

LONG ISLAND SOUND MATRIX OF CLIMATE CHANGE SENTINELS

Thirty five climate change sentinels have been identified to date for the Long Island Sound estuarine and coastal ecosystems. These sentinels are grouped into four categories: Water Quality/Quantity, Pelagic/Benthic Systems and Associated Species, Fisheries of Long Island Sound and Associated River Systems, and Coastal Habitats of Long Island Sound and Associated Species or Systems. Information is provided for each sentinel including monitoring question(s), sentinel indice (what would be measured to answer the monitoring question), and known data sets. This list will likely change as more data become available.

There is a need to distinguish a set of core parameters to be measured in addition to sentinel indices as these parameters recur frequently in the table. These core parameters are factors that are typically measured in most monitoring programs, either by multiple groups or by one group over a large geographic area. For this reason, they are not being themselves proposed as sentinel indices and, therefore, are not included in the designated column when they should be. The core parameters listed here are taken from the climate related factors column and are: precipitation, stream flow (runoff and baseflow), sea level, temperature, salinity, wind (speed and direction), relative humidity, pH, and groundwater levels. It was also noted that while pH is considered a “core parameter,” it is not well characterized in LIS and was only added to the LIS water Quality Monitoring Program in 2010.

Climate change will have affects on cross-cutting indicators. It is expected that species richness and biodiversity will change with a changing climate as well as rates of primary production in both water- and land-based systems. These cross-cutting areas require extensive synthesis of existing data sets (not included here) rather than a new monitoring program.

The following matrices and sentinels are listed in no particular order.

TABLE 1. WATER QUALITY/QUANTITY

Monitoring Question	SENTINEL	ECOLOGICAL DRIVERS	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors ⁱ	Sentinel Indices	Data Availability ⁱⁱ
<p>Is there a decreasing trend in DO in LIS? Are DO levels falling below the threshold level needed to support aquatic life (DO>1.4 ml/l) due to climate related changes?</p>	<p>Hypoxia in LIS and embayments</p>	<ul style="list-style-type: none"> Increased water temperature Wind change in speed and direction 	<p>The combination of increases in water temp and decomposition of excess algae reduces DO and leads to hypoxia; wind factors too (change in speed and direction = change in stratification)</p>	<p>No</p>	<p>Dissolved oxygen (DO) Duration of hypoxia Area affected, and severity, Wind speed and direction</p>	<ul style="list-style-type: none"> Mark Altabet (UMASS Dartmouth) research, LISS 2008 project: Geochemical Budgeting of Dissolved Gases for Understanding Long Island Sound Hypoxia. LIS Monitoring Program (1994-present)
<p>Is there an increasing trend in the salinity of groundwater? Is the depth to water declining?</p>	<p>Changes in groundwater quantity and quality</p>	<ul style="list-style-type: none"> Sea level rise Changes in precipitation Changes in salinity of groundwater Groundwater levels and base flow 	<p>Saltwater intrusion into aquifers from SLR impairs the quality of groundwater Precipitation influences amount of groundwater recharge; reduced precipitation and recharge reduce the amt of groundwater Or if precipitation increases groundwater levels could rise leading to a shallower depth to</p>	<p>Maybe (There won't be a huge change with gradual SLR)</p>	<p>Salinity Elevation of groundwater Water temperature</p>	<ul style="list-style-type: none"> USGS (NY) has long-term, island-wide WL data from ~600 wells. Some saltwater intrusion data from direct measurement and geophysical logs along LI's north shore USGS(CT) modeling groundwater – Dave Bjerklie

