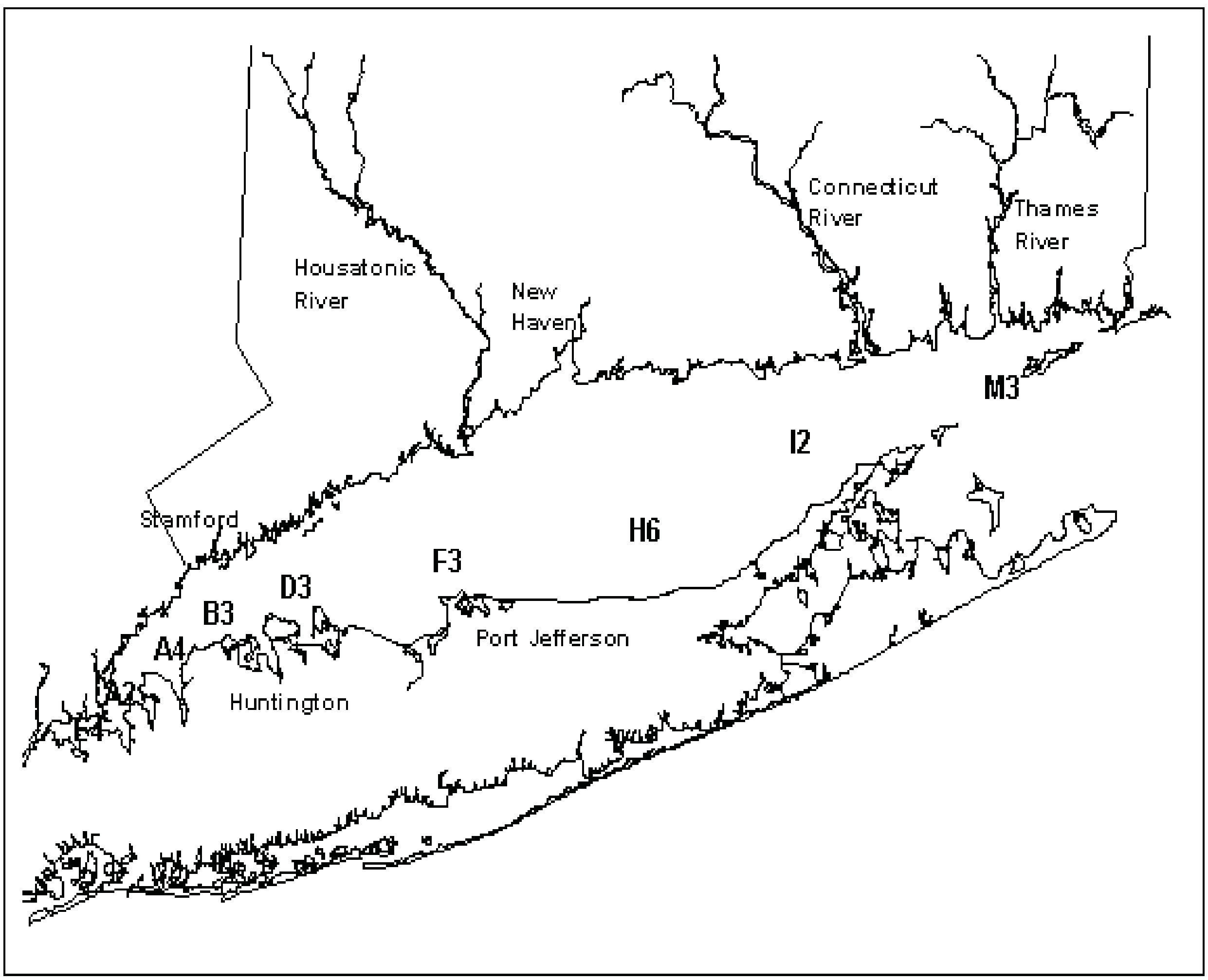


TABLE 3-3. Suggested Water Quality Criteria for Eelgrass. Parameters are based upon environmental data collected at three seagrass sites in Long Island Sound over 18 months (Koch et al., 1994).

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* 1^{-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 (Kd), 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 <u>Natural Restoration:</u> 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 <u>Public Education:</u> 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 ImpairedWater 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 -South Beach	U.S. Coast and Geodetic Survey Chart, 1958 New York State Museum collection #5539	1958 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 -Niantic River and Bay -Niantic Bay	Cottam and Munro, 1954 Northeast Utilities Service Company, 1996; Lynch and Cottam, 1937	1954 1985-1996 1936
Waterford: -Jordan Cove and Bay -White Point	Northeast Utilities Service Company, 1989 Knight and Lawton, 1974	1985 1974
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: -Shennecosett Beach -Pine Island Bay -Jupiter Point -Poquonock River -Bushy Point Beach -Mumford Point	Welsh, 1984 Barrett,1991 NOS NOAA Nautical Chart, 1985 Cottam and Munro, 1954 CT Botanical Society NOS NOAA Nautical Chart, 1985	1984 1991 1985 1954 1970 1985

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