



## MEMORANDUM

To: Mark Tedesco, John Wilson, John Whitler, Tristan Peter-Contesse, Jeremy Martinich, Ted Cochin, Louise Harrison, and Julie Rose, U.S. EPA; Sarah Deonarine, NY DEC; Antoinette Clemetson, NY Sea Grant; Jennifer Pagach and Mark Parker, CT DEP; Santiago Salinas, Stony Brook University; Mark Hoover, University of Connecticut; and Juliana Barrett, CT Sea Grant

From: Susan Asam, Marybeth Riley-Gilbert, and Liz Strange, ICF International

Date: February 9, 2010

Re: Candidate Climate Change Indicators for the LISS Sentinel Monitoring Strategy

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### 1.0 Background

ICF International and EPA are working with the Long Island Sound Study (LISS), a partner in EPA's Climate Ready Estuaries (CRE) Program, to: (1) review and synthesize information on climate change drivers and responses in Long Island Sound (LIS); (2) develop a prioritized list of indicators for monitoring climate-driven change; and (3) prepare recommendations on elements of a final monitoring plan. The work described in this memorandum builds on ICF's short synthesis document characterizing the projected changes in climate of most relevance to the Sound, current stressors and risks from climate change, and the impacts of climate change on the Sound's ecological systems (ICF, 2009).

This memo describes the process used by ICF to develop a list of candidate climate change indicators for consideration for the Long Island Sound Sentinel Monitoring Strategy. The sentinel monitoring program is planned by the LISS as a multidisciplinary, scientific approach for detecting "early warnings" of climate change impacts to LIS ecosystems using environmental indicators. Environmental indicators are used to convey scientific information on the current status of environmental conditions and changes and trends in these conditions over time. The significance of an environmental indicator is that it not only provides information about what is directly measured (e.g., water temperature) but it also provides information on the environmental condition represented by the measured parameter (e.g., water quality, aquatic habitat) (Niemeijer and de Groot, 2007). The LIS monitoring strategy will determine what and where indicators should be measured and assessed in order to detect indications of climate change effects on LIS habitats, biota, and processes.

In the following sections, we describe our review of climate change indicator development by

other estuary programs, discuss the process ICF used to identify and evaluate indicators for consideration by the LISS for climate change monitoring, and provide a summary of the indicators selected. A list of references cited in this document and the sources consulted is provided at the end of the memo. Appendix A provides a complete list of the indicators that were compiled and their sources.

## **2.0 Review of Climate Change Indicator Development by Other Programs**

To begin the process of assembling potential climate change indicators, ICF reviewed climate change indicators in use or proposed by other estuary programs, including:

- Gulf of Maine Ecosystem Indicator Partnership (ESIP, 2009);
- Chesapeake Bay (CBP, 2009a, 2009b);
- Delaware Estuary (PDE, 2008);
- Charlotte Harbor (CHNEP, 2008; Lisa Beever, CHNEP, pers. comm.); and
- Puget Sound (O'Neill et al., 2008).

Lessons learned from our review included the following:

- Few estuary programs have developed climate change indicators.
- Estuary programs that have developed or considered climate change indicators have focused on climate change effects on resources of management concern, often related to goals outlined in an estuary's Comprehensive Conservation Management Plan (CCMP).
- To the extent possible, estuary programs link climate change drivers to environmental indicators currently monitored (e.g., precipitation and air temperature changes are linked to effects on water quality indicators). This approach is cost-effective and provides information on ecological conditions under current stressors (reference conditions) for comparison with changes that may occur in the future as a result of climate change.
- Even when reference data are available, one of the most challenging aspects of developing climate change indicators is the difficulty of determining ways to distinguish a trend attributable to climate change or detect a climate signal against a backdrop of ongoing variation from other stressors.

