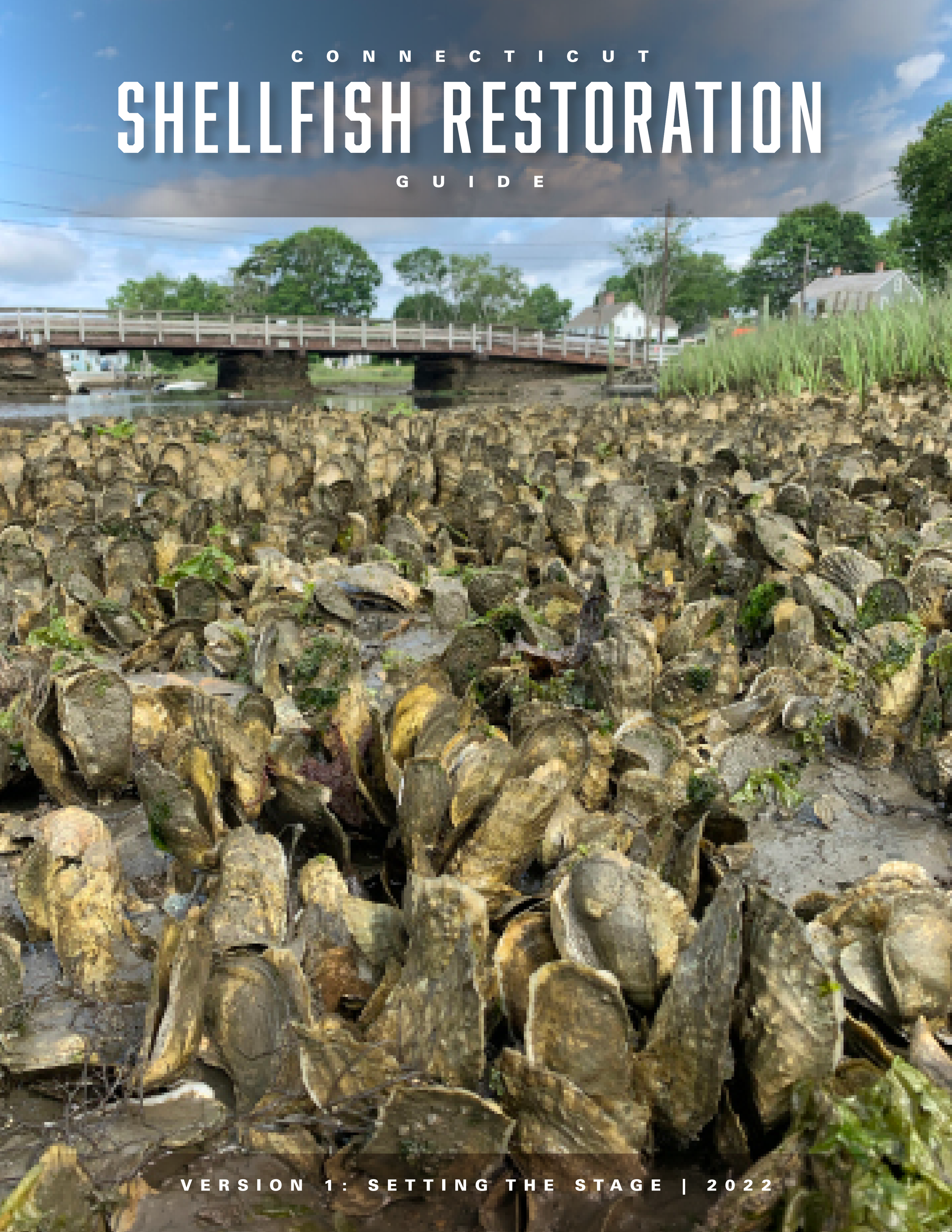
CONNECTICUT

SHELLFISH RESTORATION

GUIDE



VERSION 1: SETTING THE STAGE | 2022

COVER: Oyster bed at Clinton Harbor. Photo: Tessa Getchis

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Executive Summary

The *Connecticut Shellfish Restoration Guide* is the state's first and most comprehensive plan to lay the foundation for shellfish restoration in Connecticut's navigable waters and tributaries of Long Island Sound. For the *Guide*'s purpose, "restoration" is an umbrella term used for conservation and management practices that increase shellfish populations to achieve environmental, economic, and societal benefits. While a variety of bivalve shellfish species are of interest for restoration, the state's primary focus is on the native and habitat-forming Eastern oyster (*Crassostrea virginica*).

Aquaculture is intentionally an area of focus in the *Guide* for two main reasons. The first is because of the Connecticut shellfish industry's strong dependence on and concurrent contributions towards the listed ecosystem services that the *Guide*'s recommendations are trying to achieve. The second is because the need to expand the state's shellfish restoration efforts was first emphasized during the development of the Connecticut Shellfish Initiative Vision Plan[1] **https://shellfish.uconn.edu/wp-content/uploads/sites/62/2016/10/execsumm.pdf**. Published in 2016, the *Vision Plan* is a strategic plan to grow the state's commercial, recreational, and natural shellfish populations. Restoration of the state's natural shellfish beds was identified as one of the *Vision Plan* objectives. However, shellfish restoration efforts in Connecticut to date have been limited in number and scale. Environmental managers cite the following gaps that have hampered their ability to recommend or direct limited funding towards shellfish restoration activities:

- Up-to-date information on the status of shellfish populations
- Spatial planning tools
- Regulatory guidance
- Best management practices

To address these gaps, the state applied for and was awarded a USDA Natural Resources Conservation Service planning grant to develop the *Guide* in September 2018. The *Guide*'s development was facilitated by Connecticut Sea Grant (CTSG), UConn Extension, the Connecticut Department of Agriculture, Bureau of Aquaculture (CT DOAG BA) and the Connecticut Department of Energy and Environmental Protection (CT DEEP). Developing the *Guide* relied on a wide spectrum of shellfish expertise and perspectives from federal, state and local governments, town shellfish commissions, the shellfish aquaculture industry, recreational harvesters, academic institutions, conservation non-profits, and others.

This inclusive approach identified stakeholder needs that informed the *Guide*'s overarching vision:

Restore, manage, and conserve shellfish habitats to increase environmental, economic, and societal benefits (sometimes referred to as "ecosystem services"). The intended benefits include:

- Shellfish production (commercial and recreational)
- Improved water quality (via filtration and excess nutrient mitigation)
- Coastal habitat provision
- Fisheries production (non-shellfish)
- Shoreline stabilization

To work towards this vision, the *Guide* provides planning tools, regulatory information, and best management practices to jumpstart shellfish restoration-based project planning. The *Guide* itself, and the tools described within, draw on the best available scientific resources, including the recently completed *Long Island Sound Blue Plan Inventory*[2] https://portal.ct.gov/DEEP/Coastal-Resources/LIS-Resource-and-Use-Inventory-Home, and lessons learned from similar initiatives in other locales.

One of the *Guide*'s foundational planning tools is the *Connecticut Shellfish Restoration Interactive Map Viewer*[3] https://s.uconn.edu/ctshellfishrestoration. The *Map Viewer* is the state's first geospatial collection of key ecological, biological, and human-use data intended to assess the viability of a coastal location to support shellfish restoration. Further, qualitative oyster habitat surveys characterize, for the first time, the condition of intertidal oyster populations across the state and establish a baseline to inform the planning of future quantitative assessments.

The use of the *Guide* and its tools will result in an improved process for prioritizing, planning, permitting, and implementing restoration projects while providing sponsor agencies with confidence in funding projects with a high return of environmental, economic, and societal benefits. Ultimately, this work will contribute to the wise use, conservation, and management of shellfish and the marine environment in which these occur in Connecticut.

> To learn more about Connecticut shellfish, please visit: **http://shellfish.uconn.edu**.

Shellfishing has been a way of life for centuries and the resources within this planning guide will provide the guidance to restore shellfish beds and grow a robust industry while mitigating climate change challenges and creating a sustainable plan for the future.

*—**Katie Dykes** CT Dept. of Energy and Environmental Protection*

Shell pile in New Haven. Photo: Mystic Seaport Collections.

Definitions

Aquaculture:
As defined in CGS Sec. 22-11c **https://www.cga.ct.gov/current/pub/chap_422.htm#sec_22-11c**. "Aquaculture" means the controlled rearing, cultivation, and harvest of aquatic plants and animals in land-based and marine-based culture systems, tanks, containers, impoundments, floating or submerged nets or pens, and ponds.

Bioextraction:
the cultivation and harvest of shellfish and/or seaweed for the purpose of nutrient removal.

Coastal Jurisdiction Line:
As defined in CGS Sec. 22a-359 **https://www.cga.ct.gov/current/pub/chap_446i.htm#sec_22a-359.** The coastal jurisdiction line represents the state's regulatory jurisdiction limit with respect to tidal, coastal, and navigable waters. Historically, the state's jurisdiction ended at the high tide line. The amended statute dictates the use of a specifically determined elevation as the regulatory limit rather than relying on field evidence of the water surface elevation.

Denitrification:
the process of converting biologically available N compounds (ammonia, nitrate, nitrite) in the marine environment to inert nitrogen gas in the atmosphere.

Enhancement:
improving one or more attributes of shellfish habitats; used synonymously with the term "rehabilitation."

Living shorelines:
As defined in CSG Sec. 22a-363h **https://www.cga.ct.gov/current/pub/chap_446i.htm#sec_22a-363h**. A shoreline management practice which restores, enhances, maintains, or creates natural coastal or riparian habitat, functions, and processes and also functions to mitigate flooding or shoreline erosion. Coastal and riparian habitats include but are not limited to intertidal flats, tidal marsh, beach/dune systems, and bluffs. LS may include structural features that are combined with natural components to attenuate wave energy and currents.

Natural shellfish beds, "designated" or "managed"
As defined in Section 2326, General Statutes, 1888 and Sec. 3295 of the CGS, revision of 1918. These terms refer to the specific areas under town jurisdiction as defined

by decrees of the Superior Court to be natural oyster, clam, and mussel beds for the gathering of shellfish seed that will ultimately be planted on commercial beds. The term “bed” is used synonymously with “reef.” though it is recognized that in some locales “reef” is distinguished from “bed” as having significant vertical relief.

Natural shellfish beds, “undesignated” or “unmanaged”
Refers to areas where shellfish occur naturally but that have not been designated in Connecticut Superior Court. These areas are not designated to allow any type of commercial or recreational harvest. The term “bed” is used synonymously with “reef.”

Navigable waters
As defined in 33 CFR § 329.4 **https://www.nap.usace.army.mil/Portals/39/docs/regulatory/regs/33cfr329.pdf**. Refers to those waters that are subject to the ebb and flow of the tide and/or are presently used, or have been used in the past, or may be susceptible for use to transport interstate or foreign commerce.

Recreational shellfish harvest:
As defined in CSG Sec 26-257a **https://www.cga.ct.gov/current/pub/chap_492.htm#sec_26-257a**. Refers to the gathering of shellfish for personal consumption. Fifteen Connecticut towns manage recreational shellfishing programs in which individuals pay a fee to harvest shellfish from these areas. Because of fishing pressure, shellfish stocks need to be replenished either naturally from a nearby spawning sanctuary or via stock enhancement.

Public trust area:
As defined in C.G.S. Sec 22a-93(6). A term for submerged lands and waters waterward of mean high water in tidal, coastal, or navigable waters of the state of Connecticut. The public trust area is also sometimes referred to as tidelands and is included in the definition of ”public beach“ in C.G.S. Sec 22a-93(6) of the Connecticut Coastal Management Act.

Restoration:
A general term applied to a range of activities that can increase shellfish populations to achieve environmental, economic, and societal benefits.

Shellfish jurisdiction line:
As defined in Section 3294, General Statutes (revision of 1918) In 1881 a line was established, referred to as the Commissioners line or shellfish jurisdiction line, that divides the waters of the state into a northern and southern section. All beds south of this line are considered “State beds” and most beds north of this

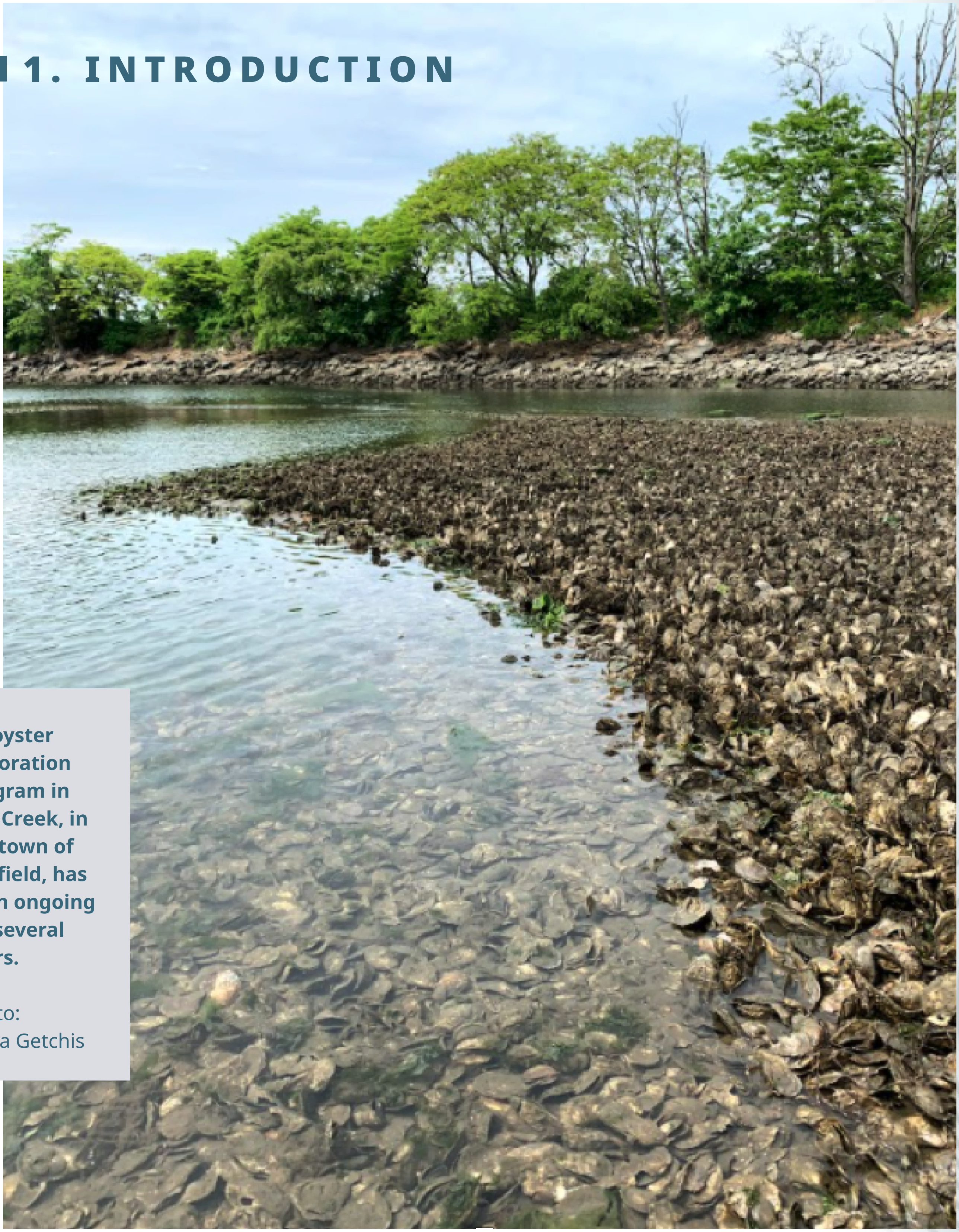
line are considered "town beds." CT DOAG BA still controls all the licensing and regulations north and south of this line, for example CT DOAG BA determines when an area will be closed to shellfishing due to a change in water quality and what licenses are needed to do certain work. Town beds are simply leased, owned or managed through the local shellfish commission. Towns may require additional local permits to work in waters under local jurisdiction. The beds north of the line in Westport, Milford, West Haven, and New Haven are exceptions to this as they are under state control.

Acronyms and Abbreviations

BMP	Best Management Practices
CCMP	Comprehensive Conservation and Management Plan
CGS	Connecticut General Statutes
CIRCA	Connecticut Institute for Resilience & Climate Adaptation
CJL	Coastal Jurisdiction Line
COP	Certificate of Permission
CSIVP	Connecticut Shellfish Initiative Vision Plan
CT DEEP	Connecticut Department of Energy and Environmental Protection
CT DEEP LWRD	Connecticut Department of Energy and Environmental Protection Land and Water Resources Division
CT DOAG	Connecticut Department of Agriculture
CT DOAG BA	Connecticut Department of Agriculture Bureau of Aquaculture
CTSG	Connecticut Sea Grant
EPA	Environmental Protection Agency
GC3	Governor's Council on Climate Change

GIS	Geographic Information Systems
HAB	Harmful Algal Bloom
HSI	Habitat Suitability Index
LiDAR	Light Detection and Ranging
LIS	Long Island Sound
LISS	Long Island Sound Study
MHW	Mean High Water
MLW	Mean Low Water
NDDB	Natural Diversity Database
NEFSC	Northeast Fisheries Science Center Milford Lab
NEIWPCC	New England Interstate Water Pollution Control Commission
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
SDF	Structures, Dredging and Fill
TNC	The Nature Conservancy
UAS	Unmanned Aircraft System
UCONN	University of Connecticut
USACE	United States Army Corps of Engineers
USDA NRCS	United States Department of Agriculture Natural Resources Conservation Service
USGS	United States Geological Survey
WWTF	Wastewater Treatment Facility

1. INTRODUCTION



An oyster restoration program in Ash Creek, in the town of Fairfield, has been ongoing for several years.

Photo: Tessa Getchis

1.1 The Ecological and Social Significance of Connecticut's Shellfish

The health of Connecticut's native bivalve shellfish species and habitats are integral to the state's Long Island Sound coastal communities, economies, and ecosystems. The prominent native species include: eastern oyster (*Crassostrea virginica*), ribbed mussel (*Geukensia demissa*), blue mussel (*Mytilus edulis*), northern quahog (*Mercenaria mercenaria*), Atlantic surf clam (*Spisula solidissima*), softshell clam (*Mya arenaria*), Atlantic razor clam (*Ensis leei*), and bay scallop (*Argopecten irradians*). The state's aquaculture industry and recreational shellfisheries provide local food and jobs, and are an important part of Connecticut's history, culture, and larger maritime economy. Collectively, bivalves and their habitats contribute to the ecosystem's biodiversity, water quality improvement, nutrient removal, habitat provisioning, shoreline stabilization, and food production[4,5]. The caliber of these ecosystem and socio-economic services is so high that shellfish habitats have been restored in impaired marine environments to recapture and ensure the longevity of the many benefits these species provide[6].

Nutrients like nitrates from fertilizers, sewage, and animal wastes that are picked up in stormwater runoff are a common stressor in estuarine environments. In volumes greater than background levels, they can fuel the excessive growth of algae, which shades the seafloor, resulting in reduced photosynthesis and oxygen production while the available oxygen in the water column is depleted as the algae die and decompose. The effect is reduced water clarity and quality to support marine life. Filter-feeding shellfish help combat the negative impacts of excess nutrients, or eutrophication, by consuming microscopic algae and storing nitrogen, effectively removing it from estuaries. As the animal grows, some of the excess nitrogen is incorporated into their shells and body tissues, while uneaten particulates are deposited as pseudofaeces which fuel the bacterially driven denitrification process[7]. Both of these processes have been shown to improve water quality[8,9].

Due to their successful nutrient removal and storage capacities, shellfish have been identified as a means to mitigate the impacts of excess nutrients, especially in places that have been formally identified as impaired due to nutrient inputs[10,11,12]. The extractive capacity of oysters in particular was examined in two coastal bays of New York[13]. Galimany and colleagues grew ribbed mussels at two Long Island Sound sites, and suggested that this species may be a good candidate for water quality restoration projects based on its wide environmental tolerance and lack of commercial or recreational harvest[14]. Bivalves have been used successfully in projects to reduce nutrient loading in other locales around the globe (e.g., Sweden[15]). These ecosystem services also have an explicit monetary value[16]. In a pilot study in the town of Greenwich, researchers have estimated that oyster and clam aquaculture provides $2.8–$5.8 million in services that remove excess nitrogen from the coastal waters[17]. Nutrient mitigation measures from oyster reef restoration in the Choptank River complex in Maryland has estimated that assimilation accounts for 199 kg N per acre per year and denitrification 225 kg N per acre per year. Using low and high nutrient trading market values, these rates are worth from $3.6 million to $18 million per year[18].

In addition to their contributions towards improving water quality, reef-forming shellfish species also enhance coastal health and resiliency through habitat production. Oyster reef habitats form through a self-reinforcing process. Adult oysters provide the settlement substrate and recruitment cue for young oysters. The settlement and subsequent growth of young oysters fuels the accumulation of shell material which represents new settlement substrate and recruitment cues for the next generation of young oysters[19]. The final result of this feedback loop is the self-sustaining construction of a three dimensional reef habitat, which provides essential structural complexity to the marine habitat[20]. It is this structural complexity that has been correlated to an increase in macrofauna diversity on oyster reefs[21]. Much like coral reefs in tropical waters, reef-forming species such as oysters create habitats that provide a refuge, reproduction, and foraging habitat for fish and invertebrates[22]. A myriad of fish and invertebrate species have been observed using Long Island Sound shellfish beds as habitat[23,24].

In their synopsis of ecosystem services provided by oyster restoration, Bruce et al. (2021) demonstrated that the abundance of fish and benthic invertebrates increases with oyster density, and that many of these species are of commercial or recreational value[25]. Resident fish and invertebrates often use reefs for reproduction, foraging, and as nursery habitat, while more ephemeral, or transient species use them for foraging. Several prior studies have shown that restored oyster reefs support higher densities of fish and crustaceans than unrestored sites[26,27] and that even deep subtidal reefs provide critical habitat[28]. Oyster reefs have been estimated to produce approximately 3 tons of additional fish per hectare per year along the Atlantic coast[29] but this assessment did not account for all potentially affected species and that calculation is simply a mean determination of enhancement across the studies that were reviewed. Models have predicted large increases (nearly 80%) of blue crabs on restored oyster reefs[30]. In their study of the Harris Creek complex of Maryland's eastern shore of the Chesapeake Bay, researchers determined that from the ~350 acres of restored reef, there is an annual return of $11 million in blue crabs and $23 million in fisheries production[31].

The natural shorelines that oyster reefs create provide structural integrity where land meets the sea, stabilizing and protecting it from erosion, allowing accretion of sediments and providing migratory corridors for fish, birds, and other wildlife. These habitats serve as the first line of defense against coastal storms, absorbing and abating wave energy and flood waters. They armor the eroding edge of salt marsh habitat to avoid the loss of stored Carbon and other ecosystem services. Nearshore fringing reefs can reflect or reduce wave energy and have been shown to stabilize the shoreline thereby reducing erosion[32]. They are also aesthetically pleasing, giving Connecticut locals and tourists a relaxing place to fish, boat, and value nature. Since the three-dimensional reef structure degrades naturally via environmental processes (e.g. subtropical storms, Nor'easters and strong winter waves) on an annual basis, accretion or growth must outpace degradation in order for the oyster reef to survive[33,34]. Furthermore, oyster's ability to form self-sustaining populations or to recover without active intervention is negatively impacted by these natural processes.

Connecticut's native shellfish species do not just strengthen the state's beloved Long Island Sound waters, these vital ecosystem-engineers are also the bedrock for the state's historic shellfisheries. The annual production of farmed shellfish, primarily oysters and northern quahog clams, was valued at nearly $25 million dollars in 2020[35] and provides more than 300 maritime jobs. A variety of species of clams, mussels, oysters, and bay scallops are valuable for the recreational harvest programs that they support in Connecticut's coastal towns. Sales of recreational shellfishing permits have been documented in excess of $100,000 annually with a multiplier effect in the millions of dollars[36]. The volunteer commissions that manage these projects spend tens of thousands of dollars per season to replenish recreational harvest areas and make efforts to recapture these funds by selling harvest permits. Subsistence shellfisheries are less understood though they should not be undervalued.

> **Connecticut's natural shellfish habitats are critical to the Long Island Sound environment and to sustaining the state's aquaculture sector, spanning more than 17,000 acres and contributing to a shellfish harvest valued at more than $23 million dollars**
>
> — ***Bryan Hurlburt*** *CT Dept. of Agriculture Commissioner*

Morris Creek, East Haven. Photo: Tessa Getchis.

1.2 The Need for Shellfish Restoration

Connecticut's shellfish populations and the marine environment in which they are found have been impacted by natural and anthropogenic factors. Historically, populations of the native oyster have occupied vast areas along the Connecticut coast (Figures 1.1, 1.2). These have remained productive, recruiting annually, in many locations in contrast to other areas of the region, country, and globe where their numbers have largely declined. However, not all oyster habitat is in optimal condition. Further, concerns about population declines in recent years in some native species of mussels, scallops, and clams have warranted research to investigate the cause and extent.

A significant threat to shellfish habitats, and oyster reefs in particular, is siltation or sedimentation and the burying of critical shell substrate. Intense precipitation events and development-related hardened impervious surfaces both have resulted in increased stormwater flow and municipal storm drain discharge volumes, significantly impacting nearshore oyster habitat. Some natural beds, considered prime oyster habitat in the past, cannot keep up with the rate of sedimentation and are rapidly being buried. This results in the loss of three-dimensional surface structure where oyster spat settle. Left unmanaged, the net result has been a reduction or failure of annual oyster recruitment and the gradual diminishment of the habitat[37]. This can be made worse by simultaneous erosion of coastal habitats like salt marshes and escarpments from which sediment can also impact nearby shellfish beds.

Shells are key building blocks for oyster beds, where they are crucially needed to enhance recruitment, maintain ecosystem function and support commercial shellfish production. But despite best efforts, Connecticut coastal waters have experienced a net shell loss over time, meaning that oyster beds cannot self-replenish without human intervention. The shell needed by people to do this is often in short supply.

During the cultivation process and harvest, aquaculture operations sort empty shell from live shellfish and store them on land or underwater. Ultimately that shell is replanted to create settlement habitat for the next season's oysters. It is a practice that has been used for decades. This work greatly improves the condition of privately farmed shellfish beds. It does not, however, address the siltation problem on the vast portions of public natural harvest beds and undesignated natural beds. An example is the Housatonic River which has been heavily worked by farmers for the past five years and remains extremely productive for seed, while the Bridgeport beds have not been worked and remain unproductive[38]. It has been shown that if harvest continues or if the natural mortality rate is increased by other means, the sole mechanism for compensation for the loss of shell is to continually replace it[39].

In 2019, over 31 million oysters were harvested commercially and an unknown quantity were harvested recreationally in Connecticut[40]. The majority of farmed oysters were sold for the half shell market, with little of that shell ever reclaimed as the state lacks any large-scale shell recycling programs. The food service sector and the seafood-consuming public lack a mechanism and economic incentives to divert the shell from landfills and return it to the beds. While some aquaculture businesses have the capacity and are returning shells to the water, ultimately more could be done to expand shell recycling from consumer marketplaces.

Eutrophication, as discussed in Section 1.1, is prevalent in Connecticut coastal waters and has been linked to a variety of environmental problems. The excess nutrients fuel naturally occuring algae productivity beyond normal levels into “algal blooms” that reduce or even eliminate oxygen in the water, killing shellfish and causing a loss of habitat and ecosystem diversity. Nutrient over-enrichment is typically accompanied by introductions of fine sediments and organic substances, creating a double threat that reduces viable shell substrate and broodstock. A subset of algae overproduction, harmful algal blooms, can also be a direct threat to shellfish health or survival as the algae may release toxins.