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			water and failure of on-site wastewater treatment systems. Groundwater acidity could change if the soil is unable to buffer CO ₂ .			
Is there an increasing trend in the abundance of human pathogens in LIS (as evidenced by abundance of specific pathogens or by beach closures)?	Human pathogens	<ul style="list-style-type: none"> • Increased precipitation • Streamflow • Groundwater level 	Increases in precipitation, runoff, and groundwater level leading to failures in on-site wastewater systems can cause increases in bacterial levels harmful to human health	Maybe	Abundance of a specific pathogen (i.e., enterococci)	LISS indicators program gets data annually from CTDEP, CTDPH and NYDOH
Is there an increase in shellfish bed closures/duration of closures due to climate related changes in harmful bacteria levels?	Shellfish bed (commercial/recreational) closures (human/economic impacts)	<ul style="list-style-type: none"> • Increased precipitation • Increased runoff • Increased bacterial levels 	Increases in precipitation and runoff can cause increases in bacterial levels harmful to human health	Maybe: increases in stormwater to CSOs can be directly linked with shellfish	# of bed closures, duration of closures per year	CT DA/BA; NYSDEC

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Is there an increase in the hydrogen ion concentration (pH) of sea water in LIS?	Acidification	CO ₂ more soluble in colder waters. pH decreases (i.e., acidification increases)	Aqueous CO ₂ concentrations tend to increase and carbonate ion concentrations CO ₃ ²⁻ would tend to decrease = new conditions would affect the ability of marine calcifying organisms to form biogenic calcium carbonate (CaCO ₃).	Yes	pH Thickness of crustaceans shells = some species would develop thinner shells (oysters, clams, mussels), others would develop thicker shells (crabs, shrimps, lobsters)	<ul style="list-style-type: none"> USGS continuously monitors pH at 1 north shore estuary site; ferry; CSHH (pH); FOB (pH); CTDEP just began sampling Robert Whitlach (UConn) research 2010
Is there a change in suspended particle concentrations in the surface waters of LIS?	Turbidity of Water Column (abiotic reduction of light penetration)	<ul style="list-style-type: none"> Increased sedimentation rate to subtidal habitats Increased precipitation Increased runoff Change in prevalent winds 	Increased precipitation leads to more runoff and sediment transport leading to impacts on plant and animal species. Winds and wave energy cause resuspension of estuarine sediment	Maybe	<ul style="list-style-type: none"> Turbidity (not secchi) Sediment accumulation rates 	<ul style="list-style-type: none"> USGS, UConn, SBU, EPA?, ACOE

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Is there an increasing trend in the frequency, distribution and/or severity of HABs in LIS?	Harmful algal blooms (HAB)	<ul style="list-style-type: none"> • Increased precipitation • Increased runoff • Changing temperature patterns • Increased groundwater discharge 	<p>Increases in precipitation and runoff carry excess nutrients from upstream sources, resulting in “blooms” of toxic algae.</p> <p>This may not be a good impact to monitor as so many parameters affect it. However, could monitor if there are HAB species that are native to warm temperate waters or warmer waters trigger a toxic stage in HAB life cycles. Disturbances of sediments as a result of increased storm activity could activate resting cysts, potentially initiating a HAB.</p>	No	<p>Cell counts (with species ID); algal toxins</p> <p>Blue mussels are used as an indicator species, as they are the bivalve shellfish which accumulates harmful algae cells quickest. Mussels are placed in cages and then set at stations and sampled every two weeks from April through July. (CT)</p>	<ul style="list-style-type: none"> • Chris Gobler (SUNY Stony Brook) is monitoring Alexandrium but unsure how long his study will continue. • NYSDEC has to monitor for the shellfish sanitation program (2006-present) • CT Dept of Agriculture/Bureau of Aquaculture (DA/BA) in the past has conducted plankton tows at 10 stations in LIS (in 10 major rivers) at intervals of 1x per month. Currently, the DA/BA is conducting plankton tows at 20 stations in LIS (10 major rivers and 10 deep water sites) at intervals of 2x per month. Gary Wikfors (NOAA NMFS, Milford) provides plankton ID training to DA/BA staff and assistance with specimen ID when necessary. • Additional monitoring has been conducted in Mumford Cove (Groton) which is the only location in CT/LIS to encounter HAB’s in recent history. • PSP monitoring data is available from 1990 to present. General plankton data is available from 1997 to present. (information from David Carey (CTDA) and Tessa Getchis (CTSG))