## **3.0 Indicator Identification and Evaluation**

To develop a systematic process for identifying and evaluating candidate indicators, ICF considered the lessons learned from other programs and consulted a number of documents that provide recommendations for developing environmental indicators (NRC, 2000; Rogers and Greenway, 2005; Niemeijer and de Groot, 2008; U.S. EPA, 2008b). Most of these documents present some form of the *pressure-state-response* framework for selecting indicators, where

*pressure* refers to the environmental stressor, *state* refers to the environmental condition resulting from the pressure, and *response* refers to a management response. The LISS used this type of framework to develop environmental indicators for its ongoing monitoring programs (LISS, 2008). ICF developed an *indicator identification and evaluation framework* based on the stressor-state-response approach, but with a focus on criteria for identifying indicators suitable for climate change monitoring. ICF's framework is outlined in Figure 1 and described in the following steps.

**Step 1.** As represented by the first element in Figure 1, we identified climate change stressors (temperature, precipitation, sea level rise) that could potentially affect Long Island Sound resources.

**Step 2.** The ICF report, *Synthesis of Climate Change Drivers and Responses in Long Island Sound* (ICF, 2009) developed previously as part of this project, provided information on LIS resources that are vulnerable to climate change stressors. To facilitate subsequent analysis, the vulnerable resources were grouped into resource categories (water quality, living marine resources, habitats, and hydrology) used by the LISS to develop other environmental indicators (LISS, 2008).

**Step 3.** The *Synthesis of Climate Change Drivers and Responses in Long Island Sound* (ICF, 2009) also included a characterization of the potential climate change effects on the resources identified as vulnerable.

**Step 4.** We compiled a broad list of potential climate change indicators by reviewing a variety of published and unpublished documents, including information on climate change indicator work by other estuary programs and documents provided to ICF by LISS partners. To determine which indicators are currently monitored, we reviewed EPA's coastal conditions reports for Long Island Sound (U.S.EPA, 2007) and for the Northeast (U.S. EPA, 2008a) as well as LIS monitoring summaries. We compiled a list of more than 120 indicators (provided in Appendix A).

**Step 5.** We reviewed the list of indicators against the findings of the literature review to identify any gaps, and then developed a number of criteria for evaluating which indicators could be suitable for monitoring climate change effects on LIS. The criteria for evaluating candidate indicators are given below, along with definitions of the criteria. Candidate indicators meeting these criteria are provided in Table 1. Each column in the table represents one of the criteria, and each row summarizes how the given indicator meets the criteria.

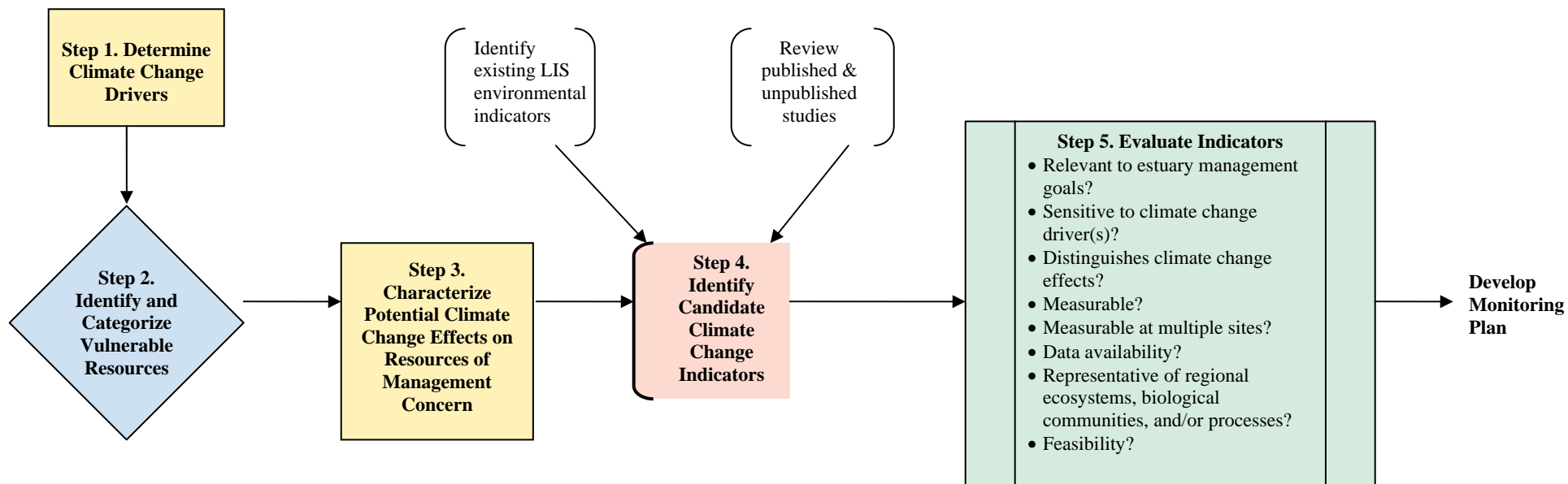
- ***Relevant to resources of management concern*** – “relevant” means that the indicator provides information on one or more of the resources identified by the LISS as a management concern (e.g., in the program's CCMP). Table 1 lists the management concerns associated with each indicator (e.g., hypoxia, water clarity).
- ***Sensitive to climate stressors*** – “sensitive” means that the indicator changes in response to changes in climate stressors. Some indicators are more responsive than others, but even when the most sensitive indicators are used, it can be difficult to detect a clear climate signal. This is because there can be a high degree of background variation as a result of natural variation and other human stressors.
- ***Direct relationship to climate change effects*** – Indicators that are most effective at distinguishing climate change effects from the effects of other stressors are those with