Over the past two decades, CT DEEP utilized the nutrient credit trading program to modernize Wastewater Treatment Facilities (WWTF) and accomplished a 65% reduction in point source nitrogen pollution. Efforts currently focus on WWTF and collection systems to minimize or eliminate overflows and bypasses, as well as assess outfall impacts to embayments and harbors. As previously stated, scientific studies have recognized shellfish and seaweed aquaculture for their ability to absorb some of those excess introduced nutrients. Nutrient credit trading programs have been proposed that compensate shellfish farmers for planting greater numbers of oysters to enhance the nutrient mitigation services that oysters provide[41]. While the value of such programs have merit and should be explored, it is imperative that the state continues to fund efforts to maintain and upgrade WWTF, collection systems, and outfalls, and to monitor nutrient flows. These improvements are key to reducing nutrients as well as bacterial, viral, and other organic loadings in nearshore waters.

Climate change stressors such as rising water temperatures and sea level, changing salinity, coastal and ocean acidification, and increased precipitation, stormwater runoff, wave energy, and siltation associated with severe storm events have placed Connecticut's shellfish populations and habitat at risk. These conditions are expected to worsen in the near future[42,43]. Commercial shellfish production, which is reliant on designated natural beds as its primary source of seed, was identified as one of the top five most imperiled agriculture sectors in the state in terms of vulnerability to climate change[44]. In their climate change preparedness plan, the Governor's Council on Climate Change (GC3) recommended three specific actions regarding shellfish: (1) examine watershed management practices and land acquisition strategies to promote and improve water quality conditions in near shore, estuarine, and freshwater areas that support or could support subtidal aquatic beds; (2) investigate options for restoring or enhancing subtidal aquatic beds to provide habitat and shoreline protection through wave dissipation; and, (3) continue monitoring distribution and conduct research to identify the likely impact of climate on subtidal aquatic beds to inform management and restoration. Among their recommendations published in 2021, the GC3 prioritized research and monitoring to address impacts to natural resources, including shellfish[45].

Historically, overfishing of wild shellfish was a significant concern, especially on the public oyster beds used as a seed supply for the aquaculture industry. However, strict regulations and corresponding enforcement have resulted in a sustainable commercial harvest. The same cannot be said for recreational harvest areas. The state gave authority to local towns to establish and create rules for such public harvest areas; however, there is no state funding for related management and enforcement activities. The volunteer commissions that manage these areas are reliant on sales of harvest permits to pay part-time wardens to patrol the areas and to purchase shellfish for replenishing their harvest areas. In most cases, towns must reseed recreational areas annually, or even more frequently, due to high fishing pressure. Many towns are now considering alternatives such as "spawner sanctuaries." These are areas that are closed to harvest, allowing shellfish to propagate. The idea behind this is that there will be a "spillover" effect in which shellfish recruit to the adjacent public harvest area.

While regulations have been put in place to reduce human impacts to shellfish populations, and recommendations made to make these habitats more resilient to climate and environmental changes and anthropogenic impacts, not all shellfish populations are in optimal condition to support ecosystem services, fisheries, and aquaculture as they have in the past. Any reduction in bivalve shellfish population or loss of habitat results in a subsequent loss of the ecological, economic, and cultural benefits derived from those shellfish. As such, the Environmental Protection Agency Long Island Sound Study (EPA LISS) has identified shellfish reefs as one of 12 priority coastal habitats. Furthermore, the bi-state *Long Island Sound Comprehensive Conservation and Management Plan* (CCMP)[46] and the *Connecticut Shellfish Initiative Vision Plan* (CSIVP)[47] have both identified the need to increase shellfish populations to enhance the ecosystem services they provide, as well as support fisheries and aquaculture production. Given their ecological, economic, and cultural importance, shellfish restoration is a priority in Connecticut. Further, one of the recommendations put forward by the CCMP (#HW-18) called for the development of "a shellfish management plan for aquaculture, recreation and restoration that ensures sustainable marine populations."

The development of this comprehensive guide that identifies goals, priorities, regulatory information, and best management practices was identified as a critical next step to overcome barriers and facilitate investment in shellfish restoration in Connecticut.

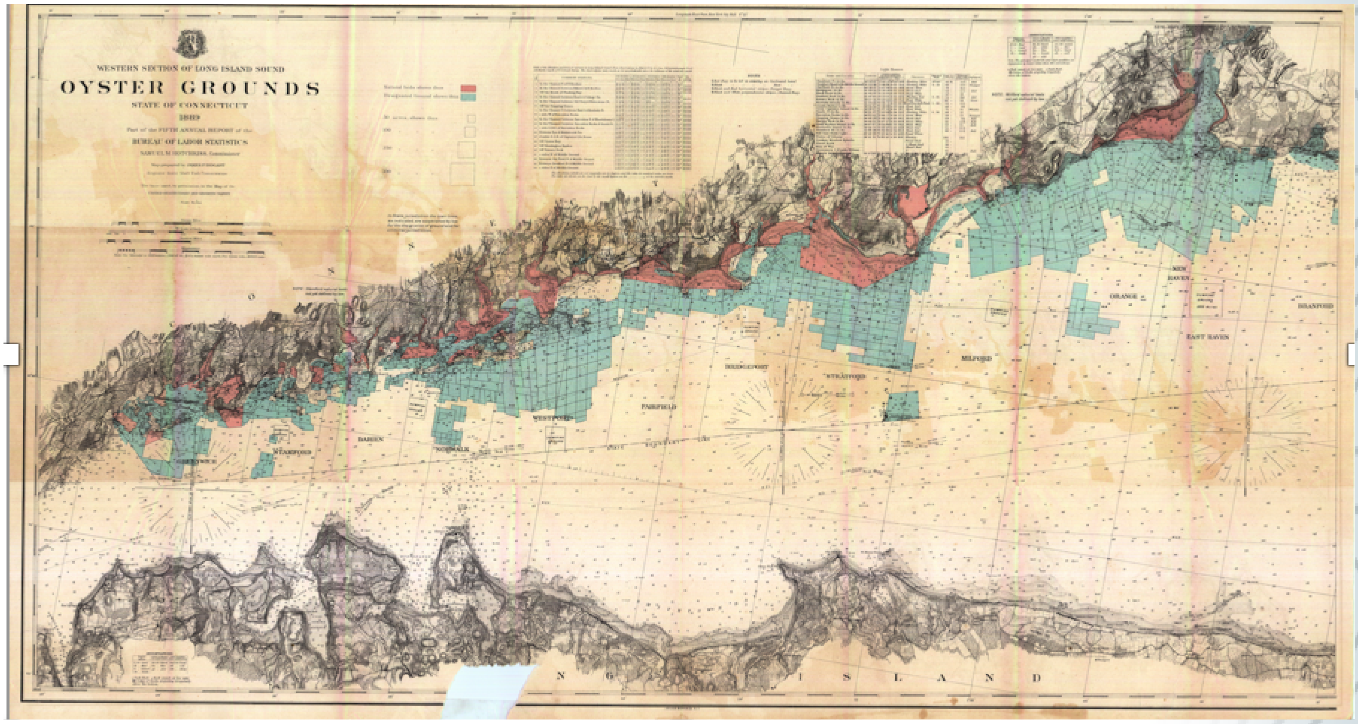


FIGURE 1.1 Western Section of Long Island Sound, Oyster Grounds, State of Connecticut (natural beds in pink shading). Source: Part of the Fifth Annual Report of the Bureau of Labor Statistics, 1889. Prepared by James P. Bogart.

FIGURE 1.2 Eastern Section of Long Island Sound, Oyster Grounds, State of Connecticut (natural beds in pink shading). Source: Part of the Fifth Annual Report of the Bureau of Labor Statistics, 1889. Prepared by James P. Bogart.

1.3 Intent of this Guide

This first version of the *Connecticut Shellfish Restoration Guide* is intended to set the stage for shellfish restoration planning and implementation. The *Guide* defines overarching restoration goals and identifies stakeholder needs and actions to jumpstart restoration planning, provides planning tools, regulatory information, and best management practices. The effort builds on the relationships, momentum and successes of the Connecticut Shellfish Initiative (CSI) that aims to grow the state's commercial, recreational, and natural shellfish populations and increase public awareness about them. The *Connecticut Shellfish Initiative Vision Plan*[48] **https://shellfish.uconn.edu/wp-content/uploads/sites/62/2016/10/execsumm.pdf** (2016) was developed at a time when there was limited information available on the spatial coverage of natural shellfish populations, especially reef-forming species such as oysters. There was also limited understanding of the extent of the ecosystem services (i.e., benefits) provided by shellfish populations and the implications (i.e., impacts) of land and resource management practices on shellfish populations. As the collective scientific and spatial knowledge on these topics has grown over the last several years, the need for a comprehensive plan for shellfish restoration became apparent. Similar to the CSI, the *Connecticut Shellfish Restoration Guide* is the culmination of the work of many stakeholders. As such, every effort has been made to reflect the philosophies, knowledge, and expertise contributed by the Steering Committee and subcommittee participants.

The *Guide* is divided into five sections:

1. Section One includes introductory material on oysters and other bivalve shellfish and their contribution to Connecticut's economy, environment and culture.
2. Section Two provides information on what is known about these native shellfish and their habitats.
3. Section Three includes recommended actions intended to lay the foundation for future restoration efforts, focused primarily on oyster habitat.
4. Section Four focuses on a spatial planning tool – a habitat suitability analysis – that, when completed, will further aid in the selection of suitable sites to achieve a variety of shellfish restoration goals.

The intended audiences for the above sections include environmental managers, researchers, policymakers and outreach professionals.

5. The fifth and final section contains regulatory information and practical guidance for restoration practitioners.

1.4 Shellfish Restoration Vision

For the purpose of the *Guide*, "restoration" is an umbrella term used for conservation and management practices that increase native marine shellfish populations to achieve environmental, economic and societal benefits. The following overarching restoration vision was developed by a diverse steering committee, and is aligned with the bi-state Long Island Sound Comprehensive Conservation and Management Plan and the Connecticut Shellfish Initiative Vision Plan. These plans identified the need to increase shellfish populations to support fisheries and aquaculture production, as well as to enhance all the valuable ecosystem services that they provide.

VISION:

Restore, manage, and conserve shellfish habitats to improve environmental, economic, and societal benefits known as "ecosystem services".

ECOSYSTEM SERVICES:

Shellfish Production
Commercial aquaculture is a $25 million industry, provides local food and jobs, and recreational shellfish production supports tourism and contributes more than $2 million to the local economy.

Coastal Habitat Provision
Reef-forming species such as oysters create habitats that provide a refuge, reproduction, and foraging habitat for fish and invertebrates.

Improved Water Quality
Filter-feeding shellfish help combat the negative impacts of excessive nutrients and clarify the water by consuming microscopic algae and storing excess nitrogen.

Fisheries Production
The abundance of marine life increases with oyster density, and many of these non-shellfish species are of commercial or recreational value.

Shoreline Stabilization
The natural reefs that oysters create provide structural integrity where land meets the sea, stabilizing and protecting it from erosion.

All of these ecosystem services are important, but the extent to which they are valued will likely vary depending on location, the goals of engaged stakeholders, funding availability, and other factors. Therefore, this *Guide* does not intend to convey that any one of these ecosystem services is ultimately and always higher priority than the others.

1.5 Geographic Focus Area

This is a statewide effort that is focused on the navigable waters of Connecticut in Long Island Sound, including its tributaries. The total coastal water area that is potentially able to support shellfish populations in this geography is 389,276 acres (Figure 1.3).

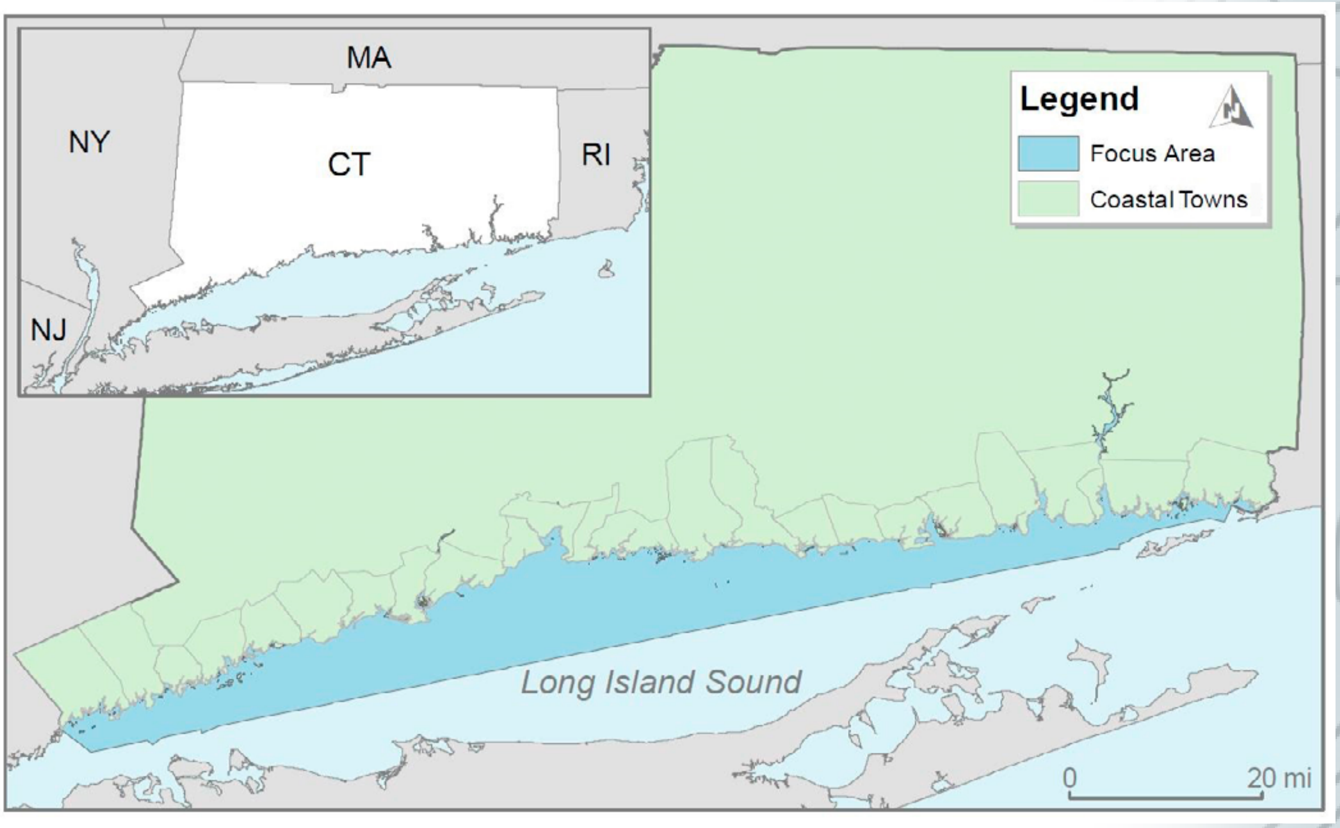
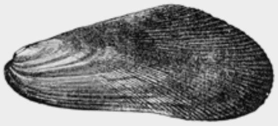
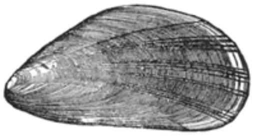
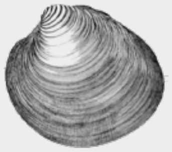
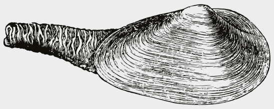
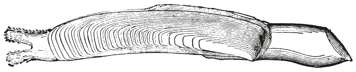


FIGURE 1.3 The focus area includes the navigable waters of Connecticut in Long Island Sound.

1.6 Species of Interest

TABLE 1.1. Common LIS shellfish species and their habitats.

SPECIES	HABITAT & SEDIMENT TYPE
Eastern oyster *Crassostrea virginica* 	Reef-forming species that attaches by cementing itself to hard surfaces including other oysters and shells; inhabits areas with firm sediments (e.g., sand, gravel, or rock) and occasionally soft muddy sediments, in intertidal and subtidal waters
Ribbed mussel *Geukensia demissa* 	Species that uses byssal threads to attach to marsh grass roots holding sediments in place in intertidal marshes
Blue mussel *Mytilus edulis* 	Reef-forming species that uses byssal threads to attach to hard surfaces including other mussels and inhabits areas of firm sediments (e.g., shell, sand, gravel, or rock) in intertidal and subtidal waters
Northern quahog *Mercenaria mercenaria* 	Burrowing species that inhabits a variety of sediments (e.g., sand, mud, gravel) in intertidal and subtidal waters
Atlantic surf clam *Spisula solidissima* 	Burrowing species that inhabits primarily fine or coarse sandy sediments in intertidal and subtidal waters
Softshell clam *Mya arenaria* 	Burrowing species that inhabits primarily sand and mud substrates in intertidal and subtidal waters
Atlantic razor clam *Ensis leei* 	Burrowing species that inhabits primarily sand and mud substrates in intertidal and subtidal waters
Bay scallop *Argopecten irradians* 	Mobile species that inhabits shallow subtidal waters and is typically associated with eelgrass beds

Images are not to scale, nor are they relative in size to one another.

1.7 Anticipated Outcomes

With this *Guide,* environmental managers and restoration practitioners now have access to information and tools that can shepherd Connecticut's future marine shellfish restoration efforts. The *Connecticut Shellfish Restoration Interactive Map Viewer*[49] **https://s.uconn.edu/ctshellfishrestoration** is the first statewide collection and analysis of key geospatial data to be used to support decision-making. Further, qualitative oyster habitat surveys characterize, for the first time, the condition of intertidal oyster populations across the state and establish a baseline to inform the planning of future quantitative assessments.

When combined, the information, tools, and conversations with Connecticut's coastal stakeholders that took place through the development of the *Guide* will aid in the identification of suitable locations and help inform a site prioritization process. The use of these resources will also result in improved planning and permitting of restoration projects and will provide sponsor agencies with confidence in their ability to fund high-priority projects that will result in the wise use, conservation, and management of shellfish and shellfish habitats.

Ultimately, the use of the information and tools in the *Guide* will lead to highly successful shellfish restoration projects that result in the improvement of critical ecosystem services.

1.8 Related Initiatives

Connecticut's natural designated clam and oyster beds have been carefully supervised and maintained for centuries, and have been a priority among the state's agriculture and environmental officials for decades. Historically, the focus of these management activities was on enhancement to increase oyster aquaculture production. Since the 1980s, there have been a number of programs that have closely involved members of the aquaculture industry and others in this work. This section outlines some of the key recent, ongoing, and planned actions specific to the designated beds that are synergistic with the recommendations and tools in this *Guide*. Restoration and enhancement activities that take place on the designated beds need not, and should not, occur in a vacuum from those that take place on undesignated beds.

In the 1980s the state purchased and planted one million bushels of oyster shell on the largest natural bed, the Bridgeport/Stratford Natural Bed. Soon after, the state implemented as part of Connecticut General Statutes (CGS) Sec. 26-237 a revolving shell fund in which oyster harvesters paid a fee for the opportunity to harvest seed from public natural beds. Those funds were then used to plant shell back on the beds. The harvested seed was subsequently planted on privately cultivated beds. While the program was successful in terms of increasing oyster production in the early- and mid-1990's, in subsequent years the shell program was not fully funded by the legislature and the collected seed oyster fees were not transferred to the Department of Agriculture. Further, the legislature eliminated the seed oyster fee statute in 2004.

The need for the previous enhancement work is one of the many factors that contributed to the development and completion of the 2016 Connecticut Shellfish Initiative VIsion Plan **https://shellfish.uconn.edu/wp-content/uploads/sites/62/2016/10/execsumm.pdf**. The CSI was modeled after NOAA's National Shellfish Initiative **https://www.fisheries.noaa.gov/national/aquaculture/national-shellfish-initiative** to increase populations of native bivalves through sustainable commercial production and restoration activities. As such, the CSI overarching goal is "to grow and protect the long-term viability of shellfisheries, shellfish populations and habitats," with one of the metrics being no net loss in natural shellfish bed habitats between 2016 (the baseline year) and 2023[50]. Key, overlapping recommendations in the CT Initiative include:

- Improve productivity of oyster beds used as a local source of seed for aquaculture
- Establish hatcheries to provide local shellfish seed
- Develop permitting guidance and application forms for projects involving shellfish habitat restoration, shoreline protection, and bioextraction projects that utilize shellfish
- Provides guidance on authorizations, licensing, and permitting for shellfish restoration.

While overall acreage of the natural beds has not decreased, the condition of some beds has declined for reasons previously described. As a result, environmental managers are exploring opportunities to restore the health and productivity of these areas. One such opportunity arose in 2020 following the shellfish market collapse due to COVID-19-related restaurant closures. The Connecticut Sea Grant Program and the Department of Agriculture Bureau of Aquaculture jointly secured funding from both the National Sea Grant Office and NOAA CARES Act to support shellfish farmers during the pandemic[51]. The resulting three-phase program allowed industry members to return to work and to be paid to help restore natural shellfish beds. Phase one included rehabilitation work of shellfish beds in six towns for the harvest, transplanting, and later sale of northern quahogs. Phase two included rehabilitation work on shellfish beds located in seven towns in early June 2020. Phase three included the purchase and planting of oversized, farmed broodstock oysters on shellfish beds in five towns. In total, 1,870 acres of public shellfish beds were rehabilitated and three acres were planted with oyster broodstock. In addition, the program provided cash and offered alternative marketing strategies for farmers. The program enrolled 33 out of a total of 51 licensed businesses, directly benefiting approximately 67% of the entire industry and helping to retain jobs and income[52]. This successful model of pairing CT shellfish industry members with restoration opportunities is one that will be used in the future. For example, federal funding will support a 2022 study that will investigate recruitment responses at varying quantities of recycled shell and broodstock oysters that will be provided by members of the industry[53].

The importance of shellfish restoration and shell recycling was recently recognized by state legislators and Governor Lamont when in July 2021 (Figure 1.4), Public Act 21-24 was signed into law. Titled "An Act Concerning Connecticut's Shellfish Restoration Program, the Connecticut Seafood Council and the Taxation of Certain Underwater Farmlands," the law expands the Department of Agriculture's Shellfish Fund Program to allow the purchase of oyster shells and mature oysters, and to initiate contracts to conduct restoration work. The Department can now receive private, state, or federal grants or direct funding to conduct shell recycling and shellfish restoration programs. This important legislative action will greatly facilitate future shellfish restoration efforts.

Though previous work prioritized the restoration of oyster beds used for aquaculture, interest in restoration is broader and hence the focus of this *Guide*. Ultimately, the *Guide* builds upon these previous successes and partnerships.

FIGURE 1.4 Governor Ned Lamont signs the shellfish restoration bill into law as government officials, legislators, municipal officials, shellfish farmers, and trade association members look on. Photo: Tessa Getchis

2.0 INFORMATION, TOOLS AND STAKEHOLDER NEEDS FOR SHELLFISH RESTORATION

The mouth of the Housatonic River marks the edge of the Bridgeport-Stratford Natural Bed, the state's largest designated natural shellfish bed. Photo: Tessa Getchis

2.1 Historic and Current Extent of Shellfish Populations in Connecticut Waters

The oyster is considered one of the most ecologically and commercially important bivalve shellfish in Connecticut and around the globe. Because of its ecological importance to coastal habitats and its valuable contribution to the economy, the native Eastern oyster *Crassostrea virginica* was designated as Connecticut's State Shellfish by the General Assembly in 1989. In their examination of the condition of oyster reefs, Beck and colleagues[54] concluded that while oysters are present in most locations examined worldwide, many reefs that were once common are now rare or functionally extinct. In 2005, due to increasing concern about the status of the native Eastern oyster, the U.S. National Marine Fisheries Service (NMFS) entertained a petition to list the species as threatened or endangered under the Endangered Species Act. A status review of the oyster determined "the long-term persistence of Eastern oysters throughout their range is not at risk now or in the foreseeable future.[55]" While the species was not listed as threatened or endangered, the team concluded that restoration is necessary to sustain populations in some locations (e.g. mid- and south Atlantic), and in other locations (e.g., Long Island Sound) restoration is considered important to maintaining the fishery and conserving ecosystem services. zu Ermgassen and colleagues reported the historic extent of oyster populations in Long Island Sound (within the waters of both Connecticut and New York) at between 5,001 and 15,000 hectares (12,358 to 37,066 acres) at the time (circa 1885-1915) when the resource was already exploited[56]. They noted that because of the extensive leasing of shellfish beds, they have likely underestimated the overall native oyster populations. Oysters still form extensive intertidal and subtidal beds along the coast of Connecticut, though evidence suggests that the current area does not reflect their historic extent[57].

Connecticut was one of the first states to grant vested rights in oyster grounds[58]. Commonly known as the two-acre law, it allowed individuals a small area for planting oysters. In 1881, the legislature passed an act establishing a State Commission for the designation of oyster grounds in areas that were not or had not been natural beds for at least 10 years[59]. In 1888 legislation was enacted to regulate harvest on the largest and most productive natural shellfish beds[60]. There have for many years been restrictions in place to prevent the overharvest on those beds, and the populations have sustained the oyster farming industry for nearly two centuries. According to the Connecticut Department of Agriculture, the current extent of the state's designated natural beds is 17,404 acres which includes 5,335 acres in state waters and 12,069 in town waters (Table 2.1). These beds span the entire shoreline, though are most concentrated in the central to western end of Long Island Sound (Figure 2.1). Several towns including Stamford, Milford, New Haven, East Haven, and the towns east of Branford (with the exception of Clinton) did not avail themselves of §2328 and §2326 of the General Statutes of 1888, and therefore the natural beds under their jurisdiction were not identified in statute.

With the exception of mangrove oysters in Brazil and some isolated bays, Connecticut remains one of the few places I know of on the Globe with large-scale and self-sustaining natural oyster beds that have survived industrial fishing. The foresight of the early environmental managers to protect these areas and industry community policing has resulted in something to be proud of.

*—**Boze Hancock**, The Nature Conservancy*

Jarvis Creek, Guilford. Photo: Tessa Getchis.

The use of the term “natural bed” to define these areas has often been the source of confusion because the term “natural” is typically thought of as referring to a wild population that is protected from harvest. For clarification purposes, in this document we refer to an area protected for public use (as designated by Superior Court) and used as a source of oyster seed as a “designated natural bed.” The term “undesignated natural bed” refers to areas that were likely to be oyster habitat historically but were never protected by law, are not designated for harvest, and have not been mapped. The mapping of these areas was begun in 2021 by the Connecticut Department of Agriculture.

In addition to designated natural beds (17,404 acres) and undesignated natural beds (currently unmapped acreage), there are greater than 60,000 acres designated for commercial harvest (aquaculture) and 10,422 for recreational harvest[61] (Figure 2.2). There are important data caveats. There is some overlap with areas in town waters that were in the 1800s established as designated natural beds but then later towns carved out small recreational harvest areas within those beds. There are some areas (e.g., Greenwich Flat Neck Point) that were formerly designated natural beds but by legislative action were leased to private industry. They have since reverted back to state control and the Department of Agriculture has resumed operating their status as designated natural beds. Collectively, the mapped shellfish acreage represents approximately greater than twenty percent of coastal waters of Connecticut.

Three species of native mussels are found in Long Island Sound including the ribbed mussel (*Guekensia demissa*), the blue mussel (*Mytilus edulis*), and the northern horse mussel (*Modiolus modiolus*). Mussels form large aggregations using byssal fibers to attach themselves to each other and other hard surfaces. The edible blue mussels form extensive subtidal beds in some areas while the ribbed mussels (considered to be inedible) typically inhabit the intertidal area of salt marshes. Horse mussels are less common, found below the high tide line and often associated with kelp beds. While ecologically important, there is no large-scale commercial fishery or cultivation of mussels in Connecticut. For this reason, their abundance and distribution has not been well-documented, making it difficult to assess population trends. However, anecdotal reports from fishers and coastal property owners about massive blue mussel die-offs have highlighted the importance of baseline distribution mapping and research to better understand these populations and their environmental vulnerability, especially to potential impacts from climate change.

While not a “habitat-forming” species, the northern quahog (*Mercenaria mercenaria*) is important from a commercial and recreational fisheries production standpoint. Populations can be found along the coast. Following a peak in production of 511,659 bags in 2008, clam production has decreased gradually over the last decade to less than half. Recent reports from some commercial harvesters indicate fewer small submarket-sized clams and littleneck clams (the smallest market size clam) in their catch.

