11TH BIENNIAL

Long Island Sound Research Conference *Proceedings* 2013

Proceedings of the Long Island Sound Research Conference held
April 19, 2013 at Danfords Hotel and Marina, Port Jefferson, NY

ACKNOWLEDGMENTS

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ISBN 978-0-9802026-5-6

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A special thank you to W. Frank Bohlen, University of CT, Marine Sciences
for his assistance with the conference program.

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PAPERS

Project *Limulus*: The Past, Present, and Future of Horseshoe Crab Population Dynamics in Long Island Sound

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Abstract

Project *Limulus* is a community based, long-term research project investigating the life history and population ecology of the American Horseshoe crab (*Limulus polyphemus*) in Long Island Sound (LIS). Since 1997, over 77,000 horseshoe crabs have been tagged with over 12,000 reported recaptures, a 15% recapture rate. Mark/recapture analyses indicates that 98% of crabs tagged in LIS are recaptured in LIS. Of the adult females that come up on the beach to mate, 15% are single, 75% are found with only one male, and approximately 10% have more than one mate. In addition to tagging, horseshoe crab spawning surveys have been conducted from 2008 to 2012 on over 30 beaches bordering LIS. Spawning Indices are 3-4 orders of magnitude lower than Delaware Bay. Spawning surveys also indicate that the spawning population is relatively stable with yearly variation. Recent analyses of the physical characteristics of beaches with spawning activity revealed no significant correlation between grain size, beach slope, beach width and spawning indices. Ongoing juvenile surveys suggest the presence of three cohorts in marshes and intertidal zones. The Connecticut Department of Energy and Environmental Protection should consider 'male only' harvests to increase egg production, juvenile recruitment and ultimately spawning density of horseshoe crabs on Connecticut beaches.

Introduction

The American horseshoe crab, *Limulus polyphemus*, inhabits the eastern coast of the United States ranging from the Yucatan Peninsula northward to Maine with spawning populations distributed intermittently along the U.S. east coast (Anderson and Shuster 2003). The highest abundance and frequency of horseshoe crabs exists between New Jersey and Virginia centered on the Delaware Bay beaches (Botton and Ropes 1987, Faurby et al. 2010). Extensive research has been conducted on horseshoe crab populations residing around the Delaware Bay and the Southeastern United States (Rudloe 1980, Shuster and Botton 1985, Botton et al. 1988, Wenner and Thompson 2000, Shuster et al. 2003). A number of studies have been conducted in the Cape Cod region of Massachusetts (Carmichael et al. 2003, James-Pirri 2005) but little information has been published on the population dynamics of *Limulus* in Rhode Island, Connecticut and New York (Sokoloff 1978, Mattei et al. 2010).

Project *Limulus,* established in 1997, is a community research endeavor whose participants tag and collect data on the population of horseshoe crabs that inhabit LIS. Participants learn the economic, medical and ecological importance of horseshoe crabs and their importance to the LIS ecosystem. Nonprofit environmental educational organizations, K-12 School groups, and undergraduate and graduate research assistants participate with the goal of promoting science literacy and monitoring the majority of LIS spawning beaches in Connecticut. The goal of Project *Limulus* is to continue to monitor and examine the population dynamics, migration patterns, and ecological links to other species in LIS. Mattei et al. 2010 has shown that the population density is significantly lower in LIS compared to that of Delaware Bay and the mating behavior is predominantly monogamous. In addition, a multi-year tag and recapture study and a genetic analysis has revealed that adult horseshoe crabs move freely and interbreed around the Sound but typically do not leave LIS (Mattei and Beekey 2009, Kasinak et al. 2011).

Recently, juvenile horseshoe crab habitat preference, abundance, size classes and distribution has been examined. In addition, an investigation into the possible connection of geomorphogical characteristics (i.e. waves, beach slope, and sediment size) has been examined to determine a correlation between physical beach characteristics and horseshoe crab spawning behavior. Here we present results from the long term mark recapture study, continued spawning density surveys and new results of juvenile abundance, age classes, recruitment and the effects of geomorphological characteristics on spawning density.

Methods

The methods for tagging and horseshoe crab spawning surveys and data on sex ratios and mating behavior have been published (Mattei et al. 2010).

Beach characteristics were measured during the summers of 2008 and 2012. Average depth was determined at each site by measuring the distance between the high tide and low tide waterlines at 5 random points along each beach. Average beach width was measured along the length of the beach. Beach slope was measured with a transect scope (DeWalt transit level). Six beach gradient measurements; spaced 40m apart at each location was used for average slope.

Sediment cores (7cm diameter x 20cm deep) were randomly collected at each site over the range of where horseshoe eggs are typically present midtide to high tide, the low tide waterline, high tide waterline and three locations in the intertidal area along a transect for a total of 30 samples per site in 2008, and 25 samples in 2012. The depth of the core was based on previous research which demonstrated that horseshoe crabs lay their eggs 15cm-30cm beneath the surface of the sediment (Willams 1987). The sediment core samples were dried for 24 hrs at 80°C. Each sample was shaken for 5 minutes (Ro-Tap Model E test sieve shaker) for 5 minutes to separate the particles into four size classes <0.05 fine sand, 0.05-1 medium sand, 1-2 coarse sand, >2 gravel millimeters). Each class of sediment sizes was weighed.

Juvenile horseshoe crab surveys were conducted in mud flats/back marshes during the summer of 2012 at 3 beaches known to have spawning horseshoe crabs, 1) Sandy Point, New Haven, 2) Milford Point, Milford and 3) Stratford Point, Stratford, Connecticut. Juvenile horseshoe crabs were found via visual sampling throughout the marsh. Juveniles were collected into a bucket and their prosomal width was measured using calipers in mm. After measuring all juveniles were released into the general area which they were found. Using previously published juvenile size classes (Sekiguchi et al. 1988 and Carmichael et al. 2003) juveniles were assigned an instar stage and grouped into cohorts at each particular beach.

Results

As of 2013, over 77,000 horseshoe crabs have been tagged and 15% (~ 15,000) recaptured with 98% found within the Sound. Of the adult females that come up on the beach to mate, 15% are single, 75% are found mating with only one male, and approximately 10% of the females have more than one mate. Median female spawning density (per m^2) across 24 beaches measured was 0.008/m^2. Sex ratios of tagged adults were found to be 61% male and 39% female averaged over 12 years. Analysis of beach width, sediment size and slope (Figure 1A-C.) shows no correlation with spawning density. Spawning adults do not demonstrate preference to mating on a beach with a certain set of physical characteristics within LIS; rather spawning densities are low on all beaches within LIS regardless of physical geomorphological characteristics.

A total of 981 juvenile horseshoe crabs were measured across the three beaches. The surveys show up to 12 cohorts living within a single back marsh. On Sandy Point in New Haven, the majority of juvenile crabs found are grouped as YOY (Young of the Year) (Figure 2A.) with the second most abundant being approximately 1-2 year old crabs. Few if any larger juvenile crabs of higher instars were found in 2012 (Figure 2B.)

Discussion

Horseshoe crab spawning densities are low and the observation that 15% of the adult females that come up to spawn are single signifies that this population is not reproducing at its maximum rate. In order to determine if horseshoe crab conservation efforts should be focused on particular beach geomorphological characteristics, we compared the spawning indices of 14 beaches against beach width, sediment size, and beach slope in 2008 and 2012. As seen in Figures 1A-C., there was no correlation with spawning density and beach characteristics. Adult horseshoe crabs were seen mating on beaches of high and low slopes, large and fine sediments and short pocket beaches and long public beaches. Rather than observing a trend for a particular set of characteristics, it was seen that overall spawning density is simply low in LIS regardless of beach type or characteristics. Therefore we believe manager cannot base conservation efforts on beaches of particular morphology, i.e. there is not an “ideal” beach found in LIS where the majority of adults go to spawn. However, like other shellfish species, we highly recommend that the Connecticut Department of Energy and Environmental Protection (CTDEEP) change their harvest regulations and ban the harvest of female horseshoe crabs.

Juvenile horseshoe crab data has not been previously gathered in LIS. Focusing on 3 beaches in 2012, the majority of juvenile crabs found were YOY (Young of the Year) that either hatched early in the summer of 2012 or juveniles who hatched in 2011 but are not yet 1 year old (Fig 1A.). The second most abundant age class is approximately 2 years old with very few older juveniles (Figure 1B.). The lack of older juveniles suggests they migrate out to the Sound, bury deeper into the sediment or experience high levels of predation. It should be noted at Sandy Point in New Haven, fisherman are known to rake for clams heavily in areas where juveniles are found. This fishing activity may be killing off parts of the juvenile population at this particular back marsh. In the future, we will be sampling the surface and deeper sediments as well as expand the number of beaches surveyed for juveniles over the next two years.

Acknowledgments

Funding for this project was provided by Connecticut Sea Grant, National Fish and Wildlife Foundation, and Disney Worldwide Conservation Fund. We also received support from the Undergraduate Research Initiative, provided by the Dean of the College of Arts & Sciences, Sacred Heart University. This work could not have been completed without the help of our undergraduate and graduate research assistants: Matt Cole, Taylor Babin, Christina Giglio, Jacquelyn Charamut, Christopher Ferullo, Corianna Mascena, Iven Sherman, Emily Efstration, Shea Jameel, Sonny Bandak, and Jo-Marie Kasinak. Data collection was also enhanced by numerous volunteers from The Nature Conservancy, The Maritime Aquarium, SoundWaters, Denison Pequotsepos Nature Center, Branford Land Trust, and the Connecticut Audubon Society. We also want to thank the Sheila Eyler of the U.S. Fish and Wildlife Service, Maryland Fishery Resource Office for all of the assistance with the tag distribution and recapture data collection from the public.

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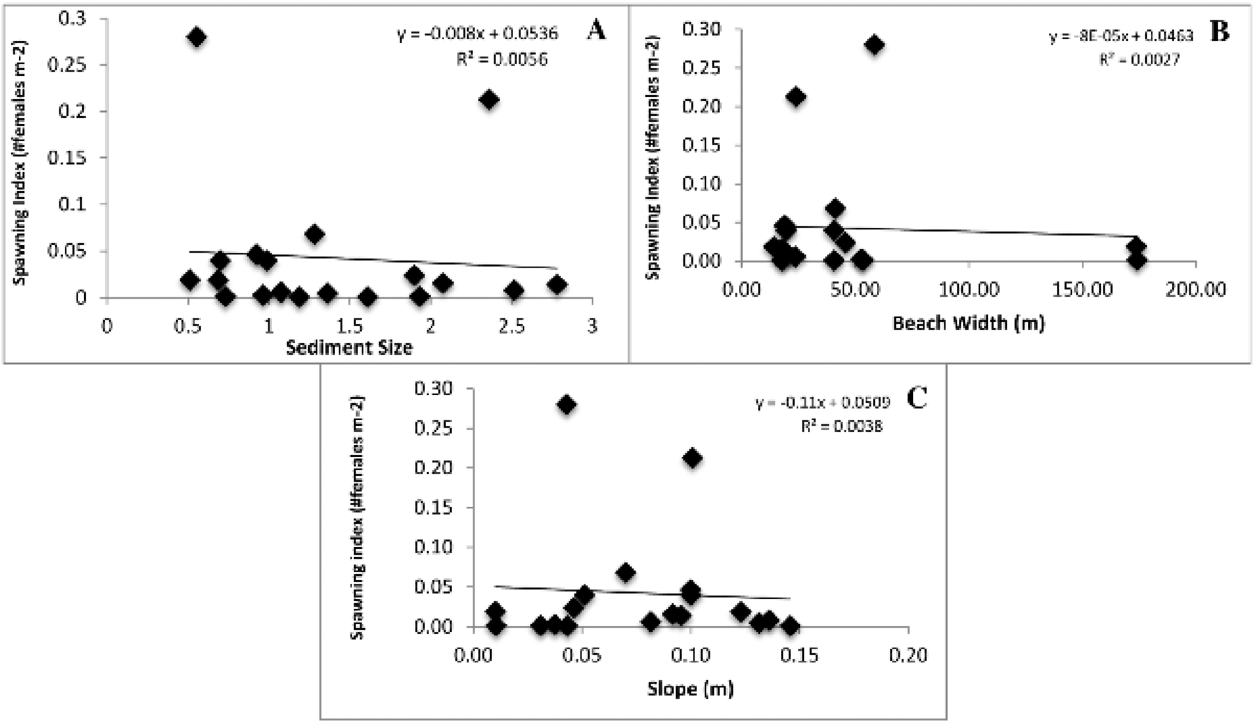
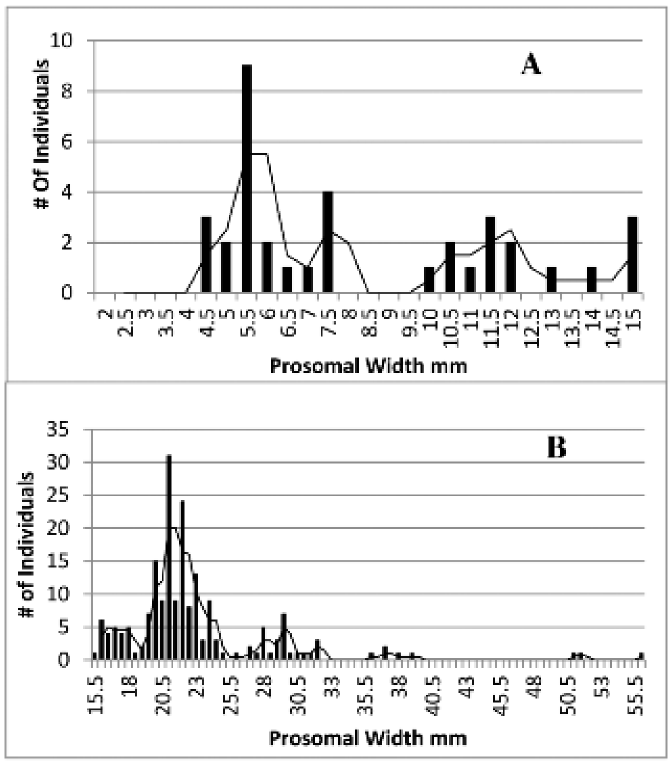


FIGURE 1
(A) Comparison of horseshoe crab spawning index vs. sediment size, (B) beach width, (C) beach slope.

FIGURE 2
Relative abundance and sizes of juvenile horseshoe crabs found at Sandy Point, New Haven during 2012, moving average is shown. (A) Juveniles' size classes from 4.5 to 15mm (young of the year, less than 1 year old). (B) Juveniles ranging from 15.5mm to 55.5mm (Ages 1-4 years old).



The Restoration of the Mouth of the Housatonic River, CT: One Point at a Time

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Abstract

Coastal regions, at the mouths of major rivers, in areas with high human population densities become polluted, compacted, invaded, degraded and lose their primary ecosystem functions. At Stratford Point, Connecticut we have begun coastal dune upland and salt marsh restoration after intensive clean-up efforts of tons of lead shot deposited at the site over a 50 year period. The Connecticut Audubon Society, The Nature Conservancy, DuPont Corporation, Sacred Heart University, and local community members have all participated in this project. The National Fish and Wildlife Foundation funded part of this project and will use the procedure and results as a model for other degraded coastal areas. Instead of boulders and rip-rap, we have utilized Geotubes at the base of the coastal dune to abate wave energy, prevent erosion and enhance sand deposition at the site. The restored dunes were stabilized with native grasses, and the upland partially planted with woody trees and shrubs. CTDEEP and the local fire department were employed to implement a controlled burn to control invasive plant species and to rid the area of a build-up of thatch that could potentially cause a devastating wildfire. The baseline data collected before restoration activities of the plants and animals found at the site will be compared to species that re-colonize the restored coastal dune system. The importance of the reference site, Milford Pt. will be discussed. Success will be measured by examining the number of native plant species that become established and by the number of bird and insect species that utilize the area compared to pre-restoration activities.

Introduction

Estuarine and coastal habitats are some of the most heavily utilized and most threatened natural systems across the globe (Lotze et al. 2006, Worm et al. 2006, Halpern et al. 2008). The coastal zone, occurring at the land-water interface, includes a mix of wetland and upland habitats. Coastal zones comprise diverse habitats that provide tangible benefits such as buffering effects of storms, filtering out pollutants in runoff, opportunities for recreation and tourism, and vital habitat for spawning grounds, nurseries, shelter, and foraging habitat for many wildlife species. Connecticut coastal habitats are subjected to high levels of disturbance that vary both in frequency and intensity including hurricanes, nor'easters, runoff, sedimentation, sea level rise, as well as coastal development and other human uses including fishing/harvesting, aquaculture, marine trades, and access for recreational activities (Greipsson 2011). The Long-term disturbance, historical loss and alteration of habitats, urbanization has increased the need for coastal habitat restoration (Madgwick and Jones 2002, Beck et al. 2011). In particular, major components of the northeastern U.S. estuarine ecosystem such as oyster reefs have been lost and greatly altered over the past 150 years to the extent that they have been classified as imperiled (Ermgassen et al. 2012).

Here we report on the first stages of a long-term collaborative coastal habitat restoration project at Stratford Point that has already included a prescribed burn, upland planting, and coastal dune construction. Milford Point, part of a federal wildlife refuge and across the Housatonic River from Stratford Point is used as a reference site for our management plan. Both sites are subject to disturbances (e.g. flooding from hurricanes and sea level rise, controlled burns, human trampling, invasive species, etc.), but have very different histories of intensity and duration of disturbance. These differences in disturbance regimes have led to ecological communities characterized by different flora and fauna. Characterization of the composition of the existing ecological community is imperative for developing a management plan for these sites and other coastal zones as it provides a baseline of information for use in future monitoring and documentation of changes affecting the area over time. Data-driven restoration efforts also allow for creation of goals or targets and a method to assess the successful completion of these goals through the long-term management of a site. It is our intent that this restoration project will serve as a model for restoration efforts in other degraded coastal zones, both in and out of the State.

Site Descriptions

Stratford Point: The Restoration Site

Stratford Point (SP) is a peninsula in the Lordship section of Stratford, Connecticut located near the mouth of the Housatonic River (Figure 1A). The site is situated between two subunits of the Stewart B. McKinney National Wildlife Refuge (Wheeler Marsh in Milford, CT and Great Meadows Marsh in Stratford, CT) and is surrounded by several additional natural areas (e.g. Long Beach/Pleasure Beach, Connecticut Audubon Society's Coastal Center at Milford Point, Charles Island and Silver Sands State Park). In the aggregate, these areas include a wide range of critical habitat types that support a significant number of Greatest Conservation Need species (per Connecticut Comprehensive Wildlife Conservation Strategy) as well as species listed in Connecticut's Threatened and Endangered Species Act.