a direct relationship to climate stressors. Water temperature, for example, is a direct function of air temperature, and is a key indicator of the suitability of estuarine waters for aquatic life. On the other hand, although phytoplankton biomass and low dissolved oxygen (DO) are good indicators of eutrophic conditions, they are only indirectly linked to climate change, and therefore may not be able to distinguish the role climate change may play in eutrophic conditions relative to the effects of other stressors. In Table 1, the column “Climate Change Effects Can Be Distinguished from Other Stressors” uses a simple “yes” or “no” designation to show whether an indicator meets this criterion. A “no” means that even though the indicator may not show a direct relationship to climate change or may not be robust under all conditions, there is the possibility that additional research (e.g., on underlying causal mechanisms) or improvements in estuary conditions (e.g., recovery from a eutrophic state) could enhance the indicator’s discriminatory ability some time in the future.

- **Measurable** – “measurable” means that the indicator can be defined and measured in quantitative terms
- **Measurable at multiple sites** – sentinel monitoring requires that indicator data are collected at multiple sites across a sampling area; the years of monitoring are given in Table 1, except where a “yes” indicates that a record is available but the years are unknown
- **Data availability** – a data record (time series of data) is needed to establish indicator values under baseline conditions, to detect climate signals, and to identify trends
- **Representative of regional ecosystems, biological communities, and/or processes** – sentinel monitoring involves intensively studying a key species, biological community or process that is representative of and can be extrapolated to the larger ecosystem or similar ecosystems in a region; in Table 1, a “yes” signifies that the indicator is representative and can be extrapolated, while a “no” means that the indicator does not meet these requirements.
- **Feasibility** – the feasibility of implementing indicator data collection is determined in part by the cost and efficiency with which the indicator can be measured; in Table 1, “TBD” means that feasibility is “to be determined” by the LISS team.

Table 1 presents the results of the indicator evaluation process, giving the subset of indicators from the list in Appendix A that are suitable candidates for climate change monitoring based on the evaluation criteria.