Natural clam beds have not been surveyed and mapped in any formal manner with the exception of a research project in Greenwich initiated jointly by the National Oceanic and Atmospheric Administration NEFSC, Greenwich Shellfish Commission, and CT DOAG BA in 2019. This survey was designed to assess nutrient reduction services provided by natural populations of *Mercenaria mercenaria* at the municipal scale. Clams were sampled using a combination of Smith-McIntyre and Ponar benthic grab samplers. Maps of clam density will be generated and mean density across the town will be calculated and all data published and shared publicly.

Long Island Sound is also home to several other species of clams including the softshell clam (*Mya arenaria*), surf clam (*Spisula solidissima*), Atlantic razor clam (*Ensis leei),* as well as the bay scallop (*Argopecten irradians*), which are important for recreational harvest. Many towns manage harvest areas where these species are gathered by the public for personal consumption. Stock enhancement and sanctuary management are an important part of ensuring the long-term productivity of these areas. Commercial and recreational harvest areas are delineated but not with respect to specific species of shellfish. Natural populations have not been surveyed.

TABLE 2.1 Connecticut Shellfish Acreage*

AREA TYPE	AREA (ACRES)	% TOTAL AREA
Connecticut navigable waters; *all*	389,276	100
Connecticut shellfish areas; *all*	86,997*	22.35
Natural beds; *all*	17,337	4.45
Natural beds*; designated, state waters*	5,335	1.37
Bridgeport	1,279	
Darien	145	
Fairfield	1,255	
Greenwich	222**	
Norwalk	170	
Stratford	2,264	
Natural beds, *designated, town waters*	12,002	3.08
Branford	80	
Bridgeport	1,254	
Clinton	288	
Darien	516	
Fairfield	900	
Greenwich	1,613	
Guilford	33	
Madison	348	
Milford	1,657	
Norwalk	1,994	
Old Saybrook	129	
Stamford	403	
Stratford	1,073	
West Haven	1,096***	
Westport	618	
Natural beds, *undesignated, town waters*	unknown****	unknown
Commercial shellfish beds (all)	61,421	15.78
Commercial shellfish beds (state)	45,265	11.63
Commercial shellfish beds (town)	16,156	4.15
Recreational shellfish beds	10,422	2.68

**This number represents the total shellfish acreage. However, there is overlap with natural beds and recreational beds in town waters. Some areas originally established in the 1800s as designated natural beds (a total of 2,183 acres statewide) were subsequently converted by towns as recreational harvest areas.*

*** There are some areas (e.g. Greenwich Flat Neck Point) that were formerly designated natural beds but by legislative action were leased to private industry. They have since reverted back to state control and the Department of Agriculture has resumed operating their status as designated natural beds.*

**** The designated natural beds in the City of West Haven are under state jurisdiction.*

***** These areas are not fully mapped. Survey work began in 2021.*

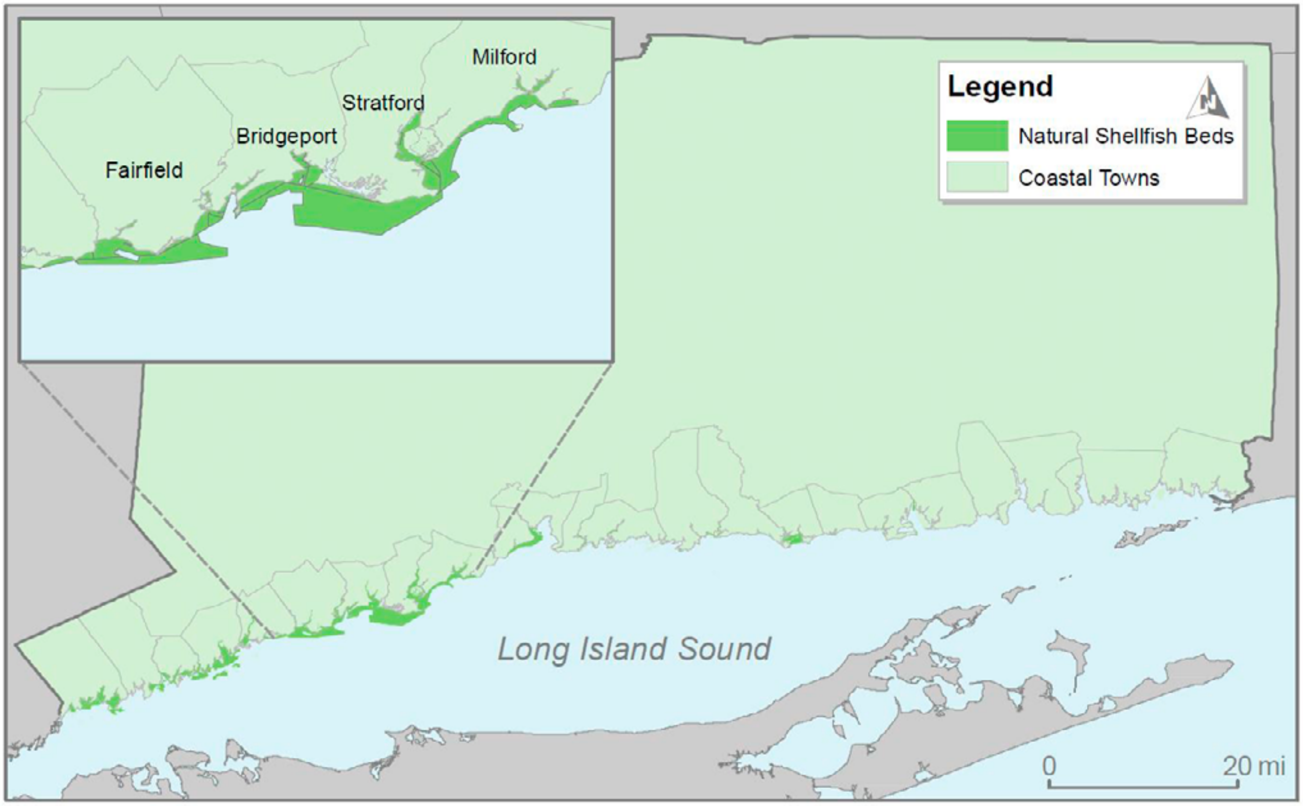


FIGURE 2.1 **Connecticut's Shellfish Areas - Designated Natural Beds**

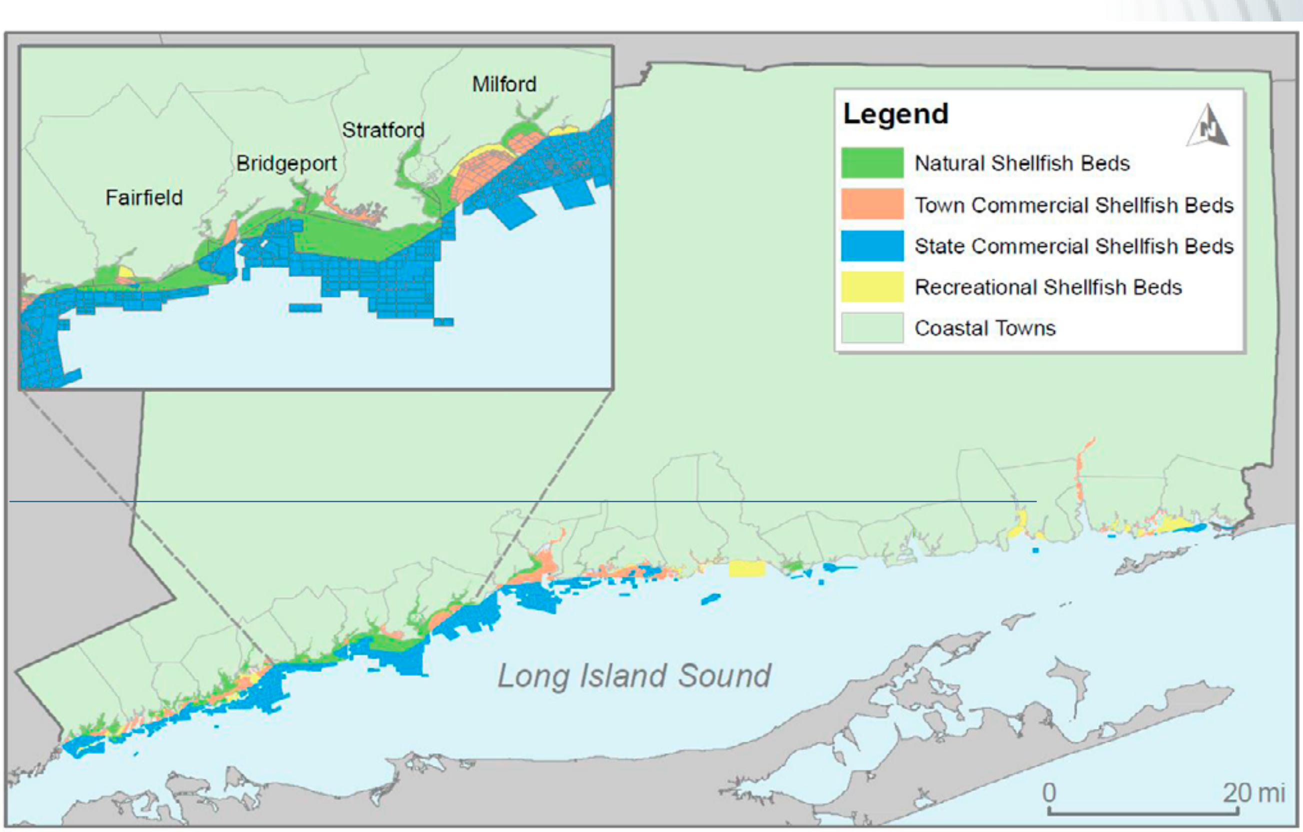


FIGURE 2.2 **Connecticut Shellfish Areas - All Types**

2.2 Relevant Data and Map Viewer

Effectively managing Connecticut's marine resources and existing human uses of Long Island Sound is dependent upon the availability and proper use of high-quality scientific and spatial data. Before engaging stakeholders in an exercise to prioritize coastal sites for shellfish restoration, it was deemed important to first find, then compile, shellfish data on population spatial distributions and on the condition of the state's shellfish habitats and marine resources. A large amount of relevant spatial and tabular data were compiled for the development of the *Guide*'s Geographic Information Systems (GIS) tool, the *Connecticut Shellfish Restoration Interactive Map Viewer*[62] **https://s.uconn.edu/ctshellfishrestoration**. The *Map Viewer* is the state's first geospatial collection of key ecological, biological, and human-use data intended to assess the viability of a coastal location to support shellfish restoration (Figure 2.3). Further, qualitative oyster habitat surveys (see Section 2.6) characterized, for the first time, the condition of intertidal oyster populations across the state and established a baseline to inform the planning of future quantitative assessments. The tool draws heavily on several key datasets compiled by government-appointed committees and subject matter experts across the state and region:

- The *LIS Blue Plan Resource and Use Inventory*[63] **https://portal.ct.gov/DEEP/Coastal-Resources/LIS-Resource-and-Use-Inventory-Home** which includes key environmental and human use data. The inventory was developed as part of the Long Island Sound Blue Plan process, a multi-year effort to establish a spatial plan to guide future use of the Sound's waters and submerged lands. It is maintained by the Connecticut Department of Energy and Environmental Protection.

- The *Aquaculture Mapping Atlas*[64] **http://cteco.uconn.edu/viewer/index.html?viewer=aquaculture** is an online map viewer containing spatial data intended for use in planning private, public, or research aquaculture activities. It contains information on the location of existing designated natural shellfish beds and recreational and commercial shellfish harvest areas. It is maintained through a partnership among the University of Connecticut Center for Land use Education and Research (UConn CLEAR), Connecticut Sea Grant and the Connecticut Department of Agriculture's Bureau of Aquaculture.

- The *Living Shorelines Story Map*[65] **https://www.arcgis.com/apps/MapSeries/index.html?appid=150edfcff35d4103afe8a20856067c05**. This story map shows the results of a site suitability analysis for potentially viable sites for living shoreline options along the Connecticut shoreline. Five data layers were used in the analysis, including fetch, bathymetry, erosion history, marsh, and beach. Four living shoreline methods were explored: beach enhancement; marsh enhancement; marsh with structures; and, offshore breakwaters. These are: beach enhancement; marsh enhancement; marsh with structures; and offshore breakwaters. This analysis provides a first-cut analysis of potential options but in no way supersedes that of a coastal engineer gathering site-specific information. This product was developed at the University of Connecticut.

The steering committee, along with LIS data experts from UConn CLEAR and CT DEEP helped to source and access these data, which have been cataloged into a single "master data ID spreadsheet." This spreadsheet includes metadata about each dataset, including links to the original data, data creator/manager, and more. The task force and steering committee engaged in a lengthy decision-making process to narrow the available data to those factors deemed most useful and of appropriate quality, and considered the following:

- Is the data a key factor for shellfish production?
- Is the data spatially and temporally relevant?
- Is the data regularly updated so as to be relevant for decision-making?
- Is the data subject to a quality assurance and quality control plan?

The steering committee used this spreadsheet to determine whether to include individual datasets in the *Connecticut Shellfish Restoration Interactive Map Viewer*. The relevant datasets were compiled into one comprehensive list and sorted (for ease of viewing) into three categories: "human uses;" "species and habitats;" and, "shellfish-related factors."

The following steps describe how the *Map Viewer* is intended to be used for decision making:

1. Identify where shellfish restoration is off limits (see Section 2.4 to learn more)
2. Identify where significant human uses exist to help avoid use conflicts (see section 5.6)

3. Identify the location of public or private access routes to the site (see section 5.6)
4. Identify where protected habitats and species exist to help avoid negative interactions (see section 5.6)
5. Characterize the condition of oyster habitat (see sections 2.6 and 5.6)
6. Identify factors that may be important to shellfish survival, growth, and reproduction (see section 5.6)
7. Identify other relevant shellfish and environmental data that may be valuable in establishing a plan for project metrics and monitoring (see Section 5.6 and 5.7)

Depending on the location and goal of the project, there may be many other non-spatial logistic and regulatory factors to consider (see Sections 5.8 to 5.11).

A step-by-step guide on how to use the *Connecticut Shellfish Restoration Interactive Map Viewer* appears in the "How To" tab in the *Map Viewer:* **https://s.uconn.edu/ctshellfishrestoration.**

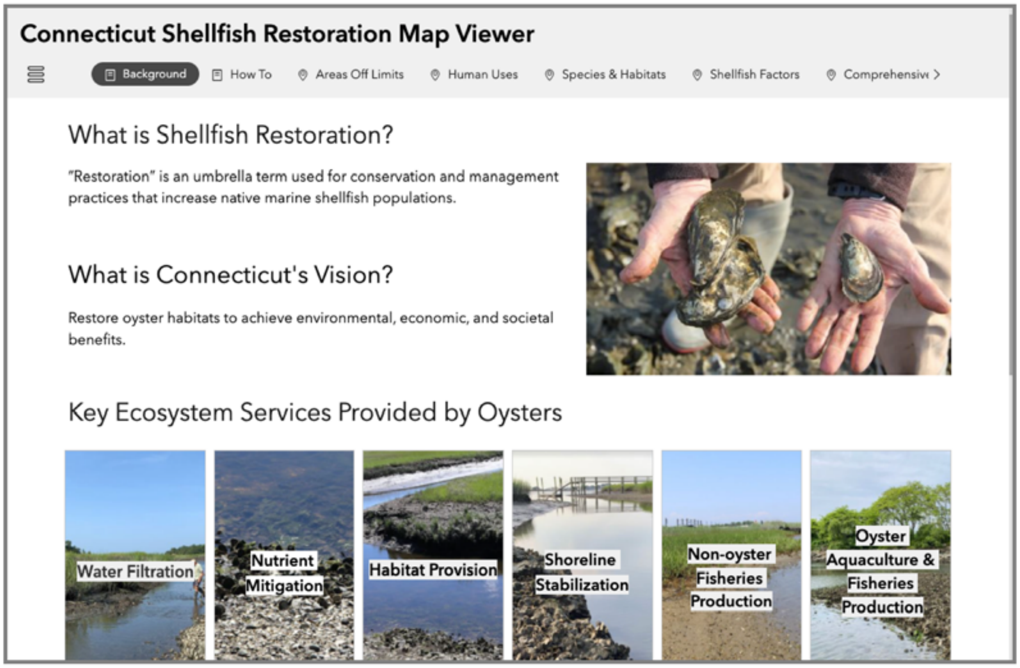


FIGURE 2.3 *The Connecticut Shellfish Restoration Interactive Map Viewer*.

2.3 The Potential Area for Shellfish Restoration

The full extent of all Long Island Sound waters includes all navigable waters of Connecticut as defined in the U.S. Code of Federal Regulations[66]. The original base data used to develop the extent of Connecticut's coastal water features in Long Island Sound was the "Hydrography" data set. "Hydrography" is a 1:24,000-scale, polygon and line feature-based layer that includes all hydrographic features depicted in the U.S. Geological Survey (USGS) 7.5-minute topographic quadrangle maps for the State of Connecticut. Connecticut's coastal waters are identified in the "*Hydrography*" polygon layer, and the attribute "*Coastal_Poly*" is used to identify waters of Long Island Sound. In certain areas, an "*Inland_Poly*" was also included where waters were known to support shellfish populations. The total area that is considered the full baseline extent of coastal water areas that are potentially able to support shellfish populations in Long Island Sound is 389,926 acres (Figure 2.4).

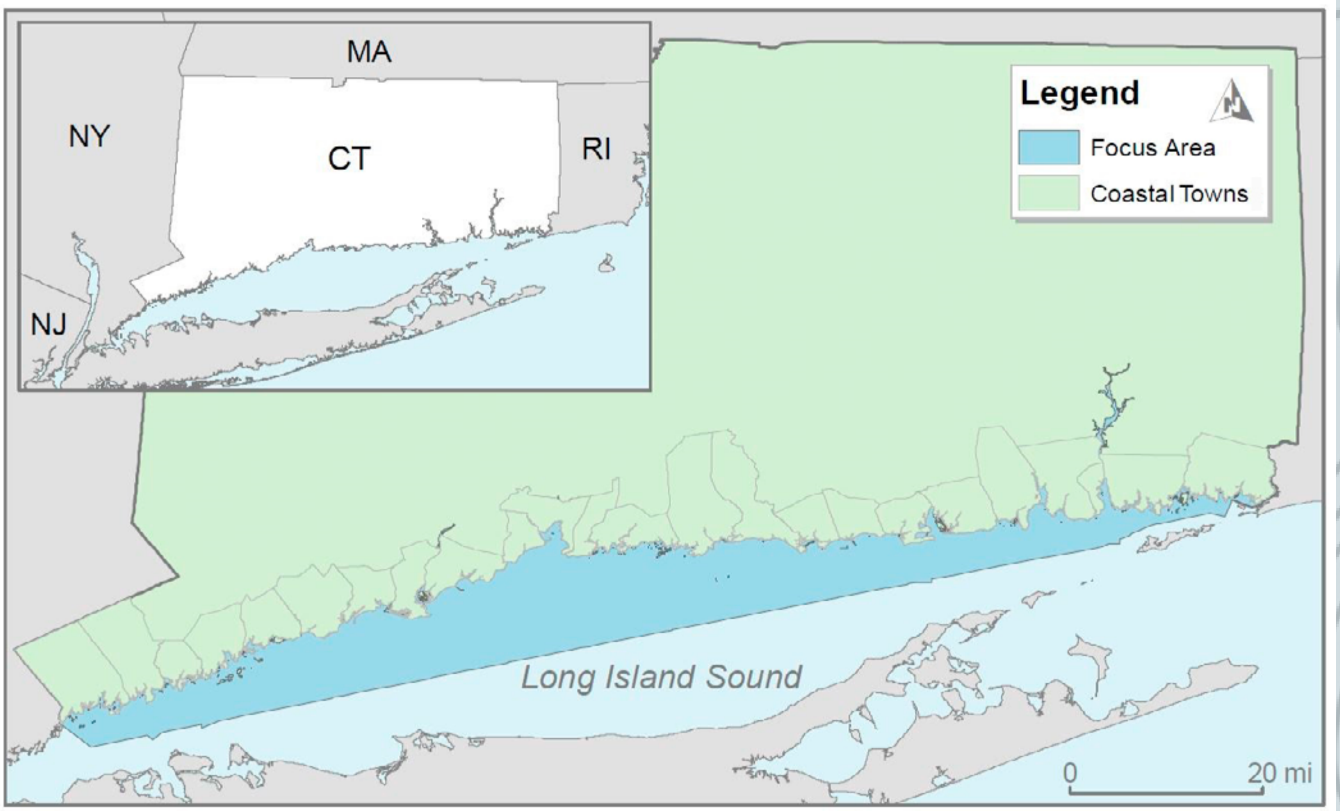


FIGURE 2.4 The full extent of the "potential" area for shellfish restoration includes all of the navigable waters of Connecticut in Long Island Sound, encompassing a total of 389,926 acres.

2.4 Areas Off Limits to Shellfish Restoration

An exclusionary analysis considers significant human uses which may conflict with shellfish restoration based on regulations which would prohibit a restoration project from being developed in a given area. State and federal regulatory agencies provided input as to the relevant regulations which would prohibit shellfish restoration in specific areas. The exclusionary analysis was developed using GIS to merge the individual layers into a single polygon layer that identifies all areas that should be excluded from consideration. The field "Legend" indicates the use type for each polygon. Additional attribute data includes the area name, description and size in acres (Table 2.2). These locations should be considered "off-limits" for restoration, as opposed to "unsuitable" for restoration, which will be addressed during habitat or site suitability analysis.

Only those areas that have a statutory or regulatory prohibition were included in this analysis rather than all potential user conflicts. The GIS analysis began with identifying and enumerating the total area of the Connecticut portion of Long Island Sound as previously described in Section 2.2 (see Figure 2.4). Next, the individual areas to be excluded were identified by type (Figure 2.5). Next, the layers were consolidated into one GIS layer called *"Areas Off Limits to Shellfish Restoration"* and the total area mapped and calculated (Figure 2.6). This layer is included as a feature in the *Connecticut Shellfish Restoration Interactive Map Viewer* **https://s.uconn.edu/ctshellfishrestoration**, and also here: **https://arcg.is/0vTnCK1**. The result of the analysis was the identification of 109,609 acres to be excluded from the total area of 389,276 acres, leaving 279,667 acres as the revised potential area for restoration (Figure 2.7).

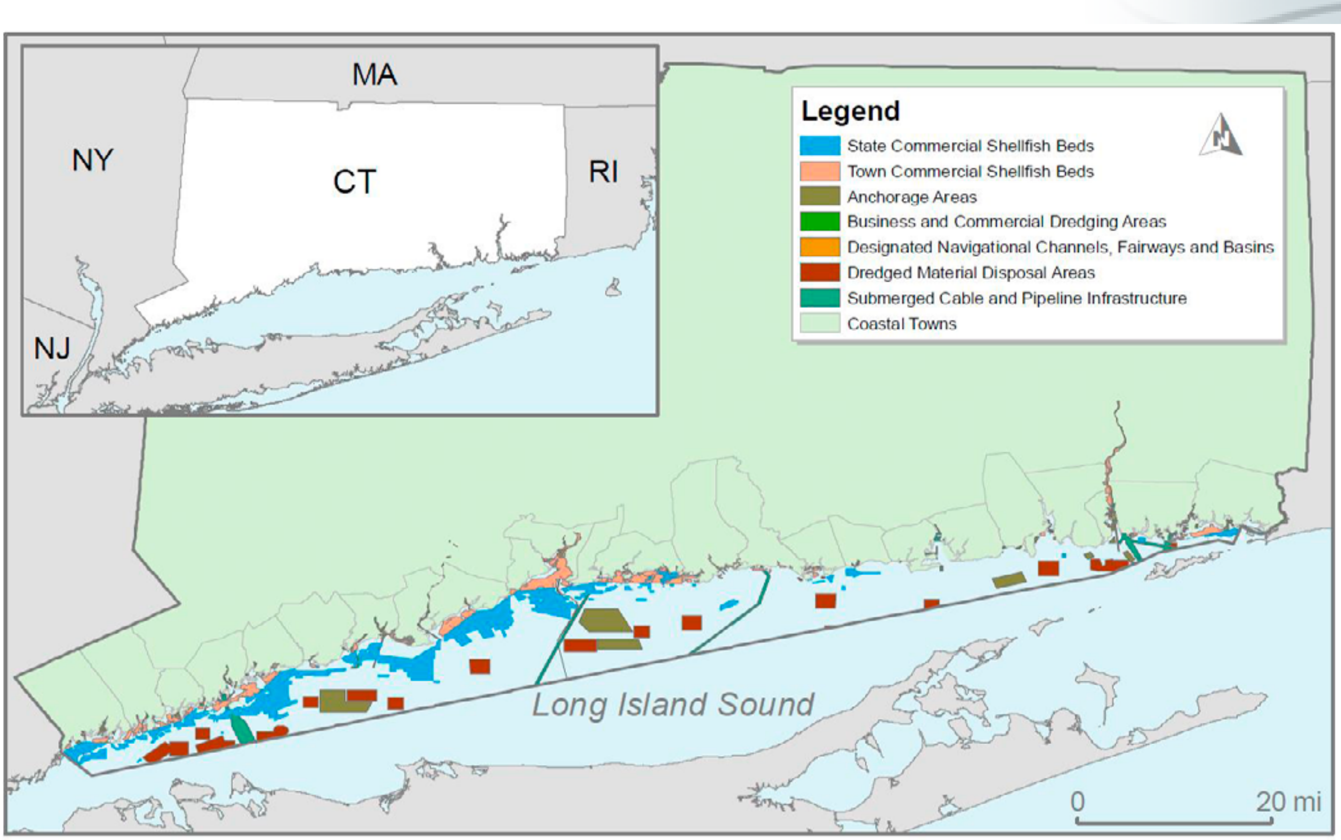


FIGURE 2.5 Results of exclusionary analysis showing excluded areas by type.

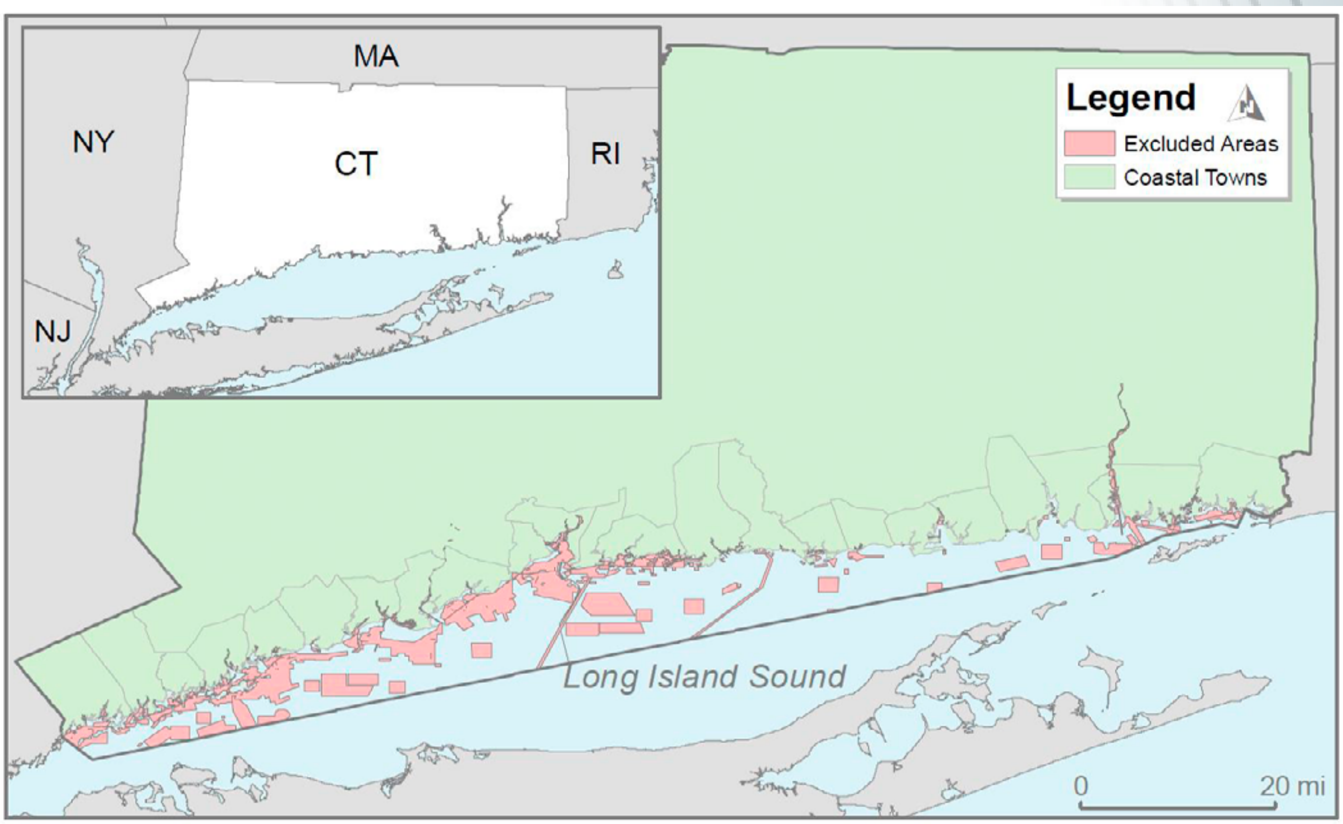


FIGURE 2.6 Results of exclusionary analysis showing total excluded area.

