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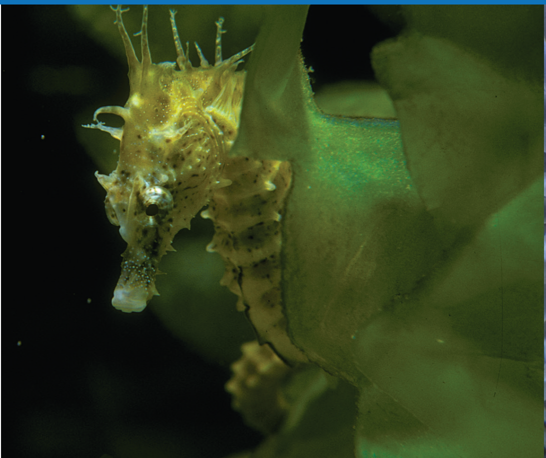
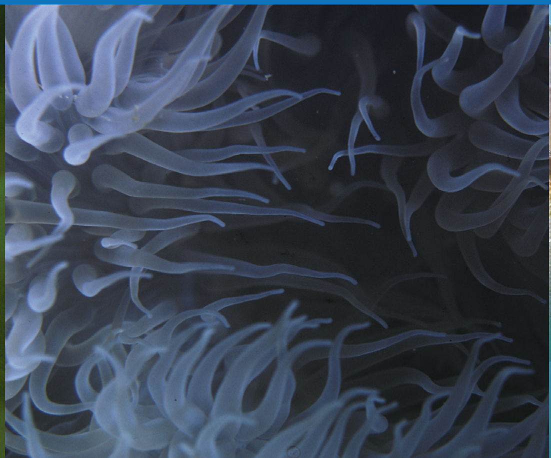
The Long Island Sound Ecological Assessment





the Long Island Sound ecological assessment 2015

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Long Island Sound and its confluence with the Connecticut River, Old Lyme, CT
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Piping Plover chicks
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section 1

introduction

From oysters and clams to herring and bass, to the 23 million people who live within 50 miles of its shore, Long Island Sound is a hub of life. Although on the surface this large body of water may look uniform, its underwater terrain and marine life is remarkably varied and complex, with different species and habitats corresponding to distinct spatial areas or geographies. To better facilitate and locate both the use and conservation of Long Island Sound, it is critical to understand its water column and seafloor habitats, the geographic areas in which they occur and the potential ecological significance associated with each of them. Despite the Sound's extraordinary importance to so many people and to the larger regional environment, no single comprehensive inventory of its most valuable and significant features exists to guide management, planning, and conservation decisions.

This regional ecological assessment is designed to enhance our understanding of ecologically notable places in Long Island Sound and the surrounding waters of Block Island Sound and the Peconic Estuary. By contributing new information and an enhanced spatial understanding of these waters to decision-makers and stakeholders, The Nature Conservancy (the Conservancy) is working to support actions that reduce conflicts among human uses and ecologically important resources. In addition, the information and insights gained through this assessment will help shape the direction of the Conservancy's conservation work in Long Island Sound.

The Nature Conservancy and others have completed numerous ecological and eco-regional analyses of the terrestrial and coastal areas associated with Long Island Sound for conservation and other purposes (Anderson et al. 2006). Examples of areas assessed include studies of the watersheds that drain to the Sound and the tidal marshes that border it. The Long Island Sound Study, for example, identified 33 stewardship sites, which capture important places located primarily along the coast. Few comparable spatially-based ecological assessments have been completed to date for the waters and seafloor of the Sound despite the existence of a large body of research associated with these offshore areas, including notable habitat classification and characterization studies. Thanks to generous contributions from many scientists, The Long Island Sound Ecological Assessment (LISEA) utilizes much of this prior work along with new and recently available data to identify spatial areas within Long Island Sound that emerge both for their biological significance and their distinct seafloor features. The Cable Fund Seafloor Mapping Project for Long Island Sound, currently underway, should also be noted. It is a large, long term project that may contribute very significantly to our spatial understanding of the underwater areas of the Sound.

LISEA is based on scientifically-credible biological and physical data regarding the geography of the Sound, organized and synthesized spatially. The methodology used was based on the Northwest Atlantic Marine Ecoregional Assessment (NAMERA) (Greene et al. 2010, Anderson et al. 2010), a large-scale marine assessment of ocean waters that extends from Cape Hatteras to the Bay of Fundy.

The LISEA assessment is primarily based on two analyses: seafloor habitats and species persistence patterns. The first includes bottom structure, sediment types and benthic organisms, and provides an important base layer for delineating spatial differences in bottom habitats and potential correlations of marine life associated with these areas. The second analysis focuses on fish and macroinvertebrates and includes information from nearly 30 years of extensive fishery trawls undertaken by the Connecticut Department of Energy and Environmental Protection (CT DEEP).

Datasets used had to meet the criteria of being: 1) credible relative to the methods and purposes of the assessment, 2) geographically extensive enough to cover most or all of the Sound, 3) pertinent to the pelagic and seafloor environment.

The primary result of the LISEA is the identification of ecologically notable places that help sustain the diversity of marine life in the Sound and surrounding waters. High value habitats or areas with elevated use by important species contribute disproportionately to the health of the overall system. Therefore LISEA is more about identifying places that sustain life over time in the Sound than it is characterizing its variety of life. The LISEA is most interested in identifying geographic locations that despite the dynamic nature of the offshore environment continue to support species diversity and relative abundance through time.

We designed our methods to highlight such places, and through this report bring them to the attention of the conservation community and resource managers.

This assessment portrays only part of the complex ecosystem of Long Island Sound. In addition to the biology of the Sound, from birds, fish and sea mammals to seagrass, seaweeds and corals, the ecological processes and physical parameters (such as hydrological circulation and dissolved oxygen) also play key roles in driving how the system functions. Therefore the LISEA should be used in conjunction with previous and future assessments to reveal a more complete picture of the interconnected and interdependent set of geographies, species, habitats and ecological processes including upland watersheds, coastal systems, and the Atlantic Ocean. Although LISEA illuminates ecologically notable places that emerge from the data and methods used, this does not mean that other areas of the Sound are not important, ecologically or otherwise. It can be argued that any and all parts of the Sound are ecologically important depending on what is being considered.

The LISEA contributes new insights into spatially significant areas of the Sound and highlights the data needs that still exist to paint a more complete picture. It revealed some significant and surprising results, such as the persistent concentration of demersal (bottom-dwelling) fish species in the sand flats south of Falkner Island, an island of the Stewart B. McKinney National Fish and Wildlife Refuge. The final outputs are summarized in a map of ecologically notable places that includes both aquatic and seafloor habitats. The LISEA also developed a state-of-the-art methodology for mapping bottom habitat types distinguished by topographic form, depth, sediment and biotic factors. These are shown spatially and depicted for all geographies of the Sound as well as Block Island Sound and the Peconic Estuary.

section 2

overview of Long Island Sound

Long Island Sound is a vital estuary of remarkable natural and human significance. In 1987, Congress designated it as an Estuary of National Significance. Surrounded by some of the most densely populated areas of the nation where 23 million people live within 50 miles of its shores, the Sound remains a diverse and productive ecosystem supporting a diverse array of plants, animals and habitats. In addition to the bluefish, striped bass, winter flounder, fluke, scup, tautog, and others that anglers seek, the Sound has fish ranging from delicate seahorses to the massive ocean sunfish. The Sound's four species of sea turtles are indicative of the surprising diversity found in this "urban sea." Within its 1,320 square miles of water and 600 miles of coastline, Long Island Sound is a highly productive living system providing key feeding, breeding and nursery area for hundreds of species. It has an important ecological role in mediating nutrient and sediment cycles and fueling critical food-webs. It is a biologically rich system that is an important source of life for the Atlantic Ocean.

The significance of Long Island Sound to people cannot be overstated. People have been living alongside and working within Long Island Sound for centuries. The Sound is a defining part of the culture and economies of Connecticut, Long Island and southeastern New York with its abundant recreational opportunities, diverse and vibrant economic activity, coastal communities, quality of life and rich history. The Sound supports 30,000 maritime industry jobs in Connecticut alone, generates $149.3 million annually from recreational fishing in Connecticut and New York, and generates $30 million in commercial finfish and shellfish landings in Connecticut. It prevents $28,500 annually in storm-related damages for every 2.5 acres of its coastal wetlands. It contributes greater than $8.9 billion (2011 dollars) annually to the economies of Connecticut and New York (Long Island Sound Study 2013).

The abundance of marine life and a nearly $9 billion dollar economy each year from fishing, tourism, the maritime industry and other uses make the Sound an important resource for nature and people.

General Description

Long Island Sound is surrounded by the land masses of the States of New York and Connecticut. Its 16,820 square mile watershed includes parts of Vermont, New Hampshire, Massachusetts, Rhode Island, New York as well as all of Connecticut.

The average depth is 63 feet and as an estuary, the salinity varies, ranging from 23 parts per thousand (ppt) in the western part of the Sound to 35 ppt in the east. The three major rivers that flow into the Sound on the Connecticut shoreline, the Housatonic, the Connecticut and the Thames, provide 90% of its fresh water. The Connecticut River alone provides 70% of the Sound's fresh water.

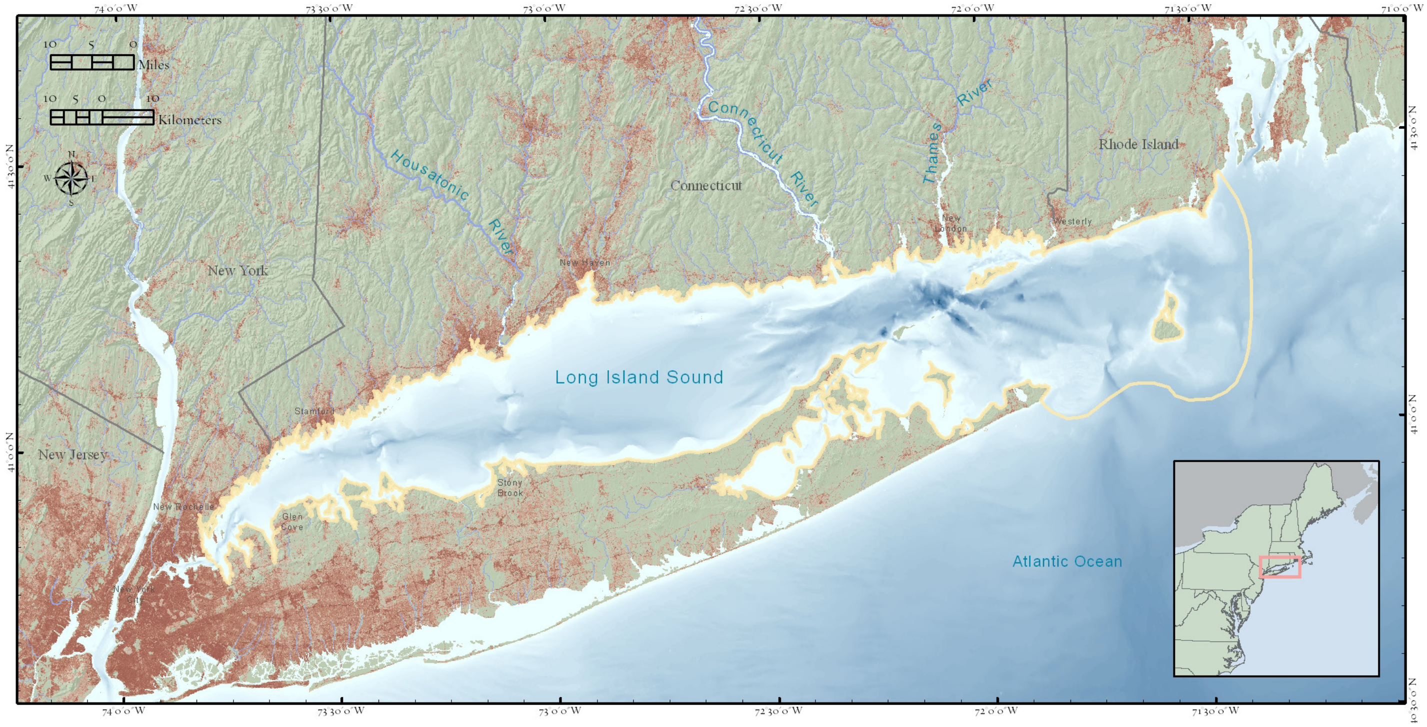


Figure 2.1. Long Island Sound Regional Context

The Sound experiences diurnal tides with the tidal range increasing from east to west. Average winter and summer water temperatures as of 2011 were 37°F winter/69°F summer (Long Island Sound Study 2013).

The Long Island Sound ecosystem is comprised of many components including the aquatic and sea floor habitats of the Sound itself, coastal areas and the largely forested freshwater upland watersheds that feed into it. Within and along the shores of the Sound are diverse habitats that include tidal salt marshes and tidal freshwater wetlands, seagrass meadows, natural shorelines and dunes, shellfish reefs, rocky reefs, rocky intertidal habitats, seafloor habitats – sand, silt/mud, gravel/boulders and 18 trillion gallons of open water. Additional habitats include cliffs, bluffs, coastal woodlands, intertidal flats, and tidal rivers.

There are 184 different finfish (145 from CT DEEP studies and 39 from historical studies), 1,200 invertebrate species documented as occurring in the Sound and 50 species that use it to spawn. The rich diversity of life in the Sound includes 92 species of sea birds, 26 mammals, 5 reptiles, 327 crustaceans, 183 molluscs and 392 arthropods. It includes 352 species of algae, 28 sponges, 56 bryozoans, 41 echinoderms, 95 cnidarians, 84 worms and just 1 plant, eelgrass (Long Island Sound Resource Center 2011). In addition, the Sound is noted for its soft corals.

Geographic Context in The Nature Conservancy's Work

Restoring the health of the world's oceans is one of the top global priorities of The Nature Conservancy because among other reasons all of the Earth's biodiversity depends on the ocean's life-support services. Estuaries such as Long Island Sound are part of this picture. The Sound is by far the largest estuary of the Southern New England/Long Island Whole System (SNE). The SNE Whole System is one of four coastal marine ecological systems that the Conservancy has identified along the Eastern seaboard. The Gulf of Maine Whole System is to the north and the Mid-Atlantic Bight to the south. The Southeastern Whole System is the fourth. These systems were established by The Conservancy in recognition of the importance of sustaining the integrity and viability of large ecosystems around the globe and the need to work at scale in achieving conservation results.

Threats to the Sound

The health and ecological integrity of the Sound is threatened by pollution, increasing and potentially incompatible uses, coastal development and the changing climate.

1. Excess nutrients from multiple sources (wastewater, fertilizer and atmospheric deposition) have resulted in:
    a) algae smothering eelgrass and other benthic habitats,
    b) destabilization, collapse and conversion of salt marshes to mud flats,
    c) harmful algal blooms that close beaches and shellfishing grounds, and
    d) hypoxia (low or no dissolved oxygen) in Long Island Sound.
2. Coastal development and hardened shorelines have degraded coastal habitats by fragmenting terrestrial, freshwater and marine exchange, while also obstructing habitats like salt marshes from advancing landward in response to sea level rise.
3. Hundreds of dams, stream crossings and other barriers block access to critical upstream fish habitats.
4. Human uses of the Sound often conflict with one another and the natural environment. Marine resource management addresses one industry or species at a time and is legally fragmented among multiple federal and state agencies, laws and local ordinances. With no existing Sound-wide authority or mechanism to coordinate and allocate increasing proposals for new and multiple uses, the Sound is vulnerable to conflicts among users and impacts to living resources.

It is this fourth challenge to the long term integrity of the Sound for which the Long Island Sound Ecological Assessment is most relevant. As mentioned in the Introduction, in order to better sustain and compatibly manage the ecological resources and uses of the Sound, it is critical to know the location of ecologically significant places so that this information can be factored into decision-making processes.

Right: Excess nitrogen comes from multiple sources such as septic systems from coastal development Credit: © Jerry and Marcy Monkman

Below: The proposed 2001 Broadwater liquefied natural gas terminal would have meant big changes for the Sound. Credit: www.marinelog.com

section 3

project approach

The ecological integrity of Long Island Sound depends on many factors ranging from ecological processes and physical parameters to the extent and condition of habitats. Within this wide and complex range of variables are ecologically notable places.

The LISEA focuses on identifying ecologically notable places (ENP) in the water and on the bottom of Long Island Sound as the primary output of the project. This focused approach should provide useful guidance for management and conservation within the broader, ongoing conservation programs existing within the Sound and its watersheds.

In support of identifying the ecologically notable places and as a foundation for seeing and understanding the submerged world of Long Island Sound, the other major output of the LISEA is the identification of seafloor habitats.

LISEA is about Places

A comprehensive spatial inventory of marine life associated with Long Island Sound would be a valuable and important project to complete and ideally would include a full array of species and life forms from finfish and marine mammals to lobsters, plankton, seabirds and even coral, no less microscopic life and tropic food webs among others. Such a project would be a major undertaking and difficult with existing data, particularly if it was to be quantitative and spatial. As desirable as such a project would be, however, this is not the aim of LISEA. The LISEA is about identifying places that are particularly notable for sustaining life over time rather than attempting to characterize its variety of life . The LISEA is most interested in identifying geographic locations that despite the dynamic nature of the offshore environment continue to support species diversity and relative abundance through time. It may be more important for management and conservation to know about places that support of life over time even as the species or life forms they support change over time. It is further recognized that with a changing climate, such places will become more critical and at the same time, potentially more difficult to identify.

Seafloor Habitats

The diversity of seafloor habitats, distinguished by the wide array of physical features, literally forms the foundation of the submerged world of Long Island Sound. We created a comprehensive map of physical habitats organized as Ecological Marine Units (EMU). The EMUs were based on depth, sediment grain size and seafloor topography and informed by the distribution of benthic organisms. Defining the bottom habitat types through the EMU analysis provides a descriptive overview of the seafloor and allows for comparisons and correlations with other elements of the Sound's biota and ecology. The EMUs are covered in detail in Chapter 5. Although the EMU's are primarily descriptive, EMU richness, or the density of different habitat types, was used as a factor in predicting ecologically notable places as described in Chapter 7. Finally, the concept of representativeness is noted. A conventional conservation approach suggests including a representation of these different bottom habitats in conservation and management efforts. See Figure 5.20 of Chapter 5.

Ecologically Notable Places

This assessment considers the following to be ecologically notable, recognizing that there are other places and definitions that could be used:

1. Geographic areas with sustained levels of marine diversity (Species persistence).

This refers to those spatially identified areas where there is a relatively sustained level in the richness and abundance of marine organisms. Richness means the relative number or diversity of species or suites of species that occur at a given location. Abundance refers to the relative size of populations at a given location for a species or suites of species. As noted above, because the Sound is such a dynamic environment, we used and emphasized the criteria of persistence over decades to identify areas of sustained significance and focused this analysis on fish and aquatic invertebrates. Benthic organisms are also important and useful for distinguishing seafloor habitats; the currently available benthic survey data, however, are not sufficient to allow for a robust, geographically consistent analysis of persistence. Other species not addressed in this assessment may also be important to consider for persistence (e.g. plankton, migratory or diving birds, marine mammals, etc.). Nonetheless, a very significant portion of aquatic species were considered, including over 100 fish and invertebrate species. These species were analyzed both individually and in functional groups. The groups included demersal, pelagic and diadromous fish species as well as invertebrates. Finally, all the species were considered and analyzed together as a combined group. The areas identified with relatively high persistence of many species are considered to be ecologically notable places.

2. Geographic areas of diverse and complex bottom habitat types (Seafloor complexity).

Complex bottom habitats are known for their rich species diversity and the LISEA considers these areas ecologically notable because of the general correlation between physical complexity and biological productivity. The data and analytical basis for identifying seafloor complexity in large part stem from the EMU work described above under Seafloor Habitats and in detail in Chapters 5 and 7. Three elements of bottom features were considered and joined as a composite to map seafloor complexity: a) hard bottoms such as rocky substrates and boulder fields; b) complex bottom bathymetry- especially areas with greater steepness or slope such as reefs and canyons; c) high levels of EMU richness or a high concentration of bottom habitat diversity within a given geographic area. The LISEA does not depict the actual marine life found in these areas that are typically difficult to sample. As such, seafloor complexity serves as a proxy for the biological communities that these habitats support. The rationale for using the physical/biological correlation approach is discussed in more detail in Chapter 7.

3. Geographic areas that perform or serve notable ecological functions (e.g. Seagrass).

These may be specific habitats or assemblages of species and natural communities such as seagrass and salt marsh (e.g. functioning as nursery for multiple organisms), shellfish beds (e.g. important in nutrient cycling and water quality) and other habitat forming organisms (e.g. sea brites).These areas could also include migratory corridors. Because of data limitations and a focus on submerged habitats, the LISEA only included seagrass beds in this category of ecologically notable places. This is an area that needs further study.

4. Geographic areas with unusual or rare species and/or habitats.

Places with rare species or habitats which may have implications for management including locally or globally endangered species. As such, the LISEA pursued data and information so these areas could be included to the extent appropriate and feasible. We initially mapped the locations of four notable species but the availability of comprehensive, quality data was limited so the final maps and portfolios do not include these species. This is an area that needs further study.

Extended Project Boundaries for Seafloor Habitats and Seafloor Complexity

The EMUs and structurally complex areas were identified for Block Island Sound and the Peconic Estuary in addition to Long Island Sound because of the benefits of seeing the connection of the Sound to these important adjacent areas. The data were also sufficiently consistent and complete enough to allow depiction of this larger geography. The landward extent associated with these areas is generally the coastal tide line.

Data Limitations

As noted in Chapter 6 and in more detail in Chapter 8, a major limitation of the trawl survey data was that they did not cover significant portions of the study area. Although the trawl data are extensive in time and geography, they are relatively sparse in the western and eastern ends of the Sound and immediately along the coast where consistent sampling is impossible. Generally the coastal limits of the trawl survey work occurred in 5 meters of depth or deeper. This means the species persistence results, while strong for the areas sampled, need to be considered in comparison to the areas sampled rather than uniformly for the Sound as a whole. For example, near shore marine life or those in embayments are not captured. There were also significant limitations in the benthic grab data because of inconsistent sampling gear, geographic extent, and sampling time period. As noted above, however, we did include an analysis for seafloor complexity that allowed us to portray a more comprehensive picture of ecologically notable places, albeit through a different methodology than used with the trawl survey data.

Depicting Ecologically Notable Places through Portfolios

The next basic step was to re-group these ecologically notable places into those associated with the seafloor (the *seafloor portfolio*) and those associated with the water column (the *water column portfolio*). Finally, to look at how the ecologically notable places come together for the Sound as a whole, the seafloor and water column portfolios were combined into an overall *integrated portfolio*.

Seafloor Portfolio

The ecologically notable places contributing to the seafloor portfolio included: seafloor complexity (hard bottoms and complex bottom bathymetry combined with areas of notable EMU richness), demersal (bottom) fish persistent areas, invertebrate persistent areas and seagrass beds.

Water Column Portfolio

The ecologically notable places in the water column included: pelagic and diadromous fish persistent areas.

Integrated Portfolio

By combining the seafloor and water column portfolios into the integrated portfolio, one set of ecologically notable places is presented. This can be considered the culmination or summary result of the LISEA. See the Ecologically Notable Places (Integrated Portfolio) map in Figure 7.14.

Ecological Importance of all Areas

The LISEA provides insight into ecologically notable places from the methods and data used. It is critical however, that this not be interpreted to suggest that other areas shown on the maps do not have ecological value. In general, all parts of the Sound are ecologically important depending on what is being considered. The Sound is a complex ecosystem with multiple habitats and ecological processes, each of which play a role in the Sound's overall ecological integrity.

Ecologically Notable Places: Detailed Descriptions

To facilitate greater insight into what the ENP actually look like on the seafloor or in the water column, we form a descriptive picture for each of the grid cells where ENP are located. An example is provided in Chapter 7. The full set of descriptions, based on the underlying data, is in Appendix D, to be completed after this report is finished.

Shellfish are an important part in the Long Island Sound Ecosystem.
Credit: Carl Lobue © The Nature Conservancy

section 4

conservation purpose

The ultimate goal of LISEA is to support the conservation of ecologically and biologically significant resources in Long Island Sound, particularly those associated with the sea floor and within the water column. An additional goal of LISEA is to contribute to the growing body of methods and approaches for identifying ecologically significant resources within coastal estuaries.

Beyond these broad goals, the assessment is intended to serve multiple conservation-related interests such as potential coastal and marine spatial planning for the Sound or The Nature Conservancy's conservation and restoration efforts. Another potential use for LISEA would be coordinating it with the Cable Fund Seafloor Mapping Project mentioned above. Examination of the correlation between ENP in LISEA with up to date field data from the Seafloor Mapping Project may reveal valuable insights and is just one example of the potential value of connecting these two assessments.

Potential conservation uses for LISEA are covered in detail in Appendix C – Report Applications.

Top: A Conservancy volunteer examines a clam while collecting eelgrass. Credit: Mark Godfrey © The Nature Conservancy

Above: The NOAA research vessel Thomas Jefferson is participating in the Seafloor Mapping Project. Credit: NOAA

section 5

seafloor habitats Long Island Sound

Introduction

In this chapter we describe and map the physical habitats of the Long Island Sound seafloor and provide the basis for identifying notable areas with respect to those habitats in Chapter 7. We used information on the distribution of benthic organisms and their relationships to the Sound's depth, sediment types, and seafloor topography to delimit a distinct set of environments representing the variety of benthic habitats in the Sound. By mapping various physical factors with thresholds informed by the distributions of biota we created a map of physical habitats likely to correspond to distinctive sets of organisms and communities for the entire sound. We hope that this seafloor map of Long Island Sound, Block Island Sound and the Peconic Estuary, will provide guidance in conservation decisions by providing an understanding of the abundance and distribution of seafloor habitat types.

Benthic organisms live in or on the sea floor and their distributions and life histories are tied to their physical environment. Filter feeders tend to dominate on more sandy bottoms while deposit feeders may dominate in fine-grained mud. Based on available benthic grab data the Sound is home to over 545 benthic species including at least:

- 111 species of arthropods
  (crabs, lobsters, shrimp, barnacles)
- 80 species of mollusks
  (clams, scallops, squid, limpets, sea slugs, snails)
- 147 species of annelids
  (sea worms)
- 12 species of echinoderms
  (sea stars, sea urchins, sea cucumbers, sand dollars)
- 4 species of cnidarians
  (corals, anemones, jellyfish)

We emphasize that this is an initial effort to define and map benthic features Sound-wide, and builds on the methods developed in the Nature Conservancy's Northwest Atlantic Marine assessment (Anderson et al. 2010). It was only possible due to the generous contributions of data and expertise from many scientists working in the Sound. Accuracy assessment, cross-validation using independent datasets, and final expert peer review are ongoing as part of the Nature Conservancy's Long Island Sound Program.

Definition of Habitats and Ecological Marine Units

To identify seafloor habitats, we developed Ecological Marine Units (EMU). An EMU is a seafloor habitat consisting of a specific combination of depth, sediment type and seabed form: for example, deep-water silt flats, shallow gravel banks, or mid-water sand slopes. We mapped EMUs comprehensively across the full study area in order to understand the types of physical habitats and their distribution. In addition, we used the EMUs to identify ecologically notable areas of the Sound, which are covered in more detail in Chapter 7. In this chapter, we focus on the EMU and the distribution of distinct seafloor habitats in Long Island Sound.

In brief, we developed individual maps of bathymetry, sediment types, and seabed forms, and then integrated them into a single map using thresholds derived from analysis of the distributions of the benthic organisms. Because these thresholds were informed by the distribution of hundreds of benthic organisms, the delineation of the EMUs and associated map conveys a large amount of information about the structure and ecology of the seafloor.

Due to the limitations of available datasets we were not able to produce a map of the individual benthic communities. However, because organism data were used to create the EMU thresholds, the EMU map may be used as a rough approximation of benthic community distributions. A benthic community refers to a group of organisms repeatedly found together within a specific environmental setting. Typically, a benthic community is broader than a single EMU: for example, a group of organisms may always be below a certain depth and within a certain substrate, but might occur across several seabed forms such as flats, depressions, and slopes. In such a case the community occurs on three EMUs. Ultimately, conservation of these habitats is necessary to protect the full diversity of species that inhabit the seafloor, and to maintain the ecosystem functions of benthic communities.

Background

The challenge of mapping seafloor habitats has produced an extensive body of research (Kostylev et al. 2001; Green et al. 2005; Auster 2006; World Wildlife Fund 2006; Todd and Greene 2008, Anderson et al. 2010). In addition, a comprehensive seafloor classification scheme has been proposed by Auster and others for Long Island Sound (Auster et al. 2009) and compared with previous schemes by Greene et al. 1999 and Valentine et al. 2005. Additionally, Madden has proposed a general scheme that is being adopted by several agencies (Madden et al. 2009). The approach used for this LISEA built on these existing schemes both explicitly and implicitly, and results can be readily compared to them. Our goal, however, was not to create a new classification system for the Sound, but to produce a map of consistently defined physical habitats that were relevant to the biological communities.

We reviewed a variety of mapping approaches already established in order to develop the methodology used here. Most existing frameworks are based on physical factors such as bathymetry, sediment grain size, sediment texture, salinity, bottom temperature, and topographic features. The frameworks are based on evidence, for example, that substrate type is correlated with community composition and abundance of both the invertebrates and demersal fish (Auster et al. 2001; Stevenson et al. 2004); habitat complexity is correlated with species composition, diversity, and richness (Etter and Grassle 1992; Kostylev et al. 2001; Serrano and Preciado 2007, reviews in Levin et al. 2001); and depth is correlated with abundance, richness, and community composition (Stevenson et al. 2004).

Auster's classification scheme for Long Island Sound includes seascape unit, depth, large-scale seafloor morphology, sediment type, small-scale seafloor morphology and modifiers to describe specific units (Figure 5.1). The EMU model may be helpful in mapping Auster's classification in the Sound as both use depth and sediment size directly. The seabed forms aggregate to form larger scale features such as ledges, ridges, channels and sandbars.

This assessment builds upon this body of knowledge to inform our understanding of the spatial distribution of benthic habitats in Long Island Sound. By using data that represent the physical factors that are known to drive species distributions and incorporating biological data to guide the mapping process, we endeavor to create a robust and meaningful set of maps which spatially synthesize all the available information.

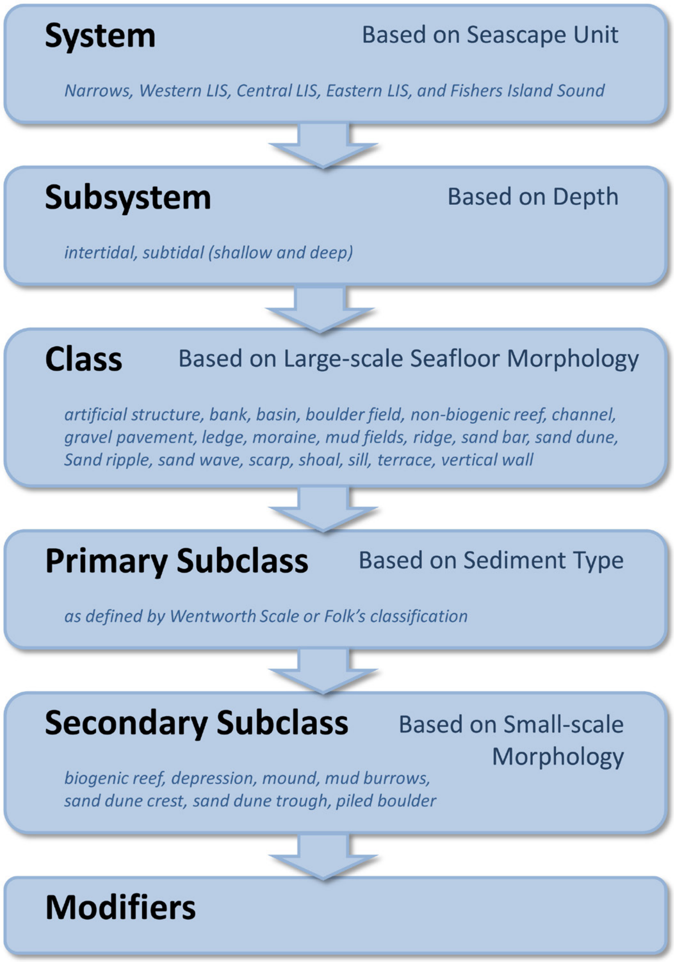


Figure 5.1. Proposed habitat classification scheme for the Long Island Sound region published in Auster, P.J., K.B. Heinonen, C. Witharana and M. McKee. 2009.

Methods

This section details how the ecological marine units were created. It includes sections on:

- Ecological Marine Unit (EMU) Components
- Organism data and analysis methods
- Bathymetry data and processing methods
- Sediment data and interpolation methods
- Hard bottom data
- Creation of the seabed forms
- Modeling of hard bottom habitats
- Simplifying the data for visualization

For readers who are primarily interested in the results we suggest you look at the individual maps of each component and study the section addressing the final EMU map.

Ecological Marine Unit (EMU) Components

To characterize the Sound and understand how the benthic community distributions are related to the physical structure of the sea floor, a spatially comprehensive data layer for each of three components was developed: bathymetry, sediment grain size and topographic or seabed forms. These components were chosen because of their well-documented correlation with the distribution and abundance of benthic organisms. Data on each physical component were compiled from separate sources and the techniques used to create a comprehensive map are discussed below. The role that the observed distribution of benthic organisms play in further defining and refining the EMU map and the associated methods are also discussed below.

Organism classification

The EMU map of physical habitats is based directly on the distribution and abundance of benthic organisms in Long Island Sound. We analyzed the distribution of species groups using benthic data (appendix A) throughout the LISEA study area and used their relationship or correlation to depth and sediment grain size to determine which depths and sediment grain sizes to use in distinguishing one EMU from another. These thresholds are also what are shown on the EMU map. A threshold, as referred to here, is a break in a continuous variable (e.g. depth or grain size) that corresponds with a change in the organism composition.

Knowledge of the species and their distributions comes from over 1,000 seafloor samples described in further detail in Appendix A – Detailed Methodologies. Groups of species with shared distribution patterns were identified, then thresholds in the physical factors were identified that correlated with changes in the community types. Specifically, we first analyzed the grab samples to identify distinct and reoccurring assemblages of benthic organisms. Second, we used recursive partitioning to relate the species assemblages to physical components of bathymetry, sediment types, and seabed forms. Third, we identified specific organism thresholds related to depth and sediment grain size. We emphasize that organism distributions were used to identify meaningful thresholds in the physical variables and that the final habitat maps of enduring physical factors reflect these thresholds. Thus, the EMU map is closely related to the physical classification schemes proposed by others and reviewed above.

To learn more about the 1,958 samples of abundance and biomass data and how they were utilized, see Appendix A – Detailed Methodologies.

Identifying thresholds for depth and sediment grain size

This section describes the creation of ecologically meaningful thresholds for the depth and sediment grain size components of the EMU. To visualize this, for example, the annelids *Exogone verugera*, and *Glycera robusta*, were common at depths below 35 meters, but uncommon in shallower water, whereas the annelid *Eunoe oerstedí* showed the reverse pattern. When we grouped all the organisms into community types and looked at all the communities at once, we found that the 35 meter threshold was a good separator for many communities. We recognized 35 meters as a depth threshold, and we used this method to determine other thresholds for depth and sediment grain size. The resulting EMUs each have a precise definition determined by the thresholds. For instance, a "deep-water flat in fine-sand" is defined as an area of < 1 degree slope, in sediments between 0.18 and 0.20 mm grain size, and water deeper than 35 meters. By mapping all the areas that meet these criteria we can see the extent of this habitat in the Sound, and we expect that many of these areas are likely habitats for *Exogone verugera* and other members of its benthic community.

By grouping all the organisms into community types and then examining thresholds that separated the communities as described above we are able to establish precise definitions or distinctions for the EMUs. For instance, "deep-water" is defined as deeper than 35 meters, and "fine-sand" is defined as sediments between 0.18 and 0.20 mm grain size. This means that the thresholds that were determined from the biological data will correspond to the EMU boundaries on the map. Changes in species composition dictated that some habitats span multiple EMU types while there are also micro-habitats embedded within the EMU types.

To determine the thresholds, each of the 1,321 benthic grab samples were assigned to a community type based on species composition, overlaid on the standardized base maps, and attributed with associated depth, sediment grain size and seabed form. We used recursive partitioning (JMP software package) to determine the thresholds within each variable that best separated the communities from each other. Recursive partitioning is a statistical method that creates decision trees to classify members of a common population (the classification types) based on a set of dependent variables (the physical variables). The analysis repeatedly partitions the dataset as cleanly as possible using the variables provided. For example, depth 1 separates communities A, B, and C from communities D and E. Depth 2 separates communities A and B from community C. Depth 3 separates A from B and so on. These partitions are identified by exhaustively searching all possible partitions and choosing the one that best separates the dataset into non-overlapping subsets. The progressions are called regression trees, and we constructed these using all samples and the variables of depth and sediment grain size.

After examining the variable contributions collectively, individual regression trees were built for depth (bathymetry) and grain size. To identify robust thresholds, we repeated the process individually for each of the three main data sources: 1) National Marine Fisheries Service (NMFS) benthic survey samples for Long Island Sound and Block Island Sound; 2) samples for Long Island Sound collected by Pelligrino and Hubbard (1983); and 3) samples for the Peconic Estuary provided by Cerrato and Maher (2007), Cerrato et al. (2009), and Cerrato et al. (2010). We identified common thresholds across the three sources. The following sections show how these thresholds were used to create the final EMU data and maps. Although the data sources were typically different in space, time, coverage and/or methods, they exhibited common points where changes in depth or sediment type was correlated with changes in benthic community type. Because of this commonality across the data sources, we were sufficiently confident in developing the thresholds.

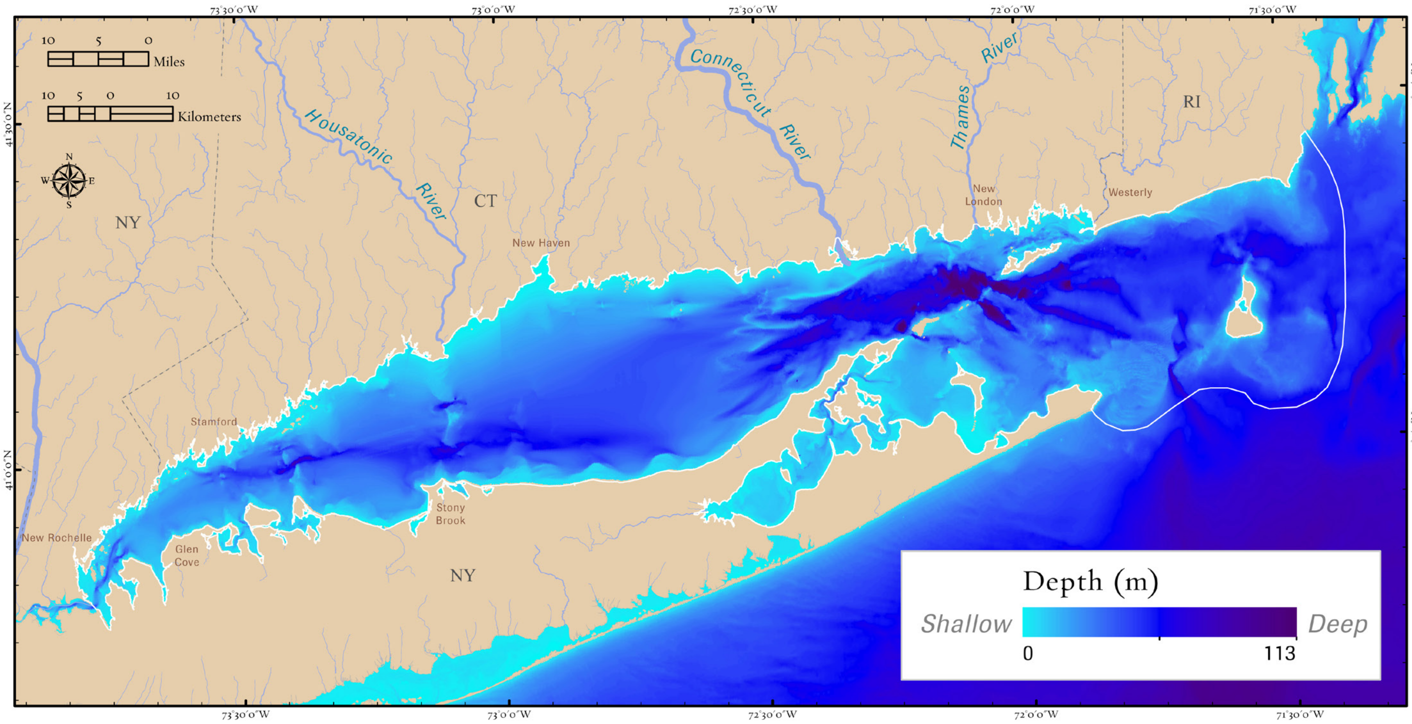


Figure 5.2. Bathymetry of Long Island Sound.