**Figure 1. Indicator identification and evaluation framework**



**Table 1. Results of indicator evaluation process.**

Candidate Indicator	Relevance to Management Goals	Sensitivity to Climate Stressors	Climate Change Effects Can Be Distinguished from Other Stressors	Measurable	Measurable at Multiple Sites	Data Record	Representative	Feasible
<i>Water Quality</i>								
Dissolved inorganic nitrogen	Nutrients	Nitrogen is limiting for algal production in estuaries. Increases in <b>precipitation and runoff</b> carry excess nitrogen to the Sound from upstream sources.	No	DIN	52 stations in LIS	1994-Present	Yes	Yes
Harmful algal blooms (HABs)	Eutrophication	Increases in <b>precipitation and runoff</b> carry excess nutrients from upstream sources, resulting in "blooms" of toxic algae.	No	cell count	Yes	TBD	Yes	TBD
Dissolved oxygen	Hypoxia	Dissolved oxygen (DO) levels indicate the availability of oxygen for aquatic organisms. The combination of increases in <b>water temperature</b> and decomposition of excess algae reduces DO and leads to hypoxia.	No	DO	52 stations in LIS	1994-Present	Yes	Yes
Salinity	Salinity	<b>Sea level rise, precipitation, and freshwater runoff</b> help determine the salinity of estuarine waters	Yes	ppt	52 stations in LIS	1994-Present	Yes	Yes
Salt wedge	Salinity	As <b>sea level rises</b> , the salt wedge will move farther upstream. The salt wedge occurs where fresh- and saltwater meet, with a layer of freshwater on the surface and a "wedge" of salt water on the bottom of the water column. Salinity intrusion into freshwater areas impairs freshwater ecosystems and water supplies	Yes	location of salinity line	Yes	TBD	No	TBD
Light penetration	Water clarity	Light penetration in waters below the surface is an indicator of turbidity. Increases in <b>precipitation and runoff</b> can increase sediment loadings and increase the turbidity of estuarine waters. Turbidity also increases when algae in surface waters die and drift to bottom.	No	Secchi depth	Yes	TBD	Yes	TBD
Beach closures	Bacteria	Increases in <b>precipitation and stormwater runoff</b> can cause an increase in bacterial levels in the estuary, resulting in beach closures or restrictions on shellfish harvest to protect human health.	No	# per yr	Yes	TBD	Yes	TBD
Shellfish harvest closures			No	# per yr	Yes	TBD	Yes	TBD

Candidate Indicator	Relevance to Management Goals	Sensitivity to Climate Stressors	Climate Change Effects Can Be Distinguished from Other Stressors	Measurable	Measurable at Multiple Sites	Data Record	Representative	Feasible
Hydrogen ion concentration of sea water	pH	A high concentration of hydrogen ions in seawater is an indicator of ocean acidity. The accumulation of carbon in the ocean from anthropogenic <b>emissions of CO2</b> has led to an increase in the hydrogen ions and the acidity of ocean waters, which impairs the ability of marine calcifiers to form their shells, skeletons and other hard parts.	Yes	pH units	Yes	TBD	Yes	TBD
Water temperature	Water temperature	Increases in <b>water temperature</b> are directly related to increases in air temperatures as a result of climate warming and will affect the distribution and abundance of coastal species.	Yes	degrees C	At least 1 station in LIS	1998-Present	Yes	Yes
<b>Marine Resources</b>								
Virginia Province Benthic Index	Benthos	Increased <b>temperature of bottom waters</b> will affect the abundance of benthic organisms	No	poor or good	80 stations in LIS	2000-Present	Yes	Yes
Phytoplankton	Plankton	Increased <b>temperatures of surface waters</b> will affect the species composition and abundance of planktonic organisms depending on species thermal tolerances.	Yes	chlorophyll-a	Yes	TBD	Yes	TBD
Zooplankton			Yes	annual biomass	Yes	TBD	Yes	TBD
Hard clam landings from fisheries monitoring or abundance from fisheries independent monitoring	Shellfish	Tidal flats provide habitat for a wide variety of invertebrates, including shellfish such as hard clams. Tidal flats will become inundated as <b>sea levels rise</b> , eventually becoming entirely submerged. This will make the invertebrate infauna of the flats inaccessible to foraging waterfowl and shorebirds.	No	bushels per yr, catch-per-unit-effort (CPUE)	Yes	1995-Present	Yes	Yes
Lobster landings from fisheries monitoring or abundance from fisheries independent monitoring	Lobsters	A decline in the Sound's lobster population in the past decade has been linked to increased <b>water temperatures</b> . As temperatures increase, plankton abundance may decline, reducing food availability for lobster, and there may be an increase in a parasite that is harmful to lobster.	Yes	pounds per yr, CPUE	7 stations in LIS	1984-Present	Yes	Yes
Incidence of Dermo or MSX in oysters	Oysters	Two 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 <b>water temperature and salinity</b> (Ford, 1996).	No	% oysters infected	Yes	TBD	Yes	TBD
Changes in range of <i>P. marinus</i> or <i>H. nelsoni</i> .			No	km	Yes	TBD	Yes	TBD