TABLE 2. PELAGIC/BENTHIC SYSTEMS and ASSOCIATED SPECIES

Monitoring Questions	SENTINEL	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
<p>Is there an increase in abundance or new occurrences of invasive species in LIS? Is there evidence that increases are associated with changes in climate-related factors (e.g. temperature, salinity, pH)?</p>	<p>Distribution, abundance of aquatic invasive species or new occurrences, particularly from a shellfish production and natural resource perspective.</p>	<ul style="list-style-type: none"> • Water temperature • pH • Salinity • Precipitation • Runoff 	<p>Changes in water temp may lead to changes in invasive species ability to compete with native species Increased nutrient loading from precipitation and runoff</p>	<p>Maybe</p>	<p>invasive spp distribution and abundance</p>	<ul style="list-style-type: none"> • Robert Whitlach (UConn) research • Nancy Balcom, CTSG • NYSDEC PRISMS • trawl surveys • Sandy Shumway (UConn) – algae; • data from other research projects
<p>Are trends evident in the LIS Benthic Index? Are there any thresholds that are being exceeded?</p>	<p>Composition, abundance of benthic (shallow and deep) fauna</p>	<ul style="list-style-type: none"> • Water temperature • pH 	<p>Increases in temp or precipitation and effects on water quality or bottom habitat will affect the abundance/health of benthic fauna; impacts within food web; Invasive species Changes in benthic faunal distributions (migration of infaunal and epifaunal invertebrates)</p>	<p>No</p>	<p>Long Island Sound Benthic Index (under development by Robert Whitlach (UConn) REMOTS Benthic camera</p>	<p>80 stations in LIS (per ICF document)</p>

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Monitoring Questions	SENTINEL	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
Are spring/summer peak concentrations of chlorophyll-a changing in association with any climate related factors? Is there evidence of changes in species composition? Have there been significant trends in the timing of the initiation and/or peak of the spring phytoplankton bloom?	Phytoplankton species composition and abundance	<ul style="list-style-type: none"> Water temperature pH 	Increases in water temperature will affect the species composition and abundance of planktonic organisms depending on thermal tolerances; impacts within food web; Changes to the timing and extent of the spring bloom	Maybe	Chlorophyll-a Nutrients HPLC and microscopy & species identification analysis biogenic silica (POM)	<ul style="list-style-type: none"> Chla: 1994-present 17 stations monthly, more in summer HPLC pigments for phytoplankton community composition: 2002-present; microscopy: 2001-2003, 2007- 10 stations monthly in LIS CTSG working with NOAA Phytoplankton Monitoring Network for LIS Ferry monitoring CTDA/BA have been and are currently monitoring phytoplankton SeaWiFS chlorophyll a (NASA) NOAA east coast remote sensing node.
Are there any trends in annual zooplankton biomass? Is there evidence of changes in zooplankton species composition?	Zooplankton species composition and abundance	<ul style="list-style-type: none"> Water temperature pH 	Increases in water temp will affect the species composition and abundance of planktonic orgs depending on thermal tolerances (and new species) Introduction of new zooplanktivorous species	Maybe	<ul style="list-style-type: none"> Annual biomass species composition species identification analysis 	<ul style="list-style-type: none"> at least 2002-2004, possibly more recently; 6 stations monthly in LIS Marybeth Decker (Yale) starting a CLIS 2xmonth gelatinous monitoring program. CTDA/BA have been and are currently monitoring zooplankton