Data Sources	Depth Thresholds (m)							
P&H[i]			14.8			29		
P&H[i] (single)			14.8	17.9	22.2	28		
NMFS[ii]		12.1	13.3			29	34	
NMFS[ii] (single)		12	14		23	29	34	36
Cerrato[iii]	(2,5,9)							
Cerrato[iii] (single)	5	12	15					
All-262 (P&N)			14			27		35
All-262 (Cerrato[iii])								
all sources			14	16				
Average[iv]	5.00	12.03	14.27	16.95	22.60	28.40	34.00	35.50
# of Sources	1	2	5	2	2	3	1	2
decision	**5**		**14**			**28**		**35**

Table 5.1. Depth thresholds from compiled sources of benthic organisms.

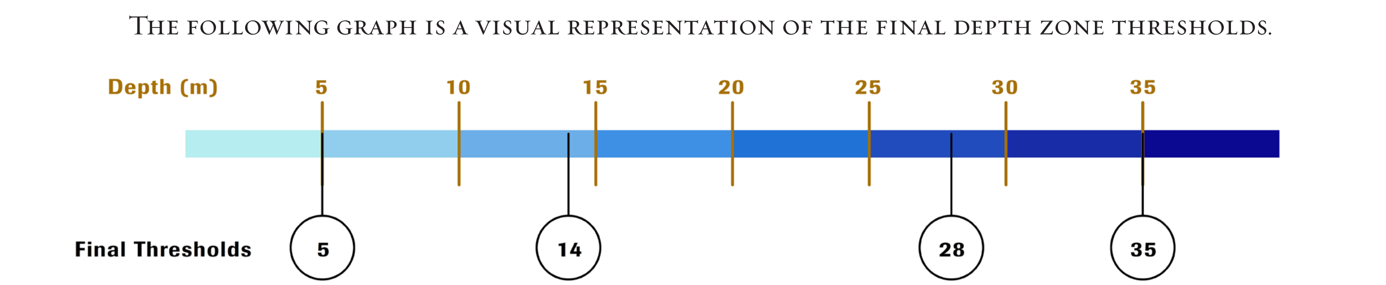
i P&H refers to the Long Island Sound samples collected by Pelligrino & Hubbard (1983).
ii NMFS refers to the compilation of Long Island Sound and Block Island Sound samples provided by the National Marine Fisheries Service.
iii Cerrato refers to the Peconic Estuary samples provided by Cerrato and Maher (2007), Cerrato et al. (2009), and Cerrato et al. (2010).
iv Average includes the results from each individual data set as well as the results from the combined datasets.

Bathymetry

A comprehensive bathymetry grid was created to characterize depths across the region (Figure 5.2), to uncover organisms' depth preferences, and to create seabed forms. The primary dataset used for mapping bathymetry was the National Geophysical Data Center's Coastal Relief Model (CRM). The CRM is a gridded bathymetric surface generated from soundings of the continental shelf and slope. The soundings are from hydrographic surveys completed between 1851 and 1965 and from survey data acquired digitally on National Ocean Service (NOS) survey vessels since 1965. Both are stored in the NOS Hydrographic Database. These are the same data sources used for the NAMERA and were deemed sufficiently current and accurate for the purposes of this assessment. The CRM was prepared in a GIS format with an 82^{m2} cell size.

These data created a continuous surface (Figure 5.2) that we then needed to simplify into meaningful categories. The thresholds identified in the section above were analyzed to determine a consensus of values (Table 5.1) to apply to the final bathymetry component of the EMUs. These consensus values were averaged to create the category breaks that were used to simplify the map into five depth zones (Figure 5.4). These zones became the depth component of the EMU map. These thresholds were: 5

Figure 5.3. Depth threshold distribution across data sources.



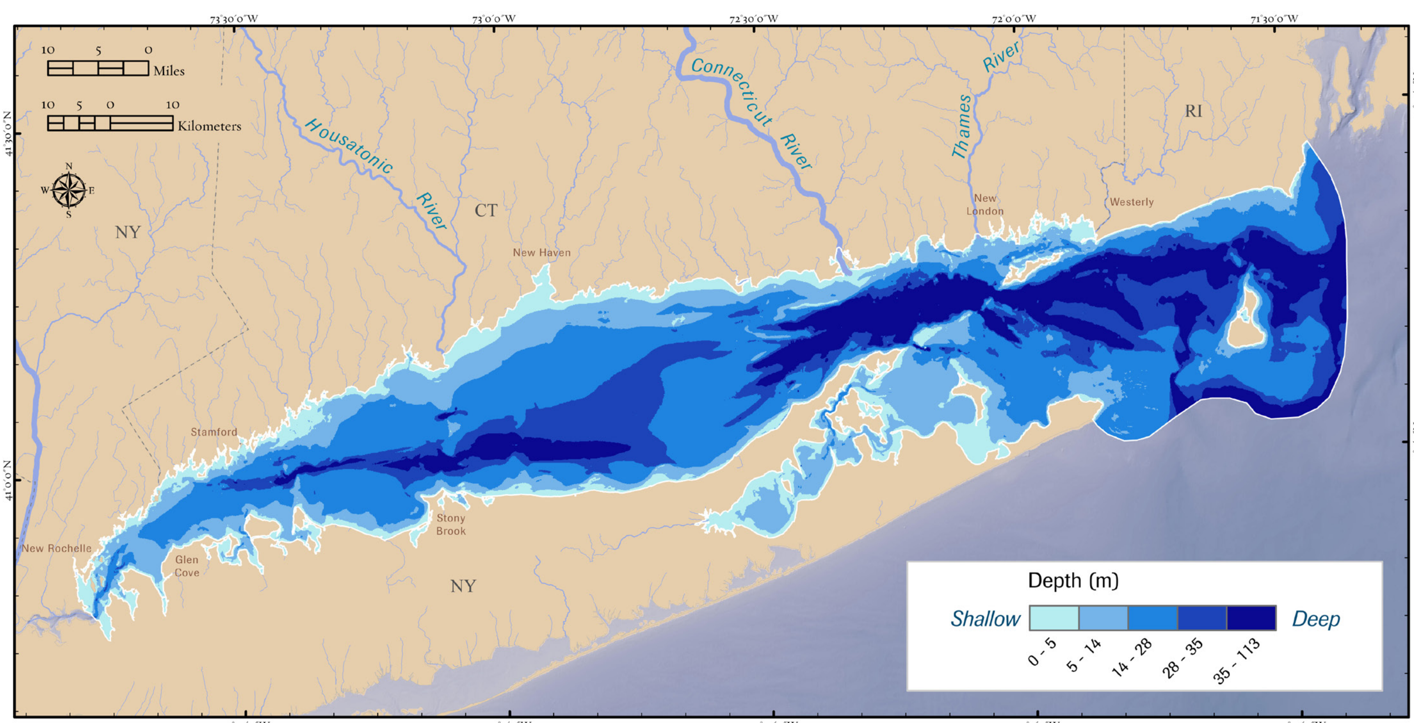


Figure 5.4. Bathymetry with depth thresholds.

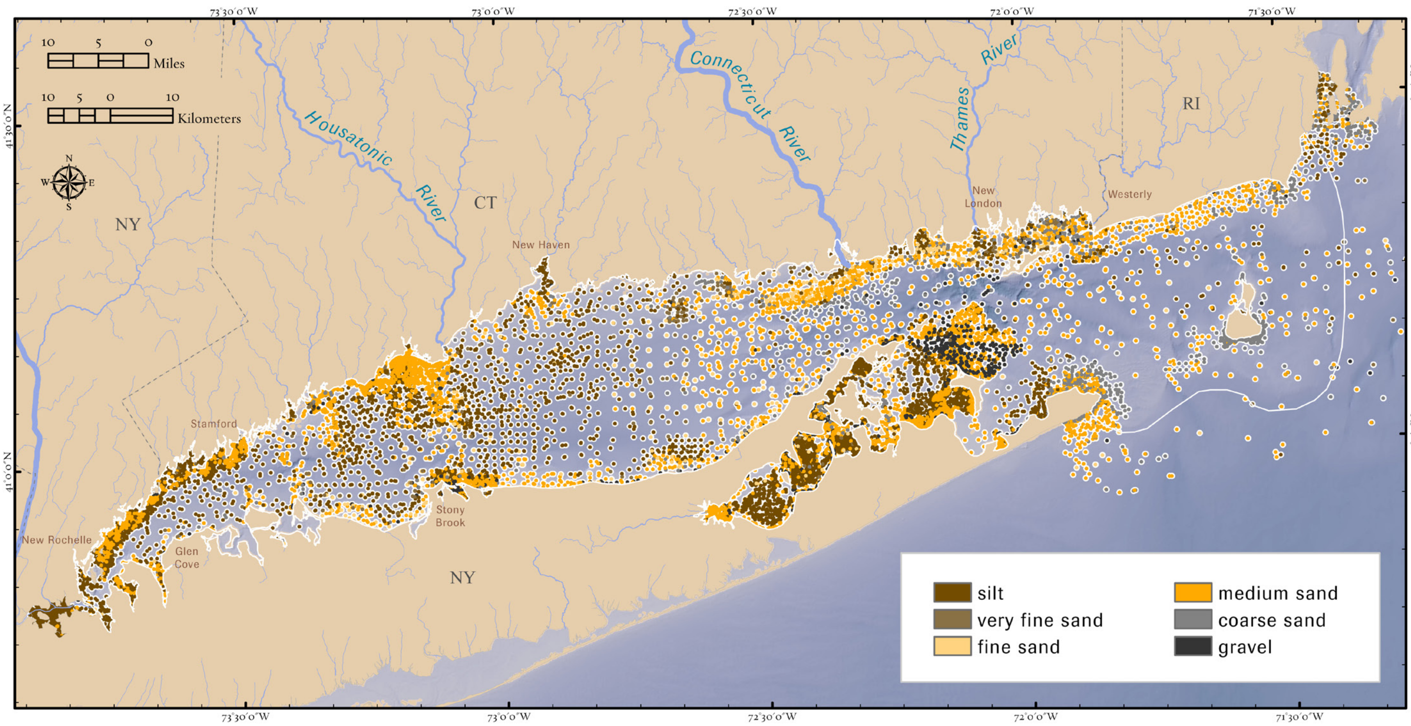


Figure 5.5. Distribution and grain type of the 14,691 sediment points.

meters, 14 (13-15) meters, 28 (27-29) meters, and 35 (35-36) meters (Figure 5.3). As noted in the previous section, these distinctions are generally correlated with changes in the distribution of benthic organisms.

Soft sediments

The various types of sediments found on the seafloor–mud, silt, sand, gravel – support a variety of species adapted to the particular characteristics of the substrates. For example, filter feeders like sponges and mussels dominate on shallow sandy bottoms while deposit feeders like polychaete worms dominate more fine-grained silts and muds where they consume detritus. However, many benthic species appear to prefer certain substrates while tolerating others, so the link between substrate and organism is not absolute.

To create a spatially complete map of sediment types we interpolated the best available point data. Interpolation is a method of creating continuous surfaces from non-continuous data – in this case a sediment map for the entire study area based on 14,691 individual sample points described below. Interpolation enables us to estimate the sediment type at locations where there are no sample data. The method we used, known as kriging, uses information from the surrounding points to estimate values for unknown areas, and generates corresponding spatially-explicit uncertainty estimates. Prior to interpolating the sediment points, we discarded points with no usable information and corrected biases in the qualitatively derived grain size estimates using methods developed by Goff et al. (2008) and using a regression equation derived from the Long Island Sound sediment data. This method allowed us to assign grain size values to the many samples that were derived from visual techniques that don't offer a direct measurement of grain size (such as usSEABED parsed data).

Substrate data for the entire study area were obtained from three sources: 1) Long Island Sound Surficial Sediment Data (Poppe et al. 2004); 2) usSEABED, a regional system that brings assorted numeric and descriptive sediment data together in a unified database (Reid et al. 2005); and 3) Stony Brook University "Benthic Mapping and Habitat Classification in the Peconic Estuary" (Cerrato and Maher 2007; Cerrato et al. 2009; Cerrato et al.

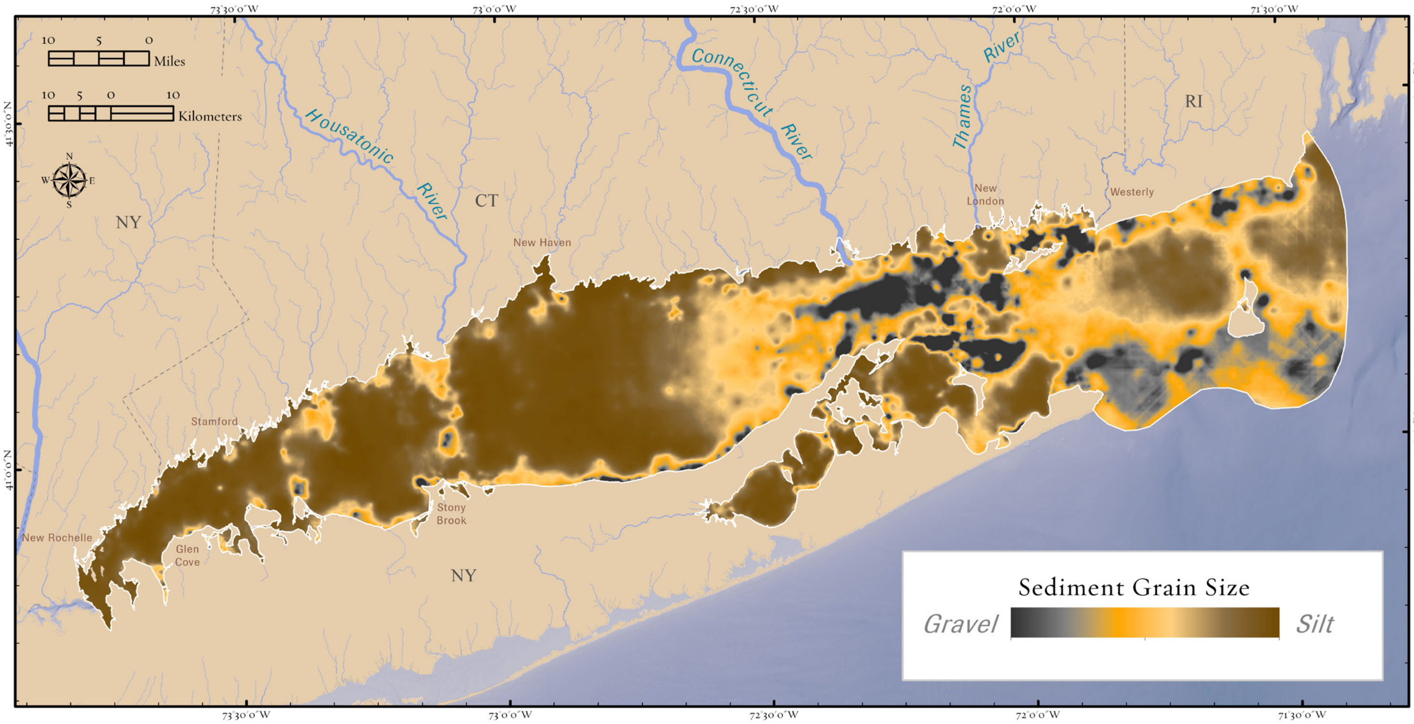


Figure 5.6. Interpolated map of soft sediments in Long Island Sound.

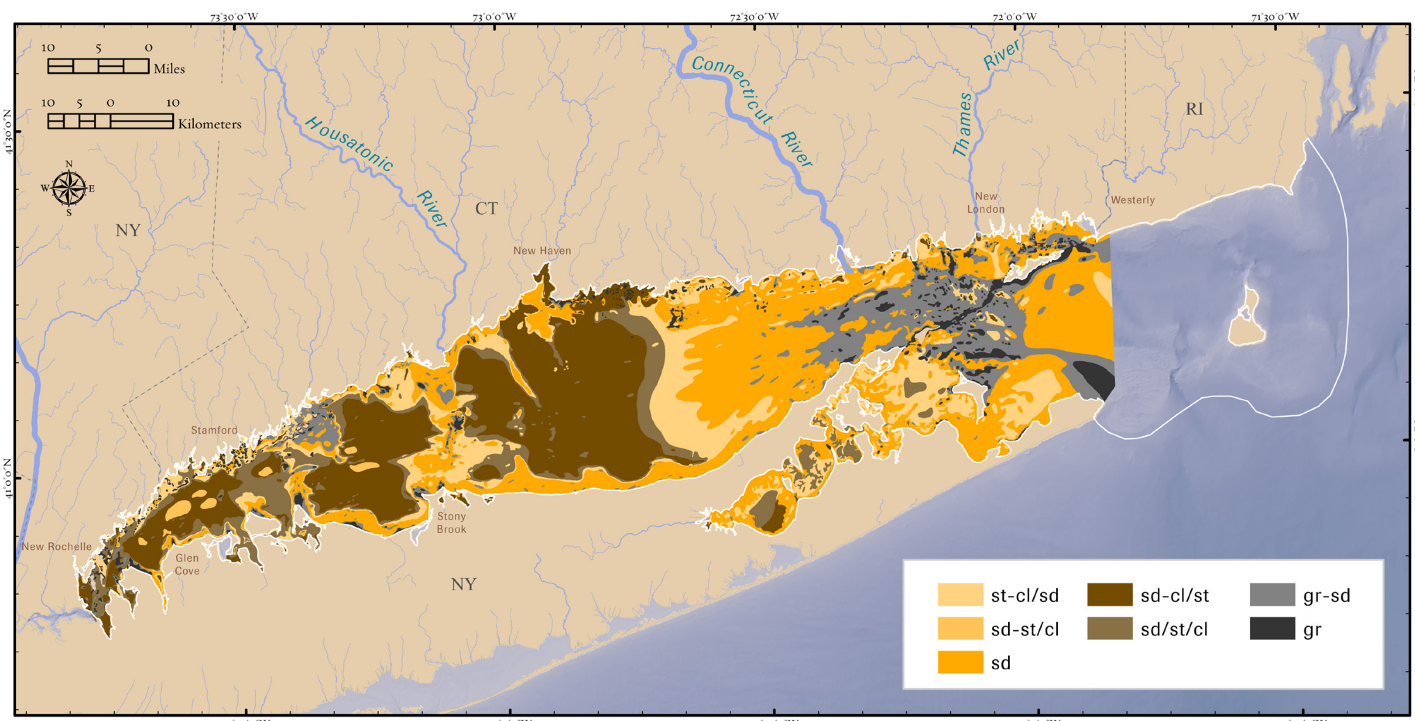


Figure 5.7. USGS sediment map.

2010). We compiled all 14,691 sediment points into a single set with common attributes including spatially-explicit information on texture, grain size, and compositional characteristic. For samples that only contained a qualitative description of the grain size (e.g. "fine sand" or "silt") we estimated the average grain size for the sample as the mean grain size of all samples with the corresponding qualitative description.

It is worth noting that not all sediment samples were evenly distributed within the study area (Figure 5.5). There were high densities of samples in the Peconic Estuary, and along the Connecticut Coast particularly around New London and west of the Housatonic River; deeper and central parts of the Sound tended to be more sparsely sampled.

Sediment samples often include a mix of mud, silt, and sand fractions, but the mean grain size has been found to be an appropriate value for interpolation (Reid et al. 2005). Using mean grain size as our attribute of interest, we interpolated the sediment points into a continuous gridded surface following methods described in Anderson et al. 2010 and expanded by Poti et al. 2011.

Refer to Appendix A for further detail on the technical aspects of the interpolation and to view the semivariogram of the data . The results of the interpolations produced a spatially complete map of average sediment grain size for the entire Sound (Figure 5.6). The sediment data reveal that the western half of the sound is dominated by mud, silts and fine sand, while the eastern half is largely coarse sand and gravel. The patterns shown correspond strongly with those of a previously released and well recognized map of the Sound (Poppe et al. 2000) that used a slightly different methodology (Figure 5.7). Our interpolated surface allowed us to create categories based on the organism classification described above and had the advantage of covering the entire study area (Long Island Sound, the Peconic Estuary and Block Island Sound). We changed the colors of the USGS map to better match the colors used in the LISEA map for comparison purposes.

As with the bathymetry, these data created a continuous surface (Figure 5.6) that we then needed to simplify into meaningful categories. The thresholds identified in the benthic organism section above were analyzed to determine a consensus of values to apply to the final sediment component of the EMUs.

	Sediment Thresholds (mm)							
Data Sources								
P&H[i]		0.07		0.13			0.29	
P&H[i] (single)		0.06		0.13			0.29	
NMFS[ii]		0.08	0.1		0.19	0.23		
NMFS[ii] (single)		0.08	0.11		0.21	0.23		
Cerrato[iii]	0.04		0.1	0.14		0.24		0.33
Cerrato[iii] (single)	0.04	0.08		0.14	0.2			0.35
All-262 (P&N)		0.08		0.14		0.22		
All-262(Cerrato[iii])		0.08			0.2			
all sources		0.08				0.22		
Average[iv]	0.04	0.08	0.10	0.14	0.20	0.23	0.29	0.34
# of Sources	1	5	2	3	3	4	1	1
Decision		**0.08**		**0.14**		**0.23**		

Table 5.2. Sediment thresholds from compiled sources of benthic organisms.

i P&H refers to the Long Island Sound samples collected by Pelligrino & Hubbard (1983).
ii NMFS refers to the compilation of Long Island Sound and Block Island Sound samples provided by the National Marine Fisheries Service.
iii Cerrato refers to the Peconic Estuary samples provided by Cerrato and Maher (2007), Cerrato et al. (2009), and Cerrato et al. (2010).
iv Average includes the results from each individual data set as well as the results from the combined datasets.

The following graph is a visual representation of the final sediment grain size thresholds.

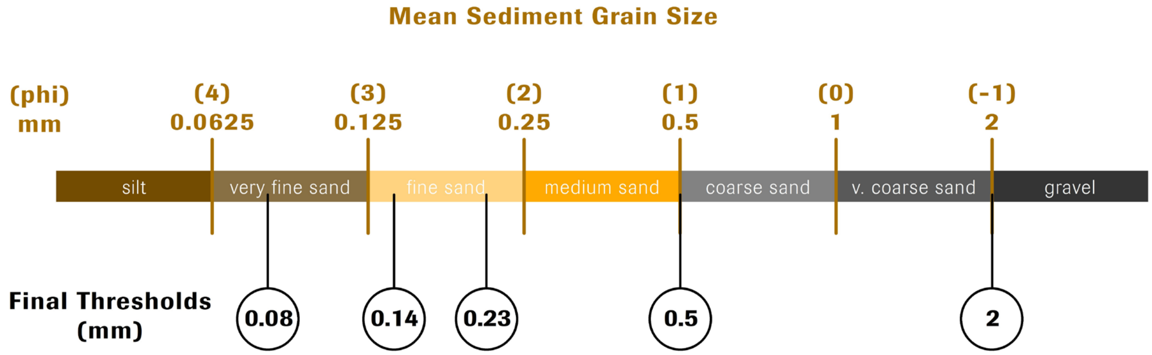


Figure 5.8. Sediment threshold distribution across data sources.

These consensus values were averaged to create category breaks that were used to simplify the map into six zones. These zones became the sediment grain size component of the EMU map. The thresholds were: 0.08 mm, 0.14 mm, and 0.23 mm (Table 5.2).

We compared the sediment cutoffs with a standard Wentworth scale and simplified the scale to reflect the cutoffs most important to the separation of benthic communities (Table 5.3). The Wentworth scale is a sediment classification system based on particle size diameter and groups particles into size classes (e.g. fine sand, clay). The threshold of each class size is twice the previous. The following chart shows how standard sediment class breaks were modified by the organism results as described above. The thresholds were used to adjust the Wentworth class breaks to align with the biologically-relevant thresholds identified above (bold numbers). The resulting scale was then simplified further by removing the distinctions for very coarse sand and distinctions between gravel types. This 'Simplified Wentworth' scale becomes the sediment component of the Ecological Marine Units map described below (Figure 5.9).

Simplifying the data for visualization

The previous sections show how the depth and sediment thresholds were identified to define the classification breaks, creating 5 depth classes and 6 sediment grain size classes. These full data layers were combined with the seabed forms, described in detail later, to create the final EMU data layer. For visual clarity, a series of simplifications were applied to the data to create maps with fewer categories.

The first example of this simplification is the consolidation of the 6 sediment classes into 3. Silt remains the same and captures those primarily depositional environments that have accumulated the finest sediments. Very fine sand, fine sand and medium sand were combined to create a sand class representing moderate grain sizes. Coarse sand and gravel were combined to represent the coarsest sediments in the study area (Figure 5.10). These simplified data were used as

Wentworth (mm)		Modified Wentworth (mm)		Simplified Wentworth (mm)	
8	medium gravel	8	medium gravel		
4	fine gravel	4	fine gravel		
2	very fine gravel	2	very fine gravel	2	gravel
1	very coarse sand	1	very coarse sand		
0.5	coarse sand	0.5	coarse sand	0.5	coarse sand
0.25	medium sand	**0.23**	medium sand	0.23	medium sand
0.125	fine sand	**0.14**	fine sand	0.14	fine sand
0.0625	very fine sand	**0.08**	very fine sand	0.08	very fine sand
0.003	silt	0.003	silt	0.003	silt

Table 5.3. Comparison of the Wentworth and Simplified Wentworth scale. Bolded numbers in middle column show where we replaced the original cutoffs with the modified ones.

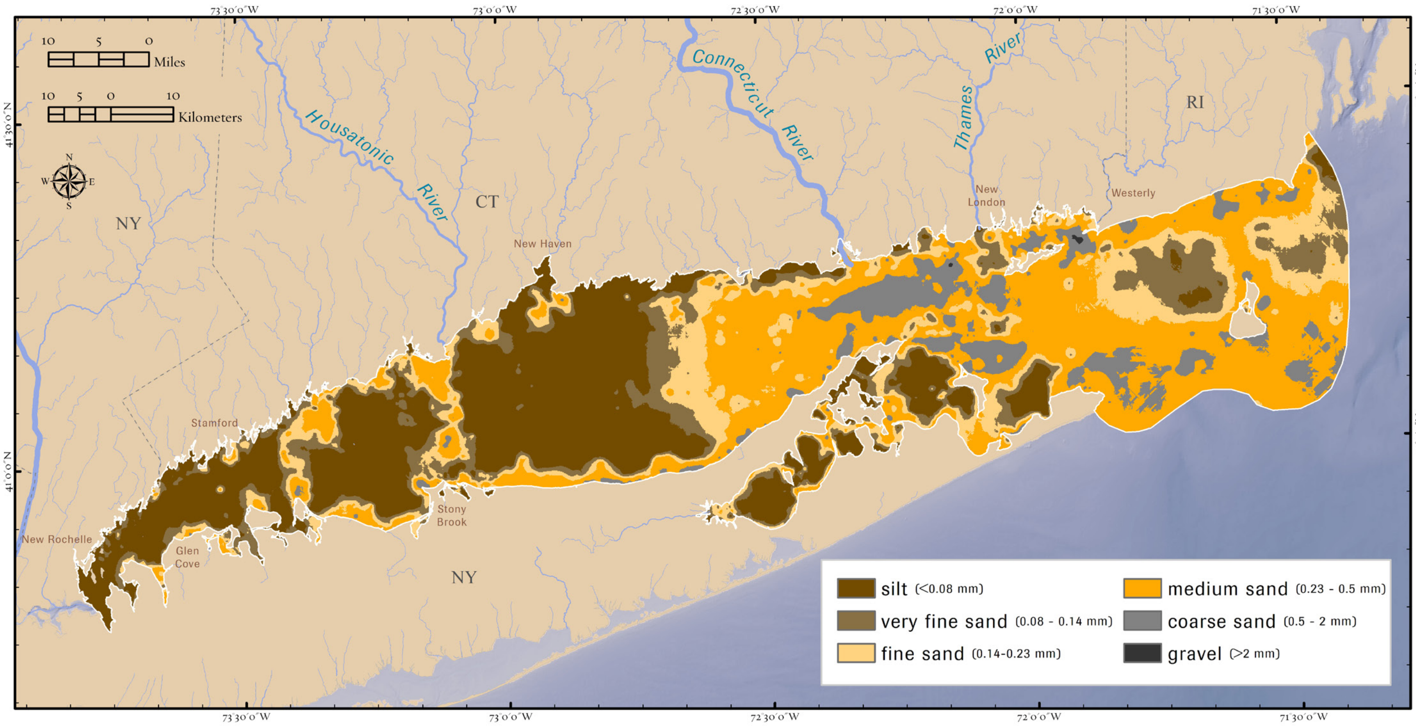


Figure 5.9. Sediment Grain Size with Simplified Wentworth thresholds.

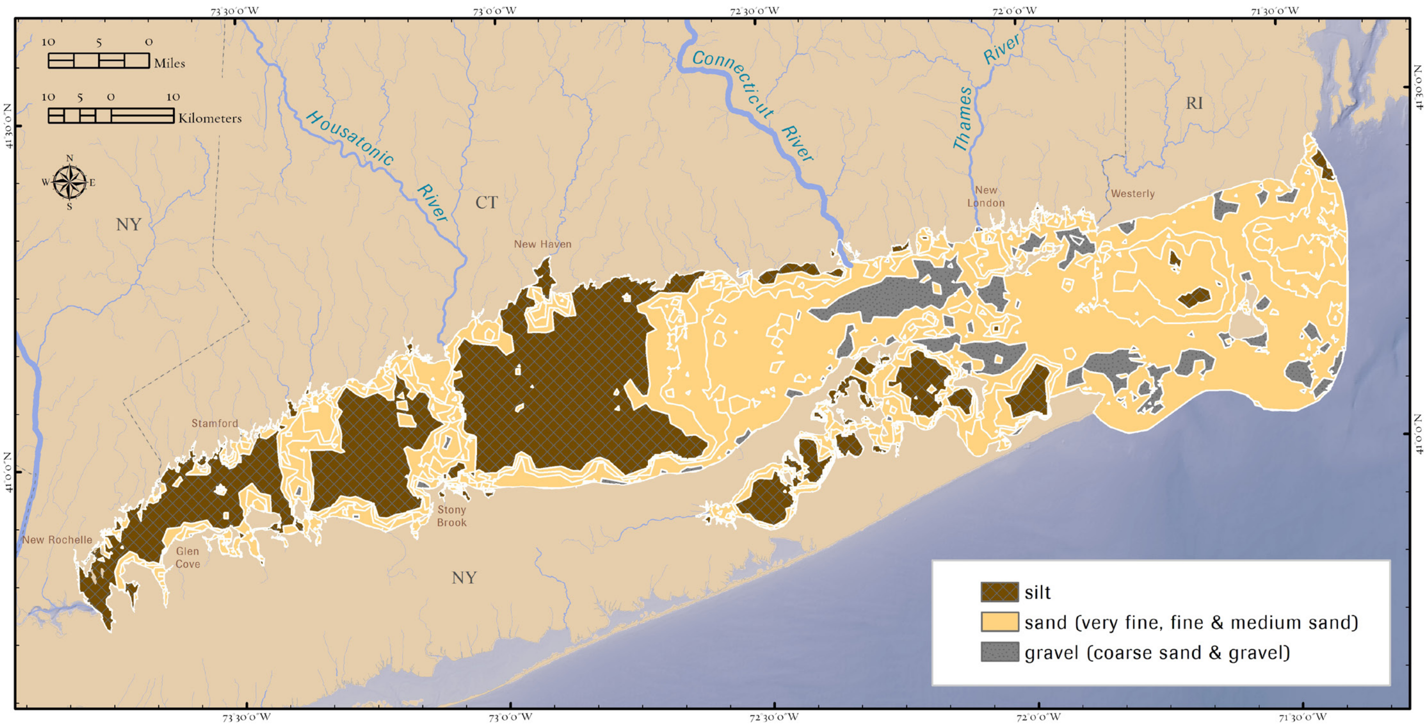


Figure 5.10. Sediment grain size class simplifications for EMU map visualization.

a visual overlay in the final EMU map, but the EMU data layer retains the full detail of the original source data.

Hard bottom

Hard bottom refers to areas of the Sound dominated by rocky substrate, boulder fields, and hard pavements (natural hard surfaces). These habitats may be colonized by marine invertebrates or support macroalgae, or they may be rock-gravel mixes that enhance the survival of juvenile fish. Although hard bottoms are known for their diversity, they are difficult to sample and are often underrepresented in studies of sea floor flora and fauna. A dataset of hard bottom point locations was extracted from sediment sample data that indicate where hard bottom has been located. These points were not used in the interpolation of soft sediments since they tend to represent the underlying bedrock or other non-erodible material upon which the soft sediments are deposited and usually do not have a meaningful grain size descriptor. In the hard bottom analysis, we identify the hard bottom points that emerge above the soft sediments.

We compiled data representing 4,158 known occurrences of hard bottom from the usSEABED, USGS East Coast Sediment Texture Database, and NOAA Nautical Chart ENC data. These were points described as: “bedrock”, “boulders”, “rock” or “rocky”. Because hard bottom patches can be small and there are likely many that aren’t mapped,

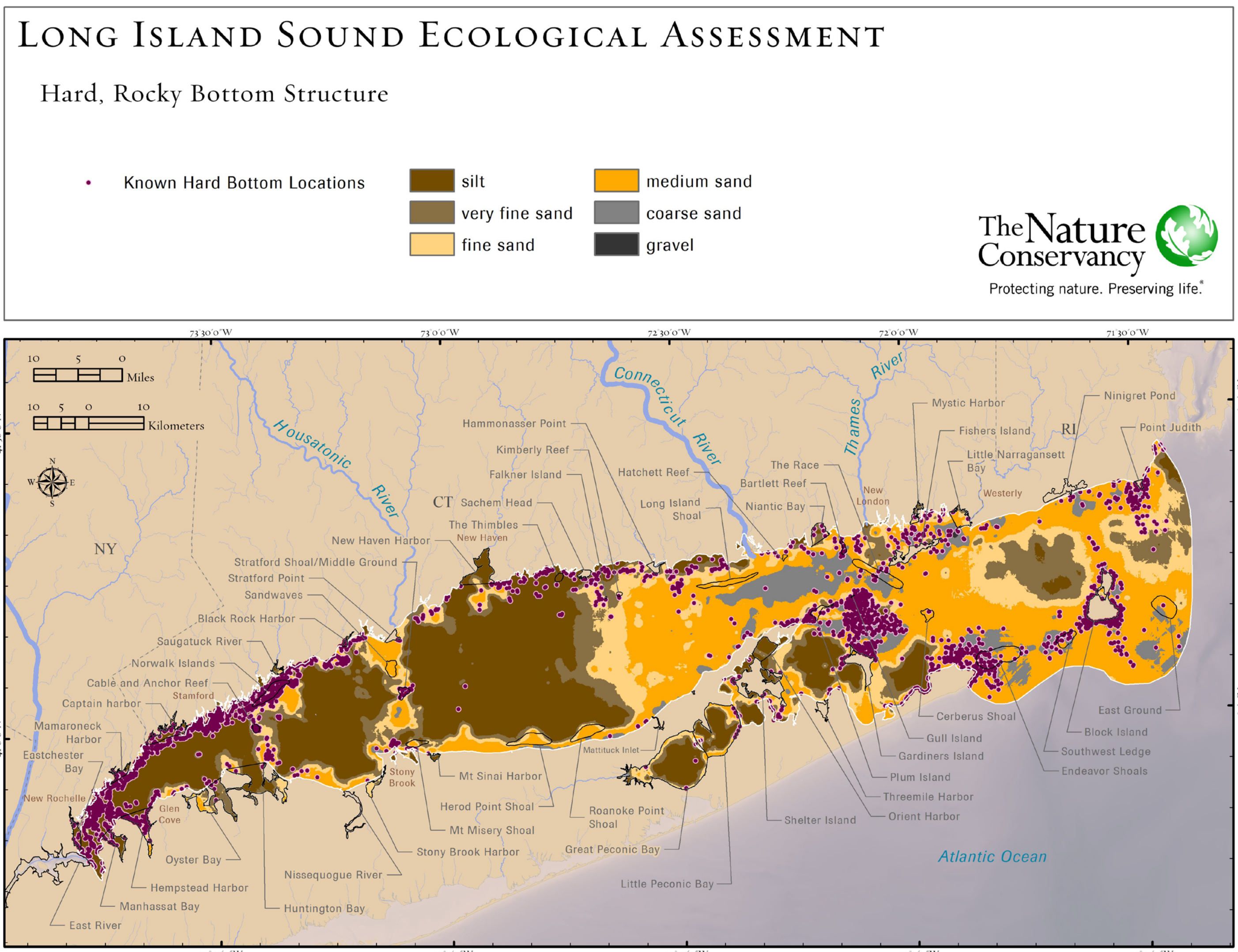


Figure 5.11. Soft sediment interpolation overlaid with known hard bottom locations.

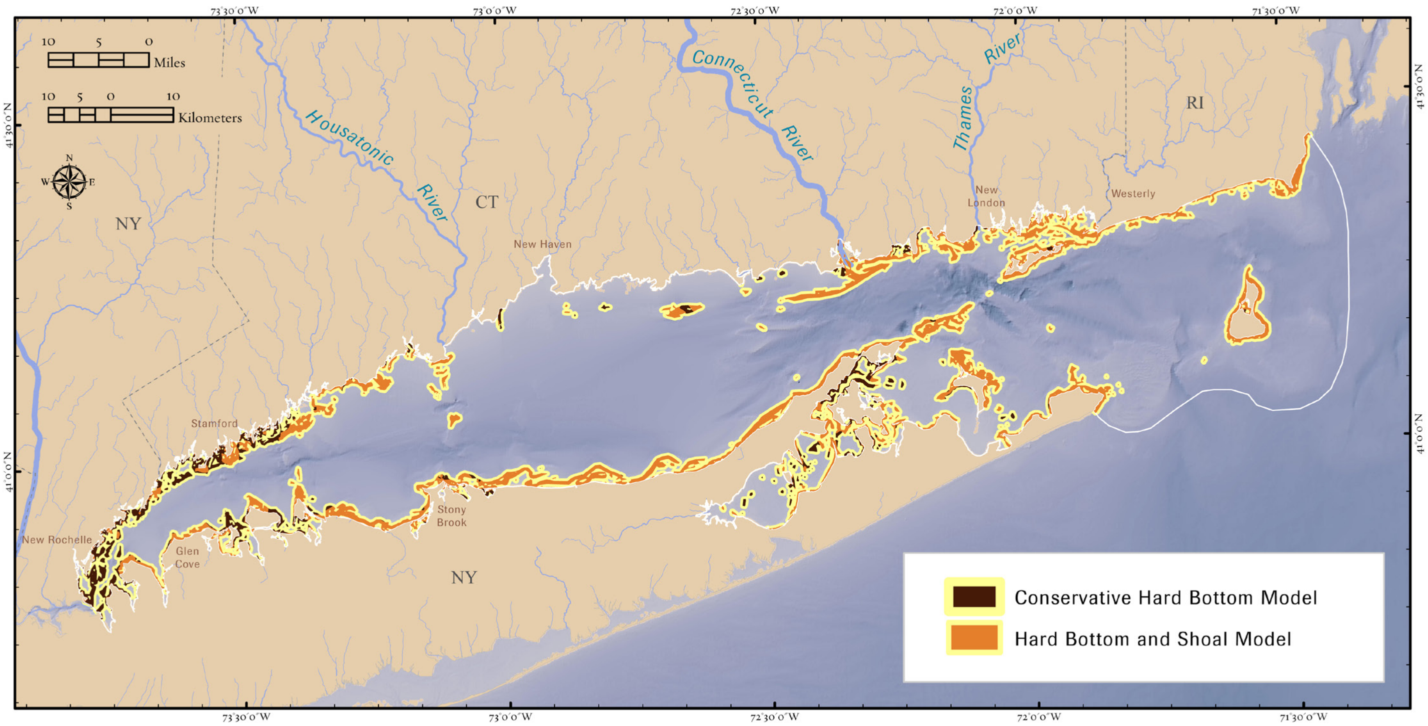


Figure 5.12. Hard bottom models.

we made an effort to create a predictive model to identify the likely occurrence of additional hard bottom habitat based on a number of available datasets. The following four variables had some predictive value and were ultimately used to create the predictive models: 1) depth (bathymetry); 2) LPI (raw landscape position index); 3) structural complexity (the standard deviation of slope within a 500 m radius); 4) interpolated sediment grain size. (For an explanation of LPI and structural complexity please see page 33 and page 76, respectively). No single combination of variables was able to capture most of the known locations while not including a significant area of known non-hard bottom areas. To address this, two predictive models were produced, each representing a different combination of variables (models): one that captures most of the known hard bottom locations, but includes non-hard bottom areas such as sandy shoals; and a second that captures very few non-hard bottom locations, but misses a good number of known hard bottom locations.