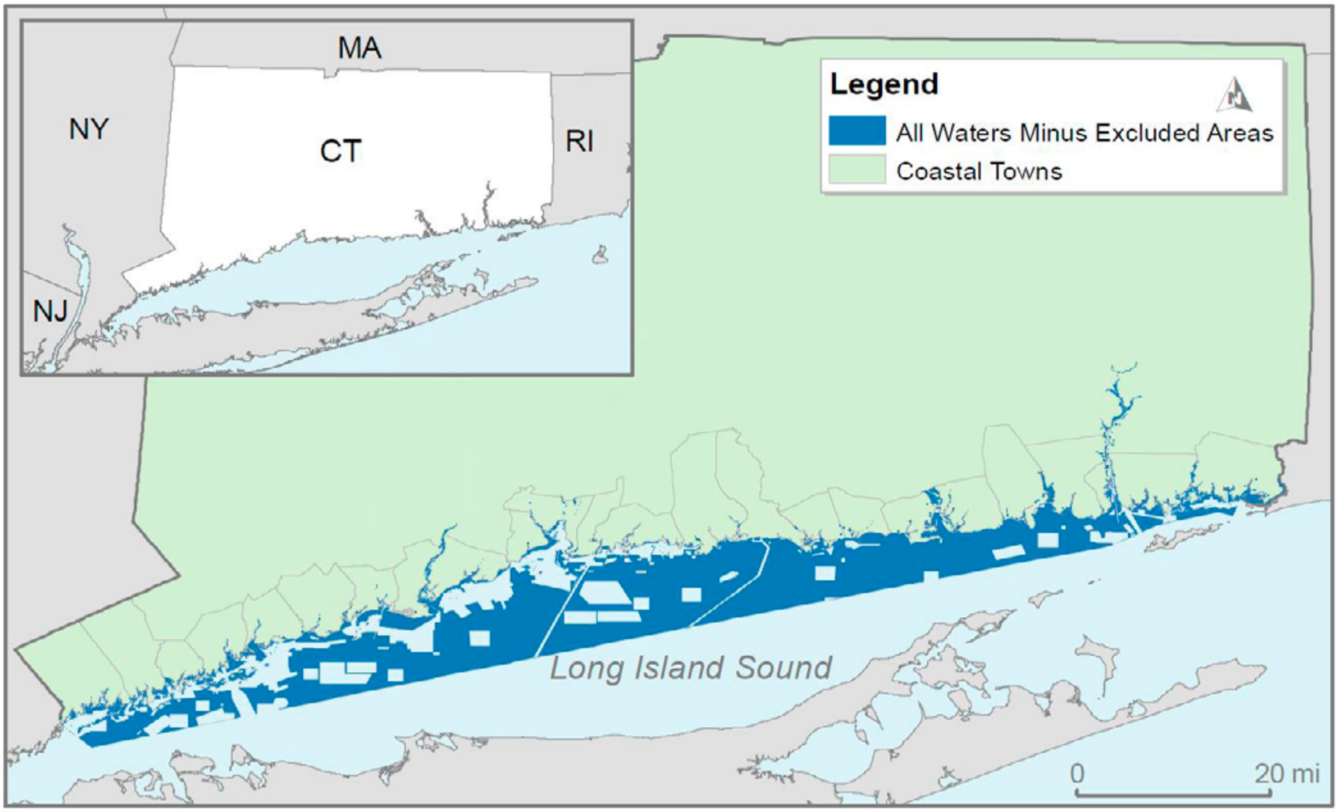


FIGURE 2.7 **Results of exclusionary analysis showing total potential area**

TABLE 2.2 **Description of Areas Off Limits to Restoration**

DATA AND SOURCE	DESCRIPTION	ACREAGE
State commercial shellfish beds *CT DOAG BA*	Privately leased areas in state waters where shellfishermen have access to the bottom for the exclusive purpose of cultivation of shellfish	45,265.10
Town commercial shellfish beds *CT DOAG BA*	Privately leased or licensed areas in town waters where shellfishermen have access to the bottom for the exclusive purpose of cultivation of shellfish	16,156.10
Anchorage areas *NOAA - CT Blue Plan*	Anchorage areas as they appear on the NOAA charts.	15,247.64
Dredged material disposal areas (active and historic) *NOAA - CT Blue Plan*	Dredged material disposal sites as they appear on the NOAA charts, in the Long Island Sound Dredged Material Management Plan	22,892.33
Submerged cable and pipeline infrastructure areas *NOAA - CT Blue Plan*	Cables, pipelines, and cable/pipeline areas	9,930.24
Designated navigational channels, fairways and basins *NOAA - CT Blue Plan*	Designated and maintained navigational channels as they appear on the NOAA-published charts.	2,581.28
Business and Commercial Dredging Areas *NOAA - CT Blue Plan*	An approximate inventory of privately maintained navigational channels, fairways, and basins, excluding facilities for individual residential use.	280.41
	GRAND TOTAL	**109,555.62**[67]

2.5 Geographic Areas of Interest for Shellfish Restoration

Excluding areas that are not feasible for restoration (explained in section 2.4. *Areas Off Limits to Shellfish Restoratio*n) is the vital first step towards highlighting the areas of interest for restoration. Identifying areas of interest for shellfish restoration requires comprehensive inventories of both regionally-focused ecological and human-dimensions data. So, in 2018, the Task Force and Steering Committee developed and distributed a spatially explicit survey that asked state and municipal officials to identify 1) areas of interest and 2) goals for shellfish restoration. Survey respondents were given a blank map on which they could indicate which species should be restored where and for what purpose(s). The responses were provided to the Connecticut Department of Agriculture, Bureau of Aquaculture, who reviewed and compiled the information into a single GIS layer called "*Shellfish Restoration Interests and Project Sites*" (Figure 2.8).

The "*Shellfish Restoration Interests and Project Sites*" layer is a geographic distribution of 7 color-categorized restoration goals (or benefits) (see Figure 2.8). This single GIS layer does not directly account for biological, ecological, environmental, or human use considerations, but is intended to be combined through an overlay with those other datasets to determine optimal restoration sites in Connecticut's waters. The Task Force and steering committee intend for this layer to be updated periodically as new interests arise and to document existing projects. This layer can be found in the *Connecticut Shellfish Restoration Map Viewer*[68] **https://s.uconn.edu/ctshellfishrestoration**, and also here: **https://arcg.is/0v48Kb0**. The identification of restoration project's interests does not imply that these are "priorities" but rather a geographically-documented representation of those interests for the implementation of future restoration projects. The prioritization process has not yet been conducted but the need to do so has been expressed (see section 3.2, *Recommendations*).

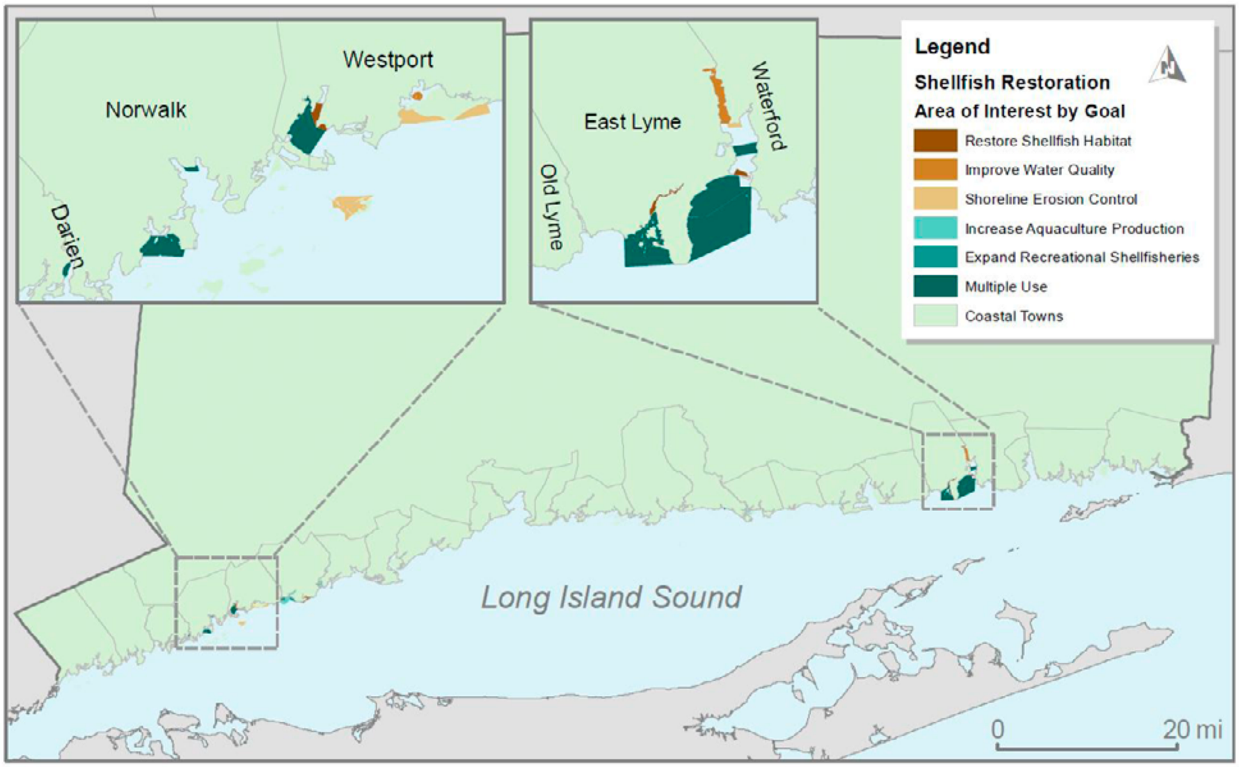


FIGURE 2.8 Examples from municipal officials who identified restoration interests by goal.

One of the goals of the Task Force and Steering Committee was to identify and begin vetting the geographic viability of sites for Connecticut's future shellfish restoration projects and/or areas. Given significant data gaps in the collective knowledge of the status of the state's shellfish populations, it was deemed unfeasible at this time to formally prioritize specific sites for shellfish restoration. However, as an introductory step towards formally selecting sites for restoration, the Task Force developed and used three determining factors (listed below) to help identify specific locations for potential shellfish restoration:

(a) human capital, (especially in terms of knowledge about the local shellfish resources and their management),

(b) community support, and

(c) an able workforce or group of committed volunteers.

Through this process, the Task Force identified four specific coastal locations in Connecticut as currently (2022) having 'significant potential' for successful shellfish restoration:

Veterans Park. Photo: Tessa Getchis.

Veterans Park (Norwalk) - There is interest in using eastern oysters, ribbed mussels, and salt marsh grasses to restore Veterans Park's coastal habitats. The identified site consists of a public park with a small fringing salt marsh and immediately beyond, a designated shellfish (oyster) bed. The intertidal portion of the bed is not harvested, and is in need of shell substrate and broodstock oysters. The salt marsh is degrading and collapsing in areas. Broad support for such a restoration project was expressed by individuals in the shellfish industry, shellfish commissions, and certain city officials.

Ash Creek (Fairfield) - There is interest in continuing what has been a small-scale but successful multi-year natural oyster bed restoration effort led by Fairfield Shellfish Commission. The restoration site, Ash Creek, is adjacent to a public park, and has been improved with the addition of shell substrate, as well as spat on shell. The majority of the bed is in the intertidal zone and is not harvested. There is broad support for this project from industry, shellfish commission, and certain city officials. For example, the shellfish commission uses collectors to capture oyster spat and after a season of growth, transplants those oysters to supplement other beds.

Ash Creek Natural Bed. Photo: Griffin O'Neill.

Greenwich Point. Photo: Tessa Getchis.

Greenwich - Scientists from the NOAA NEFSC Milford Lab, along with economists from SUNY Stony Brook and local officials have been conducting extensive surveys of the oyster and quahog populations to determine the overall economic value of the ecosystem services these shellfish provide. Given the extensive knowledge about these shellfish populations, the proposed plans for restoration projects, and the high development pressure, this Greenwich site is an ideal site to consider for future restoration projects and/or areas.

Bridgeport-Stratford Designated Natural Shellfish Bed - This subtidal area is the largest designated natural shellfish bed in the State, and is the single largest oyster seed source for the aquaculture industry. Over the last few decades, this bed has been the focus of successful management programs to uncover buried shell substrate and replant it ahead of the spawning season so the bed could be self-sustaining. Unfortunately, state funding was discontinued and the bed fell into poor condition mainly due to silt accumulation. However, federal funding supported small-scale shellfish restoration efforts in 2020, 2021 and 2022, and there is interest from state officials and industry members in continuing and expanding this work.

The identification of these four coastal locations as having “significant potential” for successful shellfish restoration represents an introductory evaluation of Connecticut waters’ optimal locations for shellfish restoration. It is important to stress that the identification of these four sites does not indicate that they hold a higher priority for restoration oversites. The Task Force recommends that in the near future the state develops a formal restoration site prioritization system (see section 3.2, *Recommendations*). The continued vetting process will rely on public and private sector shellfish restoration project leads consulting with one another to develop strong proposals for funding agencies (see Section 3.4. “*Recommendations for Policy*” #24).

2.6 Qualitative and Quantitative Surveys of Oyster Habitat

As data on the historic and current extent of Connecticut shellfish habitats were reviewed, it was determined that there was little knowledge of the condition of oyster habitat, and in fact, not all shellfish beds have even been mapped. Historic maps that indicated generally the location of natural shellfish beds were produced in the late 1800s, but have never been digitized or georeferenced[69,70]. Further, the locations of these shellfish beds have not been updated since that time. Recent efforts have been focused solely on delineating commercial and recreational shellfish harvest areas, and designated natural beds. This emphasized the need to complete mapping and oyster habitat characterization across both designated and undesignated natural beds.

In the spring and summer of 2021, staff from the CT DOAG BA and CTSG began conducting qualitative surveys of intertidal and shallow subtidal oyster habitat at sites across Connecticut.

The team met with local subject matter experts including municipal shellfish and harbor management commissions, commercial shellfish harvesters, and town officials to gather descriptive environmental data, human dimensions data, photographs, and intel on the communities' perspectives on restoration activities on their coastlines (Figure 2.9). Surveys were conducted in 15 coastal towns, with a total of 68 sites from Greenwich in the west to Stonington in the east (Figure 2.10). The sites surveyed are known to be current and historically important oyster areas based on historic maps and conversations with subject matter experts.

The purpose of these surveys is to establish baseline data on oyster habitat conditions and inform the restoration planning process. A more detailed quantitative survey of the habitat and environmental conditions at the site may be warranted depending on the goal of the restoration project (see Section 5.6 *Metrics and Monitoring*).

It is important to note that the current spatial coverage does not represent the full extent of oyster habitat. Also, while the information is intended to inform decision making, it is important that users consider that environmentally driven changes (e.g. storms) or coastal development (e.g. dock construction) may result in changes to the existing mapped habitat. While efforts will be made to map any such changes, individuals should ensure that they are viewing the most current survey data and consult the CT DOAG BA to confirm the accuracy of that data.

A plan is being developed by CT DOAG BA to work with other state, federal, and municipal officials to expand spatial coverage of oyster habitat surveys across the state and in deeper subtidal areas. Interested municipal officials (e.g. shellfish and conservation commissions, others) should contact the CT DOAG BA to identify potential new survey areas. The CT DOAG BA is considering a number of methodologies to survey and characterize natural oyster beds.

The site surveys collected the following information:

- Town and site name
- Precise site GPS coordinates
- General site description
- Shellfish bed type (i.e., designated natural; undesignated natural; recreational bed; commercial)
- Tide level (i.e., intertidal; subtidal)
- Water depth
- Substrate type (i.e., mud; sand; shell; gravel; mix)
- % coverage of shell (including live shellfish)
- Shellfish harvest area classification (prohibited; restricted; conditional; approved)
- Photographs of habitat

Photographs were taken at each site so that simple comparisons can be made during future surveys. Photographs can be helpful to characterize the habitat (e.g. sediment type, percent shell coverage, age/size composition of shellfish) and describe any surrounding habitats (e.g. salt marshes) (Figures 2.11, 2.12, 2.13).

The presence and percent coverage of shell/reef as a bottom substrate is a key measurement and serves as a predictor of oyster habitat sustainability. An abundance of shell can be indicative of historical and native shellfish populations and also provide the essential hard-bottom substrate for both restoration activities and natural juvenile recruitment. The habitat is classified following methodology developed by Grizzle and Brodeur[71] into the following categories:

1. non-reef (<10% coverage by shell)
2. low-density reef (10-50% coverage by shell)
3. high-density reef (>50% coverage by oyster shell)

Examples of these classifications in the field (Figures 2.14, 2.15, 2.16).

This survey data has been incorporated into a new GIS data layer *"Intertidal Oyster Habitat Survey Sites*" and added as a map service in the *Connecticut Shellfish Restoration Map Viewer*[72] **https://s.uconn.edu/ctshellfishrestoration**, and also here: **https://arcg.is/08Cy8G0** (Figure 2.17). The original data is available through the CT DOAG BA.

FIGURE 2.9 Shellfish and conservation commission members meet with the research team to survey shellfish beds in Old Saybrook. Photo: Griffin O'Neill

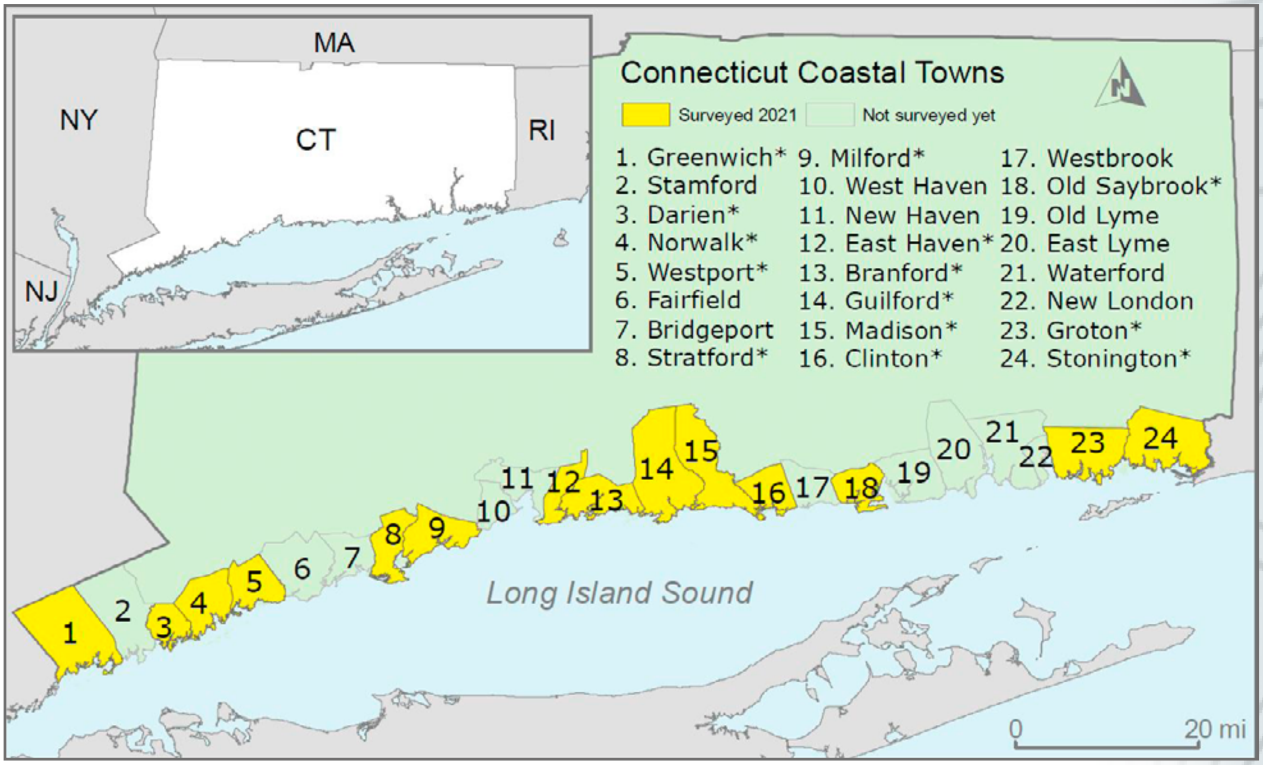


FIGURE 2.10 Locations of oyster beds surveys conducted in 2021.

FIGURE 2.11 Clusters of Eastern oysters growing vertically. Photo: Griffin O'Neill

FIGURE 2.12 Eastern oysters (left and center) growing alongside a bed of blue mussels (right) and ribbed mussels (top). Photo: Griffin O'Neill

FIGURE 2.13 Newly settled oyster spat. Photo: Zofia Baumann

FIGURE 2.14
Area characterized as a "non-reef" with shell covering less than 10% of the surface area.
Photo: Griffin O'Neill

FIGURE 2.15
Area characterized as a "low-density reef" with shell covering 10-50% of the surface area.
Photo: Tessa Getchis

FIGURE 2.16
Area characterized as "high-density reef" with shell covering greater than 50% of the surface area.
Photo: Tessa Getchis

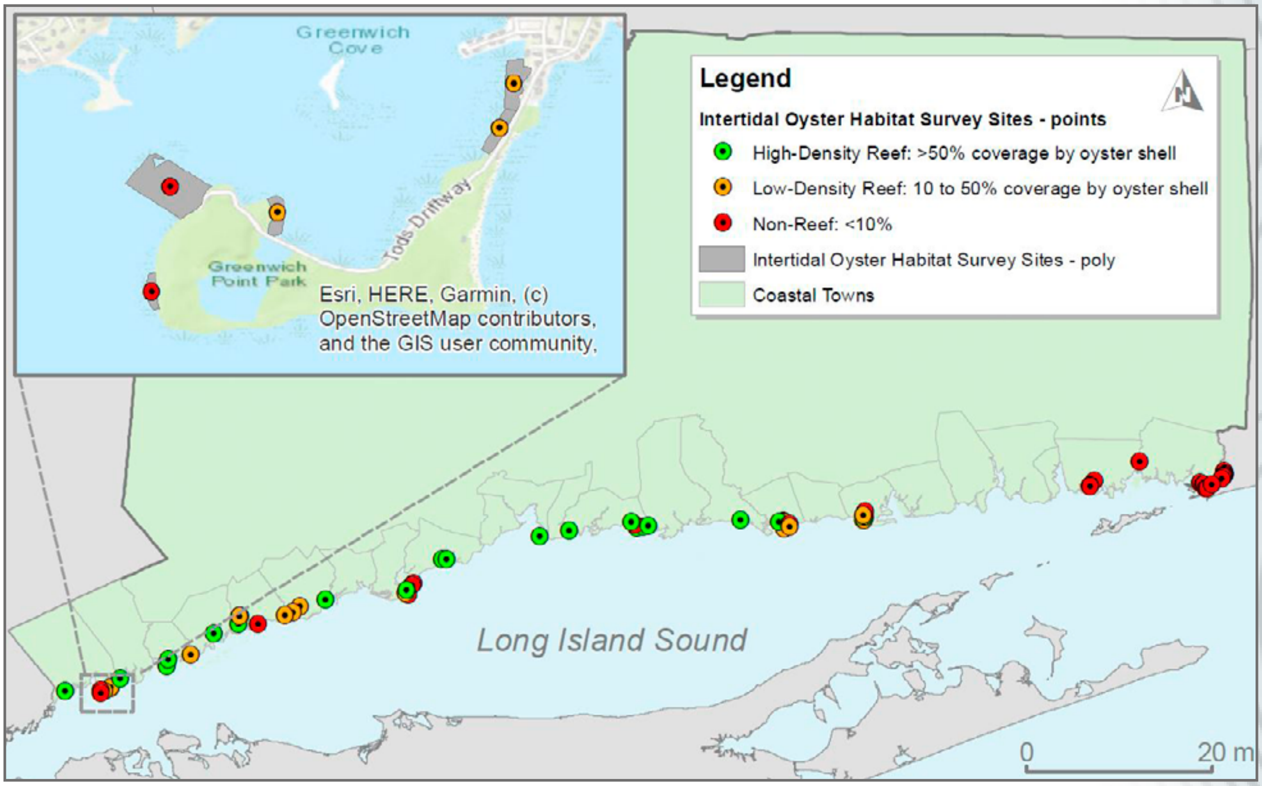


FIGURE 2.17 (A) The GIS layer "*Intertidal Oyster Habitat Survey Sites*" indicates the location of oyster surveys that characterize oyster habitat across Connecticut.

Intertidal Oyster Habitat Survey Sites

FIGURE 2.17 (B) Close up of Greenwich, CT sites.

Intertidal Oyster Habitat Survey Sites

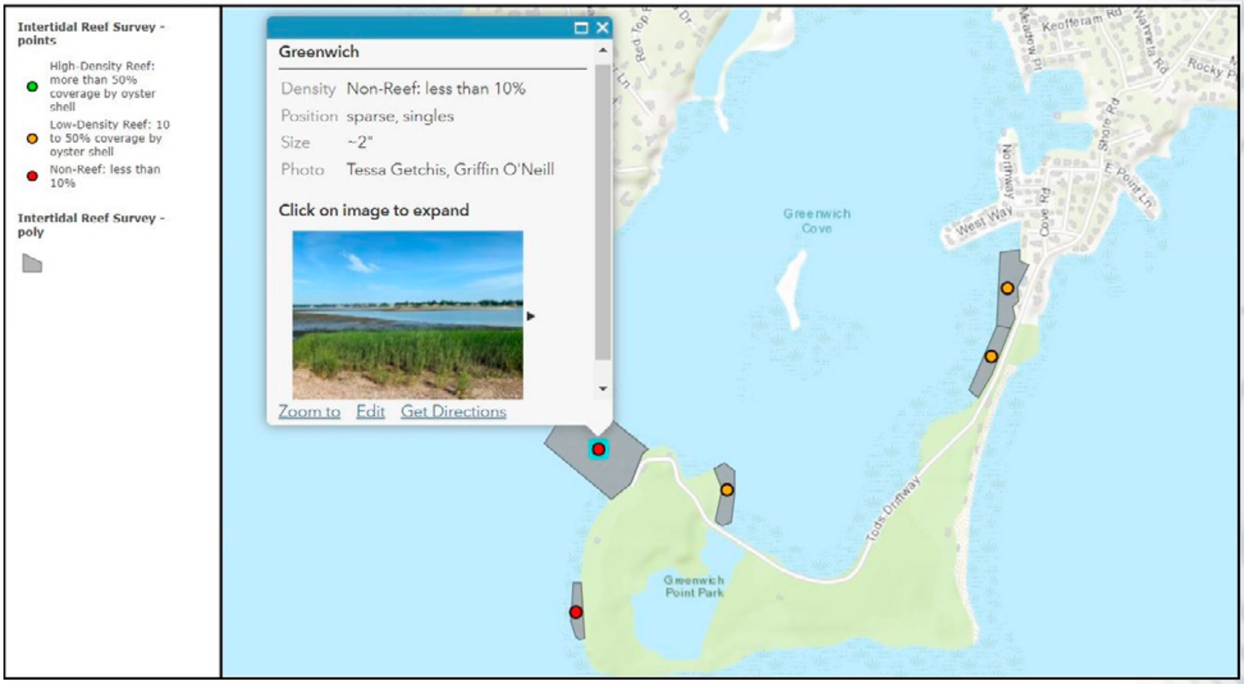


FIGURE 2.17 (C) Close up showing the site with survey information.