The property itself consists of approximately 28 acres (11.3 ha) of upland and an additional 12 acres (4.8 ha) of shallow intertidal zone. The southeast-facing section of Stratford Point's shoreline (generally referred to as the 'high energy' section of the shoreline) faces Long Island Sound and is exposed to more intense wave action and wind shear than the north-facing section of the site (the 'low-energy' beach), which faces a relatively sheltered cove at the mouth of the Housatonic River. The upland section of the site supports a coastal grassland habitat.

Due to its location, Stratford Point is an integral component in the interconnected matrix of coastal habitats located near the intersection of the Housatonic River and the Long Island Sound. In its current form, it is an important migratory stop-over site for a variety of birds, Lepidoptera and Odonata, and provides valuable wintering habitat for waterfowl. However, restoration and data-driven management of the site's coastal habitat can greatly improve its quality and functionality to a wider variety of at-risk species in the region.

Central to the restoration of Stratford Point's coastal habitat is the site's historic use and impact of subsequent remediation efforts. Stratford Point is currently owned by Sporting Goods Properties, Inc., a subsidiary of E.I. du Pont de Nemours and Company (DuPont), and is the site of the former Remington Gun Club, also referred to as the Lordship Gun Club, which operated as a trap and skeet shooting facility from 1926 to 1986. Lead shot and clay target fragments accumulated over decades in the site's upland and intertidal habitat. Large-scale remediation in 2000-2001 removed the bulk of these contaminants, and subsequent small-scale clean-up efforts have removed remaining lead 'hot spots.' While cleaned of lead shot contamination, the coastal habitats of Stratford Point lost much of their ecological integrity throughout the remediation process that removed virtually all upland, shore and intertidal vegetation.

During remediation, much of Stratford Point's upland habitat was used for dredge spoil staging and processing. After completion of the remediation, the site's upland area was backfilled with local sand, gravel and some fine-grained material from other parts of the site. The area was re-graded, flattened and subsequently re-seeded in summer 2002 with a mixture of grasses that were deemed tolerant to the prevailing environmental conditions. Large amounts of thatch built up over a ten-year period and a controlled burn in February 2012 allowed for new plant growth of native species and helped to control for some invasive plant species.

Currently, Stratford Point is in the process of ecological restoration and is being managed through a collaborative effort of University researchers, the private landholder (DuPont Corporation) and a non-profit organization (Connecticut Audubon). A 2001 conservation easement on the site now ensures that Stratford Point will remain undeveloped in perpetuity and that its habitat and conservation values are protected while remaining accessible to the general public for "ecologically responsible educational activities and recreational activities".

Milford Point: The Reference Site

Milford Point (MP) is a barrier beach complex on the east side of the Housatonic River, separating the Charles Wheeler Marsh from the Long Island Sound (Figure 1B). Much of Milford Point's upland is developed and privately owned, but approximately 10 acres is owned by the State of Connecticut and leased to the Connecticut Audubon Society (CAS). This area contains a coastal dune complex, upland early successional grassland and scrubland habitat and some stands of trees. Milford Point is surrounded by coastal habitat, with sandy beach on the Long Island Sound side and a tidal marsh fringe on the Wheeler Marsh side.

Milford Point supports a variety of state-listed plant species including Eastern Prickly Pear Cactus (*Opuntia humifusa*; Special Concern), Blazing Star (*Liatris scariosa var. novae-angliae*; Special Concern), Panic Grass *(Panicum amarum*; Threatened) and Sickle-leaved Golden Aster (*Pityopsis falcata*; Endangered), and provides breeding habitat for state-endangered Horned Lark (*Eremophila alpestris*). Comparable, intact sandy beach and dune systems at Milford Point provide suitable breeding habitat for Piping Plovers (*Charadrius melodus*; Threatened), Least Terns (*Sternula antillarum*; Threatened), and other species of conservation concern such as Horseshoe Crabs (*Limulus polyphemus*) and Diamond-back Terrapins (*Malaclemys terrapin*).

Methods

Baseline assessments of species richness and abundance for plants and terrestrial invertebrates were measured at both sites in 2011 and 2012. Both Stratford Pt. and Milford Pt. were surveyed from May through August in order to compare species richness and abundance among sites and across years. We used a permanently marked line transect sampling strategy at each site. Stratford Pt. had five transects ranging from 130 to 160 meters and Milford Pt. had three transects ranging from 100 to 80 meters. Every ten meters along the transect lines, a one m^2 quadrat was used to sample plant species, percent cover, bare ground and leaf litter. What we report here is from a combined sampling effort along three line transects with a total of 18 quadrats in May 2011 and the same 18 quadrats sampled again in June at both sites (Figure 2 and 3, respectively). In 2012, the same protocol and transect lines were used but with an increased sample size; 29 $1m^2$quadrats were sampled in May and the same 29 quadrats sampled again in June at both sites. Total area sampled was 36 m^2 in 2011 and in 58 m^2 in 2012.

Terrestrial invertebrates were sampled at both sites using pit traps that consist of glass test tubes, 15cm in length with a 3cm diameter. The tubes were filled half way up with soapy water and placed in a hole so that the top of the tube was just below ground level. Invertebrates walking along the ground fall into the tube and cannot escape. The pit traps were deployed for five days in July at both sites every 10 meters along the transect lines. In 2011, ten pit traps were deployed along transect C at Stratford Pt. and transects A and B at Milford Pt. In 2012, 25 pit traps were deployed at both sites in the same areas and also in July. The contents of the pit traps were sorted, counted and the invertebrate species were all identified to order and approximately 95% were identified to family.

Species diversity which combines species richness with evenness was calculated using the Shannon-Weiner Index (H'): Where H' = the absolute value of the Shannon-Weiner diversity index, and will be used to compare the restored site with the reference site.

Upland Planting

Revegetation of the upland at Stratford Point began in the spring of 2012 to (1) enhance migratory bird stop-over sites, (2) provide cover for winter resident wildlife, (3) increase seed rain (deposition) by birds, (4) speed natural succession in the upland area, and (5) shade out invasive plant species. Ninety-six woody plants were installed in four islands (groups). Each group consisted of two Hackberry trees (*Celtis occidentalis,*), two Red Cedars (*Juniperus virginiana),* four Beach Plums (*Prunus maritime),* four Shadbushes *(Amalanchier canadensis),* four Northern Bayberry*, (Myrica pensylvanica),* four Staghorn Sumac *(Rhus typhina),* and four Red Bearberry *(Arctostaphylos uva-ursi).* The growth and spread of these species will be measured and wildlife usage will be documented over the next 10 years.

Dune Installation

In December of 2011, an artificial dune with underlying soft erosion control structures (sediment-filled Geotubes) was installed to prevent further loss of upland along the north shore due to past storms. Both in February and again in October, 2012 the top of the dune was eroded away by major storm events. The Geotubes prevented shore erosion but the dune will need to be reinstalled.

Results and Conclusions

The top ten plant species from each site for each year are depicted in Figure 2. Prior to the prescribed burn, Stratford Pt. was dominated by mugwort (*Artemisia vulgaris*), an invasive species, and big bluestem (*Andropogon gerardii*) resulting from the initial reseeding of the site in 2002. Additionally, white sweet clover, little bluestem, and low hop clover made up 75% of the total area surveyed at the restoration site (see Figure 2). Following the prescribed burn, the percentage of bare ground increased from 13% to 30 % and leaf litter decreased from 30% to 7% from 2011 to 2012. Overall plant diversity (H' – Shannon-Weiner Index) at Stratford Pt. increased from 2.3 to 2.6 from 2011 to 2012, respectively (Figure 2). Therefore the prescribed burn did have an effect on the vegetative community. Decreased leaf litter and nutrient availability should alleviate the proliferation of invasive species. The increase in bare ground provides opportunities for native vegetation (including endangered and threatened species such as Sickle Leaved Golden Aster, Eastern Prickly Pear) to germinate and establish populations. Over the same time period, Milford Pt., our reference site, was dominated by American dune grass (*Leymus mollis*), followed by Canada bluegrass, poison ivy, and spotted knapweed. These species made up ~75% of the area that was vegetated in our quadrat samples. The percentage of bare ground at Milford Pt. decreased over the same time period from 16% in 2011 to 12% in 2012. Leaf litter decreased slightly from 44% in 2011 to 39% in 2012. Overall plant diversity remained constant at Milford from 2011 to 2012 (H' = 2.4)

Pit trap samples for terrestrial invertebrates at Stratford Pt. had variation in the proportions of the dominant terrestrial invertebrates between 2011 and 2012. More than 80% of the individuals were derived from three families including ants (*Formicidae*), pillbugs (*Armadillidiidae*), and soil mites (*Euzetidae*). However, in 2012 ants (*Formicidae*) dominated the samples (Figure 3.). The prescribed burn at Stratford Pt. allowed for a slight increase in species number and evenness and dramatically changed the amount of leaf litter and bare ground by 17-23% (Figure 3). The decline of leaf litter and thatch after the burn caused a shift in the composition of the terrestrial invertebrates. Isopod populations declined greatly from 50% (2011) to 4.4% in 2012. In addition, after the burn, ants nearly tripled in population size from 26% in 2011 to 78% of the invertebrates sampled in 2012. We predict that these population shifts should stabilize over the next few years after the initial prescribed burn. At Milford Pt. terrestrial invertebrate communities were dominated (~80%) by ants (*Formicidae*), pillbugs (Isopoda; *Armadillidiidae*), soil mites (Acariformes; *Euzetidae*), and two types of springtail (Collembola: *Entomobryomorpha* and *Symphypleona*).

The continued collection of data over the long term will allow restoration project managers to increase the predictability of success in the face of uncertainty due to variation in natural phenomena such as hurricanes and other temporal events. While year-to-year variation in plant population sizes (evenness) and species composition may occur, sites with fewer disturbances tend to be stable over the long term (Chapin et al. 2000). Currently, the highly disturbed coastal zone habitat at Stratford Pt. does not have much resilience or resistance to environmental change (Chapin et al. 2000). Stratford Pt. is dominated by invasive plant species when compared to a stable preserved coastal zone that has had minor disturbances over the years (see Figure 2). However, Milford Pt. is more resilient and resistant as the disturbance regime at Milford Point is less frequent and of lower magnitude than at Stratford Point. In late August 2011, Hurricane Irene caused saltwater inundation far up into the dune system at Milford Pt. This caused the die off of mugwort and other salt intolerant species. This die off was reflected in our 2012 surveys (Figure 2). Species composition changed slightly from year to year at both sites. At Milford Pt. dune grass remained the dominant species, mugwort declined in 2012 and Canada bluegrass (*Poa compressa*) increased.

Ultimately, a whole ecosystem approach is needed that allows for the five major estuarine habitats to be installed together. This would promote stability of the shore in the face of continued climate change events.

The Future of Stratford Point

Upon completion of this restoration, the site will consist of approximately one-half acre of coastal woodland, surrounded by coastal grass/meadow mix with a dune system on the northeast side stabilized with beach grass and woody shrubs. In front of the dune will be a 4 acre marsh dominated by *Spartina spp*. In the intertidal zone, a living shoreline will be installed with a combination of cement reef balls interlaced with shell-filled biodegradable cotton tubing. This will allow the dissipation of wave energy, reducing erosion and increasing fine-grained sediment deposition for salt marsh colonization and speed the establishment of the estuarine community. The living shoreline will make an ideal habitat for the colonization of a number of species of bivalves (e.g. *Mytilus spp., Abra spp., Crassostrea spp*, etc.). This site is restricted and commercial shellfish harvest is not allowed in this area. Finfish habitat will be greatly enhanced.

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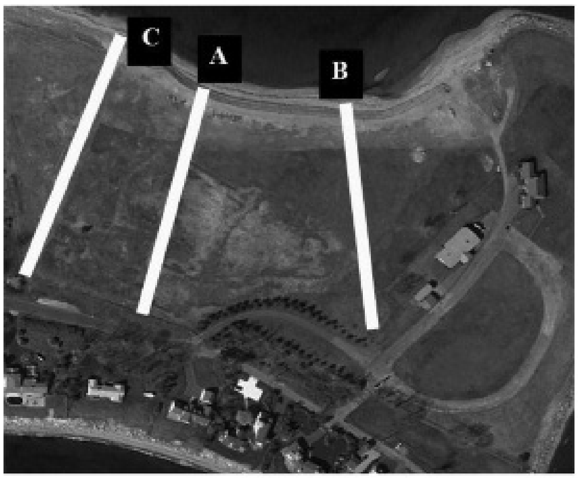

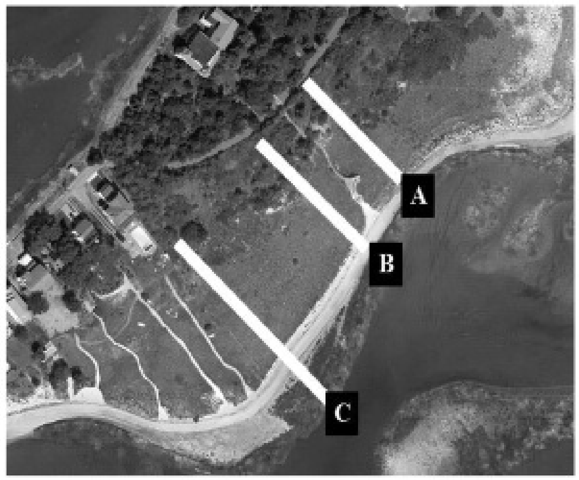

A. B.

FIGURE 1
A. A satellite map of Stratford Point with the approximate location of the line transects shown in white that were used for the vegetation and invertebrate analysis. This site was a former gun club and is currently under habitat restoration.

B. This satellite map of Milford Point depicts the approximate location of the line transects used for vegetation and invertebrate analysis. This site is our reference site or model for the restoration of Stratford Pt.

Vegetation

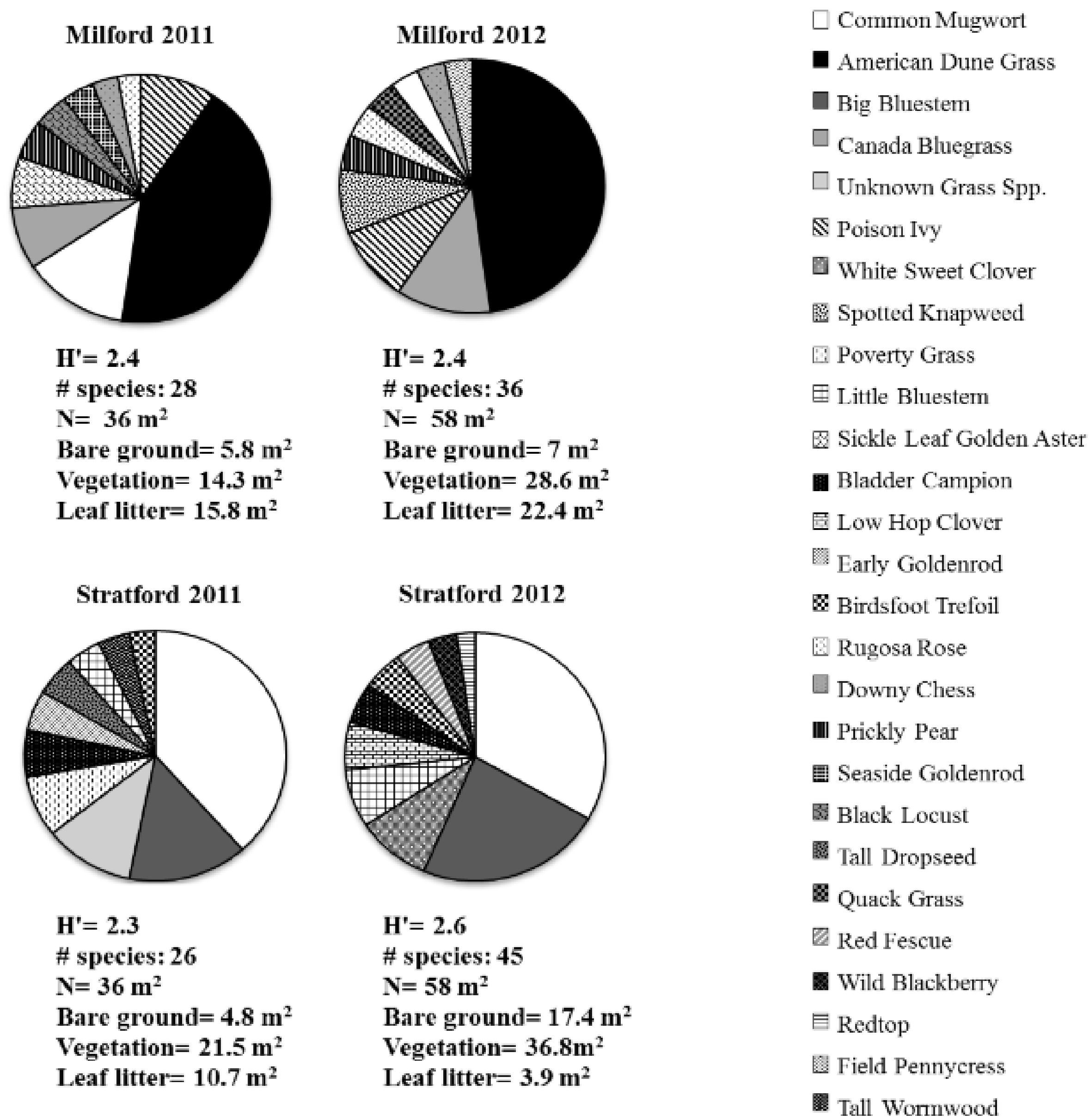

FIGURE 2

Plant biodiversity at Stratford Point and Milford Point in 2011 and 2012. H', the Shannon-Weiner Index for species diversity and evenness, is used to compare an analysis of the plant biodiversity on Stratford Point and Milford Point. The pie charts show the top ten species found at both sites over a two-year period. Each piece of the pie represents one species. The width of the piece represents its abundance in proportion to the all of the species found. N is equal to the number of 1 m2 quadrats sampled in each year at each site. (Contact authors for list of Latin species names).