The first predictive model, known as the 'hard bottom and shoal model,' is defined as an area with depth less than 9.624 meters, structural complexity greater than 0.257, and LPI greater than 40.769. This model captures 89% known hard bottom versus 11% random locations. This model relies on depth and shape characteristics of the sea floor and captures many areas that are known to contain soft, sandy sediments, and not hard bottoms, but it does a good job capturing most known hard bottom locations.

The second predictive model, the 'conservative hard bottom model', is the same as the above model, but it is further limited to only those areas with sediment grain size less than 0.1157 mm. This model captures 94% known hard bottom versus 6% random locations. This model is much more restricted in area and excludes 1,200 known hard bottom locations, but does not include the non-hard bottom shoals and other features captured by the first model. (Though it seems counter intuitive to restrict the model to only small grain sizes, it should be noted that this decision emerged from the data and was not presupposed. In this case we are not making the claim that smaller grain size = likely hard bottom. We are saying that by removing areas with grain size larger than 0.1157 mm from the previous model, the results are purer, i.e. they do not contain many random points as compared to known hard bottom. This is

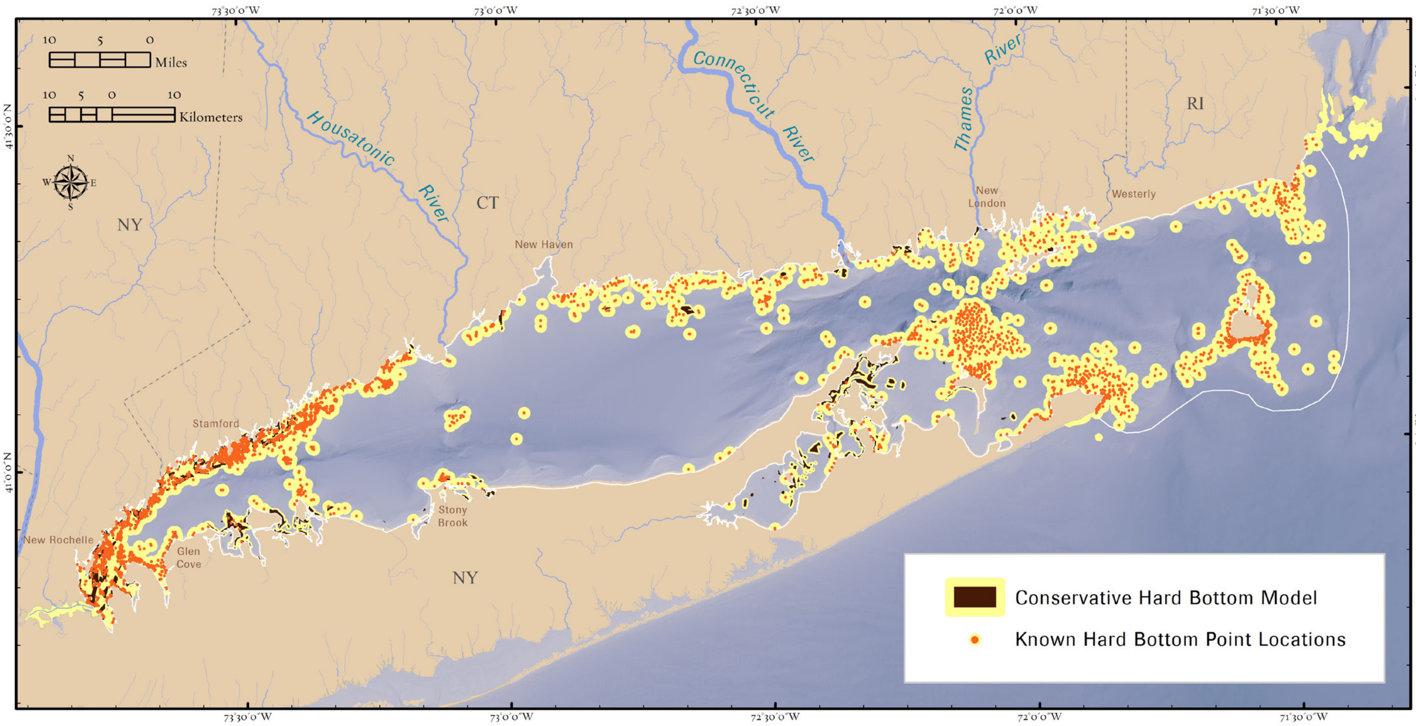


Figure 5.13. Final hard bottom component of the seafloor portfolio.

likely due to the removal of sand waves and other features that match the shape of hard bottom locations as defined in the first model). These two models are shown in Figure 5.12.

Since we have a higher confidence that the areas represented by the 'conservative hard bottom model' will contain hard bottom habitat, this model was used in the final seafloor portfolio. To create the final hard bottom map the model results were combined with known hard bottom locations from the sediment sample data noted above. To combine the points of the known hard bottom locations with the areas (polygons) of modeled hard bottom, the point locations needed to be mapped as areas as well. To achieve this, a kernel density was calculated from the known hard bottom point locations. This resulted in a map showing the relative density of known hard bottom locations throughout the study area. The regions with a density value one standard deviation over the mean and above were extracted. This created polygons representing concentrations of known hard bottom points. The resulting polygons were then combined with a 300 meter buffer of the conservative hard bottom model to create the final hard bottom map that represents both the model and known locations of hard bottom in one map (Figure 5.13). This map is also the hard bottom component of ecologically notable places described in Chapter 7.

Seabed forms

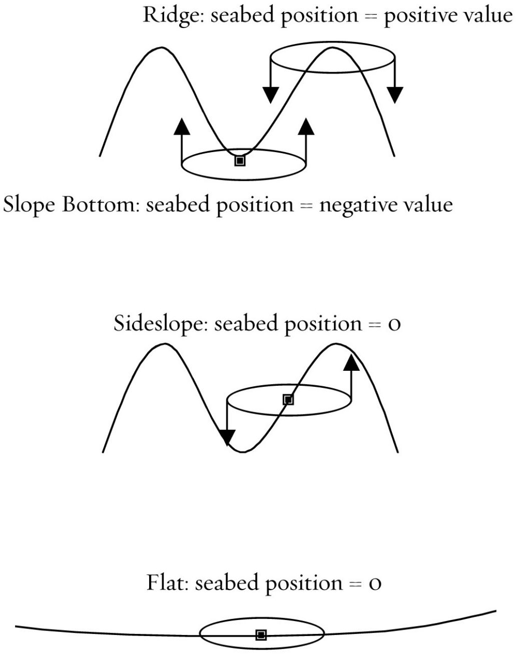
Long Island Sound is characterized by flat silty basins and shallow channels that transition to shoals and then deeper channels and trenches as the Sound spills into Block Island Sound, where the glacial moraine dominates the seafloor structure. These structures, a product of the glacial history and ocean processes that are still shaping it today, have a large influence on the distribution of benthic habitats. With this in mind, the seabed form data were developed to characterize seafloor structure in a systematic and categorical way, relevant to the scale of benthic habitats. These forms were derived from bathymetry by determining the relative vertical position, represented by the landscape position index (LPI), and degree of slope for each 84 meter x 84 meter cell of the seafloor. The units that emerge from this analysis, from high flats to depressions, represent depositional and erosional environments that typically differ in fluvial processes, sediments, and organism composition

(Wigley and Theroux 1981). More than the bathymetry that they were derived from, these forms map discrete features, such as channels, shoals and ridges that are the structural core of the EMUs.

Landscape Position Index (LPI)

A Landscape Position Index (LPI) describes the topography of the area surrounding a particular cell. For example, if the cell LPI is, on average, a higher positive value than the surrounding cells, then the cell corresponds to a higher topographic feature on the sea floor such as a ledge or shoal. Conversely, if the model cell LPI is, on average, lower or a more negative value than the surrounding cells, then it is closer to the bottom of a slope. See Figure 5.14.

Calculations were based on the methods of Fels and Zobel (1995) and we used Toposcale.aml to calculate the landscape position index for each seafloor cell. A cell's index was based on a relative position value, which is the mean of the distance-weighted elevation differences between a given point and all other model points within a specified search radius. The search radius was set at 100 cells (8,300 meters) after examining the effects of various radii. The relative position of each cell was calculated and grouped as low, middle or high depending on whether the pixel was relatively lower, similar, or relatively higher than its surroundings (Figure 5.15).



relative vertical position.

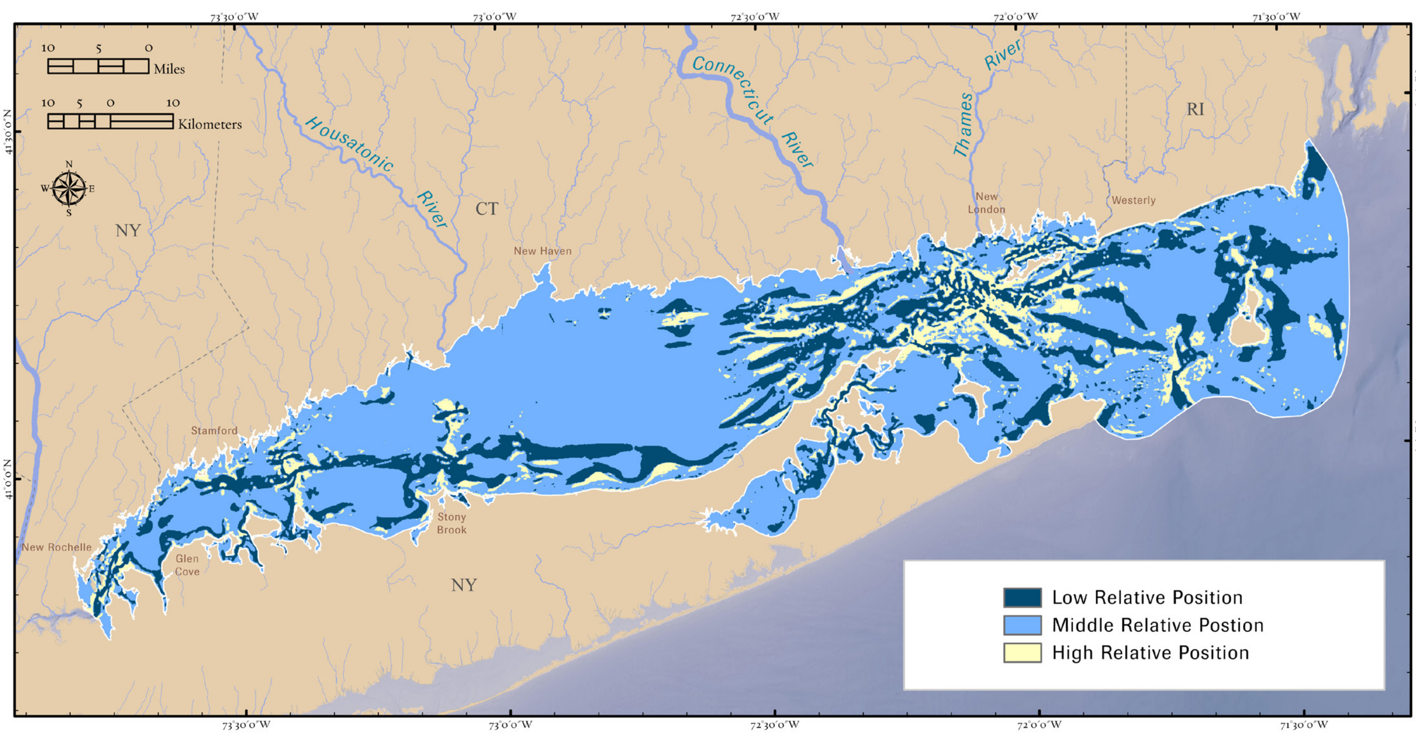


Figure 5.15. Landscape Position Index (LPI).

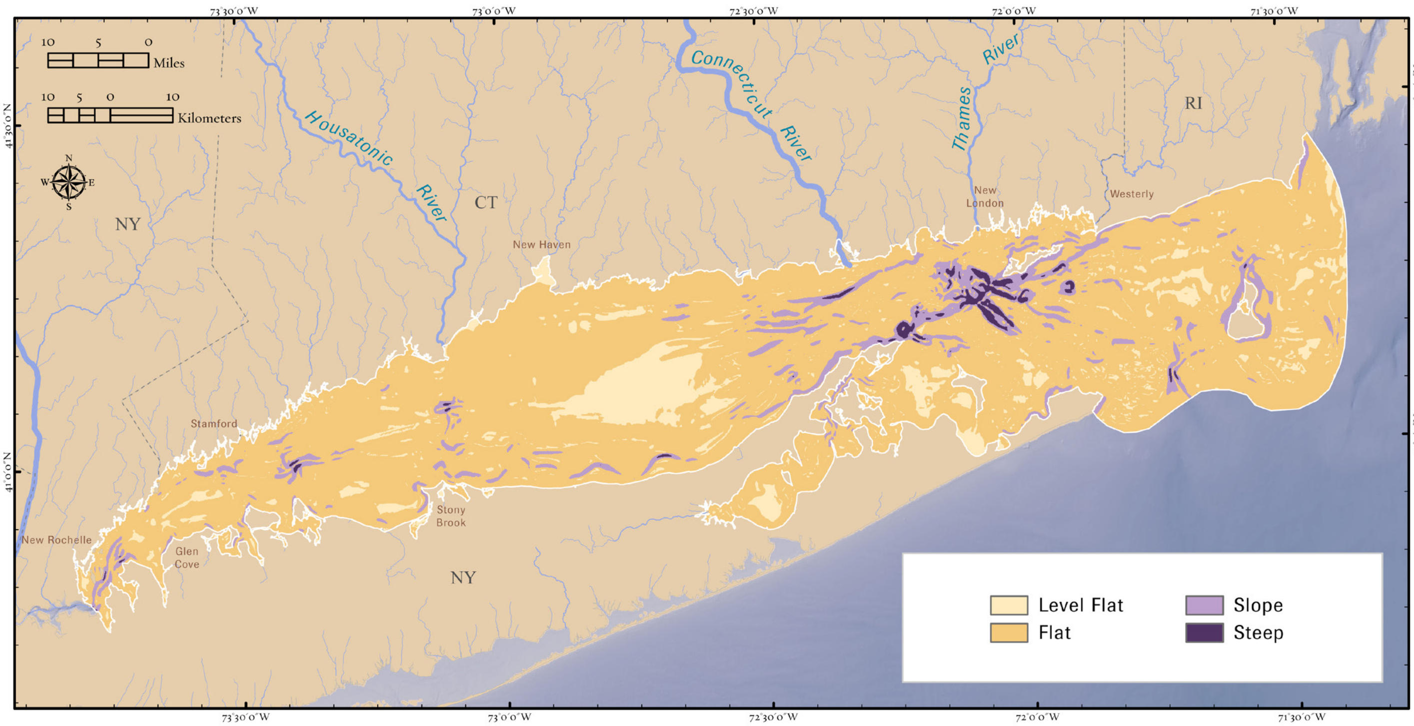


Figure 5.16. Degree of slope.

Slope

Degree of slope, the second element of the seabed forms, was used to differentiate between slopes and flats. Slope was calculated as the difference in elevation between two neighboring cells, expressed in degrees. After examining the distribution of slopes across the region, slopes were grouped according to the following degree thresholds: level flat = 0 - 0.05 degrees; flat = 0.05 - 0.8 degrees; slope = 0.8 - 2.0 degrees; steep slope or canyon = >2 degrees (Figure 5.16).

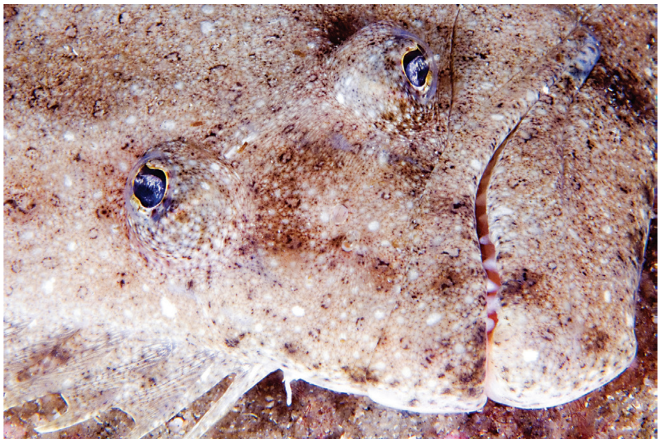
Seabed forms: combining the slope and LPI

Slope and relative position were combined to create twelve possible seabed forms ranging from high flat banks to low level bottoms. These twelve seabed forms are derived from the combinations of four slope classes and three relative vertical positions (Table 5.4, Figure 5.17 and 5.18). (Note that relative vertical position is not the same as absolute depth; it is defined as a location's position relative to its immediate surroundings). While the full variety of forms were maintained in the EMU data, for mapping, the classes were simplified into seven topographic settings which together cover the basic forms found in the study area:

1. High flat: flat areas higher than their surroundings. These tend to represent the tops of sand waves and shoals.
2. Side slope: moderately sloping regions near the tops and on the sides of features such as shoals, sand waves, and channels.
3. Steep: all areas from the steepest slope class. These highlight some the most extreme environments such as steep sides of the channels in the Race (eastern outlet of the Sound.
4. Mid level: extremely flat regions that are not particularly high or low relative to their surroundings, but similar to them. The most prominent of these is the silty center of the 'basin' in the middle of the Sound.
5. Mid flat: relatively flat and non-dynamic, but generally not as flat as "level" and similar vertically to their surroundings. This class makes up most of the Sound and can be viewed as the matrix within which the other classes lie.
6. Depression: flat areas lower than their surroundings. These tend to be channel bottoms.
7. Low slope: sloping areas lower than their surroundings. These are found on the bottom edge of ridge and channel sides.

Ecological Marine Unit map

The final ecological marine unit map defines the physical seafloor habitats and displays their distribution in Long Island Sound. As noted above, because sample information on the locations of hundreds of benthic organisms was used to guide the delineation of the individual EMUs, the map conveys a significant amount of information about the structure and ecology of the seafloor. In putting the EMU map together, we drew from the full EMU dataset to identify distinct or notable features. The dataset is easily searched for specific EMU types or for any combination of depth, sediment and seabed form. We also looked at the EMUs to see how the features correspond to areas with persistent fish or invertebrate populations. Unlike the NAMERA where there were clear spatial correlations between the EMUs and fish or invertebrate populations, there did not appear to be the same obvious correlations for the EMUs and fish/invertebrate populations for Long Island Sound. This may be because the fish and invertebrate data were not available for all of the structurally complex, hard bottom areas where the correlation may be expected to be higher. It may also be because the Sound's fish community, and at least some major invertebrate populations too, have undergone significant abundance shifts over the last 25-30 years. These shifts may be confounding spatial correlations and may be more important than the lack of data from un-trawlable grounds. Nevertheless, more work needs to be done to examine the topographically complex, hard-to-sample areas.



Close up of a flounder's eyes and mouth.
Credit: © Greg McFall

The EMU or 'Seafloor Habitat' map (Figure 5.19 and 5.20) shows the diversity of physical component combinations using the thresholds and definitions for bathymetry, sediment grain size, and seabed forms. Many of these physical component combinations, or distinct EMUs, have specific associated organism groupings as we have noted previously. One example is the deep fine-sand flats EMU for which the ten most typical species are: *Eudorella pusilla, Diastylis sculpta, Lumbrineris hebes, Photis pollex, Periploma papyratium, Tharyx dorsobranchialis, Levinsenia gracilis, Ampelisca agassizi, Diastylis quadrispinosa and Ceriantheopsis americanus*. The map shows physical habitats that are likely to have distinct biota because the thresholds for distinguishing these physical habitats are determined with biological data. It is not, however, a map of individual benthic communities. Because the methods used to collect the original benthic species data were different among each the various field investigations, it is difficult to confidently describe any EMU or group of EMUs with a specific suite of species. The total number of EMUs is simply a result of the number of depth zones, sediment classes and seabed forms.

Assembling the sub-elements to make the EMU Map

As with the sediment and seabed form layers, the final EMU map needed to be simplified for display. Figure 5.21

		relative position		
		high	mid	low
slope	level flat (0-0.05°)	high flat	mid level	depression
	flat (0.05-0.8°)		mid flat	
	slope (0.8-2°)	side slope		low slope
	steep slope (2-5.4°)	steep		

Table 5.4. Thresholds and simplification used in the seabed form model.

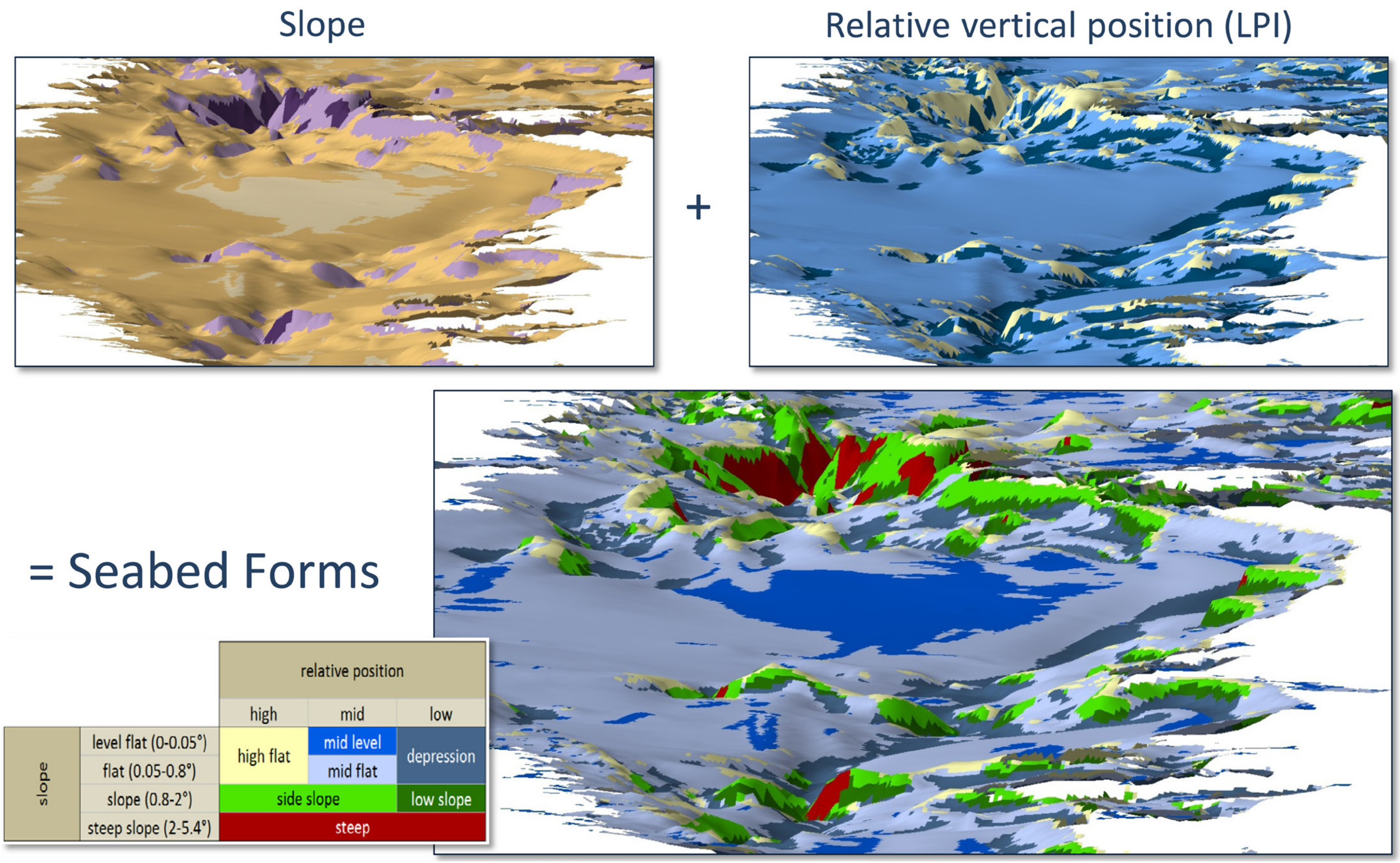


Figure 5.17. Sample depiction of seabed form components and how they come together.

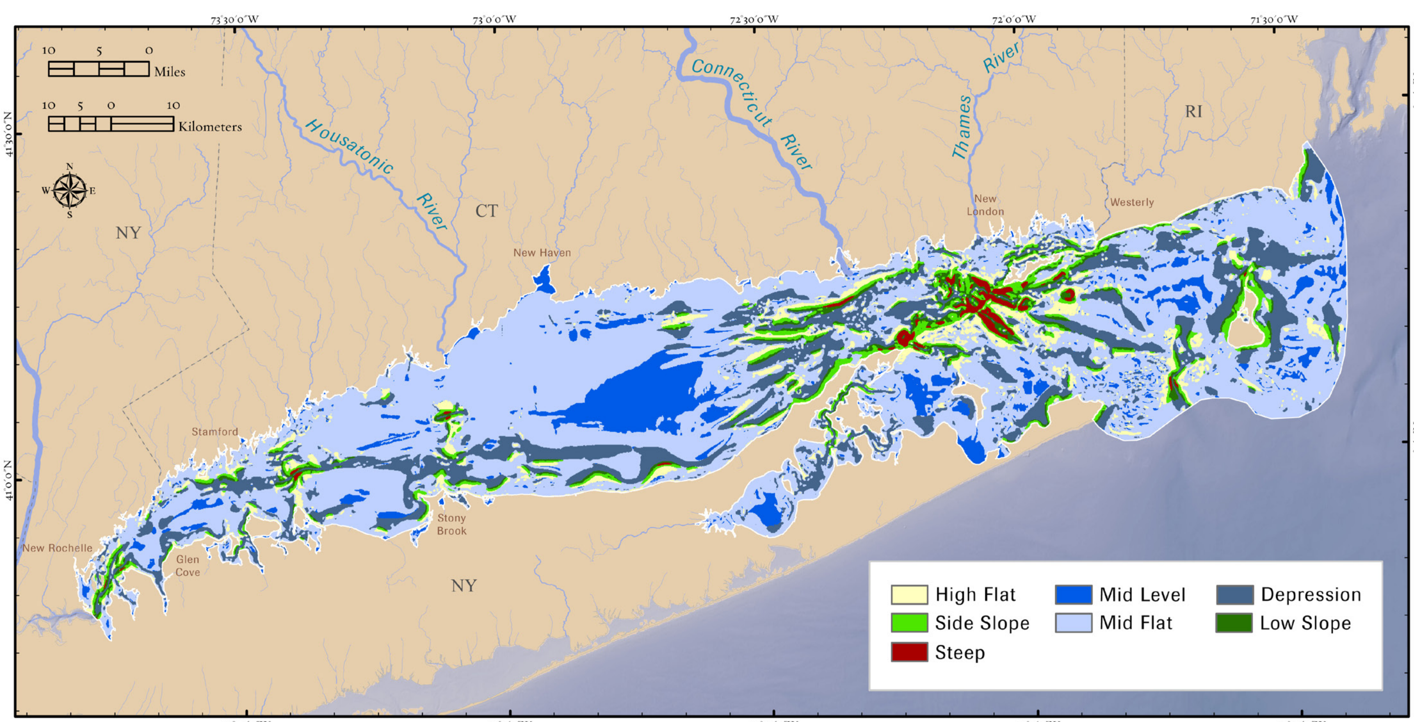


Figure 5.18. Seabed forms.

shows the result of the simplifications and their associated map colors.

The following addresses each of the components: seabed forms, bathymetry and sediment grain size and how they were simplified to make the final map.

The seabed forms were created by combining 3 slope classes with 4 Land Position Index (LPI) classes as described above; the resulting 12 classes were then simplified to the 7 seabed forms for better illustration, as shown in Figure 5.18.

For the EMU map, these 7 seabed forms were combined with the 5 depth classes to create 35 unique classes to account for the bathymetric component of the EMUs. The EMU map is then simplified into 14 classes as shown in Figure 5.21. The underlying analysis and data, which can be queried, include the more complete set of distinct classes by using the original 12 classes of seabed forms with the 5 depth classes to create 60 classes. However, this is not shown in the map; again for purposes of better illustration, the 60 classes are simplified to 14 classes.

The final EMU creation was completed by merging this bathymetric component with the sediment component. The 6 sediment classes were simplified into 3 (gravel, sand and silt, as noted above in Figure 5.10), which were overlaid on the 14 classes from the previous step to create the EMU map, delimiting a wide variety of marine features (Figure 20). For example, Stratford Shoal is delineated as a shallow, high sand flat .

The final EMU map is combined with the final hard bottom component to present a more complete picture of the abiotic foundation of the seafloor and the associated distinctions of ecological habitats that this portrays. This is illustrated in Figure 5.22.

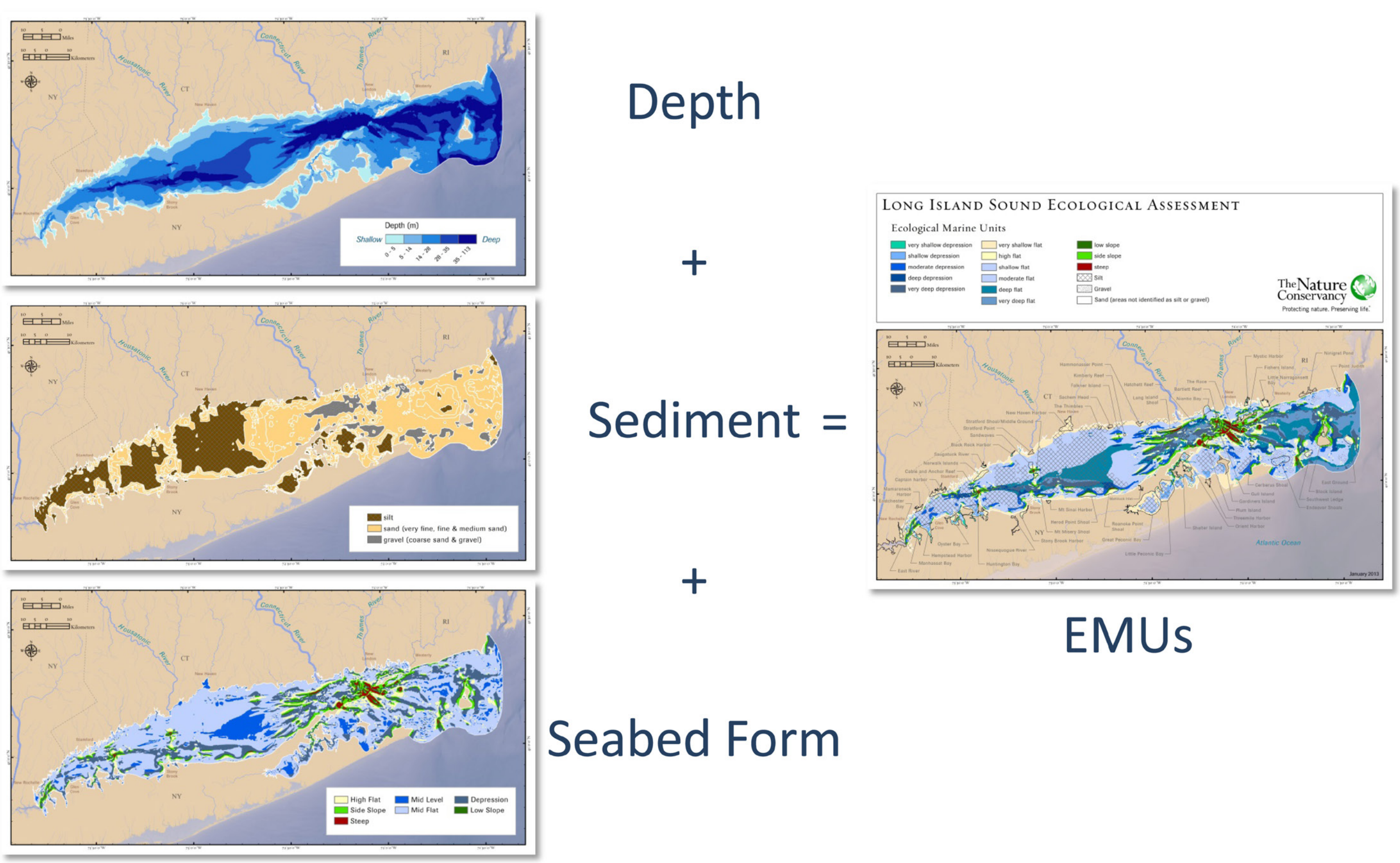


Figure 5.19. Visual depicting the combination of EMU elements to make the EMU's.

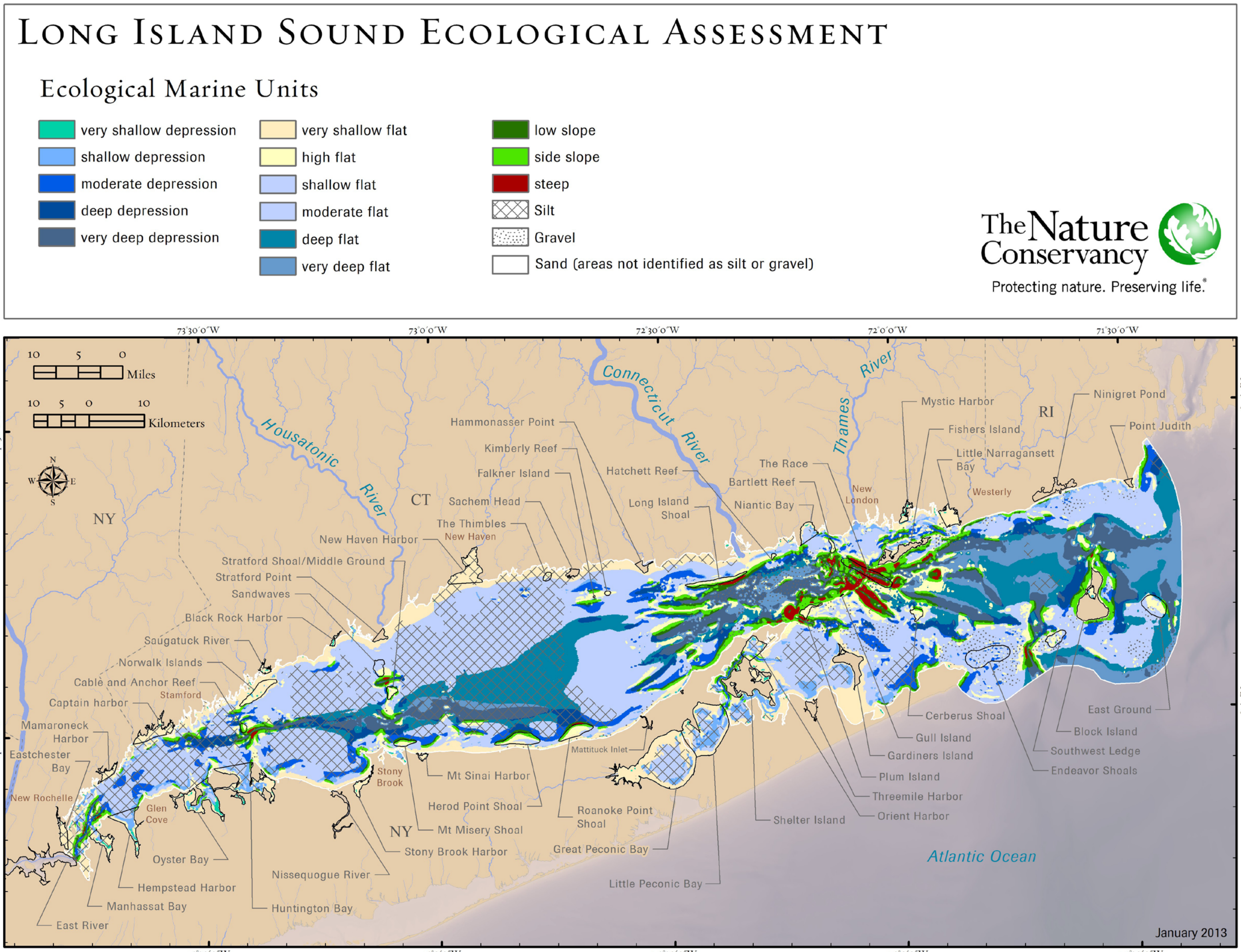


Figure 5.20. Seafloor habitats: Ecological Marine Units (EMU) based on bathymetry, sediment grain size and seabed form.

Note: areas characterized by silt are superimposed by a crosshatched pattern; areas characterized by gravel are superimposed by speckled dots; and areas of sand are those areas without texture superimposed over the colored background.

		Depth				
		very shallow (0-5m)	shallow (5-14m)	moderate (14-28m)	deep (28-35m)	very deep (35-113m)
Seabed Forms	high flat	high flat				
	mid level	very shallow flat	shallow flat	moderate flat	deep flat	very deep flat
	mid flat					
	depression	very shallow depression	shallow depression	moderate depression	deep depression	very deep depression
	side slope	side slope				
	low slope	low slope				
	steep	steep				

Figure 5.21. Seafloor habitats: color scheme for symbolizing seabed forms and depth components of EMUs.

General Discussion of Results

Examination of the seafloor habitat map reveals insights into the submerged environments of Long Island Sound, Block Island Sound, and the Peconic Estuary. Some of the insights that emerge include, but are not limited to:

1. The EMU map shows distinctions in the physical parameters of the seafloor. Although not a map of biological bottom habitats per se, the thresholds for distinguishing the physical features were determined based on biological thresholds. As such they reveal the physical distinctions of the seafloor that may be biologically relevant.
2. As is generally known and visually evident in the EMU map, the eastern part of the Sound and western portions of Block Island Sound contain the areas with the greatest slopes and bathymetric complexity. The sediments in those locations tend to be the coarsest with sands and gravels dominating. This is consistent with the higher relative tidal flow velocities, particularly through the Race.
3. A second area with relatively pronounced slopes and bathymetric complexity is south and slightly west

Note: areas characterized by silt are superimposed by a crosshatched pattern; areas characterized by gravel are superimposed by speckled dots; and areas of sand are those areas without texture superimposed over the colored background.