3.0 STAKEHOLDER NEEDS

Task force members work with a local oyster farmer to document intertidal oyster habitat in Hoadley Creek, Guilford.

Photo: Griffin O'Neill

3.1 Overview

Recommendations have been published and significant efforts have been made to improve the state's commercial and recreational shellfish beds. Until recently, limited effort had been directed towards documenting the status and condition of Connecticut's natural shellfish beds, and toward understanding restoration needs and the needs of stakeholders interested in engaging or sponsoring restoration activities. During the development of this guide, participants investigated what is known about shellfish populations and habitats. However, as it was determined that more knowledge is needed or would be useful, the steering committee also identified the following list of recommendations to inform and facilitate shellfish restoration in Connecticut.

A number of these recommendations overlap with other statewide and regional initiatives including the *Connecticut Shellfish Initiative Vision Plan (CSIVP)*[73] the *2015 Long Island Sound Comprehensive Conservation and Management Plan (CCMP)*[74] and *2020-2024 LIS CCMP Update*[75], and the *Governor's Council on Climate Change Phase 1 Report (GC3)*[76] and are referenced accordingly. This guide, and the above recommendations, can work synergistically with the efforts of those other bodies, but will require that members of each interact on a regular basis.

The list of recommendations is broken out into the following areas:

- *Data management*
- *Research and monitoring*
- *Policy*
- *Outreach*

3.2 Recommendations for Data management

#	RECOMMENDATION	DRIVERS & POTENTIAL PARTNERS
1	**Develop plan to expand spatial coverage of oyster habitat using a variety of methods as appropriate; surveys should capture at a minimum areas where there is a history of oyster habitat; update related GIS layers "*Intertidal Oyster Habitat Survey Sites*" and "*Subtidal Oyster Habitat Survey Sites.*"** *See also CSIVP #30: Improve mapping capacity, geographic coverage and public access to and use of spatial, biological, chemical, and physical data sets used for shellfish resource management.*	DOAG BA, CTSG, NOAA NEFSC Milford Lab, UConn Dept. of Natural Resource & the Environment & Dept. of Marine Sciences
2	**Get consensus from all stakeholders how currently unmapped oyster habitat will be managed once it is mapped and known.**	DOAG BA, DEEP, CTSG
3	**Develop plan to expand spatial coverage of coastal zone soil survey mapping through the National Cooperative Soil Survey which includes subaqueous soils.** *USDA NRCS began this process in 2004; federal funding announced in March 2022.*	USDA NRCS
4	**Georeference and digitize maps: (a) "*General Map of the Oyster Grounds of the State of Connecticut*" part of the *Report of the Commissioners of Shell Fisheries for 1881* (James P. Bogart); (b) "*Western, Eastern Sections of Long Island Sound Oyster Grounds, State of Connecticut 1889*" part of the *Fifth Annual Report of the Bureau of Labor Statistics* (James P. Bogart).** *See also CSIVP #30: Improve mapping capacity, geographic coverage and public access to and use of spatial, biological, chemical, and physical data sets used for shellfish resource management.*	Interested parties should contact DOAG BA which has acquired copies of these maps from the Connecticut State Library
5	**Identify and prioritize projects or locations in which the primary ecosystem service is improved shellfish production; map and quantify desired acreage.** *CT DOAG BA began a process in 2021 of prioritizing restoration work on designated natural oyster beds; in 2022, a CT DOAG BA, CTSG, & NOAA NEFSC Milford Lab research project is planned to assess oyster recruitment success following different restoration activities on these beds.* *See also: CSIVP #13 Improve productivity of oyster beds used as a local source of seed for aquaculture; CSIVP #16: Identify and implement strategies to expand recreational shellfishing opportunities where desirable and appropriate.*	DOAG BA, CTSG, NOAA NEFSC Milford Lab, shellfish commissions
6	**Identify and prioritize projects or locations in which the primary ecosystem service is improved oyster habitat; map and quantify desired acreage. A GIS-based oyster Habitat Suitability Index should be developed to achieve this.** *The task force began this process by identifying five minimum key factors (depth, substrate, dissolved oxygen, temperature, salinity) that should be included in a GIS-based oyster habitat suitability index. Available data were reviewed in 2021 and determined, at the time, that there is insufficient data in bays and harbors to develop the index.* *See also GC3 #2: Investigate options for restoring or enhancing subtidal aquatic beds to provide habitat and shoreline protection through wave dissipation; CCMP #HW-1: Complete projects that result in restoration of coastal habitat; CSIVP #30: Improve mapping capacity, geographic coverage and public access to and use of spatial, biological, chemical, and physical data sets used for shellfish resource management.*	DOAG BA, DEEP, CTSG, EPA LISS, USDA NRCS, shellfish commissions
7	**Identify and prioritize projects or locations in which the primary ecosystem service is improved water quality; map and quantify desired acreage. Data to drive analysis may include a review of impaired waters in towns associated with MS4.** *See also CCMP #WW-25: Evaluate challenges to implementation of bioextraction in Long Island Sound, including use conflicts, economic viability, permitting and testing requirements and potential environmental impacts, and make recommendations to overcome them; CSIVP #19: Develop strategies to reduce non-point/runoff and point sources of pollution that affect human and shellfish population health).*	DEEP, EPA LISS, USDA NRCS, Connecticut Conservation Districts, Yale School of Forestry
8	**Identify and prioritize projects or locations in which the primary ecosystem service is nutrient mitigation; map and quantify desired acreage.**	DOAG BA, DEEP, EPA LISS, USDA NRCS
9	**Identify and prioritize projects or locations in which the primary ecosystem service is fisheries production; map and quantify desired acreage.** *(See also CCMP #SC-3: Continue programs to promote recreational fishing and boating as healthy and sustainable activities, while incorporating education on environmental issues and ways to enhance stewardship).*	DOAG BA, DEEP, fishery trade associations
10	**Identify and prioritize projects or locations in which the primary ecosystem service is shoreline erosion control and then within these areas, assess where it makes sense to incorporate shellfish into a living shoreline; map and quantify desired acreage.** *See also GC3 #2: Investigate options for restoring or enhancing subtidal aquatic beds to provide habitat and shoreline protection through wave dissipation; CCMP #HW-1: Complete projects that result in restoration of coastal habitat; CCMP #HW-11: In lieu of hard armoring, develop and promote the use of living shoreline habitat protection methods (dunes, shorelines, coastal marshes) and standardized living shoreline monitoring protocols while considering the habitat needs of Species of Greatest Conservation Need, including forage species, and reducing wildlife conflicts.*	Consult with DEEP for all living shoreline projects, and DOAG BA for any projects that include shellfish
11	**Add newly identified restoration interests and priorities and project sites to the GIS layer called "*Shellfish Restoration Interests and Project Sites.*"**	DOAG BA, DEEP, UConn CLEAR, CTSG
12	**Integrate new maps and data sets into the *Connecticut Shellfish Restoration Interactive Map Viewer*.** *See also CSIVP #30: Improve mapping capacity, geographic coverage and public access to and use of spatial, biological, chemical, and physical data sets used for shellfish resource management.*	DOAG BA, DEEP, UConn CLEAR, CTSG

3.3 Recommendations for Research and Monitoring

#	RECOMMENDATION	DRIVERS & POTENTIAL PARTNERS
13	**Expand dissolved oxygen, salinity, temperature, and pH monitoring in existing estuaries and in data poor areas; extrapolate point data to cover the entire estuary; use this data will inform the development of a GIS-based oyster Habitat Suitability Index.** *(Save the Sound began in 2017 working with municipal groups to collect comparable data on the health of LIS bays and harbors; funding and staffing is necessary to complete this work).*	EPA LISS, Save the Sound.
14	**Expand coastal ocean acidification monitoring in collaboration with the Northeast Coastal Acidification Network.** *(See also GC3 #3: Continue monitoring distribution and conduct research to identify the likely impact of climate on subtidal aquatic beds to inform management and restoration).*	DEEP, DOAG BA, UConn Dept. of Marine Sciences.
15	**Expand research to understand the effects of climate change on shellfish habitats to inform restoration planning and observe factors that may indicate mitigation of climate change.** *(See also GC3 #3: Continue monitoring distribution and conduct research to identify the likely impact of climate on subtidal aquatic beds to inform management and restoration; CSIVP #20: Improve understanding of the effects of ocean acidification on shellfish survival and growth in Long Island Sound).*	Potential research priority for EPA LISS and CTSG; UConn Dept. of Marine Sciences, NOAA NEFSC Milford Lab, UConn CIRCA, TNC, The Sound School.
16	**Examine the health of oyster habitats, in terms of their reproduction rate and recruitment, to assess their contribution to helping populate surrounding beds where harvest is allowed.**	Potential research priority for EPA LISS and CTSG; DOAG BA, NOAA NEFSC Milford Lab.
17	**Better understand the spectrum of situations in terms of where natural oyster set vs. aquaculture set occur, and use genetics to understand patterns of genetic diversity.**	DOAG BA, NOAA NEFSC Milford Lab, Cornell University.
18	**Better understand patterns of sedimentation on important oyster beds and how to reduce sedimentation.**	UConn Dept. of Marine Sciences.
19	**Develop a larval transport model to understand where oysters are moving and at what scale or pattern (e.g. Chesapeake Bay Model by North et al. 2006; Gulf of Mexico Model by Murray et al. 2015).**	University of Maryland Center for Environmental Science - Horn Point Laboratory, NOAA NEFSC Milford Lab.
20	**Examine connectivity of shellfish beds, including designated and undesignated natural beds and spawner sanctuaries, to determine how to most effectively establish interconnected, and therefore self-sustaining, broodstock networks.** *(See also: CCMP #HW-3: Complete projects that restore or maintain habitat connectivity (i.e., river miles reconnected and/or contiguous acres of coastal habitat protected or restored). Generate supporting GIS data to help measure extent of connectivity enhanced).*	Potential research priority for EPA LISS and CTSG; NOAA NEFSC Milford Lab.
21	**Examine recruitment and age composition of northern quahog clams at historically important production sites across the state.**	Potential research priority for EPA LISS and CTSG; NOAA NEFSC Milford Lab, DOAG BA
22	**Assess the monetary value of ecosystem services that oyster beds provide.** *(See also: CSIVP #1 Determine the economic importance of shellfish harvest and cultivation).*	NOAA NEFSC Milford Lab, UConn Dept. of Agriculture and Resource Economics.

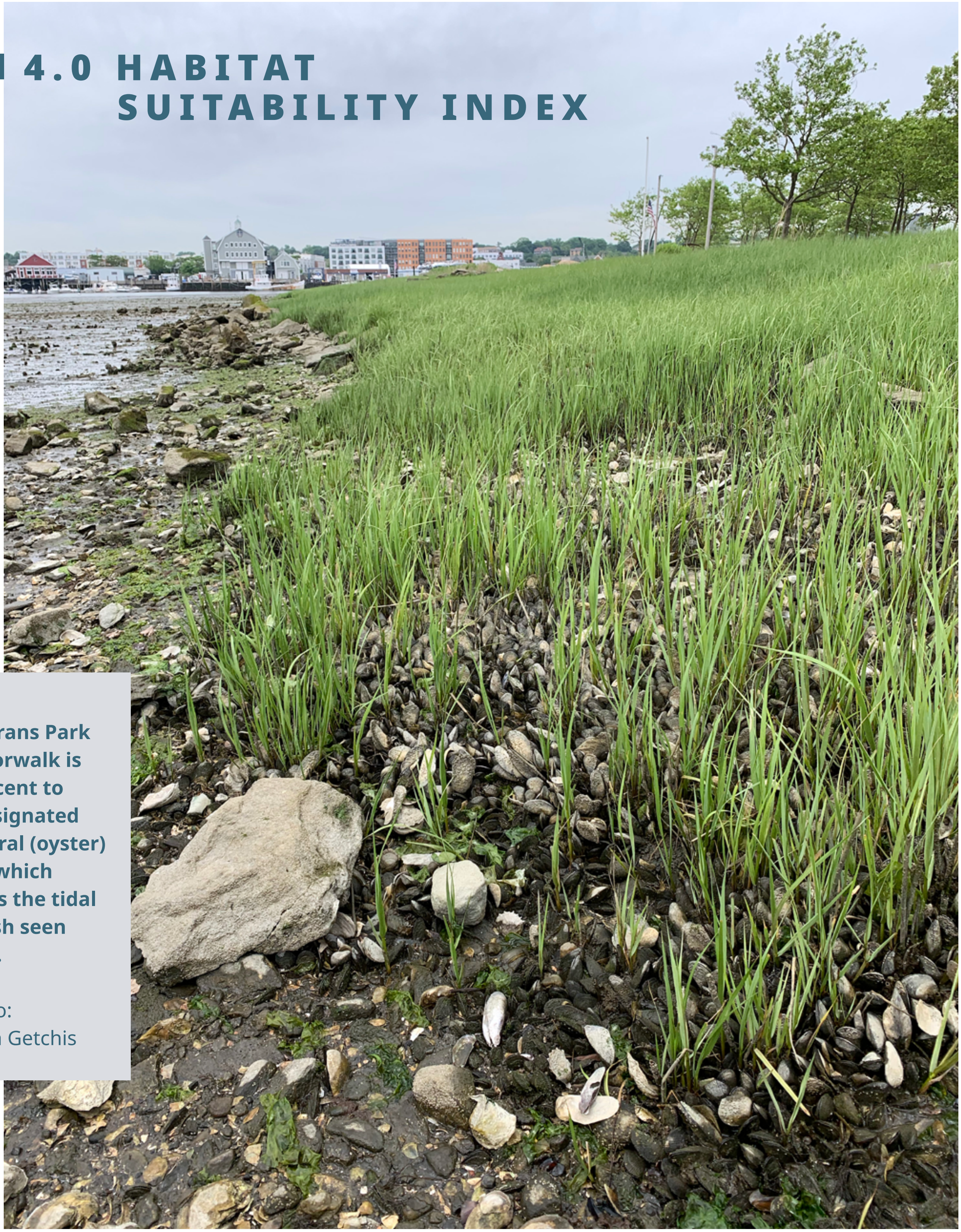
3.4 Recommendations for Policy

#	RECOMMENDATION	DRIVERS & POTENTIAL PARTNERS
23	**Establish a high-level committee, including state and federal agencies, academia, and not-for-profit partner organizations, to develop a clear strategy to implement the recommendations in this plan.**	DOAG BA, DEEP, CTSG, Pew, NOAA NEFSC Milford Lab, TNC, Connecticut Conservation Districts.
24	**Prior to approving habitat improvement or other types of coastal construction projects adjacent to shellfish beds, funding agencies should ensure that consultation has occurred with all municipal agencies with relevant authority and jurisdiction, including but not limited to the shellfish, conservation and harbor management commissions and harbor masters.** *Most, if not all funding agencies require that permits are in place or that regulatory agencies have been contacted. However, not all projects will require authorization from municipal agencies, these agencies do have authority to comment on such projects as part of the regulatory process and should be contacted early in the project development stages.*	EPA LISS, NEIWPCC, CTSG, Pew, TNC, NOAA.
25	**Engage CT DEEP Commissioner to put into state regulations that shell be included on the list of products sold for which recycled content standards are to be developed in Connecticut.** *On June 14, 2021, Governor Ned Lamont signed into law Special Act No. 21-9 "An Act Concerning Recycled Content for Products Sold in Connecticut" which states that, "Not later than December 1, 2022, the Commissioner of Energy and Environmental Protection….shall submit to the Governor… recommendations for recycled content requirements for products sold in the state and for multi-state coordination in the development of such recycled content standards…"* *See also CCMP Strategy 4-3b2: Utilize and learn from cutting edge approaches and methods to improve management options for pollution mitigation and ecosystem protection (e.g., marine spatial planning, innovative source reduction technologies, and in situ extractive technologies); CSIVP: #14: Explore oyster shell management, recovery, and recycling.*	All stakeholders.
26	**Establish sanitation protocols and regulatory guidance for shell recycling that includes requirements for transport, storage and curing of shell substrate.** *CTSG and DOAG BA received grant for this work; work began in Fall 2021.* *See also CSIVP: #14: Explore oyster shell management, recovery, and recycling.*	DOAG BA, CTSG, municipal officials.
27	**Review the potential impact, in terms available acreage in privately leased beds in nearshore waters where natural oyster recruitment occurs and eligible number of industry participants, of developing a EQIP Conservation Practice Standard for oyster bed restoration (similar to those developed in other states[77]) and make a determination on the effectiveness of such practice.** *See also GC3 #1: Examine watershed management practices and land acquisition strategies to promote and improve water quality conditions in near shore, estuarine and freshwater areas that support or could support subtidal aquatic beds; CCMP Strategy 4-3b2: Utilize and learn from cutting edge approaches and methods to improve management options for pollution mitigation and ecosystem protection (e.g., marine spatial planning, innovative source reduction technologies, and in situ extractive technologies).*	USDA NRCS, DOAG BA, CTSG shellfish industry members.
28	**Advance conservation aquaculture, whereby farmers participate in the restoration of the areas closed to shellfish harvest, e.g., by selling their seed and/or adults, or even helping with the outplanting of their farmed oysters.** *This is an ongoing effort (see section 1.8 "Related Initiatives"); plans to continue as funding allows.* *See also GC3 #1: Examine watershed management practices and land acquisition strategies to promote and improve water quality conditions in near shore, estuarine and freshwater areas that support or could support subtidal aquatic beds.*	DOAG BA, CTSG, TNC, Pew.
29	**Establish new areas of designated and non-designated natural beds to be spawning sanctuaries that are closed to harvest following restoration activities.** *CT DOAG BA is working to establish a new undesignated natural oyster bed on former shellfish beds. The bed will include non-harvest areas to maintain a viable spawning stock of oysters to recolonize the adjacent areas where harvest is allowed. Vessel monitoring will ensure compliance.* *See also GC3 #1: Examine watershed management practices and land acquisition strategies to promote and improve water quality conditions in near shore, estuarine and freshwater areas that support or could support subtidal aquatic beds.*	DOAG BA.
30	**Establish a plan to assess damage and plan restoration rebuilding/ recovery activities both at designated and undesignated natural beds following storm-related or other environmental impacts.**	DOAG BA.
31	**Expand funding opportunities for restoration including but not limited to the Connecticut Shellfish Fund (which is according to *CGS 26-237a* intended for restoration activities on state designated natural beds).**	DOAG BA; other interested parties.

3.5 Recommendations for Outreach

#	RECOMMENDATION	DRIVERS & POTENTIAL PARTNERS
32	**Continue to engage the public and bring awareness about the environmental, economic and social/cultural benefits of shellfish populations and habitats.** *See also: CCMP Strategy 2-3a2: Communicate the importance of ecosystem services to the public and municipal leaders; CSIVP #2: Improve public understanding of the ecosystem services and equivalent economic value provided by both natural and harvested shellfish populations; CSIVP #3: Develop and implement strategies to promote Connecticut's shellfish heritage.*	DOAG BA, DEEP, CTSG, NOAA NEFSC Milford Lab, EPA LISS, All interested parties.
33	**Develop and implement a workshop to provide an overview of various technologies used to survey and characterize intertidal and subtidal oyster habitat.**	CTSG, UConn CLEAR, UConn Dept. of Natural Resources and the Environment and Dept. of Marine Sciences.
34	**Establish programs that incentivize restaurants, oyster festivals, and communities to recycle shell or mechanisms that discourage the discarding of shell.** *See also CSIVP: #14: Explore oyster shell management, recovery, and recycling.*	DOAG, DEEP, CT Restaurant Association, interested parties.
35	**The NERR project work plan should have a special focus on current commercial oyster aquaculture rehabilitation and enhancement activities and practices on the historic oyster beds of the Thames River in an attempt to reestablish productivity.**	CT NERR Steering Committee; DEEP, DOAG BA, UConn CIRCA, UConn Dept. of Marine Sciences.

4.0 HABITAT SUITABILITY INDEX



Veterans Park in Norwalk is adjacent to a designated natural (oyster) bed which abuts the tidal marsh seen here.

Photo: Tessa Getchis

4.1 Overview

Spatial information and analyses have proven useful in the site selection and prioritization of shellfish restoration efforts in other locales (e.g., North Carolina's oyster sanctuaries **https://deq.nc.gov/about/divisions/marine-fisheries/habitat-information/habitat-enhancement/oyster-sanctuaries**, Florida's Apalachicola Bay System Initiative **https://marinelab.fsu.edu/absi/**, Washington state's Puget Sound Olympia oyster restoration **https://restorationfund.org/programs/olympiaoysters/#assessment_pathway)**. These efforts generated site-specific, user-friendly planning tools that have helped regulators, resource managers, and restoration practitioners to identify locations where there may be a higher likelihood of restoration success than choosing those sites without such information.

Particularly useful among the available types of spatial analyses and tools are habitat suitability index (HSI) models (hereafter referred to simply as HSIs). They have been used elsewhere to inform the siting of aquaculture, fishery production, and restoration of shellfish[78]. HSIs can consider a variety of biological, environmental, oceanographic, and shellfish production factors, sometimes called parameters, that are waterbody-specific and use data that is carefully chosen and curated by modelers. Put simply, each factor is incorporated into an HSI like an individual layer on a map, and when overlaid, the resulting output should inform users as to where restoration projects are most likely to be successful and where they are least likely to be successful. This is not altogether different from how a cell phone or GPS device uses interactive maps to overlay addresses, roads, and traffic to produce optimal driving routes. HSIs yield a composite layer that assigns scores from 0 (unsuitable) to 1 (optimal), greatly simplifying the task of choosing restoration sites that may become the target of significant future work and funding.

Different factors may have greater or lesser relevance depending on the resource management goal, and can be weighted or tuned to reflect those desired endpoints. For example, seafloor substrate type might be more useful to informing restoration projects whose goal is to restore aquatic habitat whereas average sea surface temperature might be more useful to informing where to expand aquaculture; a modeler might include, exclude, or adjust the weight of these parameters in an HSI depending on the goal.

Before developing an HSI, practitioners must determine whether the data they have is sufficient for their goals, is of high enough quality and resolution, and make other considerations. If it is determined that there is inadequate or insufficiently high-quality data, practitioners then must develop a plan to fill these gaps prior to creating the model. This can include gathering new data from site surveys, selecting proxy factors as substitutes to missing datasets, or other actions.

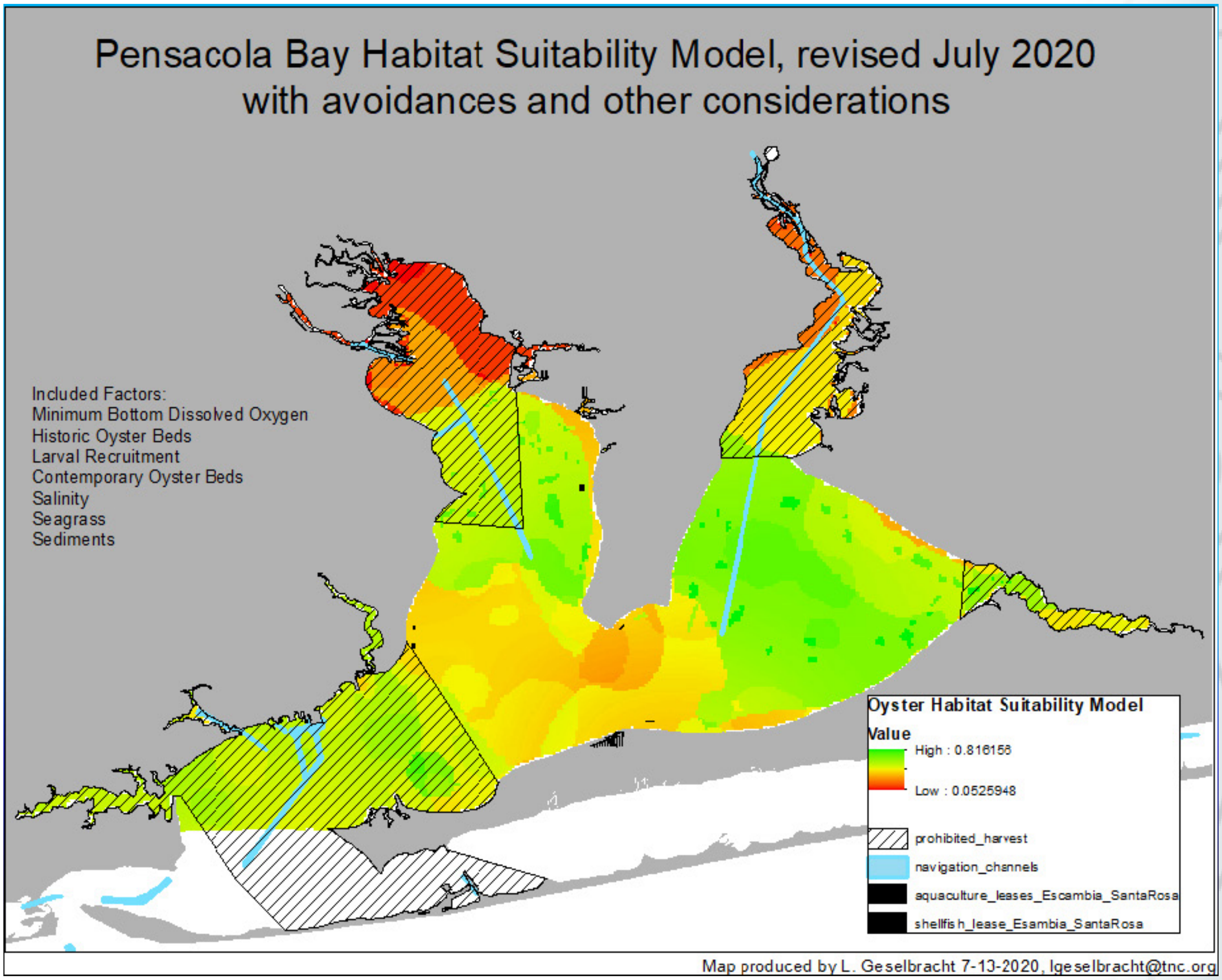


FIGURE 4.1 Oyster Habitat Suitability Model (HSM) for the Pensacola Bay System.
Source: https://marinelab.fsu.edu/media/4255/oyster_hsm_geselbracht.pdf