Terrestrial Invertebrates

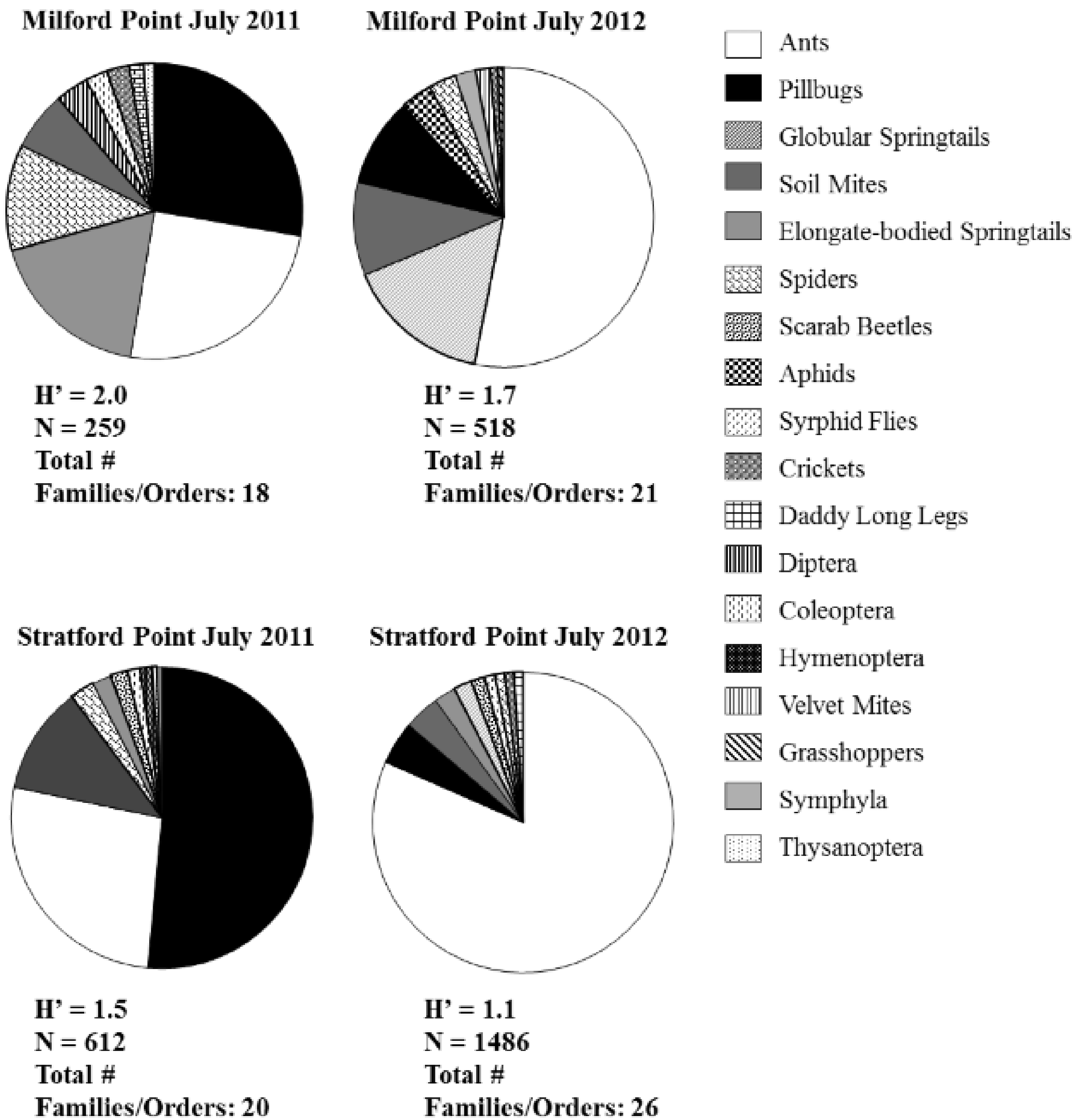

FIGURE 3
Upland invertebrate biodiversity at Stratford Point and Milford Point in 2011 and 2012. H', the Shannon-Weiner Index for species diversity and evenness, is used to compare an analysis of the upland invertebrate biodiversity on Stratford Point and Milford Point derived from pit traps set out along the transects. The pie charts show the top ten invertebrate families found at both sites over a two-year period. Each piece of the pie represents one family (unknowns were identified to order). The width of each pie piece represents its proportion; the number of individuals divided by N. N is equal to the total number of individuals found at each site in one year. (Contact authors for list of Latin family names).

A Comparative Analysis of Direct Precipitation Input into Long Island Sound

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Abstract

Freshwater inputs are important to the dynamics of coastal and estuarine waters. Sources of fresh water into Long Island Sound (LIS) include the Connecticut, Housatonic, Thames, smaller coastal rivers, and direct input from precipitation. The objective of this study was to assess precipitation's importance relative to other freshwater sources. This comparative analysis used USGS discharge data from the major rivers and NOAA radar-derived precipitation data for 2005-2012. Direct precipitation influences on LIS salinities were isolated via comparison of estuary model runs with and without precipitation input. Finally, a comparison of potential energy fluxes from direct precipitation input and major rivers was made. Results indicate that direct precipitation had a different annual cycle than river inputs. Volume inputs and total potential energy fluxes from direct precipitation were comparable to the Thames and Housatonic inputs. The impact direct precipitation had on salinities, however, was much smaller; likely due to more spatially diffuse precipitation input that caused the potential energy flux intensity to be orders of magnitude smaller than river inputs.

Introduction

Freshwater inputs are important to the dynamics of coastal and estuarine waters. Traditionally, the importance of direct input from precipitation relative to input from river discharge in Long Island Sound (LIS) has been assumed small. To our knowledge, however, a quantitative comparison has not been made between the effects of direct precipitation input and river discharge in LIS. With this in mind, this study sought to answer the following questions with a combined observational/modeling approach. How does direct input of precipitation into LIS 1) compare to precipitation over Connecticut watersheds? 2) compare to river inflows? 3) affect salinity relative to the Housatonic?

Methods

Daily discharge data for the years of 2005 to 2012 were collected via the USGS website from the farthest downstream gages of the Thames and Housatonic River watersheds. Discharge for the Thames was calculated through summation of gage data from the Quinebaug, Yantic, and Shetucket Rivers. The Housatonic River's discharge, meanwhile, was determined through the summing of both Housatonic and Naugatuck River gage data. These discharges were then averaged for every month.

Direct input of precipitation into LIS was determined for the same time frame using radarderived daily precipitation data from the NOAA National Weather Service, Advanced Hydrologic Prediction Service. These data were spatially averaged over LIS and then temporally averaged to create a monthly dataset. This was also done over the Housatonic and Thames watersheds using the same radar-derived product to compare precipitation over these watersheds to the amount falling directly on LIS.

Estuary salinities were modeled with and without direct precipitation using the Regional Ocean Modeling System (ROMS) forced with rivers, surface heat fluxes, winds, and tides for 2008. The model setup followed the methods described by Whitney and Codiga (2011). Runs with and without direct precipitation were compared to determine the effects of precipitation on estuary surface salinities. As a comparison, the surface salinity effects of the Housatonic River were isolated by tagging its plume waters with a passive tracer.

Results & Analysis

Total yearly precipitation over LIS ranged from 950 to 1500 mm over the study period. The Thames watershed received a similar amount each year. The Housatonic watershed, however, consistently received more precipitation per unit area than LIS with the largest difference observed in 2011 (a ~150 mm difference). The LIS, Housatonic, and Thames total yearly precipitation all showed similar inter-annual variability.

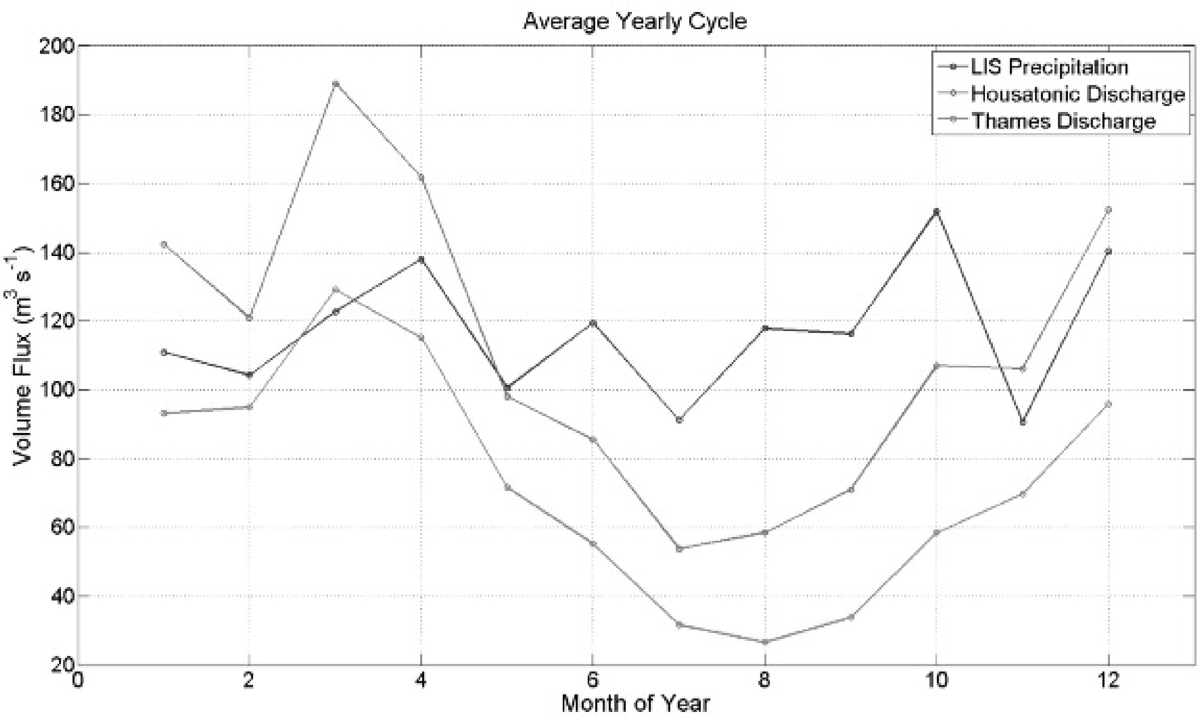


FIGURE 1
Average yearly cycle of volume flux

Volume fluxes from river discharge and LIS direct precipitation were averaged for every month to yield the average yearly cycle (Figure 1). These yearly cycles show the Housatonic and Thames Rivers to vary more throughout the year than direct input from precipitation. Direct input from precipitation was found to be larger than the Housatonic from summer to early fall and the Thames for most of the year.

Salinity in LIS was modeled with and without direct input from precipitation. Comparing these two model runs for summer 2008 (Figure 2a) indicates direct input from precipitation has a small freshening effect over most of the LIS (-0.006 ppt average) while the central sound experiences a slight increase in salinity. On the continental shelf, paired areas of increased and decreased salinity are associated with LIS buoyant outflow position changes between runs. The Housatonic's influence on salinity (Figure 2b), determined by tracing its plume waters in the same model, had a much larger effect on salinity in LIS (-0.950 ppt average), causing a decrease in salinity throughout the sound with freshening beyond 1 ppt for most of western LIS.

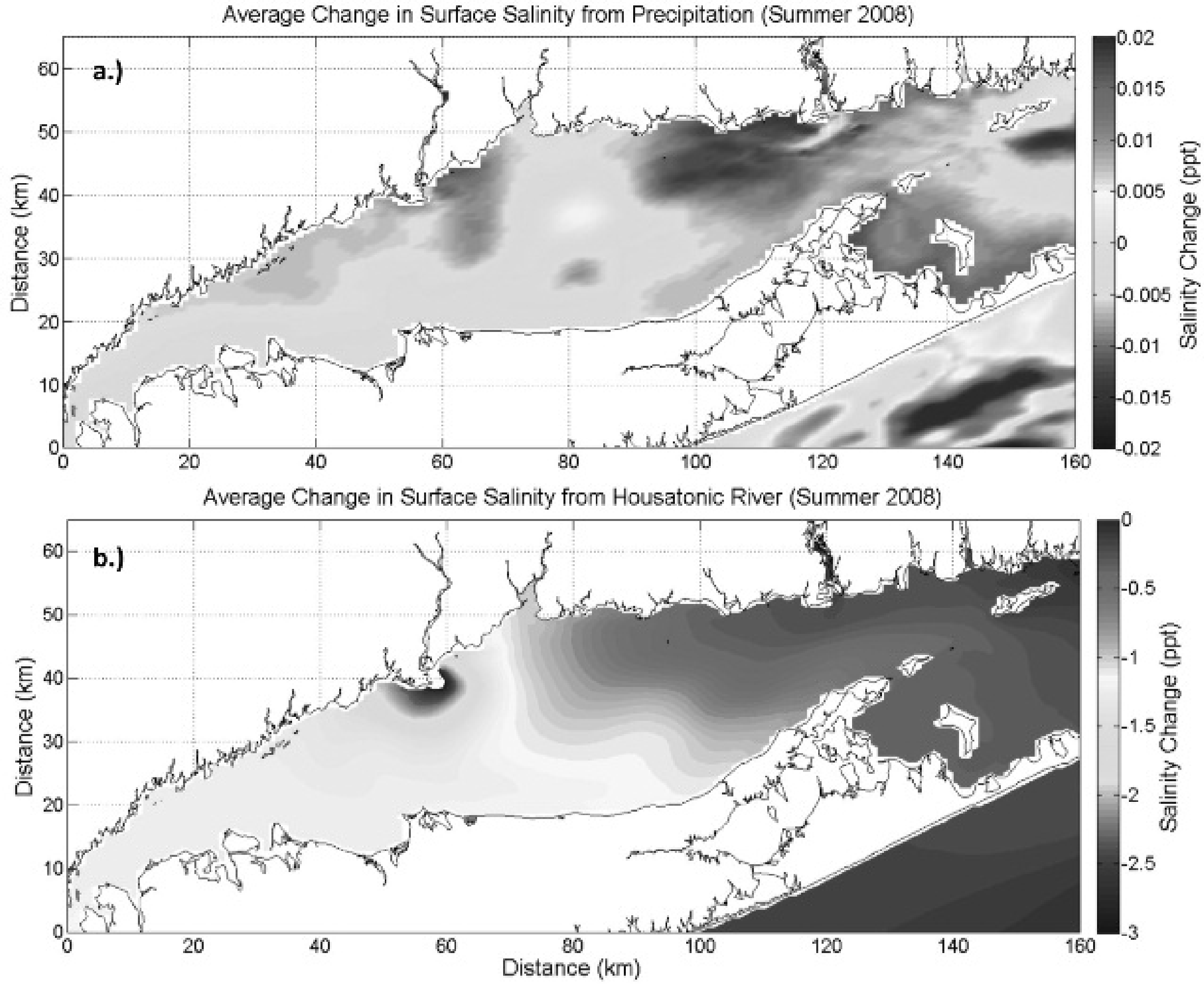


FIGURE 2
The average salinity difference due to (a) direct input from precipitation and (b) the Housatonic River

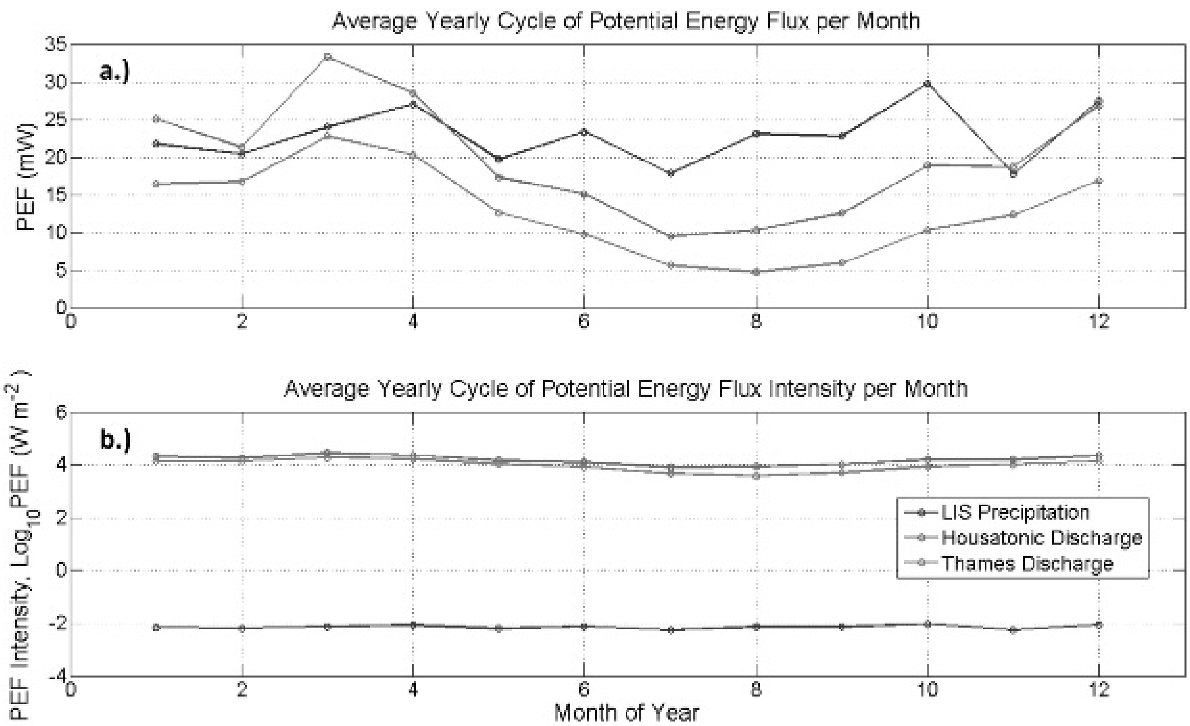
The potential energy flux (PEF) for direct precipitation and river inputs can be calculated as:

$$PEF_{precip} = gH_{LIS}\rho_{precip}Q_{precip} \tag{1a}$$

$$PEF_{river} = \frac{g}{2}(2H_{LIS} - H_{river})\rho_{river}Q_{river} \tag{1b}$$

where g is gravitational acceleration, H_{river} is the river input thickness, H_{LIS} is the average depth of LIS (approximately 20 m), ρ_{precip} and ρ_{river} are the input water densities (both taken as 1000 kg/m^3), and Q_{precip} and Q_{river} are the input volume fluxes of direct precipitation and the rivers respectively. The results of this computation (Figure 3a) indicate that direct precipitation introduces more potential energy into LIS through much of the year and should have a larger stabilizing effect. This suggestion conflicts with the weak salinity effects direct precipitation has compared to the Housatonic River input. The PEF intensity was calculated by dividing the PEF of direct precipitation by the area of LIS, and the PEF of both rivers by an estimated cross sectional area of 1200 m^2. The PEF intensity of the Housatonic and Thames Rivers were found to be six orders of magnitude larger than that of direct precipitation (Figure 3b). Hence, the river inputs are much more concentrated and therefore more capable of introducing strong stable stratification and changing surface salinities in parts of the estuary.