Candidate Indicator	Relevance to Management Goals	Sensitivity to Climate Stressors	Climate Change Effects Can Be Distinguished from Other Stressors	Measurable	Measurable at Multiple Sites	Data Record	Representative	Feasible
Relative abundance of warm- and coldwater species	Finfish	Increasing <b>water temperature</b> from climate warming is leading to a shift in the fish fauna of the Northeast, with a movement of warmwater species north. Winter flounder is a potential indicator species because there is evidence that this coldwater species is declining in Long Island Sound, Narragansett Bay and other Northeast estuaries where it was once abundant.	Yes	ratio of warm- and coldwater species	43 stations in LIS	1984-Present	Yes	Yes
Shorebirds	Waterbirds	Abundance and nesting success of waterbirds decline as a result of degradation and loss of nesting, roosting and feeding habitats with increases in <b>sea level rise</b> and inundation and erosion of marshes, marsh islands, and tidal flats.	Yes	survey counts	Yes	TBD	Yes	TBD
Colonial nesting birds			Yes	survey counts	Yes	1984-Present	Yes	Yes
Waterfowl			Yes	survey counts	Yes	TBD	Yes	TBD
<b>Estuary Habitats</b>								
Surface Elevation Tables (SETs)	Wetland Surface Elevation	Wetland surface elevation must keep pace with <b>sea level rise</b> or marshes will become inundated and “drown” if they are unable to migrate inland.	Yes	mm elevation	3 stations along LIS, in CT	2005-Present	Yes	Yes
Freshwater tidal wetlands, extent	Freshwater Tidal Wetlands	Inundation and changes in salinity due to <b>sea level rise</b> alter distribution and abundance; freshwater wetlands convert to salt marsh as increasing sea level rise pushes salinity up the estuary.	Yes	m <sup>2</sup> , by type	Yes	TBD	Yes	TBD
Salt marsh vegetation, type and extent	Salt marsh	Inundation and changes in salinity due to <b>sea level rise</b> alter distribution and abundance; wetlands convert to open water if unable to “keep pace” and migrate inland.	Yes	m <sup>2</sup> , by type	Yes	TBD	Yes	TBD
Underwater light availability	Eelgrass ( <i>Zostera marina</i> )	<b>Sea level rise</b> can reduce light penetration at existing deep edge; increased <b>precipitation and runoff</b> can increase erosion and suspended sediments; both impacts reduce water clarity, seagrass growth & survival, and the organisms that depend on sea grass habitat.	No	% of surface light	Yes	TBD	Yes	TBD
Submerged and intertidal unvegetated habitats, extent	Submerged and intertidal unvegetated habitats (esp. mudflats, sandflats)	<b>Sea level rise</b> will inundate flats and convert to open water.	Yes	m <sup>2</sup>	Yes	TBD	Yes	TBD
USGS Coastal Vulnerability Index (CVI)	Barrier Islands	<b>Sea level rise</b> erodes barriers; loss of barriers increases coastal vulnerability to higher storm surges.	Yes	four levels from low to high	Yes	TBD	Yes	TBD



Candidate Indicator	Relevance to Management Goals	Sensitivity to Climate Stressors	Climate Change Effects Can Be Distinguished from Other Stressors	Measurable	Measurable at Multiple Sites	Data Record	Representative	Feasible
<i>Hydrology</i>								
Amount in spring	Freshwater Inflow	<b>Precipitation and temperature</b> determine amount and timing of spring freshet	Yes	cfs	Yes	TBD	Yes	TBD
Water table level	Amount of groundwater	<b>Precipitation</b> influences amount of groundwater recharge; reduced precipitation & recharge reduces the amount of groundwater.	Yes	height in meters	Yes	TBD		TBD
Groundwater salinity	Quality of groundwater	Salt water intrusion into aquifers from <b>sea level rise</b> impairs the quality of groundwater.	Yes	ppt	Yes	TBD		TBD

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## Appendix A – Complete List of Climate Change Indicators Identified from Sources Consulted