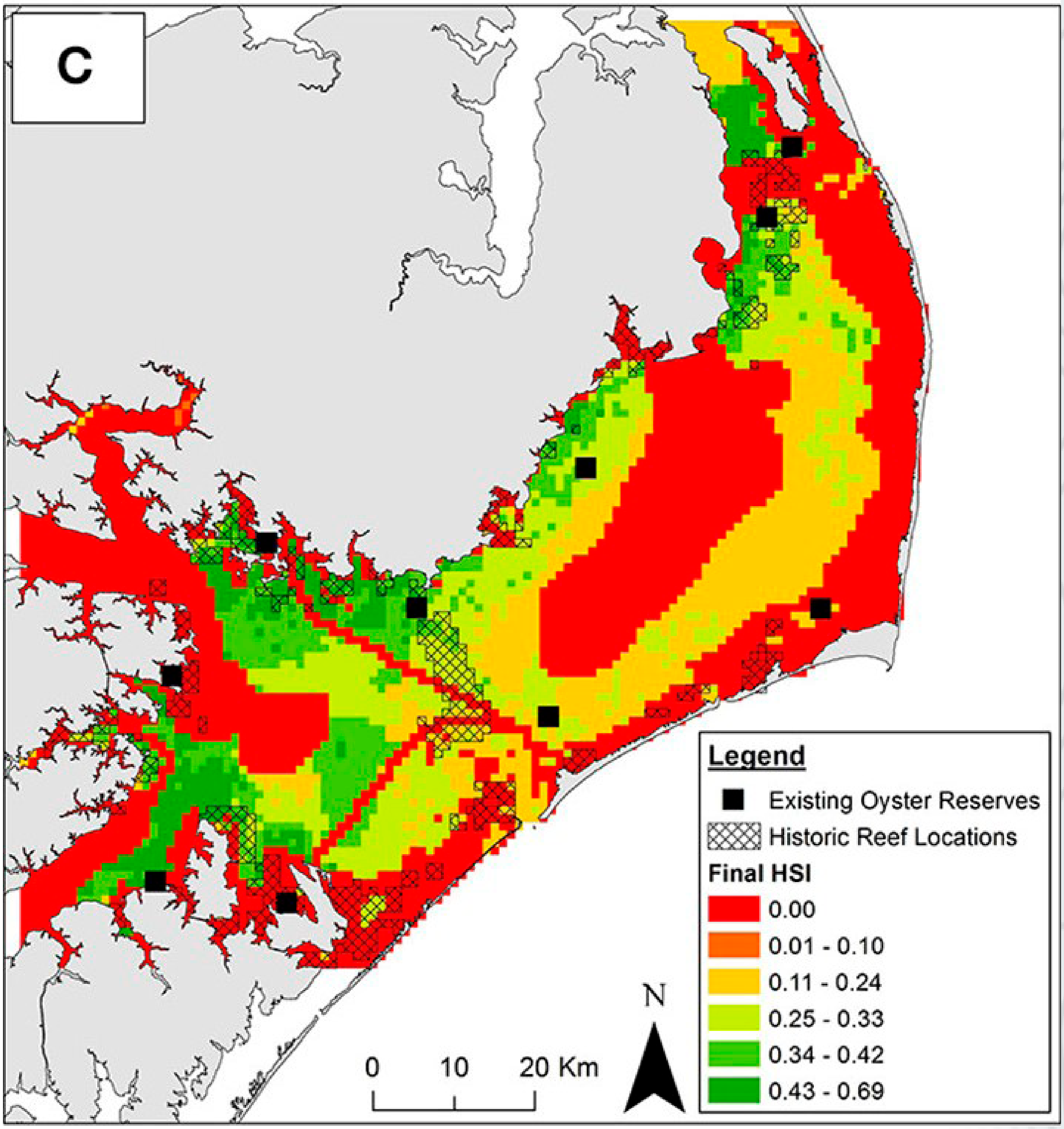


FIGURE 4.2 Habitat Suitability Index for Pamlico Sound, North Carolina
Source: Puckett et al. 2018. https://www.frontiersin.org/articles/10.3389/fmars.2018.00076/full?utm_source=S-TWT&utm_medium=SNET&utm_campaign=ECO_FMARS_XXXXXXXX_auto-dlvrit

4.2 Oyster Habitat Suitability Index

Recognizing their value in siting restoration projects, from fall 2020 to fall 2021, the task force worked with steering committee members to complete the first stage of an HSI, drawing heavily from datasets compiled by government-appointed committees and subject matter experts across the state and region. As mentioned previously (see Section 2.2 "*Relevant Data and Map Viewer*"), much of the work involved in identifying those factors was recently completed through the *Long Island Sound Blue Plan*[79] **https://portal.ct.gov/DEEP/Coastal-Resources/LIS-Blue-Plan/Blue-Plan-Basic-Background** process, which resulted in an inventory of key environmental and human use data[80]. For the HSI, relevant datasets were compiled and sorted into three categories:

a) Human uses

b) Species and habitats

c) Shellfish production factors

Eliciting expert and stakeholder input into the development of a HSI is considered a key best practice[81]. The task force and steering committee engaged in a lengthy decision-making process to narrow the available factors to those deemed most useful and of appropriate quality, and considered the following:

a) Is the data a key factor for shellfish production?

b) Is the data spatially and temporally relevant?

c) Is the data regularly updated so as to be relevant for decision-making?

d) Is the data subject to a quality assurance and quality control plan?

The task force and steering committee have recommended the following *minimum* factors for inclusion in an HSI, in no particular order, to develop an HSI for shellfish restoration specific to Connecticut waters:

(a) water depth

(b) % shell coverage (including live shellfish)

(c) sediment type

(d) salinity

(e) dissolved oxygen

(f) temperature

The suitable and optimal point or range for these factors in Long Island Sound waters have been compiled below (Tables 4.1 & 4.2).

The following factors were also considered important for siting shellfish restoration projects:

(a) subaqueous soil properties and characteristics

(b) oyster recruitment patterns

(c) oyster larval disbursement patterns

(d) oyster disease prevalence / intensity

(e) harmful algal blooms

(f) nitrogen and chlorophyll a

(g) factors that affect larval shell development and survival (includes variables such as pH, aragonite saturation state, alkalinity, and dissolved inorganic carbon)

It can be challenging to know at the outset of developing an HSI exactly which factors may be the most important to incorporate to ensure the highest likelihood of restoration success. It is possible, however, to verify the usefulness of each factor. The HSI predictions about which sites are unsuitable, suitable, or optimal can be validated by comparing them to independent datasets and/or doing field visits for verification. Some literature exists on how to do this, including specifically for oyster restoration[82]. Because Connecticut's coastal ecosystems are very dynamic, assessing habitat suitability for investments in restoration should be an iterative process, making changes and improvements when needed to maximize its utility, accuracy, and appropriateness.

Unfortunately, at the time that the task force and steering committee sought to develop an HSI in 2021, these data were either not available, not available statewide, not up-to-date, or were considered unreliable. Accordingly, the HSI was not completed in time for the publication of this *Guide*. In the near future, however, the task force and steering committee hope to move forward with the development of an HSI to inform future restoration project siting, adding to and improving upon the existing datasets and analyses conducted for this effort (Table 4.3). To do this, they will:

- Set forth as a priority follow-up action item the need to develop an HSI;
- Continue to assess data availability, quality, and appropriateness for an HSI, working closely with related efforts (e.g., the Long Island Sound Study) and experts, and store those data in a readily retrievable database; and,
- Pursue additional funding to support hiring modelers with relevant expertise.

TABLE 4.1 Habitat Suitability Index Factors for Adult Oysters

FACTOR	UNSUITABLE (above threshold or not of type)	UNSUITABLE (below threshold)	SUITABLE (range)	OPTIMAL (range)
DEPTH (m)	>2 feet above mean low water [1]	>50 ft [1]	MLW to 50ft [1,2]	**MLW to 28 ft** MLW - 20 ft [1, 2] 5 - 28 ft [3]
SEDIMENT/ BOTTOM TYPE	shifting sands and soft bottom types that are not firm enough to support the oyster's weight or vertical reef formation [4]	N/A	oyster shells, calcareous remains of other mollusks, wooden material, rocks, gravel, and solid refuse [5] rock or semi hard mud [4]	oyster shell
SALINITY		>5*	5 - 30 [4]	**10 - 28** 10 - 28 [6] 16 - 27 [7]
DISSOLVED OXYGEN (mg/L)	8 mg/L	<1mg/L	**1 - 8 mg/L @ 25°C** 1mg/L - 100% saturation [8] 20 - 100% saturation [9]	**3 - 8 mg/L @ 25°C** =(20 - 100% saturation) [9]
TEMPERATURE (°C)	> 36° C	0 ° C	0 - 36° C** [1, 4, 10]	**5 - 25° C**** 15 - 25° C [10] 5 - 25° C [11]

*Adult oysters can survive in freshwater for a duration of time but will not grow. High salinity value is beyond the normal range observed in Long Island Sound
**The entirety of LIS is within the suitable temperature range for enough months to compensate for the short hot and cold exposure periods, however the optimal range for positive growth is slightly narrower

[Credit: Bella Wasserman, Gary Wikfors, Tessa Getchis]

References:

(1) Loosanoff, V.L. & J.B. Engle. (1939). Spawning and setting of oysters in Long Island Sound in 1937, and discussion of the method for predicting the intensity and time of oyster setting. *Bulletin of the Bureau of Fisheries*. 49: 217-255. **https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/fish-bull/fb49.5.pdf**

(2) Loosanoff, V.L. & C.A. Nomejko. (1956). Relative intensity of oyster setting in different years in the same areas of Long Island Sound. *Biological Bulletin*. 111(3): 387-392. **https://doi.org/10.2307/1539145**

(3) Mackenzie Jr., C.L.(1970). Oyster culture in Long Island Sound 1966-69. *Marine Fisheries Review*. 33(1):27-40. **https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/mfr3213.pdf**

(4) Galtsoff, P.S. (1964). The American oyster *Crassostrea virginica* (Gmelin). U.S. Fish & Wildlife Service. *Fishery Bulletin.* 64:1-480. **https://books.google.com/books?hl=en&lr=&id=2zZwbKprmhoC&oi=fnd&pg=PA64&ots=fPy74_WMxB&sig=JosgkIGJ7UE-Q7H8THBdMkHNDI8#v=onepage&q&f=false**

(5) Starke, A., Levinton, J.S. & M. Doall. (2011). Restoration of *Crassostrea virginica* (Gmelin) to the Hudson River, USA: A spatiotemporal modeling approach. *Journal of Shellfish Research*. 30(3):671-684.

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(11) Bayne, B. (2017). Temperature Effects and Other Manifestations of Stress. Chapter 8 In: *Biology of Oysters*. Developments in Aquaculture and Fisheries Science. Volume 41. Academic Press. 862pp.

TABLE 4.2 Habitat Suitability Index Factors for Larval Oysters.

FACTOR	UNSUITABLE (above threshold or not of type)	UNSUITABLE (below threshold)	SUITABLE (range)	OPTIMAL (range)
DEPTH (m)	>2 feet above mean low water [1]	>50 ft [1]	MLW to 50ft [1,2]	**MLW to 28 ft** MLW - 20 ft [1, 2] 5 - 28 ft [3]
SEDIMENT/ BOTTOM TYPE	shifting sands and soft bottom types that are not firm enough to support the oyster's weight or vertical reef formation [4]	N/A	oyster shells, calcareous remains of other mollusks, wooden material, rocks, gravel, and solid refuse [5] rock or semihard mud [4]	oyster shell
SALINITY		< 15	**15 - 35*** 17.5 - >35 [6] 15 - 35 [7] 15 - 27 [8] >17.5 [9]	**17.5 - 22.5** 17.5 - 22.5 [6] 22.5 [7]
DISSOLVED OXYGEN (mg/L)	8 mg/L	< 1.7 mg/L	>1.7 mg/L [10]	>1.7 mg/L [10]
TEMPERATURE (°C)	> 32.5° C	< 15° C	**15 - 34° C* [4]** 20 - 30° C [9] >16.4° C+ [11]	**22 - 32.5° C** >22° C [4] 30 - 32.5° C [8] 32.5° C [9]

*References with the widest range for environmental variables were selected. Extreme values at the ends of these salinity and temperature ranges are tolerable for a short period of time, however, mat not be tolerable for sustained durations.

[Credit: Bella Wasserman, Gary Wikfors, Tessa Getchis]

References:

(1) Loosanoff, V.L. & J.B. Engle. (1938). Spawning and setting of oysters in Long Island Sound in 1937, and discussion of the method for predicting the intensity and time of oyster setting. *Bulletin of the Bureau of Fisheries*. 49:217-255. **https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/fish-bull/fb49.5.pdf**

(2) Loosanoff, V.L. & C.A. Nomejko. (1956). Relative intensity of oyster setting in different years in the same areas of Long Island Sound. *Biological Bulletin*. 111(3): 387-392. **https://doi.org/10.2307/1539145**

(3) Mackenzie Jr., C.L.(1970). Oyster culture in Long Island Sound 1966-69. *Marine Fisheries Review*. 33(1):27-40. **https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/mfr3213.pdf**

(4) Galtsoff, P.S. (1964). The American oyster *Crassostrea virginica* (Gmelin). U.S. Fish & Wildlife Service. *Fishery Bulletin*. 64:1-480. **https://books.google.com/books?hl=en&lr=&id=2zZwbKprmhoC&oi=fnd&pg=PA64&ots=fPy74_WMxB&sig=JosgkIGJ7UE-Q7H8THBdMkHNDI8#v=onepage&q&f=false**

(5) Starke, A., Levinton, J.S. & M. Doall. (2011). Restoration of *Crassostrea virginica* (Gmelin) to the Hudson River, USA: A spatiotemporal modeling approach. *Journal of Shellfish Research*. 30(3):671-684.

(6) Davis, H.C. (1958). Survival and growth of clam and oyster larvae at different salinities. *Biological Bulletin*. 114(3):296–307.

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(8) Davis, H.C. & A. Calabrese. (1964). Combined effects of temperature and salinity on development of eggs and growth of larvae of *M. mercenaria* and *C. virginica*. U.S. Fish & Wildlife Service. *Fishery Bulletin*. 63:643-655.

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TABLE 4.3 **Habitat Suitability Index Progress and Recommendations.**

STAGE 1: COMPLETE	STAGE 2: IN PROGRESS	STAGE 3: FUTURE EFFORTS
Initiate a planning process to: ▶ Identify potential areas available for restoration. ▶ Exclude areas where restoration is prohibited for regulatory reasons. ▶ Gather expert input to identify key factors relevant to restoration. ▶ Compile and store available data.	Identify data considered to be the (a) minimum and (b) ideal factors to develop a Habitat Suitability Index: ▶ Identify data gaps and develop a plan for addressing these. ▶ Compile and store additional data as it becomes available. ▶ Pursue funding to hire modeler(s).	Develop baseline Habitat Suitability Index using the factors considered to be the minimum needed. ▶ Engage shellfish habitat and physiology subject-matter experts to refine baseline Habitat Suitability Index using other factors as data become available. ▶ Apply additional data to the development of a more robust Habitat Suitability Index that considers minimum factors and incorporates additional factors.

4.3 Key Data Sources

The most comprehensive effort to date to gather and consolidate this environmental, water quality and human use data for the region is the *Long Island Sound Blue Plan Inventory* http://cteco.uconn.edu/projects/blueplan/index.htm. The collection comprises geospatial and other datasets from a variety of local, state, federal and other sources. Here we have included data sets that may be key to habitat suitability analysis for shellfish restoration.

PROGRAM	AGENCY & BACKGROUND	TESTING PARAMETERS
Long Island Sound Water Quality Monitoring Program [Long Island Sound Water Quality and Hypoxia Monitoring Program Overview (ct.gov)]	Connecticut Department of Energy and Environmental Protection, with funding provided by the Long Island Sound Study, has been conducting the program since 1991.	▶ water temperature, salinity, dissolved nitrogen, particulate nitrogen, water clarity, and dissolved oxygen ▶ water samples are collected year-round at 17 stations on a monthly basis, but from mid-June to mid-September every other week at 48 stations.
Real-Time Monitoring on Long Island Sound Buoys [UConn's Long Island Sound Observatory]	The Long Island Sound Integrated Coastal Observing System (LISICOS) was established in 2003 as a component of a regional/national ocean observing system.	▶ Various water quality and weather related measurements; type depend on station. ▶ Continuous, real-time sampling stations.
The Unified Water Study [Water Monitoring: Ecological Health - Save the Sound]	The Unified Water Study, launched in 2017, includes more than 20 organizations, including citizen volunteer groups.	▶ dissolved oxygen, turbidity, chlorophyll-a, temperature, salinity, nutrients, and macroalgae. ▶ monitoring 35+ harbors, bays, and other coastal waters.
USGS Monitors Streams and Rivers [USGS | National Water Dashboard;] [New England Water Science Center - Data & Tools (usgs.gov)]	The US Geological Survey conducts water quality monitoring in streams and rivers that connect to Long Island Sound.	▶ Each station measures flow in cubic feet per second and gauge height, and some include DO and pH measurements. ▶ Shoreline coverage is not extensive, but CT DOAG BA has found correlations between elevated flows and water quality.
Sound Health Explorer - [Data Sources | Sound Health Explorer]	Save the Sound launched this website that grades coastal beaches by looking at high bacterial counts that lead to beach closures and comparing them to national averages. Rainfall is also featured on the site, allowing users to see which beaches suffer from bacterial contamination as a result of polluted stormwater runoff or from very local sources of fecal pollution such as a leaking municipal sewer line.	▶ Bacterial (Fecal coliform) counts; rainfall. ▶ Soundwide coverage adjacent to bathing beaches.

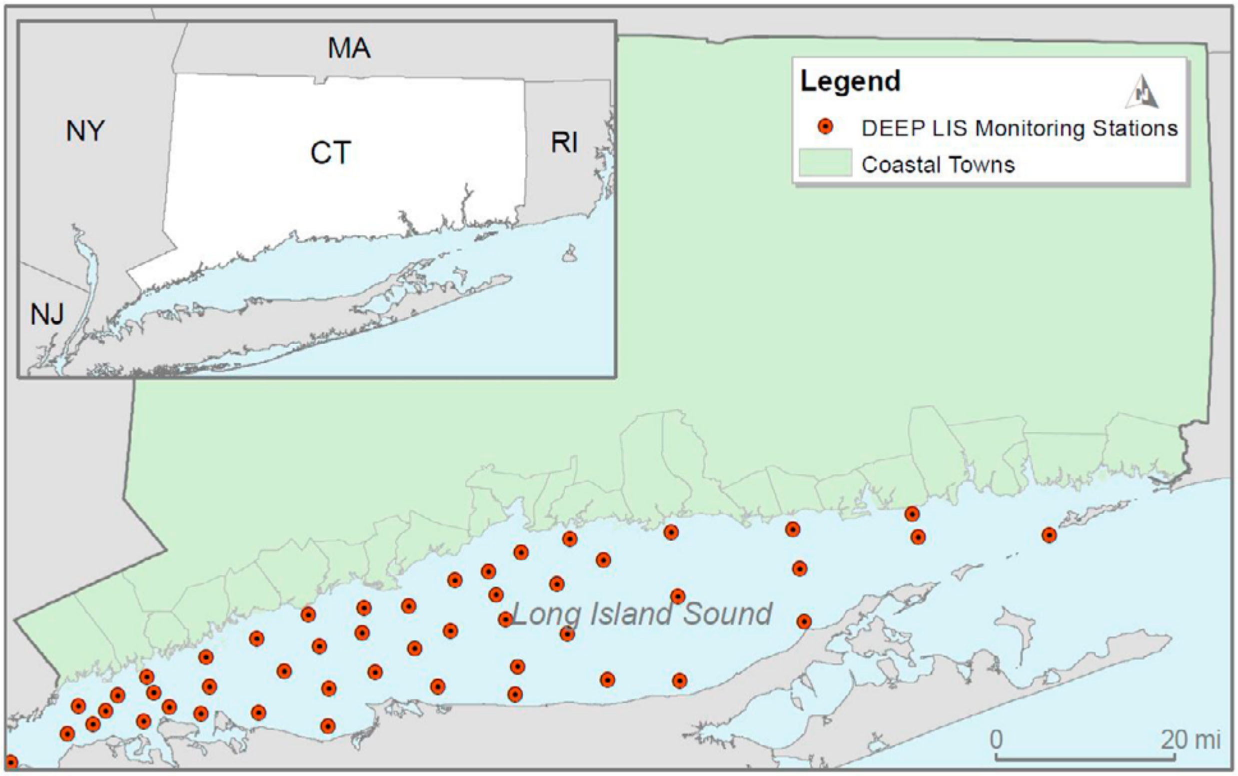

FIGURE 4.3 CT DEEP Water Sampling Stations. Source: CT DEEP

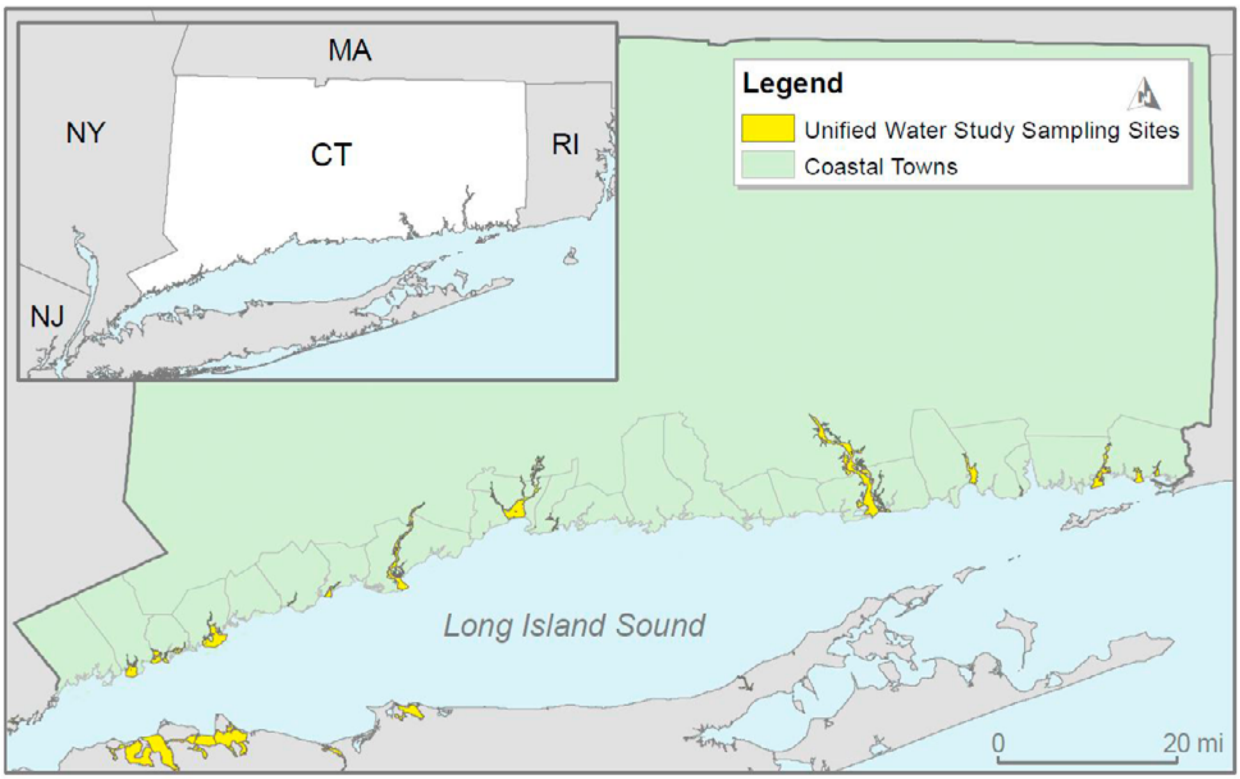

FIGURE 4.4 Unified Water Study Sampling Stations in Bays and Harbors
Source: Save the Sound

5.0 PROJECT PLANNING GUIDANCE FOR PRACTITIONERS

Hoadley Creek in Guilford has both a privately leased commercial shellfish bed and an undesignated natural oyster bed.

Photo: Tessa Getchis

5.1 Overview 83

Well-planned and implemented restoration efforts can provide many ecological, economic and cultural benefits. However, there are risks inherent in any project. This section identifies key recommendations for how to design projects so that they are most likely to be successful and achieve the project-specific goals, and also to prevent or minimize potential risks. Depending on the activity, local, state, and/or federal authorizations may be required and applicants must abide by established regulations and policies. In addition, “best management practices” (BMPs) for shellfish restoration have been established or adopted from previously published efforts[83,84]. These BMPs can be described as activities or measures designed to ensure the highest possible likelihood of success while minimizing negative impacts.

The regulations, policies, and BMPs described below are crafted based on the best available science, experience and the historical context of shellfish in Connecticut. They suit the specific environmental and socio-economic landscape of Connecticut’s Long Island Sound watershed and the legal landscape of the State of Connecticut. The BMPs are intended to provide high-level guidance to restoration practitioners, but cannot address all aspects of an individual project. As recommended by McCann, (2019)[85] “restoration practitioners and permitting agencies must work together to develop mutually agreeable conditions allowing restoration activities to proceed and to minimize potential public health risks.”

This section identifies the major steps of the shellfish restoration planning process. This section is broken down into the following discrete subsections:

- 5.2 Project Goals, Objectives, and Outcomes
- 5.3 Stakeholders
- 5.4 Funding Opportunities
- 5.5 Authorizations and the Permitting Process
- 5.6 Site Selection
- 5.7 Monitoring and Metrics
- 5.8 Shellfish Types and Sources
- 5.9 Substrate Types
- 5.10 Shell Recycling
- 5.11 Design and construction

Regulations, policies, and best management practices may change over time based on emerging science, data, and practice, so it is important to revisit the website *Online Resource Guide for Connecticut Shellfish* http://shellfish.uconn.edu to see if there have been revisions made to this *Guide* and *Connecticut Shellfish Restoration Interactive Map Viewer.* When in doubt, refer directly to the regulatory agencies (see contact list in Table 5.1).

5.2 Project Goals, Objectives, and Outcomes:

While the overall vision is to improve shellfish habitat, establishing one or more specific goals is the first step in planning the restoration project. A list of specific, measurable and time bound objectives should be included. Alternatives should be considered and discussed with regulatory agencies. Use the following flowchart to begin the planning process.

PROBLEM	▶ What is the present condition or status of the habitat? What has been lost and why (if known)?
GOALS	▶ What is the desired future condition? What ecosystem services will be gained, and how?
OBJECTIVES	▶ What will be the primary actions used to achieve the goal(s)? Make these specific and timebound measures.
ALTERNATIVES	▶ Do alternatives exist?
OUTCOMES	▶ What is the desired outcome of these actions in the short-term?
FINAL CONDITION	▶ What is the final condition expected in the long-term?

FIGURE 5.1 Shellfish commission members meet with the research team to survey beds in the town of Greenwich. Photo: Griffin O'Neill

5.3 Stakeholders

FIGURE 5.2 Shellfish commission members, city officials and shellfish farmers meet with the research team to survey beds in the city of Norwalk. Photo: Griffin O'Neill

Once a project goal(s) has been established, it is recommended to seek out stakeholders with local experience and subject matter expertise to help inform the planning process, even if a specific site might not yet be identified.

Stakeholders can serve in a role to:

- Identify restoration needs
- Identify or gather background on sites of interest
- Build a network of local partners and volunteers
- Identify existing uses and user groups
- Gain access to/ host site visits
- Provide long term institutional support for the program

Potential stakeholders may include but should not be limited to the following:

State and Federal Authorities

- Connecticut Department of Agriculture - Bureau of Aquaculture
- Connecticut Department of Energy and Environmental Protection
- Army Corps of Engineers - Regulatory Division
- National Marine Fisheries Service, Habitat and Ecosystem Services Division
- EPA - Water Division, Wetlands Protection Section

Town Authorities

- Shellfish Commission
- Conservation Commission
- Harbor Management Commission
- Health Department

Other Government Agencies

- USDA Natural Resources Conservation Service
- Economic development council or organizations
- Tourism development councils or organizations

Environmental Organizations

- Land Trusts Operating in Connecticut
- Connecticut Conservation Districts
- The Nature Conservancy
- The Pew Charitable Trusts
- Audubon
- Community-based water quality monitoring groups

Research Organizations

- NOAA NEFSC Milford Lab
- Local colleges and universities

Private Sector and Coastal Community Members

- Neighboring home and business owners
- Shellfish farm operations
- Shellfish restaurateurs, seafood retailers, shellfish shucking establishments
- Recreational fishing associations
- Environmental consultants
- Engineering firms (helpful when planning restoration)

5.4 Funding Opportunities

Restoration practitioners often rely on funding that is external to their organization or program. This means that they may need to supplement their own budgets by seeking additional funds. Funds and/or match for grants for shellfish restoration may be acquired through grants, private donors, or other entities or options. The *Connecticut Shellfish Restoration Grants Directory*, prepared for this *Guide,* is available to view as a **Google Sheet** here: **https://docs.google.com/spreadsheets/d/1asn_zfgoOVXAO7BcXt0K2BbqE3NTtO3-_TVPwYTnfuE/edit?usp=sharing**. This open-access spreadsheet is a collection of funding opportunities specific to shellfish restoration, and includes the following information: Grant Title; Funder; Link; Location; Type of Organization; Funding Uses; and, Description. It is designed to be a living document that will be updated on an as-needed basis; as such, it cannot be guaranteed that the information in the Directory will always be up-to-date. Note that there is a separate, editable column titled "Comments/Suggestions" where users may add relevant information specific to each funding opportunity.