FIGURE 3
Average yearly cycle of (a) PEF (b) and PEF intensity.



Conclusions

Total yearly precipitation over LIS was found to be similar to that over the Housatonic and Thames River watersheds; but with a different annual cycle. On average, direct input from precipitation was larger than the Housatonic and Thames River inflows during summer and early fall. Despite this larger input, however, simulation results indicated that the influence direct precipitation has on average LIS surface salinity was two orders of magnitude smaller than that of the Housatonic River (-0.006 ppt vs. -0.95 ppt). Comparison of potential energy fluxes from direct precipitation and the Housatonic and Thames Rivers shows that while direct precipitation has a larger net PEF, its PEF intensity is approximately six orders of magnitude smaller. Hence, the concentrated nature of the river inputs allows them to more strongly influence salinities than the spatially diffuse direct precipitation inputs.

Acknowledgements

NSF Grant 0955967 (Physical Oceanography) “CAREER: The Influence of Distributed River Inputs and Coastal Embayments on Dynamics in Large Estuaries” supported this work.

Citations

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Mercury Accumulation in Bluefish (*Pomatomus saltatrix*) in Long Island Sound

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Abstract

This study was designed to measure tissue Hg concentrations in juvenile and adult bluefish in Long Island Sound. Bluefish tissue mercury contents reported in this study were compared with results from Skinner et al. (2009) and allow for a determination of recent trends in LIS bluefish Hg (2006-2010). Bluefish (48) collected with the assistance of CT DEEP within LIS represented a wide range of lengths (426 mm – 845 mm) and weights (617 - 5352 g). Measured bluefish Hg concentrations (wet weight) in this study ranged from 0.139 – 0.784 mg/kg. Mean Hg concentrations (0.187 ± 0.030 mg/kg) measured in this study for bluefish in the size range of 305-508 mm were lower in comparison to the results of Skinner et al. (2009) for LIS bluefish sampled in 2006 (0.266 ± 0.114 mg/kg). For bluefish > 508 mm, mean Hg concentrations (0.331 ± 0.167 mg/kg) measured in this study for bluefish were similar in comparison to the results of Skinner et al. (2009) for LIS bluefish sampled in 2006 (0.348 ± 0.130 mg/kg). No significant length-Hg relationship was observed for bluefish in the size category 305-508 mm. In contrast, significant linear length-Hg relationships were observed for all bluefish analyzed and for the size category >508 mm ($y = 0.0012x + 0.43$; $r^2 = 0.70$). The linear length-Hg relationship for bluefish > 508 mm was also significant for the combined CT DEEP 2006 and SCSU 2010 data ($y = 0.0012x + 0.45$; $r^2 = 0.50$).

Introduction

Bluefish (*Pomatomus saltatrix*) are a schooling, migratory pelagic species common in Long Island Sound. Most North American bluefish are migratory, spending their summers in the north, and their winters in the south around Florida and the Gulf Stream (Pottern et al., 1989; Adams et al., 2003). Bluefish was the third most frequently caught species in Connecticut coastal waters in 2008 (1,532,797 million fish) (CT DEP, 2009). Mercury contents in LIS bluefish collected in 2002 averaged 0.14 ± 0.06 mg/kg (Hammerschmidt and Fitzgerald, 2006) while those sampled from Northern New Jersey during 2004-2008 averaged 0.32 ± 0.03 mg/kg (Burger, 2009). Differences in bluefish migration patterns, and associated past differences in dietary exposure, are major sources of mercury variation between these locations. The US EPA regulatory advisory level for safe fish consumption is 0.3 mg Hg per kg wet weight consumed (US EPA, 2006).

Connecticut fish consumption advisories currently allow low risk groups to increase their consumption of bluefish from one meal every two months to one meal per month of bluefish greater than 25 inches long (www.ct.gov/dph/lib/dph/environmental_health/eoha/pdf/ ificatchit09-english.pdf). Although recent declines in mercury contents in fish have been noted for some fish species, a positive correlation has been shown for elevated body burden mercury and recreational anglers who consume the fish they catch (Gobeille et al., 2006). Relationships between mercury and fish size are important as previous research has shown that tissue mercury content increases non-linearly in large fish, fish anglers most likely keep and eat (Piraino and Taylor, 2009; Burger, 2009).

This study was designed to measure tissue mercury concentrations in juvenile and adult bluefish (*Pomatomus saltatrix*) in Long Island Sound. The goal of this study was to determine the concentrations of mercury in LIS bluefish and test the following hypotheses: (1) LIS bluefish tissue mercury concentrations will positively correlate with weight and length; and (2) LIS bluefish tissue mercury concentrations will be less than mercury tissue contents measured in previous studies (Skinner et al., 2009).

Methods

Bluefish were collected by Connecticut Department of Energy and Environmental Protection (DEEP) personnel during the Fall 2010 (Sept.-Oct). Each bluefish was assigned a unique identifying number and was weighed to the nearest gram and measured for total length to the nearest millimeter. Samples of skinless (skin and scales removed) axial muscle (approx 25-30 grams wet weight) were removed from the dorsal region above the operculum on each side of the fish using a stainless-steel scalpel. Each fish tissue sample was freeze-dried for 48 hours (Labconco FreeZone 4.5L Benchtop Freeze-Dry System), weighed (gram dry weight), homogenized using a mortar and pestle, and stored in clear borosilicate 20 ml ICHEM certified vials.

Freeze-dried fish tissue samples (0.005-0.040 g; duplicate samples from each filet) were analyzed directly for mercury by thermal decomposition amalgamation and atomic absorption spectrophotometry using a Milestone DMA-80 direct mercury analyzer according to EPA Method 7473 (USEPA 1998). The mercury analyzer was calibrated using the National Research Council of Canada (DORM-3; fish protein; 0.382 mg/kg Hg). Mercury calibration curves (range of 2.5 – 20 ng Hg) were highly significant (mean $R^2 = 0.9998$). For quality assurance, blanks (empty nickel sample boats) were analyzed every 6 samples to assess instrument accuracy and potential drift. All nickel sample boats were conditioned at 650°C in a muffle furnace for 30 minutes to minimize mercury concentrations in blanks. Analyses of mercury standard reference material TORT-2 lobster hepatopancreas (0.27 ± 0.06 mg/kg Hg) yielded good agreement with certified values (95-104% recoveries of certified values).

Results and Discussion

Forty eight bluefish were collected during September-October 2010 with the assistance of CT DEEP primarily within north central and eastern Long Island Sound and represented a wide range of lengths (426 mm – 845 mm) and weights (617 - 5352 g). Measured bluefish mercury concentrations (wet weight) ranged from 0.139 - 0.784 mg/kg. For comparison to results of the Skinner et al. (2009), bluefish were grouped into two separate size range categories: 305-508 mm and > 508 mm (Table 1). Mean mercury concentrations (0.187 ± 0.030 mg/kg) measured in this study for bluefish in the size range of 305-508 mm were lower in comparison to the results of Skinner et al. (2009) for bluefish sampled in 2006 (0.266 ± 0.114 mg/kg) (Table 1). For bluefish > 508 mm, mean mercury concentrations (0.331 ± 0.167 mg/kg) measured in this study for bluefish were similar in comparison to the results of Skinner et al. (2009) for bluefish sampled in 2006 (0.348 ± 0.130 mg/kg) (Table 1).

No significant length-mercury relationship was observed for bluefish in the size category 305-508 mm (Figure 1). In contrast, significant linear length-mercury relationships were observed for all bluefish analyzed and for the size category >508 mm (Figure 1). The linear length-mercury relationship determined in this study for bluefish > 508 mm was very similar to the length-mercury relationship for the 2006 and 2007 combined bluefish mercury measurements calculated by Skinner et al. (2009).

The US EPA regulatory advisory level for safe fish consumption is 0.3 mg Hg per kg wet weight consumed. Results of this study show that the 0.3 mg Hg per kg wet weight consumed is exceeded for many Long Island Sound bluefish exceeding 24 inches (600 mm) length (Figure 1). This result is consistent with the Connecticut fish consumption advisory that currently allows low risk groups to increase their consumption of bluefish from one meal every two months to one meal per month of bluefish greater than 25 inches long (www.ct.gov/dph/lib/dph/environmental_health/eoha/pdf/ ificatchit09-english.pdf).

TABLE 1
Comparison of length, weight and mercury concentrations for bluefish tissues taken from Long Island Sound in 2006 (Skinner et al., 2009) and 2010 (This Study).

Source	Year	n	Length (mm)	Weight (g)	Mercury (mg/kg wet wt.)
			Bluefish (305 – 508 mm)		
CT DEEP[a]	2006	25	411 ± 47	663 ± 228	0.266 ± 0.114
			322 – 480	285 – 1050	0.118 – 0.495
SCSU	2010	23	449 ± 15	866 ± 108	0.187 ± 0.030
			426 – 477	617 – 1021	0.139 – 0.252
			Bluefish (>508 mm)		
CT DEEP	2006	111	684 ± 73	2716 ± 925	0.348 ± 0.130
			524 – 816	461 – 5865	0.016 – 0.694
SCSU	2010	25	655 ± 116	2664 ± 1381	0.331 ± 0.167
			527 – 845	1247 – 5352	0.184 – 0.784

[a] CT DEEP; Connecticut Department of Energy and Environmental Protection (Skinner et al., 2009).

FIGURE 1
Combined length – mercury relationship for Long Island Sound bluefish
reported by Skinner et al. (2009) (●) and this study (○). Solid line represents results of a linear regression analysis of combined mercury data for bluefish >508 mm (y = 0.0012x – 0.45; r2 = 0.50). Dashed line (0.3 mg Hg per kg wet weight) represents the US EPA regulatory advisory level for safe fish consumption.

Summary

Results of this 2010-2011 CSU supported research support the following summary statements:

1) Forty eight bluefish collected with the assistance of CT DEEP within Long Island Sound represented a wide range of lengths (426 mm – 845 mm) and weights (617 - 5352 g). Measured bluefish mercury concentrations (wet weight) ranged from 0.139 - 0.784 mg/kg.
2) Measured mean mercury concentration for bluefish > 508 mm in this study (2010) were similar to mean mercury concentrations for similarly sized bluefish examined in CT DEEP surveys for bluefish captured in 2006.
3) The US EPA regulatory advisory level for safe fish consumption is 0.3 mg Hg per kg wet weight consumed. Results of this study show that the 0.3 mg Hg per kg wet weight consumed is exceeded in Long Island bluefish exceeding 24 inches in length.

Acknowledgements

Support for this research project was provided by a 2010-2011 CSU Faculty Research Grant awarded to Vincent Breslin and funds provided to the Center for Coastal and Marine Studies from the Werth Family Foundation, Woodbridge, CT. The authors thank Kurt Gotchall, CT DEEP, for coordinating the collection of bluefish for this research. We also thank Lawrence Skinner, New York State Department of Conservation, for providing the 2006 bluefish mercury data.

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Detection of Perfluorinated Compounds in Wastewater Effluent Entering the Long Island Sound Watershed

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Abstract

Perfluorinated compounds (PFCs) have been extensively used for their unique properties in numerous industrial and commercial applications since the 1950's. The properties include chemical stability that confers resistance to biotic and abiotic environmental degradation which has led to their ubiquitous presence in practically every environmental compartment, and distribution worldwide. Wastewater treatment facilities (WWTFs) are considered a major point source for the entry of PFCs to the aqueous environment. The presence of PFCs in wastewater effluents impacting the Long Island Sound (LIS) watershed was investigated in the spring and summer of 2012. A survey of the effluents of 11 wastewater treatment facilities (WWTFs) confirmed PFCs to be present in concentrations ranges consistent with literature values. The bioaccumulative 8 carbon chain species, PFOA and PFOS, were found to be the most prevalent PFCs in the effluent stream (with average (range) concentrations of 28 (16-63) and 15 (1-65) ng/L respectively. While the presence of these compounds has been reported for many water bodies and sediments, partitioning data between environmental compartments is limited. An important factor in the fate and distribution of these target compounds is the scavenging by particulates, therefore partitioning of PFCs between effluent dissolved and particulate phases was also investigated.

Introduction

Effluent waters from waste water treatment facilities (WWTFs) discharging into local waterways are known point source of nutrients and trace contaminants. Many of these micro pollutants are classified as 'Emerging Contaminants', as they are often detected in environmental samples due to their prolific uses and applications, yet the consequences of their presence is still yet to be fully understood. Perfluoroalkyl compounds (PFCs) are an example of commercially useful anthropogenic compounds which have gained widespread use due to their distinctive chemical characteristics. These include water and oil repellency, chemical and thermal stability and inertness, and surface active properties in both aqueous and solvent systems that are unparalleled . PFCs have been used commercially since the 1950's, in applications such as stain repellants in products that include textiles and paper packaging, as surfactants and dispersants in formulations such as paints, cosmetics, lubricants and firefighting foam, and in the production of fluoropolymers such as Teflon®. The physical chemical properties which produce such commercially useful characteristics also impart the essential characteristics of persistent organic pollutants (POPs); they are environmentally persistent, bioaccumulative and toxic (PBT). Bioconcentration and bioaccumulation are a function of chain length, with perfluorosulfonic acids (PFSAs) being more bioaccumulative than perfluorocarboxylic acids (PFCAs), and shorter chained (7 or less fluorinated carbons) PFCAs not considered bioaccumulative, even though they are environmentally persistent and are found in detectable levels in wildlife . PFCs have been shown to induce toxic effects including hepatotoxicity, immunotoxicity and developmental toxicity, as well as hormonal effects . Mounting evidence of the PBT nature of PFCs lead to the voluntary discontinuation of PFOS and related compounds by the principal manufacturer, 3M, working with the US EPA between 2000 and 2002, as well as inclusion of these compounds to the Stockholm Convention on POPs in 2009, thereby restricting manufacture and use. However PFCs emissions continue to be of global concern as production in developing regions increased to fulfill industrial demands as well as the continued production and use of numerous new PFCs, many of which are less soluble and more volatile than the perfluorinated acids, and are capable of long-range atmospheric transport. These include fluorotelomer alcohols (FTOHs) and perfluoroalkyl sulfonamides (FASAs), compounds which have also been shown to degrade to the persistent PFCAs and PFSAs in both the atmosphere as well as under aerobic conditions, such as in activated sewage sludge . The discharge of municipal wastewater from WWTFs is one the principal point sources of PFCs to the aquatic environment. Moreover, a number of studies suggest that concentration of some PFCs, such as PFOA and PFOS, are higher in the final effluent than in the influent waters, suggesting that formation of these final persistent degradation products from precursor compounds is occurring during the waste water treatment process.

The partitioning of persistent organic pollutants describes the tendency of a compound to be found in, or to move to or from, an environmental phase or compartment. Understanding the distributions of PBT pollutants and obtaining reliable expressions for partitioning is key for environmental modeling, to be able to predict the impact of human activities on the environment and to determine the potential for human exposure . Few studies have investigated the partitioning of PFCs between the dissolved and suspended particulate matter (SPM), and no study to date, to the authors knowledge, has investigated the partitioning of PFCs onto wastewater effluent SPM (efSPM). The aims of this study were to determine the occurrence, range of mass flows and partitioning behaviors of PFCAs and PFSAs in treated wastewater effluent discharging into the LIS watershed from several CT WWTFs. Though the presence. of PFCs has been reported in a growing number of aquatic systems, this is the first report on the presence of the compounds in the LIS- CT shoreline region.

Methods

Suspended particulate matter (SPM) extraction: SPM was collected on polypropylene (PP) filters during sample filtration. PP filters were placed into pre-cleaned 15mL PP centrifuge tubes, 10ng absolute of PFC recovery standard mix was spiked onto each filter, and then extracted twice by sonication in methanol. Extracts were reduced then cleaned using ENVI-carb .

Aqueous phase extraction: Two 250 mL samples of filtrate were placed into pre-cleaned 500mL PP bottles and spiked with 10ng of the PFC recovery standard mix for solid phase extraction (SPE) using a method previously described . Oasis HLB Plus (225mg) SPE cartridges (Waters Corporation, Milford, MA) were mounted on a Miniprep® vacuum manifold, however all poly(tetrafluoroethylene) (PTFE) materials, such as the were removed and replaced by PP counterparts to avoid any potential fluoropolymer contamination. Extraction cartridges were pre-cleaned with methanol then conditioned with MilliQ water. Samples were extracted at a flow rate of 50 µL/sec, washed with 10% Methanol, dried under vacuum for 20 minutes then eluted with methanol into a PP tube. Elutes were concentrated under a gentle stream of ultra-high purity nitrogen to a final volume of 1mL. .

Results and Discussion

Occurrence: The concentrations of the target PFCs in the effluent of the 12 WWTFs sampled in the spring and the 6 facilities sampled in the summer of 2012 are summarized in Tables 6 and 7 respectively. Consistent with literature reports, PFOA was the most dominant of the PFCAs, with an average concentration of 28ng L^{-1} (16-63ng L^{-1} range), and PFOS was the major PFSA detected with an average concentration of 15ng L^{-1} (1-65ng L^{-1} range) (Figure 1). The concentrations of PCFs observed in the CT WWTFs are generally similar in magnitude to those reported in locations in China , Germany , Iowa , Georgia and Oregon (Schultz et al. 2006) and were considerably lower than PFC concentrations reported in Taiwan (Lin et al. 2010) and those determined locally in New York . Total mass loading of total PFCs to the LIS, assuming 1 billion gallons of treated effluent per day loading rate, was calculated to be in the range of 73-475 kg per year (Figure 2). There were no significant differences in PFC concentrations in summer compared with spring.

The relative concentrations of the PFC congeners vary across the published data, though the most commonly detected in the highest concentrations (and also most often studied) are PFOA and PFOS. However there is an increase in the occurrence and concentration of the shorter chained PFCs such as PFPA, PFHxA and PFHpA compared to initial studies where PFOA was the PFCA most often detected in relatively larger concentrations. This trend towards shorter PFC species was observed here, as the average concentrations of PFPA and PFHxA were similar to that of PFOA. This is likely a reflection of recent industrial and environmental stewardship programs, instituted here in the US by the EPA in 2005, restricting the uses and applications of the longer chain (C>7) perfluoralkyl compounds and instead substituting with the shorter chain PFCs that have been found to have no bioaccumulation potential.