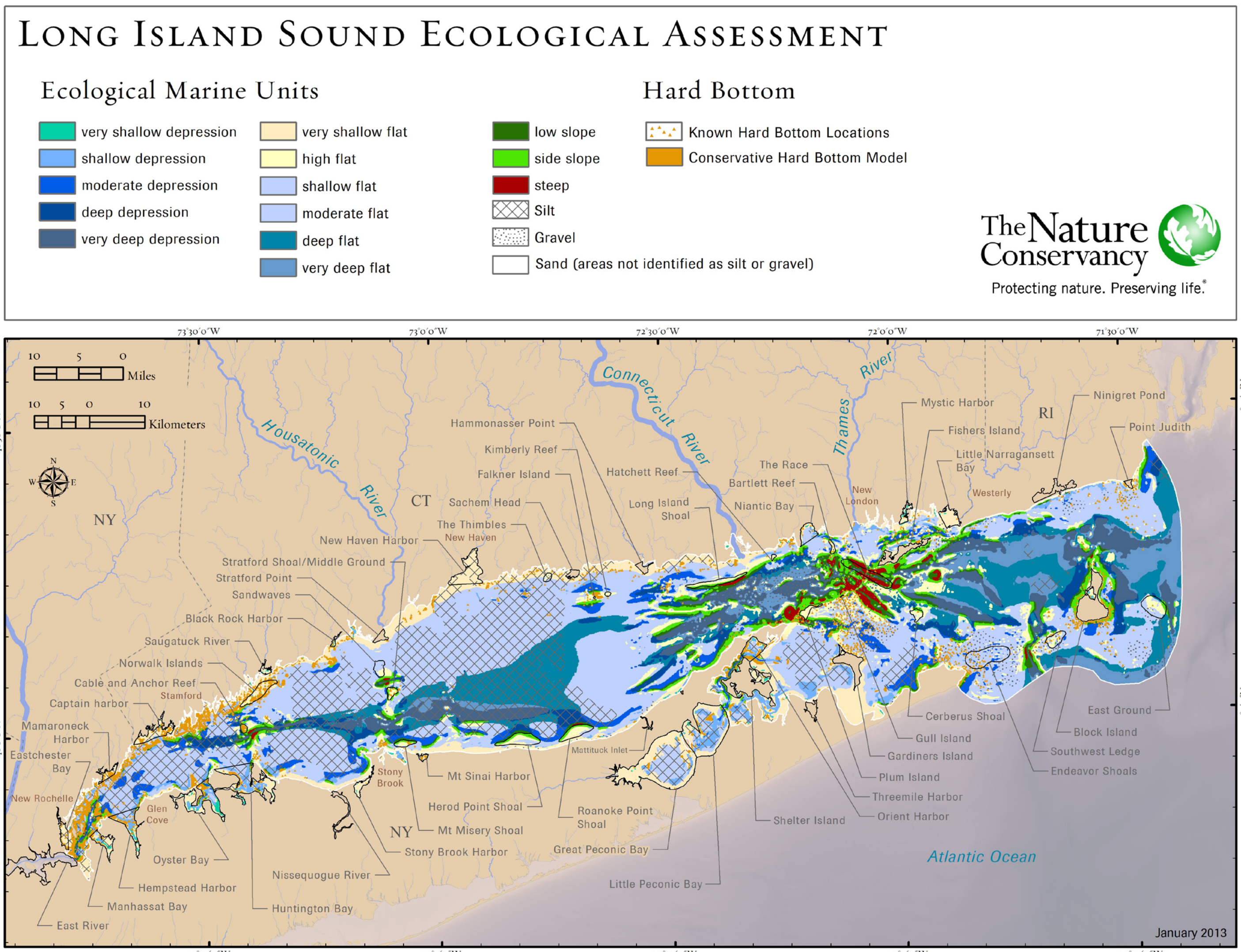
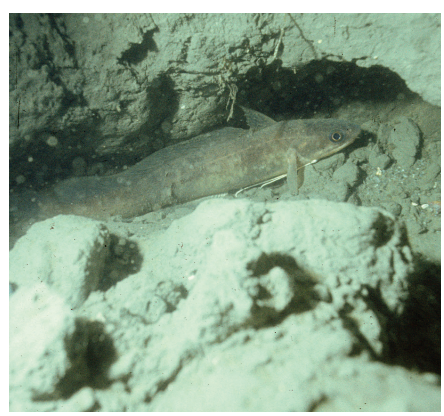


Figure 5.22. Seafloor habitats summary map: Ecological Marine Units (EMU) with hard bottom model and locations.

of the Connecticut River. The features of this area connect and blend into the Race and Fishers Island Sound noted above.

4. The western-most part of the Sound also contains bathymetric complexity, including Stratford Shoal west to the East River, New York.
5. A nearly east-west distribution of distinct flats and depressions runs from Captain's Harbor, CT to Mattituck Inlet, Long Island, NY.
6. A large fraction of the Sound is characterized by relatively shallow to moderately deep flats.
7. Silts dominate in the mid to western Sound and the Peconic Estuary .Sands dominate in the mid to eastern Sound and out into Block Island Sound. Gravels are also prevalent in the eastern third of the Sound and Block Island Sound.
8. Hard bottom is particularly pronounced along most of the northern shore of the Sound, in Fisher's Island Sound through the Race and extending into the northeastern portion of the Peconic Estuary. The Western portion of the Sound has hard bottom on both the north and south shores, however the northern shore of the western third of the Sound has what appears to be the greatest hard bottom density and extent in the Sound as a whole. A strand of hard bottom extends from Huntington Bay to Cable and Anchor Reef. The mid Connecticut shore is also notable for hard bottom including areas around places such as Faulkner Island off the Town of Guilford. There is relatively little hard bottom on the south shore of the Sound.

Ecological Marine Units (EMU) distinguish seafloor habitats of Long Island Sound.
Credit: © Robert DeGoursey



section 6

species persistence in Long Island Sound

Introduction

Long Island Sound is known for its productive waters, a result of its many freshwater inputs, complex circulation patterns, and varied seafloor topography. Accordingly, sustained catches of diadromous, demersal and pelagic fish have fueled the local economy for centuries.

Fish comprise the most diverse class of living vertebrates globally, with over 45,000 species. Their diversity may be explained by the diversity of available fish habitats, and the extraordinary genetic plasticity of fish (Shumway, 2008). The richness, abundance, and community composition of marine fish have been shown to correlate with physical habitats, and with special oceanographic processes occurring within them on a regional or local scale (Roff and Evans 2002). Specific habitats often occur where there are physical or structural anomalies, such as anomalies of temperature, primary productivity, topography, and geographically isolated setting. For demersal fish, species abundance has been found to be associated with depth, temperature, sediment type, sediment diversity, and habitat complexity (Mahon *et al.* 1998, Stevenson *et al.* 2004, Auster *et al.* 2001, Lough *et al.* 1989, Charton and Perez-Ruzafa 1998, DeLong and Collie2004, Lindholm *et al.* 1999.)

Macroinvertebrates, such as lobsters, crabs, and horseshoe crabs, are also a distinctive part of the Sound's marine diversity. In this chapter, in addition to fish, we examine the persistence patterns of 8 commercially important or ecologically interesting species for which we had information from the trawl surveys: American lobster (*Homarus americanus*), blue crab (*Callinectes sapidus*), bobtail squid (*Sepiola*), boreal squid (*Illex illecebrosus*), horseshoe crab (*Limulus polyphemus*), long-finned squid (*Loligo pealeii*), mantis shrimp (*Squilla empusa*), and rock crab (*Cancer irroratus*). The full array of invertebrates found in the Sound is discussed in the seafloor habitats section (page 15).

The focus of this chapter is on identifying those places in the Sound that have been persistently important to fish and invertebrate productivity for decades. The heterogeneous aspect of the Sound ensures that not all areas are equivalently important with respect to productivity and diversity. For instance, the river mouths, deep basins, and shallow banks are tied to water masses with distinct layering and corresponding species diversity. To identify these areas, we applied a single consistent methodology, based on

Along with 95 species of fish, 19 macro-invertebrates were assessed such as American lobster.
Credit: © Robert DeGoursey

the persistent presence of individual species over decades, to find places that may be particularly important for the conservation of fish and macro-invertebrates.

We focused on persistence instead of abundance because the latter varies greatly from year to year, reflecting temporal variation in population sizes, fluctuating prey bases, and other factors unrelated to the physical structure of the region. In contrast, places where species have been persistently found over decades are more likely to correlate with perennial factors important to productivity and diversity. The methods were designed to identify the places that are important to many species. However, these methods also allowed us to examine trends in abundance over time and highlight places where a particular species appears to be increasing or decreasing in abundance. For detailed analysis of the species abundance patterns in the Sound we suggest readers refer to CT DEEP website reports.

Methods

For each fish and macroinvertebrate species present in the Sound, we examined their distribution, abundance trends, and areas of persistence in the region. Specifically, three questions concerning the distribution of the species were addressed with this analysis:

- What is the general distribution of the species in the region? (distribution)
- Where in the region has the abundance been increasing or decreasing? (trends in abundance)
- Where in the region has the species been consistently found over time with the highest persistence? (analysis of persistence included correcting for level of surveying effort)

Datasets

We obtained data on fish and invertebrates from the Connecticut Department of Energy and Environmental Protection's Long Island Sound Trawl Survey (LISTS). The goal of LISTS is to collect, manage, synthesize and interpret fishery-independent data on the living resources of Long Island Sound for fishery management and information needs of Connecticut biologists, fishery managers, lawmakers and the public. Among other things, the survey provides annual total counts and biomass for all finfish and invertebrate species taken, a species list for Long Island Sound and an annual index of counts and biomass per standard tow for 40 common species.

Since 1984, over 5,700 trawls have been taken on a survey grid divided into 1.85 x 3.7 km (I by 2 minute) rectangles. Sampling is divided into spring and fall periods; 40 sites are sampled per month for a total of 200 yearly samples. Sampling is random and stratified based on depth (4 zones) and bottom sediment type (3 types). Rocky reef areas are not sampled because they are inaccessible to the trawl (Figure 6.1).

Before 1991, there was more frequent sampling in trawling from April to November @ 40 tows/month. Six fixed sites were sampled in the Narrows between 2000-2006. Summer sampling using a small mesh net was under taken in the early 1990s.

A table of sample dates by time period follows:

	Year																									
Cruise	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
April	-	-	35	40	40	40	40	40	-	40	40	40	40	40	40	40	40	40	40	40	40	40	-	40	40	40
May	13	41	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
June	19	5	41	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	39	40	40	40	40	40
July	35	40	40	40	40	40	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
August	34	40	40	40	40	40	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
September	35	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	-	40
Sept/Oct	-	-	-	-	-	-	-	-	-	40	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
October	35	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	-	40	40	-	40	40	40
November	29	40	40	40	40	40	40	-	-	-	-	-	-	-	-	-	-	-	-	40	-	-	-	-	-	-
Total	200	246	316	320	320	320	297	200	160	240	240	200	200	200	200	200	200	200	200	200	199	200	120	200	160	200

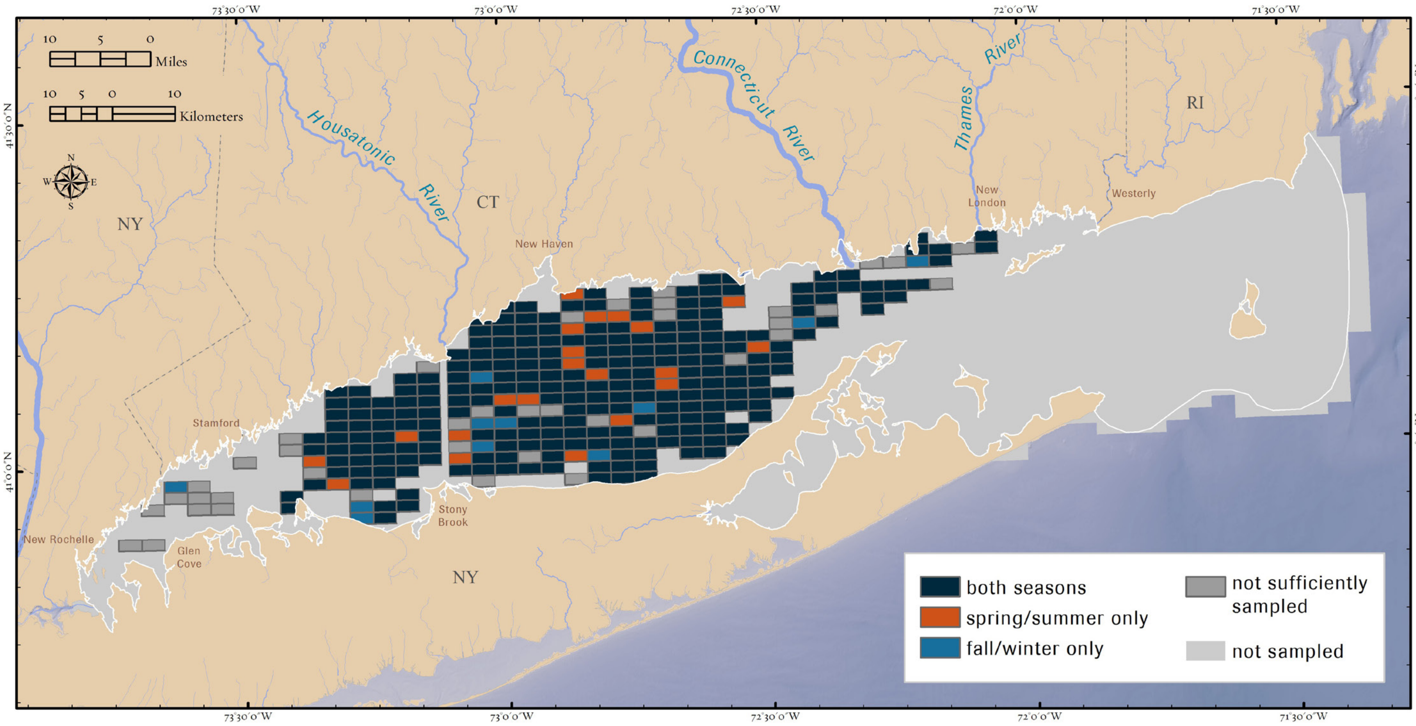


Figure 6.1. Distribution and resolution of the trawl survey dataset.

The catch from each 30-minute tow is sorted by species and each individual counted. Length, age, and weight are recorded for a subset of recreationally or commercially important species. Additionally surface and bottom water salinity and temperature are taken for each sample location.

For this analysis, we used all available bottom surveys from 1984 – 2009. We calculated the persistence metrics on an individual species basis to account for differences in the catchability of each species.

Grouping of the data by octads

Individual trawl survey points do not overlap exactly from year to year. Thus, in order to calculate temporal trends in abundance and persistence we adopted the CT DEEP grid of 1X2 minute rectangles as our sampling unit. Each rectangle contains multiple survey points covering a range of years. We grouped the data into eight- or nine-year time intervals (octads) to allow for a robust analysis of persistence trends over time. This was necessary because not all cells were sampled in every year, and species differ in their detectability. We found that using the octad grouping ensured that most cells contained at least one survey point from each time period (1984-1992, 1993-2001, and 2002-2009). Each cell was scored based on the presence of each species within each octad. Cells that did not have survey points in at least two of the three octads were excluded from the analysis. We do not expect changes in the sampling schedule to substantively impact the results noting that we are comparing differences between cells not differences between time periods. The changes in sample schedule apply to all cells.

Correcting for survey effort and catchability

A characteristic of the stratified random design of the trawl survey is that different cells received varying degrees of sampling effort. Additionally, different species vary in their susceptibility to being caught by the survey gear. To account for this we used statistical methods to adjust the persistence value based on the effort expended and the catchability of the species. For each species we tested whether there was a significant relationship between effort and detection, and for those that had a significant relationship, we compared the actual detection to the expected detection.

Specifically, for each species we ran a linear regression of species detection by fishing effort using all cells and all years. For species that exhibited a significant relationship ($P < 0.01$) we used the regression model to estimate the amount of fishing effort needed to detect the species. Next, for each cell, we calculated the amount of detection expected for the species, given the amount of effort expended in the cell. Finally, we calculated how much higher or lower the observed detection rate was than the expected detection rate using the standardized residuals of the regression. This technique allowed us to determine for each cell whether there was adequate sampling to detect the species of interest and whether the species was detected at rates higher or lower than expected. For example, alewife (*Alosa pseudoharengus*) detection was significantly related to sampling effort ($R2 = 0.44$, $P < 0.001$) and within each octad it took an estimated four sampling events to detect the presence of alewife (Figure 6.2).

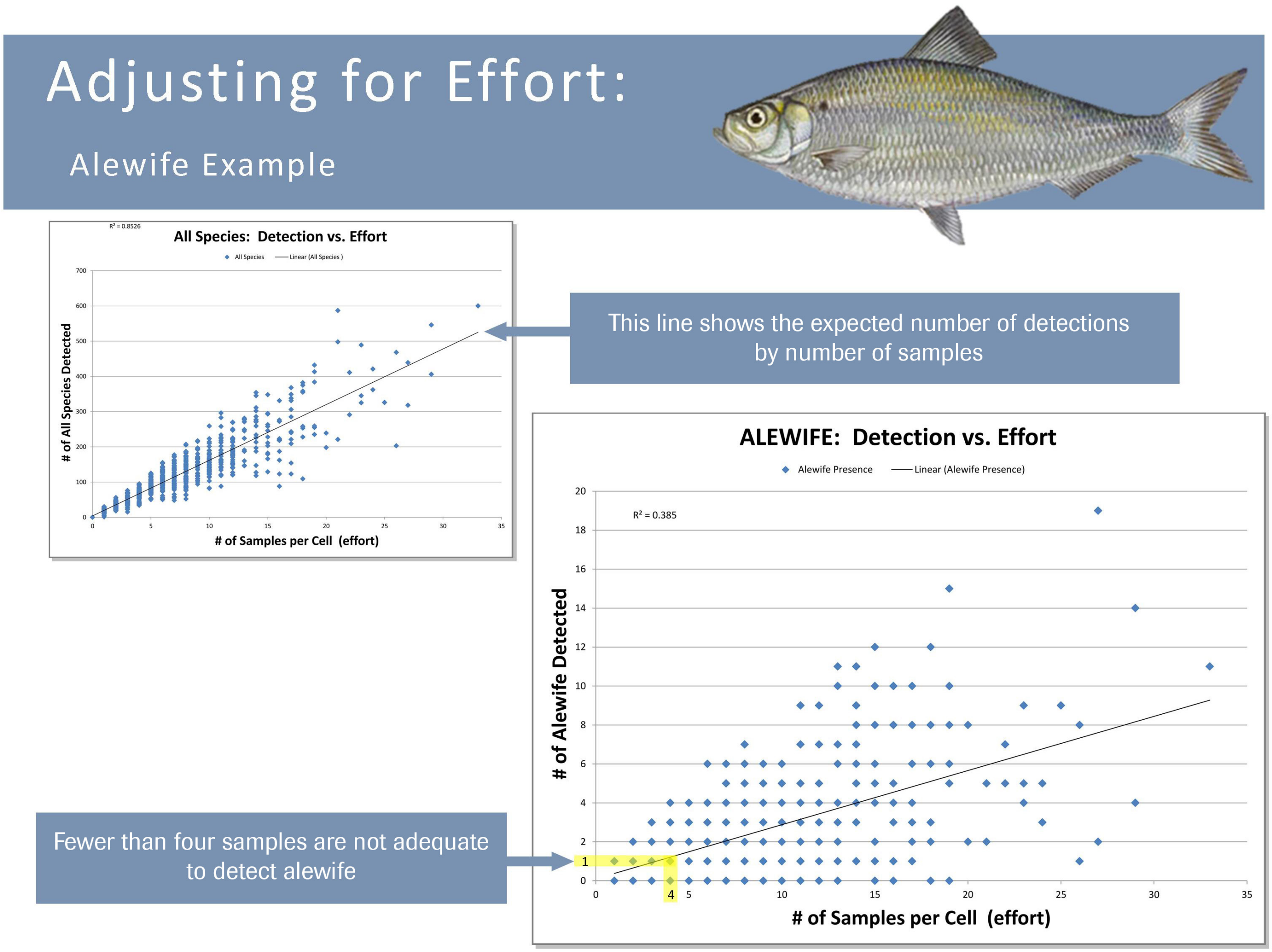


Figure 6.2. Relationship between sampling effort and detection for Alewife and for all species. The graph shows sampling effort, as number of trawls (x axis) plotted against the number of trawls that detected the species (y axis).

Samples					Detection				Residuals				
Cell	Octad 1	Octad 2	Octad 3	Below Threshold	ALW 1	ALW 2	ALW 3	Persitence	ALW 1	ALW 2	ALW 3	# Negative	Total Res.
1428	20	27	15	0	8	19	10	3	2	11	6	0	19
1433	17	10	17	0	2	1	2	3	-3	-2	-3	3	-8
617	2	8	12	1	0	5	9	2	-1	3	6	1	8

Table 6.1. Example of effort correction for Alewife.

Box 1 of Table 6.1 shows the sampling effort across three octads (labeled as decades). Box 2 shows the detection levels across the same three octads. Box 3 shows the degree to which the detection is higher or lower than expected (in standard normalized units).

For each species, scores were calculated for every cell by tabulating the amount of effort expended, the detectability of the species, and the number of times the species was actually detected. Consider the following three cells (Table 6.1):

- Cell 1428 was sampled 20 times during the first octad and Alewife was detected eight times, two standard deviations more than expected,
- Cell 1433 was sampled 17 times during the first octad and Alewife was detected two times, three standard deviations less than expected,
- Cell 0617 was only sampled two times, not enough times to detect the species and the species was not detected.

In this example, alewife was present and detected more often than expected in the first cell, present but detected less than expected in the second cell, and its presence is unknown in the third cell because there was not enough sampling effort. The associated standard deviation values are used to weight the persistence value and correct for the number of samples (effort).

Efficacy of correcting for survey effort and catchability

Limitations: As noted above, a limitation of these surveys is that different species demonstrate varying degrees of susceptibility to being caught by the survey gear (i.e., catch coefficients for cod are much higher than those for wolffish or other species). Otter trawl systems like the one utilized to conduct survey sampling are specifically designed to capture a variety of demersal fish species, including many of the species analyzed in this assessment. It is important to note, however, that the catch rates for various species within the group are variable. Catchability coefficients are generally higher for demersal, round-bodied species (e.g., Atlantic cod, haddock, pollock), and lower for flat-bodied fish (e.g., Atlantic halibut, summer flounder) and pelagic species (e.g., Bluefin tuna, Atlantic herring). In addition, catch rates at any given location can be heavily influenced by day/night differences in species distribution within in the water column, and by seasonal variations in species distribution within their geographic range. Some species are also able to avoid capture in trawls by using sensory or behavioral capabilities.

Additionally, trawl samples are particularly difficult to conduct in areas of high habitat complexity. As stated earlier, the survey misses nearshore areas and some offshore areas due to survey vessel depth limitations. Many of these coastal areas, especially bays and estuaries, are critical for early life stages of fish. Finally, any shifts in movement due to changes in temperature caused by climate change may not be reflected in these snapshots.

Efficacy: The principal factor in why we believe the methods for correcting for effort were appropriate and effective for identifying ENP (where there was adequate sampling) is that LISEA is not comparing one fish with another. It is comparing one place with another. All analyses were conducted on a species by species basis to account for differences in the catchability of each species. Ideally we would have all species, all life stages, all vari-

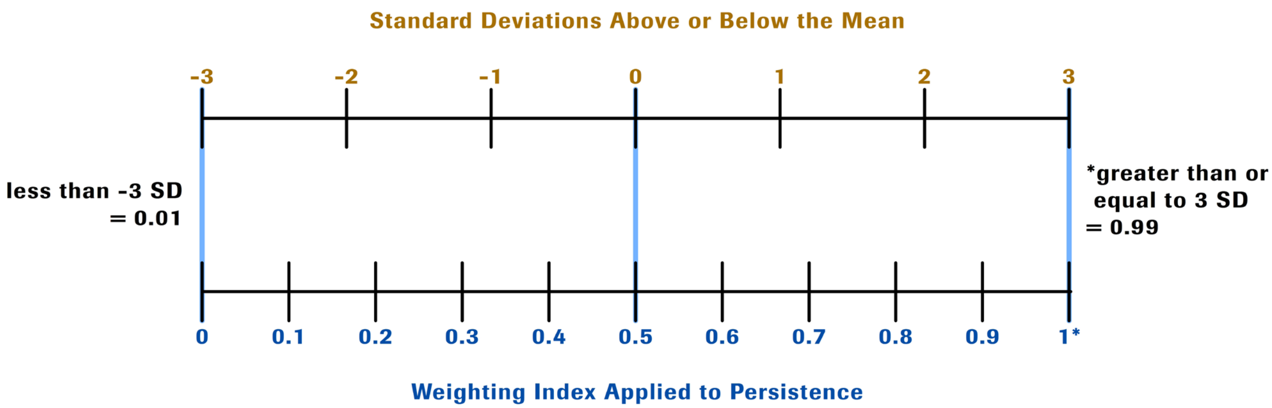


Figure 6.3. The transformation of the weighing factor to create a decimal index representing the relative amount of detection above (0.5 – 0.99) or below (0.01 – 0.49) the expected value based on effort.

ability in seasonality, water column location, etc. as a more complete set of data to use in comparing one place with another. However, we do have a very large portion of that ideal sampling, enough that places or cells which support high persistence over time can be identified whether we have the full ideal sampling or not. Another key element is the consistency of sampling methods between the cells. Although there was more sampling in earlier years, all cells that were trawled and sufficient to be counted were subject to the same trawl methods and equipment. Patterns of sampling should be reasonably comparable between cells. For example, if a trawl tended to miss a species or life stage in one area because of the limits of the trawl equipment or method, that same pattern would generally apply to other areas as well. As such, the data allows the cells to be compared for relative persistence.

Persistence

Persistence refers to the consistency with which a species was caught in the same cell over time. Because fish move seasonally and their abundances fluctuate widely from year to year, their life patterns can be very complicated. Persistence is an effective way to sort out the importance of a particular place, such as a shoal or slope that has been a continuous stronghold for the species over time. We overlaid the persistence patterns of many individual species to detect places that appear to be strongholds for a particular species group or for a wide diversity of species. The resulting maps convey a large amount of information about the relative importance or notability of particular places with respect to fish and invertebrates.

To be included in this analysis, a cell had to have sufficient sampling, 1 to 4 survey amples, depending on the species, in each of two or three octads to assure a minimum level of detection. Therefore if a cell had 1 to 4 samples in only one octad it was not used. In the first step we scored each sufficient cell (integers from 1 to 3) based on the presence of the species of interest within each octad:

Score 1 = The species was present in 1 out of the sampled octads

Score 2 = The species was present in 2 out of the sampled octads

Score 3 = The species was present in 3 out of the sampled octads

Weighted persistence

To create a single score that captures both the persistence and the relative level of detection not explained by effort, we created a 'weighted persistence' for each species in each sample cell. Since the degree of detection is correlated with abundance, this 'weighting' of the persistence value integrates abundance to some extent. The standardized residual of the regression described in the section above was transformed into a decimal index (Figure 6.3) that was added to the persistence integer. The final combined value describes the persistence of the species in a given

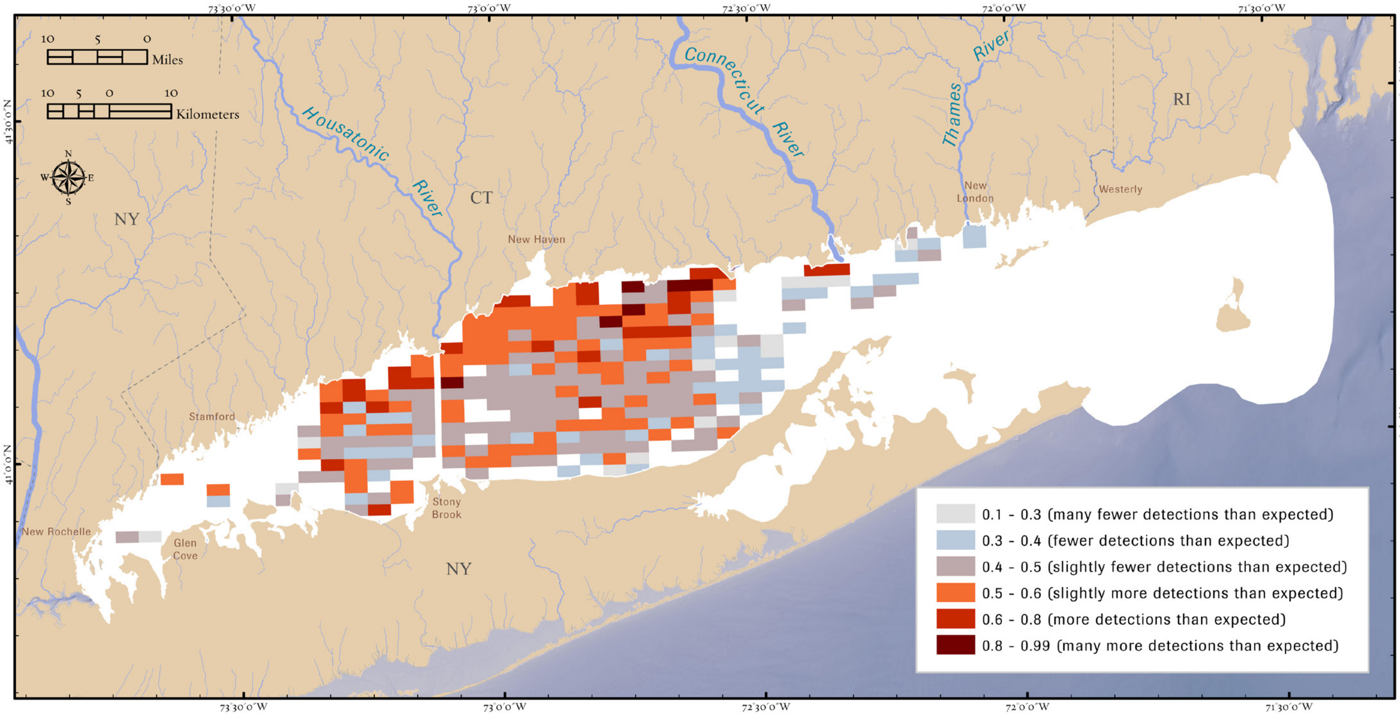


Figure 6.4. a) Alewife persistence.

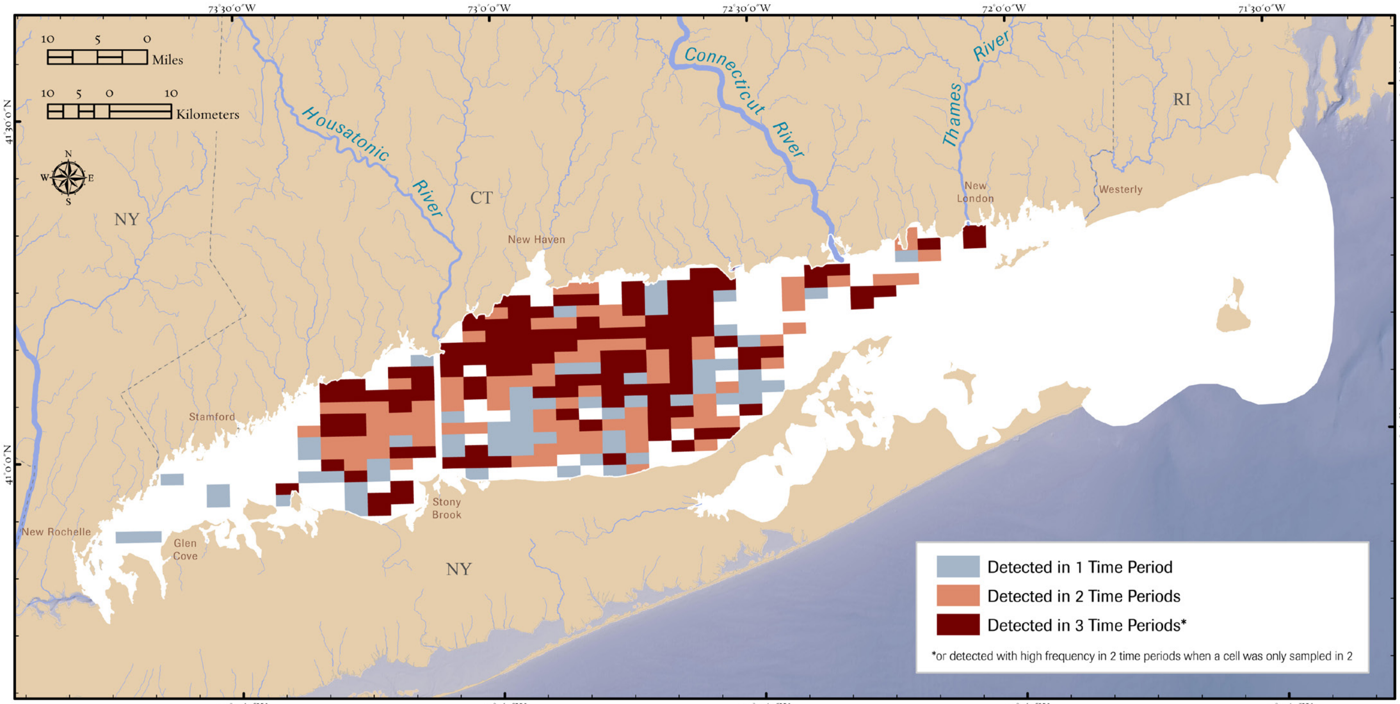


Figure 6.4. b) Alewife detections.

cell as well as the amount of detection above or below that expected based on the amount of effort.

In the alewife example above (Table 6.1), the species was detected in cell 1428 in all three octads at an average rate of two standard deviations more than expected. Two standard deviations rounds to 0.8 after the transformation, so this cell received a score of 3.8. In contrast cell 1433 received a score of 3.0 because although alewife was detected in all three octads, it was at a rate three standard deviations below the mean expected. Please see the key in Figure 6.4b which provides written descriptions for each of the weighing factors (0.01 – 0.99). When calculated for every cell the result is a map showing clearly where the species is persistently found. By combining an examination of species presence over time through the three octads (Figure 6.4a) with the relative abundance of detection (Figure 6.4b), a summary of weighted persistence is found as depicted in Figure 6.5.

High weighted persistence

High weighted persistence accounts for both high species persistence and high relative abundance and is referred to later in the report. Please note that, as explained further below, abundance is estimated by using frequency of detection, not counts of individuals.

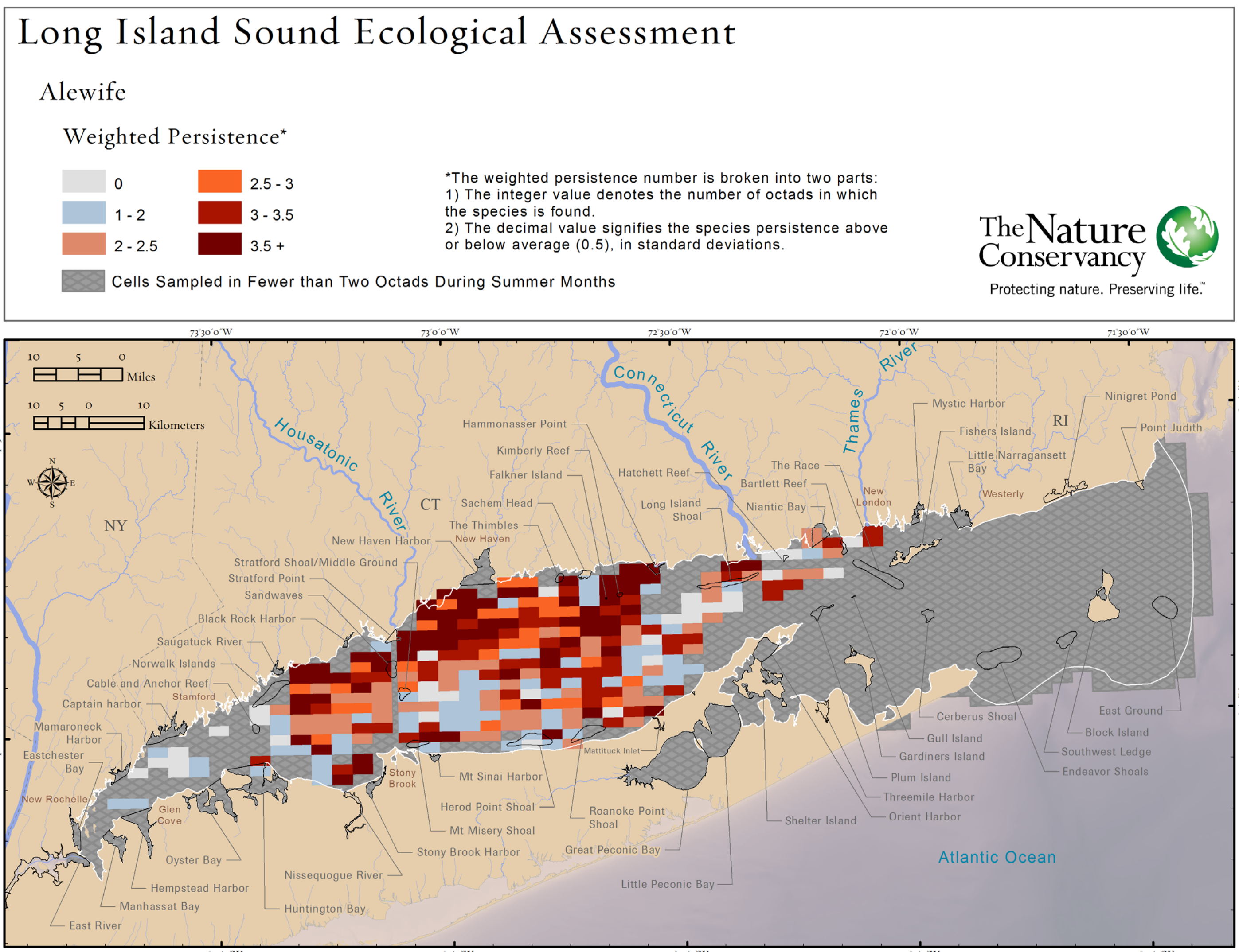


Figure 6.5. Alewife weighted persistence.

High weighted persistence is considered to be those areas (or grid cells) where a species has been present in all 3 octads with an average frequency of detection higher than expected. This translates to a weighted persistence score of 3.6 or higher. The “higher than expected” detection (the 0.6 portion of the 3.6 score) means the minimum frequency of detection, as an average for the 3 octads, approaches 1 standard deviation above the mean. Since high weighted persistence is a minimum of 3.6, the average frequency of detection can also be higher, or many more detections than expected.

The persistence patterns for individual species can be found in the Appendix B.

Trends in abundance

Using the frequency of detection data described above, trends in average abundance over three octads were calculated for each cell for each species. Rather than using the average number or weight of fish per trawl, we have defined abundance as the frequency of detection. If a species is detected in the same cell in a high proportion of trawls it is considered to have high abundance. This allows us to avoid the effects of dynamic population shifts and highlight places with persistent species residence. To allow for consistency in comparing average abundance, only cells with 3 octads of sampling were used. As a result, only 65 species have trend data; about 50% of all cells for those 65 species had trend values, although some species had much

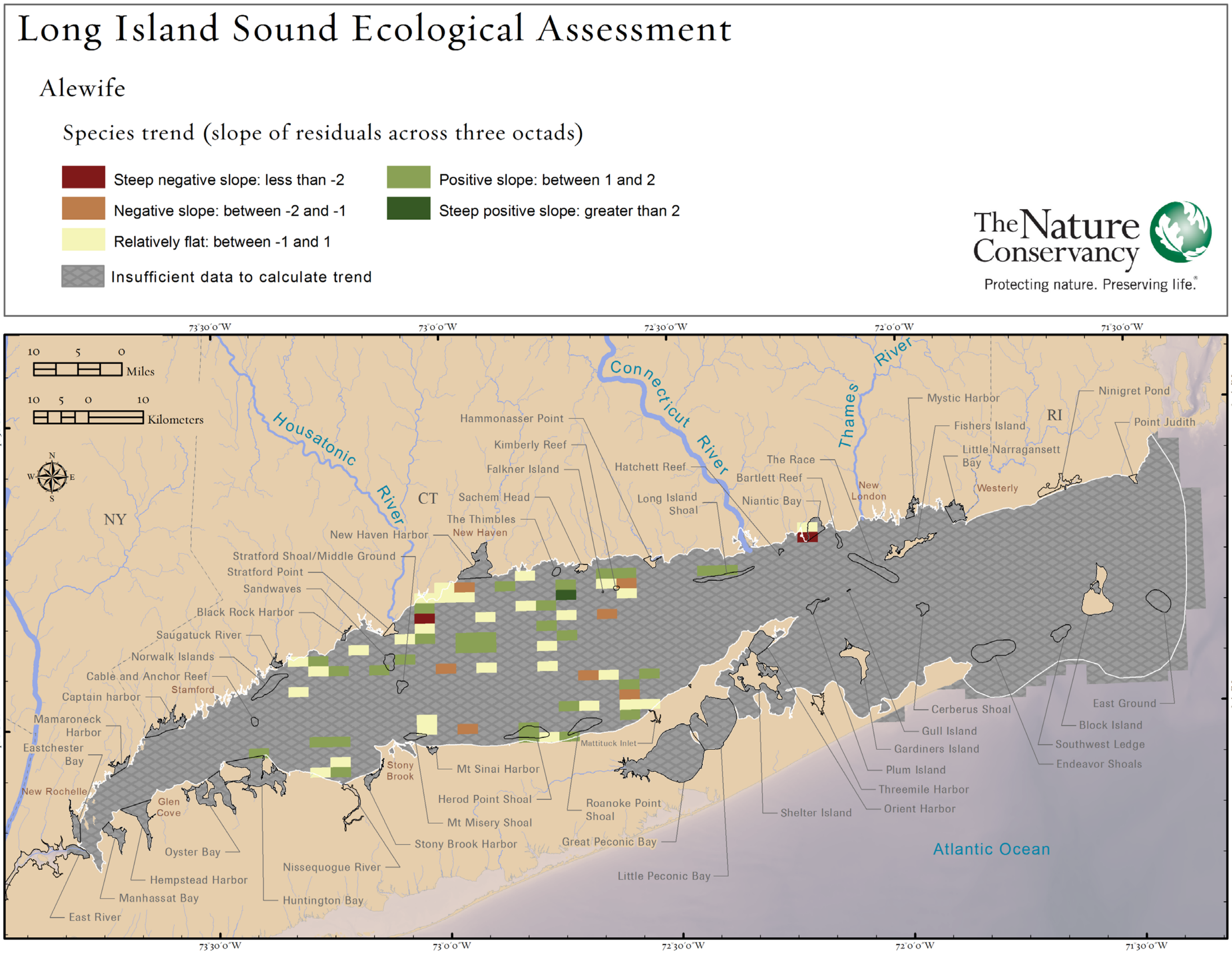


Figure 6.6. Alewife trend.

better coverage than others (see Appendix B for maps of all species). For this analysis, a linear regression line was fit to the residuals of the adjusted persistence score for each of the three successive octads. Regression lines with a P-value less than 0.1 (90% probability) were considered to show a significant trend. Positive slopes indicated an increasing trend in abundance, negative slopes indicated a decreasing trend, and insignificant regressions indicated no trend. By mapping these results for each species, the spatial locations where changes in abundance were detected were highlighted.

