**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 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**

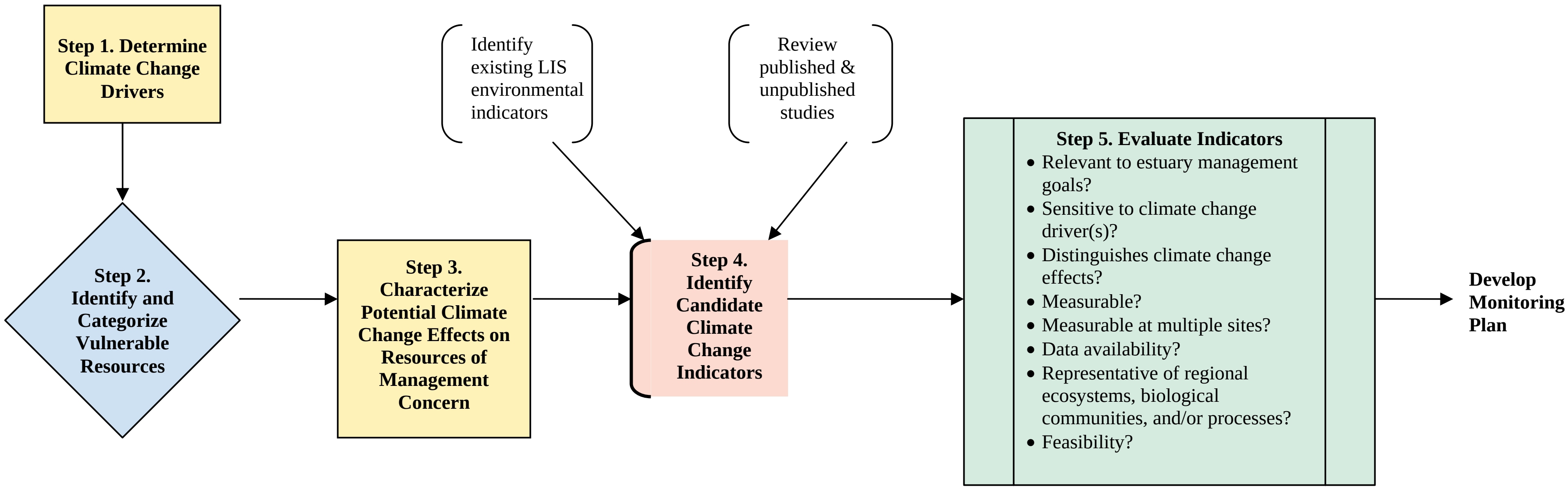

**Table 1. Results of indicator evaluation process.**

| 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 |
|---|---|---|---|---|---|---|---|---|
| ***Water Quality*** | | | | | | | | |
| Dissolved inorganic nitrogen | Nutrients | Nitrogen is limiting for algal production in estuaries. Increases in **precipitation and runoff** 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 **precipitation and runoff** 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 **water temperature** and decomposition of excess algae reduces DO and leads to hypoxia. | No | DO | 52 stations in LIS | 1994-Present | Yes | Yes |
| Salinity | Salinity | **Sea level rise, precipitation, and freshwater runoff** help determine the salinity of estuarine waters | Yes | ppt | 52 stations in LIS | 1994-Present | Yes | Yes |
| Salt wedge | Salinity | As **sea level rises**, 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 **precipitation and runoff** 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 | Secci depth | Yes | TBD | Yes | TBD |
| Beach closures | Bacteria | Increases in **precipitation and stormwater runoff** 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 **emissions of CO2** 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 **water temperature** 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 |
| | ***Marine Resources*** | | | | | | | |
| Virginia Province Benthic Index | Benthos | Increased **temperature of bottom waters** will affect the abundance of benthic organisms | No | poor or good | 80 stations in LIS | 2000-Present | Yes | Yes |
| Phytoplankton | Plankton | Increased **temperatures of surface waters** 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 **sea levels rise,** 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 **water temperatures**. 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 *Perkinsus marinus* , which causes the disease Dermo, and *Haplosporidium nelsoni* , which causes MSX .The incidence of both diseases has been linked to increases in **water temperature and salinity** (Ford, 1996). | No | % oysters infected | Yes | TBD | Yes | TBD |
| Changes in range of *P. marinus* or *H. nelsoni* . | | | 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 **water temperature** 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 **sea level rise** 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 |
| | ***Estuary Habitats*** | | | | | | | |
| Surface Elevation Tables (SETs) | Wetland Surface Elevation | Wetland surface elevation must keep pace with **sea level rise** 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 **sea level rise** alter distribution and abundance; freshwater wetlands convert to salt marsh as increasing sea level rise pushes salinity up the estuary. | Yes | $m^2$, by type | Yes | TBD | Yes | TBD |
| Salt marsh vegetation, type and extent | Salt marsh | 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 inland. | Yes | $m^2$, by type | Yes | TBD | Yes | TBD |
| Underwater light availability | Eelgrass (*Zostera marina* ) | **Sea level rise** can reduce light penetration at existing deep edge; increased **precipitation and runoff** 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) | **Sea level rise** will inundate flats and convert to open water. | Yes | $m^2$ | Yes | TBD | Yes | TBD |
| USGS Coastal Vulnerability Index (CVI) | Barrier Islands | **Sea level rise** 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 |
|---|---|---|---|---|---|---|---|---|
| ***Hydrology*** | | | | | | | | |
| Amount in spring | Freshwater Inflow | **Precipitation and temperature** determine amount and timing of spring freshet | Yes | cfs | Yes | TBD | Yes | TBD |
| Water table level | Amount of groundwater | **Precipitation** 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 **sea level rise** 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 (*Enterococci*, 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 |
| *Distichlis spicata*, 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 |
| *Juncus gerardii*, 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 plower, 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 |
| *Salicornia bigelovii*, 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 |
| *Spartina alterniflora*, extent of | Rozsa, 2009 |
| *Spartina patens*, 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 |

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|---|---|
| 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 |