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			Shifts to jellyfish from crustacean plankton			
<p>Have there been long term declines in cold-water species in LIS and increases in warm-water species?</p> <p>Is there any evidence that habitat of nearshore fishes are being harmed by increases in coastal erosion related to sea level rise?</p>	Finfish (Distribution and Abundance)	<ul style="list-style-type: none"> • Water temperature • SLR • Runoff & precipitation • Stream Flow 	Increasing water temp is leading to a shift in the fish fauna of the northeast, with a movement of species north and warm-adapted species replacing cold-adapted species in LIS. Shift in finfish community (particularly juveniles) from one dominated by boreal species to one dominated by mid-Atlantic species	Maybe (management activities hard to separate)	Trend analyses (similarity coefficient /regression) of survey catch data; correlation of adaptation group abundance and individual species, with LIS temperature data	<p>1984-present (directed sampling over shorter time periods); CTDEP, NYSDEC striped bass-would need a consistent protocol. 200 stratified random samples chosen annually from 310 stations in LIS plus directed sampling in WLIS</p> <p>Penny Howell (CTDEP)/Peter Auster (UConn) paper NY DEC beginning surveys on N shore of LI</p>
Are there changes in the distribution and abundance of benthic algae species that are associated with climate-related factors?	Benthic Macroalgae	<ul style="list-style-type: none"> • Precipitation • Increased turbidity • Water temperature 	Some marine species could decrease locally if freshwater overwhelms current habitat	Likely	<ul style="list-style-type: none"> • Specific species studies 	<p>There is published work on light levels and temperature requirements.</p> <p>Monitoring by Millstone Environmental Lab.</p>

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			<p>turbidity could decrease available light necessary for photosynthesis and reproduction.</p> <p>Many cold water LIS algae, including kelp, are at their southern temperature range in LIS. Populations could die with warmer water temperatures.</p>			
Are there changes over time in hard substrate subtidal communities?	Hard substrate subtidal communities	Water temperature	Changes in water temperature may cause changes in trophic ecology of species based on food conditions, predator-prey interactions, flow	Yes	Distribution and abundance of shallow water suspension feeders; macroalgae; Benthic foraminifera	<p>Historic datasets from Peter Auster (UConn)(various times and locations) could provide general patterns</p> <p>Foram data: 1996/97 E. Thomas et al.(Yale) 1961/62 M. Buzas; 1948 F. Parker</p>

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Monitoring Questions	SENTINEL	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
			regimes			

TABLE 3. FISHERIES OF LONG ISLAND SOUND and ASSOCIATED RIVER SYSTEMS

Monitoring Question	SENTINEL	Ecological Drivers	Sensitivity and linkages to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
Is there a decreasing trend in the abundance of adult and/or larval lobster associated with any climate-related factors? Is there evidence that as water temps increase, plankton abundance is declining? If declines are occurring, is there evidence of reduced food availability for larval stages of lobster?	Lobster	<ul style="list-style-type: none"> Water temperature + contributing factors (see lobster study) pH 	Lobsters are stressed and populations are declining	Maybe	Lobster larval abundance from fisheries independent monitoring Catch per unit effort	7 stations in LIS; 1984-Present; DEC did for a couple years
Is there evidence of increased calcinosis or paramoebiasis in lobster associated with any climate-related factors?			Warm water temperatures contribute to calcinosis in lobster gills and kidney.	Yes	Indices derived from fishery monitoring and/or independent surveys	Cornell Cooperative Extension sampling of commercial catch
			Paramoebiasis (<i>Neoparamoeba pemaquidensis</i>) (a parasite that attacks the nervous system	Maybe	Distribution in the water column; also invaded soft tissue, however, it is	Limited data collection occurred in CT 2001-2002, 2007. Pathogen not currently monitored Molecular test was developed and is available

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Have water temps exceeded the 20°C tolerance threshold of lobster? Are water temperatures more frequently exceeding (and for longer periods of time) the 20°C threshold for lobsters?			of lobsters) Metabolic reaction to chronic exposure to elevated temperatures; respiratory stress at temperatures > 20°C documented in lab studies	Yes	uncertain whether or not this infection is primary or secondary Analysis of catch distributions in LIS Trawl Survey and LIS commercial catch (sea sampling and landings data). Assays to measure heat shock protein	1976 – present; no current assay work
Is there evidence of declines in crustaceans associated with increased ocean acidification in LIS?	All Shellfish (clams, mussels, oysters, scallops)	pH	Shellfish are stressed and their decline is caused by ocean acidification. CO ₂ levels have increased 40% in the past 150 yrs and are projected to double this century.	Yes	<ul style="list-style-type: none"> • pH • alkalinity • CO₂ concentration 	Chris Gobler (SUNY Stony Brook) current shellfish research