There was much variation among the species results. Species such as horseshoe crab (*Limulus polyphemus*), clearnose skate (*Raja eglanteria*), and bay anchovy (*Anchoa mitchilli*), showed significant increasing trends across the Sound over the 3 octads. (90% or more cells with a trend greater than zero). Others such as hogchoker (*Trinectes maculatus*) and sea raven (*Hemitripterus americanus*) generally were decreasing in the region (90% or more cells with less than zero trend). Alewife had relatively flat trends (Figure 6.6).

By mapping out the trends across all species we can observe which areas have been showing significant trends, either positive or negative. Areas that seem to show strong positive trends appear to be concentrated along the coast, especially around river mouths. In particular, Long Island Shoal, southwest of New Haven Harbor, north of Hun-

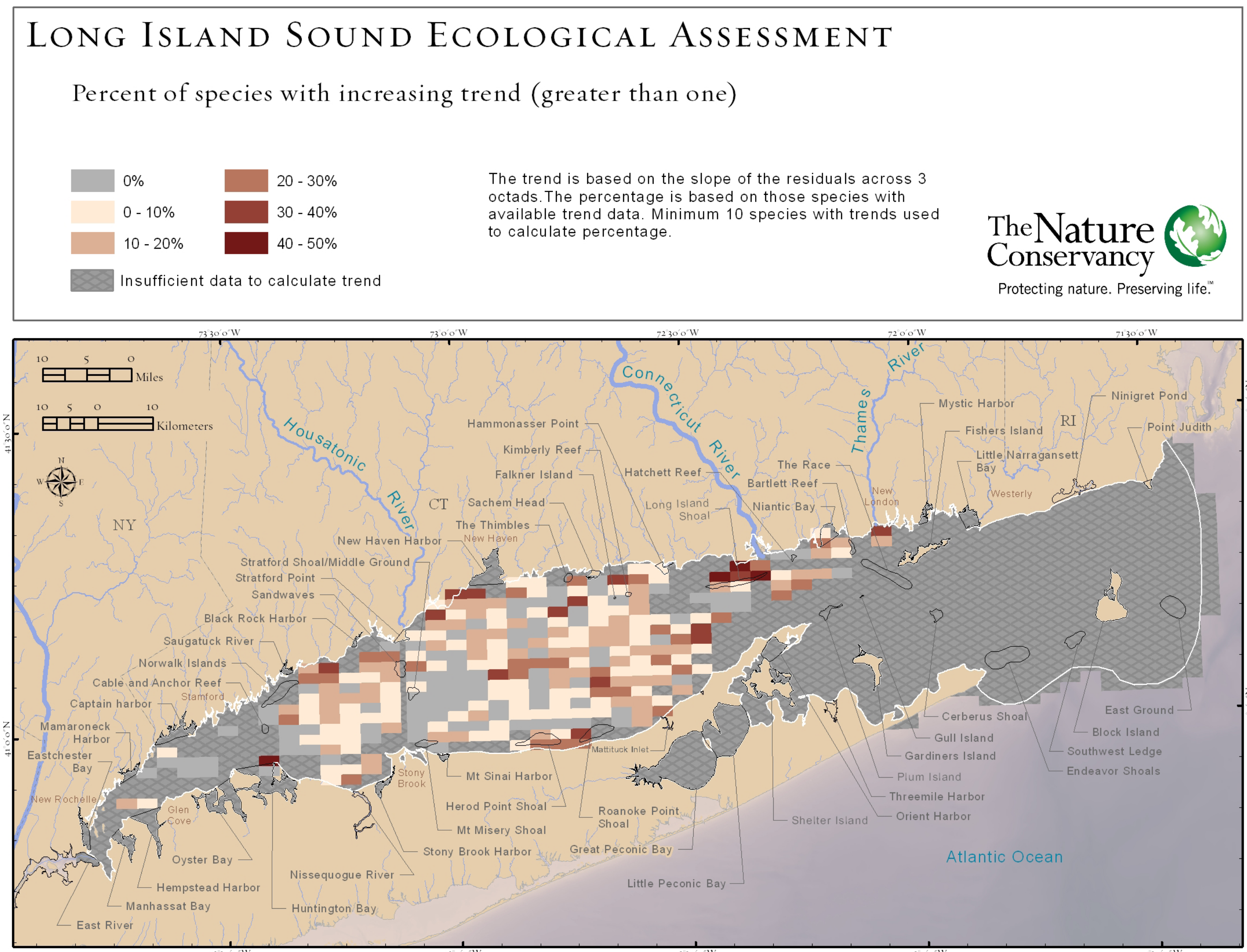


Figure 6.7. Percentage of species with increasing trend.

tington Bay, and Herod Point Shoal, show not only a high number of species with increasing trends, but also species with very significantly positive trends (greater than three slope). There are also a substantial number of species that show positive trends in the deeper parts of the Sound, however their slopes tended to be flatter (Figure 6.7).

The trend maps are useful for illustrating changes in the distribution patterns for individual species and when combined they may help to signify changing conditions in the Sound. However, because these measures describe a cell only relative to itself and are not a measure of a cell relative to other cells, we do not feel that an increasing trend should promote a cell to ecologically notable place status. Ecologically notable places are meant to capture those places that have consistently contributed to the persistence of species even under changing conditions.

In general, there were fewer species with decreasing trends (Figure 6.8), and the degree to which species were decreasing was less significant than those with positive trends. Many of the same places that show positive trends, however, also show negative ones. In the same part of the central area of the Sound, for instance, there are a large number of species with decreasing trends. Very few species here showed a flat trend. Other areas with decreasing trends included Niantic Bay, outside Huntington Bay and New Haven Harbor, and Herod Point Shoal.

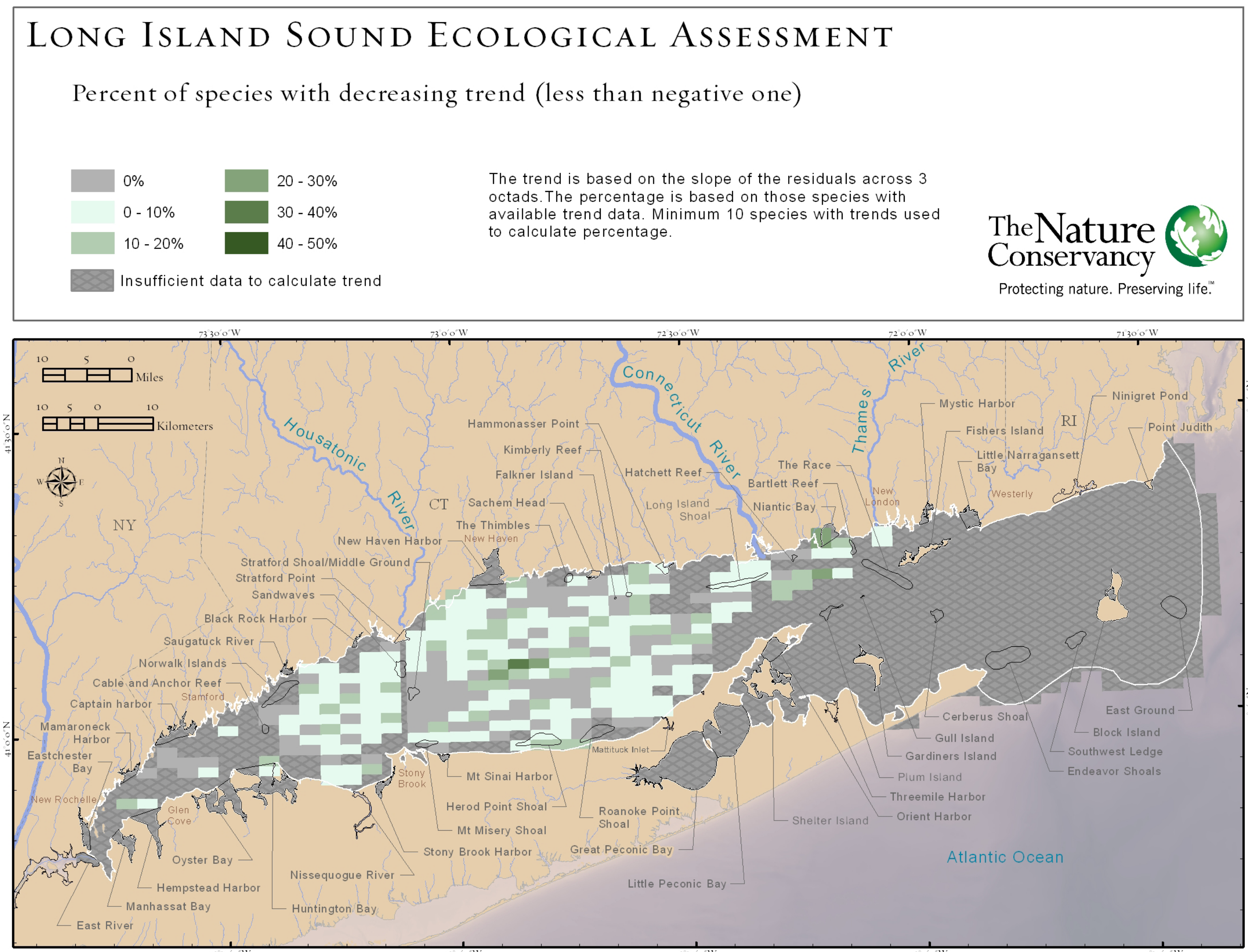


Figure 6.8. Percentage of species with decreasing trend.

We also examined where some of the most significantly increasing and decreasing trends in species persistence have been occurring by highlighting those areas with at least three species with a slope greater than 2, less than -2, or some combination of the two (Figure 6.9). In general, the patterns are similar as to what has been described above; Herrod Point Shoal, north of Huntington Bay, and Niantic Bay are places that appear to have both significant increasing and decreasing trends. Species with increasing trends were concentrated along the Connecticut coastline particularly between the Connecticut River and Long Island Shoal. Decreasing trends tended to be in deeper waters. It may be that these are cold-adapted species struggling against increasing temperature.

Data Limitations

A major limitation of the trawl survey data was that they only covered a portion of the study area. Although there are trawl survey data for both the eastern and western ends of the Sound, the geographic coverage for these areas is much less complete than for the remainder of the Sound. Coastal areas are also very limited, as can be seen on the maps. Further, all trawl surveys tend to emphasize soft sediment areas and avoid hard bottom or structurally complex areas (boulder field, rocky shores, canyons, seamounts, etc.) that may contain some of the most important areas for fish and other forms of marine life. Although we adjusted for catchability, catch rates at any given location can

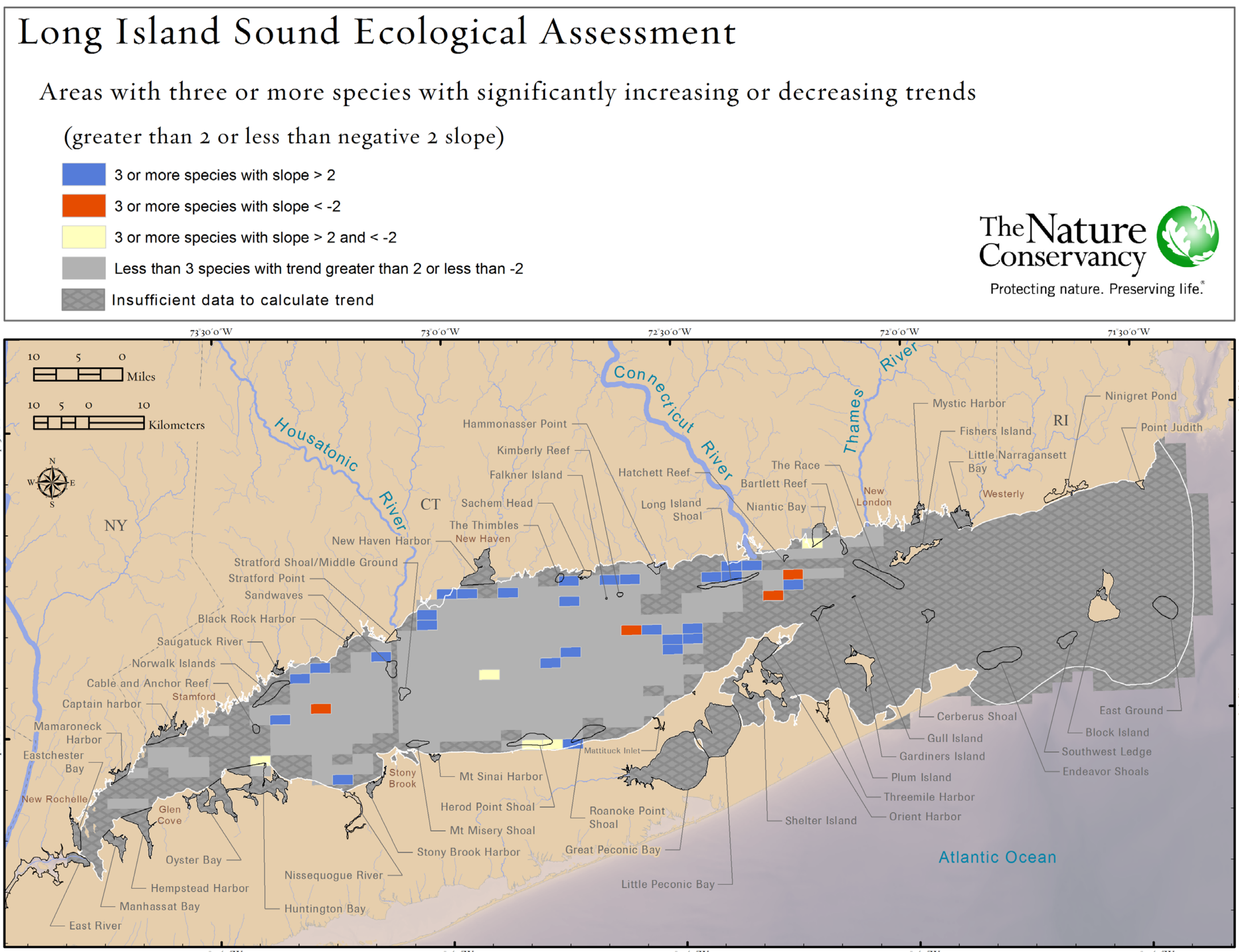


Figure 6.9. Summary of significantly increasing and decreasing trends.

be heavily influenced by day/night differences in species distribution within the water column, and by seasonal variations in species distribution within their geographic range. As noted above, some species are also able to avoid capture in trawls by using sensory or behavioral capabilities. By focusing on persistence across decades and by correcting the data for sampling effort and detectability, we accounted for many of these inconsistencies. Thus our results can be interpreted with confidence in the areas where we had data, but it is difficult to project beyond the footprint of the survey.

Results and Synthesis

Species groups

There were 114 species present in the trawl sampling over the three octads.

To analyze fish and invertebrate persistence patterns we grouped the species into three fish groups: diadromous, demersal, and pelagic, and one macro-invertebrate group. Details on the species included in each group are given below. The total number of species found in a cell over the entire sampling period ranged from 6 to 51, with the highest levels of richness across all trawls being at the coast and river mouths, and in the central basin.

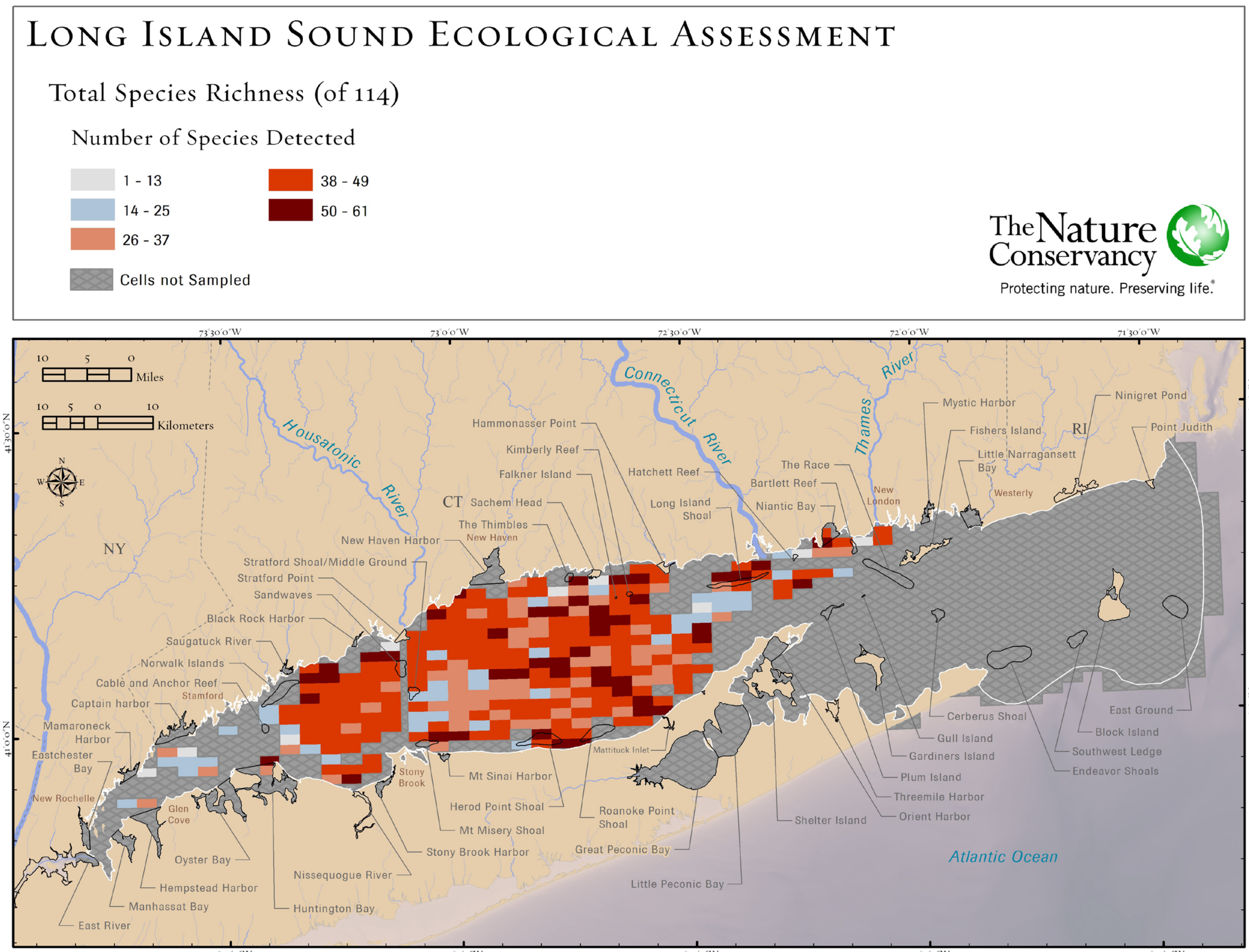


Figure 6.10. Species richness based on all 114 species.

Grouping individual species into functionally-related groups allows the larger body of information that comes from multiple species to be used and integrated in the process of identifying places, or cells, that are ecologically notable – in short, a greater set of indicators or signals to differentiate these areas. Utilizing these groups instead of lumping all species together allows the distinct characteristics between groups to be accounted for. This allows us to see which areas appear most significant for each group and to see a diversity of places that may be ecologically notable.

By highlighting cells that have shown persistence of multiple species within each group we capture areas that are ecologically notable. We hypothesize that these areas contain the conditions or resources needed to persistently support marine life, whether for spawning, rearing, foraging, refuge, or other ecological needs of the target species. Within each species group, we have focused on a count of the number of species with a high weighted persistence score.

Species richness

We also looked at what areas had the greatest species richness, or the number of species present in an area. (Figure 6.10). We included an inset of the species richness analysis in the maps of weighted persistence to allow for comparison of the two – species richness alone compared to the consideration of both weighted persistence and species richness. The species richness insets shown on the maps correspond to the species group being depicted; e.g., figure 6.11 shows the weighted persistence of demersal fish and the inset shows the species richness of demersal fish.

Demersal fish

Fifty-nine species were classified as demersal fish. This group included the majority of all the sampled species and many familiar fish such as cod, skates and flounder (Table 6.2). Weighted Persistence patterns for this group showed a concentration of high persistence areas in the central region of the Sound, particularly in the deeper sand flats directly south of Falkner Island. This area had 28-34 demersal species total, and 14-15 demersal species with persistence scores of 3.6 or greater (“high weighted persistence”).

To explore demersal fish persistence patterns further they were grouped into five subgroups (see Table 6.2). Three subgroups,) sharks and skates, gadids, and flatfish, represent taxonomically similar species; A fourth subgroup represents six species that are structure oriented. The remaining species constituted the fifth subgroup which, other than searobins, were less abundant but fall into a wide variety of taxa and life history types. Each of these 5 groups are mapped below.

Table 6.2. Demersal fish subgroups.

Common Name / ***Scientific Name***	**Subgroup**
Barndoor skate *Dipturus laevis*	Elasmobranch
Clearnose skate *Raja eglanteria*	Elasmobranch
Little skate *Leucoraja erinacea*	Elasmobranch
Roughtail stingray *Dasyatis centroura*	Elasmobranch
Smooth dogfish *Mustelus canis*	Elasmobranch
Spiny dogfish *Squalus acanthius*	Elasmobranch
Winter skate *Leucoraja ocellata*	Elasmobranch
Atlantic cod *Gadus morhua*	Gadids
Fourbeard rockling *Enchelyopus cimbrius*	Gadids
Haddock *Melanogrammus aeglefinus*	Gadids
Pollock *Pollachius virens*	Gadids
Red hake *Urophycis chuss*	Gadids
Silver hake *Merluccius bilinearis*	Gadids
Spotted hake *Urophycis regia*	Gadids
Fourspot flounder *Paralichthys oblongus*	Pleuronectids

Table 6.2 Continued. Demersal fish subgroups.

Hogchoker *Trinectes maculatus*	Pleuronectids
Smallmouth flounder *Etropus microstomus*	Pleuronectids
Summer flounder *Paralichthys dentatus*	Pleuronectids
Windowpane flounder *Scophthalmus aquosus*	Pleuronectids
Winter flounder *Pseudopleuronectes american*	Pleuronectids
Yellowtail flounder *Pleuronectes ferrugineus*	Pleuronectids
Black sea bass *Centropristes striata*	structure oriented
Cunner *Tautogolabrus adspersus*	structure oriented
Oyster toadfish *Opsanus tau*	structure oriented
Rock Gunnel *Pholis gunnellus*	structure oriented
Scup *Stenotomus chrysops*	structure oriented
Tautog *Tautoga onitis*	structure oriented
American sand lance *Ammodytes americanus*	Other: misc.
Atlantic silverside *Menidia menidia*	Other: misc.
Atlantic croaker *Micropogonias undulatus*	Other: misc.
Bigeye *Priacanthus arenatus*	Other: misc.
Spot *Leiostomus xanthurus*	Other: misc.
Striped searobin *Prionotus evolans*	Other: misc.
Conger eel *Conger oceanicus*	Other: misc.
Dwarf goatfish *Upeneus parvus*	Other: misc.
Fawn cusk-eel *Lepophidium profundorum*	Other: misc.
Feather blenny *Hypsoblennius hentz*	Other: misc.

Goosefish/monkfish *Lophius americanus*	Other: misc.
Grubby *Myoxocephalus aeneus*	Other: misc.
Lined seahorse *Hippocampus erectus*	Other: misc.
Longhorn sculpin *Myoxocephalus octodecemspin*	Other: misc.
Lumpfish *Cyclopterus lumpus*	Other: misc.
Naked goby *Gobiosoma bosci*	Other: misc.
Northern kingfish *Menticirrhus saxatilis*	Other: misc.
Northern Pipefish *Syngnathus fuscus*	Other: misc.
Northern Puffer *Sphoeroides maculatus*	Other: misc.
Northern Searobin *Prionotus carolinus*	Other: misc.
Northern Sennet *Sphyraena borealis*	Other: misc.
Northern Stargazer *Astroscopus guttatus*	Other: misc.
Ocean Pout *Macrozoarces americanus*	Other: misc.
Planehead Filefish *Monacanthus hispidus*	Other: misc.
Red Cornetfish *Fistularia petimba*	Other: misc.
Red Goatfish *Mullus auratus*	Other: misc.
Sea Raven *Hemitripterus americanus*	Other: misc.
Seasnail *Liparis atlanticus*	Other: misc.
Short Bigeye *Pristigenys alta*	Other: misc.
Striped Burrfish *Chilomycterus schoepfi*	Other: misc.
Striped Cusk-Eel *Ophidion marginatum*	Other: misc.
Weakfish *Cynoscion regalis*	Other: misc.

Winter Flounder, a demersal fish assessed by LISEA.
Credit: NOAA

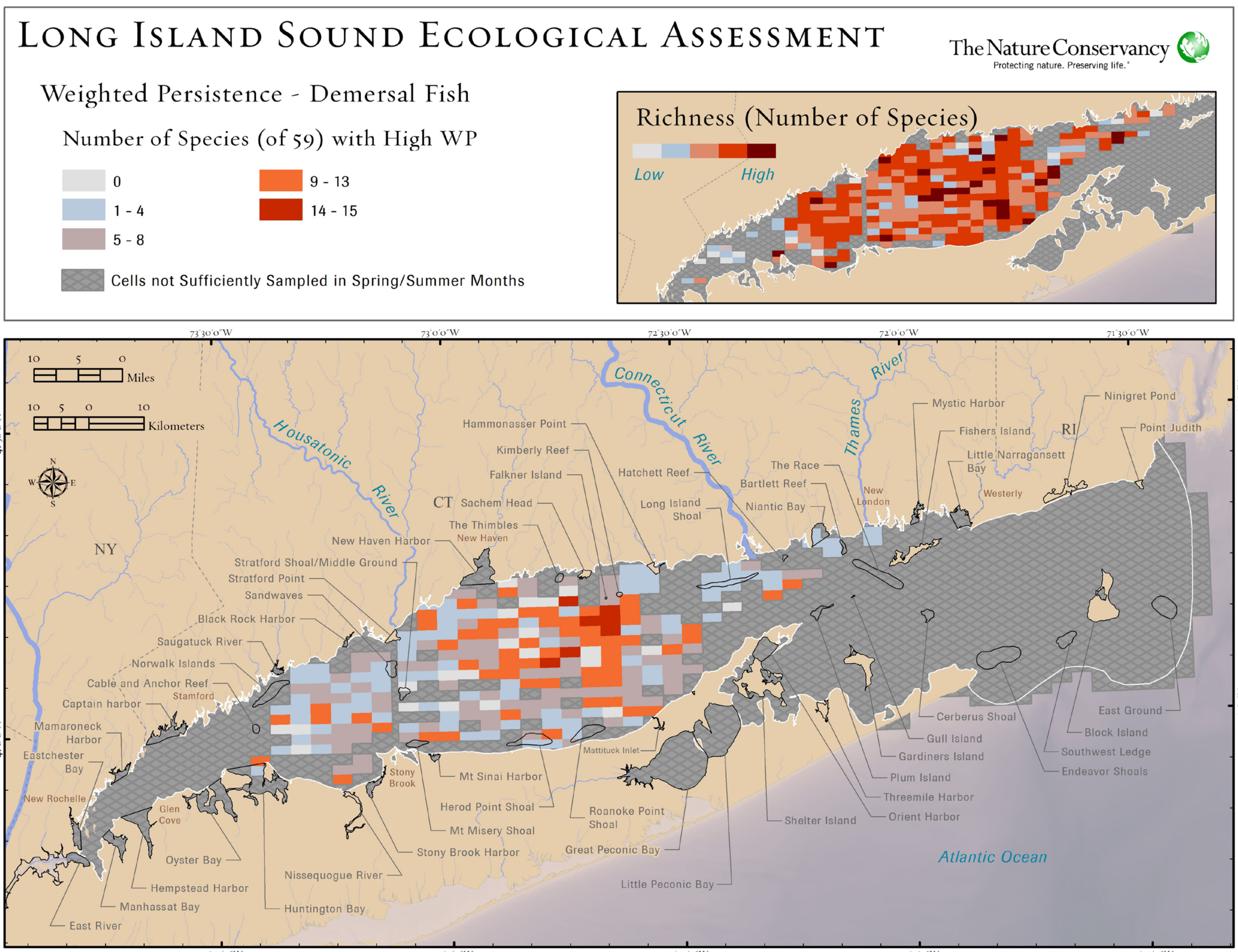


Figure 6.11. Demersal fish weighted persistence (with demersal fish richness inset). High WP is a score of 3.6 or higher.

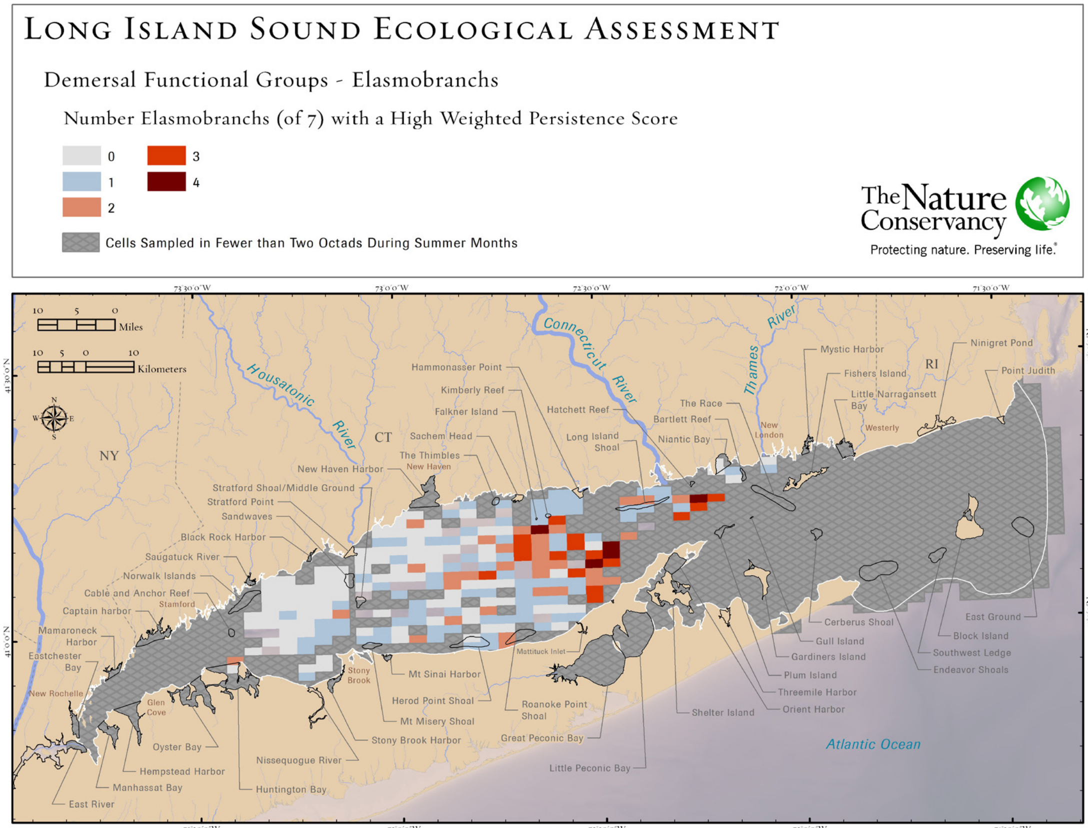


Figure 6.12.
Elasmobranch (skates and rays) subgroup weighted persistence.

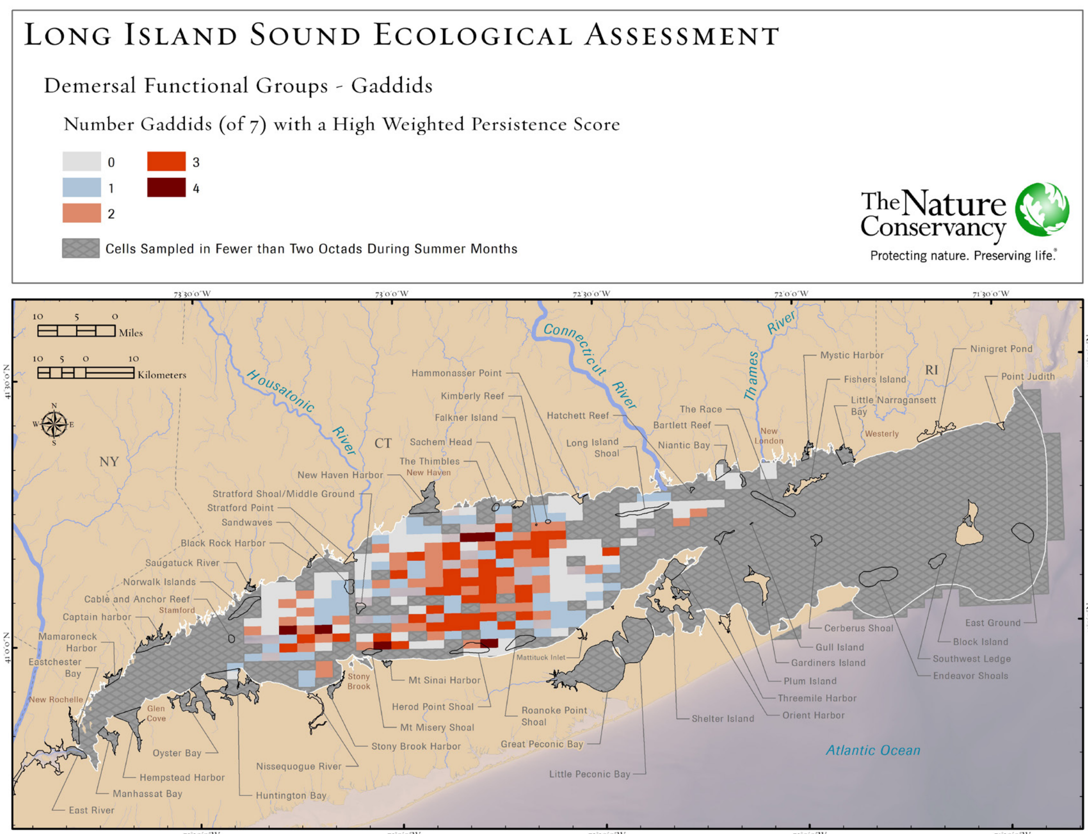


Figure 6.13.
Gadids (cod and haddock) subgroup weighted persistence.

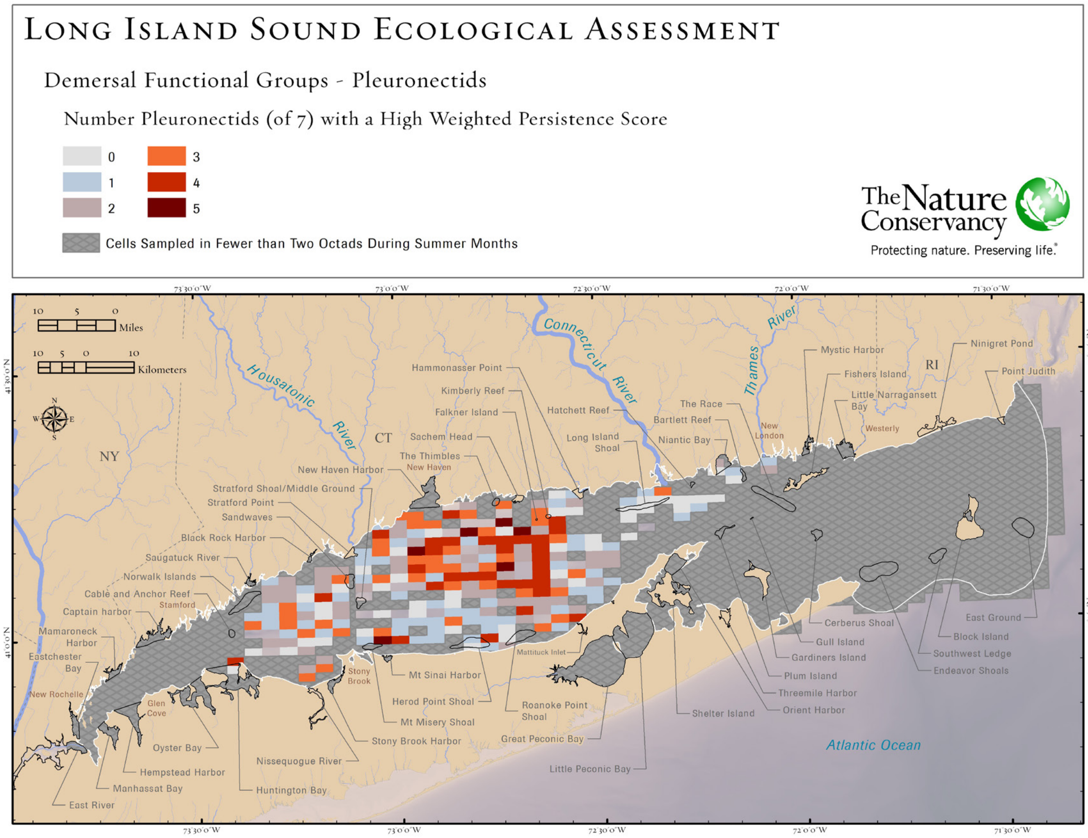


Figure 6.14. Pleuronectid subgroup weighted persistence.

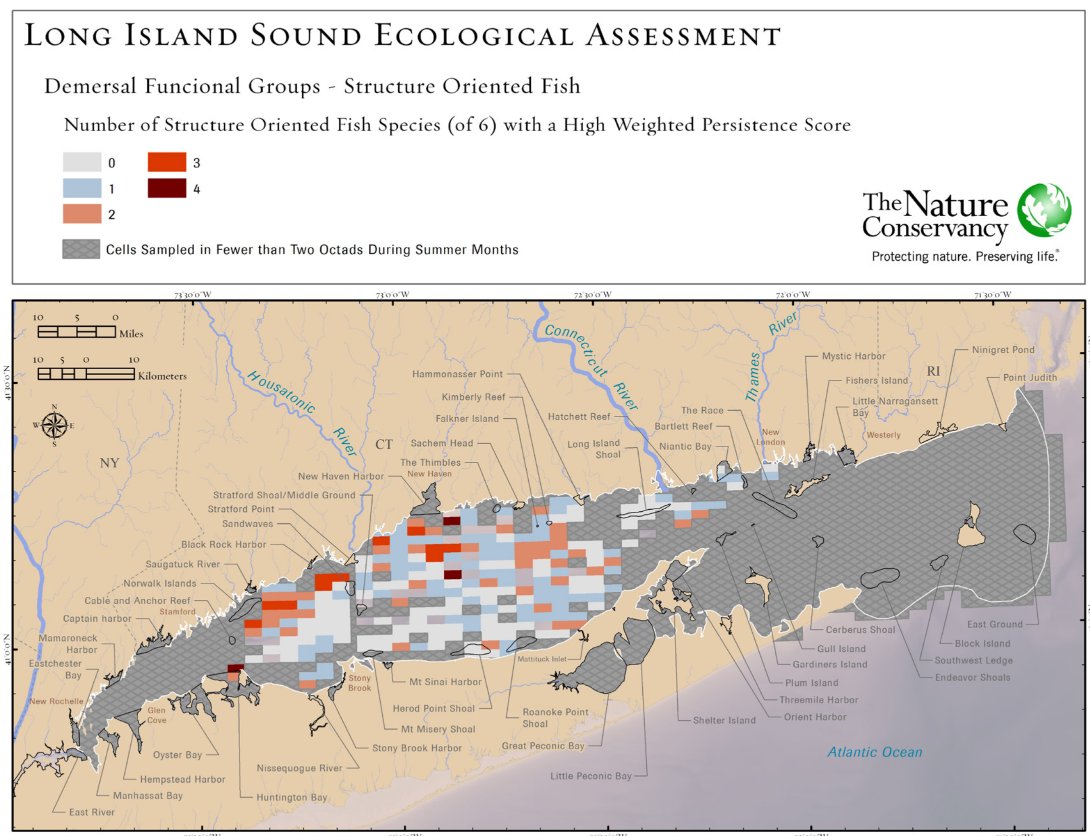


Figure 6.15. Structure-oriented subgroup weighted persistence.