Indicators	Sources
Air temperature	LISS, 2009a, 2009c; PDE, 2008; ESIP, 2009
Alewife, abundance of	LISS, 2008
American lobster, abundance of	LISS, 2009c
Atlantic salmon, abundance of	LISS, 2008
Atmospheric pressure*	LISS, 2009a, 2009c
Bacteria ( <i>Enterococci</i> , Fecal Coliform)	U.S. EPA, 2007
Beach closure days	LISS, 2008; U.S. EPA 2007; PSP, 2009
Benthic index (Virginia Province Benthic Index)	LISS, 2009b
Benthic macroinvertebrate abundance/diversity	LISS, 2009a
Benthic marine algae, abundance	LISS, 2009a
Biochemical Oxygen Demand	U.S. EPA, 2007
Bioturbation pattern/rates	LISS, 2009a
Blue crabs, abundance of	LISS, 2009c; PDE, 2008
Bluefish, abundance of	LISS, 2008
Bottom water, temperature of	LISS, 2008, 2009c
Brackish marsh, extent of	Rozsa, 2009; PDE, 2008
Chemical contaminants in bivalve mollusks, concentrations of	LISS, 2009b
Chlorophyll-a	LISS, 2009a, 2009c; ESIP, 2009
Coastal Erosion	LISS, 2009a
Colored Dissolved Organic Matter (CDOM)	U.S. EPA, 2007
Community structure (plankton, benthos, fish)	LISS, 2009c
Cunner, abundance of	LISS, 2008
Currents, direction	LISS, 2009a
Currents, strength	LISS, 2009a
Dissolved organic matter	LISS, 2009a
Dissolved organic nitrogen	LISS, 2009a; ESIP, 2009
Dissolved organic phosphorus	LISS, 2009a
Dissolved Oxygen	LISS, 2009a, 2009c; ESIP, 2009; PSP, 2009
<i>Distichlis spicata</i> , extent of	Rozsa, 2009
Drought, frequency and intensity	CHNEP, 2009
Drought, length of persistence (months)	LISS, 2009a
Eelgrass beds, distribution of	LISS, 2009b; ESIP, 2009; PSP, 2009
Fall frost, date of first appearance	LISS, 2009a, 2009c
Filtering capacity of suspension feeders, changes in	LISS, 2009a
Fish biomass index	LISS, 2008; PDE, 2008; ESIP, 2009; PSP, 2009
Fish community composition	LISS, 2009a; ESIP, 2009
Fish consumption advisories, number of	PSP, 2009
Flood recurrence interval	CHNEP, 2009
Flooding	CHNEP, 2009

Flows-annual, seasonal high flows	LISS, 2009a, 2009c
Flows-annual, seasonal low flows	LISS, 2009a, 2009c
Forage fish, abundance of	LISS, 2008
Freshwater marsh, extent of	Rozsa, 2009; PDE, 2008; PSP, 2009
Freshwater wetlands, species composition	LISS, 2009a
Groundwater table, height at particular date	LISS, 2009a, 2009c
Habitat connectivity	PSP, 2009
Halinity, Sound water	LISS, 2009a; PDE, 2008
Hard clam harvest, annual bushels	LISS, 2008
Harmful Algal Blooms	LISS, 2009b
Herring, abundance of	LISS, 2008
High marsh, change in total extent	Rozsa, 2009; PDE, 2008
Hypoxia, annual frequency of, in bottom waters in LIS	LISS, 2008; PSP, 2009
Impoundments, presence in Spring	Rozsa, 2009
Inundation	LISS, 2009a
<i>Juncus gerardii</i> , transgression of	Rozsa, 2009
Least tern, abundance	LISS, 2009b
Lobster landings, annual in millions of pounds	LISS, 2008
Low marsh, area converted to intertidal flats (year over year)	Rozsa, 2009; PSP, 2009
Low marsh, change in total extent	Rozsa, 2009; PDE, 2008
Marine ice, dates of first and last appearances	LISS, 2009a, 2009c
Number of high pulses	U.S. EPA, 2007
Nutrient flux between sediments and water column	LISS, 2009a
Organic carbon	U.S. EPA, 2007
Osprey, abundance	LISS, 2009b
Oyster harvest, annual bushels	LISS, 2008; PDE, 2008
PAR (light attenuation, k)	U.S. EPA, 2007b
pH	LISS, 2009a
Pathogens, in water	LISS, 2009c
Phragmites	LISS, 2009b
Piping plover, abundance of	LISS, 2009b
Plankton, abundance	LISS, 2009a
Plant diseases, such as powdery mildew in lilacs	LISS, 2009c
Pollutant loadings	LISS, 2009a
Population Density	ESIP, 2009; PDE, 2008; TGB-PSEIWG, 2002
Pore water dissolved oxygen	LISS, 2009a
Pore water hydrogen sulfide	LISS, 2009a
Pore water iron	LISS, 2009a
Pore water manganese	LISS, 2009a
Pore water nitrogen	LISS, 2009a
Pore water phosphorus	LISS, 2009a
Precipitation, annual as rain*	LISS, 2009a; ESIP, 2009
Precipitation, annual as snow*	LISS, 2009a; ESIP, 2009
Precipitation, annual number of 1 inch events	LISS, 2009a; ESIP, 2009; CHNEP, 2009
Precipitation, annual total*	LISS, 2009a; ESIP, 2009; CHNEP, 2009
Presence of cold/warm water species	LISS, 2008
RedOx state/cycling	LISS, 2009a