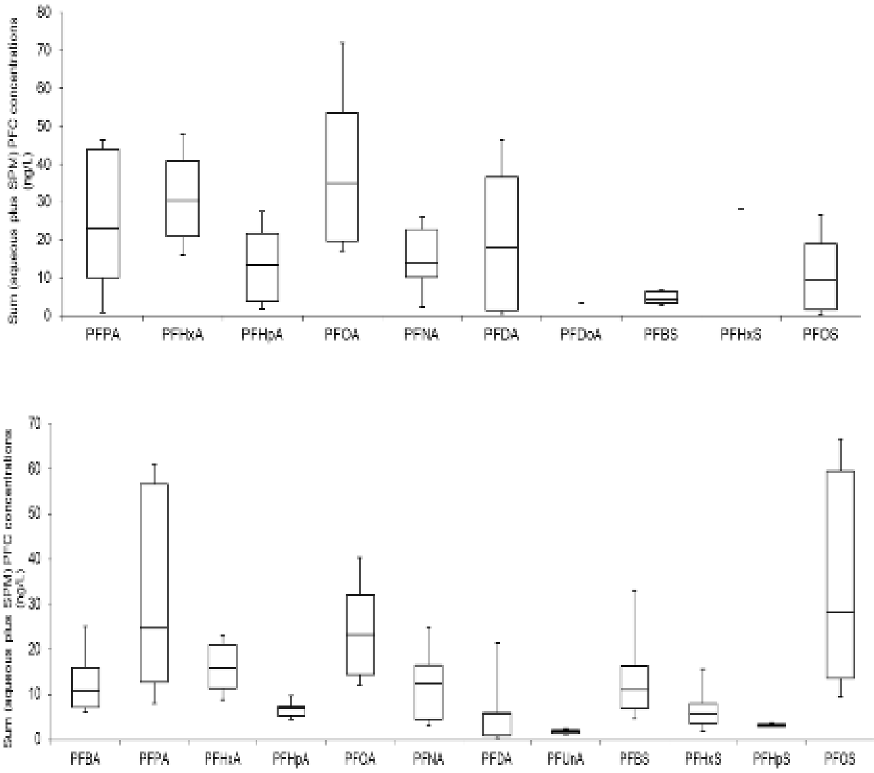

FIGURE 1A AND B
Box plots showing mean, 10th and 90th percentile, and range of total PFC concentrations detected in the effluent of (A-top) 11 CT WWTFs, spring 2011 and (B-bottom) of the 6 WWTFs located along the Housatonic River, summer 2012.

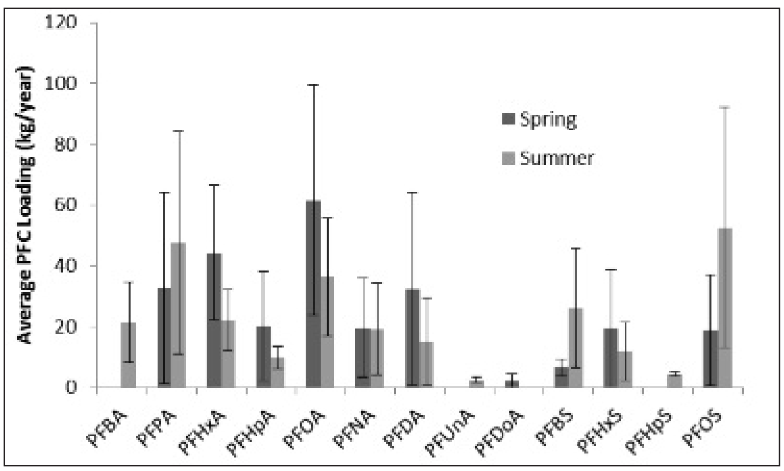

FIGURE 2 Estimated concentrations (average ± range) of total PFC loadings to the LIS (Kg per year) assuming discharge rate of 1 billion gallons per day.

Partitioning Behavior: The partitioning of persistent organic pollutants describes the tendency of a compound to be found in, or to move to or from, an environmental phase or compartment. Understanding the distributions of PBT pollutants, and obtaining reliable expressions for partitioning processes is key for environmental modeling, to be able to predict the impact of human activities on the environment and to determine the potential for human exposure . Fine effluent particulate matter that does not settle out may provide a vector by which hydrophobic contaminants pass through treatment process. Additionally, studies have shown that efSPM is a high quality food source for benthic biota and therefore could be an effective pathway for the transport of pollutants into the food chain.

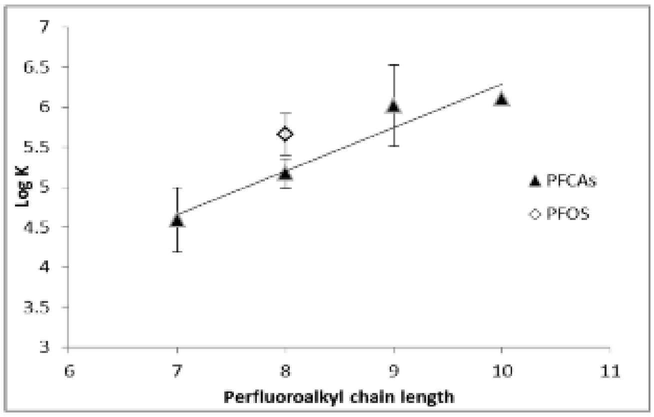

FIGURE 3
Correlation of perfluoroalkyl chain length and Log KOC. Comparison of values obtained for PFCAs and PFOS.

In the waste water effluent sampled, shorter chain PFCAs (C_4 – C_7) and PFSAs (PFBS, PFHxS and PFHpS) were detected in the dissolved phase only, owing to their higher solubility. Longer chained (>C_8) PFCAs and PFSAs were detected in both dissolved and particulate phases. Partitioning constants were derived from the following equations: $K_d = C_{ss}/C_w$ where the C_{ss} is the efSPM PFC concentration (ng/kg dry weight) and C_w is the dissolved PFC concentration (ng/L) and $K_{oc} = K_d/f_{oc}$. Consistent with the literature reports on SPM or sediment partitioning, results show that the partitioning coefficient for PFCs detected in both aqueous and efSPM phases is directly proportional to the length of the fluoro-alkyl chain with a long unit increase of 0.6 per fluoro-alkyl moiety (Figure 3). Higgins and Luthy (2006) reported each CF_2 moiety contributes 0.5-0.6 log units to log K_{oc} for partitioning to bed sediment, and Labadie and Chevreuil (2010) reported log K_{OC} increased by approximately 0.8 log units for both PFCAs and PFSAs with riverine SPM.

Reported partitioning constants for SPM are generally higher than those reported for bed sediment investigations however the partitioning constants derived for the PFCs detected in this study are approximately 1 log unit greater than those previously published. Further investigations are needed to verify if this enhanced partitioning is due to the nature of efSPM or a function of experimental artifact.

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Interdisciplinary Before-After-Control-Impact Study of Tidal Restoration on the West River, New Haven, CT

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Abstract

Tide gates are flap valves added to some estuaries to restrict tidal flushing for purposes of agriculture or to control flooding and mosquitos. Three of ten gates on the West River in New Haven, CT have been replaced with self-regulating ones (SRTGs) that close only in the event of storm surges. The result has been an increase in tidal range of about 1 m along with a dramatic increase in salinity. These changes in salinity and tidal range will enhance a broad range of ecosystem services, altering vegetation, fish and bird communities, and changing the way that people perceive and use the upstream river and surrounding land.

We have studied all these aspects of the river restoration, first in 1995-96 (Casagrande, 1997), and much more intensively in the last two years. We are comparing these results to a control site, the Mill River (New Haven), which has a similar watershed and tide gates that are not being altered. We hope to continue our measurements over the next three years to compare conditions before and after the restoration as well as between the control and treatment sites. In this way, our research is an interdisciplinary Before-After-Control-Impact (BACI) experiment conducted at a large scale. Our ultimate goal is to evaluate the effectiveness of the restoration and to provide guidance to ecosystem managers on how to design and prioritize similar efforts in the future.

Study Sites

The West River estuary on the border of West Haven and New Haven, Connecticut, has been tide gated for nearly a century, creating a degraded fresh-tidal ecosystem with impaired water quality and reduced biodiversity. These changes have significantly altered fish and bird community composition (Lewis and Casagrande, 1997; Moore et al., 1997). They may also have changed the way people perceive, value, and use the park. Save the Sound has obtained major funding from the American Recovery and Reinvestment Act (ARRA) via NOAA to install SRTGs that will remain open except during rare flood events. Installation of the SRTGs was completed in fall 2012. The new gates enhance salt water flushing and dramatically increase tidal range, water quality, and salinity in the marsh. These will in turn generate a cascade of environmental benefits to living marine resources.

Approach

This is a unique opportunity to assess restoration success in a landscape-scale BACI experiment. Anticipating this restoration, we collected “before” data (both biophysical and social) from both the restoration site and a similar system (Mill River), also located within New Haven, where tide gates will not be altered. Both the experimental and control marshes have watersheds of similar size and land use, population demographics, land development patterns, and many other variables. The area immediately upstream of both sets of tide gates is parkland. We propose to continue and to expand these measurements after installation of the tide gates, to quantify the impact of the project and evaluate its effectiveness. Importantly, we expect the marsh to respond quickly enough to make an assessment possible in the two years of the proposed grant. The proposed research is truly multidisciplinary, as physical, biological, and human aspects of the ecosystem restoration all will be evaluated. We briefly describe them below.

Hydrology and Water Quality

We have monitored both the experimental and control systems with YSI 6920 sondes every 15 minutes for 18 months, with data on water depth, salinity, dissolved oxygen, pH, turbidity, and temperature transmitted by telemetry to the web[4]. Figure 1 illustrates water depth measurements for the experimental and control sites for April 2011, a typical period before installation of the SRTGs. With both sets of tidegates closed, the tidal range (caused mainly by fresh water backing up behind the closed tidegates) is essentially identical at the control and treatment sites. Importantly, this is true both for daily tides and in the way the two systems respond to storm events. This indicates that the Mill River is a suitable physical control for the West River. (The other parameters we measured show comparable similarity.)

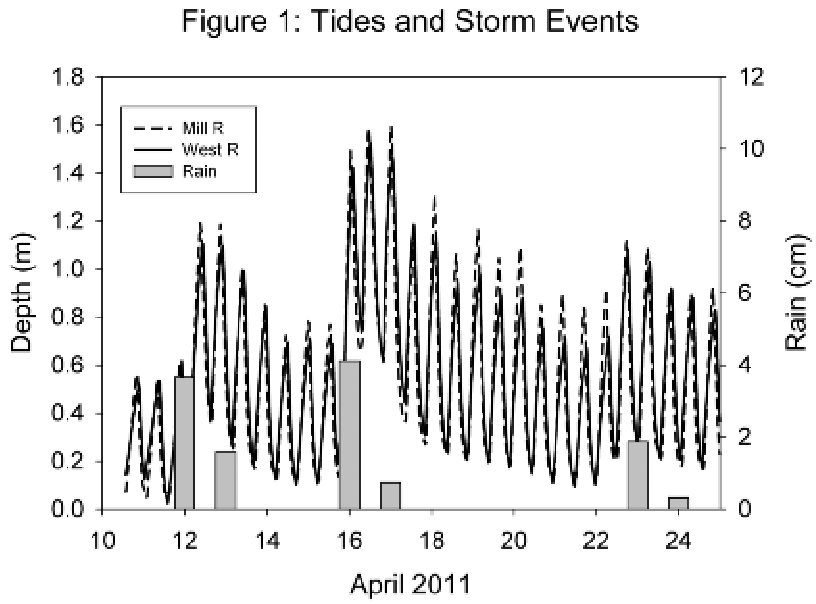

Figure 1

Tides and Storm Events. Tidal stage measured at a location 100 m upstream from the tide gates on the West (impact) and Mill (control) Rivers for a period in April 2011, before SRTGs were installed. Bars show rainfall recorded at nearby Tweed Airport. There is a close correspondence between the two sites both in terms of the daily tidal cycle and the response of the two rivers to storm events. Tides upstream from the gates are caused by fresh water backing up behind the tide gates.In June 2012, the first two of the tide gates on the West R were opened temporarily. The tidal range increased dramatically, similar to what has occurred when the three gates were fully opened permanently.

Figure 2 shows the dramatic, instantaneous increase in tidal range that resulted from the opening. With all three gates open, the difference in tidal between the control and impact sites is about one meter. It should be noted that the SRTGs can be closed by the operators at any time, if desired. This means that the site could be used as an experimental system. At present, we are continuing monitoring with the YSI sondes and plan to add water depth measurements at additional locations along with vertical salinity profiles at several key spots.

[4] http://www.ysieconet.com/public/WebUI/Default.aspx?hidCustomerID=205

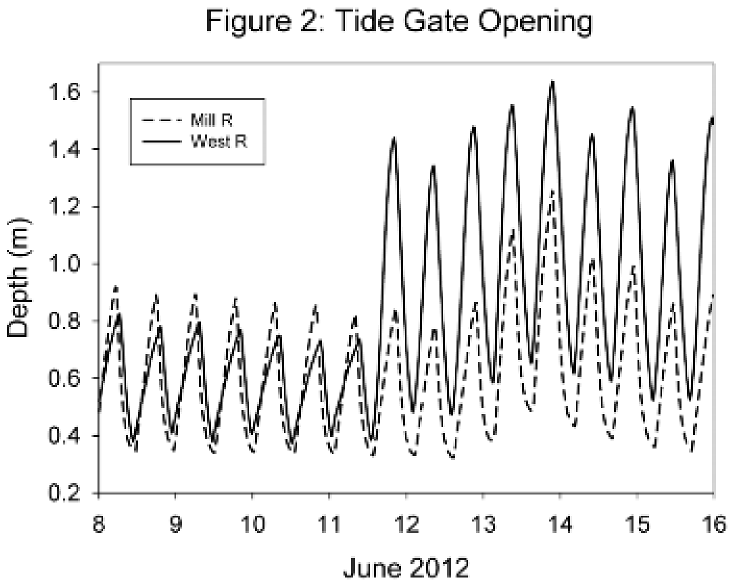

FIGURE 2
Tide Gate Opening: Response of the lower West River to opening of two of three SRTGs on 11 June 2012. Before opening, the two rivers closely tracked each other. After opening, the West River's tidal range increased markedly, while its timing continued to match that of the Mill River. Currently, with three gates open, the tidal range of the lower West River is even greater.

Vegetation

Both the changes in salinity and frequency of inundation after the restoration are expected to affect plant communities. Long before the restoration, at both sites a fixed 50 m × 50 m grid was superimposed on a GIS map of lowland areas. At each node, a permanent 1 m × 1 m plot was laid out. All vegetation in each plot was identified, usually to species. In cases where identification was not achieved, herbarium species were collected and preserved for future analysis. The plots will be reoccupied post-restoration in order to map vegetation changes over time. In addition, large scale changes can be evaluated from aerial photographs. Forested areas of the two sites have been characterized via a combination of rapid, on-site surveys and high-resolution color infrared aerial photos. These methods will be repeated in the proposed post-restoration portion of the study.

Fish

Fish populations should respond within the first year because the open tide gates will modify salinity and enhance access to productive marsh habitat and spawning habitat. Indeed, we have already observed a sharp increase in angler activity following tide gate modification. This change is partly a consequence of species migrating upstream through the gates. We will continue sampling fishes at multiple fixed stations in each system. We will sample in order to quantify the relative abundance of seasonally-resident sport fish species (*e.g.*, bluefish *Pomatomus saltatrix*, striped bass *Morone saxatilis*), marsh-resident species (*e.g.*, mummichog *Fundulus spp.*), and migratory species of conservation interest (river herring *Alosa spp*.).

Birds

To analyze the effects of biophysical changes on trophic dynamics in our system, we are measuring changes in the relative abundances of avian foraging guilds (groups of bird species defined by what and how they eat) as we did in 1996 (Lewis and Casagrande, 1997). Waterbirds and shorebirds are top-level consumers that feed primarily on fish and aquatic invertebrates forming an important link in energy transport systems (Erwin, 1996). As these prey populations change in West River Memorial Park, we expect to see changes in the avian community as well. Other salt marsh restorations in Connecticut have successfully improved vegetation, macroinvertebrates, fish and bird use (Brawley et al., 1998). Bird communities in salt marshes are also affected by vegetation structure and size of marsh among other habitat variables (Benoit and Askins, 1999, 2002). While the marsh along the West River was dramatically altered when it was added to the Memorial Park in the early part of the last century, and it is surrounded by an urban landscape, there is evidence that bird species in Long Island Sound salt marshes adapt to less than pristine landscape contexts (Shriver et al., 2004).

Avian diversity and abundance are useful for interpreting changes in restoration efforts. Therefore, we are monitoring species richness and overall abundance after tide gate alteration at both sites. The methods and analysis used for this portion of the survey will be identical to those used in 1995 and in 2010, to allow for before and after comparisons (BACI design). In collaboration with the Saltmarsh Habitat and Avian Research Program (SHARP) and the CTDEEP, we will incorporate callback surveys based on protocols developed by SHARP into our survey. These data will help improve assessment of the population of more secretive marsh birds in the park, and will also contribute to the CT DEEP database and to SHARP's larger database covering Long Island Sound, New England and the mid-Atlantic states. For analysis, SHARP will share data from other reference sites for regional comparisons.

Humans

It is critical to include humans in our analysis because they are the ultimate beneficiaries of ecosystem services, and they decide whether further ecosystem restorations take place. Because human social data were not collected between 1995 and the installation of the new tide gates, the human dimension does not conform to a true BACI design. Our goal is to quantify changes in human perceptions and behavior over a three-year time frame. The first year data, which are being collected now, coincide with the official September 2012 opening of the new gates. Some behaviors (esp. fishing) have already begun to change from 1995 patterns. However, most changes will either begin or accelerate over the three year duration of this study as people gradually notice and communicate about biophysical changes. Our interviews and surveys will allow us to attribute perceptual and behavioral changes to the biophysical changes of restoration, which will be experimentally verified using the BACI design.