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Monitoring Question	SENTINEL	Ecological Drivers	Sensitivity and linkages to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
<p>Are there any trends in oyster landings? Are there increasing trends in one or more oyster diseases? Is there any association of oyster declines with increases in parasites that are linked to increases in salinity and water temp?</p>	<p>Eastern Oysters (shellfish): Changes in populations due to Dermo and/or MSX; ocean acidification; potentially invasive species that are predatory or compete for resources</p>	<ul style="list-style-type: none"> • Water temp (primary factor) • Salinity (secondary factor) for both Dermo and MSX. Both linked to increased precipitation 	<p>Changes in oyster populations due to Dermo and/or MSX: Two protozoan parasites reduce the survival of infected oysters, including <i>Perkinsus marinus</i>, which causes the disease Dermo, and <i>Haplosporidium nelsoni</i>, which causes MSX. The incidence of both diseases has been linked to increases in water temp and salinity (Ford, 1996)</p> <p>pH change effects on calcification (Table 1)</p>	<p>Yes</p>	<p>% oyster infected per square area (need to take into account disease prevalence AND intensity)</p>	<p>For LIS, there is no monitoring by any public agency in NY; MADL perform regular monitoring for farm raised oyster in Oyster Bay for the account of Frank M. Flowers and Sons (3X/yr since 2005) but the data are confidential as it relates to a commercial operation. CT Aquaculture Bureau (contact for list of geographic location and frequency</p>

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Monitoring Question	SENTINEL	Ecological Drivers	Sensitivity and linkages to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
Are there changes in disease prevalence and parasites in Northern Quahogs?	Northern Quahog (shellfish): Changes in populations due to disease (QPX), ocean acidification, potentially invasive species that are predatory or compete for resources	<ul style="list-style-type: none"> • Water temp (primary) • Salinity (secondary) Both linked to increased precipitation	QPX (Quahog Parasite Unknown)	Yes	% infection clams per square area (need to take into account disease prevalence AND intensity) Range changes in parasites	CT DA/BA has 10 sites that are monitored at least annually and more frequently if there is history of a disease problem. Bassam Allem (SUNY) has ongoing monitoring
Are there changes in bay scallop population abundance?	Bay Scallops (shellfish): Changes in populations due to habitat loss (eelgrass); ocean acidification; potentially invasive species that are predatory or compete for resources	Increased precipitation Decreased salinity Further loss of habitat (eelgrass) Increased nutrients leading to degraded water quality	Increased/decreased pH effects on calcification/shell formation?	Maybe	Distribution and abundance of shellfish and habitat (eelgrass)	NY DEC/CT DEP through USFWS (biennial surveys) NOAA NMFS Milford Laboratory conducts periodic sampling in eastern LIS, as does Millstone Lab
Is there a change in finfish pathogen abundance and occurrence?	Finfish	<ul style="list-style-type: none"> • Temperature • Increased precipitation • Salinity 	Pathogens (i.e., Mycobacteria): Climate change could affect Bluefish ecotoparasite	Maybe	Proportion of population infected with the pathogen or annual index of mortalities	NY DEC contracted MADL to do monitoring for this in LIS and Hudson River in 2007-09. No current funding. Mark Fast (SUNY) has some baseline data