Diadromous fish

The diadromous fish group included 13 species that utilize both fresh and salt water during their life histories.

Persistence patterns for these species centered on the outlets of large freshwater river systems draining into the Sound, especially the Housatonic and Connecticut Rivers (Figure 6.17). These areas had 5-7 diadromous species total, and 4-5 of those had persistence scores of 3.6 or greater (the threshold value for high weighted persistence).

Alewife *(Alosa pseudoharengus)*	Gizzard shad *(Dorosoma cepedianum)*
American eel *(Anguilla rostrata)*	Hickory shad *(Alosa mediocris)*
American shad *(Alosa sapidissima)*	Rainbow smelt *(Osmerus mordax)*
Atlantic salmon *(Salmo salar)*	Sea lamprey *(Petromyzon marinus)*
Atlantic sturgeon *(Acipenser oxyrinchus)*	Striped bass *(Morone saxatilis)*
Atlantic tomcod *(Microgadus tomcod)*	White perch *(Morone americana)*
Blueback herring *(Alosa aestivalis)*	

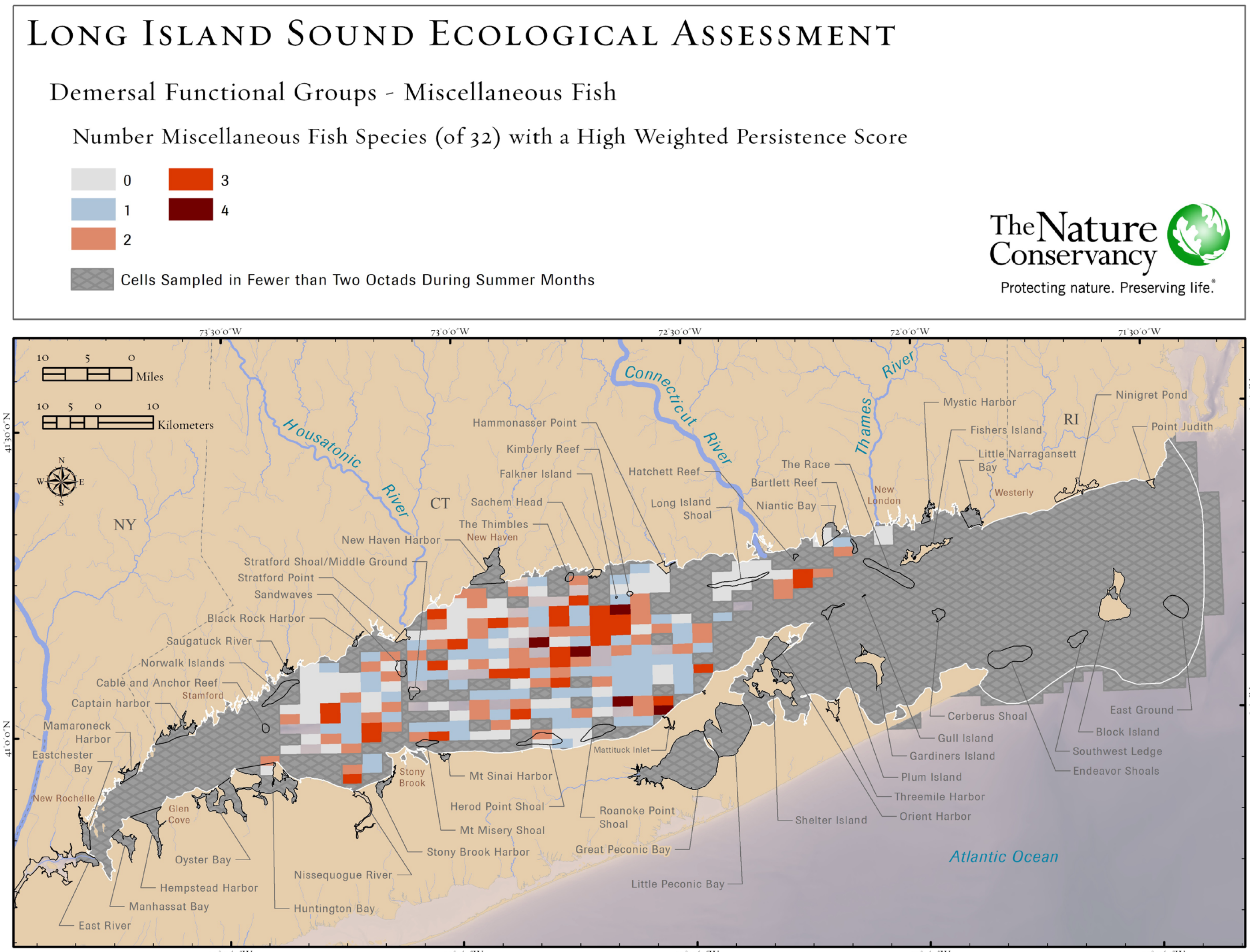


Figure 6.16. Miscellaneous subgroup weighted persistence.

Atlantic salmon (foreground) are included in the diadromous fish sampling.
Credit: © Hans-Petter Fjeld

The pelagic fish species group includes Crevalle jack show here.
Credit: © Kevin Lawyer

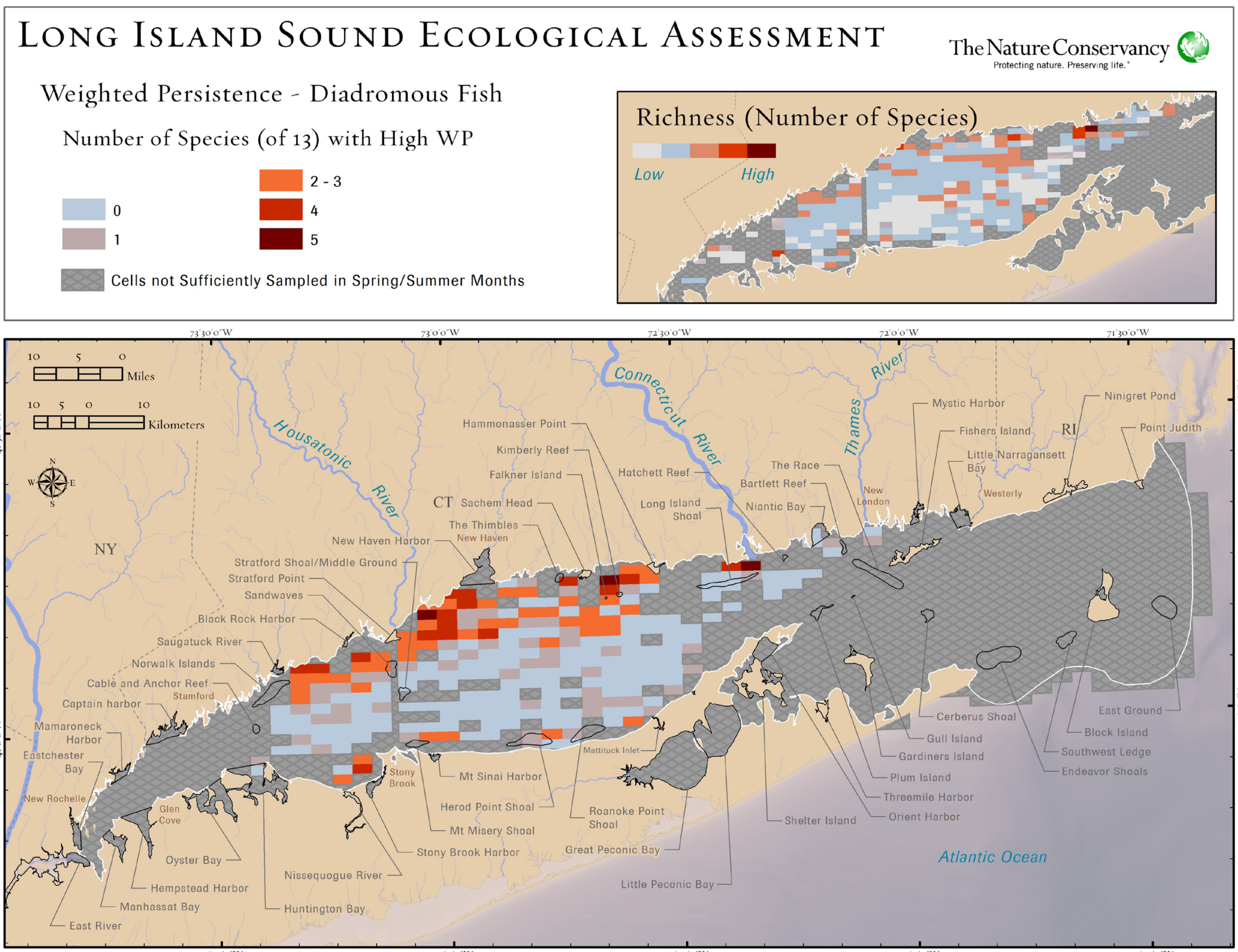


Figure 6.17. Diadromous fish weighted persistence (with richness).

Pelagic fish

The pelagic fish group consisted of 23 species that characteristically use the water column and may migrate in or out of the Sound during particular seasons or years. The list includes:

- Atlantic bonito (*Sarda sarda*)
- Atlantic herring (*Clupea harengus*)
- Atlantic mackerel (*Scomber scombrus*)
- Atlantic menhaden (*Brevoortia tyrannus*)
- Banded rudderfish (*Seriola zonata*)
- Bay anchovy (*Anchoa mitchilli*)
- Bigeye scad (*Selar crumenophthalmus*)
- Blue runner (*Caranx crysos*)
- Bluefish (*Pomatomus saltatrix*)
- Butterfish (*Peprilus triacanthus*)
- Crevalle jack (*Caranx hippos*)
- Gray triggerfish (*Balistes capriscus*)
- Lookdown (*Selene vomer*)
- Mackerel scad (*Decapterus macarellus*)
- Moonfish (*Selene setapinnis*)
- Rough scad (*Trachurus lathami*)
- Round herring (*Etrumeus teres*)
- Round scad (*Decapterus punctatus*)
- Sandbar shark (*Carcharhinus plumbeus*)
- Sharksucker (*Echeneis naucrates*)
- Spanish mackerel (*Scomberomorus maculatus*)
- Striped anchovy (*Anchoa hepsetus*)
- Yellow jack (*Caranx bartholomaei*)

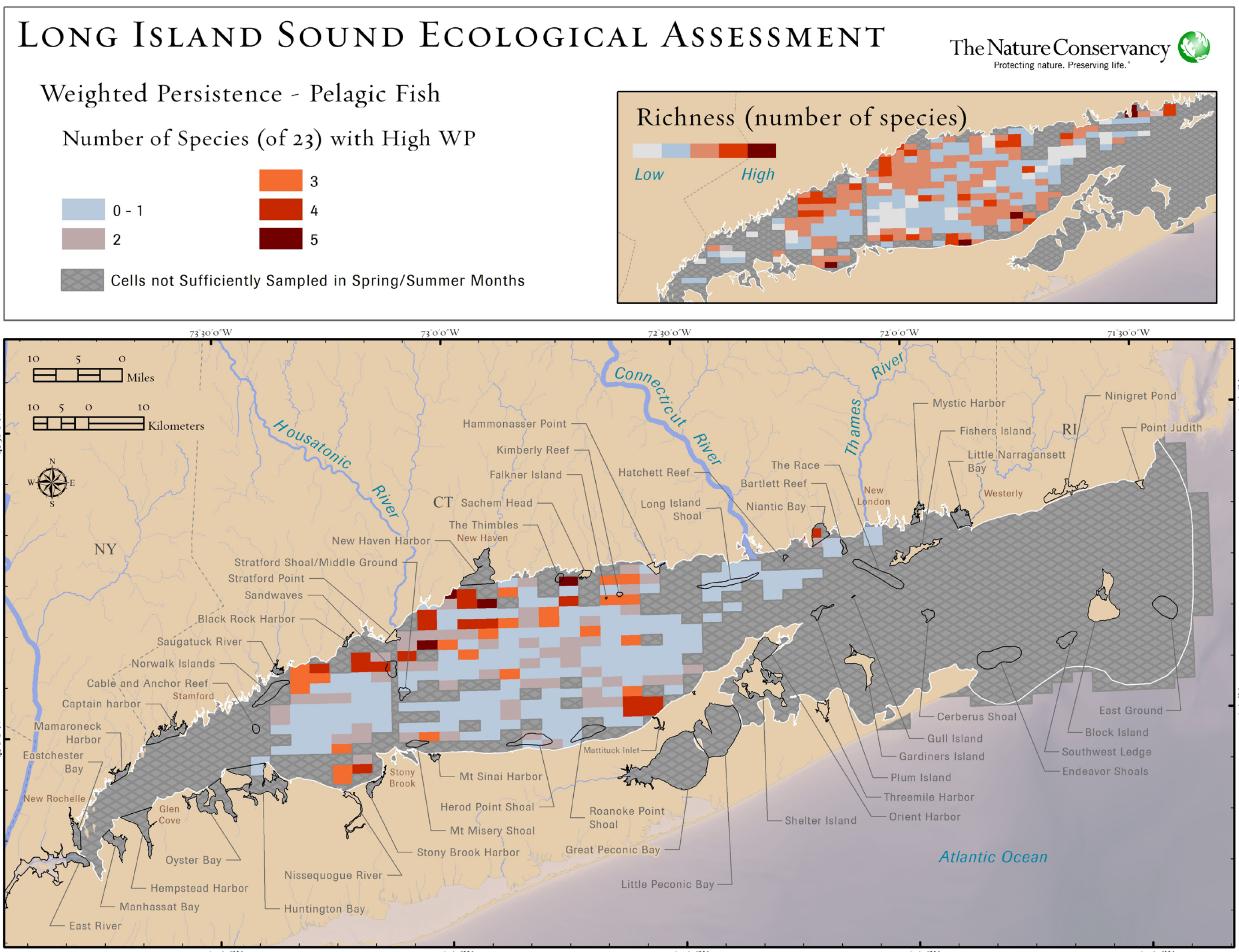


Figure 6.18. Pelagic fish weighted persistence (with richness).

Persistence patterns for this group are concentrated along the coastal region of the northern Sound and the Smithtown Bay and Mattituck Inlet areas along the south coast. These areas had 9-15 total species with 4-5 of them having persistence scores of 3.6 or higher (high weighted persistence) (Figure 6.18).

Macroinvertebrates

The macroinvertebrate group consisted of 8 species that were consistently detected in the trawl samples. There were another 11 invertebrates, or 19 in all, that were detected as part of the overall sampling and used in the species richness analysis noted above). We calculated persistence values, corrected them for effort and calculated their weighted persistence score for each cell using the same methods as for the fish species. The invertebrate group included:

American lobster *(Homarus americanus)*	Horseshoe crab *(Limulus Polyphemus)*
Blue crab *(Callinectes sapidus)*	Long-Finned squid *(Loligo pealeii)*
Bobtail squid *(Sepiola)*	Mantis shrimp *(Squilla empusa)*
Boreal squid *(Illex illecebrosus)*	Rock crab *(Cancer irroratus)*

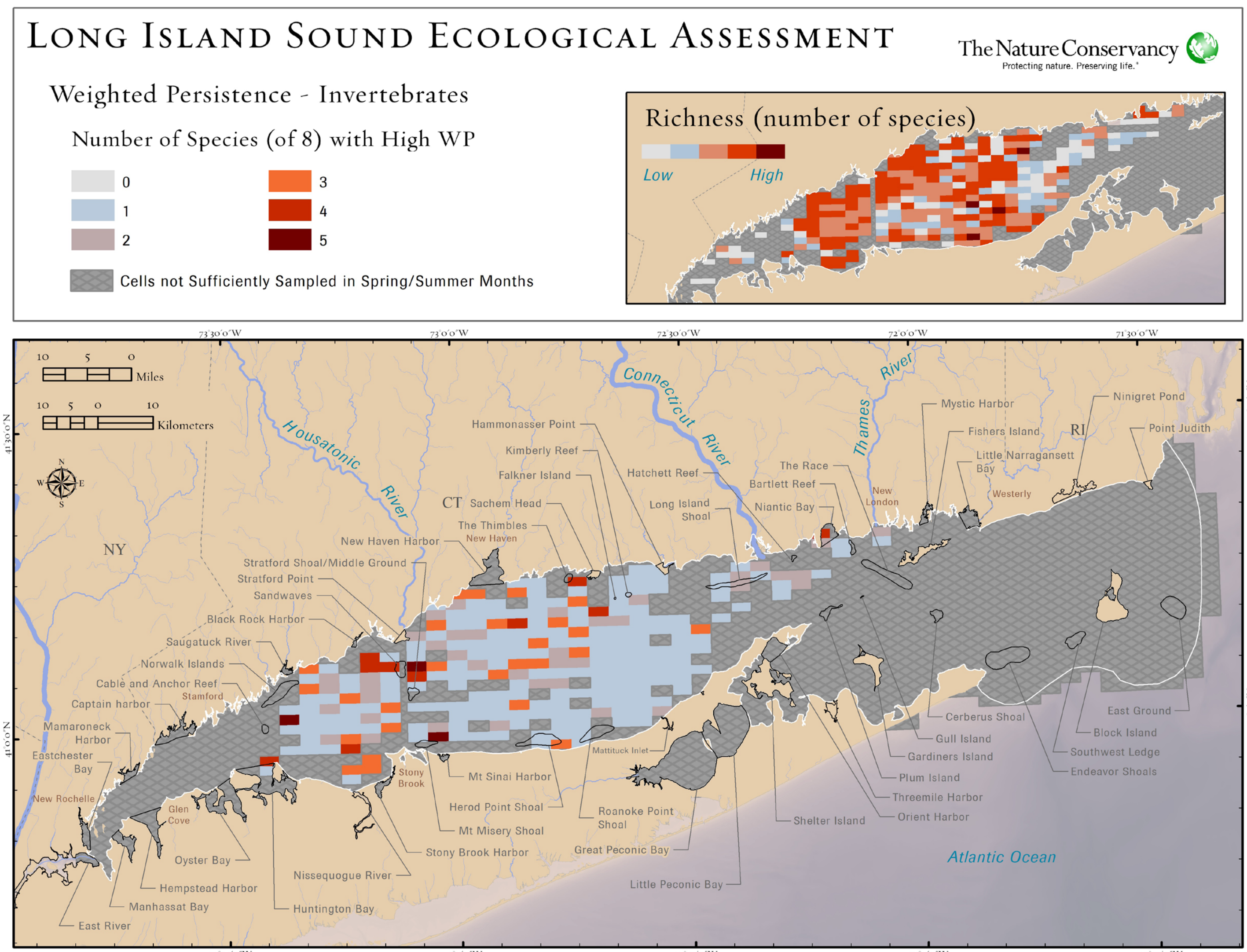


Figure 6.19. Invertebrate weighted persistence (with richness).

The patterns revealed by the analysis identified the Stratford Shoal, Mt. Misery Shoal and Anchor reef areas as places of particularly high persistence. These areas had 5-6 invertebrate species present and 4-5 of those had persistence scores of 3.6 or greater (high weighted persistence). This suggests that these shoals are particularly important to these species (Figure 6.19).

Persistence patterns across groups

We examined the persistence patterns across species groups by overlaying the previous maps and examining their correspondence across groups. For the most part, the dominant demersal fish areas did not overlap with the other groups. Out of 59 high scoring cells, 6 overlapped with pelagic areas and one with invertebrate areas (Figure 6.20). Overlap was higher among the other groups. Twenty-five of the 56 cells identified for diadromous fish overlapped with other groups, and 34 of the 39 cells identified for pelagic fish overlapped with other groups.

In summary, notable areas where species have been persistently found over 26 years at levels higher than expected were different for each species group. Diadromous species centered on the mouths of large rivers. Pelagic species also favored the river mouths as well as coastal regions both north and south. Demersal species were concentrated in the north central area of the Sound just south of Falkner Island. Invertebrate areas were concentrated along the western shoals.

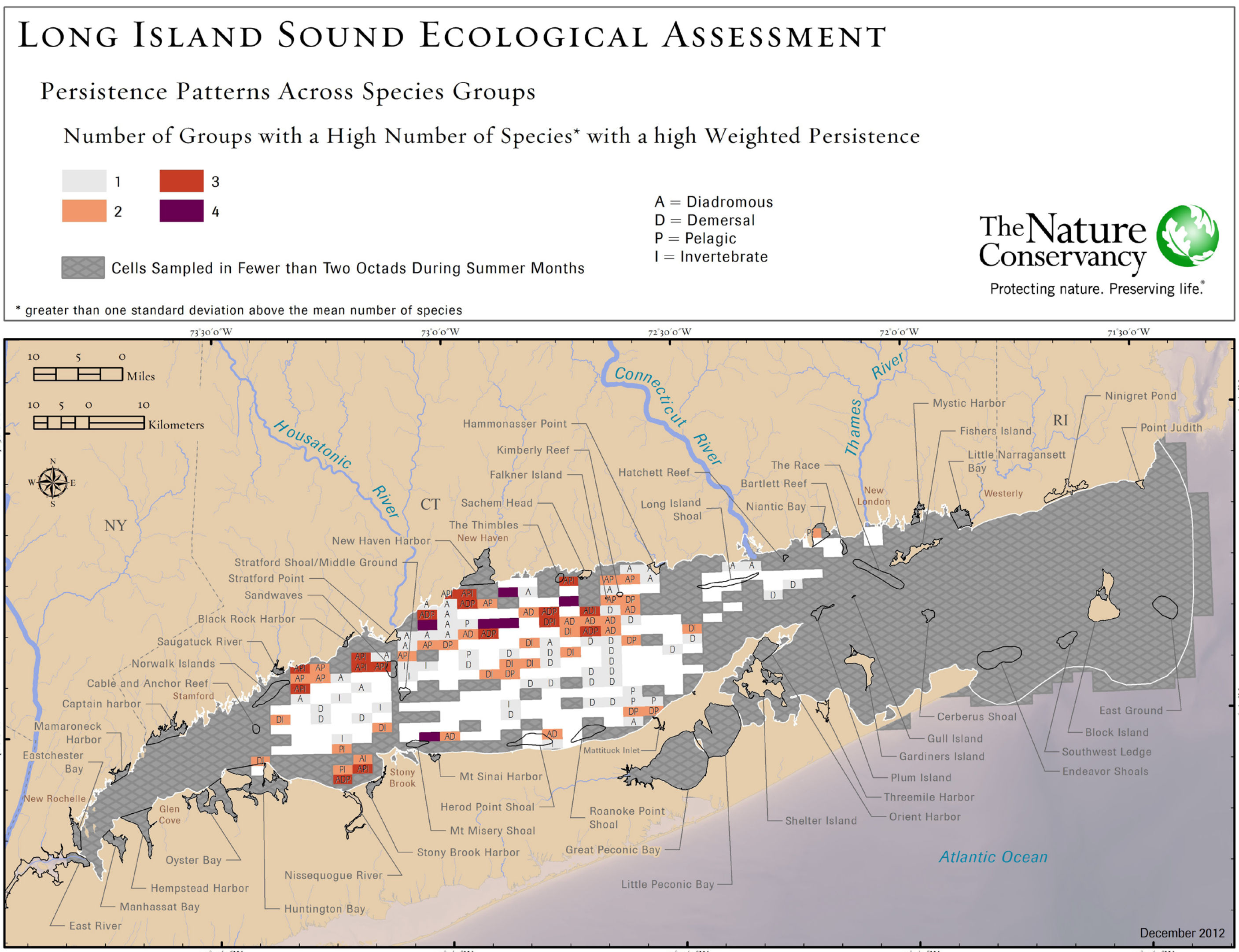


Figure 6.20. Weighted persistence across all species groups.

section 7

ecologically notable places in Long Island Sound

Introduction

The aim of this assessment is to identify notable areas that help sustain the diversity of marine life in the Sound. Places with distinctive ecological features or high-quality common habitats contribute disproportionally to the maintenance of resilient systems and vigorous populations. There are also places that may or may not have easily discernible features yet the biological data reveal them to be spatially significant with relatively high species persistence and diversity. We designed our methods to highlight such places, and through this report, bring them to the attention of the conservation community and policy-makers. Results may inform and contribute to the development of strategies to conserve these places and add to the ongoing and necessary work already performed by state and academic biologists, such as monitoring fish stocks and water quality, and mapping benthic community distributions.

Ecologically notable places (ENP) is the term we have used to refer to these spatially-relevant places in Long Island Sound. As described in Chapter 3, for this assessment there are three fundamental parameters that were used for identifying ecologically notably places:

1. **Species persistence,**
2. **Seafloor complexity and**
3. **Seagrass areas.**

Species persistence is based on long-term field data for fish and invertebrates and provides direct insights into where relatively high concentrations of marine life are actually located. Those areas with the highest numbers of persistent species with strong levels of detection are considered ecologically notable. The **Seagrass** component considers that any areas with detected seagrass, based on the most recent field-based information, are ecologically notable.

Seafloor complexity uses the physical complexity of the seafloor as a predictor or proxy for marine life. The greater the complexity, the greater is the prediction of relative marine life significance (e.g. diversity, persistence and/or abundance). Physical and biological data are used both to delineate and to model seafloor complexity, which is then expected to be correlated to marine life based on relevant literature as described below.

The ecologically notable places of this assessment, then, are based on both direct biological data and summary modeling. It is recognized that a proxy or model, while able to provide potentially valuable insight, is not the same as field data. As such, we have presented each of these analyses separately – the biological data and modeling - to allow for this distinction to be discernible in the results.

Ecologically Notable Places portfolios

In addition to combining species persistence, seafloor complexity and seagrass to depict a single summary of ecologically notable places, the components within each of these are further grouped into two portfolios to depict the two basic submerged environments of the Sound: the seafloor and the water column. Distinguishing ecologically notable places in the seafloor from those in the water column may prove useful for management, conservation or further study. The seafloor portfolio contains the components most affiliated with the seafloor and includes seafloor species persistence, seagrass and seafloor complexity. The water column portfolio contains the species persistence components most affiliated with the water column. Finally, the seafloor and water column portfolios of ecologically notable places are combined into an overall integrated portfolio. This is the full summary of ecologically notable places identified through this assessment.

Species Persistence

Chapter 6 places the fish and invertebrates into 4 groups and develops weighted species persistence results for each, including consideration of species richness. These are the pelagic, demersal, and diadromous fish groups plus the invertebrate group. From this composite of persistence, frequency of detection and species richness, *criteria were developed for distinguishing ecologically notable places for each group*. They represent a selection of the highest ranking persistence areas and as such are a subset of the Chapter 6 results.. The criteria used were as follows: for a given group, cells where the number of species with high weighted persistence relative to all other cells were 1 standard deviation above the mean or greater were considered to be ecologically notable. For example, in the demersal fish group, 9 species represented 1 standard deviation above the mean and these areas are considered ecologically notable. Within this ecologically notable set, we further distinguished areas where the number of species were greater at 2 standard deviations above the mean, e.g. for the demersal fish group, this corresponded to 14 species.

The ecologically notable places identified for each of the groups are presented below. The maps show the 1 standard deviation results in orange and the 2 standard deviation

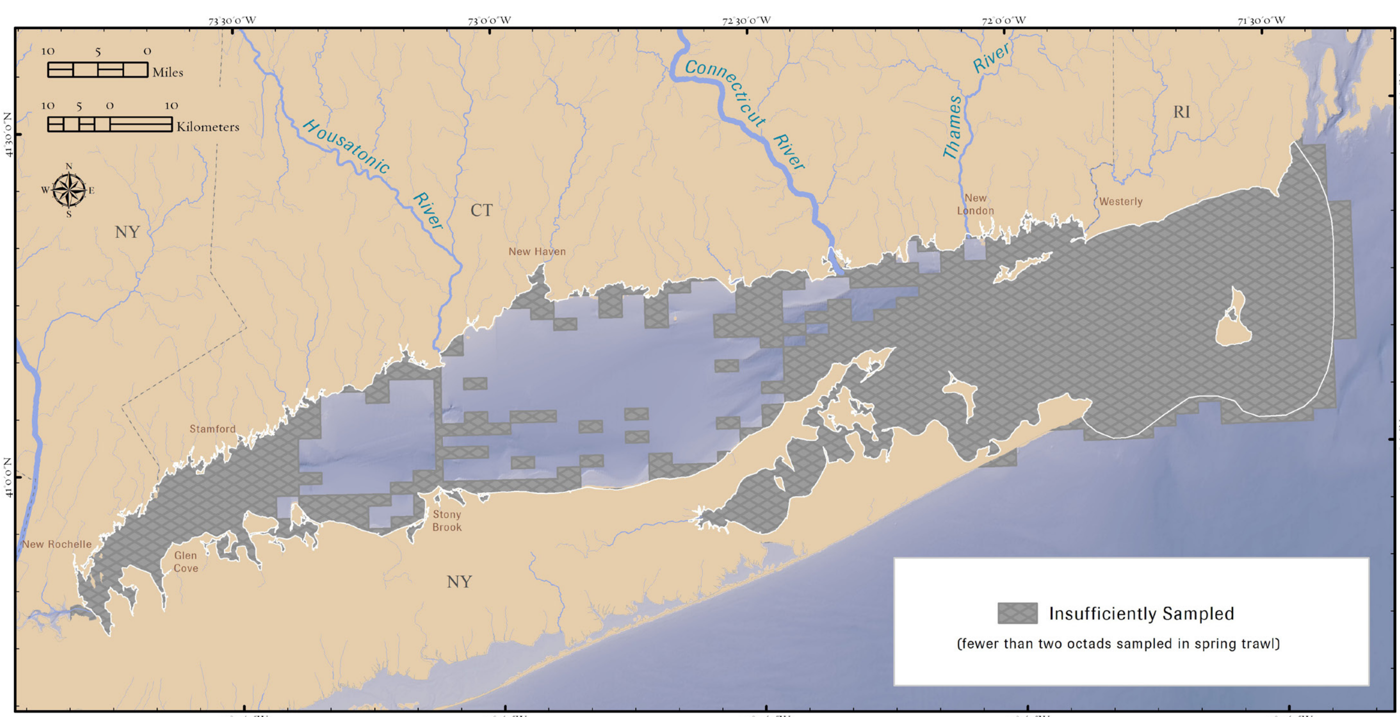


Figure 7.1. Areas sufficiently sampled for a persistence score (light gray). Darker gray patterned areas were sampled in fewer than two of the three octads in spring months and insufficient for the analysis. This map is used in subsequent figures.

results in dark red. As mentioned previously, based on available data, coastal areas and parts of the eastern and western Sound are not well represented.

1. ***Demersal fish persistent areas***: places where many species of demersal fish have been repeatedly and consistently found over three octads of sampling (Figure 7.2). Cells with at least nine demersal fish species with a high weighted persistence (high WP) score (at or over 3.6) were included. The weighted persistence scoring is described previously in Chapter 6.

2. ***Pelagic fish persistent areas***: places where many species of pelagic fish have been repeatedly and consistently found over three octads of sampling (Figure 7.3). Cells with at least three pelagic fish species with a high weighted persistence score (at or over 3.6) were included.

3. ***Diadromous fish persistent areas***: places where many species of diadromous fish have been repeatedly and consistently found over three octads of sampling (Figure 7.4). Cells with at least two diadromous fish species with a high weighted persistence score (at or over 3.6 were included.

4. ***Invertebrates persistent areas***: places where many species of invertebrates have been repeatedly and consistently found over two decades of sampling (Figure 7.5). Cells with at least three invertebrate species with a high weighted persistence score (at or over 3.6) were included.

Seafloor Complexity

Seafloor structural complexity refers to the variety of shapes of the sea bottom, the severity and variety of slopes and changes in depth, and the roughness of the surface itself (e.g. rocky substrates). It also includes consideration of places with high bottom habitat diversity within a given area. Our methods account for each of these characteristics through: 1) hard bottoms (as developed in Chapter 5), which relates to surface roughness; 2) bathymetric complexity (developed below with information from Chapter 5, which relates to the shapes of the sea bottom; and 3) EMU richness (developed below as a subset of the EMU's from Chapter 5) which relates to high bottom habitat diversity.

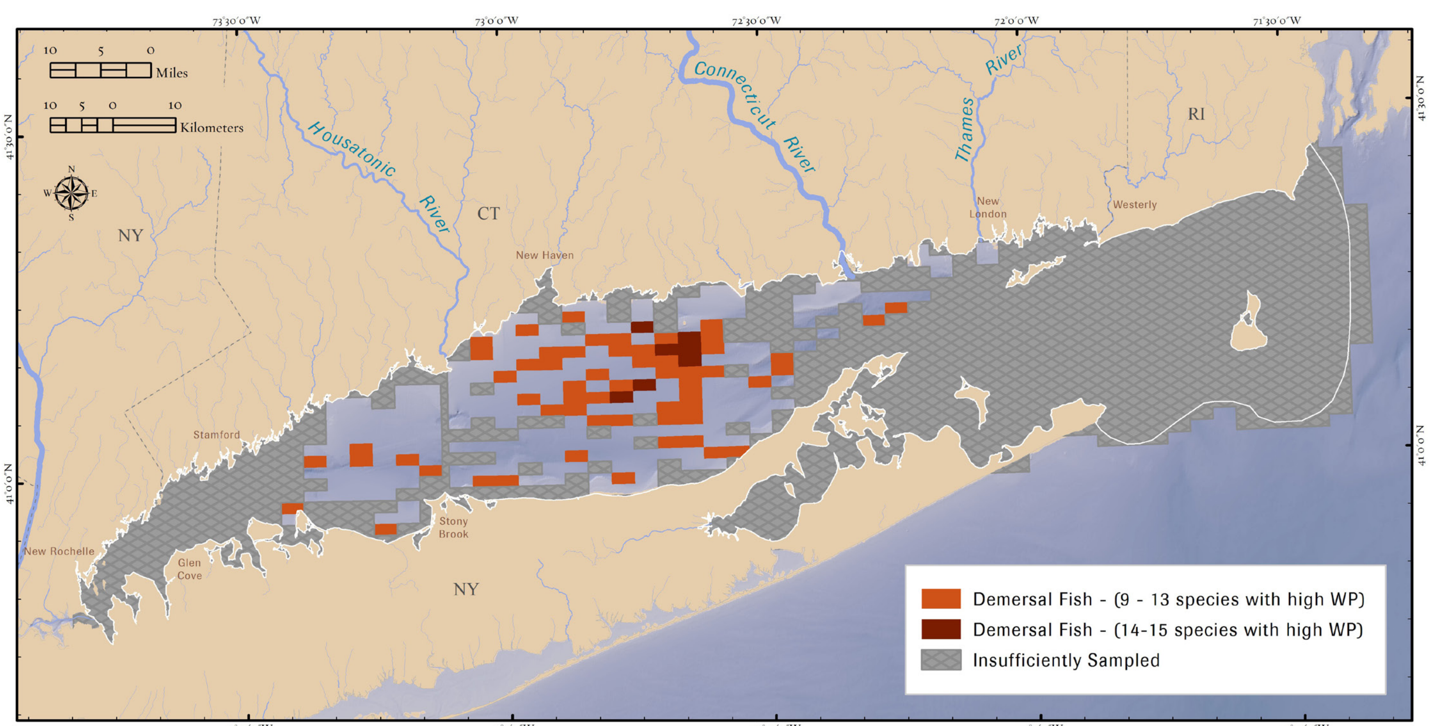


Figure 7.2. Demersal fish persistent areas.

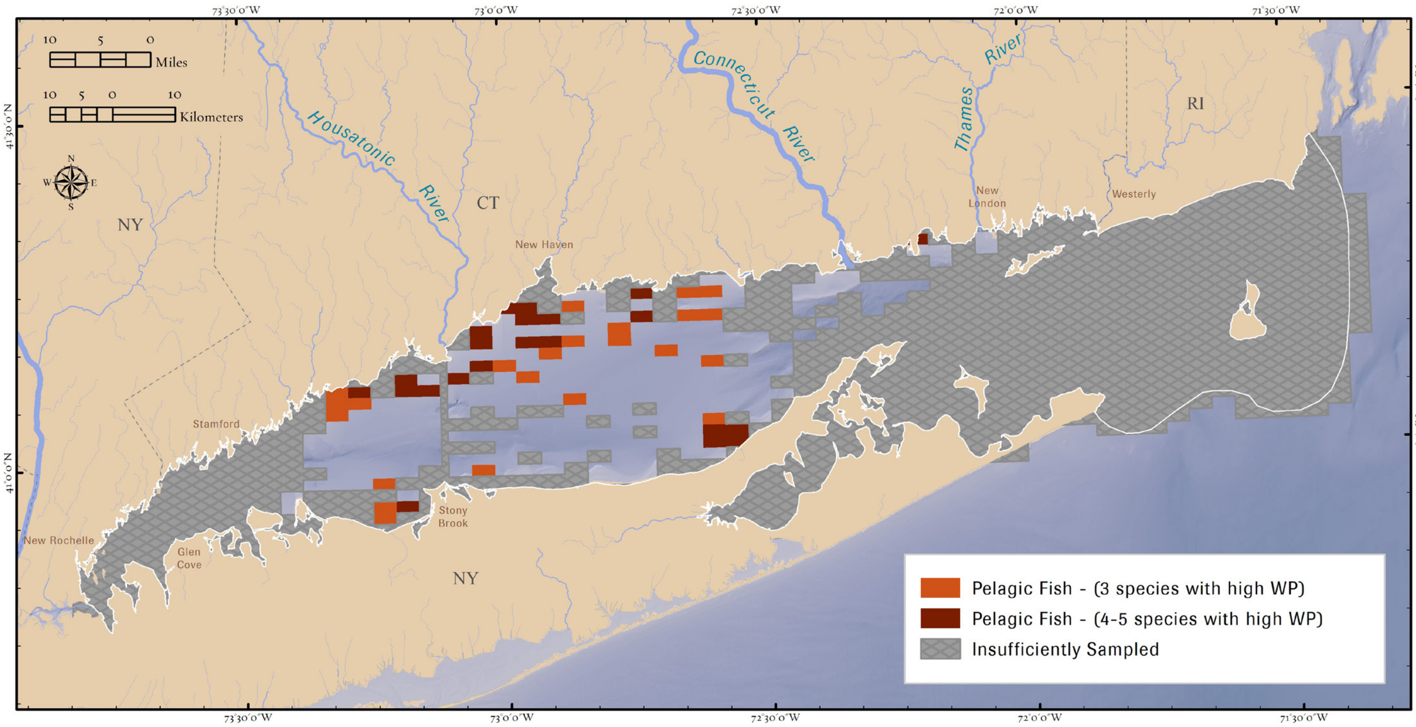


Figure 7.3. Pelagic fish persistent areas.