Conclusions

Restoration of tidal flushing in the West River, New Haven, CT, is an opportunity for an interdisciplinary Before-After-Control-Impact (BACI) experiment conducted at a large scale. Data on hydrology, water quality, vegetation, birds, fish, and people have been collected before the restoration took place. We plan to repeat these measurements now that installation of self-regulating tide gates is completed. Our ultimate goal is to evaluate the effectiveness of the restoration and to provide guidance to ecosystem managers on how to design and prioritize similar efforts in the future.

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ABSTRACTS

Internal Waves and Mixing in the Western Long Island Sound

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Western Long Island Sound (WLIS) bottom waters experience low dissolved oxygen levels (hypoxia) in the summertime. Prior research indicates that variability in the vertical mixing of oxygen into the bottom waters is a determining factor controlling the severity and duration of this seasonal hypoxia. The relative importance of the mechanisms that control this mixing has been unclear, however. In other estuaries, tidal cycles of mixing have been observed due to either tidal modulation of stratification or tidal growth of the bottom boundary layer (BBL) creating periods of increased shear. Because the currents in the WLIS are fairly weak, it seems unlikely that either of these mechanisms is significant on its own, however. Our observations indicate that in the WLIS, the tidal cycle of stratification varies only weakly and that the maximum height of the BBL is only 25% of the water depth.

We examine the possibility that, in the WLIS, internal waves result in increased mixing through increased shear or by depression of isopycnals into regions of increased shear. A tidal cycle of internal waves creating a strong mid-flood pycnocline depression is observed in temperature records from a thermistor chain deployed in the WLIS near Execution Rocks in 2009. Depression of near-surface waters during the flood tide results in near-bottom temperature and oxygen increases and a salinity decrease as warmer, more oxygenated, and fresher waters are brought downwards. Evidence that vertical mixing is associated with these internal events is seen in the correlation of near-bottom subtidal tendencies with near-bottom internal wave energies and amplitudes. During near-bottom warming periods, which are presumably associated with periods of increased vertical mixing causing ventilation of the bottom waters, the strength of internal waves that occur is greater, the mean pycnocline depressions are deeper, a breakdown in stratification occurs during the flood, and the re-establishment of the pycnocline is weaker. These observations imply that, during the summertime period of thermal stratification in the WLIS region near Execution Rocks, internal waves may be a significant vertical mixing mechanism.

Changing Vulnerability of Coast to Storm Surges in Long Island Sound

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Rising mean sea level over the next 50 years will lead to changes in the expected interval between flooding events due large storm surges. The geometry of the coastline, the characteristics of the storms and the dynamics of coastal circulation generally cause larger surges in the western end of the Sound during extra tropical cyclones (nor-easters). For the same reasons, the response to tropical cyclones (hurricanes), which generally occur in late summer and early fall is less variable. To assess the impact of rising sea levels on coastal infrastructure, we define a vulnerability index based on the expected change in the return interval of events that are currently expected once every 25 years. We then use available long sea level data records and a range of sea level projections to describe how the vulnerability index is distributed along the Sound for a range of plausible scenarios. We conclude that it is likely that the coastal communities in the east will be substantially more vulnerable to flooding in the future.

Exchange Flux and Residence Time in Long Island Sound

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Estimates for exchange flux at different longitudinal sections are obtained using a standard Eulerian analysis and an isohaline analysis using an isohaline transport function (MacCready, 2011; Sutherland et al., 2011). Analyses afford potentially useful results within Long Island Sound concerning:

- Tidally averaged exchange flux and salt flux magnitudes
- Salt water residence time
- Relative magnitudes of tidal correlations to the horizontal salt flux
- A useful comparison of results from Eulerian and isohaline methods

Wind-driven Near Surface Current Variability in Western LIS

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The critical patterns of currents and circulation responded by the wind are essential for predicting the transport and fate of particles and dissolved materials in the near surface water column. We report an analysis of wind-driven surface circulation patterns and related dynamical properties in western LIS. Near surface measurements were obtained using radial velocities derived from HF RADAR systems (CODAR: Coastal Ocean Dynamics Application Radar), and the rest of the water column was observed by ADCPs (Acoustic Doppler Current Profiler). The lateral (acorss-sound) and axial (along-sound) circulation patterns from the observation would be compared with the results of wind driven circulation analytical models (Winant, 2004) and the Coriolis force could be one of the significant components for the circulation pattern.

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University of Connecticut's Slocum Gliders – The First Glider Observations from Two Autonomous Days in Central Long Island Sound

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Autonomous underwater vehicles (AUVs) enhance the continuous remote collection of temporal data (i.e. metocean buoys) by providing significant and relatively long duration spatial coverage. University of Connecticut's (UConn) Marine Sciences Department owns two Slocum Electric Gliders, an AUV which moves through the water by changing buoyancy and center of mass resulting in a sawtooth pattern of up and down profiles through the water column, all the while moving forward to preprogrammed destinations. UConn's gliders carry a scientific payload which includes a SeaBird Electronics CTD sensor, a WetLabs ECO Puck Triplet (two backscatter, one chlorophyll), and an Aanderaa oxygen optode. One of these gliders was recently deployed for the first time in Long Island Sound near UConn's Central Sound metocean buoy. We present the logistics and results of the two day deployment and include comparisons with data from the Central Sound buoy. Future deployments and how the gliders can be used to augment our current data acquisition network within Long Island Sound are also discussed.

Seaweed Aquaculture: An Opportunity for Nutrient Bioextraction in Long Island Sound and Adjacent Urbanized Estuaries

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The objective of this study is to design, demonstrate, and promote the bioextraction of inorganic nutrients from coastal waters using native seaweeds (the red seaweed, *Gracilaria tikvahiae* & the sugar kelp, *Saccharina latissima*. Nutrient extraction for bioremediation was tested using *G. tikvahiae* at two sites: one off Fairfield, CT (LIS); and at the other at the mouth of the Bronx River estuary (BRE), during the summer and fall of 2011 and 2012. *Gracilaria* at the BRE site grew 11.8% and 10.0% d^{-1} at 0.5m and 1.0m deep, respectively, in Aug. 2011. The growth rate in July, 2012 was even as high as 16.5% and 14.9% d^{-1} at 0.5m and 0.25m deep, respectively. Growth rates at the LIS site were 5.9% and 6.0% d^{-1} at the same depths. We have designed a *hypothetical* nutrient bioextraction 1 hectare *Gracilaria* farm system that assumes 4 m spacing between longlines. Our *hypothetical* one hectare nutrient bioextraction *Gracilaria* farm system at the LIS site(in 2011) could remove 2.6 kg N ha^{-1} mon^{-1} from Aug.-Oct., and 5.5 kg N ha^{-1} mon^{-1} in Sept. and Oct. at the BRE site. During Aug. 2011 at the BRE site, nitrogen could be removed at 10.3 kg N ha^{-1} mon^{-1}. These results suggest that nutrients were being rapidly assimilated and used to fuel the growth of new *Gracilaria* tissue at the BRE site, while nutrients appeared to limit the growth of *Gracilaria* at the LIS site during July and Aug. A winter crop, the sugar kelp, *Saccharina latissima* was farmed at the LIS during the winter of 2012. After outplanting juvenile kelp (<1mm), we have found that our aquacultured kelp grew as much as 3.0 m in length and had a yield as much as 18 kg m^{-1} after 5 months (Dec.-May). Our *hypothetical* one hectare nutrient bioextraction kelp farm system at the LIS site with 5-10m spacing between longlines could remove 46-87 kg N ha^{-1} during that winter-spring growing season. These results suggest that seaweed aquaculture can be a useful technique for nutrient bioextraction in urbanized coastal waters. Since N removal varies with site and season, seaweed bioextraction could be best applied at nutrient hot spots in LIS and New York estuaries.

Pharmaceuticals and Personal Care Products in Western Long Island Sound

Bruce Brownawell; Pablo Lara-Martin; Anne Cooper Doherty; and Xiaolin Li

There has been considerable interest over recent years on the occurrence of sewage derived contaminants that have sometimes been termed pharmaceuticals and personal care products (PPCPs). In this talk we review results from a combination of recent studies of the distribution of PPCPs in western and central Long Island Sound (LIS), where most of the sewage inputs are concentrated in the East River to the west of the Throgs Neck Bridge. Our work has primarily focused on studies on sources and fate of several classes of surfactants and selected surfactant metabolites including: the nonionic surfacatants alkylphenol ethoxylates (APEO) and their moderately estrogenic metabolites including nonylphenol (NP), and alcohol ethoxylates; cationic surfactants dialkyldimethylammonium compounds (DADMAC), benzalkonium compounds (BAC), and akyltrimethylammonium compounds (ATMAC); and anionic surfactants linear alkylbenzene sulfonates (LAS) and their metabolites, and alkylethoxylate ethers (AES). In one transect of surficial sediments from the Throgs Neck Bridge to a station north of Mt Sinai, NY the occurrence of 70 pharmaceuticals was also analyzed. The concentrations of PCPPs decrease sometimes sharply with distance from the Throgs Neck Bridge. The cationic surfactants are present in the highest abundances, with especially high levels (over 100 µg/g) found near a CSO discharge in Bowery Bay. The most hydrophobic DADMACs typically comprise over 80% of the cationic surfactants, and appear to be especially stable associated with particles during eastward transport into the Sound. These are among the properties that make them excellent tracers of sewage influence in sediments. An application of the use of DADMAC as a potentially useful tracer of sediment metal sources in LIS is illustrated. Nonylphenol ethoxylate metabolites, which include NP, are the next most abundant class of sediment contaminants measured, especially in areas around Bowery Bay and Flushing Bays. We also review results from a tidal cycle study of bottom and surface waters at a site east of the “last” NYC wastewater treatment plant (Tallman Island) and west of the Throgs Neck Bridge where anionic and nonionic surfactants and pharmaceuticals were measured. As expected, concentrations were highest on ebb tides and somewhat high in surface waters more impacted by freshwater sewage inputs. Furthermore, the relative abundance of more soluble surfactant metabolites and most pharmaceuticals was much higher in the dissolved phase than in suspended or surficial sediments. The controls on the spatial distributions of PPCPs will be discussed and the concentrations will be compared to those in other sewage impacted estuaries in the region and worldwide.

Distribution of Endocrine Disrupting Pollutants in the Housatonic River Estuary

J. Elmoznino and P. Vlahos

Waste water treatment facilities (WWTFs) input fresh water, nutrients, and contaminants into our local waterways. While nutrient loads and concentrations for some pollutants are regulated, there are many emerging contaminants that are not controlled for as the full range of toxic effects are still to be determined, and the regulatory framework controlling their usage and allowable inputs into coastal waters has yet to be established. The water and sediment of the Long Island Sound (LIS) are routinely sampled for concentration data of classical persistent organic pollutants, however there are numerous emerging contaminants, with known endocrine disrupting and bioaccumulating properties, that have yet to be detected in this economically important region. It is critically important to investigate the inputs of emerging contaminant throughout the LIS, in order to determine the potential impacts on this estuarine ecosystem. Several waste water treatment facilities (WWTF) which discharge into the LIS watershed were tested for several classes of known endocrine disrupting compounds (EDCs); perfluorinated compounds (PFCs), phthalates esters (PAEs), phenolic compounds (nonylphenol, octylphenol and bisphenol A) and steroidal estrogens. WWTFs are a known point source of these pollutants. While these EDCs have been detected in many water bodies and sediments, partitioning data between environmental compartments is limited. An important factor in the fate and distribution of these target compounds is the scavenging by particulates which increases as a function of ionic strength. In order to determine the effect of salinity on the partitioning of ionic pollutants, the fate and distribution of the perfluoroalkyl compounds between the sediment, suspended particulate and dissolved phases was further investigated this summer during a field survey undertaken along the salinity gradient of the Housatonic River Estuary.

Acidification: The Other Nutrient Loading Problem in Long Island Sound

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The combustion of fossil fuels during the past century has enriched levels of CO_2 in the world’s oceans, decreasing ocean pH and leading to ‘ocean acidification’. The continuation of these processes this century will alter the growth, survival, and diversity of marine organisms that synthesize $CaCO_3$ such as shellfish as well as non-calcifying animals such as larval finfish. Excessive nutrient loading into coastal ecosystems such as Long Island Sound (LIS) promotes algal productivity and the subsequent microbial consumption of this organic matter lowers oxygen levels and contributes toward hypoxia in LIS. A second, often overlooked consequence of microbial degradation of organic matter is the production of CO_2 and reduction in pH associated with that process. To assess the potential for eutrophication-driven acidification in LIS, the concentrations of dissolved oxygen, CO_2, and pH were vertically profiled in LIS during the onset and demise of hypoxia in August of 2012. Measurements revealed that hypoxic bottom water in LIS had levels of CO2 not expected in the world’s surface oceans until the late 22nd century as well depressed levels of pH. These elevated CO_2 levels remained elevated even as hypoxia dissipated and bottom waters were reoxygenated. The levels of CO_2 and pH in LIS bottom waters persisted at levels (>2,000 ppm, < 7.5 units, respectively) previously shown to yield elevated mortality in larval finfish and shellfish suggesting that acidification, which has been intensified by climate change, may be currently altering the ability of LIS to support robust fisheries. The compounded effects of global ocean acidification may exacerbate these impacts in the future, even if oxygen conditions improve.

Developing a Chemical Passive Sampling Network in Long Island Sound

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Long Island Sound (LIS) is an urban estuary that is impacted by significant loadings of anthropogenic contaminants. Labor intensive and costly water extraction techniques have historically limited the resolution of contaminant concentration ranges. This in turn has limited our knowledge of contaminant fate and transport and of particular concern, the risk of human exposure. Here we present results from a new passive sampling time-series at eight stations along LIS to illustrate spatial and temporal resolution that can be obtained using passive sampling networks. Data for polycyclic aromatic hydrocarbons and currently used pesticides from May 2011 to May 2012, the first beta testing year are presented. The time series generates a powerful synoptic view of organic compound concentrations and distributions that can readily be expanded to other emerging contaminants.

Long Island Sound Dissolved Oxygen Climatology

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The amount of dissolved oxygen in Long Island Sound is probably the most important parameter determining habitat quality. The Long Island Sound Integrated Coastal Observing System (LISICOS) maintains two buoys which measure dissolved oxygen in Western Long Island Sound where the lowest levels are present. These buoys have been deployed over the past ten years recording high temporal resolution dissolved oxygen data continuously. Using these measurements a long term data record of bottom dissolved oxygen is used to calculate the climatology with high precision. Analyzing these data provides new insight into the variability and duration of hypoxia in Western Long Island Sound and allows one to compare today's conditions to the expected variability.

Can the Copepod *Acartia Tonsa* Adapt to Climatic Warming? Within-Population Genetic Variation in Life History Traits

Benjamin L. Cournoyer and Hans G. Dam

A challenge to ocean scientists is to predict the response of the biota to projected climate change. Adaption requires within-population genetic variation for temperature-sensitive life history traits, and heritability of these traits. Both of these requirements can be tested in reaction norms studies among families within a population. Here a split-family design was used to determine if the calanoid copepod *Acartia tonsa*, from Long Island Sound, harbors sufficient genetic variation in temperature-sensitive life history traits to evolve in response to projected global temperature increases. Egg production, Life span, and Lifetime fecundity displayed significant broad sense heritabilities; 0.69±0.18, 0.39±0.15, and 0.27±0.13 and temperature by family interactions ($p<0.05$). This indicates that within families, significant tradeoffs impacting fitness exist with projected global temperature increases. However, when all families were pooled, representing the population, none of the life history traits differed between the temperature treatments. Results indicate *A. tonsa* has the capacity to evolutionarily cope with global warning. If survival remains unchanged, the composition of successful families will likely change, but the fitness of the Long Island Sound population will remain unchanged.

Effect of Temperature on Local and Latitudinal Shell Growth and Respiration Patterns of the Eastern Oyster *Crassostrea virginica*

Joshua P. Lord and Robert B. Whitlatch

The impact that temperature has on oyster shell growth and metabolism was investigated locally and over a large geographic range. Oyster shell morphology was compared at 28 sites from south Florida to New Brunswick and, using multiple linear regression, a significant positive correlation was found between shell thickness and both temperature and salinity. At southern sites, shell weights accounted for 23% more of the total weight of the oyster than at northern sites, likely due to higher precipitation of $CaCO_3$ in warmer water. The impact of temperature on shell growth was also investigated under laboratory conditions and it was found that Long Island Sound oysters showed 12 times higher shell growth rates due exclusively to shell thickening in response to winter water temperatures that were experimentally elevated 6 ^{o}C. Oyster oxygen consumption was measured as a proxy for metabolism at experimentally elevated temperatures for laboratory and field experiments in order to compare responses to thermal stress with latitude. These respiration measurements were made during winter and summer at 20 sites along the east coast of the US and revealed different responses to elevated temperatures with latitude. While respiration rates were much higher during summer than winter at all sites, northern oysters were more tolerant of higher temperatures during the summer and southern oysters displayed the opposite pattern. These results highlight seasonal and geographic variability in metabolic rate and suggest that oysters in the southern US may be near their thermal limits during elevated summer water temperatures. The shell growth and metabolic patterns established here emphasize the influence that temperature has on oyster morphology and physiology and could be used to predict oyster responses to climate change.

The Role of Ctenophores in Nutrient Regeneration in Long Island Sound

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Gelatinous zooplankton blooms have been increasing in magnitude and frequency globally. Seasonal variations in food availability and temperature can trigger a population bloom and subsequent crash in coastal and estuarine waters. Long Island Sound (LIS) is a highly-productive urban estuary. Due to its proximity to New York City and annual summer hypoxia, there has been substantial focus on anthropogenic nutrient inputs and reductions to LIS. When determining nutrient budgets, an important process is the recycling of nutrients within a system. Gelatinous zooplankton, including the most common species in LIS, the ctenophore *Mnemiopsis leidyi*, are capable of significant rates of nutrient regeneration. During 2011, the population biomass of *M. leidyi* was monitored and nutrient regeneration rates (i.e., NO_3^-, PO_4^{3-}) were calculated based on laboratory experiments. Preliminary results from 2011 indicate that ctenophores in LIS have the potential, at times, to overturn substantial amounts of these nutrients daily. However, in 2012, the ctenophore bloom never occurred suggesting that rates of nutrient regeneration by gelatinous zooplankton also can vary widely on an interannual basis, complicating the assessment of the nutrient budget for LIS.