It is highly beneficial to have a georeferenced map of the target 'restored" condition for an estuary or system. This sets the expectation for funders and other stakeholders and demonstrates that an individual project is one piece of the ultimate goal and that individual projects are cumulative, not the end condition desired for the system.

FIGURE 5.3 Task force members collaborate with the local shellfish commission to survey oyster habitat in the Poquonnock River, Groton.
Photo: Tessa Getchis

5.5 Authorizations and the Permitting Process

To initiate the application process, a site(s) must be selected and the project footprint known. The *Long Island Sound Blue*[86] *Plan* provides information and policies that can be used for project siting, as well as guidelines for consistency with the *Plan*[87] and with the *Connecticut Coastal Management Act*. It is recommended that the applicant consult with local, state, and federal regulators early in the planning process to better understand the regulatory requirements for the proposed activity.

An overview of the role of the key regulatory agencies (Table 5.1) and regulatory roadmap (Figure 5.3) are provided. The regulatory process includes a review of the purpose and benefits of the proposed activities. The intent is to minimize user conflicts and interactions with protected species and habitats (See Section 5.5 "Site Selection") and includes the authorization of:

- project siting (where the activity will occur);
- source, use and final disposition of the shellfish;
- placement of shell or artificial substrates;
- use of gear or structures to contain shellfish; and,
- living shorelines that utilize shellfish or promote shellfish habitat

The CT DOAG BA serves as the lead regulatory agency and should be the first point of contact for shellfish restoration activities including projects that utilize shellfish to achieve ecosystem benefits. The CT DEEP and the USACE are other key agencies. Other local authorizations may be necessary depending on where the project occurs in the coastal zone (See Figure 5.4).

The regulatory agencies serve in a role to:

- Provide an overview of the regulatory process, timeframes, and any required interagency coordination;
- Identify the relevant application forms, authorizations, licenses, and permits;
- Identify areas where there may be competing uses or protected species and habitats;
- Identify what site-specific data exists to inform the project planning; and,
- Identify what metrics are important to determine project success.

TABLE 5.1 Overview of Roles of Key Regulatory Agencies for Shellfish Restoration*.
**Note: Coordination with other federal, state, or local agencies may be required.*

AGENCY	ROLE	REQUIRED AUTHORIZATIONS
Connecticut Department of Agriculture - Bureau of Aquaculture	▶ Coordinates joint agency application process for projects sited on designated shellfish areas ▶ Coordinates projects not on designated shellfish beds incorporating shellfish ▶ Establishes state policy for shell recycling; requires applicants to coordinate with local health and land use officials; review and comment on recycling SOP ▶ Conducts or authorizes shellfish disease and harmful algae surveillance; develops management strategies	▶ License for shellfish seed importation ▶ Final disposition of shellfish ▶ Shellfish Aquaculture Restoration Certificate of Permission
Connecticut Department of Energy and Environmental Protection	▶ Authorizes license for activities in tidal wetlands, placement of structures, dredging and fill under state statutes (this includes shell) and modifications to existing in-water facilities ▶ Coordinates *Long Island Sound Blue Plan* and *Coastal Zone Management* consistency review ▶ Coordinates among CT DEEP Land and Water Resources Division, Fisheries Division and Boating Division ▶ Conducts Natural Diversity Database (NDDB) Review ▶ Conducts inspections for complaints of violations of areas where permits are authorized; may pursue enforcement action	▶ Structures, Dredging and Fill (SDF) License ▶ Certificate of Permission ▶ 401 Water Quality Certification
US Army Corps of Engineers	▶ Authorizes placement of structures and fill under federal guidelines depending on project specifics ▶ Coordinates federal review with National Marine Fisheries Service, U.S. Fish & Wildlife Service, U.S. Environmental Protection Agency and other agencies as necessary	▶ Individual Permit ▶ General Permit #10 or Letter of Permission
Town officials	▶ Review project proposal and provide comments and relevant authorizations; dependent on project location	▶ Land use approvals (e.g. zoning, wetlands, etc.)

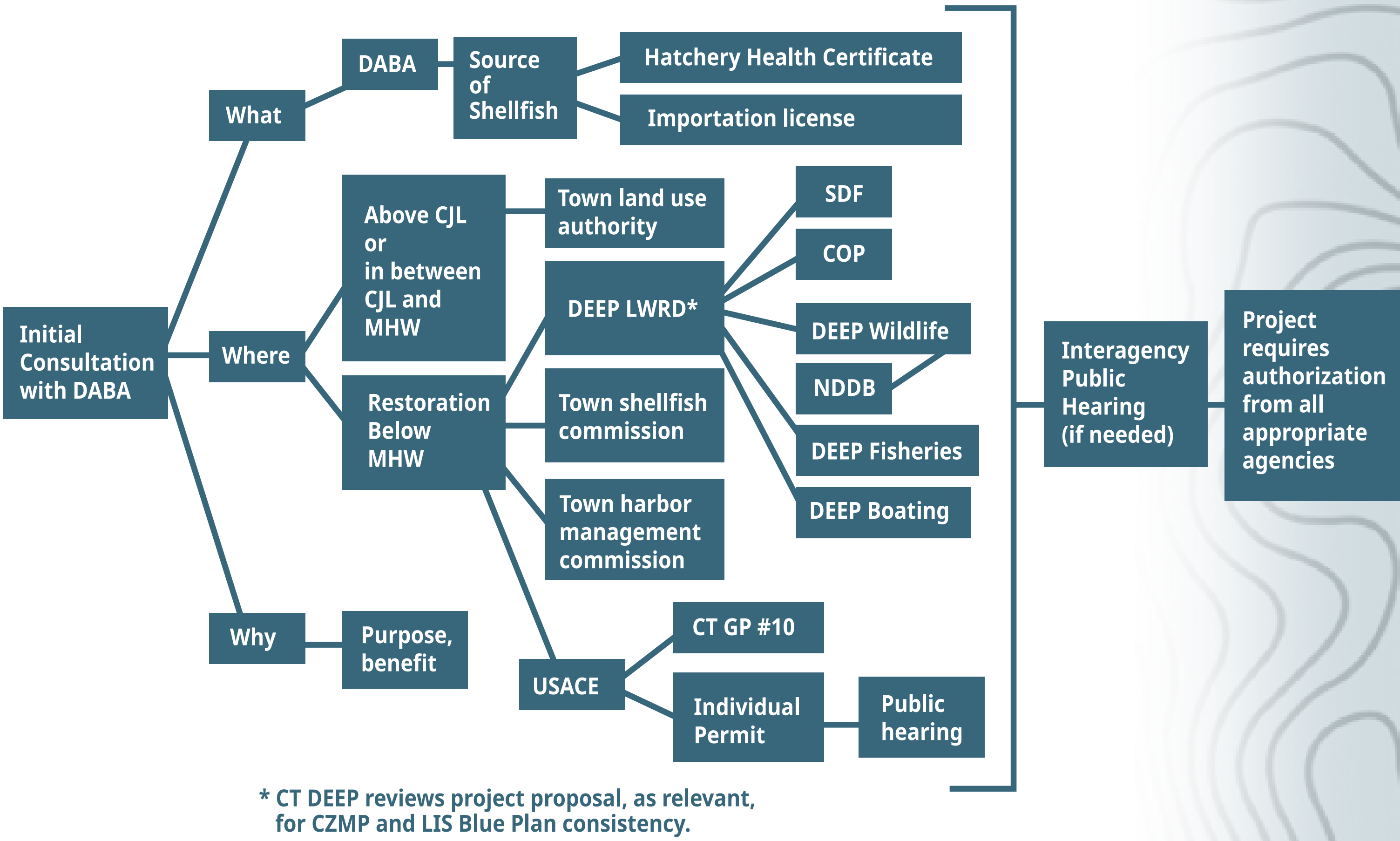

FIGURE 5.3 Permitting roadmap for shellfish restoration.

KEY TO ACRONYMS:

CJL = Coastal Jurisdiction Line

COP = Certificate of Permission

GP = General Permit

CT DABA = CT Department of Agriculture, Bureau of Aquaculture

CT DEEP = CT Department of Energy and Environmental Protection

LWRD = Land and Water Resources Division (of CT DEEP)

MHW = Mean High Water

NDDB = Natural Diversity Database

SDF = Structures, Dredging and Fill permit

USACE = U.S. Army Corps of Engineers

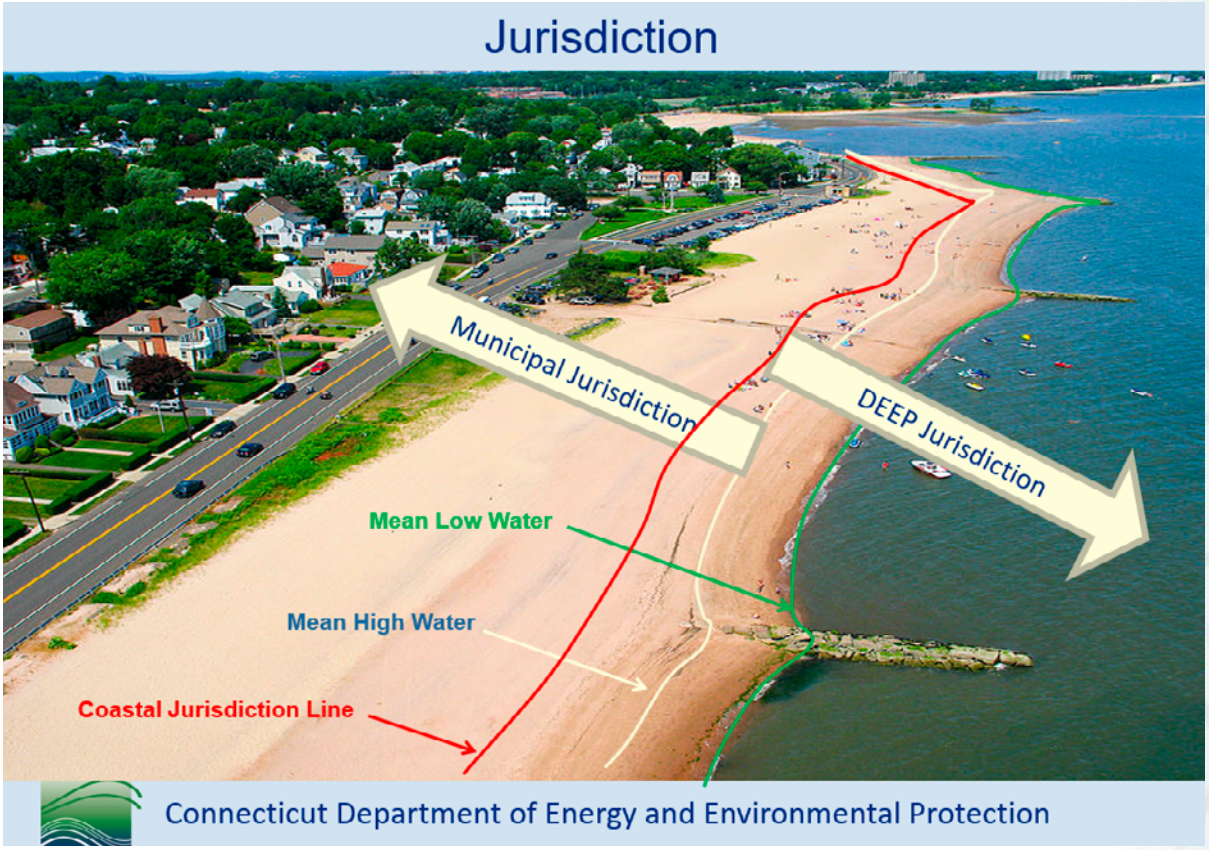

FIGURE 5.4 Coastal Jurisdictional Boundaries. Source: CT DEEP

5.6 Site Selection

The first step in the site selection process is to identify and avoid areas that are off limits to shellfish restoration. The next step is to review the available environmental and human use data to exclude other unsuitable sites and narrow potentially suitable sites into one or more optimal sites[88]. The *Connecticut Shellfish Restoration Interactive Map Viewer*[89] **https://s.uconn.edu/ctshellfishrestoration** has been developed to aid in this process, and can be used to complete the checklist below (Table 5.2). While the map viewer can be a powerful decision-making tool, the available spatial data for some human use and environmental factors is limited. A site survey may be required to collect more information about whether the proposed area supports shellfish survival, growth, and reproduction, and is suitable from a logistical and regulatory perspective (Figure 5.5).

TABLE 5.2. **Initial Site Selection Checklist**

	TOPIC	CONTEXT	BMP | POLICY	KEY INFORMATION
1 ✓	**Does the state allow restoration activities to occur in this area?**	Shellfish restoration work is prohibited in certain areas within the Connecticut waters of Long Island Sound due to existing statutory or regulatory restrictions. These locations have been identified and a map created to inform decision making.	BMP: Avoid areas considered "off limits" by state and federal agencies	To identify areas off limits, see Map Viewer, select tab "*Comprehensive List*" and in the "*Base Layers and Boundaries*" list check: ▶ "*Areas Off Limits to Shellfish Restoration*"
2 ✓	**Will the activity occur in an area with significant human uses?**	In most cases, the activity must be compatible with or present minimal impact on existing human uses of the site.	BMP: Avoid areas that present greater than minimal impacts to existing human uses.	To identify mapped human uses, see Map Viewer, select tab "*Comprehensive List*" and in the "*Human Uses*" list check: ▶ all layers
3 ✓	**Is the site located on public or private property?**	Applicants proposing activity on private property must be the owner of such property, or have written authorization from the property owner, to use the site for the described activity. Land-based projects may also be subject to local land use and zoning regulations.	Policy: Obtain written permission to use the proposed site BMP: Consult with neighbors about the location, size, scope and duration of activity.	If unknown, contact town hall to identify adjacent property owners
4 ✓	**Where are the public or private access routes to the site?**	Restoration work proposed in intertidal and shallow subtidal areas may require access via land through public or private property.	BMP: Use public access routes whenever possible to minimize crossing private property. BMP: Be respectful of adjacent property owners. Restrict activities to between sunrise and sunset, limit noise and any foul odors, and keep the area free of litter.	To identify public access areas, see Map Viewer, select tab "*Comprehensive List*" and from the "*Human Uses*" list check: ▶ "*Boat launches*" ▶ "*Coastal Access Sites*" ▶ "*Public Access Beaches*"
5 ✓	**What is the current condition of the oyster habitat?**	The presence and percent coverage of shell/reef as a bottom substrate is a key measurement and serves as a predictor of oyster habitat sustainability. An abundance of shell can be indicative of historical and native shellfish populations and also provide the essential hard-bottom substrate for both restoration activities and natural juvenile recruitment.	BMP: Prioritize areas that have less than 50% shell coverage. Use the following categories suggested by researchers[90]: non-reef (>10% coverage by shell); low-density reef (10-50% coverage by shell), and high-density reef (>50% coverage by oyster shell).	To identify reef coverage, see Map Viewer, select tab "*Comprehensive List*" and from the "*Species and Habitats*" list check: ▶ "*Intertidal oyster habitat survey sites*" (spatial coverage limited)
6 ✓	**Does the area currently support shellfish populations?**	It is important to establish if the habitat is suitable for shellfish growth or if remediation would be necessary before proceeding with restoration activities. Projects that require environmental remediation may require significant funding and regulatory authorizations.	BMP: Demonstrate that the site supports shellfish survival, growth, and reproduction. BMP: Determine if the habitat has been surveyed and confirm with CT DOAG BA that the habitat characterization reflects the current condition (ie. there have been no changes since the most recent survey)	To identify potential sites, see Map Viewer, select tab "*Comprehensive List*" and from the "*Human Uses*" list check: ▶ "*Commercial shellfish beds; State Waters*", ▶ "*Commercial shellfish beds; Town Waters*", ▶ "*Managed natural shellfish beds; state & town waters*", ▶ "*Recreational shellfish beds*", and ▶ "*Intertidal Oyster Habitat Survey Sites*" (spatial coverage limited),
7 ✓	**Is there larval recruitment to the site?**	Larval recruitment is an indicator of larval availability. Shellfish produce gametes that are fertilized in the water column and settle to the substrate.	BMP: Consider seasonal timing of shellfish recruitment especially when placing settlement substrates. BMP: If possible, collect data on recruitment in the immediate area	Site-specific data unavailable See section 3.3 "*Recommendations - Research and Monitoring*"
8 ✓	**What is depth range?**	Depth is a key determinant of where oysters and other shellfish live. In Long Island Sound, oysters were historically found primarily in shallow bays, creeks, and coves until in 1875, the aquaculture industry began transplanting and farming them in deeper waters depth.	BMP: Select sites with the optimal depth range for shellfish.	See Tables 4.1, 4.2 "*Habitat Suitability Index Factors for Adult and Larval Oysters*" To view depths, see Map Viewer, select tab "*Comprehensive List*" and from the "*Misc*" list check: ▶ "*LIS Bathymetry*"
9 ✓	**What is the sediment type?**	Sediment properties and characteristics such as soil particle size, rock fragment (which includes shell) content, acid sulfate soils, salinity, and soil reaction class are considered important factors for habitat suitability and have been included in several indices[91,92]. Reef building species need firm substrates otherwise shellfish and substrate augmentations may sink. If regularly stirred up into the water column, soft sediments may settle on and kill shellfish.	BMP: Chooses areas with sediment types appropriate for the species and intended goal.	See Table 1.1. "*Common LIS Shellfish Species and Their Habitats*" See Tables 4.1, 4.2 "*Habitat Suitability Index Factors for Adult and Larval Oysters*" To identify sediment data, see Map Viewer, select tab "*Comprehensive List*" and from the "*Shellfish Factors*" list check: ▶ "*Distribution of Surficial Sediments*" ▶ "*Subaqueous Soils*" (soils spatial coverage limited to Niantic River & Bay, Jordan Cove, Little Narragansett Bay, Branford)
10 ✓	**What is the temperature range?**	Oysters are tolerant to rapid changes in temperature[93]. They can also tolerate prolonged exposure to subzero temperatures, as well as exposure for hours to air temperatures over 100° F and survive[94]. Temperature is a major trigger for spawning oysters and is stock-specific meaning that the exact trigger temperature varies geographically[95]. Oyster spawning in LIS generally commences in early July and ends in early September[96]. Temperature can be used to predict the timing and intensity of oyster setting[97]. Temperature, along with salinity, is an important factor influencing Dermo disease, though infections decline at temperatures below 15-20°C. Dermo disease is endemic in Connecticut, but typically found to be at low intensity. Shellfish reefs are prone to being scoured by wintertime ice.	BMP: Avoid siting projects areas subject to significant ice accumulation. BMP: The departure above and below normal temperature should be used in predicting the intensity and time of oyster setting.	See Tables 4.1, 4.2 "*Habitat Suitability Index Factors for Adult and Larval Oysters*" To view temperature data, see Map Viewer, select tab "*Comprehensive List*" and from the "Shellfish Factors" list check: ▶ "*Temperature (bottom)*" (limited spatial coverage in embayments and rivers) ▶ CT DEEP maintains fixed water sampling stations in LIS. Geospatial maps not currently available but links to bi-weekly summaries, monitoring schedule, season summary can be found here: https://portal.ct.gov/DEEP/Water/LIS-Monitoring/LIS-Water-Quality-and-Hypoxia-Monitoring-Program-Overview Learn more about LIS water quality monitoring in the Sound, harbors and embayments here: https://longislandsoundstudy.net/research-monitoring/water-quality-monitoring/
11 ✓	**What is the sedimentation rate?**	Sediment accumulation rate should be considered. Areas with high deposition rates may not be appropriate for some projects. USGS Stream Gauge Data can be used to understand potential sedimentation rates and hydrodynamics of the project location.	BMP: For projects aimed to improve the condition of oyster bed or reef habitat, avoid areas of high sediment deposition.	To view stream gauge data, see Map Viewer, select tab "*Comprehensive List*" and from the "*Misc.*" list check: ▶ "*Live Stream Gauge Data*"
12 ✓	**What is the salinity range?**	Oysters are euryhaline and both adults and larvae can tolerate a wide salinity range typical of LIS and its coves and embayments[98]. Oysters may be stressed when exposed to abnormal fluctuations in salinity caused by drought, flooding or modifications to river flows, and growth stunted at a salinity of 7.5 or below[99]. Also, previously mentioned, salinity is one of the two most important factors influencing the pathogen *Perkinsus* for Dermo disease in oysters. Dermo is endemic in Connecticut, but typically found to be at low intensity. Prolonged periods of low salinity are unfavorable for the pathogen.	BMP: Avoid areas with prolonged periods of freshwater input or areas where modifications to nearby river flows are planned or proposed BMP: Consider the historic and current Dermo disease prevalence and intensity at the proposed site.	See Tables 4.1, 4.2 "*Habitat Suitability Index Factors for Adult and Larval Oysters*" To view salinity data, see Map Viewer, select tab "*Comprehensive List*" and from the "*Shellfish Factors*" list check: ▶ "*Salinity (ppt) (Bottom)*" (limited spatial coverage in embayments and rivers) ▶ CT DEEP maintains fixed water sampling stations in LIS. Geospatial maps not currently available but links to bi-weekly summaries, monitoring schedule, season summary can be found here: https://portal.ct.gov/DEEP/Water/LIS-Monitoring/LIS-Water-Quality-and-Hypoxia-Monitoring-Program-Overview Learn more about LIS water quality monitoring in the Sound, harbors and embayments here: https://longislandsoundstudy.net/research-monitoring/water-quality-monitoring/
13 ✓	**What is the pH range?**	Oysters and estuarine shellfish are exposed to diel and seasonal pH changes, however, adverse effects may be observed when rapid non-normal pH fluctuations occur. Exposure to low pH conditions is widely reported to affect the survival and performance of mollusc larvae[100] with bivalves considered to be among the most highly susceptible[101]. Below pH 6.75 and above pH 8.75, the rate of growth of oysters in LIS has beenshown to decrease rapidly[102].	BMP: Avoid sites associated with extreme water acidity for sensitive species, including clams and oysters	Spatial coverage of pH data is limited. See Section 3.3 *Recommendations - Research and Monitoring*
14 ✓	**What is the dissolved oxygen level?**	Though oysters are tolerant to hypoxic conditions for periods of time, prolonged anoxia (lacking oxygen) or hypoxia (low dissolved oxygen) conditions will affect survival, growth, and reproduction.	BMP: Identify and avoid sites known to be impacted by prolonged summertime anoxia or hypoxia	See Tables 4.1, 4.2 "*Habitat Suitability Index Factors for Adult and Larval Oysters*" To view dissolved oxygen data and hypoxia maps, see Map Viewer, select tab "*Comprehensive List*" and from the "Shellfish Factors" list check: ▶ Seasonal hypoxia maps can be found here: https://portal.ct.gov/DEEP/Water/LIS-Monitoring/LIS-Water-Quality-Monitoring-Maps CT DEEP maintains fixed water sampling stations in LIS. Geospatial maps not currently available but links to bi-weekly summaries, monitoring schedule, season summary can be found here: https://portal.ct.gov/DEEP/Water/LIS-Monitoring/LIS-Water-Quality-and-Hypoxia-Monitoring-Program-Overview Learn more about LIS water quality monitoring in the Sound, harbors and embayments here: https://longislandsoundstudy.net/research-monitoring/water-quality-monitoring/
15 ✓	**Is the area susceptible to erosion?**	Living shorelines maintain continuity of the natural land–water interface, reducing erosion while providing habitat value and enhancing coastal resilience.	BMP: Avoid placing projects in high erosion areas unless they are specifically designed to increase erosion control. BMP: As available, use surveys, photographs, and personal observations to identify areas impacted, or threatened by erosion.	To view shoreline change data, see Map Viewer, select tab "*Comprehensive List*" and from the "*Misc.*" list check: ▶ "*Shoreline change - short term*" ▶ "*Shoreline change - long term*" ▶ "Living shorelines"
16 ✓	**What is the velocity and direction of the current?**	Water velocity is an important factor regulating food delivery, filtration, and spat settlement. Increasing water velocities across reefs to 15 cm s-1 increases the rate of food delivery[103,104.] however exceedance of that rate results in sediment resuspension or cessation of oyster filtration, yielding no or cessation of oyster filtration, yielding no net reduction in seston concentrations[105,106,107]. Water currents are a key factor relative to productivity of bottom areas for oyster settlement[108].	BMP: Avoid areas where the water velocity may limit filtration and spat recruitment.	To view current data, see Map Viewer, select tab "*Comprehensive List*" and from the "*Misc.*" list check: ▶ "*Surface Currents*" ▶ "*Bottom Currents*" (Limited spatial coverage in nearshore area)
17 ✓	**Is there history or presence of harmful algal blooms (HABs)?**	HABs have impacted Long Island (New York) water quality, environmental health and shellfish production since the 1980's. However, HABs have not been documented at the same intensity and frequency, and blooms have not significantly impacted shellfish production in Connecticut's portion of Long Island Sound. The CT DOAG BA has been monitoring for HABs and their associated biotoxins since 1997, and has recently expanded spatial and temporal coverage. UConn researchers have been analyzing phytoplankton samples for the CT DEEP Water Quality Program since 2002.	BMP: Avoid areas with recurring presence of HABS or better studied to understand the actual impact of HABs on restoration projects	To learn more about HABs in LIS, see: *Harmful Algal Blooms in Connecticut* (includes annual report) https://portal.ct.gov/DOAG/Aquaculture1/Aquaculture/Harmful-Algal-Blooms
18 ✓	**What is the water classification relative to food safety?**	Nearshore areas receive high inputs of point and nonpoint source pollution. The consumption of contaminated shellfish harvested from waters classified as less than "Approved" may present a human health risk. Shellfish classifications can be used to understand areas impacted by these pollution sources; however some areas not approved for direct harvest may have lower classifications for administrative purposes.	Policy: Activities in waters classified as less than "Approved" will require adequate surveillance by DEEP ENCON under the minimum requirements of the National Shellfish Sanitation Program - Model Ordinance to prevent illegal harvest of shellfish.	To view water classification data, see Map Viewer, select tab "*Comprehensive List*" and from the "*Shellfish Factors*" list check: ▶ "*Shellfish classification areas*" Contact CT DOAG BA with questions
19 ✓	**Are there point and nonpoint sources of pollution?**	Knowing the sources of such water quality impacts can be useful in planning projects, especially those aimed to improve water quality and commercial and recreational shellfisheries production. The most recent "Assessed and Impaired Waterbodies" data can be used to understand which areas are more impacted by point and non-point pollution sources.	BMP: Determine the classification of the shellfish harvest area and the reason for the classification.	To view Assessed and Impaired Waterbodies, see Map Viewer, select tab "*Comprehensive List*" and from the "*Misc.*" list check: ▶ "*2020 305b Assessed Rivers*" ▶ "*2020 Impaired Rivers*" ▶ "*MS4 (stormwater) 2020 Impaired Rivers*" ▶ "*2020 305b Assessed Estuaries*" ▶ "*2020 Impaired Estuaries*" ▶ "*MS4 (stormwater) 2020 Impaired Estuaries*"

5.7 Metrics and Monitoring

There are minimum universal metrics and environmental variables that have been recommended for inclusion in all restoration projects [109](Table 5.3). These help to determine the level of success of restoration projects, and they should be clearly outlined in the restoration plan. It is recommended that sampling be done at the restoration site and at a control or natural reference site in the year prior to construction, and during post-construction monitoring. During the implementation stage these measurements may be continuous or taken at defined intervals. The frequency of sampling depends on the specific objectives of the project (i.e., the specific water quality parameter(s) the project aims to improve) and the available funding. It is advised that the plan is reviewed and supported by qualified scientists including environmental managers to ensure that collected data are useful in evaluating the anticipated outcomes. Depending on the specific project goals and objectives and available funding, additional higher order metrics should be considered (Table 5.4).