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			<p>prevalence, abundance, seasonality, location, pathology.</p> <p>Not enough info yet to link Viral Hemorrhagic Septicemia (VHS) and climate change (better as intermittent research rather than continuous monitoring).</p>		<p>directly attributable to this disease (difficult)</p> <p>Parasite prevalence, abundance, seasonality, location, pathology: including but not limited to: Lironeca, Lernanthropus, Lernaenichus</p>	
<p>Are changes in seasonal water temps affecting the timing of diadromous fish runs to/from ocean waters?</p>	<p>Diadromous fish</p>	<ul style="list-style-type: none"> •Water temperature •Sea Level Rise •Runoff & precipitation •Stream Flow 	<p>Temperature changes could impact the timing of diadromous fish runs both to and from the sea. But won't affect the miles of passable rivers unless thermal gradients become so high that cold water</p>	<p>Maybe (management activities hard to separate)</p>	<p>Trend analyses (similarity coefficient /regression) of survey catch data; correlation of adaptation group abundance and individual species, with</p>	<p>LISS indicators program gets info from Greenwich, Norwich, Holyoke Dam</p>

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Monitoring Question	SENTINEL	Ecological Drivers	Sensitivity and linkages to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
			anadromous fish don't go up as far.		LIS temperature data NY would only see changes to timing, more applicable in CT	

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS

Monitoring Question	SENTINEL	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
<p>Is there evidence of inundation of tidal flats? Are hard clam landings declining in association with decreases in the area of tidal flats?</p>	<p>Shellfish: Molluscan reefs (Eastern oysters and blue mussels) Tidal flats and subtidal populations (northern quahogs and other non-commercially important bivalves) Salt marsh bivalves (ribbed mussels)</p>	<ul style="list-style-type: none"> • Water temperature • pH • Precipitation changes • runoff • Sea level rise and changes in habitat • increased predators/invasives with changing habitat 	<p>Sea level rise will cause inundation of tidal flats Molluscan reef impacts??</p>	<p>Maybe</p>	<p>Hard clam landings from monitoring Bushels or bag-counts (CT) per yr, catch-per-unit-effort (CPUE) acres of tidal flats density per acre # shellfish harvest closures/yr Recruitment</p>	<p>CT DA/BA has recruitment data from 1997 to present. Disease sampling is conducted at approx 45 stations per year, and data are from 1997 to present</p>
<p>Is there evidence of loss of marsh or change in low to high marsh ratio? Is there evidence of species declines associated with salt marsh loss or degradation that is related to sea level rise inundation or increases in erosion or storm surge?</p>	<p>Salt marshes and associated species</p>	<ul style="list-style-type: none"> • Sea level rise • Salinity • Precipitation • Stream flow • Runoff • Groundwater flow • Wind 	<p>Inundation and changes in salinity due to sea level rise alter distribution and abundance; wetlands convert to open water if unable to ‘Keep pace’ and migrate landward; changes in sediment supply could affect ability to maintain area; Increased freshwater</p>	<p>Maybe</p>	<p>Change in low:high marsh ratio Elevation (Surface elevation tables - SET’s); m², by veg type; transects; Extent of Phragmites Chronology of marsh elevation and accretion (SETs & Pb210)</p>	<p>SET's in CT and NY aerial imagery; Suffolk Co. Community College has transects, compare with 1970s imagery; USGS continuous tide-level monitoring at 4 NY embayments; one site with continuous QW (DO, Salinity, pH, turbidity, temp.) and two sites with temp and SC/sal Chris Elphick (UConn)– data on broad cover types for some salt marshes with GPS locations</p>