Evaluation of Plankton Patch Sizes

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Algal blooms appear in patches and become visible at time and space scales that are not fully resolved by conventional ship operations. For this reason, remote sensing was used to estimate the size and the time during which a patch could be observed. The recognition of patches as a function of time was estimated from mesoscale features to patch sizes in the meter range. It was recognized that there is a limit to detect the dynamics of a patch with satellite coverage due to the lack of temporal and spatial resolution that is needed to resolve bloom development. An example of a plankton patch in Long Island Sound was analyzed with hyperspectral data that were obtained with Hyperspectral Imager for the Coastal Oceans (HICO) and spectral analysis permitted the identification of the major photosynthetic pigments.

Life Cycle of the Blue Crab, *Calinectes sapidus*, in Eastern Long Island Sound

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Blue crabs provide a popular recreational fishery throughout Long Island Sound (LIS). Crabbers report that the abundance of blue crabs in the Sound is highly variable from year to year and that recent catches have been exceptionally good. The blue crab population in LIS may be increasing as a result of global warming. Although extensively studied in Chesapeake Bay and other regions, there are no published investigations on the life cycle of the blue crab in Long Island Sound. For this study, crabs were sampled with traps every 2-3 weeks for over a year along the length of 3 estuaries in eastern Connecticut: the Poquonnock River, Mystic River and Birch Plain Creek/Bakers Cove. They were also sampled in LIS several days each week over the year with an otter trawl towed south of the mouth of the Thames River. The carapace width (CW) and sex were determined for all crabs. The GPS coordinates, water temperature, salinity, and depth were recorded for each trap or trawl. Males with CW >130mm and all mature females were tagged. Larval crabs were sampled by towing a 250μ mesh neuston net near the surface in Pine Island Bay. Over 70% of the crabs caught in the rivers were males and ≈15% were immature females compared with 5% males and no immature females in LIS. Over a third of the female crabs sampled in LIS were egg bearing whereas none were gravid in the upper estuaries. Blue crabs were most abundant in the upper third of each estuary and very few blue crabs were caught in the lower portions where green and spider crabs dominated. Blue crab catches per unit effort in the estuaries and LIS were low in the early spring, increased in June, reached a maximum in August and declined in the late fall. Blue crab zoea and megalops larvae were present in July and August. These results indicate that there are many similarities and some differences in the life cycle of the blue crab in LIS compared with other regions. The mature male and female crabs mate in the upper estuarine portion of the rivers. The males remain in the rivers whereas the females migrate to LIS where their eggs are extruded and develop and release planktonic zoeal larvae. The zoea metamorphose into the megalopal stage which complete the cycle by migrating back to the upper estuaries where they develop into juvenile male and female crabs. This study must continue for several years to measure the interannual variability of crab abundance and to determine possible causes.

Project *Limulus*: The Past, Present, and Future of Horseshoe Crab Population Dynamics in Long Island Sound

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Project *Limulus* is a long term research project investigating the life history and population ecology of the American Horseshoe crab *(Limulus polyphemus)* in Long Island Sound (LIS). Since the inception of Project *Limulus* in 1997, over 77,000 horseshoe crabs have been tagged with over 12,000 reported recaptures, a 15% recapture rate. Mark/recapture analyses indicate that data has shown that 98% of crabs tagged in LIS are recaptured in LIS. In addition to tagging, horseshoe crab spawning surveys have been conducted from 2008 to 2012 on over 30 beaches bordering LIS. Spawning Indices are 3-4 orders of magnitude lower than Delaware Bay. Spawning surveys also indicate that the spawning population is relatively stable with yearly variation. Recent correlation analyses between beach geomorphology and spawning indices reveal no significant correlation between grain size, beach slope, beach width and spawning indices. Ongoing juvenile surveys suggest the presence of three cohorts in marshes and intertidal zones. The present and future management of LIS horseshoe crabs will be discussed.

Microzooplankton Grazing During Blooms of the Toxic Dinoflagellate *Alexandrium* Sp. in Long Island Sound

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Microzooplankton are recognized as dominant grazers of primary production in oceanic waters. However, there are few studies documenting microzooplankton grazing during toxic algal blooms, on both chlorophyll *a* and, importantly, the toxic cells themselves. The goal of this study was to measure microzooplankton grazing impact during blooms of toxic dinoflagellate *Alexandrium* in Northport Harbor, Long Island Sound, USA. We conducted dilution experiments before, during and after the 2010 and 2011 toxic *Alexandrium* blooms. In conjunction with standard dilution experiment measurements (e.g. chl. *a*, microoplankton biomass), we used a molecular probe and fluorescent *in situ* hybridization *(FISH) to label Alexandrium spp.* cells. Therefore, we were able to measure grazing impact separately on total phytoplankton (chl. *a*) and on *Alexandrium*.

Main findings of our study are: 1) Microzooplankton grazing patterns differed for phytoplankton community and *Alexandrium*. Slopes of dilution experiments were always negative when the variable was total chlorophyll. That is, as grazers were diluted, the net growth rate of phytoplankton increased. In contrast, when the variable was *Alexandrium*, slopes were flat, negative or positive. Thus, grazers had negligible, negative or positive effects on *Alexandrium* net growth rate. 2) Grazing always exceeded phytoplankton growth when the currency was total chlorophyll. In the case of *Alexandrium*, this was only the case during the bloom demise in 2011. 3) The positive effect of grazers on *Alexandrium* growth hint at trophic cascades within the microzooplankton, or concentration-dependent allelopathy or mixotrophy by *Alexandrium*. The results show that even while microzooplankton may have a strong direct effect on total phytoplankton, they do not impact *Alexandrium* the same way. Microzooplankton grazing relaxation or grazing-mediated enhancement on *Alexandrium* may be an important factor in toxic bloom initiation and persistence.

Seasonality of Long-term Warming in Long Island Sound and Zooplankton Community Changes

E. Rice and G. Stewart

Annual average surface temperatures in the Central Basin of Long Island Sound (LIS) have increased at 0.03°C/yr since 1976. Most of the increase is occurring during summer and early fall. The dominant summer-fall species of zooplankton *(A.tonsa)* shows significant reduction in prosome length relative to the 1950s, while the winter-spring species *(A. hudsonica)* shows no change in prosome length. 5yrs of zooplankton collection also indicates a loss of large copepod diversity relative to the 1950s. Nonmetric Multidimensional Scaling (NMDS) analysis of interannual summer data indicates that “warm-water” and “cool-water” species are found on opposite ends of the temperature gradient for summer, suggesting small changes in summer temperature can be associated with large-scale diversity patterns. Two years of new data on ctenophore abundance in LIS indicates a strong population peak in summer and persistance at low levels throughout the year. This research suggests the seasonality of long-term warming can be an important factor in analyzing the effect of climate change on LIS.

Continued Expansion of *Alexandrium* Blooms and PSP-biotoxin Closures of Shellfish Beds in Long Island Sound

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Since 2006, red tides caused by the toxic dinoflagellate *Alexandrium* that causes paralytic shellfish poisoning- or PSP-induced shellfish bed closures have become annual occurrences in LIS waters. For the past five consecutive years, more than 7,000 acres of shellfish beds across all of Huntington and Northport Bays have been closed to shellfishing by the NYSDEC due to PSP contamination of bivalves, sometimes with saxitoxin levels of more than an order of magnitude above the closure limit. In 2012, the Mattituck Inlet and Creek, NY, hosted an *Alexandrium* population that caused shellfish in this region to accumulate levels of saxitoxin over the FDA regulatory limit and was closed to shellfishing by the NYSDEC for more than a month. This was the first ever PSP shellfish bed closure in Mattituck and only the second location to be closed to due to PSP on Long Island Sound. In addition, in 2012, Shinnecock Bay and Sag Harbor Cove, NY, were closed for the second and first time ever, respectively. These findings suggest that PSP is expanding in NY and in Long Island Sound. Given that *Alexandrium* cells have been detected at more than 40 sites across the NY and CT coastlines of LIS from Little Neck Bay, NY, to the Mystic Harbor, CT, there exists the potential for *Alexandrium* blooms to continue to expand in the future. Beyond detailing this expansion, this talk will review the multiple factors that have contributed to the recurrence and intensification of PSP events in LIS. For example, while low densities of *Alexandrium* cysts can be found in most LIS sediments, Northport Bay has witnessed an order of magnitude increase in the densities of cysts in its sediments during the past five years, meaning there is a cyst population capable of continually re-seeding Northport Bay each year to cause these toxic *Alexandrium* blooms. Research has also demonstrated that enhanced nitrogen loading from waste water sources such as sewage treatment plants, septic tanks, and cesspools promotes the intensification of *Alexandrium* blooms. Accordingly, the region which experiences the most intense blooms in LIS, Northport Harbor, receives discharge from a sewage treatment plant as well as discharge of groundwater that is enriched in nitrogen from septic tanks and cesspools. Another factor that is important in bloom occurrence is physical circulation of water or, more specifically, the lack of such circulation which allows *Alexandrium* cells to accumulate as they grow and prevents flushing of the nitrogen-rich waters which fuel blooms.

The Development of a Bio-physical Model for the Study of PSP Outbreaks in Long Island Sound Embayments

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Prior to 2006, algal blooms in Long Island Sound, LIS, were viewed as nuisances that primarily contributed to hypoxia. Today, the annual occurrence of harmful algal blooms in LIS is a growing ecological, economic, and human health threat. Of particular concern is paralytic shellfish poisoning, PSP, caused by blooms of Alexandrium fundyense, a relatively new phenomenon that is already affecting a several Long Island Sound's embayments and threatening others including those in Connecticut. In Northport and Huntington Bays along the north shore of Long Island Alexandrium blooms of ~two month duration have occurred every spring since 2006 and have caused the closure of the shellfish beds in these areas for six of the past seven years. While Alexandrium cells have been found on LIS waters since the 1980s, an open question is what has changed to cause this species to suddenly bloom at high densities in these particular water bodies. To address this issue and possible remedies, we are undertaking the development of a highly detailed bio-physical model of these areas that will provide a description of bloom dynamics, cell movement and dispersion patterns.. The first step in this process is the construction of set of nested physical circulation models composed of an existing and skilled LIS-wide ROMS model to provide the boundary conditions to drive an FVCOM model with its high spatial and vertical resolution in the embayments. This talk will focus on the development of the nested models as they apply to Northport and Huntington Bays and an assessment of their skill in reproducing the observed tidal and circulation features of the area.

The Restoration of the Mouth of the Housatonic River, CT: One Point at a Time

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Coastal regions, at the mouths of major rivers, in areas with high human population densities become polluted, compacted, invaded, degraded and lose their primary ecosystem functions. At Stratford Point, Connecticut we have begun coastal dune upland and salt marsh restoration after intensive clean-up efforts of tons of lead shot deposited at the site over a 50 year period. The Connecticut Audubon Society, The Nature Conservancy, DuPont Corporation, Sacred Heart University, The Housatonic River Estuary Commission and local community members have all participated in this project. The National Fish and Wildlife Foundation funded part of this project and will use the procedure as a model for other coastal areas. Instead of boulders and rip-rap, we have utilized Geotubes to abate wave energy, prevent erosion and enhance sand deposition at the site. We have restored dunes to the site and stabilized them with native grasses, perennials, woody trees and shrubs. The local fire department was employed to implement a controlled burn to control invasive plant species and to rid the area of a build-up of thatch that could potentially cause a devastating wildfire. The baseline data collected before restoration activities of the plants and animals found at the site will be compared to species that re-colonize the restored coastal dune system. The importance of the reference site, Milford Pt. will be discussed. Success will be measured by examining the number of native plant species that become established and by the number of bird and insect species that utilize the area compared to pre-restoration activities.

Development and Application of a Long Island Sound Gis-based Eelgrass Habitat Suitability Index Model

Justin Eddings (Cornell Coop. Ext.); Jamie Vaudrey (UCONN); Chris Pickerell (Cornell Coop. Ext.); Lorne Brousseau (Cornell Coop. Ext.); and Charles Yarish (UCONN)

Seagrass (including eelgrass, *Zostera marina L.*) has been identified as a valuable habitat and an indicator of good water quality but in the past century, approximately 90% of seagrass beds have been lost due to natural and anthropogenic causes. In some areas, seagrass is used to identify criteria for watershed management, setting load limits that are protective of seagrass habitats. In an effort to preserve and support the growth of eelgrass habitats in Long Island Sound, the Long Island Sound Study requested a GIS model for evaluating current and potential eelgrass habitats in relation to the physical and chemical habitat characteristics. The model employs bathymetry and tidal range as a first estimator of suitable area, assuming an adequate level of light must reach the bottom for eelgrass to be successful. Habitat characteristic data available from a variety of sources were used to rank areas within the Long Island Sound, and based on literature values of suitable ranges, were set in place for each parameter. The following parameters were reclassified on a weighted scale in ArcGIS: percent of light reaching the bottom - 50, sediment characteristics (grain size - 10, organic content - 10), oxygen - 10, and temperature - 20. The areas were summed to a maximum score of 100, with 100 being the most suitable. The development of the Sound-wide model is complete. Application of the model to a number of case study sites was conducted in the summer, 2012, for validation of the model. The 'mini-model' results will assist with targeting restoration activities to suitable areas and identifying barriers to restoration throughout Long Island Sound.

Connecticut Department of Environmental Protection Long Island Sound Ambient Water Quality Monitoring Program: Overview and Analysis of Program Data

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Since 1991 the Connecticut Department of Energy and Environmental Protection (CTDEEP) has conducted monthly water quality surveys on Long Island Sound. These surveys include hydrographic profiles measuring physical parameters including temperature, dissolved oxygen, salinity, irradiance and more recently pH. Water samples are collected and processed and preserved for chemical and biological analysis. Chemical parameters measured include silica, carbon, nitrogen, phosphorous, chlorophyll and TSS. Biological parameters include phytoplankton samples collected at 10 sites and zooplankton samples collected at 6 sites throughout LIS. An extensive long-term data base housing the programs survey data is available by request. Staff from the monitoring program will provide an overview of the monitoring program; review data collected by the program and discuss changes made to the program over the years to better address the research needs within Long Island Sound. Monitoring program staff will discuss cooperative EPA surveys conducted from 2000 through 2006 and again in 2010. A review of the findings from the programs August 2009 three day 24 hour survey of western LIS aboard the OSV Bold will also be presented. CT DEEP encourages the research community to make use of the monitoring program and resultant data base and hopes that this presentation will give those that may not be familiar with the program a better understanding of the data and opportunities that are available through the LIS Monitoring program.

Developing a Sound Criterion: The Past, Present, and Future of the LISS Environmental Indicators Program

Jason Krumholz, USEPA Long Island Sound Office and NOAA Fisheries Milford Laboratory
Robert Burg, New England Interstate Environmental Pollution Control Commission and
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Julie Rose, NOAA Fisheries Milford Laboratory
Mark Tedesco, USEPA Long Island Sound Office

The Long Island Sound Study (LISS) Environmental Indicators program is an important assessment, reporting, and outreach tool which has been used by scientists, managers, advocacy organizations, and educational groups for over a decade. The current program consists of over 50 indicators compiled from a wide variety of data sources including LISS funded monitoring efforts, state and federal agencies, and individual research programs, and covers a wide range of topics grouped into four topic areas: water quality, marine and coastal animals, habitat, and land use/population. The environmental indicators project and website recently completed an extensive review and update process in 2010. Building on the forward momentum established by this successful process, this presentation will focus on the future direction for the LISS Environmental Indicators program, including the development of climate change metrics, increased use of multimetric indices, and the potential benefits and challenges of developing a Long Island Sound 'Report Card'.

Estimating Cloud Fraction Over Long Island Sound Using Satellite-derived Estimates of Surface Solar Irradiance

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Clouds have a great influence on the Earth's surface energy budget. Their ability to alter incoming and outgoing shortwave and longwave radiation makes knowing their fractional sky cover (cloud fraction) critical in studies involving energy balances at the surface and aloft and in climate change. Measurements of cloud fraction, however, have traditionally been limited to ground-based observations. This dependence has placed emphasis on the need to use remote sensing methods. Using satellite-derived estimates of surface solar irradiance in conjunction with a method for estimating cloud fraction from ground-based broadband shortwave radiometer measurements, cloud fraction estimates are produced for Long Island Sound (LIS) during the time period of 1 June 2004 to 30 September 2004. These estimates of cloud fraction are then validated for the time period of 1 June 2004 to 14 Aug 2004 using METAR observations at four airports around LIS. Results show generally higher agreement between the satellite-derived estimates and METAR observations under the cloudiest of conditions.

POSTERS

A New Planar Optical Sensor for Measuring 2-D Manganese Distributions in Marine Sediments

Jaime P. Soto Neira; QingZhi Zhu; and Robert Aller

Manganese is widely distributed on earth and is essential for almost all living organisms. In marine environments,where Mn II,II and IV are the predominant oxidation states, It's involved in a diverse set of chemical reactions, being directly linked to carbon, nitrogen and sulfur cycles by participating during the formation, preservation and remineralization of organic matter, as well as, in remotion, transport and remobilization of trace metals.

This study summarize our successful attempts to develop a chemical optode with capabilities to perform two and three dimensional measurements of dissolved manganese (Mn II) in marine pore waters, with a low impact over the sedimentary structures of the sample and with an appropriate dynamic rage for being used in environmental studies, as well as shows the preliminary results of its use in natural sediments collected in Smithtown Bay, Long Island Sound.

Our sensing scheme involves both chemical and numerical aspects, where the first is based on the immobilization of the complex formed by the metallation reaction of 4,4',4",4"' -(Porphirine-5,10,15, 20-tetrayl) Tetrakis (benzenesulfonic acid) with cadmium, previously reported as a suitable indicator for measurements of our analyte in marine environments (Soto-Neira et al.,2012), into a supporting slide of polyurethane; while the collection and interpretation of two dimensional absorbance data involves the use of color space transformations, as well as, solving partial differential equations to translate the electronic signal from the detector device into chemical units of concentration.

Based on our preliminary results we conclude that our sensor represent an useful tool to understand and measuring how natural processes modifies the spatial-temporal distribution of our analyte in marine sedimentary environments.

Distribution of Direct Groundwater Seepage into Port Jefferson Harbor

Carley Grant and Caitlin Young

Coastal embayments along northwestern Long Island receive groundwater inputs from the island's thick aquifer sequence. The distribution of seepage in Port Jefferson Harbor was examined by a near shoreline survey of dissolved radon concentration. Radon is enriched in groundwater and elevated levels of dissolved radon in the surface water are an indication of groundwater seepage. Radon concentrations were measured at 72 intervals using a Radon-in-air detection system known as RAD-7 modified with a RAD Aqua in order to measure Radon emanation from surface water in a closed loop system. Radon activity ranged from 27.8 ± 76.0 to 736.3 ± 388.5 Bq/m^3 with the highest values indicating more rapid seepage of groundwater along the eastern shore. This shoreline is backed by a 50 meter high bluff. The most rapid seepage seems to be found at an impinged point in the southeast corner. Port Jefferson Harbor is a focal point for groundwater discharge and likely a proxy for other embayments along the northwestern shore of Long Island.