Imagery can be a valuable tool for shellfish restoration in intertidal and shallow subtidal waters. Photographs and videos can be a cost-effective means to achieve a simple before-after comparison. In intertidal areas, it is recommended that several photo stations be permanently established where the project can be easily documented by having photos taken before, during and after construction, and then annually (during the same period) for 5-10 years. There are examples of community engagement platforms that have been used photograph as a means for oyster habitat characterization[110]. High resolution satellite imagery has been proven a reliable means for distinguishing oyster reefs from other adjacent habitats though it can be expensive and labor intensive[111]. Unoccupied aircraft systems (UAS) such as drones are also becoming a more affordable method to capture images and videos of intertidal areas that are difficult to access[112]. Coupled with a GPS receiver, the entire perimeter of the habitat can be mapped and delineated (Figure 5.6). Flight-based Light detecting and ranging (LiDAR) is a remote sensing method that is used to examine land surface features and involves emitting a pulsed laser light to measure distance to the land surface. LiDAR has be used to identify and map oyster reefs, obtain information about intertidal oyster habitat (e.g. vertical relief, oyster density), and to prioritize areas for restoration[,113,114].

The aforementioned methods tend to lose definition in subtidal habitats, and is an area where greater study and refinement is needed. Acoustic methods such as side-scan sonar technology underwater videography have proven useful to survey and characterizing oyster reefs[115,116,].

The development of a Quality Assurance/Quality Control plan for all data collected or created is important to ensure that the data used in decision making will lead to desirable outcomes, save time, and cost less money. Quality assurance (QA) are the processes or methods used to prevent errors from being introduced into the data, while quality control (QC) are processes or tools to identify errors already in the data.

TABLE 5.3. Universal metrics and environmental variables that have been recommended for inclusion in all restoration projects[117].

METRICS:
▶ reef aerial dimension ▶ reef height ▶ oyster density ▶ oyster size-frequency distributions
ENVIRONMENTAL VARIABLES:
▶ water temperature ▶ salinity ▶ dissolved oxygen

TABLE 5.4. Examples of additional metrics, environmental variables and shellfish production factors that may be included depending on project goals.

METRICS:
▶ Shell density (% coverage) ▶ Oyster recruitment, timing and density ▶ Diversity of benthic and pelagic fishes and invertebrates ▶ Habitat connectivity ▶ Area of shellfish habitat restored ▶ Area of marsh grass restored
ENVIRONMENTAL VARIABLES:
▶ pH ▶ sedimentation rates and patterns ▶ Total nitrogen ▶ Denitrification rate
SHELLFISH PRODUCTION FACTORS:
▶ shellfish condition index (a measure of health) ▶ gonad development (a measure of reproductive status) ▶ sex ratio (ratio of male to female shellfish) ▶ shell volume ▶ Disease, prevalence and intensity ▶ Predators, presence and impact

These types of metrics are critical for project planning and to determine restoration success[118]. Metrics for oyster reef restoration have been previously developed:

A successfully restored reef should reflect the following:

- A “minimum threshold” of 15 oysters and 15 grams dry weight per square meter covering at least 30 percent of the target restoration area at six years post restoration;
- A “target” of 50 oysters and 50 grams dry weight per square meter covering at least 30 percent of the target restoration area at six years post restoration;
- Two or more oyster year classes present; and,
- Stable or increasing spatial extent, reef height, and shell budget.

A successfully restored tributary should reflect the following:

- 50 to 100 percent of the currently restorable oyster habitat has oyster reefs that meet the reef-level metrics above. Restorable habitat is defined as area that, at a minimum, has appropriate bottom quality and water quality for oyster survival; and,
- 8 to 16 percent of historic habitat, and preferably more, has oyster reefs that meet the reef-level metrics above.

FIGURE 5.6a Drone image captured from oyster habitat survey at Ash Creek in Fairfield: overview. Photo: Chandi Witharana

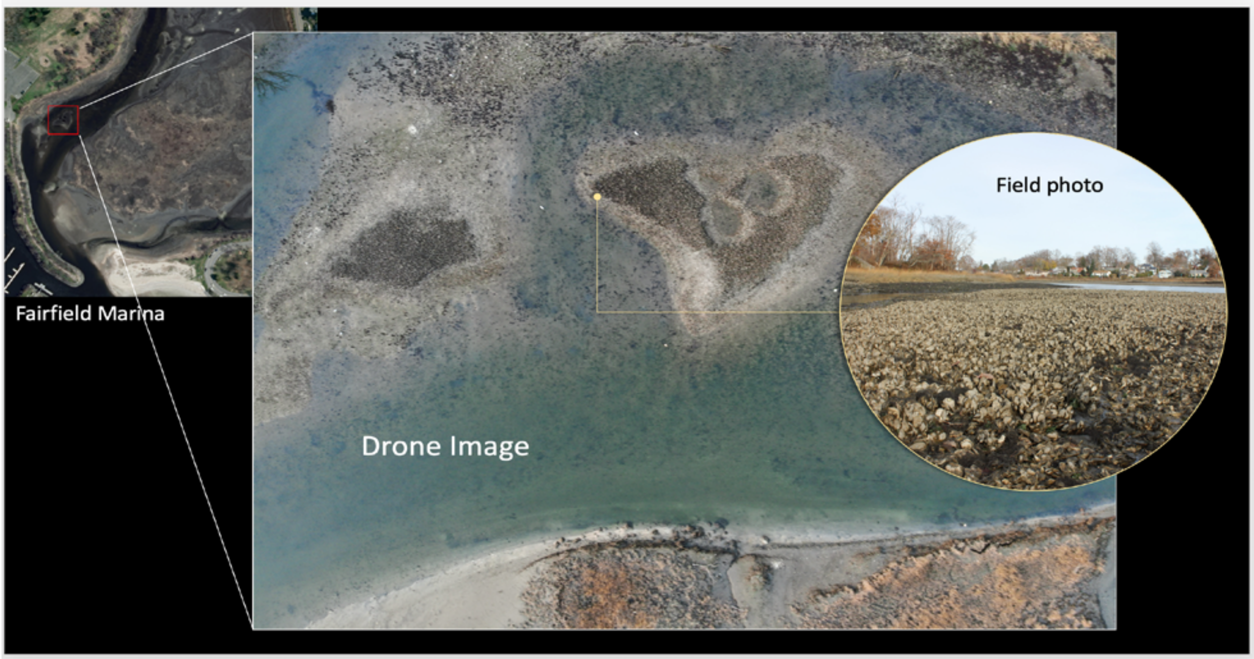

FIGURE 5.6b Drone image captured from oyster habitat survey at Ash Creek in Fairfield: overview and cross-sectional view. Photo: Chandi Witharana

5.8 Shellfish Types and Sources

The type and source of shellfish selected for use in restoration efforts is critical. First and foremost, restoration practitioners should consider the potential for this species to provide benefits in terms of ecosystem services (e.g. improved water quality and habitat, shoreline erosion control) or fisheries or farming production. Does the species fit the intended project goal? Once the appropriate species has been selected, there are other factors to consider.

This section describes regulatory requirements and best management practices along these lines. *The Connecticut Shellfish Restoration Map Viewer* [119] **https://s.uconn.edu/ctshellfishrestoration** has been developed to aid in this process, and can be used to answer many of the project considerations in the checklist below. ***Always consult with state and federal regulators before placing any shellfish in the water as one or more authorizations will be required.***

	TOPIC	CONTEXT	BMP | POLICY	KEY INFORMATION
✓	**Native species**	Evidence has shown that the intentional or accidental release of non-native species can have enormous environmental and economic consequences[120]. The introduction of non-native shellfish or shells has been shown to be a vector for invasive species, and responsible for the spread of pests, parasites, and diseases[121].	Policy: Native shellfish must be used BMP: Use wild broodstock when possible[122].	See Table 1.1 for list of common native shellfish species
✓	**Genetic diversity**	Important issues include the degree to which genetic diversity is maintained in hatchery-produced individuals compared with natural populations[123] and the source of broodstock[124]. CT has extensive natural and self-sustaining oyster reefs that supply seed to the aquaculture industry. Restoration practices should therefore be conducted in a way that protects these reefs[125]. Evaluation of the genetic diversity and population structure of shellfish populations are the best guide for determining possible differences between intended source and receiving populations for restoration. Several practical measures can help to maximize genetic diversity of hatchery-produced individuals even in the absence of information on population genetics.	BMP: Use large numbers of locally (from exact bed within CT waters) collected "wild" broodstock[126] for hatchery production of seed to allow for the maintenance of genetic diversity and patterns of local adaptation. If broodstock are not available or too sparse for collection, match wild sources to environmental conditions where planting of seed will occur[127]. BMP: Rotate local broodstock source for spawning (e.g. use different sets of wild broodstock for each spawning) and planting (e.g. plant reefs multiple times with seed produced by different sets of broodstock) to maximize representation of the wild gene pool and genetic diversity at supplemented reefs. BMP: When feasible, use discrete pair matings or mass spawns that maintain close to 1:1 sex ratios to produce seed for restoration and maximize the genetic diversity in hatchery-produced invididuals. BMP: Document source of spat (e.g. broodstock source reef, lineage, hatchery).	Extensive work on eastern oysters in the Chesapeake Bay has shown that using large numbers of local, "wild" broodstock in hatchery-based restoration programs and planting reefs multiple times (especially if broodstock numbers are low) can increase genetic diversity at restored sites[128].
✓	**Disease**	Several shellfish diseases are endemic to Long Island Sound. As these diseases are endemic, all restored populations will be affected by these diseases in time. Consequently it is critical to select broodstock most likely to display both adaptation to local conditions (as described above) and the endemic diseases. The local genotype will impart genetic adaptation to local conditions, and broodstock from areas of high disease load will also impart the highest level of tolerance to the diseases that have developed through natural selection or selective breeding[129]. While using broodstock with the highest available tolerance to endemic diseases is critical, it is also necessary to ensure that any shellfish stock is disease free at the time of introduction and does not pose a threat to natural and farmed shellfish populations. The shellfish disease history of the site should be investigated. The plan must address 1) how long the shellfish will remain on site and 2) the final disposition of the shellfish being used.	BMP: Follow CT DOAG BA disease management recommendation to utilize CT DOAG BA approved and locally (Connecticut) sourced seed (wild, cultivated, or hatchery product) from a licensed shellfish harvester or hatchery. Policy: All shellfish imported from outside of Connecticut waters must be seed size (2 inches or less). Two years of disease pathology reports from a laboratory approved by CT DOAG BA must be submitted via hard copy or email to CT DOAG BA prior to importation. This activity requires a license. Policy: Shellfish samples are required to be submitted annually post construction to CT DOAG BA for disease pathology assessments to be conducted at the project administrator's expense. This policy applies to local and imported oysters. If disease prevalence and intensity is found to be above background levels in the restoration area based on CT DOAG BA data, a shellfish depopulation plan may be required to be conducted and paid for by the administrator and overseen by CT DOAG BA.	Contact CT DOAG BA to request database on MSX and Dermo disease prevalence and intensity for oysters (data available from 1997 through present)

5.9 Substrate Types

Reef-building shellfish such as oysters require hard surfaces or at least some form of consolidated substrate to which they can attach. The substrate is also necessary to develop the vertical elevation that is critical for reducing the sediment loads that need to be processed by the shellfish[130]. Further, oyster density was found to be fourfold higher on high-relief reefs than low relief reefs with recruitment and reef accretion correlated to oyster density[131]. While the height above sediment varies by location, vertical elevation of substrate has proved to be highly beneficial. Natural oyster mortality contributes much needed shell substrate, but where a significant oyster population is lacking, the substrate can consist of other shell types and natural materials (Table 5.5), or artificial materials (Table 5.6).

Shell is the prefered substrate for most restoration goals. However, in some situations, alternative substrates are preferred. Rock has been shown to be more effective than surf clam shell as it is not brittle, does not break down, and does not lose rugosity[132]. While natural substrates are preferred, they are not always available or practical. Any shell-based substrate used for shellfish restoration other than the native shell of the area is considered an “artificial” material[133]. A review of alternative substrates for oyster reef restoration is available[134]. The substrate of choice will depend on the goals of the specific restoration project[135].

Best Management Practices:

- ***Always consult with state and federal regulators before placing any materials or gear in the water as one or more authorizations will be required.***
- Avoid plastic.
- Use biodegradable materials when possible.
- When biodegradable materials are unavailable or unsuitable, use rock or concrete.
- When purchasing or collecting shell, adhere to state policies (see Section 5.10 *Shell Recycling*)
- Consider the aesthetics of substrates, especially when proposed in exposed intertidal areas and near private property.
- Consider seasonal ice and how it may impact concrete and other substrates.
- Consider the shape and position of spat collectors in relation to mean low water and direction of the current as these; factors impact the distribution of spat on the collectors[136].
- Avoid planting cultch or other substrates higher than two feet above the mean low water mark level, and target areas one foot below low-water mark as this is where oyster larvae set most abundantly[137].

(a) **(b)**

FIGURE 5.7 Shellfish commission member installing concrete coated oyster spat collectors (a); oyster seed settled on collectors (b). Photo: Tim Macklin

TABLE 5.5 Natural substrates

TYPE	DESCRIPTION
Shell otherwise known as "cultch"	Suitable shell material comes from bivalves and marine snails, including quahog, oyster, conch, surf and softshell clam, scallop, mussel, and slipper snail. Shell may also be reclaimed from sites that have been buried in silt.
Cobblestones and boulders	When strategically placed into the marine environment, natural rock can provide a substrate for shellfish recruitment. They can also be utilized in living shoreline designs, arranged in linear sills, in order to attenuate wave energy and allow sediment to fall out of suspension
Limestone	Limestone has been demonstrated to be as effective as shell for recruiting oysters[138].

TABLE 5.6. Artificial substrates

TYPE	DESCRIPTION
Concrete	Concrete is similar enough to the chemical composition of shell that it is a good alternative substrate for shellfish when it is placed into the marine environment. Some concrete designs are designed to maximize the surface area where shellfish can settle[139]. This includes both concrete rubble, and brand-named and prefabricated structures engineered for a specific purpose. However, concrete can weather very easily (unlike rock or shell) and compromise the attachment mechanism or be vulnerable to ice damage. New concrete designs with increased surface area for shellfish settlement are being explored[140].
Porcelain	Crushed porcelain (e.g., reclaimed toilets and sinks) can increase habitat complexity, vertical relief, and maximize surface area for the recruitment of certain shellfish species.
Gabion cages	This type of gear can be used to contain live shellfish, or shell material, to recruit shellfish. The cages are fairly large and rest on the bottom. They may also be stacked and made into a retaining wall or bulkhead, providing better habitat than steel sheet-pile when this kind of structure is necessary. Potentially, these can be used as an acceptable component of a sill when designing a living shoreline project, in lower-energy areas only.
Bags or cages	These materials can be used to contain live shellfish or shell material to recruit shellfish. They can hang suspended in the water column or rest on the bottom. Potentially, they can be used as an acceptable component of a sill when designing a living shoreline project, in lower-energy areas only.
Rope or chain	These materials can be used as a substrate option in areas unsuitable to bags and/or cages - for example, when placing structures on the bottom is not the best option. While not habitat-forming, ropes and chains supporting shellfish can aid with projects aimed to improve water quality.
Biodegradable products	Examples are natural fiber materials, including coconut fiber (coir) logs or blankets, tree trunks/logs, root wads, dimensional lumber. While not well-suited to growing oysters or other species of shellfish, these materials can be used to stabilize a site where shellfish are to be grown. Providing stabilization helps ensure that the planted shellfish will survive, reproduce, and persist for many years. These materials also serve to retain sediment, prevent erosion, and provide a long lasting habitat of shellfish. One notable example is in tidal marsh restoration, where ribbed mussels can be planted.

5.10 Shell Recycling

Restoration practitioners may depend on or be involved in shell recycling programs to secure shell substrate. Oyster shell, or the shells of other bivalves, are used as substrate or for stocking seed using remote setting techniques; however, the shell itself may pose threats similar to the use of live shellfish. Research has shown that a shell quarantine of a month or longer can significantly reduce the risk of shellfish disease transfer[141].

Shell can be purchased or sourced from a variety of locations such as shell recycling programs, shucking facilities, restaurants or shellfish festivals. It is important to know the source of the shell purchased or collected. Similar to using live shellfish in restoration efforts (see Section 5.8 *Shellfish Type and Source*), there are risks associated with the use of shell substrate. Shell that is not cured properly may carry native or non-native nuisance species or serve as vectors shellfish disease when placed in the water.

The state regulatory agencies have developed the *Shell Recycling Regulatory Guidance* document (to obtain a copy, contact CT DOAG BA). Some shoreline municipalities have special ordinances pertaining to shell piling/recycling. Contact the local Public Health and Zoning Departments in the municipality where the project is proposed to learn if these apply in the proposed project area. For guidance on sanitation related to shell recycling, consult the National Shellfish Sanitation Program-Model Ordinance (NSSP-MO): Chapter XIII @03. E. Equipment Condition, Cleaning, Maintenance, and Construction of Non-Food Contact surfaces https://www.fda.gov/food/federalstate-food-programs/national-shellfish-sanitation-program-nssp.

FIGURE 5.8 Oyster shells collected from local restaurants in Fairfield. Photo: Tim Macklin

FIGURE 5.9 Shell recycling pile at commercial oyster farm. Photo: Tessa Getchis

	TOPIC	BMP | POLICY
✓	**Shell purchase**	Policy: Any purchase of shell must be pre-approved by CT DOAG BA.
✓	**Shell curing and storage**	Policy: Applicants must submit a written plan for CT DOAG BA approval for the operation of any shell recycling program. The plan should indicate the site location, designate an area and protocol for sanitation, an area for shell pile storage, and shell pile maintenance schedule. Depending on the location, there may be further municipal requirements. BMP: Avoid establishing shell recycling sites in residential areas. Policy: Have a dedicated space, away from areas where runoff can impact the waters of LIS, for shell storage. Any in-water placement of shell, or any other materials, requires a permit from USACE and CT DEEP (see Section 5.5 *Authorizations and the Permitting Process*). Policy: Have a dedicated space, away from the facility's garbage area, for dropping off cleaned and sanitized containers. Policy: Have a source of potable water for the cleaning, sanitizing, and drying of vehicles and all containers used for transport. Policy: Reclaimed shell must be sun cured on land for a minimum of six months. Multiple shell piles may be necessary. Policy: Have a written schedule for the maintenance of the shell and shell curing site that documents timing of shell deposition and curing, and strategies used to control pests, odor, and other nuisances.
✓	**Shell**	If vehicles used to transport shell are also transporting food products, there are several considerations and rules to follow: Policy: There must be separation of the shell (garbage) from the food. This separation can either be: (a) *physical* - a separate enclosed area within the vehicle, or a large sealable, leak proof container capable of holding the smaller containers, or (b) *temporal* - no shell (garbage) can be in the transport vehicle at the same time as food products. Policy: All containers for transporting shell, including any larger holding bins) must be labeled "garbage," be waterproof, able to be fully sealed, and comply with non-food contact surface requirements (see next column) BMP: Consider the pick-up schedule for various facilities and adjust to avoid excessive shell waste build up, odor, and other nuisances, like flies. BMP: Determine how, and at what frequency, will cleaned and sanitized storage containers be returned to the pick-up sites.

5.11 Design and Construction

Regardless of the restoration goal, careful consideration must be given to the design and construction of the project. Site information is critical, and depending on the project type, may include: habitat type, bathymetry, salinity, wave energy and prevailing direction, prevailing wind speed and direction, elevation, sediment type, vegetation, and if applicable, erosion rate. Because of the high variability of the Connecticut shoreline and physical parameters, what works in one area may not be applicable to another site. The physical design of the restoration project at the selected site(s) should be performed by a certified coastal engineer, or other professional, in consultation with state and federal regulators. The materials used must be approved by state and federal regulatory agencies including, but not limited to, the US Army Corps of Engineers (USACE), National Marine Fisheries Service (NMFS), Environmental Protection Agency (EPA), Connecticut Department of Energy and Environmental Protection (CT DEEP), and the Connecticut Department of Agriculture, Bureau of Aquaculture (CT DOAG BA).

The CT DEEP encourages the use of natural shoreline protection methods over shoreline “armoring.” Living shorelines are constructed using native plant and animal species and biodegradable materials. Incorporating marsh vegetation and natural fiber erosion control products, in combination with harder structures provides added stability. Hardening shorelines with sea walls, riprap, and groins is a short-term fix that increases the rate of erosion, destroys habitat, and results in costly structural damage as well as property loss. Living Shoreline projects in CT protect, create, or enhance natural habitat and function to mitigate shoreline erosion and flooding. Not all shellfish restoration projects will be considered living shorelines and not all living shoreline projects include shellfish restoration. Site specifics are critical in considering restoration/living shoreline projects.

See section ”*Recommended Reading*” for educational resources on living shorelines.

FIGURE 5.10 Construction of rock sill along Fenwick Point in Old Saybrook. Photo: Juliana Barrett

FIGURE 5.11 Completed rock sill along coastline of Fenwick Point in Old Saybrook. Photo: Juliana Barrett

	TOPIC	BMP | POLICY	KEY INFORMATION
✓	**Living**	BMP: Bags, cages, rope/chain, and other forms of containers are commonly used for water quality improvement projects to keep shells in place so that oyster spat will settle and begin building a natural reef. Suitable substrates for water quality improvement projects are large cobblestones and boulders, prefabricated concrete structures like Reef Balls, Oyster Castles, or Reefmaker products, and concrete or porcelain rubble. BMP: Use a certified coastal engineer and restoration ecologist to conduct site assessment and prepare the permit application(s). BMP: Invite regulators to a site visit at the beginning of the planning process BMP: For living shorelines, consider appropriate timing for either the planting of native marsh plant seeds (February/March), or plugs (April). A protective breakwater of some kind may be needed to slow wave energy depending on site conditions. BMP: The use of heavy machinery is typically restricted during certain times of the year to avoid disturbing wildlife, and work may need to be conducted during low tide. BMP: Some coastal communities may restrict use of heavy equipment during the summer months, so meetings with local authorities is strongly recommended.	CT DEEP Living Shoreline Website: https://portal.ct.gov/DEEP/Coastal-Resources/Coastal-Management/Living-Shorelines

FIGURE 5.12 Oysters and blue mussel colonizing the inside of a Reef Ball at Stratford Point's Living Shoreline. Photo: Jennifer Mattei

FIGURE 5.13 Stratford Point's Living Shoreline with Reef Balls used as a breakwater protecting the marsh toe and slowly becoming an oyster reef. Photo: Jennifer Mattei

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RECOMMENDED READING

General Shellfish Restoration Resources:
The Oyster Restoration Workgroup Website: http://www.oyster-restoration.org

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LIVING SHORELINE RESOURCES:

Methods for nature-based shoreline stabilization techniques **https://www.habitatblueprint.noaa.gov/living-shorelines/**

Living Shorelines - Connecticut Institute for Resilience & Climate Adaptation (CIRCA) **https://circa.uconn.edu/living-shorelines**

Living Shorelines Permit Process - CT DEEP (*Note that projects involving shellfish follow a different process that begins with CT DOAG BA (see Section 5.5 *Authorizations and the Permitting Process*)
https://portal.ct.gov/-/media/DEEP/coastal-resources/coastal_management/Living_Shorelines/LS_PermitProcess.pdf?la=e

Living Shorelines Primer on Techniques and Projects - CT DEEP **https://portal.ct.gov/DEEP/Coastal-Resources/Coastal-Management/Living-Shorelines**

The Coastal Hazards Guide for Beaches and Dunes; checklist for getting started on living shorelines design
https://beachduneguide.uconn.edu/get-started/

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APPENDIX: DATA MAINTENANCE

Throughout the development of this *Guide*, several spatial tools and datasets were created to inform decision making and the future siting of shellfish restoration efforts. These items rely heavily on data that was generated for other, often related efforts in Connecticut, but also on information gathered specifically for this *Guide*. The task force and steering committee have agreed that these products/tools/datasets can and should be used not solely for short-term restoration efforts, but also for longer-term ones. Therefore, maintaining, updating, and even improving upon these items is imperative to informing successful future restoration in Connecticut's ever-changing estuarine environment.

This Appendix contains recommendations regarding the maintenance and upgrading of data sets and decision-making tools developed through this effort. For the purposes of this Appendix, these data fall into two categories:

1. Data gathered/generated directly through this effort. Data and tools generated through this effort including: *Connecticut Shellfish Restoration Interactive Map Viewer* **https://s.uconn.edu/ctshellfishrestoration**, *the following GIS layers/ map services: "Areas Off Limits to Shellfish Restoration", "Shellfish Restoration Interests and Project Sites*", "*Intertidal Oyster Habitat Survey Sites"* and "*Subtidal Oyster Habitat Survey Sites"* (a work in progress), and some of the individual geospatial layers contained therein. The task force has transitioned these products to state agencies that will maintain ownership of these data and tools, and will be able to edit them in the future.

2. Data imported from other sources/entities. Some of the data that has been incorporated into the *Connecticut Shellfish Restoration Interactive Map Viewer* **https://s.uconn.edu/ctshellfishrestoration** were created and are now maintained by other entities; these include, for example, data drawn from the *Aquaculture Mapping Atlas* **http://cteco.uconn.edu/viewer/index.html?viewer=aquaculture** and *Long Island Sound Blue Plan* **https://portal.ct.gov/DEEP/Coastal-Resources/LIS-Blue-Plan/Long-Island-Sound-Blue-Plan-Home.** As such, the task force and steering committee are not able to make alterations or updates to those data that "reside" elsewhere. However, the task force and steering committee may work with these entities to discuss how those external datasets and tools might better inform future shellfish restoration.

A.1 Data Maintenance Recommendations

TOOL	TASK, FREQUENCY	OWNER
Connecticut Shellfish Restoration Map Viewer **https://s.uconn.edu/ctshellfishrestoration**	Annually: Review all data layers to determine if there is updated, expanded or higher-resolution data available; assess relevance of existing data. Annually: Maintenance and check of GIS services; check accessibility of links to external databases (photos from surveys, etc.), map services. Repair broken links.	CT DOAG BA; CT DEEP; CTSG; UConn CLEAR
"Areas Off Limits to Shellfish Restoration" (GIS layer, map service) **https://arcg.is/0vTnCK1**	Annually: Revisit and determine if additional exclusion areas necessary; update associated potential areas that remain after exclusionary analysis if changes; update Table 2.2 "*Areas Off Limits to Shellfish Restoration*" Annually: Update analysis to reflect changes to underlying data layers used in exclusionary analysis; town and state managed shellfish bed layers change frequently.	CT DOAG BA, CT DEEP; USACE
"Shellfish Restoration Interests and Project Sites" (GIS layer; map service) **https://arcg.is/0v48Kb0**	Annually: Update potential project areas data as additional information becomes available.	CT DOAG BA; CT DEEP; CTSG
"Intertidal Oyster Habitat Survey Sites" (GIS Layer; map service); **https://arcg.is/08Cy8G0**	As funding allows: expand spatial coverage At least every five years: update.	CT DOAG BA;_CTSG
"Subtidal Oyster Bed Survey Sites" (planned for 2022)	As funding allows: begin documenting spatial coverage At least every five years: update.	CT DOAG BA;_CTSG
Aquaculture Mapping Atlas **http://cteco.uconn.edu/viewer/index.html?viewer=aquaculture**	Annually: Add relevant new data layers to *Aquaculture Mapping Atlas*. Annually: Updates to connect to map services following data review and maintenance to ensure that changes are synchronized across mapping tools.	CT DOAG BA; CTSG; UConn CLEAR