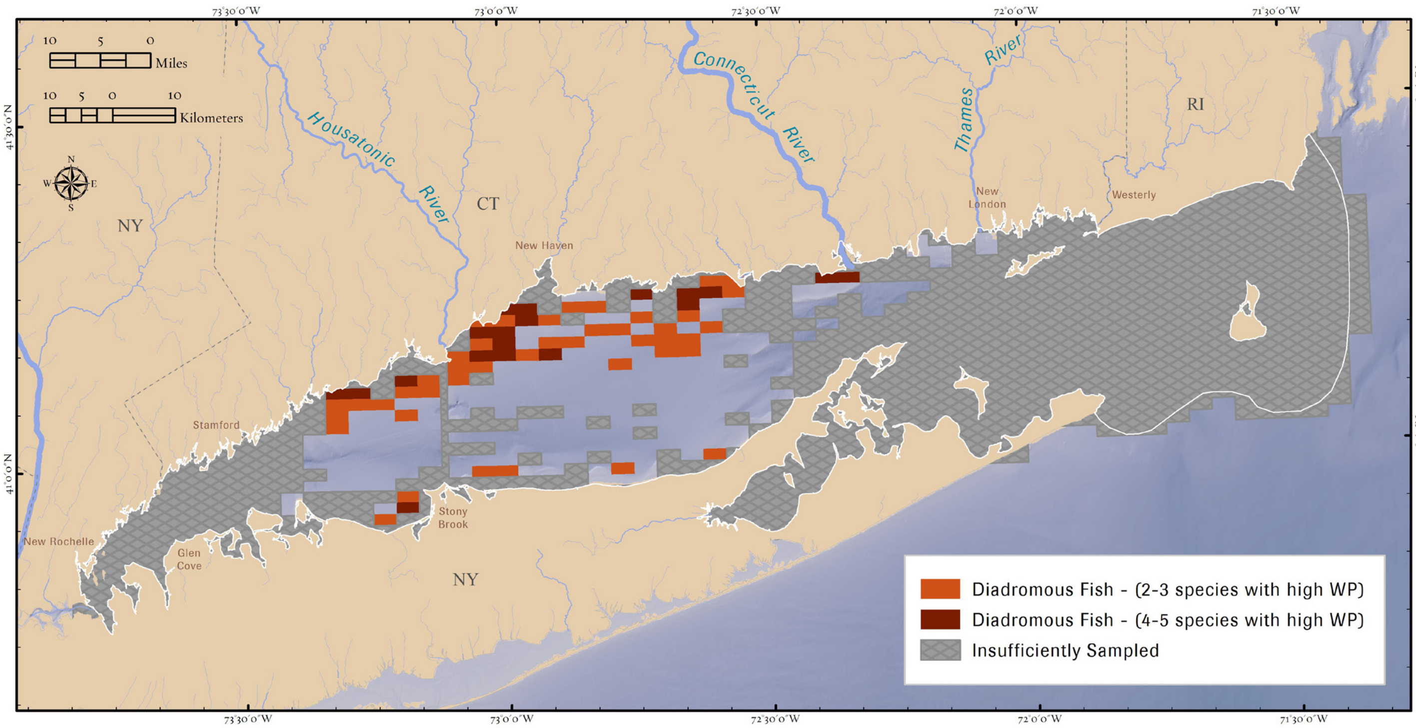


Figure 7.4. Diadromous fish persistent areas.

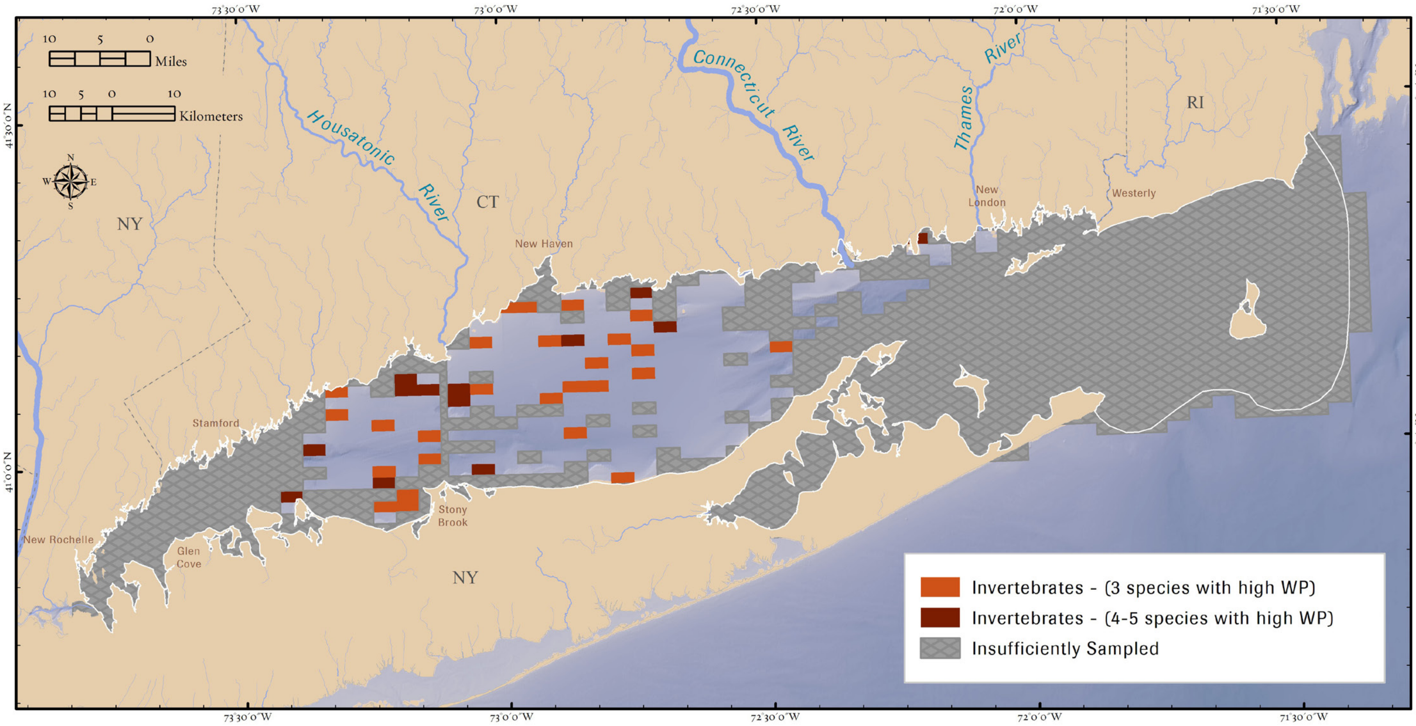


Figure 7.5. Invertebrate persistent areas.

To see the similarity and differences of bathymetric complexity and EMU richness (2 and 3 above), these two parameters are combined into one map.

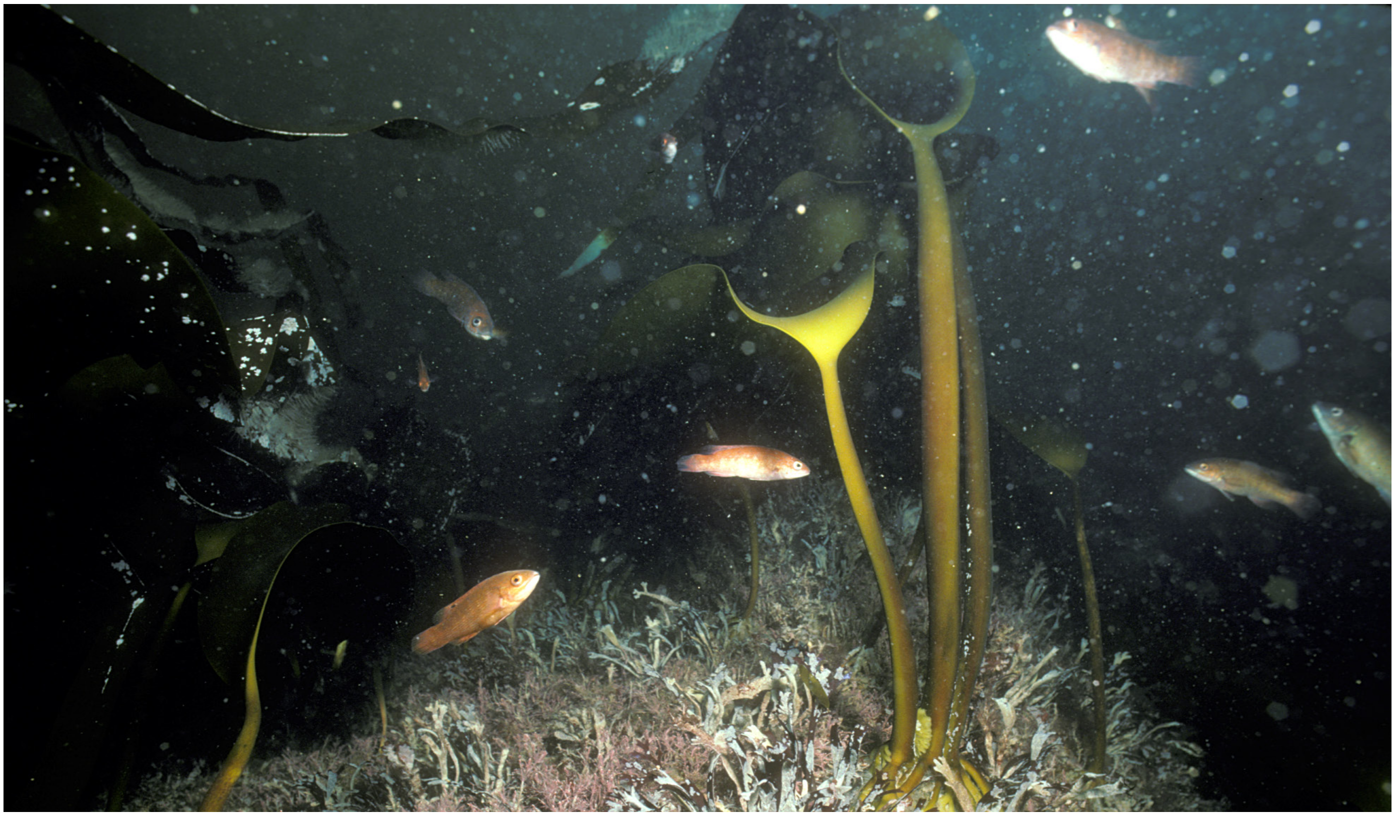
The final seafloor complexity map is created by combining the hard bottom parameter with the bathymetric complexity and EMU richness parameters (1, 2, and 3 above). Because the data on which this map is built extends to all of Long Island Sound, Block Island Sound, and the Peconic Estuary, this map covers the full extent of the study area.

Seafloor complexity as a proxy for marine life

Seafloor complexity is considered a component of the ecologically notable areas based on the correlation between structural complexity and biological diversity - and often abundance - that is well documented in the literature. For example, structural components of the environment attract organisms and serve as a center of biological activity (Peters and Cross 1992). Features such as ledges, shoals, banks, shelves, canyons, and depressions, influence the feeding and shelter-seeking behavior of many species, and small-scale variations in abundance and distribution can be partially attributed to variation in topographic structure (Auster et al. 1995). Because the LISEA does not have sufficient data to confirm the biology in all of these areas, seafloor complexity can be a predictive metric only. As such, the ecological notability of these areas is not as robust as for fish persistence, which is based on extensive field data. However, because of the probable ecological value of these areas and the need to better understand them before activities take place which may disturb them, we include seafloor complexity as a component of ENP.

1. Hard bottom areas:

These are places with rocky substrates, boulder fields, natural hard surfaces, or rock-gravel mixes that support a distinctive biota and enhance the survival of juvenile fish. Known hard bottom locations were combined with a predictive model of all hard bottom locations to create the hard bottom component of the ENPs (as described in more detail in Chapter 5). The map is also shown in Figure 7.6.



Seafloor complexity is generally correlated with greater biological diversity and marine life activity.
Credit: © Peter Auster

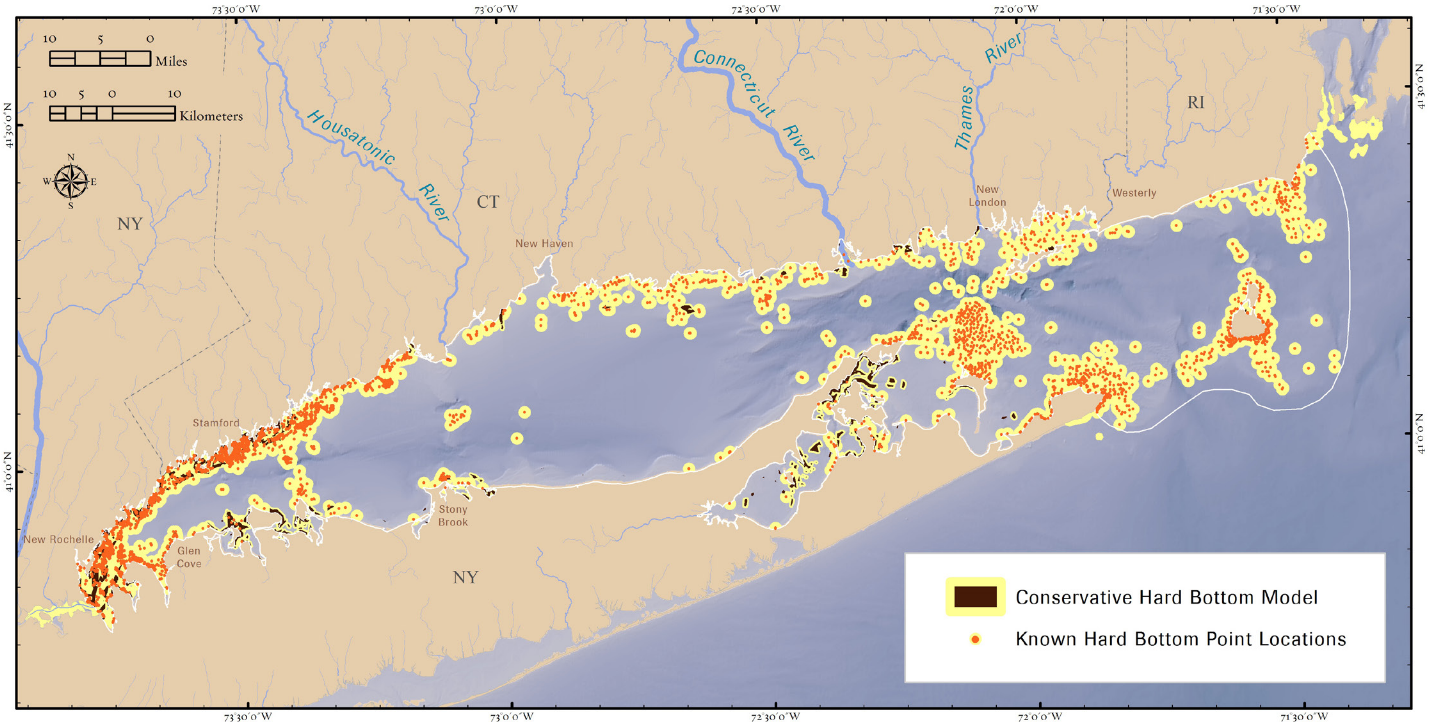


Figure 7.6. Known hard bottom point locations and locations identified as hard bottom using a conservative modeling procedure.

2. Bathymetric complexity:

This measure captures areas with varied steepness or slope within such formations as reefs, canyons, ridges, and channels. Maps of topographic complexity based on these bathymetric data highlight hard bottom (Dunn and Halpin 2009) and other complex habitats valuable for marine life (Rhode Island Coastal Resources Management Council 2011). Like hard bottoms, those areas with the greatest bathymetric variety are generally predicted to be associated with greater concentrations of marine life – whether for diversity and/or abundance. However, as with hard bottoms, this is a predictive metric for ENP and carries with it the same considerations as noted for hard bottoms above. Starting with data and analysis from Chapter 5, the method for generating bathymetric complexity involved creating a raster (grid) dataset representing the relative complexity across the entire study area using a focal statistic neighborhood analysis. The standard deviation of slope within 500 m and within 1,000 meters of each raster cell was calculated. These grids were then added to create a surface that represents the topographic variability with some weighting for proximity. The resulting map (Figure 7.7) distinguishes those areas with an environment of variable slope from more homogeneous environments. The most complex areas are derived from this information and carried forward as a component of overall seafloor

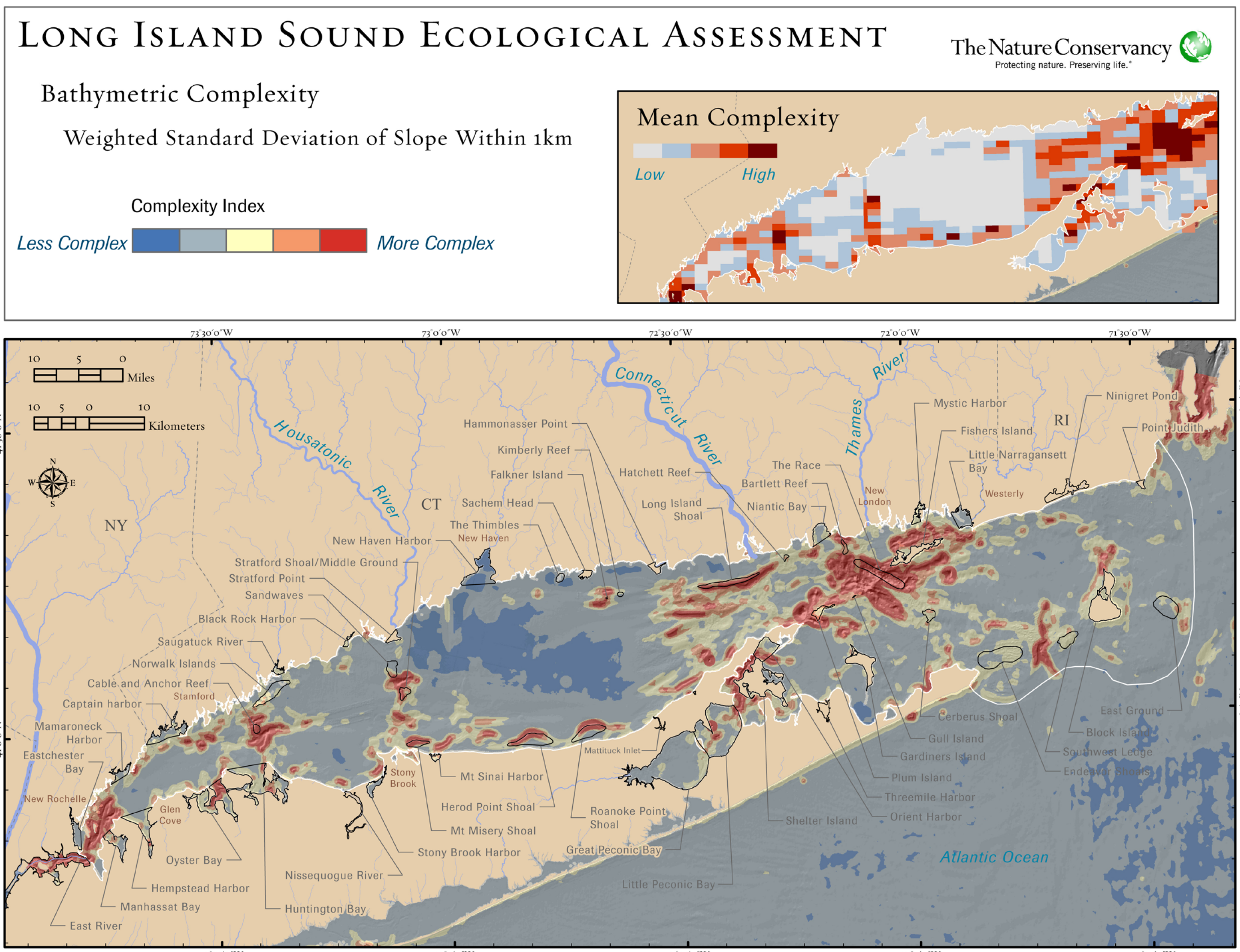


Figure 7.7. Bathymetric complexity: weighted standard deviation of slope within 1km

complexity (see Figure 7.9). Specifically, those areas with a value one standard deviation above the mean or greater are used.

3. EMU richness:

This metric is derived from the EMUs covered in Chapter 5. As with hard bottoms and bathymetric complexity, areas with a high concentration of different EMUs are expected to have greater biodiversity and/or other marine life significance. This is because a high variability of habitats within a given area may be more likely to have a corresponding variability of species. (Figure 7.8). The focal statistic neighborhood analysis used to create the bathymetric complexity map was also used to create the map representing EMU

Black Sea bass and hard bottom structure.
Credit: © www.laptewproductions.com

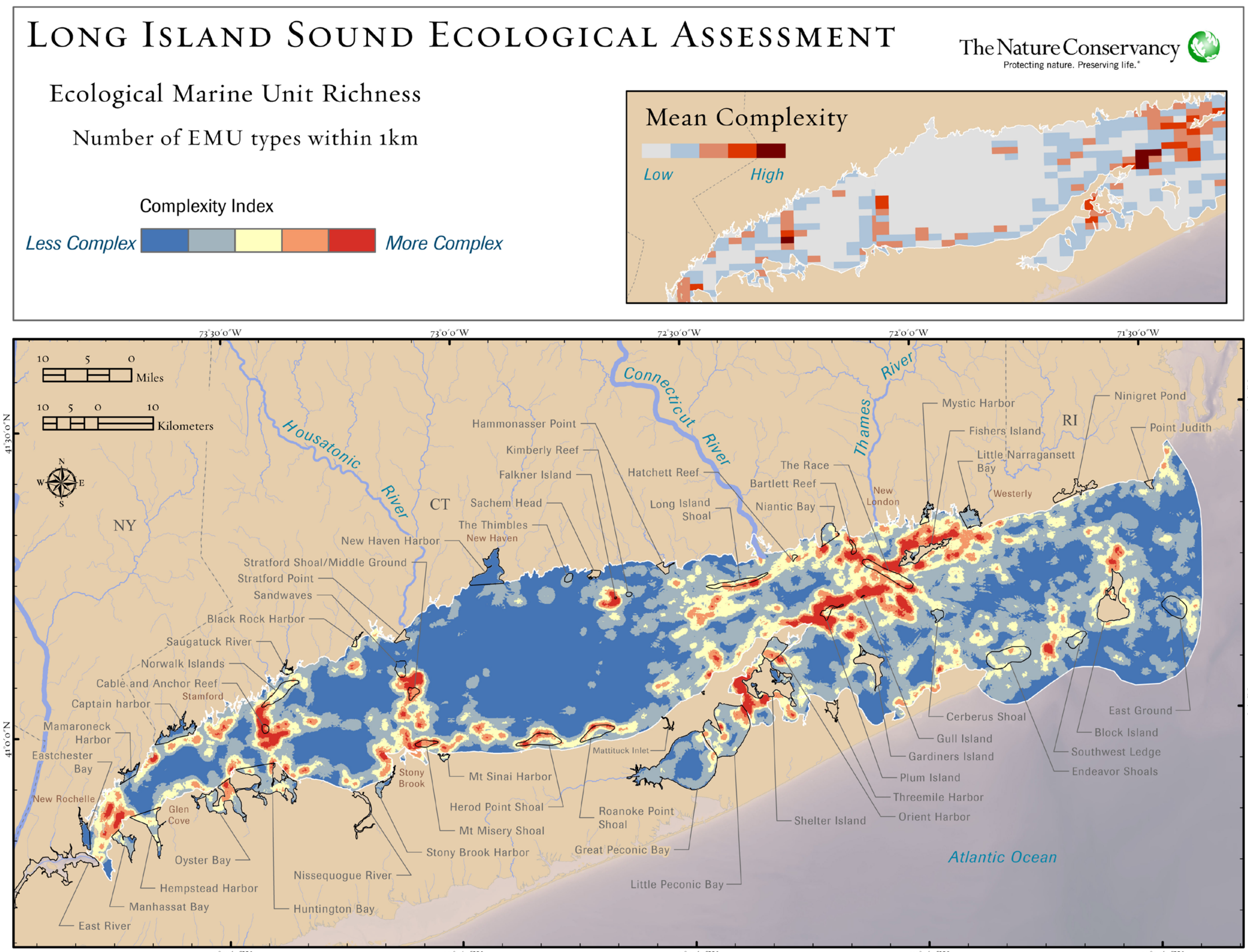


Figure 7.8. EMU richness.

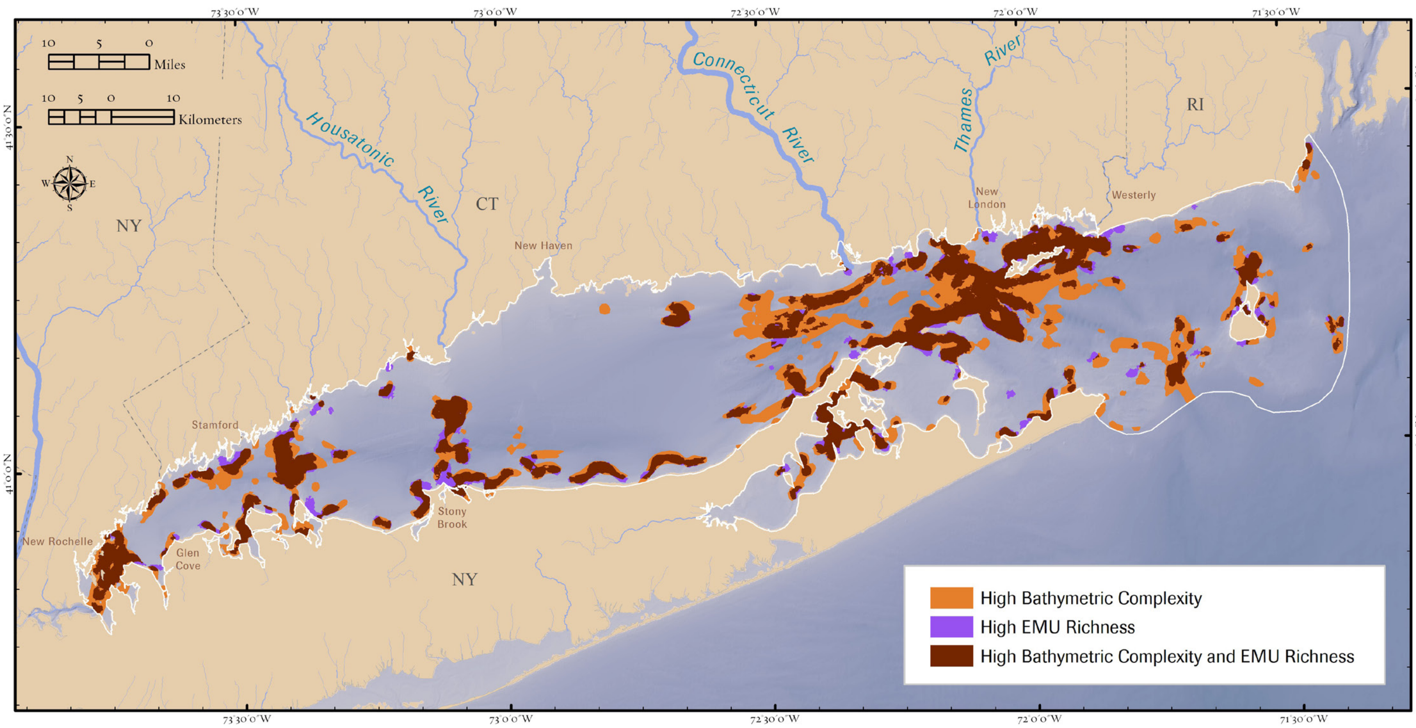


Figure 7.9. Bathymetric complexity, EMU richness, and their overlap.

richness by calculating the number of different EMU types within one kilometer of each cell. The resulting map distinguishes those areas with a large variety of slopes, depths, LPI, and sediment type. The areas with the greatest EMU richness derived from this analysis are carried forward as a component of overall seafloor complexity (see Figure 7.9). Specifically, those areas with a value one standard deviation above the mean or greater are used. As a predictive

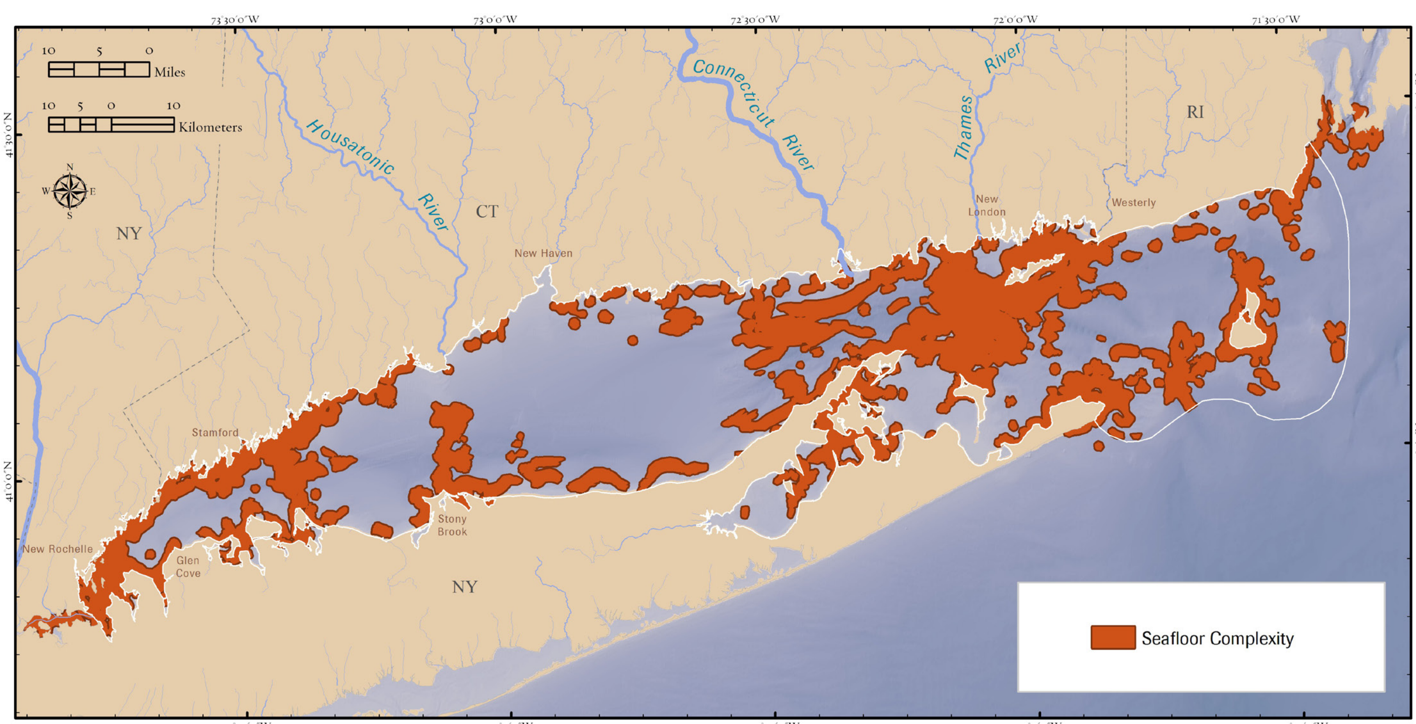


Figure 7.10. Seafloor complexity: hard bottom, bathymetric complexity and EMU richness

metric of ecological notability, EMU richness carries the same considerations as noted above for hard bottoms and bathymetric complexity.

4. Bathymetric complexity and EMU richness combined:
The high end of bathymetric complexity and EMU richness are used as components of the seafloor complexity model and shown together in Figure 7.9. Although consideration of bathymetric complexity is embedded in the EMUs, EMUs distinctly account for depth and sediment grain size. As such both bathymetric complexity and EMU richness are important, but there can be significant overlap between them as well. Figure 7.9 shows both the commonality and distinctions of these components. Taken together these datasets capture places with a high degree of topographic complexity as well as places with variability in depth and sediment grain size. This combined data layer, with the addition of hard bottom becomes the seafloor complexity component of the ENPs.

5. Seafloor complexity:
The variety of bathymetric features, depth and sediment types as described above are within a scale range of 100s of meters whereas the hard bottom component represents complexity at a smaller, local scale. Together these features map a complex environment at multiple scales and constitute the seafloor complexity component of our ecologically notable places. See Figure 7.10.

Seagrass Beds

Seagrass (*Zostera marina*) beds are used for foraging and shelter by many species of fish and other marine organisms, and their ecological importance is well-supported in the literature. The seagrass beds shown as ecologically notable places in this assessment are based on the NWI and CT DEEP data sources..

Long Island Sound eelgrass.
Credit: © Cornell Cooperative Extension Marine Program, www.seagrassLI.org

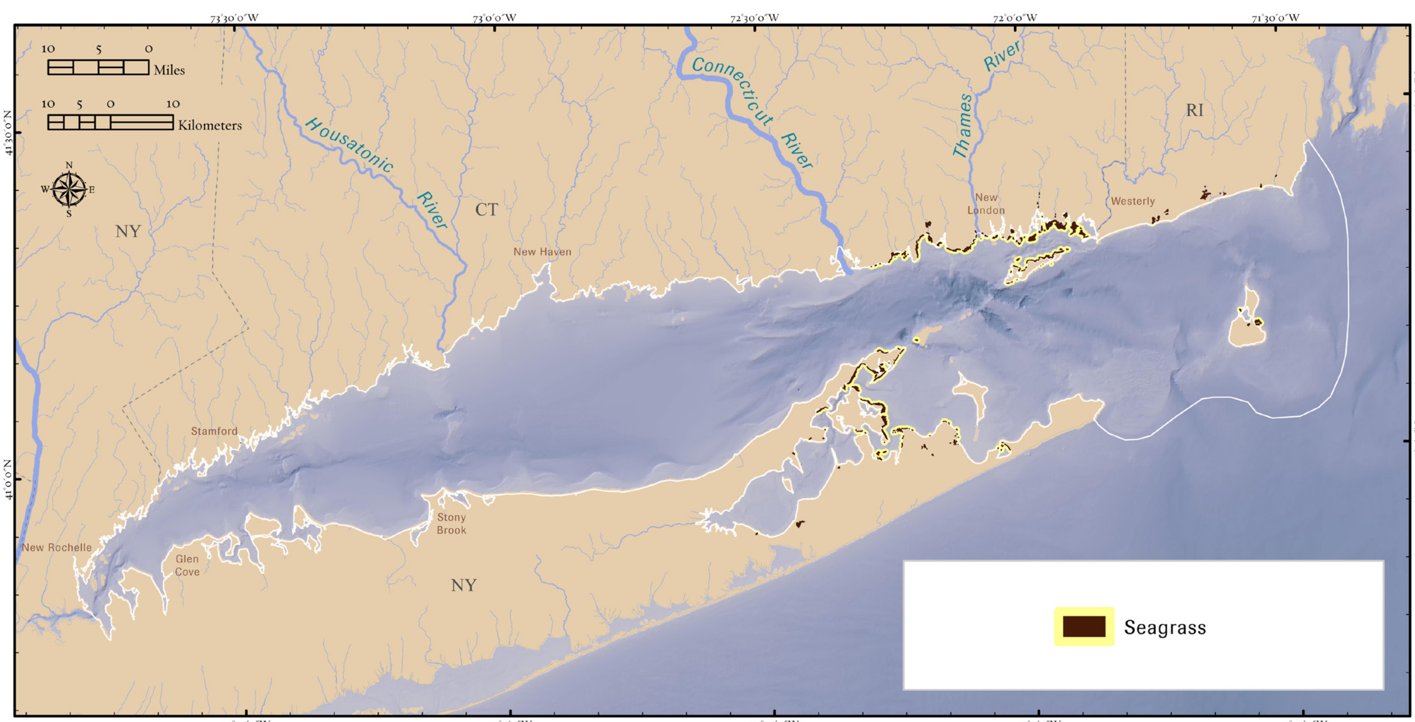


Figure 7.11. Seagrass beds. Actual seagrass features are highlighted for visual clarity and occupy much smaller areas.

The Seafloor Portfolio

The ecologically notable places included in the seafloor portfolio include: species persistence for bottom affiliated species, seagrass and seafloor complexity. The bottom affiliated species areas include demersal fish persistent areas and invertebrate persistent areas (*Organisms* as referred to in Figure 7.12). Seafloor complexity as described above includes hard bottom, bathymetric complexity and EMU richness. The distinction is made on the map between data-derived ecologically notable places (species persistence and seagrass) and model- derived ecologically notable places (seafloor complexity).

Water Column Portfolio

The ecologically notable places in the water column portfolio include the pelagic fish persistent areas and diadromous fish persistent areas. These are the fish groups found throughout the water column without a major dependence or affiliation with the seafloor. The water column portfolio ENPs are all derived from field data and there is no component that is model derived. See Figure 7.13.

Integrated Portfolio

The integrated portfolio combines the seafloor and water column portfolios into one set of ecologically notable plac-

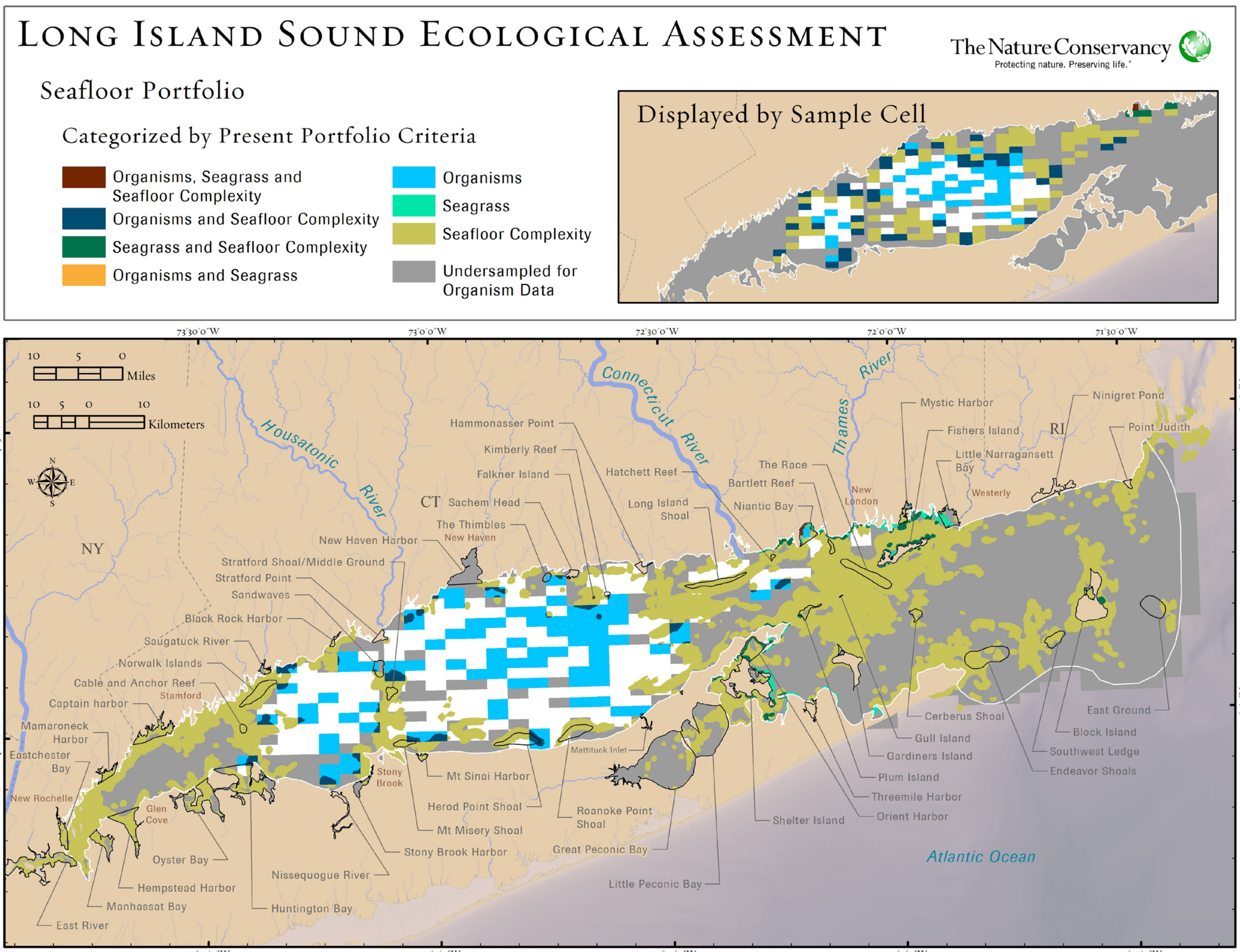


Figure 7.12. Seafloor portfolio.

Note: white and gray areas do not suggest these areas are not ecologically important. Gray areas were not sufficiently sampled and both white and gray areas may be significant for considerations not addressed by the LISEA methodologies or data.

es (Figure 7.14) as a final summary result of the LISEA. Each area shown has met a specific set of selection criteria. These places are highlighted as deserving further investigation for their potential importance in policy-making, management and conservation action. Reference back to the seafloor and water column portfolios can be made to identify which type of ecologically notable places applies to a particular location.

The map of the ecologically notable places in the integrated portfolio includes both the data-based and model-based areas. It is noted that outside of the Sound, the map only shows notable seafloor complexity and contains no species-based information. The same is true for the areas within the Sound that lacked sufficient biological data (shown in gray on the map).