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Monitoring Question	SENTINEL	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indice	Data Availability
			input from increased precipitation = increased Phragmites; changes in sediment supply (linked to changes in precipitation)			
Is sea level rise inundating brackish or freshwater marshes? Is the natural vegetation of these wetlands being replaced by salt-tolerant plants? Is there evidence that wetland changes are affecting fish and wildlife species?	Brackish and freshwater tidal marshes and associated species	<ul style="list-style-type: none"> • Sea level rise • Increased precipitation • Air temperature • Increased runoff • Changes in groundwater • Salinity 	Inundation and changes in salinity due to sea level rise (salt wedge) alter distribution and abundance; wetlands may convert to salt marsh if unable to 'Keep pace' and migrate landward; changes in spring freshet may impact marshes; changes in groundwater supply could affect plant species composition	Maybe	m ² by marsh type; spring freshet (measure freshwater inflow)	CT marshes mapped from aerial photography; some transects for CT River marshes; Chris Elphick (UConn) has data on broad cover types for some brackish marshes with GPS locations Nels Barrett (NRCS) set up permanent transects in CT River freshwater tidal marshes (1995)
Is there evidence of changes in the composition or abundance of coastal vegetation communities? Are any changes	Coastal forests, shrublands, grasslands	<ul style="list-style-type: none"> • Air temperature • Changes in precipitation • Sea level rise • Changes in groundwater (salinity, height of 	Increased air temps will affect phenology, distribution and abundance of terrestrial plants	Yes	invasive species distribution and abundance; Veg transects/plots; Species composition; Changes in timing of	Permanent plots in just a few sites Bloom timing: Historical info (100y) from horticultural societies (Bronx) & arboretums LI Botanical Society; Perhaps migratory beekeepers.

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associated with climate-related factors (<i>e.g.</i> sea level rise inundation, changes in water or air temps)?		groundwater table, etc)	Move from freshwater species to saltwater-tolerant species; increases in invasive species		plant blooms	
Is erosion of sea cliffs/bluffs/escarpments showing an increasing trend in association with climate-related factors (<i>e.g.</i> increased storm activity)?	Sea Cliffs/Bluffs and Escarpments (Primarily NY)	<ul style="list-style-type: none"> •Increased precipitation •Sea level rise •Changing groundwater levels •Winds 	Changed wind will change wave energy and storm intensity; Sea level rise, increased precipitation and stronger storms will lead to increased erosion	Maybe (stronger storms will increase erosion, but may not be distinguishable as climate change effects)	m ² lost (possibly using aerial photos)	
Is the area of tidal flats declining in association with increased inundation from sea level rise? Are shorebirds and other species dependent on tidal flats declining?	Unvegetated nearshore submerged and intertidal, habitats (mudflats, sandflats, rocky intertidal)	Sea level rise	Sea level rise will inundate flats and convert to open water, changing the extent of this habitat; impacts to animals dependent on tidal flat fauna, and rocky intertidal fauna	Yes	m ²	
Is there evidence of increased erosion of barriers related to increases in sea level rise or storm surges?	Barrier beaches/islands	Sea level rise	Sea level rise erodes barriers; loss of barriers increases coastal vulnerability to higher/stronger	No (except for inundation as a direct	USGS Coastal Vulnerability Index (CVI)	USGS Coastal Vulnerability Index (CVI)

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Is there an overall loss of barriers due to sea level rise?			storm surges	result of relative sea level rise)		
Is there evidence of declines in bird species dependent on salt marshes? Is there evidence of loss of marsh islands affecting nesting success of colonial nesting birds? Are shorebirds and waterfowl (residents or seasonal migrants) showing decreasing population trends as a result of climate-related factors including loss of habitat due to SLR?	Changes to marsh birds, colonial nesting birds, shorebirds, waterfowl	Sea level rise	Changes in bird population abundance, fecundity, number of nest sites Loss of coastal habitats Potential loss of SAV and other food sources	Yes	Survey counts	<ul style="list-style-type: none"> •CT DEP and NYSDEC have limited data; •Chris Elphick (UConn) has detailed data for saltmarsh and seaside sparrow, general data on other species that frequent salt marshes during the summer; •other bird data sets include International Bird Survey, eBird
Are relative abundances of insect species showing any changes in association with climate-related factors? Are there any seasonal effects? Is there evidence of insect infestations	Insects	<ul style="list-style-type: none"> •Increased temperatures •Precipitation •Sea level rise •Groundwater levels •Salinity 	Slight changes in the climate might affect winter survival (+ or -) of new southern insect species. In general, insects might be good indicators if other factors are also considered	Maybe	Abundance of particular species of insects	Invasive species that are doing damage are being monitored. (USDA, USFS)