River discharge (monthly median)	LISS, 2009a; PSP, 2009
River discharge, duration of high pulses (mean)	LISS, 2009a; PSP, 2009
River ice, peak extent	LISS, 2009a
<i>Salicornia bigelovii</i> , extent of	Rozsa, 2009
Salinity, change in groundwater	LISS, 2009c
Salinity, river or other fresh waters	Rozsa, 2009, LISS 2009c; PDE, 2008
Salt marsh sharp-tailed sparrow, abundance	Rozsa, 2009
Salt marsh, species	LISS, 2009a
Salt wedge position	Rozsa, 2009
Saltwater marsh, extent of	Rozsa, 2009; PDE, 2008; ESIP, 2009
Scup, abundance of	LISS, 2008
Sea grass, extent of	LISS, 2009a
Sea level rise, particular location	LISS, 2009a, 2009c; PDE, 2008; ESIP, 2009; CHNEP, 2009
Seals, abundance of	LISS, 2008
Secchi depth	MBP, 2008; ESIP, 2009
Sediment quality index	LISS, 2009b
Sediment toxicity	LISS, 2009a; PSP, 2009
Sediment, concentration suspended	Rozsa, 2009
Shad, abundance of	LISS, 2008; PDE, 2008
Shellfish beds, distribution of	LISS, 2009b; PDE, 2008
Shellfish harvest area closures	LISS, 2009b; PSP, 2009
Shellfish sanitation data	MBP, 2008; ESIP, 2009
<i>Spartina alterniflora</i> , extent of	Rozsa, 2009
<i>Spartina patens</i> , extent of	Rozsa, 2009
Species at Risk index	TGB-PSEIWG, 2002
Specific conductance	LISS, 2009a
Spring bloom, timing	LISS, 2009c
Spring freshet, timing of arrival	Rozsa, 2009
Spring freshet, volume	Rozsa, 2009
Spring thaw date	LISS, 2009a, 2009c
Storm frequency	LISS, 2009a
Storm intensity	LISS, 2009a
Stratification	LISS, 2009a, 2009c
Striped bass, abundance of	LISS, 2008; PDE, 2008
Submerged and intertidal unvegetated habitat, extent	LISS, 2009a
Summer flounder, abundance of	LISS, 2008
Surface water, temperature of	LISS, 2008, 2009c
Tautog, abundance of	LISS, 2008
Tidal Restrictions, Locations of	ESIP, 2009
Total Suspended Solids (TSS)	U.S. EPA, 2007; PDE, 2008
Toxins associated with HABs	LISS, 2009c
Turbidity	LISS, 2009a, 2009c ; PDE, 2008
Upland border dieback	Rozsa, 2009
USGS Coastal Vulnerability Index (CVI)-vulnerability to sea level rise	USGS, 1999
Water clarity	LISS, 2009a

Water color	LISS, 2009a
Water depth	LISS, 2009a
Weakfish, abundance of	LISS, 2008
Wetland surface elevation (SET, surface elevation table)	NOAA, 2008
Wind direction	LISS, 2009a
Wind speed	LISS, 2009a
Winter flounder, abundance of	LISS, 2008