We show two different views of the Integrated Portfolio to portray differing patterns and relationships within the data. Figure 7.14 shows all the ENPs and the extent of overlap for the variety of ENP components. Areas where the seafloor and water column portfolios overlap may suggest greater ecological notability than areas notable for bottom or water column features alone.

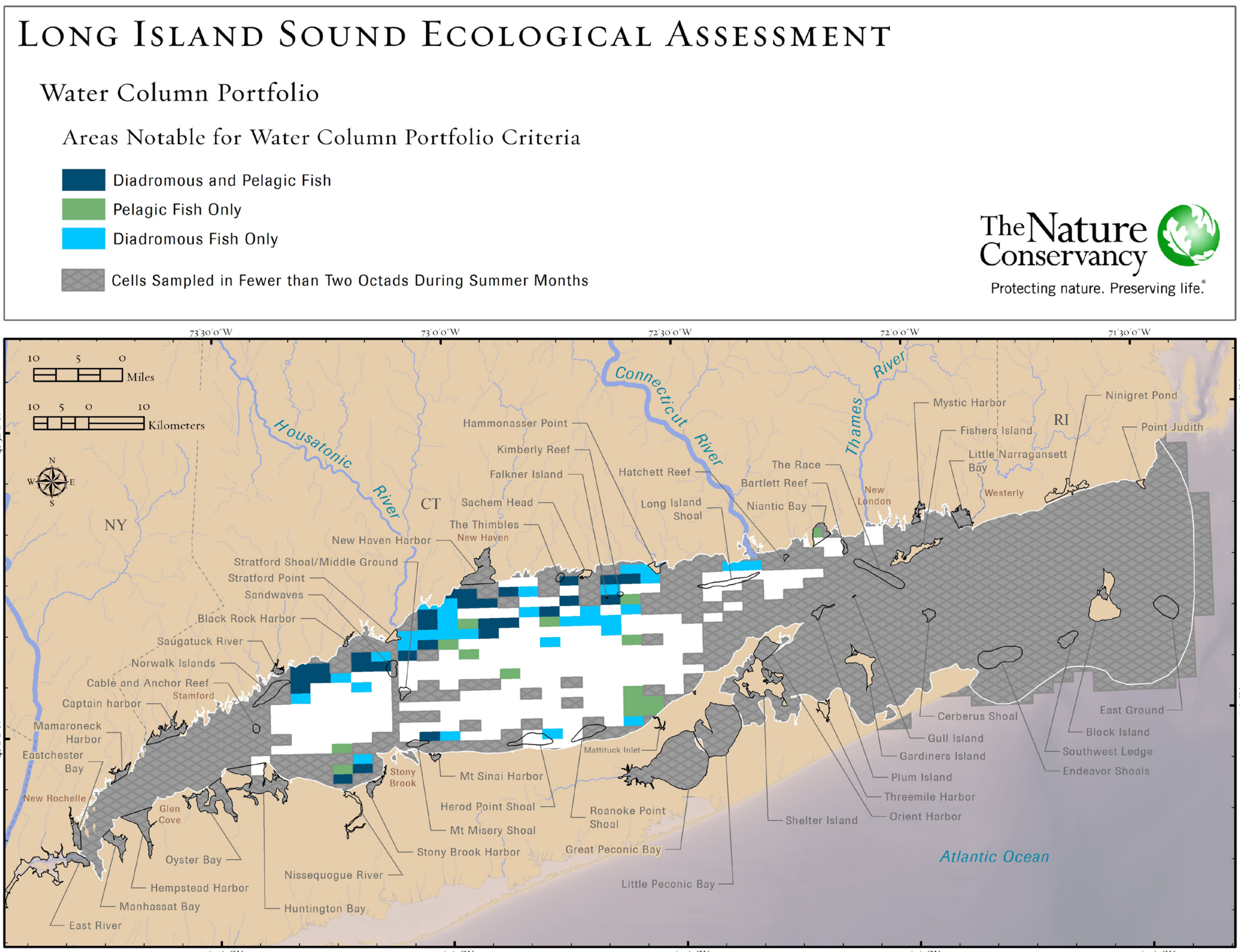


Figure 7.13. Water column portfolio.

Note: white and gray areas do not suggest these areas are not ecologically important as noted in Figure 7.12.

A second way of displaying the same information is shown in Figure 7.15 where the seafloor portfolio components are shown with the underlying EMUs, allowing the reader to visualize the seafloor structure that may be an important driver in the patterns of notable places for those communities. The water column portfolio is then displayed as a transparent overlay completing the integrated portfolio.

Ecological importance of all areas

The integrated portfolio maps (Figure 7.14 and 7.15) illuminate ecologically notable places that merit close and careful consideration, however all areas of the Sound contribute to the productivity of this estuarine ecosystem. Gray areas were not sufficiently sampled. White areas had adequate sampling but did not meet the LISEA-based selection criteria. Both white and gray areas may be significant for other factors or considerations beyond the scope of LISEA. In addition to the life these areas directly support (e.g. large, flat muddy areas support much life), they may also serve as transition or support areas to the ENP. The LISEA ENPs shown here emerge from the data and methods used. The Sound is a complex ecosystem with multiple habitats and ecological processes. All areas of the Sound play different roles and provide different functions and values.

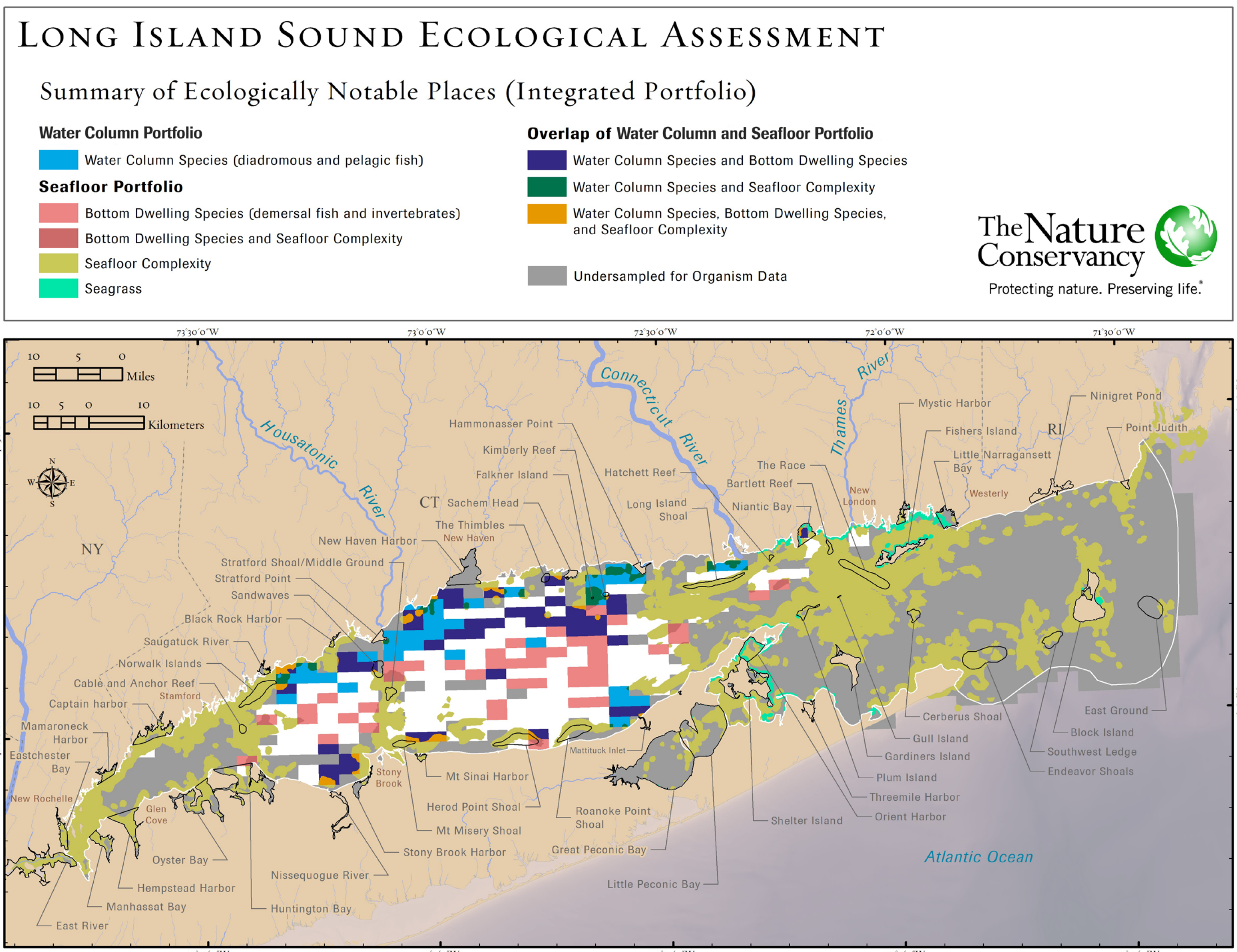


Figure 7.14. Integrated portfolio: Summary of Ecologically Notable Places.

Note: white and gray areas do not suggest these areas are not ecologically important as noted in Figure 7.12.

Blue crab on bottom structure.
Credit: © Robert Bachand

Four-bearded rockling in western LIS.
Credit: © Robert Bachand

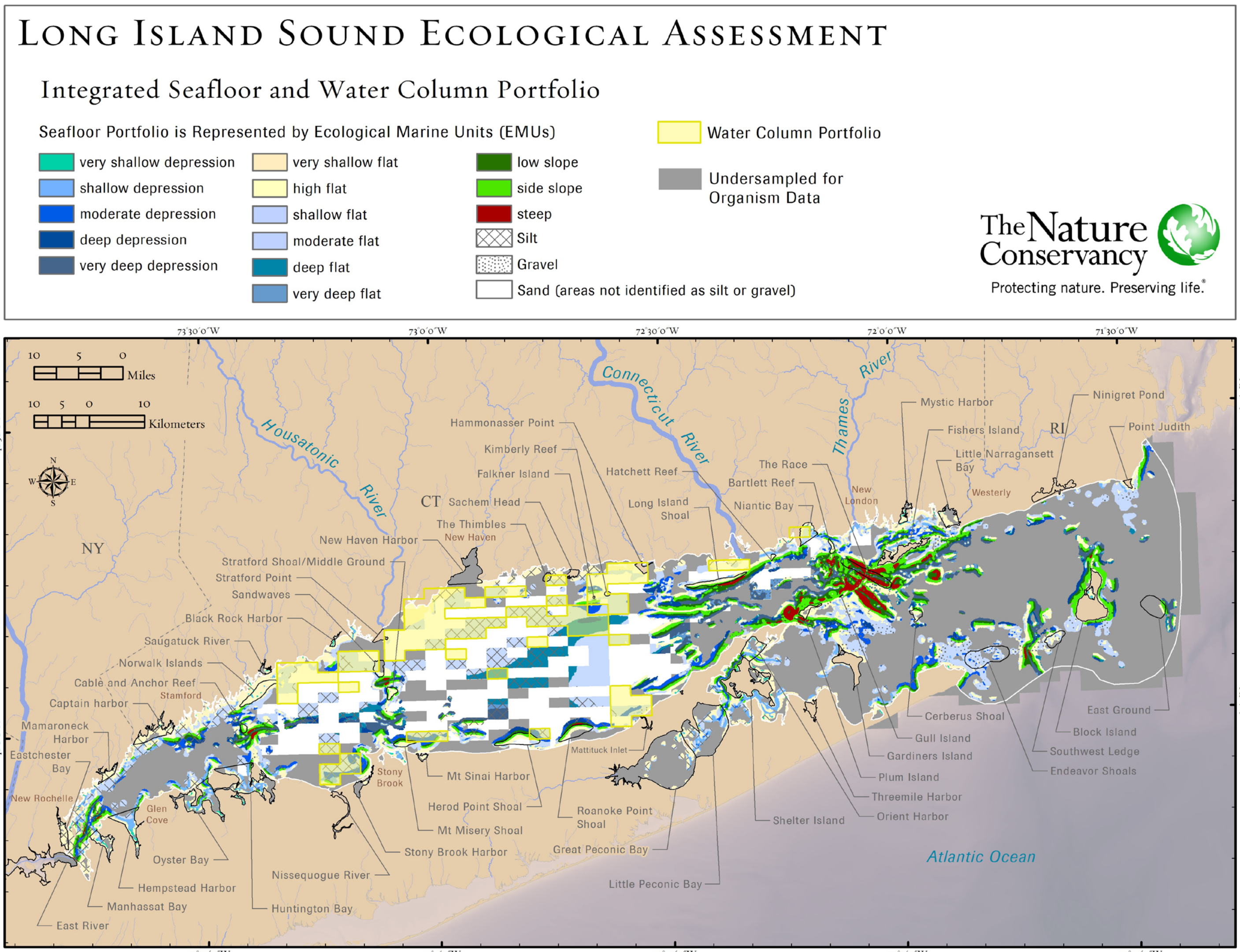


Figure 7.15. Integrated portfolio: Summary of Ecologically Notable Places. (with simplified Water Column Portfolio. Seafloor Portfolio areas are depicted by the underlying seafloor habitats).

Note: white and gray areas do not suggest these areas are not ecologically important as noted in Figure 7.12.

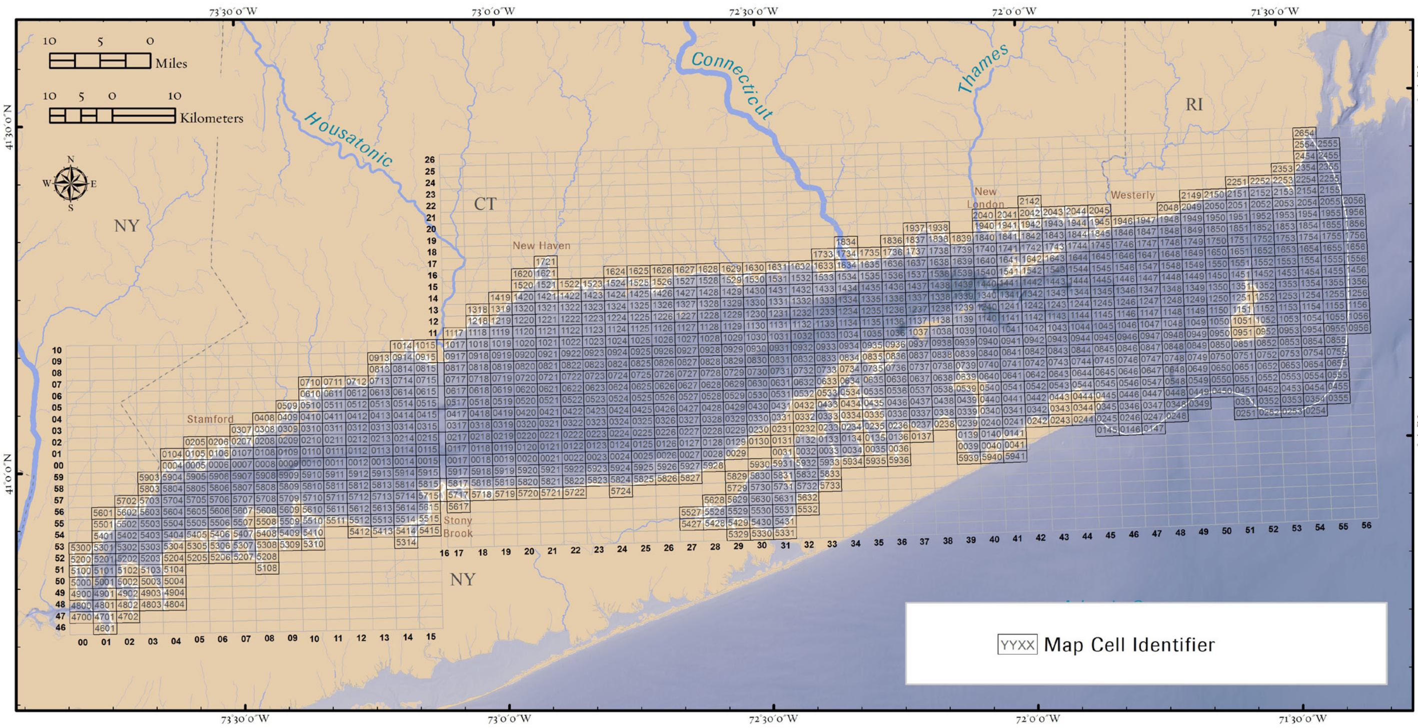


Figure 7.16. Map index.

Northern star coral.
Credit: © Robert Bachand

Ecologically Notable Places: Detailed Descriptions

To facilitate greater insight into what the ENP actually look like on the seafloor and in the water column we form a descriptive picture for each of the grid cells where ENP are located. The full set of descriptions, based on the underlying data, is to be found in Appendix D. In essence, the basis for the ENP within each grid cell is unpacked and described along with other data and descriptive parameters. The descriptions include details about the ecologically notable species, habitat and/or seafloor complexity within the cell. These describe the EMUs within the ENP and associated physical features such as depth, shape or the presence of hard bottom. It also includes further information such as trends and species richness in addition to other parameters.

To illustrate this feature of the project, we provide an example on the next page.

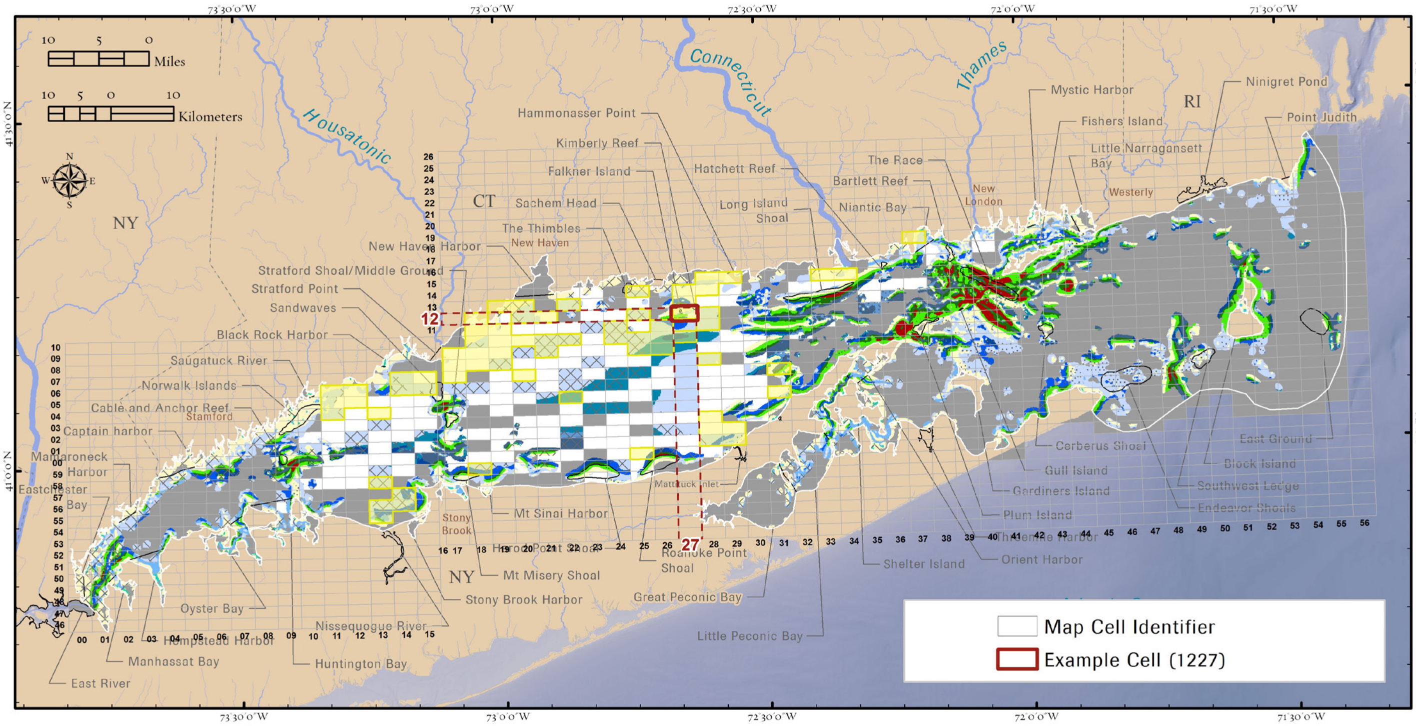


Figure 7.17. Map index with Ecologically Notable Places.

The index shown in figure 7.16 is used to identify the locations of Ecologically Notable Places so they can be correlated with detailed descriptions. This is the same grid cell system used for the fisheries trawl data.

Appendix D will provide a cell by cell description of the properties that contributed to its status as an ecologically notable place and give a general description of the site. Figure 7.17 shows the location of an example site described below.

Cell 1227 is located on the northern end of the sound, about 4 km south of the shore. It is situated at the north-eastern extent of the Sound's central basin, where the fine sediments transition from very fine sands to coarser medium grain sand as we head east toward the high energy flows of the Race. The seabed here has a composition of 36 distinct EMU types with flat to moderate slopes and ranging from a moderate depth of about 24 meters to Falkner's Island where it meets the island's waterline. The eastern edge of the cell contains a portion of Kimberly Reef. The cell is known to contain 41 of the 114 species used in the LISEA analysis. This includes 23 of the 59 demersal fish, 6 of the 8 invertebrates, 5 of the 13 diadromous fish, and 7 of the 23 pelagic species. There were no significant trends in species detection rates, the closest being black sea bass that increased at a rate of 0.9 standard deviations per octad.

Cell 1227 is included in the seafloor portfolio due to its high concentration of confirmed and modeled hard bottom and a high degree of EMU richness and bathymetric complexity, but not due to its weighted persistence of seafloor organism (demersal or invertebrate) scores. It does contain a borderline number of demersal species with a high weighted persistence, with 8 of the required 9 species with scores of 3.6 or higher. These species are: fourspot flounder; little skate; northern searobin; scup; summer flounder; spotted hake; silver hake; and winter-pane flounder. Benthic species known to occur in this cell include 4 polychaetes: *Asabellides oculata*, *Clymenella zonalis*, *Spiophanes bombyx* and *Nephtsy picta* and 1 bivalve: *Tellina agilis*.

This cell is included in the water column portfolio due to both diadromous (alewife and American shad) and pelagic (bluefish, butterfish and menhaden) species with high weighted persistence scores. The cell is relatively close to the outlet of a size 2 river, being about 10 kilometers from Clinton Harbor. The cells central position in the sound provides it with moderate ranges of salinity (27-29 ppt) and temperature (15-21° Celsius) and dissolved oxygen levels that are infrequently anoxic (4-8 mg/L).

American eel.
Credit: © Robert Bachand

General Discussion of Results

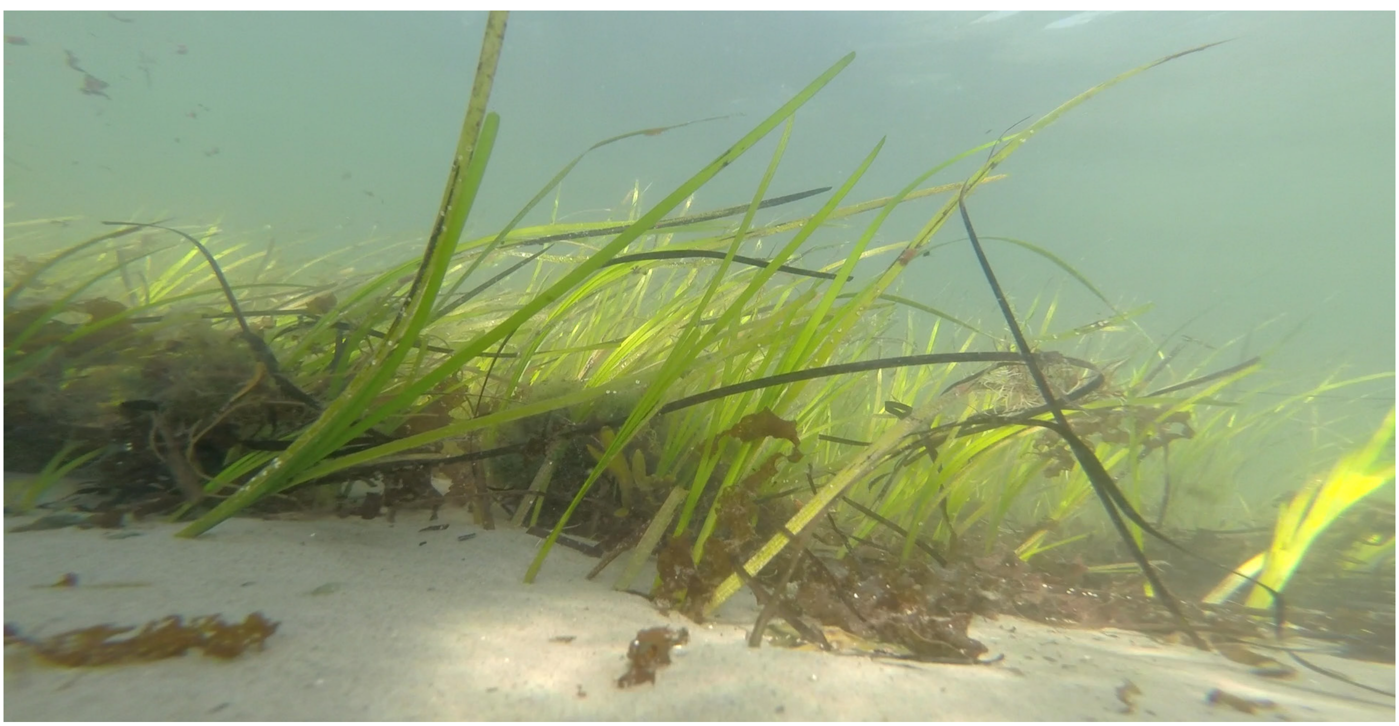
Examining the seafloor, water column and integrated portfolios as well as the component ecologically notable places that make these up reveal insights into the submerged environments of Long Island Sound. Some of the insights that emerge include, but are not limited to:

1. The persistence of diadromous and pelagic fish generally appears to be stronger near the coast rather than in the more open parts of the Sound.

2. Diadromous fish, as generally expected, are most persistent near the mouths of coastal rivers. The Housatonic and Connecticut Rivers along with the East and West Rivers in the Guilford area of Connecticut and the Nissequogue River on Long Island were notable.

3. The persistence of demersal fish is generally strongest in the middle of the Sound. It is particularly notable south of Falkner Island.

4. The highest persistence of macroinvertebrates is concentrated along the western shoals.



Seagrass located by Fisher's Island in the eastern part of Long Island Sound
Credit: © Kristie Giannetto

5. The highest levels of species richness (Chapter 6) tend to be located along the coast and at river mouths, and in the central basin of the Sound.

6. There appears to be some correlation between species persistence and seafloor features. The spatial concentration of high weighted persistence for demersal fish in the central basin (Figure 7.2) resembles the spatial transitions for depth (figure 5.4), sediment transition from very fine sand to fine sand (figure 5.9) and transition of shape (figure 5.18). This and other possible correlations need further examination.

7. Despite the correlation noted in number 6 above, there generally does not appear to be other obvious correlations between the EMUs and the fish/invertebrate results for Long Island Sound. The lack of clear correlation may be because the fish and invertebrate data generally were not available for the structurally complex, hard bottom areas where the correlation may be expected to be higher. Conversely, it may also be because the differences in EMUs in the areas where there is fish and invertebrate data may not be striking enough to correlate with the fish persistence results. It may also reflect distributional changes due to documented warming trends in the Sound and the Atlantic Ocean. These shifts may be confounding spatial correlations and may be more important than the lack of data from un-trawlable grounds. Further examination of the demersal fish and invertebrate results with the EMUs is warranted.

8. No single subgroup of demersal fish dominated the pattern of the overall group. This indicates that the group patterns represent a combination of the sub-groups and are not being driven by one particular resource use.

9. Despite better water quality and overall ecological integrity generally ascribed to the eastern part of the Sound, results of analyses presented here suggest that all sections of the Sound contain ecologically notable places. These findings are based on both the distribution of areas of high species persistence and seafloor complexity.

10. The ecologically notable places are distributed across the broad geographic range of the Sound. There are not just a few hot spots in particular parts of the Sound.

Sea anemone, part of the complex ecosystem
that is Long Island Sound.
Credit: © Robert Bachand

11. In addition to identifying some ecologically notable places, LISEA also highlights significant data gaps that exist. These are described in various parts of the report including Chapter 8 – Data Needs. Examples of some of the known notable submerged areas which we do not have appropriate data to display are shellfish beds. This is also true for rare species. Although some of these areas may have been accounted for by other criteria, this remains an important gap that needs to be filled.

12. A more geographically complete picture of the Sound is portrayed by using both biological data and seafloor complexity. Biological data were included where they were available and seafloor complexity as a proxy provided information for locations where empirical biological data were sparse or nonexistent. The ecologically notable complex seafloor areas tend to occur in those places where there is a lack of viable biological data and areas with robust biological data tend to be in the areas without pronounced seafloor complexity. Although each of these two classification approaches are different and the results are therefore not directly comparable or uniform, together they allow depiction of ecologically notable places across the Sound's diverse geography.

section 8

data needs

This ecosystem assessment project was conducted by compiling available datasets to characterize the sedimentary environment, the benthos and the water column across the study geography. However, as the available data were assembled many data gaps were identified. The section on Data Limitations discussed in Chapter 3 makes clear the need for biological data in the eastern and western portions of the Sound and along the shore and in embayments. Because of the great difficulty in conducting trawl surveys in these areas other methods will be necessary.

Another example of data gaps is the lack of a complete acoustic survey of the study area. Acoustic surveys of the seafloor (e.g. side scan sonar or multibeam bathymetry) have become the underwater analog of aerial photography and provide a previously unavailable view of the spatial patterning of sedimentary environments on the seafloor (e.g. Ryan and Flood 1996; Greenstreet et al. 1997). The acoustic remote sensing tools currently employed in geophysical surveys (side scan sonar, multibeam bathymetry, etc.) collect continuous data across large areas and thus have the potential to characterize bottom type at a level of resolution well beyond traditional discrete bottom sampling methods (e.g., cores, grab samples, etc.) (Ryan and Flood 1996). With this technology, large areas of the seafloor can be rapidly and efficiently surveyed, and analytical techniques previously limited to terrestrial ecology can be applied to mapping marine benthic landscapes. Once interpreted, these acoustic records can reveal the location and extent of areas of similar bottom type and the boundaries between areas of dissimilar sediment characteristics. These approaches have been successful in describing the distribution of sedimentary environments which are the most important component of benthic habitats. Not only

would a complete acoustic survey reveal the distribution and extent of different soft sediment textures across the study area, but it would more completely identify the locations and configurations of the hard bottom habitats that have not been characterized to date.

There is also no contemporary comprehensive benthic faunal survey conducted in a single season (ideally fall) that characterizes the full geography using a uniform method (e.g. sampling gear, sieve size and taxonomy). The only Sound-wide survey in Long Island Sound was conducted by Reid et al. (1979) and that study was restricted to soft sediments. Pellegrino and Hubbard (1983) conducted a more recent survey of the soft sediments in the Sound but those samples were restricted to Connecticut waters. Both of these studies also focused on deeper waters; intertidal and shallow subtidal benthic communities have not been systematically assessed. A contemporary benthic faunal survey should be undertaken to better characterize these communities across the study area. The study design for a comprehensive benthic survey could either follow a grid of sample points at fixed intervals similar to Reid et al. (1979) and Pellegrino and Hubbard (1983), or it could be conducted in a more efficient and parsimonious design based on a stratified random design following either the geophysical provinces identified in an acoustic survey (Maher 2006) or the EMUs identified in this study.

Our understanding of the Long Island Sound ecosystem would also benefit from surveys to characterize zooplankton and small nekton communities. Pairing plankton surveys with fish and benthos sampling would quantify critical energy transfer within the system.

Recurring monitoring of all of these parameters would help to reveal important interannual variability or temporal changes that may be responding to water quality, temperature or other ecosystem or climatic changes.

Finally, shellfish beds are notable submerged areas; however data characterizing these species were not available for this assessment. Although we may have captured some areas important to shellfish communities through other criteria, this ecologically and economically important component remains a gap to fill.

Photo Credit: © Jerry Monkman

section 9

conclusion

Overview of Results

The LISEA project has identified seafloor habitats and ecologically notable places in the submerged areas of Long Island Sound. This assessment provides The Nature Conservancy with its first significant guidance for understanding the aquatic and seafloor worlds of Long Island Sound and will help direct conservation work on the ground. There are several potential conservation uses of the LISEA by The Nature Conservancy and others suggested in Chapter 4 and covered in detail in Appendix C.

In Chapter 5, we describe and map the physical habitats of the Long Island Sound, Block Island Sound and the Peconic Estuary seafloor. By mapping various physical factors with thresholds informed by the distributions of biota, we created a map of physical habitats likely to correspond to distinctive sets of organisms and communities for the entire study area. The summary map of these seafloor habitats is Figure 5.22. A discussion of results pertaining to these seafloor habitats is provided at the end of Chapter 5.

In Chapter 6, we focus on identifying those places in the Sound that have been persistently important to fish and invertebrate productivity for decades. To identify these areas, we applied a single consistent methodology, based on the presence of individual species over decades, to find places that may be particularly important for the conservation of fish and macro-invertebrates. Patterns of species persistence for demersal, pelagic and diadromous fish as well as the macroinvertebrates, based on the CT DEEP trawl survey data, are used in Chapter 7 to identify ecologically notable places. We also examined trends in abundance and species richness.

Chapter 7 represents the culmination of work to identify ecologically notable areas. It is based on analysis of the seafloor habitat work presented and further analysis of seafloor complexity along with species persistence insights (Figure 7.14)

The ecologically notable places identified here represent areas that play a key role in sustaining the marine life and integrity of the Sound. As such, they make a valuable contribution to the economic and social well-being of people that rely on and enjoy the Sound - from commercial activities and recreational fishing to the quality of life associated with a water body of high ecological integrity.

The identification of ecologically notable places through the LISEA is based on current data There are likely additional and/or different ecologically notable places that would emerge with additional data or different classification methods. One example of useful additional data would be information on the seasonality and distribution of diving birds. Other useful data are the locations of seasonally-based cool-water refugia or areas used by marine life to escape hypoxia. The LISEA results presented here can, at a minimum, serve as a guide to identifying geographic or spatial areas that deserve greater attention and investigation. Such investigations can help us better understand the relative importance of the ecologically notable places and their vulnerability to disturbances, whether natural or due to human activities.

Next Steps

The following is a list of next steps for advancing the understanding of ecologically notable places in the study area:

1. An examination of the relationships between seafloor complexity (particularly hard and rocky bottom habitats) and resident biota needs to be undertaken. Sampling methods would have to be tailored to this difficult-to-sample environment.
2. Our understanding of the Long Island Sound ecosystem would also benefit from surveys to characterize zooplankton and small nekton communities. If these were paired with fish and benthos sampling they might capture energy transfer in the system.
3. Recurring monitoring of all of these parameters would help to reveal interesting interannual variability or temporal changes that may be responding to water quality, temperature or other ecosystem or climatic changes.
4. A more complete acoustic survey of the study area would reveal the full extent of different soft sediment textures, and identify the locations of hard bottom habitats that have not been characterized to date. A contemporary benthic faunal survey from a single season over the full study area would improve our understanding of the benthic communities of Long Island Sound. These data limitations are described in more detail in the previous chapter.
5. There are large areas with multi-beam data which should be examined and integrated into any update of LISEA particularly including but not limited to validating LISEA methods and providing information in the "gray areas" (see maps above) where the biological trawl data was unavailable or insufficient.
6. The findings of the LISEA should be communicated to the Cable Fund Seafloor Mapping Project, currently underway, to determine if there are ways the two projects can strengthen or complement each other. The Seafloor Mapping project may be able to provide biological data or biological insights into a) areas without sufficient trawl-based data, and b) areas of seafloor complexity where it may be possible to examine the extent of correlation between marine life and the seafloor. An update of the LISEA project should include all applicable results of the Seafloor Mapping project including the role it may play in revealing more detailed, in-the-water realities associated with the ENP.
7. The ecologically notable places identified in this report should be further characterized by intensive studies. For example, why does the area south of Faulkner Island show up as a particularly notable place for demersal fish? Existing data and papers along with new field work and information may reveal more about the exact nature and significance of the ENP.
8. The LISEA project identified ENP but did not additionally search for and analyze what factors or conditions influence the persistence of marine species and ENP. The role of seafloor features is of keen interest but it is also important to examine the role of physical parameters, from water quality to circulation patterns. Other factors should also be considered such as trophic dynamics, presence/absence of heavy metals, and pesticides, etc.
9. The findings of LISEA should be reexamined to identify any potential correlations that may have been overlooked in this report. These could be between

the biota and physical features, between the biota and geography, between elements of the biota or any other types of correlation that may be meaningful. Clearly work beyond the capacity of the existing LISEA is important to further our understanding of this subject and inform conservation and management.

10. An internal and external review of the project and its methods have substantiated the basic approach and methods used for LISEA. Notwithstanding this point, it may be helpful to further evaluate and provide additional discussion of the uncertainties associated with the LISEA methodologies. For example, would shifting the time periods of the trawl survey used in the analysis change the results? Although this is not expected to fundamentally alter the results as discussed above in Chapter 6 it would be an interesting and potentially important evaluation to make.

11. Places that perform important ecological functions need more study to provide a more complete picture of ENP. An example of this could be tidal inlets where natural hydrology is a prominent part of ecological integrity.

12. An analysis of the finfish community in the Sound showed a distinct change after 1997 that is generally associated with warming trends in the Sound and Atlantic Ocean (Howell & Auster 2012). A changing climate will likely be a major factor in how ENP may change over time. Climate needs to be explicitly addressed in future follow-up steps, including the use and analysis of ongoing CT DEEP trawl data.

13. A project which would be worthwhile as a follow-up to LISEA is to assemble, map and analyze the smaller-scale acoustic, benthic and other sampling and data that exists for characterizing the Sound. Although limited in space and time and not directly applicable to the methods of LISEA, a comparison of such information with LISEA could serve to help validate the LISEA methods or highlight further the uncertainties or limitations. As an example, Flood and Cerrato have mapped a portion of the near-shore areas of Port Jefferson Harbor. The Army Corps of Engineers data collected for dredging evaluations is another example. Although these data were initially considered for LISEA, they were not used because of its spatial limitations—however they could add significantly to the project contemplated here as a next step.

14. The LISEA report intentionally steers clear of suggesting how the results might be applied in a planning context. Developing illustrative guidance or a theoretical example could be a useful next step, particularly if it is in concert with a planning initiative that has interest in LISEA.

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section 10

list of figures and tables

section 11

data sources

Dataset	Data Category	Name	Source
NGDC 3 arc-second U.S. Coastal Relief Model (CRM)	Bathymetric Data	nyli_3arcsec	NOAA
Long Island Sound Surficial Sediment Data	Sediment; Hard Bottom	seddata_g83.shp	USGS Woods Hole (Poppe *et al.* 2007)
usSEABED	Sediment; Hard Bottom	alt_prs.shp; alt_ext.shp	USGS Woods Hole (Reid *et al.* 2005)
Benthic Sediment and Fauna Data for the Peconic Estuary	Sediment; Hard Bottom; Benthic Fauna	PeconicsBenthic.mdb	Stony Brook University (Cerrato and Maher 2007; Cerrato *et al.* 2009; Cerrato *et al.* 2010)
Long Island Sound Surficial Sediment Polygons	Sediment	listex.shp	USGS Woods Hole (Poppe *et al.*)
Eastern US Sediment Texture 2005	Hard Bottom	ecstdb2005.shp	USGS Woods Hole
NOAA Electronic Nautical Chart (ENC)	Hard Bottom		NOAA
NMFS Benthic Samples	Benthic Fauna	benthic_pts.gdb	NEFSC
Pellegrino & Hubbard Benthic Samples	Benthic Fauna		Pellegrino & Hubbard (1983)
A Study of Marine Recreational Fisheries in Connecticut: Long Island Sound Trawl Survey	Trawl Based Fisheries Data	CTDEEP_fisheries.mdb	CT DEEP
Long Island Sound Water Quality Monitoring	Water Column Data (salinity, temperature, DO, secchi depth)	DEP_LIS_Monitoring.mdb	CT DEEP
CTDEEP Seagrass	Submerged Aquatic Vegetation	CT_DEEP_eelgrass_data.gdb	CT DEEP
River Systems	River Mouths	NHDM0109.gdb; NHDM0110.gdb	National Hydrographic Database (NHD)

section 12

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Sea raven eating a lobster.
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