Distribution of Pesticides in the Housatonic River and Long Island Sound as Determined Through Passive Samplers, Water Extractions and Live Oyster Deployment

Kristin Raub; Penny Vlahos

Three different methods were used to measure pesticide concentrations in the Housatonic River near Ansonia, CT to directly off of the mouth of the river in Long Island Sound. This study focuses on ten pesticides; atrazine, prebane, dieldrin, atrazine desethyl, malathion, metolachlor, prometon, carbaryl, propargite, and diazinon. The first method involved collecting water samples along a sampling transect. Pesticides were extracted using solid-phase extraction (SPE) and analyzed by gas chromatography/mass spectrometry (GC/MS). Passive samplers were deployed along with bags of live Eastern oysters (*Crassostrea virginia*) for ten days. Eastern oysters were chosen because of their natural abundance in the region and commercial consumption by humans. The passive samplers consisted of titanium plates coated with ethylene vinyl acetate (EVA) to absorb compounds from the surrounding water column. The oyster tissue was freeze dried and extracted with acetonitrile. Compound concentrations were compared between the various extraction methods and an estimate for EVA-plate extraction efficiency compared to live oysters was made. The end goal is to establish reliable sampling techniques for organic contaminants in coastal systems in order to reduce human exposure and health risks.

Mercury Accumulation in Long Island Sound Bluefish

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Bluefish (*Pomatomus saltatrix*) are a schooling, migratory pelagic species common in Long Island Sound and are an important vector in the trophic transfer of mercury (Hg) to humans. Relationships between Hg and fish size are important as previous research has shown that tissue Hg content increases in large fish; the fish anglers most likely keep and eat. This study was designed to measure tissue Hg concentrations in juvenile and adult bluefish in Long Island Sound. Bluefish tissue mercury contents reported in this study were compared with results from Skinner et al. (2009) and allow for a determination of recent trends in LIS bluefish Hg (2006-2010). Bluefish (48) collected with the assistance of CT DEEP within LIS represented a wide range of lengths (432 mm – 845 mm) and weights (771 - 5352 g). Samples of skinless axial muscle were removed from the dorsal region above the operculum on each side of the fish using a stainless-steel scalpel. Fish tissue samples were freeze-dried, homogenized using a mortar and pestle, and analyzed directly for mercury by thermal decomposition amalgamation and atomic absorption spectrophotometry using a Milestone DMA-80 direct mercury analyzer according to EPA Method 7473. Measured bluefish Hg concentrations (wet weight) in this study ranged from 0.141 – 0.598 mg/kg). Mean Hg concentrations (0.187 ± 0.030 mg/kg) measured in this study for bluefish in the size range of 305-508 mm were lower in comparison to the results of Skinner et al. (2009) for LIS bluefish sampled in 2006 (0.266 ± 0.114 mg/kg) and 2007 (0.285 ± 0.046 mg/kg). For bluefish > 508 mm, mean Hg concentrations (0.331 ± 0.167 mg/kg) measured in this study for bluefish were similar in comparison to the results of Skinner et al. (2009) for LIS bluefish sampled in 2006 (0.348 ± 0.130 mg/kg) and 2007 (0.372 ± 0.159 mg/kg). No significant length-Hg relationship was observed for bluefish in the size category 305-508 mm. In contrast, significant linear length-Hg relationships were observed for all bluefish analyzed and for the size category >508 mm ($y = 0.0012x + 0.43$; $r^2 = 0.70$). The linear length-Hg relationship for bluefish > 508 mm was also significant for the combined CT DEEP 2006 and SCSU 2010 data ($y = 0.0012x + 0.45$; $r^2 = 0.50$).

Nitrogen Removal Capacity of a Connecticut Tributary to Long Island Sound: Assessing Distribution and Controls

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A pilot project examining dissolved inorganic nitrogen (DIN) removal in the Niantic River, CT tributary to Long Island Sound was conducted in the summer-fall of 2012. Denitrification and anaerobic ammonium oxidation (ANAMMOX) were measured with 15N tracer and mapped with high spatial resolution, along with gradients in geochemical analytes in sediments and water column, and microbial community composition and gene expression with respect to denitrification and ANAMMOX. The Niantic served as a small model system for the purposes of: 1) Determining how the overall N removal capacity changes throughout the estuary and mapping spatial N removal "hot-spots";.2) Quantifying shifts in denitrification and ANAMMOX rates in response to observed changes in sediment and water chemistry along the estuarine axis; 3) Assessing how much of the spatial variance in denitrification and ANAMMOX results from changes in microbial community composition and expression; 4) Using multivariate analysis (PCA) to examine linkages among geochemical drivers, the distribution of N removal rates, and the ANAMMOX / denitrifier microbial communities; 5) Developing and calibrating molecular based methods of estimating denitrification and ANAMMOX activity (Q-PCR and QRT-PCR) against 15N tracer-based rate estimates. Preliminary results from the removal rate measurements and the geochemical analyses show relatively low rates of both denitrification and ANAMMOX throughout the estuary largely attributable to low water column nitrate and minimal new nitrate input from the watershed. Despite the higher organic content of upstream sediments, denitrification and ANAMMOX rates were lowest up river and coincident with porewater hydrogen sulfide concentrations in excess of two milimolar. The high rates of sulfate reduction upstream (and extant sulfide levels), were supported by terrestrial organic matter inputs and may have played a role in suppressing both DIN removal reactions. The microbial molecular work has only recently been initiated.

Patterns of Copepod Abundance and Seasonality in Long Island Sound for the Period 2002-2012

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Because of copepods' trophic importance and their short generation time, changes in their patterns of abundance and composition are indicators of environmental perturbations and water quality trends. Copepods have been collected monthly at six stations along the central axis of Long Island Sound since 2002 by the CT DEEP LIS water quality monitoring program. The mean yearly total copepod abundance shows a pattern of decrease from west to east, whereas the opposite occurs for species richness At least 4 different orders (Calanoida, Cyclopoida, Poecilostomatoida and Harpacticoida) were represented in the study and calanoids dominated the copepod composition with three major species (*Acartia hudsonica, Temora longicornis, Acartia tonsa). Acartia hudsonica* and *Temora longicornis* belong to the winter-spring assemblage. Centropages spp., Pseudocalanus sp. and Tortanus discaudatus are also present at this time with relatively much lower abundance to the other two species. The summer-fall assemblage is dominated by *Acartia tonsa*. Three other low-abundance species, *Labidocera aestiva, Parvocalanus crassirostris*, and *Pseudodiaptomus* sp. are reported during this time period. Typically *Acartia tonsa* and *Parvocalanus crassirostris* are found in the Sound from June to December. However, during the year 2009-2012, they continued into winter months. If this change persists, then we might be witnessing a broadening of the growth season of these warm-water species.

Sea-Floor Geology in Long Island Sound, Offshore of the North Fork of Long Island, New York

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Over 150 square kilometers of multibeam bathymetry and sidescan-sonar backscatter data have been collected in eastern Long Island Sound adjacent to the north fork of Long Island, New York. These data, originally collected as part of hydrographic surveys by the National Oceanic and Atmospheric Administration (NOAA) in 2008, have since been ground-truthed by obtaining sediment samples and bottom photography in 2009 and 2010 by the U.S. Geological Survey. These data are integrated to create maps with interpreted sediment distributions and sea-floor features. These base maps can be used for benthic habitat studies, sea-floor monitoring, and resource management. Sediments in the area are generally sand and gravel, reflecting the glacial history and modern high-energy environment. Boulders are seen in the bathymetric and sidescan-sonar data covering the submerged northern flank of the Harbor Hill-Roanoke Point-Orient Point moraine, which is adjacent to the shoreline. Sand waves, megaripples, and shipwrecks are also visible in the bathymetric and sidescan-sonar data. Sand-wave asymmetry and scour around boulders suggest sediment transport in the study area is complex. In general, however, transport is to the east near-shore, to the west offshore, and around the flanks of shoals, which may help maintain these features. Bottom photography shows that sandy areas are commonly rippled, while gravel and bouldery areas tend to be overgrown with sessile fauna and flora.

Interpretative Reports Available Online: Orient Point: http://pubs.usgs.gov/of/2010/1100/,
Plum Island: http://pubs.usgs.gov/of/2010/1005/, Rocky Point: http://pubs.usgs.gov/of/2010/1007/,
Duck Pond Point: http://pubs.usgs.gov/of/2011/1149/

Sediment Copper and Zinc Zonation at Norwalk Harbor and the Norwalk Islands

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Marine sediment samples were collected (n=40) in and around Norwalk Harbor. Sediments were analyzed for copper and zinc concentrations using flame atomic absorption spectrophotometry, grain size distribution using laser diffraction, and percent organic content using loss on ignition. There were strong collations between each metal and both grain size and organic content. In addition, metal concentrations showed strong covariance. These correlations suggest that sediment characteristics constitute the dominant influence on metal concentrations as compared, for example, with source proximity. Spatial distribution of these variables was analyzed using GIS-generated maps. Four distinct zones of heavy metal concentration were identified. The inner harbor and lower Norwalk river had the highest concentrations as well as the finest sediments and most organic material. The lowest concentrations were in the waters surrounding the Norwalk Islands. Sediment metal concentrations in each zone were compared with NOAA's National Status and Trends guidelines for sediment quality for Effects Range Low and Effects Range Median. While the ERL was exceeded, at times significantly, in a number of samples, the ERM was not. Of particular significance, the Norwalk oyster beds coincide with one of the low concentration zones.

Sentinel Monitoring for Climate Change in the Long Island Sound Ecosystem

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The Sentinel Monitoring for Climate Change Program in Long Island Sound (SMCCP) is a multidisciplinary scientific approach to provide early warnings of climate change impacts to Long Island Sound (LIS) estuarine and coastal ecosystems, species, and processes to facilitate appropriate and timely management decisions and adaptation responses. These warnings will be based on assessments of climate-related changes to the indicators/sentinels recommended in the strategy, available on-line at the Long Island Sound Study website.

The current phase of this cooperative monitoring program is directed toward implementing a pilot monitoring project utilizing the identified 'sentinels,' or climate change indices, identified in the Sentinel Monitoring for Climate Change in the LIS Estuarine and Coastal Ecosystem Strategy (SMCC). A Pilot Monitoring grant has been awarded for an initial round of monitoring several priority sentinels that are expected to reveal a discernable climate change signal when compared to historical baseline data. In addition, plans are being made to issue a request for proposals for synthesis of existing and newly obtained data for additional future rounds of pilot monitoring of climate change sentinels.

This poster presentation illustrates the current status of the SMCCP, particularly information on a Data Citation Clearinghouse that has been designed to enter and house climate change related research and monitoring conducted in and around Long Island Sound. The clearinghouse will soon be available for researchers to input their related information and/or find local climate change resources.

Spatial Variations in Surface Sediment Mercury in Connecticut Coastal Embayments

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Mercury (Hg) sources in LIS include legacy contamination from the hat making industry along the Housatonic river to modern sources including atmospheric deposition due to MSW and coal combustion and the discharge of treated sewage and industrial wastewaters. Mercury is a neurotoxin that can affect human health primarily through the consumption of fish and shellfish. This study examined Hg concentrations in surface sediment samples from seven Connecticut coastal embayments (west-east); Norwalk Harbor (2011; n=8), Black Rock Harbor (2012; n=10), Bridgeport Harbor (2012; n=11), the lower Housatonic River (2008; n=31), New Haven Harbor (2011; n=14 and 2012; n=15), the Connecticut River south of Hamburg Cove (2012; n=14) and New London Harbor/Thames River (2007; n=20 and 2008; n=14). Sediment samples were collected from each embayment using a ponar grab and were homogenized, freeze-dried, and analyzed for Hg by thermal decomposition amalgamation and atomic absorption spectrophotometry using a Milestone DMA-80 direct mercury analyzer according to EPA Method 7473. Mercury concentrations exceeded crustal abundance within each embayment and sediment Hg concentrations ranged from 0.01 – 3.70 mg/kg. Median Hg concentrations were highest for Black Rock harbor sediments (0.461 mg/kg) and lowest for Connecticut river sediments (0.103 mg/kg). Mercury "hot spots" (defined as Hg concentrations > or = 1.0 mg/kg; <5% of samples analyzed) were present in four of the seven harbors. The highest sediment Hg concentration of 3.70 mg/kg was measured at the mouth of the Norwalk River adjacent to a former landfill. Mercury concentrations within each respective embayment increased with increasing sediment loss on ignition and co-varied with other sediment contaminants.

The Restoration of the Mouth of the Housatonic River, CT: A Reference Site

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A main practice in ecological restoration is use of a reference site as a target to measure the success of a project. Due to human activity, there are few remaining pristine or natural reference sites to use as baselines for restoration work, particularly along the highly developed Connecticut coastline. At Stratford Point, CT we have begun an upland coastal dune and tidal marsh restoration project using Milford Point, CT, a nearby coastal area, as a reference site. Milford Point is part of the Stewart B. McKinney National Wildlife Refuge and home to state listed threatened and endangered species. The site consists of a coastal marsh, dune and upland grassland system we hope to mirror in the completed restoration of Stratford Pt. While Milford Pt. is being used as the reference site for the Stratford Pt. restoration project, the site is not without its own ecological problems. Invasive plant species are common in the upland areas, development has encroached on the upland grassland and the recent Tropical Storm Irene reduced the population size of endangered plant species present. Baseline vegetation data were collected in one m2 quadrat every 10 m along permanent transects and plant species, percent cover, bare ground and leaf litter were recorded in May, June, July 2011 and 2012. A clear difference in plant community composition was observed between Milford and Stratford Pt. in terms of both species percent cover, percentage leaf litter and percentage bare ground. The top 5 plant species based on percent cover at Stratford Pt. were either invasive or introduced from a seed mix during a 2000-2001 ecological remediation, while the top 5 plant species at Milford Pt. were a combination of native and invasive species. Overall plant diversity (Shannon-Weiner diversity index) remained constant from summer 2011 to summer 2012 at Milford Pt. (H' = 2.4) while increasing at Stratford Point over the same time period (H' 2011 = 2.3, H' 2012 = 2.6). Adaptive management, long-term continual monitoring and stakeholder involvement at both the reference site and the restoration site are crucial to project success. The overall project goal is to expand the coastal system near the mouth of the Housatonic River and establish corridors to encourage colonization of native species at Stratford Point while enhancing survival of native species at Milford Point.

New Haven Harbor Water Quality Monitoring Program

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Long Island Sound is an ecologically diverse environment with rich and varied ecosystems for marine organisms while also providing important environmental and recreational services for Connecticut and New York residents. Despite its ecological and economic importance, water quality throughout the Sound is vastly under-monitored, particularly in the especially vulnerable and densely populated coastal embayments. The Long Island Sound Study recently highlighted the importance of expanding and integrating water quality monitoring efforts throughout the Sound to provide uniform, reliable near-shore monitoring data to watershed managers and the broader scientific/technical community. In response, students and faculty of the Center for Coastal and Marine Studies at SCSU recently established a long-term water quality monitoring program at Long Wharf Pier, New Haven harbor. Weekly water quality testing began at this location in January 2012. Water quality testing at this location occurs once per week coinciding with high tide. Water quality and meteorological parameters measured include salinity (ppt), specific conductance (mS/cm), dissolved oxygen (mg/L), air and water temperature (°C), wind speed (m/s), relative humidity (%), light intensity (lux), secchi disk depth (m), turbidity (NTU), and pH. Chlorophyll a measurements at this location will begin in February 2013. Results of the first year's water quality monitoring will be shown along with comparisons to similar water quality results from other regional water quality monitoring programs (LISICOS buoy data; CT DEEP water quality monitoring).

Diel Hypoxia in Nearshore Waters of the Western Sound

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Hypoxia has been well documented in bottom waters of the western Sound. Yet hypoxia also occurs in the nearshore waters, including important nursery areas for fish. These areas may experience diel hypoxia due to the diurnal cycle of photosynthesis during daylight hours and photorespiration at night. In such situations oxygen minima occur in early morning. We measured oxygen concentration of nearshore waters at Rye Marshlands (Rye, NY) from early morning to late afternoon using a YSI model 58 Oxygen Meter. Salinity was measured with a temperature-compensated Reichert-Jung Refractometer. As expected oxygen concentration was lowest in early morning and rose throughout the daylight hours. To compare years we measured oxygen concentration at the same site, on the same days, in the early 1990's (1991, 1992) and then again in 2004, 2011 and 2012. Nearshore waters were frequently hypoxic, with dissolved oxygen levels < 60% SAT, in early morning and hyperoxic (>100% SAT) in afternoon. There was great similarity in the diel oxygen cycle among years.

Does Hypoxia-exposure Alter Gill Oxygen Diffusion Distance in Killifish?

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Juvenile striped Killifish (*Fundulus majalis*) inhabit shallow marsh pools and nearshore waters which become warm and hypoxic during summer months. To investigate potential physiological and morphological adaptations of killifish to this environment we studied gill morphology. As shown by Fick's equation for diffusion, gill surface area (GSA) and oxygen diffusion distance are important parameters for oxygen uptake at the gills. Gills were sampled from fish in the Sound, and from those maintained in normoxic (7 mg $O2\ L^{-1}$) or hypoxic (1 mg $O2\ L^{-1}$) water in the laboratory for 24 hours or 9 days. Fish were weighted, measured and gills were fixed in Karnovsky's solution. For scanning electron microscopy (SEM) they were rinsed, dehydrated in a graded ETOH series, and critically point dried, sputter-coated and were observed with ISR-SR-50 SEM. To measure oxygen diffusion distance from water to blood, samples were embedded in Araldite 502/Embed 812 ™ plastic medium for transmission electron microscopy (TEM). Stained (uranyl acetate and calcinated lead citrate) thin sections were examined using a FEI/Philips Morgagni 268 transmission electron microscope (TEM). Gill lamellar diffusion distance was measured using the technique of Matey et al., 2008. Oxygen diffusion distance will be compared among wild caught, normoxia-exposed and hypoxia-exposed killifish.

NOTES