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS

Monitoring Question	SENTINEL	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indice	Data Availability
related to temperature changes (<i>e.g.</i> seasonal changes such as extended winters or increasing trends in air temps)? Is there evidence of shifts in species/subspecies distribution related to temperature or precipitation changes?			Increased abundance and distribution of mosquitoes and other insects			
Is there evidence of new terrestrial invasions associated with climate related factors?	Distribution and Abundance of Terrestrial Invasive species (plant and animal)	<ul style="list-style-type: none"> • Increased air temp • Changes in precipitation 			Distribution and abundance of new invasive species	CT/NY Invasive plant groups

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Monitoring Question	SENTINEL	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indice	Data Availability
Is there evidence of declines in eelgrass in association with decreases in light penetration as a result of climate-related factors (including secondary effects such as increased turbidity)? Is there any evidence of declines in species that depend on this habitat (<i>e.g.</i> for protection, as a nursery habitat, for food)?	Eelgrass (<i>Zostera marina</i>) and organisms that depend on eelgrass habitat/food	<ul style="list-style-type: none"> •Salinity •Precipitation •Runoff •Sea level rise •Increased water temp •Salinity •pH •Groundwater •Winds 	<p>Increases in precipitation and runoff can increase nutrient loadings and increase turbidity and epiphytic growth. Turbidity also increases with algae blooms at the surface.</p> <p>Loss of habitat due to SLR</p> <p>Eelgrass sensitive to water temp, salinity, and pH changes</p> <p>Southern (VA) genotypes could move north</p>	Maybe	Secchi depth (light penetration) Eelgrass distribution Salinity	USFWS 2002, 2006, 2009 to be released soon Jamie Vaudrey (UConn) and Jim Kremer (UConn) research
Is there evidence of declines in species of SAV or species dependent on SAV that is associated with climate-related factors? Are there changes in the distribution and abundance of SAV due to changes in the salt wedge?	SAV (other than eelgrass)	<ul style="list-style-type: none"> •Precipitation •Runoff •Increased turbidity •Increased nutrients •SLR •Water temperature •Salinity (salt wedge) •pH 	<p>Increases in precipitation and runoff can increase nutrient loadings and increase turbidity</p>	Maybe	Secchi depth (light penetration) SAV abundance and distribution Salinity Water temperature pH	CT River Study (1995-97) Juliana Barrett (CTSG)

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS

Monitoring Question	SENTINEL	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indice	Data Availability
Is there evidence that changes in marine mammal or sea turtle abundances or distributions are associated with changes in climate-related factors (e.g. ocean warming or secondary effects of warming)?	Marine Mammals & Sea Turtles	<ul style="list-style-type: none"> • Sea level rise • Temperature • Runoff 	Observable changes in distribution and range, relative abundance, changes in preferences for nearshore nursery waters, availability and preferences in haul out sites and rookeries, incidence of disease (due to toxic blooms), changes in overall survival associated with potential changes in available food sources; changes in T could decrease the incidence of cold-stunning; Runoff linked to increased pathogen occurrence	Maybe; this is important to the public	• Distribution Data	Riverhead Foundation, CRESLI, Woods Hole Institute, Norwalk Aquarium, Mystic Aquarium
Question(s) will depend on habitat within the embayment including open water, fringe marsh, shoreline and	Coastal Embayments including fringe marsh, shorelines, and tidal creeks	<ul style="list-style-type: none"> • Sea level rise • Salinity • precipitation • Runoff • Erosion 	Inundation and changes in salinity due to sea level rise may alter distribution and abundance of marsh,	Maybe	Dependent on question	

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Monitoring Question	SENTINEL	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
tidal creek.			drown/erode shoreline and drown tidal creeks			

ⁱ This column may change in the future as our knowledge also changes.

ⁱⁱ This column does not stress importance, only pulls together information.